Contents

Three-dimensional distribution of heavy metals in the areas of tailing pits of the Kryvyi Rih mining and processing objects

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It was determined the regularity of distribution of heavy metals in areas adjacent to the ore-dressing and mining objects, which have the largest impact on pollution of the environment in Kryvyi Rih. As the objects of research, soils from ravines and tailing pits located close to mining and processing objects were taken. Specification of geochemical concentrations of heavy metals was done by atomic emission spectral analysis and atomic absorption spectral analysis. The results were correlated with the maximum allowable concentrations established by the normative documents. The results of the performed studies have confirmed that the accumulation of heavy metals in the geologic environment is affected by mining and processing plants, as well as by domestic waste and municipal wastewater. As an additional factor of the distribution of heavy metals in soils, prevailing winds and ground relief have been taken into account. Also, the trend to active absorption of some part of heavy metals by vegetation has been confirmed. In combination with periodic recultivation works, it significantly reduces concentrations of heavy metals to the levels not exceeding the maximum allowable concentrations.

Key words*: heavy metals, atomic emission spectral analysis, maximum allowable concentrations, atomic absorption spectral analysis, tailing pits*

Introduction

One of the basic principles of the balanced management of natural resources is the development of industrial metallurgy-related objects in such a way that favourable ecological conditions for future generations will be provided. This principle began to be implemented in the system of the subsurface resources management only recently and now is not sufficiently popular. In the majority of countries with metallurgy industry, the following method of mineral recourses management is used: if there is a need in a mineral product, and if such a mineral product is available, the mineral product is mined without control. The principle above means the strict monitoring of works for mining and processing iron ore in such a way that the iron ore production volume would be sufficient for satisfying the minimum required volume at present, the remaining iron ore would be sufficient for satisfying future needs, and there would be sufficient time for the environment self-restoring. Considering this, it is arguable that the population carrying capacity of the geologic environment of the Kryvyi Rih iron-ore region is closely related to the problem of the rational use of mineral recourses in the iron-ore region.

It is evident that the situation in the studied region at present is close to environmentally unsafe. The anthropogenic impact on the geological environment exceeds the maximum level allowed for the population carrying capacity of the region. According to research (Hrin, 1980), (Korzhnev, 2000, 2003*)*, (Kurilo, 2014), (Sadovnikov, 1984*)*, *(*Taranov, 2001) the basic hazardous substances are migrating waste products of imperfect production processes, such as gas emission products, wastewaters, and mine waters, which contain toxic substances and enter soils and water-storage reservoirs. Some analyses showed that especially technogenically loaded natural objects are sedimentary rocks of the studied area. In scientific studies (Stetsenko and Ivanchenko, 2016) it is stated that the sedimentary complex is represented by quaternary and prequaternary (Paleogene, Neogene) deposits that overlap the complex of metamorphic rocks of the Krivoy Rog series. Their power is not sustained, and, mainly, depends on the relief of the indigenous species. In the eastern regions, it is 20-25 m, in the western - it reaches 55-60m.

The city of Kryvy Rih is located in the central part of the Ukrainian crystalline massif. The geological construction of the city and its vicinity consists of the Quaternary loams (3-25m of thickness), which are bedded with Neogene clay, sand or cracked limestones (5-11m). Over the Neogene sediments, the Precambrian crystalline rocks (granites) which extend to the surface only in river valleys are lying. Common chernozems are the primary genetic group of soils in the suburban and urban areas of Kryvyi Rih. As Kryvyi Rih Region is the

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largest iron ore mining and processing region in Ukraine, these soils become the primary objects of the influence of all iron processing enterprises, such as ArcelorMittal Kryvyi Rih, Kryvbasshakhtozakryttia, Mekhanobrchermet, and Central Mining and Processing Integrated Plant. All these enterprises are located within the townsite and pollute the environment to a large extent (Fig. 1).

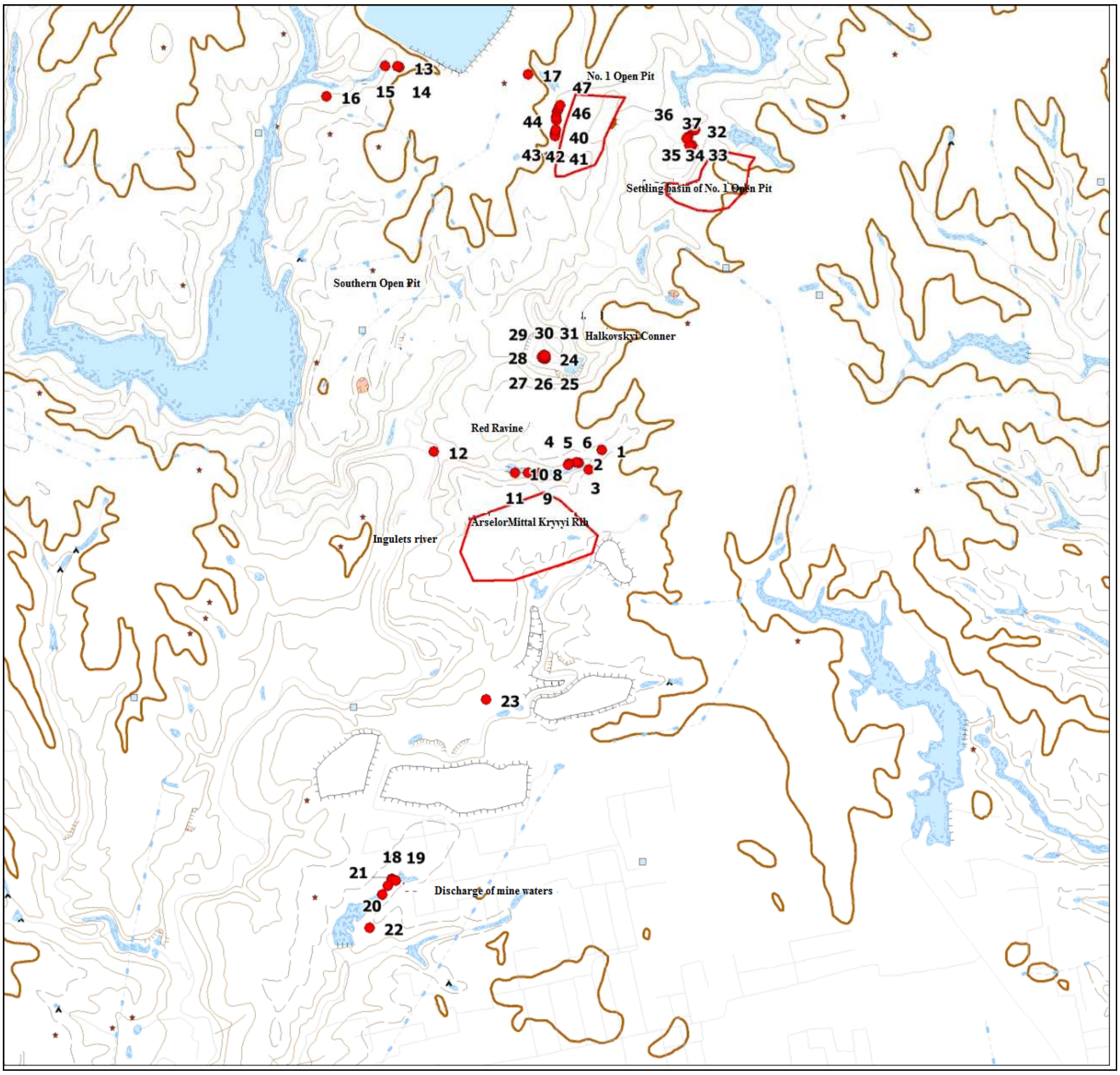

Fig. 1. Summarised map of the research objects.

Material and methods

To determine the three-dimensional distribution of heavy metals in Kryvyi Rih, Ukraine, some literary sources were studied (Klos, 2012; Kurbatova, 2004; Saprishkin, 1984; Voskresenskaya, 2013) and four sites for studies were chosen. These sites are the Red Ravine, which is located at a distance of 3 km from ArcelorMittal Kryvyi Rih; the Svystunov Ravine, which is virtually the containment pond of Kryvbasshakhtozakryttia; the tailing pit, used for hydro projection now, which is located between Mekhanobrchermet, South Open Pit, and Hihant-Glyboka Mine, and the area adjacent to No. 1 Open Pit, including the tailing pit of the Central Mining and Processing Integrated Plant. At these sites, samples were taken from soils presented by black soil, industrial silt, loam, aqua-gel, sand with the addition of oil products and bottom sediments, and mud.

Specification of geochemical concentrations of heavy metals was done by atomic emission spectral analysis and atomic absorption spectral analysis following the scientific research (Jovinskiy and Kruchenko, 2007). The results were correlated with the maximum allowable concentrations established by the normative documents.

To determine the concentrations of chemical elements in samples of soils, bottom sediments and vegetation in them, an atomic-emission spectral analysis was used, which was performed in the laboratory of the Institute of

Geochemistry, Mineralogy and ore formation named after M.P Semenenko National Academy of Sciences of Ukraine on the STE-1 spectrograph of large dispersion (4.7 A0 / mm). Investigated sample, roughly 200 mesh (to powder form), are burned in a vertical arc of an alternating current of 20 A, 220 V from a coal electrode crater. The received spectra of samples are fixed on a photographic plate. After that, the interpretation of the spectra by the method of comparison of blackening of the lines with the reference samples is carried out (Fig. 2).

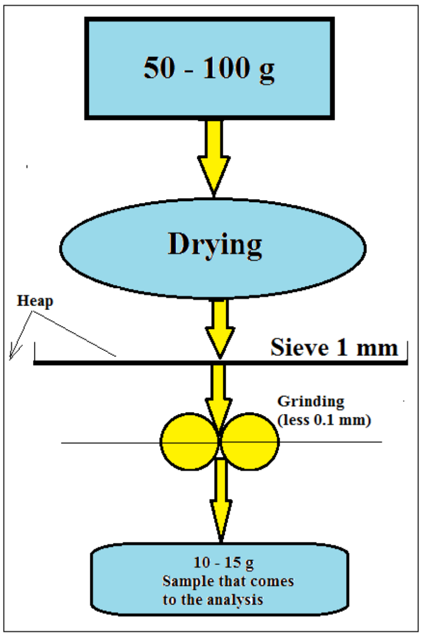

Fig. 2. The scheme of preparation of samples.

The density of the line of each element in the spectrum is proportional to its content in the sample and corresponds to the standard described by Rusanov (1971). Preliminary preparation of samples was carried out in the same laboratory.

For a more accurate understanding of the content of heavy metals in the selected samples, the results of atomic emission spectral analysis were compared with the results of the atomic-adsorption spectral analysis. The last one was done with the help of the ground-breaking iCE 3300 AA Spectrometer (Fig. 3) which makes even the most complicated analyses simple.

Fig. 3. Thermo Scientific iCE 3300 AA Spectrometer.

It was chosen because among its characteristics there are: high precision, exceptional optical stability and new universal titanium burner with improved solids capability increases the efficiency and accuracy of your flame analysis. The iCE 3300 has an unrivalled flame sensitivity which is achieved by high-efficiency nebulization through a fully inert impact bead, spoiler and spray chamber. The new finned universal titanium burner ensures exceptional atomization, even with the most difficult samples. The fully automatic gas box uses binary flow control for safe, reliable and repeatable analysis with all flame types. All critical parameters can be optimised automatically if required – burner height, gas flows, even optical instrument parameters. The iCE

3300 accepts the GFS33 Integrated Graphite Furnace and Auto-sampler Module which offers the best in detection limits with minimum interferences. Dynamic optical temperature feedback ensures accurate heating rates up to 3000 ºC per second regardless of cuvette age.

The GFS33 has unrivalled graphite furnace automation. Huge capacity and infinite solution preparation facilities cater for all needs. The auto-sampler remains permanently in alignment with the furnace eliminating the need to re-align the probe every time the furnace is fitted.

Results and discussion

Red Ravine

Tab. 1. The content of heavy metals in Red Ravine.

Sample	Height [m]	Ni	Cr	Cu	Pb	Zn
1	90	60	60	100	60	80
2	87	50	100	60	80	60
3	83	50	60	50	30	0
4	84	50	80	60	30	30
5	74	50	80	50	40	0
6	74	50	60	80	60	80
7	80	50	80	50	40	50
8	73	50	60	60	40	80
9	73	50	0	60	40	0
10	73	50	0	50	30	50
11	73	50	80	0	0	0
12	35	50	60	60	60	80

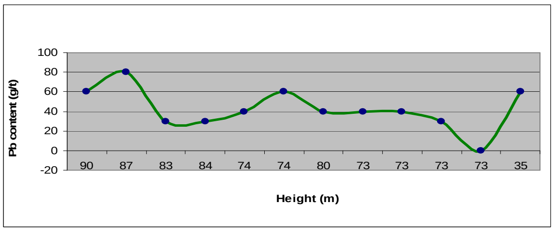

Fig. 4. Distribution of Pb along the Red Ravine depending on the relief.

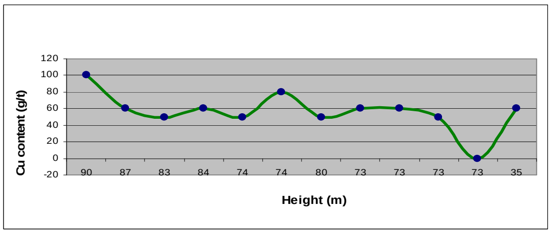

Fig. 5. Distribution of Cu along the Red Ravine depending on the relief.

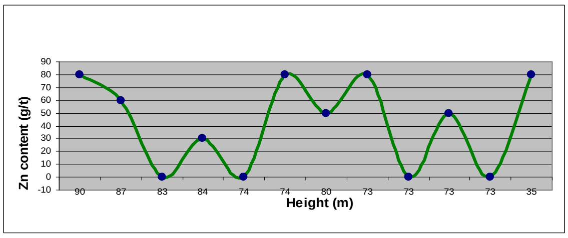

Fig. 6. Distribution of Zn along the Red Ravine depending on the relief

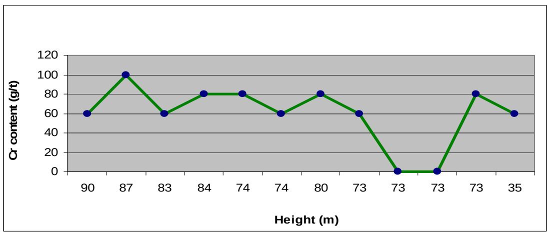

Fig. 7. Distribution of Cr along the Red Ravine depending on the relief.

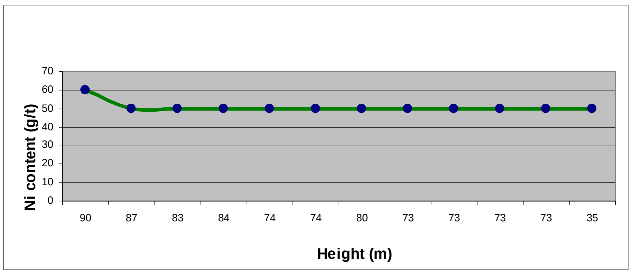

Fig. 8. Distribution of Ni along the Red Ravine depending on the relief.

As is seen from the plot of lead (Pb) (see Tab. 1 & Fig. 4) distribution at the Red Ravine, the lead content in soil is not characterised by large differences. Along the whole length of the relief, excluding several points, the lead content ranges from 30 – 32 mg/kg to 60 mg/kg. The maximum values 60 – 80 mg/kg are characteristic for the *estuary* and end of the ravine. Such lead concentration distribution is caused by the accumulation of a large amount of domestic waste in the ravine *estuary* (Fig. 9) and by the neighbourhood of ArcelorMittal Kryvyi Rih.

Fig. 9. The estuary of the Red Ravine.

The lead-containing elements are transferred to the middle part of the ravine due to water flow and east wind, which, according to archival meteorological data, is prevailing in this geographical area. At the middle part of the ravine, the gradual washout of lead-containing elements also takes place, as well as the washout due to periodical recultivation works provided by the local municipal administration. These two factors cause that the lead concentration in the middle part of the ravine only slightly exceeds the maximum allowed concentration, notwithstanding the immediate vicinity of ArcelorMittal Kryvyi Rih. The high lead concentration at the end of the ravine profile is caused by the dam located at the end of the ravine (Fig. 10), which prevents the further migration of heavy metals.

Fig. 10. The end of the Red Ravine.

According to some study works, there is an opinion that the lead distribution is caused by the washout of lead-containing elements by plants and further accumulation of the lead-containing elements in the humus layer. It is arguable that this opinion is correct due to the vicinity of the park area. Unfortunately, no experimental data are confirming this opinion.

The distribution of copper (Cu) (Tab. 1 & Fig. 5) concentration along the ravine profile is similar to the distribution of lead concentration, but with some differences. According to the study results, the copper concentration, as well as the lead concentration, is high at the *estuary* of the ravine (100 mg/kg), that is, the copper concentration is twice as large as the maximum allowable concentration in soil (55 mg/kg). Further, along with the ravine profile, the copper distribution is almost uniform, with a slight excess of the maximum allowable concentration in some areas. At the end of the ravine, the copper-containing elements do not accumulate, in contrast to the lead-containing elements. It is possible that this feature is caused by that the copper concentration depends on vegetation in a greater degree than the lead concentration. According to the results of studies (published electronically), there is a direct relationship between copper concentration in soil and copper absorption by vegetation. Copper concentration of 60 mg/kg is considered excessive. As is seen from the results of the atomic emission spectral analysis of the soil samples taken at the ravine, the average copper concentration conforms to this limit value. So, the copper-containing elements that could reach the end and accumulate at the end of the ravine are absorbed by vegetation due to the copper absorption capacity of the vegetation.

According to the effective normative documents, the approximate allowable concentration of zinc (Zn) (Tab. 1 & Fig. 6) in soil is 100 mg/kg. Relying on the results of the atomic emission spectral analysis, it is possible to state that the copper concentrations in the soils of the Red Ravine do not exceed the established limit values. However, the results of the comparative atomic emission spectral analysis with 2M HNO3 and 0,5M HCl demonstrate that this statement is not correct, as two analysis procedures have shown that the zinc concentration is from 154.87 mg/kg through 670.73 mg/kg for the majority of soil samples. The average zinc concentration is about 200 mg/kg, that is, exceeds the approximate allowable concentration two-fold. The zinc concentration at the ravine *estuary* is as high as the concentrations of the other studied heavy metals. The zinc concentration does not change along the ravine profile. The concentration does not depend on ground relief, prevailing winds, and water flows. The conclusion, which is possible on the basis of the data characterising the zinc concentration at the ravine end, is that recultivation works in combination with the absorption of migrating zinc-containing elements by vegetation have a positive impact on the reduction of zinc concentration at the ravine end, as no maximum concentration values were registered in the area adjacent to the dam.

Chromium (Cr) (Tab. 1 & Fig. 7) is somewhat distinctive among the elements analysed. The established maximum allowable chromium concentration is 100 mg/kg. According to the results of the atomic emission spectral analysis, the chromium concentrations do not exceed the maximum allowable values. The results of the atomic emission spectral analysis using 0,5M HCl confirm this conclusion and demonstrate that the chromium concentrations are relatively low. The results of the atomic emission spectral analysis with 2M HNO_3 demonstrate that the concentrations are higher and range from 104 mg/kg through 159 mg/kg, that is, the error is relatively low as compared with the preceding data. Therefore, it is possible to state that the first analysis results are reliable.

Considering the special properties of chromium, it is possible to assume that the sources of pollution of the Red Ravine are ArcelorMittal Kryvyi Rih and sediments of residential wastewater, as the ravine begins at the town district with private houses. According to the study results (Kovda, 1985, Baiseitiva, 2014, Dobrovolskiy, 1983), chromium in soils easy forms compounds with organic substances. Chromium migrates as a colloid component of a mechanical suspension. Usually, the characteristic feature of chromium is lack of its biogenic accumulation in a humus layer, as is confirmed by the results obtained by the authors of this paper (chromium concentrations do not exceed the maximum allowable concentration). Chromium is almost evenly distributed along the ravine profile depending on humus content (to a lesser extent), on grain-size composition (to a greater extent), and, particularly, on the accumulation of silt fraction, which is present in the Red Ravine in a sufficient amount.

According to the normative documents, the approximate allowable concentration of total nickel (Ni) (Tab. 1 & Fig. 8) in soils is 20 – 80 mg/kg. The study results demonstrate that the average nickel content in the soils of the Red Ravine does not exceed the maximum allowable value along the whole ravine profile and is 50 mg/kg and, occasionally, 60 mg/kg. It is stated (Perelman, 1984; Chertko, 2008; Drugov, 2007; Cholodov, 2006), that nickel in soils is not characterised by high mobility. Nickel basically concentrates in silt fraction. Depending on the thickness of soil covering, nickel migrates, in cationic form, in molecular solutions and compounds, although migration in mechanical suspensions is also possible. The properties above are characteristic, with sufficient accuracy, for the Red Ravine, and make it possible to explain the uniform distribution of nickel along the ravine profile. It is also possible that the low nickel concentrations at the Red Ravine are only caused by ArcelorMittal Kryvyi Rih, as there are no other plants and any enterprises where waste, oil, or gasoline might be burned. It is probable that there are other factors, specifically recultivation works, which have a positive effect of the dynamic characteristics of accumulation of heavy metals at the Red Ravine.

Ravine of Svystunova

Tab. 2. The content of heavy metals in Ravine of Svystunova.

Sample	Height [m]	Ni	Cr	Cu	Pb	Zn
18	88	50	0	50	0	80
19	86	50	0	10	0	0
20	88	50	20	8	10	0
21	84	50	30	10	0	0
22	83	50	50	20	30	0
23	96	50	30	10	10	80

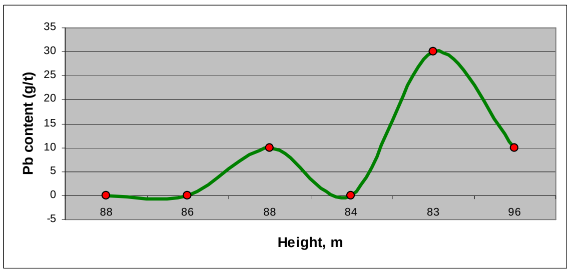

Fig. 11. Distribution of Pb along the Ravine of Svystunova depending on the relief.

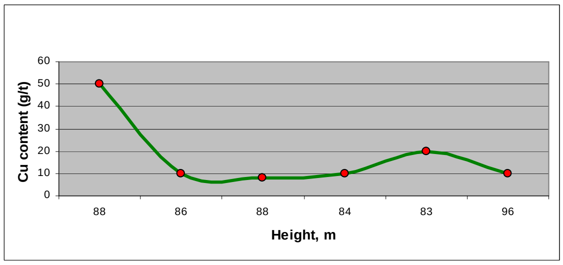

Fig. 12. Distribution of Cu along the Ravine of Svystunova depending on the relief.

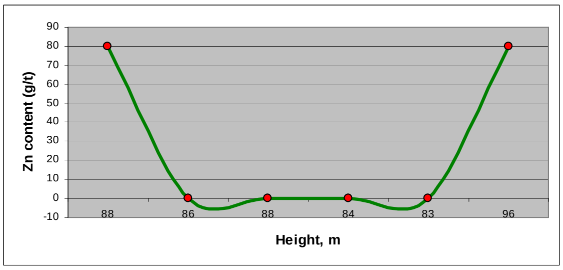

Fig. 13. Distribution of Zn along the Ravine of Svystunova depending on the relief.

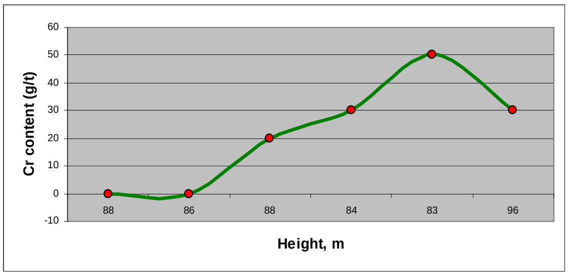

Fig. 14. .Distribution of Cr along the Ravine of Svystunova depending on the relief.

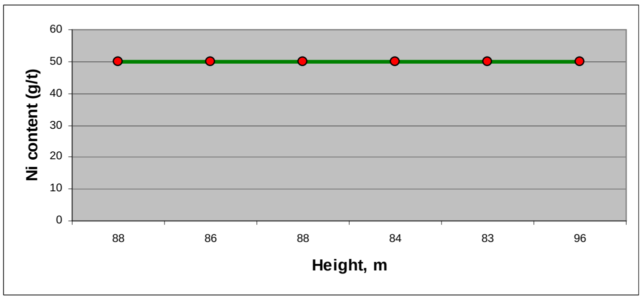

Fig. 15. Distribution of Ni along the Ravine of Svystunova depending on the relief.

The Ravine of Svystunova is used as a containment pond for the discharge of mine waters from four Kryvyi Rih mining plants (Fig. 16).

Fig. 16. Ravine of Svystunova.

According to the results of the ecological inspection performed in 2015, the annual volume of accumulated highly mineralised mine waters in the Svystunov Ravine is 12 million cubic meters. In the Ravine of Svystunova, mine waters are settled, additives in the mine waters are deposited, and then the cleared waters are discharged into the Ingulets River. Due to the dosed discharge of mine waters from the Svystunov Ravine according to the established limits, the concentration of heavy metals accumulated at the ravine has been significantly reduced. As is shown in Table 2, the concentration of each of the analysed elements does not exceed the maximum allowable concentration. It should be noted that there are some characteristic features of the heavy metal distribution along the ravine.

The concentrations (see Tab. 2 & Fig. 11, 14) of chromium and lead increase from the ravine *estuary* to the ravine's end, so it is possible to assume the significant impact of water and air flows on the concentrations.

The distribution of nickel (Fig. 15) along the ravine is as uniform as that at the Red Ravine, confirming the statement that nickel in soils is not characterised by high mobility. The continuous sedimentation of various impurities along the ravine promotes the formation of extensive silt deposits as basic environment for the nickel concentration. Because of this, the nickel concentration distribution along the ravine is uniform, as is shown on the plot of distribution.

The copper (Fig. 12) concentration along the ravine profile is significantly reduced in the area near the ravine end. The analysis results demonstrate the availability of fluctuations of copper concentration (8 – 20mg/kg) due to the absorption of part of nickel-containing elements by vegetation additionally to the discharge of excessive mine waters into the Ingulets River.

Tailing pit between Mekhanobrchermet, South Open Pit, and Hihant-Glyboka Mine

Tab. 3. The content of heavy metals in tailing pit between Mekhanobrchermet, South Open Pit, and Hihant-Glyboka Mine.

Sample	Height [m]	Ni	Cr	Cu	Pb	Zn
24	80	50	50	20	30	60
25	78	50	30	10	20	50
26	81	50	3	30	50	0
27	76	50	30	20	20	100
28	71	50	0	10	20	100
29	71	50	0	30	20	100
30	80	50	0	20	20	80
31	83	50	30	0	20	0

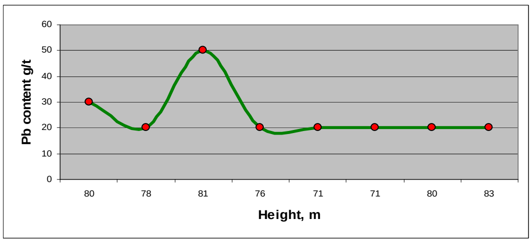

Fig. 17. Distribution of Pb in tailing pit between Mekhanobrchermet, South Open Pit, and Hihant-Glyboka Mine depending on the relief.

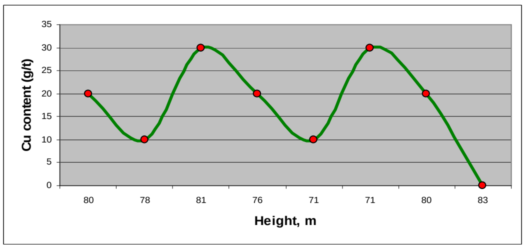

Fig. 18. .Distribution of Cu in tailing pit between Mekhanobrchermet, South Open Pit, and Hihant-Glyboka Mine depending on the relief.

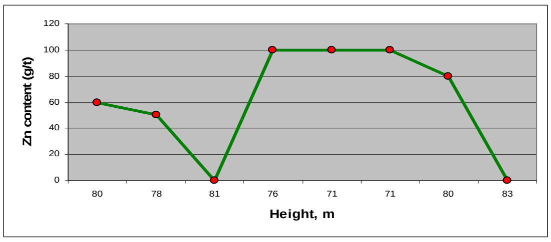

Fig. 19. Distribution of Zn in tailing pit between Mekhanobrchermet, South Open Pit, and Hihant-Glyboka Mine depending on the relief.

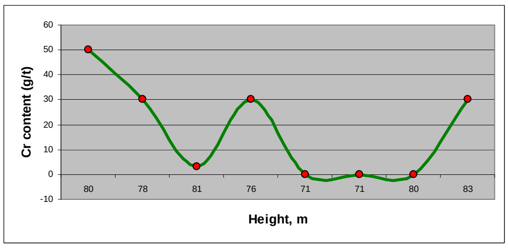

Fig. 20. Distribution of Cr in tailing pit between Mekhanobrchermet, South Open Pit, and Hihant-Glyboka Mine depending on the relief.

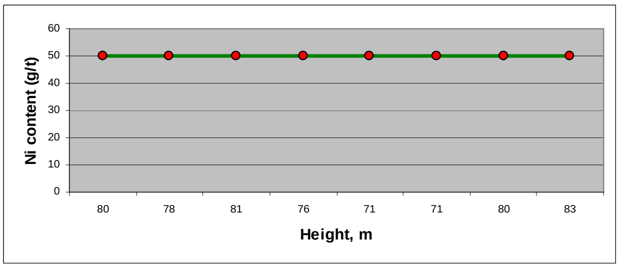

Fig. 21. Distribution of Ni in tailing pit between Mekhanobrchermet, South Open Pit, and Hihant-Glyboka Mine depending on the relief.

The third study area that is the tailing pit (Fig. 22) located between Mekhanobrchermet, South Open Pit, and Hihant-Glyboka Mine is characterised by relatively uniform ground relief with altitude differences not more than 8 – 10m.

Fig. 22. Tailing pit between Mekhanobrchermet, South Open Pit, and Hihant-Glyboka Mine.

The location of the tailing pit is the cause of availability of various sediments and formations within the tailing pit. The samples taken within the pit are presented by various bottom deposits, products of iron-ore dressing, mud mixed with mine waste, sediments from mine water, and ordinary quartz sand.

When analysing the plot of lead (Tab. 3 & Fig. 17) concentration distribution along the tailing pit perimeter, No. 26 point should be distinguished. At this point, the lead concentration is 50 mg/kg, that is, the lead concentration is one and a half the maximum allowable concentration. As compared with the other values, this maximum value is abnormal and may be considered unreliable. The other factor, which does not allow the lead concentration distribution plot to be accepted, is the low lead concentrations (lower than the concentrations determined by atomic emission spectral analysis) obtained by atomic absorption spectral analysis with 2M HNO_3 and 0,5M HCl. The difference between the results obtained by using these analysis procedures is far less as compared with the results of the atomic emission spectral analysis. The results of the atomic absorption spectral analysis are more reliable. Therefore, the lead concentration along the perimeter of the tailing pit is uniform, probably due to lack of any express factors promoting migration of lead.

According to the results (Tab. 3 & Fig. 18) of the atomic emission spectral analysis, the copper concentration distribution along the tailing pit profile is characterised by periodical changes in directions of increase and decrease. Although the lead concentrations do not exceed the maximum allowable concentration, the sampling inspection of the data by atomic emission spectral analysis has demonstrated that the data at some points should be rejected. As a result, the copper concentration distribution is more uniform and smooth and is 15 – 20mg/kg on the average. Such low copper concentrations can be caused by a large amount of vegetation, which absorbs lead-containing elements, and the vicinity of the Saksagan River. Lead-containing elements reaching the river does not have a significant impact on the ecological state of the river but contribute to the unfavourable ecological state of the environment caused by the tailing pits of the Motherland Mine located down-stream of the river.

The zinc (Tab. 3 & Fig. 19) concentrations obtained in the studied area are contradictory. According to the plot of zinc concentration distribution obtained from the results of atomic emission spectral analysis, the zinc concentrations are close to the maximum allowable concentration at the west edge of the tailing pit, which is located nearer to the South Open Pit and far away from the Saksagan River. At the other points along the perimeter of the tailing pit, the zinc concentrations are significantly lower. It is possible that this feature is caused by the transfer of settled particles of zinc-containing elements by the east wind from the higher east bank to the lower (by 10m) west bank of the tailing pit. According to the results of the sampling atomic emission spectral analysis, the zinc concentration distribution plot is not correct, so the maximum allowable concentration at the west bank of the tailing pit is not achieved, and the average zinc concentration is 20 – 60 mg/kg. These data demonstrate that there are no active external factors affecting the process of accumulation of zinc-containing elements. According to the opinion of the authors of this paper, such factors are improbable. Because of this, the zinc concentration distribution plot obtained according to the results of the atomic emission spectral analysis is accepted.

The plot of chromium (see Tab. 3 & Fig. 20) concentration distribution is also doubtful. According to the results of the atomic emission spectral analysis, the accumulation of chromium-containing elements depends on the change of the relief height along the perimeter of the tailing pit. There is the trend to the accumulation of zinc-containing elements in the higher north-east areas of the tailing pit. There is virtually no zinc concentration in the south-west areas of the tailing pit. These results were considered as doubtful. Therefore, the samples were additionally analysed by performing atomic absorption spectral analysis procedure. The analysis results obtained were absolutely different. The conclusion is that the first method and the method with atomic absorption spectral analysis procedure with 2M HNO_3 are not correct, because the first method provides underestimate concentration values, and the second method provides overestimate values. The optimal is the method with atomic absorption spectral analysis with 0,5M HCl because the results of the atomic absorption spectral analysis with 0,5M HCl correspond to the actual chromium concentration of 30 – 60 mg/kg to the greater extent. The location of ore mining and processing plants close to the river with a water storage basin positively promotes processes of accumulation and deposition of silt fraction. From the preceding description, it is known that these processes are more characteristic for chromium accumulation as compared with hummus.

The fourth study area encompasses sufficiently ample territory (Fig. 23). For this reason, the area was divided into three parts: the tailing pit of the Central Mining and Processing Integrated Plant, which is located at the thalwegs of the Great Lozovatka and Small Lozovatka ravines; the perimeter of the tailing pit of No. 1 Open Pit, and the west edge of No. 1 Open Pit.

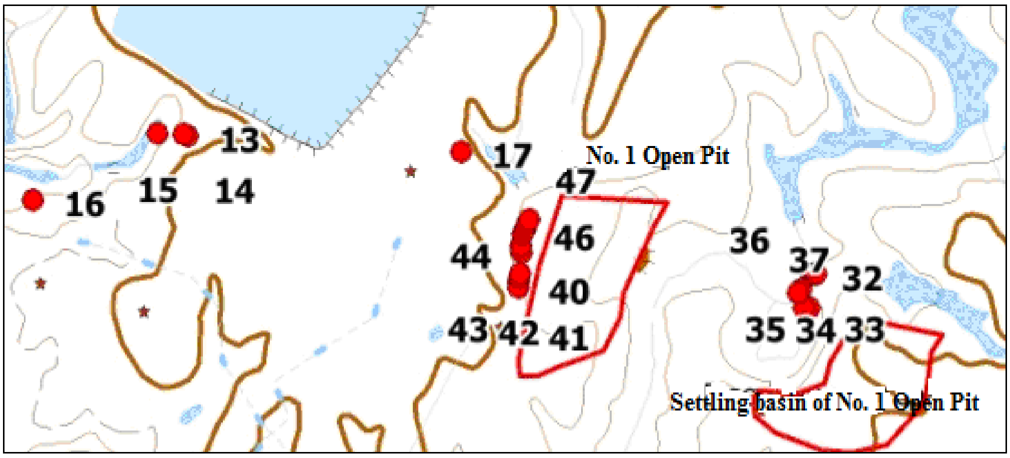

Fig. 23. An overview map of the northern research objects.

The results of the study of the distribution of heavy metals within the tailing pit of the Central Mining and Processing Integrated Plant by using the aforementioned methods have demonstrated the inaccuracy of the method with atomic emission spectral analysis, because both the procedures of atomic absorption spectral analysis with 2M HNO_3 and 0,5M HCl has confirmed the presence of higher concentrations of heavy metals, as compared with atomic emission spectral analysis. The results of the analysis of the distribution of heavy metals along the tailing pit profile have demonstrated only the excess of the maximum allowable concentration of chromium (the average chromium concentration is 150 – 160 mg/kg). The concentrations of other elements fluctuate (except nickel) but do not exceed the maximum allowable values. These results confirm the conclusion that heavy metals do not have a significant impact on chemical processes possible for deposit accumulation in the current conditions.

When analysing the three-dimensional distribution of heavy metals, such as copper, lead, and nickel, within the tailing pit of No. 1 Open Pit, the trend is detected for the accumulation of heavy metals in higher concentrations if the study areas are located close to the tailing pit. The more is the distance between the study areas and the tailing pit; the lesser is the concentration of heavy metals in the area. Analysing the plot of chromium distribution (Tab. 4 & Fig. 24), the increase of chromium concentration at a distance from the tailing pit margin is caused by the effect of municipal wastewater but not the impact of No. 1 Open Pit.

Tab. 4. Distribution of heavy metals along the tailing pit of No. 1 Open Pit.

Height [m]	**Cr**
14	43
17	10
19	20
23	25
24	8
73	32
70	59
45	76

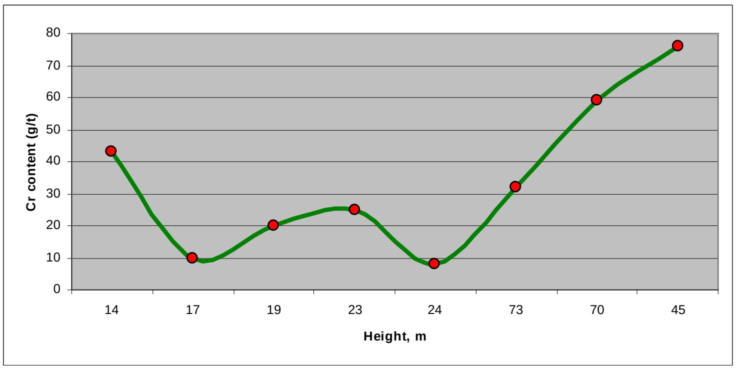

Fig. 24. Distribution of Cr along the tailing pit of No. 1 Open Pit depending on the relief.

It should be noted that the concentrations of all the elements do not exceed the maximum allowable concentrations for these elements. It is possible to explain this feature by the vicinity of the significantly larger tailing pit of the Central Mining and Processing Integrated Plant, which receives the most amount of mining waste.

The last object studied is the west edge of No. 1 Open Pit (Tab. 5). This area is unique by that samples were taken directly at the mining plant.

West edge of No. 1 Open Pit

Tab. 5. Distribution of heavy metals along the edge of No. 1 Open Pit.

Sample	**Height** [m]	**Ni**	**Cr**	**Cu**	**Pb**	**Zn**
40	69	100	200	100	40	80
41	72	300	50	100	30	200
42	71	40	60	60	40	0
43	70	50	50	50	50	0
44	76	10	10	10	10	0
45	78	20	30	20	20	0
46	81	80	50	50	40	50
47	79	20	40	20	40	0
48	79	80	50	40	40	0
49	79	80	60	40	40	50

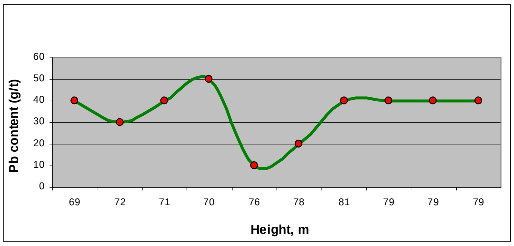

Fig. 25. Distribution of Pb along the edge of No. 1 Open Pit depending on the relief

Fig. 26. Distribution of Cu along the edge of No. 1 Open Pit depending on the relief

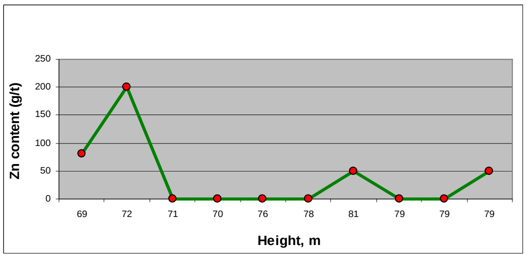

Fig. 27. Distribution of Zn along the edge of No. 1 Open Pit depending on the relief

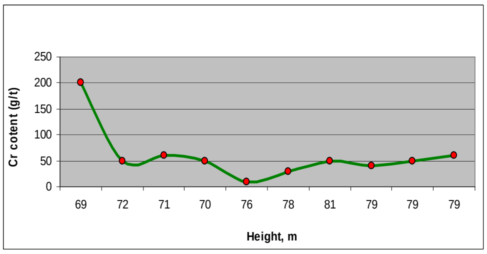

Fig. 28. Distribution of Cr along the edge of No. 1 Open Pit depending on the relief

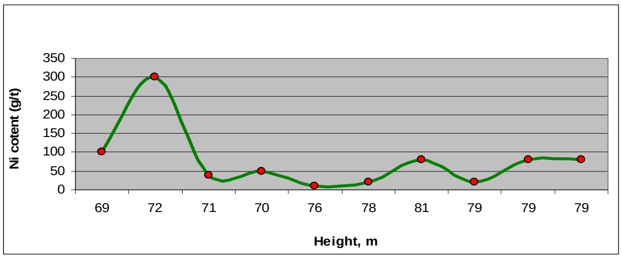

Fig. 29. Distribution of Ni along the edge of No. 1 Open Pit depending on the relief.

In the south-west part of the pit edge, the concentrations of all the heavy metals (see Fig. 25-29) increase and exceed the maximum allowable concentrations. The west part of the pit edge is characterised by the even distribution of heavy metals, which concentrations are close to the maximum allowable concentrations. It is possible that the accumulation of heavy metals in these areas is caused by the impact of prevailing north-east winds, which promote the transfer of deposits with accumulated heavy metals.

Conclusions

The results of the performed studies have confirmed that the accumulation of heavy metals in the geologic environment is affected by mining and processing plants, as well as by domestic waste and municipal wastewater. Additionally, prevailing winds and ground relief have been taken into account as additional factors in the distribution of heavy metals. The trend to active absorption of some part of heavy metals by vegetation has been confirmed. The absorption of heavy metals, in combination with periodic recultivation works, significantly reduces concentrations of heavy metals to the levels not exceeding the maximum allowable concentrations, excluding the concentrations of heavy metals in areas which are located close to mining sites.

In our opinion, in order to achieve more significant results, the reclamation works of the geological environment in Kryvy Rih has to be complemented by some additional measures. Regarding the objects located in the centre of the city (Red Ravine, the tailing pit, used for hydro projection now, which is located between Mekhanobrchermet, South Open Pit, and Hihant-Glyboka Mine), regular annual removal and replacement of contaminated soil would be appropriate. As follows, several goals could be achieved: the risk to human health could be significantly reduced because, despite the proximity to the metallurgical enterprise, the area along the ponds in the Red Ravine is still considered as "beach" ones. Also, the probability of intensive subsidence and failure within the tailings storage could be reduced because the regular flooding by mine water creates a constant risk in those areas. Another additional measure to remediation works may be the active use of plant adaptation possibilities. Namely, the practical use of the research results of the Orlovsky breeding institute in Kryvy Rih. In the city boundaries, the use of plant-concentrates of heavy metals may be appropriate, because, in this case, it is possible to remove their subterranean and underground masses regularly (the best would be every 2-3 years) and plant the area with new green plantations. On the outskirts of the city, it would be more appropriate to use plants that are not characterised by the accumulation of heavy metals in fruits and are relatively stable to the conditions typical for the vicinity of quarries and tailing storages. Among such plants, according to climatic and geological conditions of the Kryvyi Rih, the most suitable would be sea buckthorn, currant, raspberry and cherry.

These measures can significantly improve the efficiency of remediation works, and therefore reduce the level of anthropogenic load on the geological environment, allowing assimilation processes proceed times faster.

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Position of the chosen industrial companies in connection to the mining

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Mining is connected with various industrial sectors. Especially mining and metallurgy present one of the most important sectors in some countries, presenting contribution to the state economy. Therefore, its position is greatly influenced by the position of the connected industrial companies, mainly metallurgy and metal production. On the other hand, the ability of the company to develop and introduce its activity to the market depends on its financial performance. The goal of the contribution is to evaluate the position of 50 chosen industrial companies in Slovakia from the view of chosen performance and indebtedness indexes. Similarly, we analyse the size categories and position of the companies in the area of restructuring, liquidation and payment orders. The analysis had been made by statistic program R that is proper for the creation of statistic models and data analysis. The result of the evaluation in the contribution presents cluster analysis, through which we determine companies' clusters from chosen sectors according to chosen financial indexes. The results confirm the position of the analysed companies in the frame of the sector is satisfactory. Improvement of the economic activity of industrial companies determines conditions for the possible improvement of mining and metallurgical business activity and finds the sources of companies' growth.

Keywords: *mining, industrial companies, metallurgy, financial performance, Slovakia*

Introduction

One of the most significant factors, influencing industrial companies, is the high energy consumption. Thus, energy-saving alternative mining and mineral processing methods are considered to improve the processes economically and environmentally (Kamradt et al., 2018). As for the connection of mining and metallurgical industry, there is necessary to do multi-disciplinary research to develop a concept of ores mining and its using in metallurgical production. Such a concept had been developed by Kamradt et al. (2012) for the recovery of base and trace metals from the bearing dumps. The concept can combine resource-efficient use in mineral processing and sustainable utilisation of mines. Presently industrial companies need to improve their competitive power for optimum allocation of their resources and stimulation of the growth in the market.

An integral competitive power indicator for companies and industries provides a basis for creating a monitoring database of competitive power ratings for industries, enhancing transparency of national companies' success, as compared with similar foreign industrial companies and governmental support of the best companies on a competitive basis (Danilová and Karetniková, 2016). Improvement of the economic activity of industrial enterprises implies the development of new methods, forms and mechanisms of creating and mastering of new competitive products designed to ensure the predominant position of enterprises on domestic and foreign markets. It appears that in contemporary entrepreneurial environment industrial enterprises that are able to realise regular and targeted changes survives. Therefore, the ability of the company to develop and introduce to the market its new product depends on its financial performance (Kulikova et al., 2016). These changes or innovations are implemented not only for survival but also for gaining significant market position. Innovation is supposed to be the creative destruction of current status, and a tool to enhance long-term competitiveness and necessary condition for a successful business (Peterková and Ludvík, 2015).

Industrial companies must achieve continuous improvement in all areas of business when financial improvement had special effects on company improvement (Gumerov et al., 2015). The purpose of the paper is to determine conditions for the possible improvement of mining and metallurgical enterprises activity of the business and find the source of their growth. Mining and metallurgical companies have an irreplaceable task in the country economy – in the creation of working posts, the flexibility of the market mechanism and the creation of value added.

State of the problems

The mining and metallurgy present one of the important sectors in some countries. It has its strategic importance and plays a pivotal role in influencing the economy of the country (Karthick and Kasthuri, 2015). The mining industry is closely connected with other industrial sectors, especially metallurgy. Both industries are very similar, for example, due to the generation of residues (Cruz-Hernández et al., 2018). It is alarming that

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waste from mining and metallurgy presents an opportunity for integrated economic development, particularly in the recycling sector. In this area, Mulopo (2015) investigates the recovery of water and the selective removal of valuable metals from acid mine drainage (AMD) using sulfidation media (CaS) derived from waste gypsum. The major problem has always been that the mining sector generates a large number of waste streams which show strong differences in time. Also, Muravyov et al. (2014) investigated the process for the recovery of copper and zinc from mining and metallurgical wastes. The work is a perspective and a promising technique for the complex treatment of mining and metallurgical wastes. Some materials, produced in metallurgy, are used in mining (Malewski, 2017; Feroze and Genc, 2016). The desire to reduce the cost of coal mining leads among others to look for new, more cost-effective ways to protect mines. Rotkegel et al. (2013) show that the mine support is more than 60% by weight and material costs. Therefore, the work focused on the search for more efficient mine supports should primarily include high-performance. One task was to develop a new type of mining and metallurgy production, serving especially as economic pillars (Rao et al., 2018). Also, Tost et al. (2018) explore if the current efforts of the largest mining companies are aligned with the efforts of companies from other industry sectors. According to Vilamová et al. (2016), the evaluation of metallurgical organisations will not be based solely on the technical parameters, but also on the criteria affecting the cost of the entire process, including the logistics aspects. In the long run, this concept can bring metallurgical organisations many competitive advantages of use quality quantification model. Kozel et al. (2017) use a Balanced Scorecard, which represents a suitable tool for increasing the competitiveness of industrial companies and It allows measuring the performance of metallurgical companies in a more complex manner.

Metallurgical industry can be divided into the metallurgy of iron and steel – black metallurgy, producing around 95% of metallurgical production whole world. Raw iron is produced in a blast furnace. The iron is processed further to the steel, which means iron alloy (Fe), carbon (C) and small percentage of other elements, as for example aluminium (Al), manganese (Mn), silicon (Si), chrome (Cr) or nickel (Ni) (so-called alloying mixture) that improve physical and chemical characteristics of the steel. Also, iron scrap or waste is used for steel production. The second group presents metallurgy of non-ferrous metals, where production of aluminium (Al) belongs, and tin (Sn), lead (Pb), and nickel (Ni) or mercury (Hg). The elements are negligible due to their content, but due to their importance, there is necessary to consider also with an orientation to the obtaining and processing of precious stones – gold (Au), silver (Ag) and platinum (Pt) (Majerčaková, 1988). Metal production is represented by the iron and steel industry. These industrial sectors are connected with high consumption of material and energies, providing from mining. More than half of the material input presents output by way of waste gas and solid waste – secondary products. The most serious emissions are polluting elements, emitted to the air, while emissions from agglomeration treatments are prevailing. Despite considerable effort to decrease emission, the rate of the sector on whole emissions to the air is in EU considerable at a high number of polluting elements, mainly in case of some heavy metals and PCDD/F. The rate of repeatedly used and recycled solid waste / secondary products had been increased considerably, but noticeable volumes are further stocking at the waste stocks (European Commission, 2014).

Any company that is part of the economy in a given state exists in a specific environment that is influencing the company, which is called the business environment. Presently emphasise is given to the overcoming of a various obstacle in business, as, for example, survival at the market and achievement of appropriate profit. To achieve mentioned goals, there is necessary to create a strategy of the company, at which considerable changes must be accepted in an external and internal environment that force the company to adapt, as well as to improve and innovate its product or service. The assumption for such obstacles overcoming presents a complex financial evaluation of the company position in the economy. The base is to make ex-post and ex-ante analysis according to accounting reports – balance sheet, loss and profit statement and internal documents, informing about some employees, sale and supply activity, etc. There is necessary to mention that the finances of the company are influenced by great number of mentioned internal and external indexes, as, for example, interest rate, accounting method, used in the chosen company. Measuring of performance through financial indexes can be viewed as a system that presents file of indexes, used for quantification of company effectiveness and efficiency of its activity. It can be perceived as a process of reporting, giving feedback to employees according to the results of their activity. From the strategic view, we identify two various aspects of the system for measuring business performance. It reflects process, used during the selection of proper performance measures in the frame of organisation strategy. On the other hand, the system provides information necessary for doubting of importance and strategy applying in the company (Rodrigues, 2018).

Impact of specific property and capital structure of the companies from the sector to the financial health of the company can be extended by the impact of the companies in the living environment. Great importance from this view is given to the production of a considerable volume of waste with various chemical and physical structures (Fazekašová et al., 2015). In the past, the majority of waste had been stocking on the dumps in the immediate surrounding of metallurgical operations without regard to their character and structure, as well as without possibility of their future selective using. Presently, the majority of metallurgical waste is recycled or used in the frame of other industrial sectors. Despite mentioned, there are still wastes that make problems due to their impossible using. Emissions of metallurgical companies present traditional polluting elements: TZL, SO_2, NO_X a CO. Presently, the attention is given to the pollution by heavy and other metals, as, for example, arsenic, mercury, lead, chromium and cadmium, which contaminate not only surrounding of the companies but mainly soil fond. Similar problems are in the area of establishment of Technological Knowledge Intensive Business Services - (T KIBS) in the company from the area of mineral water wells had been evaluated by Ferencz et al. (2015), presenting very simple and purpose build model for T KIBS implementation. The approach decreases the costs considerably on T KIBS implementation in practice, and the company obtains qualified top specialists and developers for relatively low cost during the necessary period. In the end, the implementation of the model influences positively financial health of the company due to the cost decreasing and profit increasing from the area of mineral water wells in Slovakia.

Methodology and data

The goal of the contribution is a detailed analysis of the position of 50 biggest companies through achieved profit in the area of metal production and metallurgy in 2016. For the achievement of the main goal, basic general logical methods were used – analysis, synthesis, comparing, induction, deduction and selection. Due to the detailed analysis and detail explanation of results, statistical methods are used, based on analysis by Pearson correlation coefficient. The analysis is made in statistic program R that is convenient for creation of statistic models, data analysis and graphical analysis of data.

The analysed sample presents a selection of biggest companies from the view of achieved profit in sector Metal production and Metallurgy. According to economic structure SK NACE, companies in the sector deal with the following activities:

- Forging, stamping, stamping and rolling of metals; powder metallurgy [25500],
- Cultivation [25620],
- Casting of light metals [24530],
- Casting of other non-ferrous metals [24540],
- Iron casting [24510],
- Processing and surface metal treatment [25610],
- Wire drawing cold [24340],
- Cold forming or cold storage [24330],
- Production of wire products, chains and springs [25930],
- Aluminum production [24420],
- Production of metal constructions [25110],
- Packages production from light metals [25920],
- Production of steam boiler except for boilers for central heating [25300],
- Production of radiators and boilers for central heating [25210],
- Production of pipelines, hollow profiles, and related accessories from steel [24200],
- Production of raw iron and steel and ferry-alloy [24100],
- Locks and hinges production [25720].

Figure 1 illustrates analysed companies, structured according to size categories. This provides one of the basic information about the companies. Further, we considered the number of employees, operation in the frame of the region, but we defined chosen companies also from the view of debt, restructuring, ownership, payment order and liquidation.

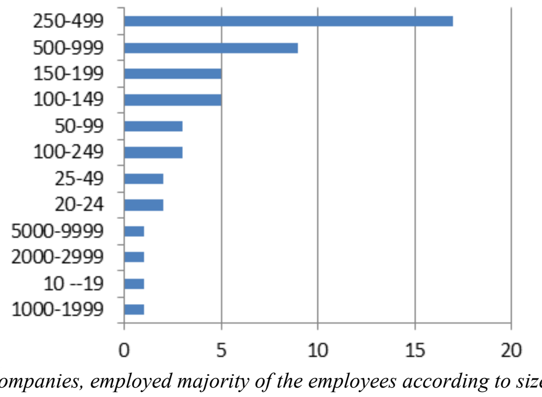

Fig. 1. Companies, employed majority of the employees according to size category
Source: own processing according to companies database.

According to the document of Ministry of Economy in Slovakia (2017) „Characteristics of metal and metal production in Slovakia in 2015-2016“, the sector records proven decrease of sales, which caused also decreasing of employees. Production of raw iron and steel and ferry-alloy (SK NACE 241) in 7 companies had been provided by 11 063 employees (annual decrease by 5,2 %), in the first half of 2016 10 996 employees had been working (annual decrease by 2,4 %); and in three quarters in 2016 average recorded number of employees was 10 985 (annual decrease by 1,5 %). By the end of the year, we recorded an average number of employees at level 10 955, presenting according to annual comparing decrease by 0,98 %. Production of pipelines, hollow profiles and accessories from steel (SK NACE 242) in 7 companies had been provided by 3 519 employees (annual decrease by 2,2 %), in first half it was 3 471 persons (annual decrease by 5 %) and in three quarters in 2016 average recorded number of employees was 3 524 (annual decrease by 4,1 %); to the end 2016 average recorded number of employees was 3 523 (annual decrease by 0,10 %).

In production of other products during first steel processing (SK NACE 243) - in 12 companies 2203 employees worked (annual growth by 12 %), in first half of the year the number presented 2 160 persons (annual growth by 0,5 %) and in three quarters in 2016 the average number of employees was 2 156 (annual decrease by 1,6 %), to the end of the year the average number of employees presented 2 169 (annual growth by 1,6 %). A similar development can be shown by rates of the companies according to the individual county in Slovakia, illustrated by Figure 2.

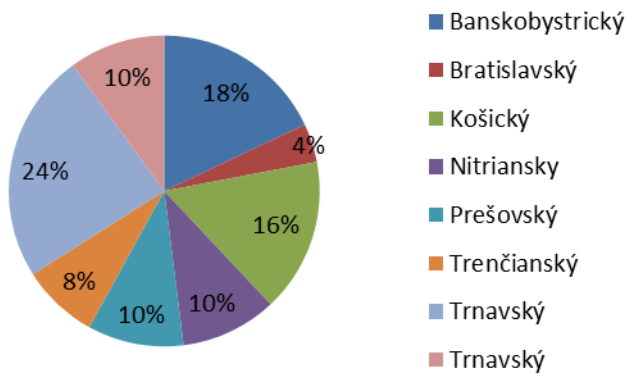

Fig. 2. Percentage rates of the metallurgical companies according to the individual county in Slovakia
Source: own processing according to companies database.

From the view of ownership, companies present in 27 cases foreign ownership, private domestic ownership is presenting by 8 companies, and 13 companies are ranked to the international private ownership. Table 1 follows chosen indexes from a legal view as, for example, restructuring, payment orders and liquidation. Due to the holding of economic growth and providing of stable financial performance company can use, for example, a restructuring that presents important attribute of whole business sphere transforming. The need of restructuring means first of all decision of its implementation, but it is also closely connected with the effectiveness of economic activity in given economic environment that could influence payment orders, liquidation of the company or its indebtedness.

Tab. 1. Review of chosen indexes from the legal view

	Yes	*No*
Debts	*2*	*48*
Restructuring	*Terminated restructuring*	*49*
Payment orders	*12*	*38*
Cancellation	*0*	*50*
Liquidation	*0*	*50*

Source: own processing according to companies database

Data show that 48 companies do not record any debts against social and health insurance authorities or other state administration. On the other hand, two companies record the debts. In the case of one company, the restructuring terminated in 2016 and other companies do not have any problems in the legal area. In the research we dealt with chosen indexes of performance – ROE – return on equity, debt / EBITDA (earnings before interest, taxes and depreciation), profit margin, total indebtedness, net debt, but also flow indicators, obtained from financial reports of chosen companies, mainly equity, sales, profit and value added.

Results

Table 2 presents basic descriptive statistics of chosen financial indexes as, for example, average, standard deviation, median, minimum and maximum. The statistics can describe qualitative and quantitative characteristics of the searching sample. Descriptive data statistics is necessary mainly for relations analysis through the Pearson correlation coefficient.

Tab. 2. Descriptive statistics of chosen financial indexes.

	average	*standard deviation*	*minimum*	*maximum*	*median*
ROE	*18,1*	*45,7*	*-123,0*	*239,4*	*14,3*
Debt/EBITDA	*-4,4*	*35,4*	*-197,8*	*9,4*	*0,9*
Profit margin	*4,7*	*12,4*	*-65,5*	*42,7*	*4,2*
Equity	*48991785,3*	*167199895,4*	*-17605788,0*	*1173044000,0*	*12363939,0*
Total indebtedness	*65,9*	*38,2*	*16,5*	*210,1*	*63,5*
Sales	*115626400,9*	*285796685,5*	*23803592,0*	*2034734000,0*	*43061754,5*
Profit	*9680067,5*	*38219519,4*	*-15770571,0*	*270514000,0*	*1791221,0*
Value added	*27935071,9*	*94653521,1*	*530774,0*	*678766000,0*	*8881440,5*
EBITDA	*11453543,0*	*33415931,3*	*-11813318,0*	*228839000,0*	*3996170,0*
EBITDA margin	*7,9*	*12,3*	*-49,1*	*29,2*	*8,2*
Net debt	*856670,5*	*24691823,3*	*-123128000,0*	*76474777,0*	*-57208,0*
Net debt/EBITDA	*-3,6*	*27,7*	*-196,4*	*7,6*	*-0,1*

Source: own processing according to the database of companies

Table 2 shows various disproportions between financial indexes. As for ROE, there is the difference between the minimal and maximal value of the indexes – while company with the worst ROE – negative 123 % (the company is illiquid), company with the highest liquidity managed to evaluate equity by 239, 4 %. In average, analysed companies achieve values of equity, sales, value added at the level of positive numbers.

Subsequently, we used the method of the cluster, dividing companies into clusters according to the similarity of the indexes and at the same time according to the characteristics of other clusters indexes. According to chosen financial indexes, we can rank companies to individual clusters that have similar characteristics and that are different from companies' characteristics in other clusters. During the process, we used the Ward method, while due to the determination of similarity Euclidean distance had been used. The statistical analysis had been done in program R that is appropriate for the creation of statistic models and data analysis, and it is convenient for creation of graphical data analysis. However, due to the cluster analysis, there is necessary to exclude statistically important, but weaker dependences, since they could distort the result of cluster analysis. Figure 3 illustrates for example that for debt/EBITDA, equity, net debt, net debt/EBITDA, all coefficients are statistically unimportant.

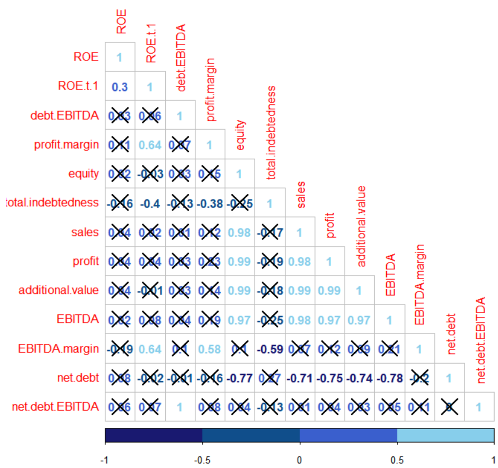

Fig. 3. Analysis of relations by Spearman correlation coefficient
Source: own processing in R program.

For EBITDA indexes and additional value, some of their mutual correlations are statistically important at the level with 0, 05 importance. It means there could be a problem to create clusters in cluster analysis. Therefore, there is necessary to use analysis of main components. Consequently, there is necessary to determine how many components must be in former financial indexes. According to the screen plot of main components and variance of original data, we determined 6 main components that explain 95, 83 % of original data variance (Fig. 4).

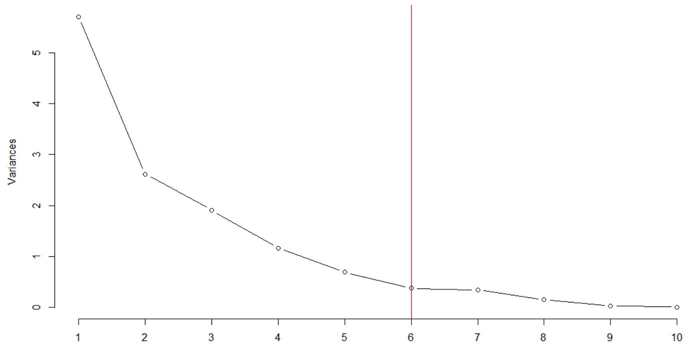

Fig. 4. Screen plot of main components
Source: own processing in R program.

The further process presented a selection of some companies' clusters in the analysis. According to the heuristic approach, we divided file to 8 clusters. However, we resulted also from previous Screen plot, where x-axis illustrates the number of clusters and y-axis presents an internal cluster by the sum of squares. Decisive criteria are minimising of internal cluster sum of squares, presenting optimal state (Fig. 5).

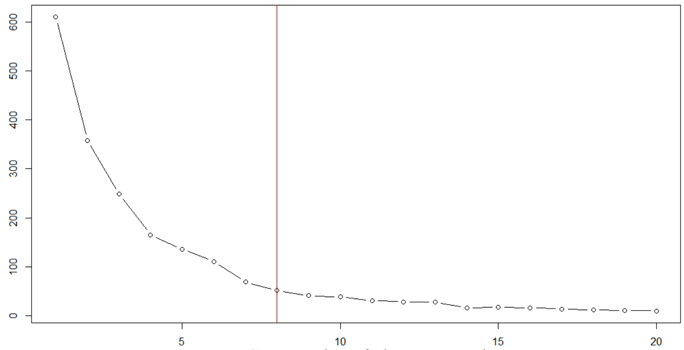

Fig. 5. Screen plot of clusters number
Source: own processing in R program.

Consequently, clusters had been illustrated in a hierarchic tree, where individual clusters are denoted in Figure 6. Every company is denoted by the number. 8 clusters are created that are mutually heterogeneous, but companies in the frame of its cluster are homogeneous.

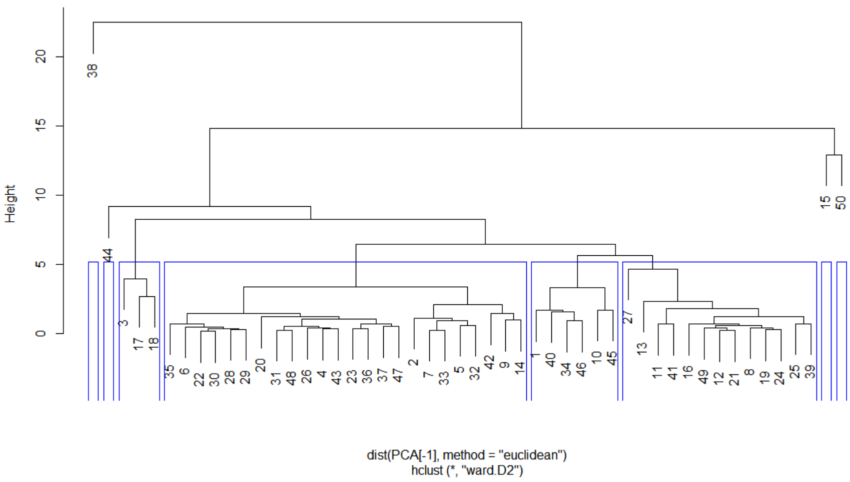

Fig. 6. Hierarchic trees from companies cluster
Source: own processing in R program.

Discussion

Results of the analysis present clusters of companies. We can see there are 8 clusters, where 4 clusters consist of one company, 4 clusters consist 3,6,13 and 24 companies from the area of metal production and metallurgy. Some companies in clusters influenced chosen financial indexes. Alone companies in clusters present result of extreme values of financial performance against other comparing companies. However, the prevailing part of companies creates numerous clusters that are similar to the view of their financial indexes. Table 3 presents centroids (averages) from created clusters of companies. Average values of financial indexes from most numerous clusters are denoted by yellow colour (Tab. 3).

Tab. 3. Centroids of created clusters.

Group.1	ROE	ROE.t.1	debt.EBITDA	profit.margin	equity
1	56.54254	56.438000	0.1349862	10.938175	32820567
2	10.93964	13.193304	2.7897279	2.263540	12804782
3	-69.98098	0.000000	0.0426860	14.725469	-10783589
4	16.34484	12.074063	0.1726122	8.136488	62734915
5	0.00000	0.000000	-197.8250000	-2.452580	-371247
6	23.06086	4.597856	0.0000000	13.409900	1170000000
7	239.42430	-0.510190	-2.6682300	18.134420	2397000
8	0.00000	-146.129000	-1.0048400	-65.541400	-13000000

	total.indebtedness	sales	profit	additional.value
1	64.60291	143173582	11783730	31769087
2	66.47627	58131985	1142263	8449175
3	157.06320	36065447	5239866	2482800
4	30.82524	94977951	8612935	23206401
5	101.37140	93518613	-2283486	5184351
6	33.88400	2030000000	271000000	679000000
7	95.53665	31647000	5739000	8913000
8	210.11150	24255900	-16000000	1363912

Source: own processing in R program.

Average index ROE in 2016 presents 16, 34 %, in the previous year it was 12, 07 %. Value of equity is over 62 million Euro, sales almost 95 million Euro and profit achieved average value 8, 6 million Eur. Generally, the financial situation of the companies in the analysed area is sufficient, not only from the view of the analysed indexes but also from the view of the number of restructuring, payment orders, debts and liquidations.

Summary

During the recent economic crisis and the recovery period, there is a need to study the position of the companies that contribute to economic growth. Many studies attempted to understand the contribution of individual sectors to the state economy. Such studies express the situation in individual sectors, reaction to the crisis and geopolitical situation in single Europe. There is space to deal also with other sectors, connected with mining, as well as to study the influence of a single mining sector to other industries. Affect the financial health of the mining enterprise may also affect the various legislative and technical changes. According to Mikoláš (2015), the implementation of brown coal mining beyond the existing TEL together with the use of clean coal technologies and renewable energy solutions programs, including energy savings can provide a stable fuel and energy balance of the Czech Republic until at least the year 2060, if the reserves at Bilina and CSA open-cast (II. phase) will be used. If the resources from the CSA open-cast are also used in the III. and IV. phase, the balance is secured beyond the horizon of the year 2100.

***Acknowledgement**: The contribution is part of the project VEGA No. 1/0515/18 "The decision-making model of process of evaluating raw material policy of regions" and project KEGA No 031/TUKE-4/2016 "Education of university students with technical orientation to the need of global job market."*

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Reliability of parallel and serial centrifugal pumps for dewatering in mining process

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In the mining process, besides the semiliquid mixture, mud, slurry, and rocks, there are large volumes of water to remove in order to keep production moving. The present paper will determine the application of centrifugal pumps connection in series and parallel form for dewatering in mining industry process. Initially studied the reliability of a centrifugal pumps connection in parallel and serial at a different frequency of rotation (DFR) and flow rates, to measure the behaviour of the head and flow of fluid transported. The process of calculation completed for a different rotational set of frequency for parallel and series connection, the head, hydraulic power, mechanical power, pump efficiency, and net position suction head required calculated in (2200, 2600. 2800 and 3000 [r.p.m]) respectively. The determination of energy efficiency and reliability based limits for the recommendable operating region of a variable speed driven (VSD) are discussed. As well focused to analyse the performance of individual characteristic curves of the serial and parallel centrifugal pumps. The application part considers the suitable operating conditions for VSD controlled pumping system and the basic options for monitoring the flow rate of each parallel and serial pumps. In addition for dewatering mining industry process to transport higher flow rates parallel pumps connection, and for higher discharge heads serial pumps connection are discussed, the head capacity can be increased by connecting more pumps in series, or the flow rate capacity can be increased by connecting more pumps in parallel. As well specific energy consumption of the serial with parallel pumping system could be optimised with individual pump. More results of realising (DFR) and (VSD) in real life of series and parallel systems could be gathered with simulated and experimental system situations. The advantage of pumps connection in parallel and serial configuration guarantee quality, reliability and transport maximum performance at minimum cost.

Keywords: *Pumps connection, VSD operation, reliability, Mine dewatering, Height head, huge volume*

Introduction

Centrifugal pumps are used in various industries and considered as one of the most important components in any processing equipment that should be preserved with fluids as an important part of its business. Centrifugal pumps are usually part of a larger system, and therefore their reliability can affect the productivity of system. In the viewpoint of reliability, considerable attention has been paid to centrifugal pumps in recent years (Erickson et al., 2000). Centrifugal pumps are one of the most important mechanisms in any liquid transport process. Reliability and maintainability of a centrifugal pumps in overall access play an important role in proper maintenance strategy (Singh et al., 2013).

More results of realising energy savings in real life pumping systems could be gathered with simulated and experimental system situations. Especially case examples for pumping systems serial and parallel would give interesting information of the benefits of the proposed strategy. The dewatering operation in the mining process is significantly important because the mine water is intensely treating the environment by natural resources, environmental degradation and pollution of the environmental (Stojiljkovic et al., 2014). At present, industrial water and acid mine drainage (AMD) are considered as the main sources of water pollution in many countries (Švandová et al., 2016). Various technologies have been proposed to deal with dewatering of mining processes, such as absorption, filtration, membrane technology and physical, mechanical, biological, and photochemical method (Sviatskii et al., 2016). The connection of centrifugal pumps in series and parallel system assists in removing the ground water, which is a common problem in the mining process, and developing a mine below groundwater level presents many challenges. Poorly controlled groundwater will have negative impacts on the safety, efficiency, and economics of mining operations. If groundwater can be controlled by a planned program of dewatering (GWE, 2013).

This article concentrates on the methods that allow the analysis of parallel and serial centrifugal pumps reliability performance operation of a frequency converter computer controlled, as monitoring of analysis device. Computer controlled frequency converter required in automated and in practice by current demands, computer-aided technology must often are used (Božek, 2013). First of all, the determination of energy efficiency, reliability based limits for recommendable operating region of variable speed driven VSD, and then calculating the head, hydraulic power, mechanical power, net position suction head are reflected for laboratory pumping system (Qazizada et al., 2016).

The paper focused on series and parallel connection centrifugal pumps system that are commonly used in the mining industry, municipal pumping applications, and the laboratory tests have been carried out. However,

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the methods studied according to the objectives of this paper can also be applied to other centrifugal pump types, such as axial flow pump, gear pump and peripheral flow pumps, if allowed by their characteristics. The methods observed the using of centrifugal pumps reliability analysis based on the characteristics of functional curves and reliability at various speeds of rotation.

This paper focuses on three actions of parallel and serial centrifugal pumps connection systems: the first part of action considers practical conditions for VSD-controlled. The second part of action focuses on basic options for monitoring of flow rate for each parallel and serial pumping system. The third part describes the application of methods for applying energy efficiency control strategy in a VSD controlled system. In our paper, we focused on the visualisation of pumps specifications in the proximity to obtain suitable results from research (Brodnianska, 2016).

Many authors were completed their research in the area of dewatering in the mining industry process and reliability analysis of double connection centrifugal pumps system. Kimberly, Pyzdrowski, Schiller and Smith start to understand the basic of centrifugal pump operation, by starting from such fundamentals as head and pressure, the authors have developed practical tips for specification and operation that provide for cost-effectiveness and reliability (Kimberly et al., 2002). Sivakumara. Ramezanianpourb and O'Halloran worked with Mine Water Treatment Using a Vacuum Membrane Distillation System (Sivakumara et al., 2013). Flygt and Godwin are brands of Xylem, and this group wrote the dewatering pump handbook for mining process (Xylem, 2013). Tru-Flo Pumping Systems provides the Heli-Flo dewatering pumps system for mining industry process (Truflo, 2017). Viholainen, Kortelainen, Ahonen, Aranto and Vakkilainen, studded methods for the control of serial and parallel–connected pump systems by a computer control frequency converter have been proposed in (Viholainen et al., 2009). Božek worked on research that it is necessary to be concerned about automation data gathering about device component (Impeller, Shaft, carcase, bearing) operation mode in real conditions (Božek, 2014).

Material and methods

The methodology of mine dewatering and demonstration of parallel and series pumps connection

The mine dewatering process at the extraction well can be divided into two parts. First part is the well pump, which brings the mine water from about 120 m deep to the surface and delivers it with a pressure head of 3 bars to the pressure boosting system. The second part is the pressurised boosting system which provides the distribution and required pre-set pressure at the connected clusters and buildings. Because the system needs to operate fully automatic and demand-driven a pressurised buffer system for a start or stop operation of the well pumps is applied in the case that the distributions flow is less than the required minimum flow of the well pumps (Verhoeven, 2014). Parallel centrifugal pumps applied in parallel when they receive liquid from the same suction manifold, and discharge into a common discharge manifold. Parallel pumping system can provide a very high percentage of full flow at low cost compared to the full redundancy alternative (ITT, 2010). Series pumping can reduce costs by using a combination of smaller pumps rather than a single larger pump to accomplish a certain pumping task. This may reduce installation costs as well as operating costs. Series pumping using two or more smaller pumps to handle the total pumping requirement will also provide a high degree of standby capacity. The standby percentage will generally be a high percentage of total system requirements (ITT, 2010). Domestic water pressure booster systems in modern tall buildings, often benefit from combination series-parallel variable speed pumping. The maximum production of parallel and serial centrifugal pumps connection system is possible by ensuring minimum shutdown and breakdowns to increase the availability of pumps (Mohammadi et al., 2016). The connection of centrifugal pumps in the form of parallel and series are illustrated in Figure 1.

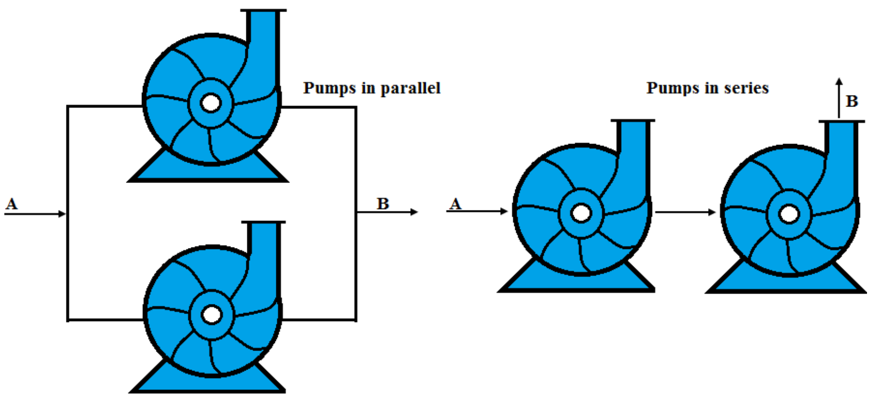

Fig. 1. Connection system of parallel and series pumps.

The instrument we have used for the experiment was produced by Edibon Company. The experiment has been done in Kabul Polytechnic University, the structure of the series pumps are made separately, not as a two-stage pump system.

The parallel and series centrifugal pumps are utilised for mining dewatering process from deep wells and groundwater of mining. Open groundwater dewatering technique is the simplest mine dewatering techniques approach, with potentially the lowest capital costs. The method involves allowing groundwater to enter the pit, then directing it to pumps, from where it is pumped away to the surface. The drawback with this approach is that water levels cannot easily be lowered in advance of mining. Hence there will always be water and wet areas within the base of the pit, which can constrain the choices of mining methods and reduce operational efficiency. There are two key advantages to these techniques. Firstly, appropriately designed and constructed wells will normally produce clean water with very little suspended solids, thereby reducing water treatment requirements. Secondly, an array of wells can be used as a pre-drainage system to lower groundwater levels in advance of mining and to maintain groundwater levels below the base of an open well (GWE, 2013). In some cases, the need to transfer water reveres in mining operations in the high mountains increasingly rely on water being pumped up from sea level for their process needs (Maron, 2014). Mining water can be extremely acidic and leaches or dissolves the rock ore minerals more intensively than common surface or underground water (Geldová, 2000). Mine dewatering is the removal of percolated or logged water from mines to ensure the safety of operating personnel and to safeguard the machinery involved in excavation (Kumar et al., 2013). In an open well mining application, the types of mine dewatering centrifugal pumps one may require to complete the job successfully are high volume pumps for short horizontal discharge, medium head and high head, in both diesel and electric powered centrifugal configurations (Aquatech, 2016). At present, mine dewatering process takes an important place in the range of extracting mine products for open pit mines (Tyulenev, 2017). During the dewatering process of mining, it is necessary to monitor and control the process and detect possible errors caused reduce device reliability (Božek, 2014). For deeper open pits, higher discharge heads are achieved by arranging pumps in series. When two pumps are arranged in serial, their resulting pump performance curve is obtained by adding their heads at the same flow rate as indicated in Figure 2.

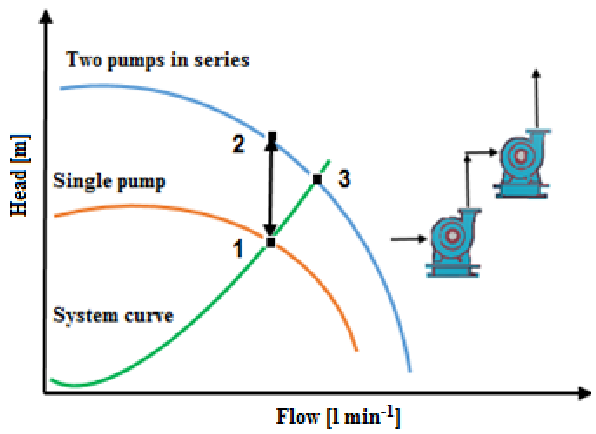

Fig. 2. Performance curves of series pumps arrangement.

Centrifugal pumps in series are used to overcome larger system head loss then one pump can handle alone. For two identical pumps in series, the head will be twice the head of a single pump at the same flow rate. With constant flow rate the combined head moves from 1 to 2. In practice, the combined head and flow rated moved along the system curve to 3 (Orhan, 2012).

Higher flow rates can be achieved with multiple units in parallel. When two or more pumps are arranged in parallel, their resulting performance curves are obtained by adding their flow rates at the same head as indicated in Figure 3.

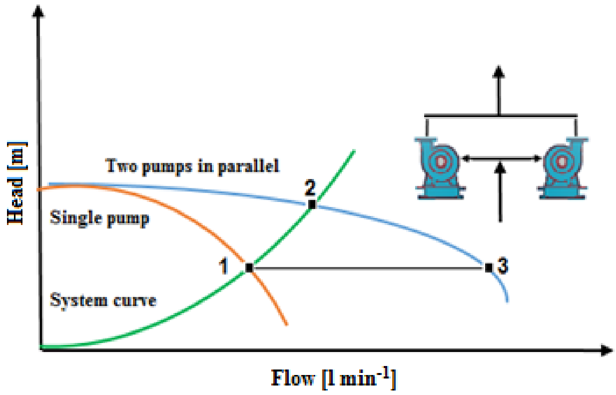

Fig. 3. Performance curves of parallel pumps arrangement.

From the experimental methodology point of view, the connection configuration of devices in parallel and serial form have arranged manually for both Figure 2 and Figure 3. Centrifugal pumps in parallel are used to overcome larger volume flows than one pump can handle alone. For two identical pumps in parallel, the flow rate will double (moving from 1 to 2) compared to a single pump if the head is kept constant. In practice, the combined head and volume flow move along the system curve as indicated from 1 to 3. If one of the pumps in parallel or series stops, the operation point moves along the system resistance curve from point 3 to point 1 – the head and flow rate are decreased (*Orhan, 2012*).

Applied formulas and the pump's characteristics assessment

A brief description of centrifugal pumps characteristics such as head, net position suction head, power, efficiency, and similarity laws are given below:

The characteristic of this device is the guidance required to provide the delivery head, which is necessary for delivering the fluid against of linear resistance in the piping system.

$$H = \frac{P_2 - P_1}{\rho g} \tag{1}$$

Where ρ is fluid density, g is the acceleration of gravity, P_1 and P_2 shows the pressure drop at the beginning and the end of the pump.

The power supplied to fluid generates liquid energy per unit of volume.

Therefore, the power association is between the mechanical energy conversion of the pump and the liquid inside into pump.

The delivery of power to liquid is expressed by hydraulic power or output power P_w:

$$P_w = \rho g Q H \tag{2}$$

Where ρ is fluid density, g is the acceleration due gravity, H is the head, and Q is the flow rate of the liquid.

The mechanical power P_f supplied by the motor to pump, called control power, input power and can be calculated:

$$P_f = \omega\, T = \frac{2\pi}{60}\, nT \tag{3}$$

Where n is the frequency of rotation [rpm] (rpm, revolutions per minute), T is torque [Nm], ω is angular axis speed in [rad sec^{-1}] (*Edibon, 2014*).

The pump efficiency η is defined as the ratio of power supplied to the liquid and the power supplied to drive the pump.

$$\eta = \frac{P_w}{P_f} = \frac{\rho g Q H}{\frac{2\pi}{60} nT} \tag{4}$$

Where ρ is fluid density, g is the acceleration due gravity, P_f is mechanical power, P_w is hydraulic power. If there are no losses, $P_w = P_f$, and the efficiency is 100 %, but it is not the case in operation.

Required net position suction head ($NPSH_R$) is a function of the pump, and it is defined as follows:

$$NPSH_R = (\frac{P_1}{\rho g} + \frac{w_1^2}{2g} - \frac{P^*}{\rho g}) \tag{5}$$

Where P^* is the transported liquid's steam, P_1 is pressure and w_1 is the velocity of liquid inside the pump.

$$w = \frac{Q}{A} \tag{6}$$

Where A, [m^2] is the circular surface area of the impeller which is calculated as:

$$A = \frac{\pi}{4} D^2 \tag{7}$$

Where D [m] is impeller diameter.

Similarity laws represent the mathematical relationship between variables that are related to pump performance:

$$Q = \left(\frac{n}{n_n}\right) Q_n \tag{8}$$

$$H = \left(\frac{n}{n_n}\right)^2 H_n \tag{9}$$

$$P = \left(\frac{n}{n_n}\right)^3 P_n \tag{10}$$

$$NPSH_R = \left(\frac{n}{n_n}\right)^2 NPSH_{Rn} \tag{11}$$

Where n is the current frequency of revolution in [rpm] of the pump and subscript n denotes the functioning value at the nominal speed pump (Karassik, 1998).

Procedure of experiments

During investigation, the computer controlled multi-pumps of series and parallel are used, the computer technology and digitisation are now commonplace in every social sphere, touching our everyday lives (Rybar, 2017).

The investigation of experiment has been done in Kabul Polytechnic University for centrifugal pumps which were manufactured by Edibon Company.

This instrument allows checking the reliability of serial and parallel centrifugal pumps at different speeds of rotation.

Through testing of experimentation, both centrifugal pumps are connected in series and parallel form. We set the frequency of rotation in 3000 [r.p.m], for this turning speed we write the flow Q evacuated by the pumps, both section pressures, inlet pressure P_1 and discharge pressures P_2, as well the torque, T [Nm]. Then, we fix a new frequency of rotation to measure the flow Q evacuated by the pumps, both section P_1 and discharge P_2 pressures and the torque, T [Nm] to obtain the average values of measured data.

We also controlled the change of flow in four steps of valve changing to obtain new data information for different speeds of rotation (2200, 2600, 2800 and 3000 [r.p.m]).

The data of Q, P_1, P_2 and T at a different rotation of speed for series centrifugal pumps are shown in Table 1.

Tab. 1. Experiment data of two series centrifugal pumps.

n = 3000 [r.p.m]	**Number**	**1**	**2**	**3**	**4**	**5**
	Q [l min^{-1}]	18.23	16.92	13.55	7.8	4.61
	P_1 [bar]	-0.03	-0.03	-0.02	-0.01	-0.01
	P_2 [bar]	1.21	1.46	1.89	2.28	2.31
	T [Nm]	0.37	0.45	0.59	0.71	0.72
n = 2800 [r.p.m]	**Number**	**1**	**2**	**3**	**4**	**5**
	Q [l min^{-1}]	17.52	15.34	14.45	11.45	6.44
	P_1 [bar]	-0.02	-0.02	-0.02	-0.01	-0.01
	P_2 [bar]	1.31	1.52	1.55	1.91	2.06
	T [Nm]	0.4	0.47	0.48	0.59	0.64
n = 2600 [r.p.m]	**Number**	**1**	**2**	**3**	**4**	**5**
	Q [l min^{-1}]	16.91	15.45	12.02	8.19	5.45
	P_1 [bar]	-0.03	-0.02	-0.01	-0.01	-0.01
	P_2 [bar]	0.95	1.4	1.77	1.9	2
	T [Nm]	0.29	0.43	0.55	0.59	0.62
n = 2200 [r.p.m]	**Number**	**1**	**2**	**3**	**4**	**5**
	Q [l min^{-1}]	16.53	14.82	10.98	8.23	4.28
	P_1 [bar]	-0.03	-0.02	-0.02	-0.01	-0.01
	P_2 [bar]	0.8	1.06	1.59	1.68	1.7
	T [Nm]	0.24	0.33	0.49	0.52	0.53

In similar circumstances, we received new data during of experiment Q, P_1, P_2 and T at a different rotation of speeds (2200, 2600. 2800 and 3000 [r.p.m]) for parallel centrifugal pumps that are shown in Table 2.

Tab. 2. Experiment data of two parallel centrifugal pumps.

n = 3000 [r.p.m]	**Number**	**1**	**2**	**3**	**4**	**5**
	Q [l min^{-1}]	28.77	26.84	24.37	21.27	17
	P_1 [bar]	-0.02	-0.02	-0.02	-0.01	-0.01
	P_2 [bar]	0.83	0.84	0.86	0.87	0.88
	T [Nm]	0.26	0.27	0.28	0.29	0.3
n = 2800 [r.p.m]	**Number**	**1**	**2**	**3**	**4**	**5**
	Q [l min^{-1}]	27.97	23.13	18.77	12.55	6.11
	P_1 [bar]	-0.02	-0.02	-0.01	-0.01	-0.01
	P_2 [bar]	0.83	0.86	0.89	0.91	0.96
	T [Nm]	0.25	0.26	0.27	0.28	0.29
n = 2600 [r.p.m]	**Number**	**1**	**2**	**3**	**4**	**5**
	Q [l min^{-1}]	26.16	21.08	15.27	8.82	4.51
	P_1 [bar]	-0.02	-0.01	-0.01	-0.01	-0.01
	P_2 [bar]	0.82	0.85	0.87	0.9	0.94
	T [Nm]	0.24	0.25	0.26	0.28	0.29
n = 2200 [r.p.m]	**Number**	**1**	**2**	**3**	**4**	**5**
	Q [l min^{-1}]	24.01	17.21	12.05	8.67	3.9
	P_1 [bar]	-0.01	-0.01	-0.01	-0.01	-0.01
	P_2 [bar]	0.8	0.83	0.91	0.93	0.96
	T [Nm]	0.24	0.25	0.26	0.28	0.29

Results

From the perspective of comparison and reliability, this study explains the effect of different frequencies of rotation DFR on the employment of two centrifugal pumps in serial and parallel system. The results show that the VSD and DFR of serial and parallel centrifugal pumps can be determined by using the principles of energy efficiency, the limitations of this operating range are strongly dependent on the rotation speed of the pump. The measurement values computed only for four steps of DFR (2200, 2600, 2800, and 3000 [r.p.m]). Table 3 indicates the series pumps configuration results at 3000 [r.p.m]. For each current flow Q in Table 3, calculated the hydraulic power P_w, mechanical power P_f, pump efficiency η, H-head, and $NPSH_R$ using equations (1, 2, 3, 4, 5, and 6). The pumps and system curves in Figure 4, which depends to series pumps, and the Figure 5, which relates to parallel pumps, indicates reduce of efficiency in four steps of different rotating speeds (2200, 2600, 2800 and 3000 rpm) that have undesirable effects on pump's reliability, particularly when pump efforts at 2200 rpm or slow revolutions per minute..

Correspondingly in Table 4, the similar measurement procedure for rotational frequency sets of parallel joining have been done, and the mechanical power P_f, hydraulic power P_w, head H, the efficiency of pump η and $NPSH_R$ calculated for (2200, 2600, 2800 and 3000 rpm).

The affinity laws outcomes for series and parallel pumps in Table 5 and Table 6 (that can be used to estimate the effect of fluid change, efficiency, speed, or size of any dynamic pump) are calculated via using equations (8, 9, 10, and 11), and using measured values of Table 3 and Table 4 for series and parallel pumps separately.

The pump efficiency is usually estimated directly relate to rotational speed, therefore the efficiency curves and pump curves followed the similarity laws using equations (8) and (9). When the pump is driven outside from the operating area, the pump efficiency reduced and may be susceptible to unsafe effects.

As a result for dewatering mining process, a higher flow rates can be achieved with parallel pumps connection, and the series pump connection are used to overcome larger volume. Even though the research was carried out on small and low productive capacity centrifugal pumps in the laboratory of Kabul Polytechnic University but the study will consider requirements for centrifugal pumps connection in the serial and parallel form in mine dewatering process. The advantage of pumps connection in parallel and serial configuration guarantee quality, durability and deliver maximum performance at minimum cost. Centrifugal pump in series is used to overcome larger system head loss. Therefore, for two identical pumps in series, the head will be twice to transfer liquid to a high height, for instance, for 800 [m] we could connect more than two pumps in a series configuration, this should be noted that the transfer of liquids to high head depended to the capacity of the pump. In an open source mining application, the dewatering pumps we may require to overcome the job successfully by parallel pumps for short horizontal discharge, medium head and high head to 700 [m] series centrifugal configurations are useful. When two or more pumps are arranged in parallel form caused to overcome larger volume flows than one pump. Through the experimental investigation, the head capacity can be increased by connecting more pumps in series, or the flow rate capacity can be increased by connecting more pumps in parallel. If we require a heavy duty to transfer dirty water, wastewater or slurries dredging pumps can be used.

Tab. 3. Calculated experimental values for two series centrifugal pumps.

***n* = 3000 [r.p.m]**					
Number	**1**	**2**	**3**	**4**	5
Q [l min^{-1}]	18.23	16.92	13.55	7.8	4.61
H [m]	12.67	15.22	19.51	23.39	23.70
P_W [W]	37.67	42.01	43.13	29.77	17.82
P_f [W]	116.23	141.37	185.35	223.0	226.2
η [%]	32.41	29.72	23.27	13.34	7.88
w [m s^{-1}]	0.42	0.39	0.31	0.18	0.10
$NPSH_R$ [m]	0.29	0.16	-0.008	-0.24	-0.34
n = 2800 [r.p.m]					
Number	**1**	**2**	**3**	**4**	**5**
Q [l min^{-1}]	17.52	15.34	14.45	11.45	6.44
H [m]	13.59	15.73	16.04	19.61	21.15
P_W [W]	38.83	39.37	37.81	36.64	22.21
P_f [W]	117.28	137.81	140.74	172.9	187.6
η [%]	33.11	28.57	26.86	21.17	11.83
w [m s^{-1}]	0.41	0.361	0.34	0.26	0.15
$NPSH_R$ [m]	0.32	0.13	0.06	-0.04	-0.29
n = 2600 [r.p.m]					
Number	**1**	**2**	**3**	**4**	**5**
Q [l min^{-1}]	16.91	15.45	12.02	8.19	5.45
H [m]	10.01	14.50	18.18	19.51	20.53
P_W [W]	27.61	36.56	35.65	26.07	18.25
P_f [W]	78.95	117.07	149.74	160.6	168.8
H [%]	34.97	31.23	23.81	16.22	10.81
w [m s^{-1}]	0.39	0.36	0.28	0.19	0.12
$NPSH_R$ [m]	0.16	0.14	-0.01	-0.22	-0.32
n = 2200 [r.p.m]					
Number	**1**	**2**	**3**	**4**	**5**
Q [l min^{-1}]	16.53	14.82	10.98	8.23	4.28
H [m]	8.48	11.03	16.45	17.26	17.47
P_W [W]	22.86	26.67	29.46	23.18	12.19
P_f [W]	55.29	76.02	112.88	119.8	122.1
η [%]	41.35	35.08	26.09	19.34	9.98
w [m s^{-1}]	0.38	0.34	0.25	0.19	0.10
$NPSH_R$ [m]	0.13	0.08	-0.18	-0.22	-0.35

Calculating characteristics of centrifugal pumps according to equations and tables data shows that the rotational speed, torque, power, shaft, and efficiency affects the reliability of the pump.

The workout and calculation of serial and parallel centrifuge pumps characteristics according to the mentioned equations are as follows:

At the start of the experiment, we write the experimental data. At first, we measured the water temperature at the begging of test t_1 = 21 [°C] and then at the end of test t_2 = 23 [°C]. Eventually, we obtain the average temperature of water t_{av}= 22 [°C].

Regarding the average temperature, gravity acceleration and water density from physical properties of the table have been selected 9.81 [m s^{-1}] and 997.9 [kg m^{-3}] correspondingly, then calculated each value only for four steps of speed revolutions (2200, 2600, 2800 and 3000 [rpm]).

At 3000 [rpm], for current *Q* measured each value in Table 3, for example, power output, power input, pumping efficiency, liquid velocity, head *H*, and $NPSH_R$, using Equations (1, 2, 3,4, 5 and 6). For the circular surface area, we use Equation (7). All measured values for 3000 [r.p.m.] are shown in Table 3; similar measurement procedure was performed for a different rotating frequency set (2800, 2600 and 2200 [r.p.m.]) too. The measured values for two centrifuge pumps in series configuration are shown in Table 3.

Centrifugal pumps are over and over again controlled by adjusting their speed, which affects the flow of pump and output pressure. Many pumping systems require a change in flow or pressure. To get a different operating point either system curve or pump curve must be changed.

Preferably, the pump operates in its best efficiency point BEP, if the pump operates out of operating area, the pump efficiency decreases and may be susceptible to damaging effects.

For two series coupling of centrifugal pumps, the pump and system curves at different rotation speed are shown in Figure 4.

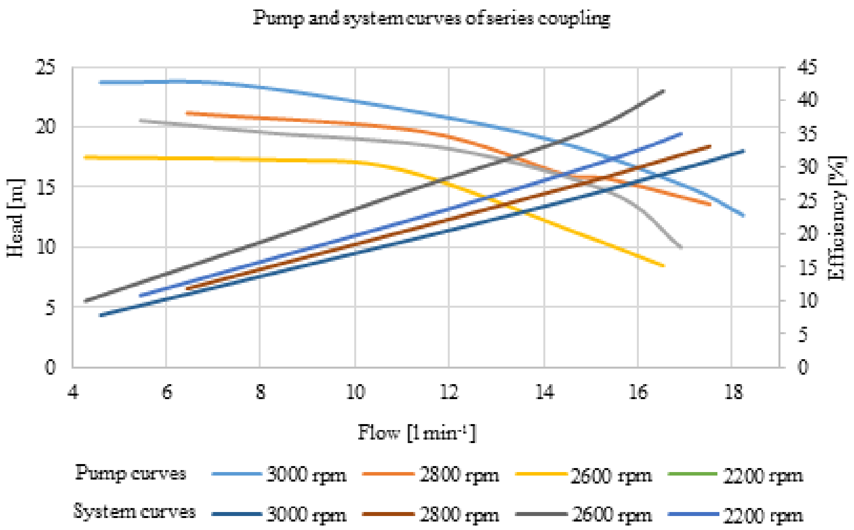

Fig. 4. The series pumps system and pump curves shape when these pumps are driven at different rotational speeds.

For each flow *Q*, the values of output power, input power, the velocity of liquid, efficiency, head, and $NPSH_R$ were calculated and are given in Table 4 for (2200, 2600. 2800 and 3000 rpm) independently. Measured values for two parallel centrifugal pumps are shown in Table 4.

Tab. 4 Calculated experimental values for two parallel centrifugal pumps

n = 3000 [r.p.m]					
Number	**1**	**2**	**3**	**4**	**5**
Q [l min^{-1}]	28.77	26.84	24.37	21.27	17
H [m]	8.68	8.78	8.99	8.99	9.09
P_w [W]	40.75	38.47	35.74	31.19	25.21
P_f [W]	81.68	84.82	87.96	91.10	94.24
η [%]	49.89	45.35	40.63	34.24	26.75
w [m s^{-1}]	0.67	0.63	0.57	0.50	0.40
$NPSH_R$ [m]	1.74	1.45	1.11	0.82	0.38
n = 2800 [r.p.m]					
Number	**1**	**2**	**3**	**4**	**5**
Q [l min^{-1}]	27.97	23.13	18.77	12.55	6.11
H [m]	8.68	8.99	9.19	9.40	9.91
P_w [W]	39.62	33.92	28.15	19.24	9.87
P_f [W]	73.30	76.23	79.16	82.10	85.03
η [%]	54.05	44.49	35.56	23.43	11.61
w [m s^{-1}]	0.65	0.54	0.44	0.29	0.14
$NPSH_R$ [m]	1.62	0.94	0.55	0.02	-0.30
n = 2600 [r.p.m]					
Number	**1**	**2**	**3**	**4**	**5**
Q [l min^{-1}]	26.16	21.08	15.27	8.82	4.51
H [m]	8.58	8.78	8.99	9.29	9.70
P_w [W]	36.62	30.21	22.39	13.37	7.14
P_f [W]	65.34	68.06	70.79	76.23	78.95
η [%]	56.04	44.38	31.63	17.54	9.04
w [m s^{-1}]	0.61	0.49	0.36	0.20	0.10
$NPSH_R$ [m]	1.35	0.80	0.22	-0.19	-0.35
n = 2200 [r.p.m]					
Number	**1**	**2**	**3**	**4**	**5**
Q [l min^{-1}]	24.01	17.21	12.05	8.67	3.9
H [m]	8.27	8.58	9.40	9.60	9.91
P_w [W]	32.41	24.09	18.47	13.58	6.30
P_f [W]	55.29	57.59	59.89	64.50	66.81
η [%]	58.62	41.83	30.84	21.05	9.43
w [m s^{-1}]	0.56	0.40	0.28	0.20	0.09
$NPSH_R$ [m]	1.16	0.40	-0.01	-0.20	-0.36

Preferably for VSD pump in four steps, the system curves consists mainly dynamic head, and pump usually works at best efficiency point BEP. If the system curve has a significant portion of the static head, changing the rotational speed can change the point of operation.

Figure 5 is completed from data of Table 4 by making the all pump and efficiency curves. Efficiency decreases affected pumps reliability, the resulting operating point locations with four different system curve shapes are given in Figure 5.

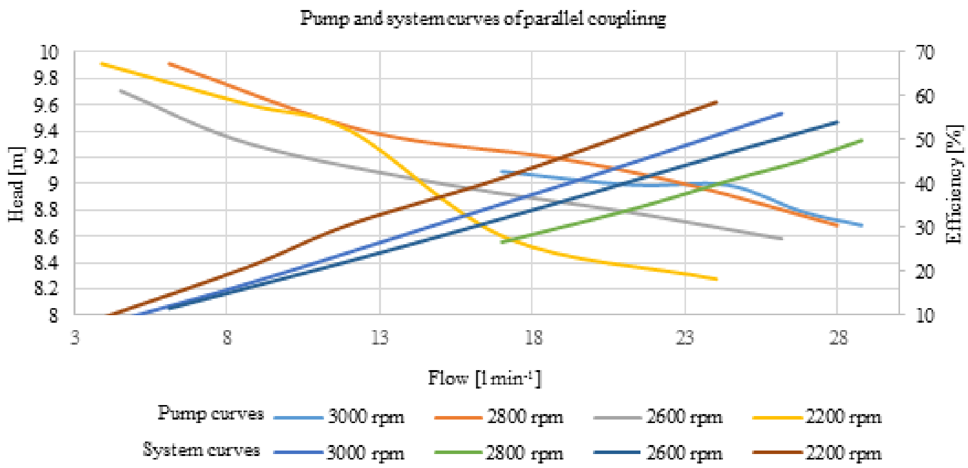

Fig. 5. The Parallel pumps system and pump curves shape at different rotational speeds.

In addition, the figures report the estimated decrease of the pump characteristic life as a function of relative flow rate and adverse events that may occur if centrifugal pumps are driven outside its recommendable operating region at fixed speed.

The similarity laws are calculated using equations (10, 11, 12 and 13), experimental data are calculated for parallel and serial centrifugal pumps given in Table 5 and Table 6, which can be used to estimate the effect of the fluid change, Efficiency, speed or size of any turbo-dynamic device.

Tab. 5. The similarity rules of two parallel coupling centrifugal pumps.

$\boldsymbol{n}$ [r.p.m]	$\boldsymbol{Q_n}$ [l min^{-1}]	$\boldsymbol{H_n}$ [m]	$\boldsymbol{P_{fn}}$ [W]	**NSPH$_{Rn}$** [m]
2	26.85	7.56	66.41	1.52
3	25.97	7.48	58.69	1.40
4	22.13	6.14	39.58	0.97

Tab. 6. The similarity rules of two series coupling centrifugal pumps.

$\boldsymbol{n}$ [r min^{-1}]	$\boldsymbol{Q_n}$ [l min^{-1}]	$\boldsymbol{H_n}$ [m]	$\boldsymbol{P_{fn}}$ [W]	**NSPH$_{Rn}$** [m]
2	17.01	11.03	94.50	0.25
3	16.26	11.71	93.90	0.14
4	14.30	7.16	47.83	0.12

The net position suction head requires $NPSH_R$ a minimum level, so $NPSH_R$ does not tend to reach zero at very low speeds. The issue of this paper which is done experimentally, (reliability of parallel and serial centrifugal pumps for dewatering in mining process) represents the issue to find the solution of subject and problems related to centrifugal pumps reliability for dewatering of mining process (Černecký, 2015).

Conclusion and summary

This article represented, the current flow control function tested with (*QH*) curve, based on the pump flow estimate. This study was considered for the management of control strategy that includes efficient operation as well as avoiding the conditions that can reduce the reliability of pumps.

This research focused on series and parallel pumping systems which operate to achieve a wide range of flow for mining process, to determine the energy efficient control strategies for VSD controlled pumping systems by applying on three main research areas. The first part of the procedure is evaluated with suitable operating conditions for VSD by controlled coupling pumping connection system. The second part of the application considers the main flow monitoring capabilities for each parallel and serial pumps. The third application area, the method of implementation energy control, to save a VSD control for serial and parallel pumping system.

The accuracy of the used (series and parallel) pumps operation point estimation methods were evaluated to be sufficient for the presented sub-optimisation of VSD controlled pumps. As well, the specific energy consumption of the serial with parallel pumping system could be optimised with the individual pump system. More results of realising energy savings in real life of coupling pumping systems could be gathered with simulated and experimental system situations. Especially case examples for pumping systems serial and parallel pumping units would give interesting information of the benefits of the proposed strategy (mining process). This study was carried out for the estimation of the pump model operating point position, which can be performed by a frequency converter. The pump curve $Q = f(H)$ and the system curve $\eta = f(Q)$ based methods are calculated. For maximum efficiency on $\eta = f(Q)$, curve we will calculate the annual power consumption of serial and parallel pumps according to pumps operating hours per year.

Application of these methods was evaluated by laboratory measurements with serial and parallel centrifugal pumps. The results showed that application of the model-based method for estimating performance points was measured. Future research about serial and parallel pumps will be on a flow recirculation for dewatering of mining process.

Using the characteristics of functional curves, head performance curves, flow rate, efficiency, mechanical power, hydraulic power, velocity, the position of the suction head, reliability analysis of two pumps based on performance curve of, and the recommended operating range of the VSD are studied.

Parallel and serial pumps can also measure pump flow, to determine the actual operating point location of centrifugal pumps.

In addition, production critical applications can be equipped with backup pumps that are started if the operating pumps fail. However in practice, the major part of series and parallel pumping systems may only have a motor phase current, and a process related measurement, which do not directly indicate the operational efficiency, hydraulically and mechanical reliability of the pumps. Nowadays, there are numerous condition and efficiency monitoring products available for coupling pumping systems, generally considered as an energy efficient control approach, the actual operating point locations of a VSD pump may well be found in regions with a lower pump efficiency and higher risk for a mechanical failure of the pump, which may remain undetected by visual check-ups. As a result, the issue of the study was the reliability of a centrifugal pump at different rotational speeds and flow rates. The use of common energy efficiency and reliability based criteria the determination of the recommendable operating region of a VSD coupling centrifugal pumps were investigated.

The monitoring of series and parallel centrifugal pumps operation utilising the information available from a frequency converter. The variable-speed-driven of coupling centrifugal pumps are widely used in mining process applications, and often the coupling pumps may be driven in adverse operating conditions, which can lead to increase the energy and maintenance costs for the connected pumping system. Although the research focuses on series and parallel centrifugal pumps, the tested properties, can also be used for other types of centrifuge pumps such as gear pumps, peripheral and axial pumps.

***Acknowledgements**: This paper was prepared within the work on a research project KEGA MŠ SR 003TU Z-4/2016: Research and education laboratory for robotics and RFBR research project No 18-08-00772 A. Also this work was done as a result of the project SAMRS/2013/ of the Slovak official development assistance supporting the cooperation between the Slovak University of Technology in Bratislava (STU) and the Kabul Polytechnic University (KPU) in Afghanistan.*

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The Efficiency of Use of Heating Cables in Wells of Complicated Stock

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Depending on geological, physical and technological conditions and the composition of extracted fluids, the process of exploitation of producing wells can be complicated by asphalt-paraffin-resin deposition (APRD) on the surface of downhole equipment. Scientists and industrial workers have studied factors like pressure, temperature, the nature of wettability of the wetted surface, oil flow rate, resin, asphaltene and paraffin wax percentage in reservoir oil composition. That gives an opportunity to resolve problems of APRD prevention and removal purposefully. Methods of APRD prevention in oil producing wells were analysed, data of measuring of the thickness of APRD, formed on downhole equipment in the process of producing well exploitation, were obtained and treated during this research work. In addition, the depth where intensified paraffin formation starts was determined. It was recommended what devices and technologies for APRD prevention and removal to use to decrease the number of workovers and flushing of producing wells. The technology of APRD prevention by maintaining oil flow temperature with heating cable employment is proposed. During operation, the cable heats the internal or external surface of tubing string which, in turn, heat the fluid that moves through the string to the temperature equal or exceeding the temperature of deposition formation.

Keywords: *asphalt-paraffin-resin deposition, sucker-rod pumping units, heating lines, well, paraffin deposition, equipment failures, solid particles.*

Introduction

During exploitation of wells by sucker-rod pumping units different complications occur: high viscosity of reservoir fluid, high curvature of wellbore, presence of sand formation of APRD and inorganic salts, gas influence, which lead to considerable decrease of well flow rate, and sometimes cause full termination of well operation (Ivanova et al., 2016, Ivanova et al., 2016, Baranov et al., 2017).

During oil production, the pressure and the temperature in producing wells decrease, gas evolves, the flow of fluids is cooled. This results in a decrease of oil solubility and APRD precipitation in sucker-rod pump and tubing string. (Fig. 1) (Baranov et al., 2017, Drachuk et al., 2017, Galikeev et al., 2015, Persiyancev, 2000).

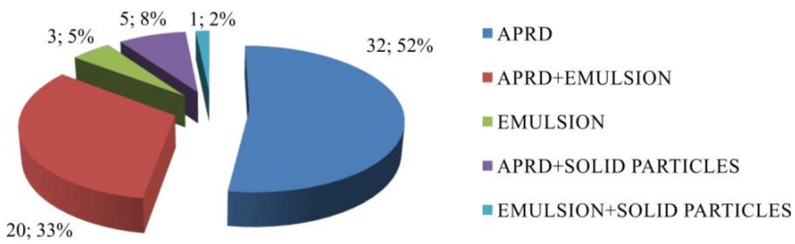

Fig. 1. Typical causes of complications in operation of sucker-rod pumping units.

Formation of APRD is influenced by (Baranov et al., 2017):

- downhole pressure drop below bubble point pressure, it results in hydrodynamic equilibrium imbalance,
- intensive gas evolution from oil,
- temperature decrease in the reservoir and wellbore,
- change of liquid-gas mixture motion speed,

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- the surface condition of the tubing string and sucker-rods,
- oil water ratio,
- hydrocarbon composition of every mixture phase.

Formation of paraffin deposition in wells occurs when pressure and temperature decrease and oil degasification begins. If downhole pressure exceeds bubble point pressure in the wellbore, the system remains in an equilibrium state, and only liquids move before reaching the area, where the pressure is equal to bubble point pressure (Ibragimov et al., 2000, Nasyrov et al., 2011). Then, the equilibrium state is disturbed, the volume of gas phase increases, the liquid phase becomes imbalanced and causes precipitation of paraffin. That is why the point of wax precipitation can be located at any depth and depends on well operation conditions. If the downhole pressure is lower than bubble point pressure, equilibrium state of the reservoir is disturbed, wax precipitates in the bed as well as in wellbore, starting from the bottom of the well. Paraffin deposition intensifies when downhole pressure and pre-critical temperature are reducing (Babalyan, 1965, Bogomol'nyj, 2003).

In the pumping method of exploitation, intake pressure p_{pr} is lower than bubble point pressure p_s. It results in wax precipitation in pump suction and on production casing walls. The tubing string is divided into two zones. The first one includes the outlet side of the pump with sudden pressure increase, exceeding bubble point pressure. Liquid moves in this interval. In the second zone, the pressure decreases to bubble point pressure and below with intensive paraffin precipitation. As for natural flow wells, if downhole pressure is kept equal to bubble point pressure, wax precipitation should be expected in tubing string (Gavrilyuk et al., 2014, Guskova et al., 1999).

If the downhole pressure is reduced to values equal to p_s or lower than p_s in order to stimulate inflow, the probability of gas evolution and wax precipitation increases in every interval including wellbore and tubing string (Getman et al., 2014).

The following processes contribute to deposition and formation of plugs of precipitated paraffin:

- adsorptive processes which occur on boundary metal - paraffin - tarry substances;
- products of reservoir damage, solid particles;
- surface roughness;
- moving speed and structure of liquid-gas mixture flow
- electrokinetic effects, causing electrification of both pipe wall surface and paraffin crystals surface, which intensify adhesion of paraffin to metal (Guskova et al., 2010).

Paraffin deposition on the internal surface of the tubing string starts on the depth, where the temperature of the well corresponds to paraffin crystallisation point. APRD accumulation in the flow channel of tubing string leads to pumping units output decrease, reducing of time between overhauls (Guskova et al., 2010, Egorov, 2013). Thickness of APRD gradually increases from the place 500 - 900 m deep, where they start accumulating and reaches its peak on depth of 50-200 m from the top of the well, then it slowly decreases to 1-2 mm near the well-head (Ivanova et al., 2011, Abramov et al., 2014, Božek, 2013). Deposition diagram is drawn according to the results of the study of the thickness of APRD formation on tubing string walls during pipe removal from the well (Fig. 2). It is observed that both the intensity of paraffin deposition and amount of hot oiling operations decrease under peak fluid viscosity (water cut is less than 75%) (Ivanova et al., 2017, Baranov et al., 2017).

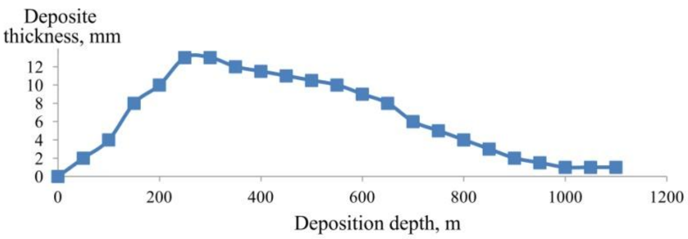

Fig. 2. Measurements of deposite thickness during well servicing.

The paraffin falling out of oil and its covering of the walls of pipes are contributed by the decline of temperature and pressure of the moving flow of fluid in the well by tubing to their defined critical values. Thus, one of the important factors, influencing on the formation of ARPD, is a decline of the temperature of the liquid below than the temperature of saturation (to the temperature of the beginning of paraffin crystallisation). This condition is the necessary condition for the formation of paraffin deposits. The producing fluid (emulsion) cools down because of the heat exchange with surrounding rocks during the lifting and soil during the collection and transportation, and also as a result of phase transitions. The decline of reservoir pressure below the pressure of saturation also brings to cooling down of the flow and change of oil composition. Here at rare gases and lightest hydrocarbons transit to the gas area. Degassing for different oils variously influences on the paraffin saturation point. This fact is explained not only by the change of dissolving ability in relation to it but also flocculating action on micelles of asphaltenes. From many literature sources, it follows that ARPD in the hole walls can be found beginning from the depth approximately 1000 m to the depth 200...50 m (achieving a maximum here). Higher the layer of ARPD diminishes due to washing off deposits by the flow of the well fluid.

The factor, strongly influencing on the ability of ARPD formation on the surface of pipes with the change of temperature is also the liquid flow velocity. It determines the hydrodynamic regime. It is known that at the debits of oil more than 70 ton/day paraffin deposits are not observed. The characteristics of the surface substantially influence the formation of deposits. The considerable roughness of the surface (height of combs of 7–9 km and more) helps in the formation of paraffin deposits, and high polarity of pipes' surface, vice versa, hinders the formation of deposits (Seredyuk et al., 2009).

Results and discussion

The analysis of deposits in tubing strings has demonstrated that:

- paraffin content in deposits increases from bottom to the top of the well reaching peak value near the well-head;
- paraffin melting temperature decreases from the bottom to the top of the well;
- in a period of full paraffin blockage of pipes paraffin deposits reach 10 – 15 % (by weight) of paraffin accumulated in oil;
- hydrophilic nature of the surface leads to a decrease in the intensity of paraffin sticking;
- the more infusible paraffin is, the greater adhesion and sticking abilities of crystals are observed.

In the presence of one or several factors complicating the oil production process, wells are converted to complicated stock which consists of more than 50% of the whole amount of wells equipped by sucker-rod pumping units. This stock is exposed to significant risk of premature failures of equipment which cause downtime of well. Table 1 demonstrates the distribution of premature failures of sucker-rod pumping units. It was identified that sucker-rod breakage occurs due to oscillatory loads caused by APRD formation, corrosion impact of environment on the column and metal fatigue.

Tab. 1. Causes of failures of sucker-rod pumping units of the well stock.

Causes of failures of sucker-rod pumping units	**2015**		**2016**	
	Amount of failures	**%**	**Amount of failures**	**%**
Sucker-rod breakage	41	36	43	39
Sucker-rod twist-off	12	11	14	12
Failure of sucker-rod pump	39	35	34	31
Leakage of submersible equipment	6	5	9	8
Other	15	13	11	10

The main part of wells shut down for well servicing due to sucker-rod breakage, or twist-off is complicated by APRD (table 2). Three types of complications occur the most often during well exploitation in Udmurtia: APRD formation, highly viscous water-oil emulsion formation and solid particles in well production.

Tab. 2. Causes of failures of candidate wells.

well	**Actual cause of failure**	**Complication in submersible equipment operation**
1	Sucker-rod breakage	APRD, solid particles
2	Sucker-rod breakage	APRD, solid particles
3	Sucker-rod twist-off	APRD, emulsion
4	Sucker-rod breakage	APRD, emulsion, solid particles
5	Sucker-rod breakage	APRD
6	Valve choking	APRD
7	Sucker-rod breakage	APRD, emulsion
8	Sucker-rod breakage	APRD
9	Valve choking	APRD
10	Sucker-rod breakage	APRD

APRD formation on the external surface of sucker-rod string and the internal surface of the tubing string is entailed by the growth of peak loads and decrease in minimal loads applied to horse-head of beam unit (Fig. 3). It leads to normal well operation failure and the growth of force of hydrodynamic friction in the tubing string, that can cause accidents resulting in well killing and well servicing. APRD formation increases the load applied to horse-head, reducing the operational life of the downhole equipment. As a result, the amount of premature failures increases and wells are brought in well stock subject to frequent workover. These all cause a decrease in time between overhauls.

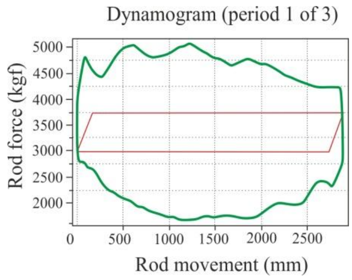

Fig. 3. Dynamogram of well № 1.

The time between overhauls (TBO) is one of the indicators characterising well operation in time. The time between overhauls - is mean time of continuous well operation in days between two overhauls. TBO is determined for active wells stock, all well stocks and every recovery method.

Calculation of TBO of well operation is made for the rolling year, i.e. for 12 months from the beginning of the analysed period. It is also calculated for the current month (for 30 or 31 days from the beginning of the analysed period).

The number of workovers includes all workovers, carried due to failures of downhole equipment of well stock happened during the calculation period. In addition, it includes conducting well interventions for bottom-hole treatment to increase well productivity.

Workovers connected with the following factors are not taken into account during TBO calculation:

- wellhead accessories replacement;
- change of the length of pipe suspension within the limit of 100 metres;
- polished rod replacement.

Workovers, connected with well flushing, well shifting, replacement of one operation mode with another, change of equipment type, removal of sand plugs, scaling and APRD, are taken into account during calculation of TBO of well operation.

The main directions of well interventions for increasing of TBO of wells equipped with sucker-rod pumping units include the following:

1. downhole equipment condition monitoring,
2. the control of bringing the well on to stable production,
3. carrying out mitigation response in well operation.

Struggle against APRD is conducted by two directions: prevention from APRD formation and removal of APRD.

In order to prevent from APRD formation, it is recommended to carry out the following operations:

- injection of inhibitors (RTF-1 (РТФ-1 Russian State Standard), RT-1M (РТ-1М), SNPH-7941 (СНПХ-7941), dissolvan 4316 (диссолван 4316), etc.) in the tubular annulus by dosage pumps. Depending on oil properties and its water cut, the dose ranges from 50 to 200 g per tonne of the produced fluid. The dosage is carried out through wellhead dosage units UDE (УДЭ), UDS(УДС) in the amount of 50-100 g per cubic meter of the produced fluid.
- applying lined pipes;
- exclusion of flushing of the bottom-hole zone with fresh water;
- applying special well-killing fluids (oil based hydrophobic emulsion solutions, etc.).
- To remove APRD, it is recommended to carry out the following operations:
- hot oiling of the tubing string and steaming by mobile dewaxing unit 2ADP-12/150 (2АДП-12/150), modernised mobile dewaxing unit ADPM-16/150 (АДПМ-16/150 Russian State Standard) and mobile steam heaters;
- flushing of tubing string by solvents RT-1U (РТ-1У), SNPH-7870A (СНПХ-7870А), hexane fraction, solutions of surfactants ML-72 (МЛ-72), ML-80 (МЛ-80), hydrophobic-emulsive solutions;
- hot water well flushing with inhibitors RTF-1 (РТФ-1), RT-1M (РТ-1М);

- in the case of small wellbore deviation (zenith angle of the wellbore is 5 - 10º), lamellar scraper on sucker-rods with rod rotator may be used.

Thermal methods of APRD removal have found the widest use. These methods are based on the combined effect on APRD to melt it and reduce the power of adhesion to the surface. Hot oiling and hot water well flushing are the most widely used on oilfields of Udmurtia.

Despite considerable efficiency, dewaxing of wells by means of hot oiling has several drawbacks. The high flow rate of stock-tank oil (up to 30 cubic meters per well) is required for well treatment. Under small reservoir pressure the main part of mud migrates to producing reservoir, that results in sudden well killing and reduces its productivity. In some wells, the share of non-return of oil is up to 50%.

Deposits flushed out to the top of the well after well cleanout go through valve units, clogging them and causing premature failures of oilfield equipment. The major drawback of oil dewaxing by hot water is the absence of heat source on the well. The use of special heating cable lines in order to prevent from APRD formation will allow increasing of purge period, decreasing amount of failures of downhole equipment, caused by APRD formation.

Paraffin-based oil has a considerable share of all oil produced on oilfields of Udmurtia. Production of paraffin-base oil is entailed by the occurrence of new phases in oil flow - gas bubbles and paraffin crystals. Complications caused by paraffin crystals deposition in the bottom-hole zone as well as in tubing string, ground-based communication lines and tanks lead to a decrease in oil recovery. To reduce the number of failures caused by APRD formation, it is necessary to break schedules of well flushing by chemicals as well as schedules of dewaxing by means of hot oiling.

As for wells equipped by the sucker-rod pump, well fluid can be heated by heating cable only in the case if it runs outside the tubing string (Fig. 4) because there are sucker rods inside.

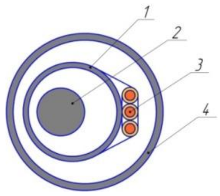

Fig. 4. The location of the heating cable in the well for warming the fluid in the well: 1 - tubing string, 2 - sucker-rods, 3 - heating cable, 4 – casing.

Heating cable lines are widely used in oil production to remove APRD formations on downhole equipment. This technology is an alternative to thermal treatment of wells by hot oiling.

Selection of candidate wells for installation of cable lines is carried out in accordance with specific requirements:

- the presence of free power on package transformer substation (PTS);
- increased necessity in use of heating cable lines. It is related to the wells with the ineffectiveness of hot oiling as well as wells with complicated access for special machinery;
- small purge period (less than 60 days) and high frequency of repairs caused by APRD (more than two times a year).

Having analysed well stock subject to frequent workover, it is proposed to equip 10 wells with heating cable lines to reduce the number of well workovers. Candidate wells are demonstrated in table 3.

Tab. 3. Candidate wells for installation of heating cable lines.

well №	The number of workovers, operations per year	TBO, days	Purge period, days
1	4	72	30
2	5	48	29
3	4	73	32
4	3	106	35
5	2	172	32
6	5	48	30
7	2	175	31
8	5	46	30
9	3	107	30
10	2	178	30

Automated self-regulating line heater (АСЛН-1) for well fluid heating consists (structurally) from heating and electronic parts. The scheme of the unit is demonstrated in Fig. 5.

Heating part is presented as heating cable with termination device. Cable type, cross-section diameter and material of electric conductors are determined after heat calculation and depend on well operation conditions, the viscosity of fluid produced, interval and intensity of APRD formation. The electronic part of the unit is presented as a field control station. Field control station consists of electronic power elements and the heating control unit.

Field control station has the following degrees of protection:

- from current overload;
- of resistance of insulation of heater (threshold value 300 kOhm);
- from overheat of heating cable accordingly to the mean temperature of the electric conductor.

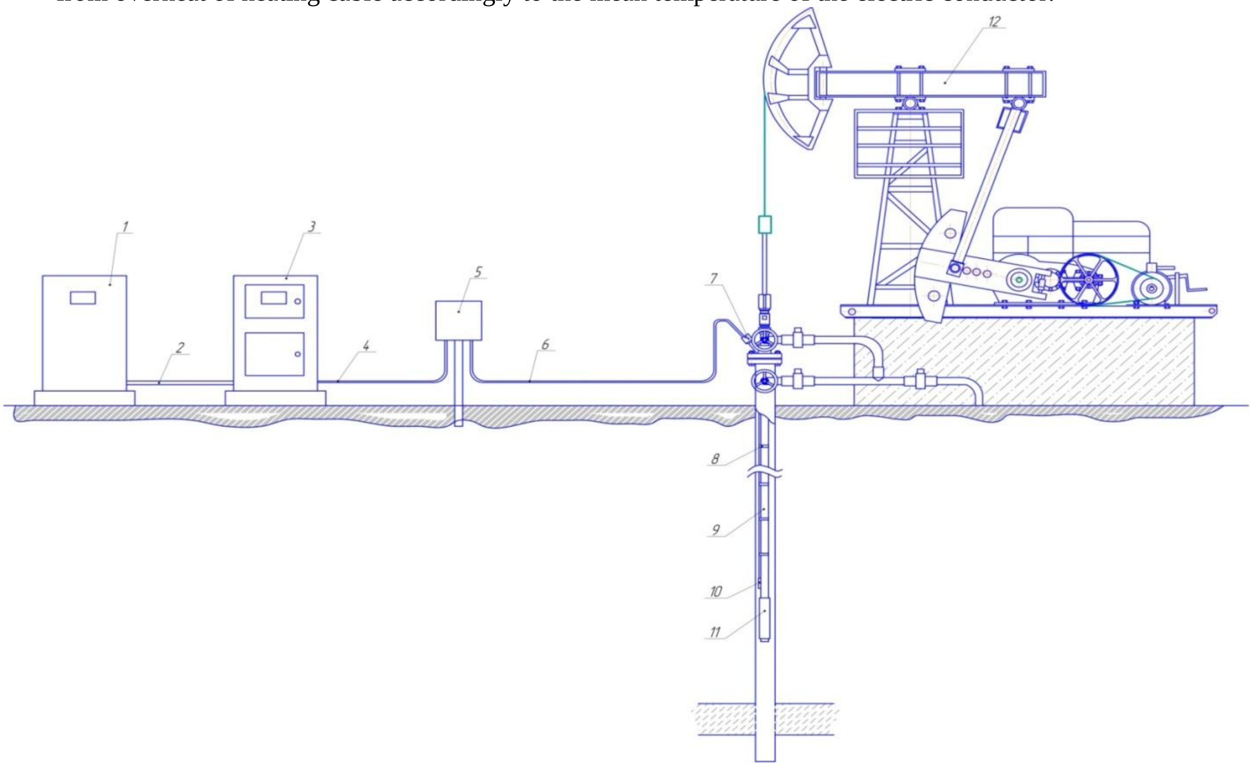

Fig. 5. Schematic location of heating cable unit on the well: 1 - transformer substation, 2 - feed cable of the unit, 3 - heating cable control station, 4 - power line, 5 - terminal box, 6 - heating cable, 7 - cable inlet device with sealing gland, 8 - metal belts for cable fixing, 9 - tubing string, 10 - termination device of heating cable, 11 - sucker-rod pump, 12 - beam-pumping unit.

There are three possible variants of control station work: "Manual", "0", "Automate". In mode "Manual" protection accordingly, insulation resistance and temperature of electric conductors of the cable are switched off. This mode is used for power circuit checking.

Programming of control station is carried out in mode "0". Mode "Automate" is used as major and allows manageable and controlled exploitation of the unit. The pressurisation of the inlet of cable in the well is fulfilled by special cable inlet device with sealing gland, also being an auxiliary element.

On the surface, electric conductors are inserted in terminal box. Terminal box is connected to control station by power conducting cable. To provide automatic regulation of heating over the temperature, a resistance thermometer (temperature sensor) is connected to the heating cable control station, connected via a cable to the control station.

The main technical characteristics of АСЛН-1 (Russian State Standard) heater are demonstrated in table 4 (Vdovin E.A., 2005).

The heating cable is installed on the external wall of the tubing string by means of steel belts for cable fixing and protector-centralisers.

The growth of heated reservoir fluid ΔT on the top of the well is determined by the formula:

$$\Delta T = \frac{7.5 \times P}{Q},\ ^{\circ}C \qquad (1)$$

where P – the power of heating cable line, kW; Q – well flow rate, tonnes per day.

Tab. 4. The main technical characteristics of the АСЛН-1 heater.

Name	АСЛН-1 heater *Russian State Standard*
Heating cable length, m	1300
Cable type	КНМПпБП-120 3х10 Russian State Standard
Cross-section of electric conductors, mm^2	10
Electric resistance of conductors to direct current, Ohm	
for cable	3.77
for control station	0.4
Electric resistance of insulation, MOhm	
for cable	10000
for control station	10000
Peak temperature of insulation of electric conductors, °C	+120
Well fluid	Oil, gas, gas condensate, reservoir water with the content of H_2S, CO_2 being up to 0.003%

In this unit cable of type, КНМПпБП-120 is used. It is a flat cable with conductors made of steel and copper wires isolated from each other by polypropylene insulation, the cable is armoured by the steel galvanised band, with a continuously allowable temperature of heating of conductors being equal to 1200 °C.

Setting depth of heating cable depends on the depth of intensive paraffin precipitation. For oils of vereiskian - bashkirian horizon the depth of paraffin deposits reaches the value from 200 to 1300 m. Peak thickness of deposits changes in the interval from 200 to 300 m (Fig. 5).

Paraffin melting temperature on vereiskian - bashkirian object is 51.40 °C. Reservoir temperature is 24 °C. To compensate heat losses during lifting of reservoir fluid and provide the temperature of APRD melting 270 °C are necessary.

Then power needed to keep the temperature higher than the point of paraffin crystallisation for well №1 will be:

$$P = \frac{Q \times \Delta T}{7.5} = \frac{13.5 \times 15}{7.5} = 27 \text{ , } kW/h \qquad (2)$$

Calculations for wells № 2 – 10 are carried similarly. The results of the calculations for these wells are demonstrated in table 5.

Tab. 5. The power of heating cable line for wells.

Well №	***Qж, cmpd***	***ΔT, °C***	***P, kW/h***
1	13.5	15	27
2	12.5	16.2	27
3	7.8	26	27
4	16.7	12	27
5	12	17	27
6	9	23	27
7	14.1	14.4	27
8	15.2	13.5	27
9	19	10.8	27
10	19.2	10.5	27

Interval of APRD formation varies from the depth of 1000 m to the top of the well. Fluid flow rate before installation of heating cable was 25 cmpd. After installation of heating cable amount of hot oiling decreased by more than 3 times (Fig. 6). By means of that, we managed to bring out the wells from well stock subject to frequent workover with a drop in failures caused by APRD and reduce the number of workovers by 3 times. In addition, the time between failures (TBF) was increased. The time between overhauls increased from 36 to 873 days. Before implementation of the heating cable, it was necessary to carry out dewaxing of downhole treatment using hot oiling every 30 days. After the implementation of this equipment, the well dewaxing treatment was not necessary. The results of pilot testing are demonstrated in Fig. 7.

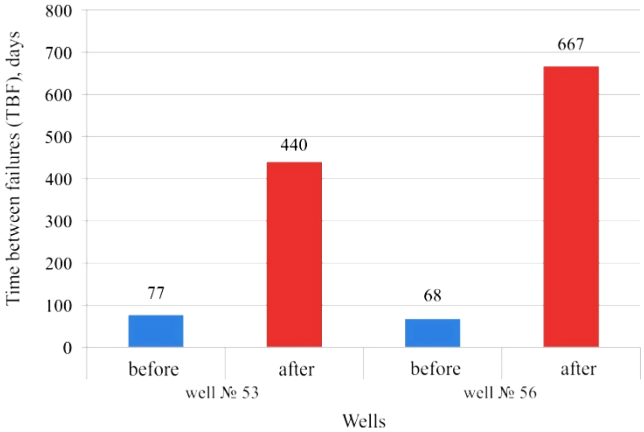

Fig. 6. Increase in TBF of wells.

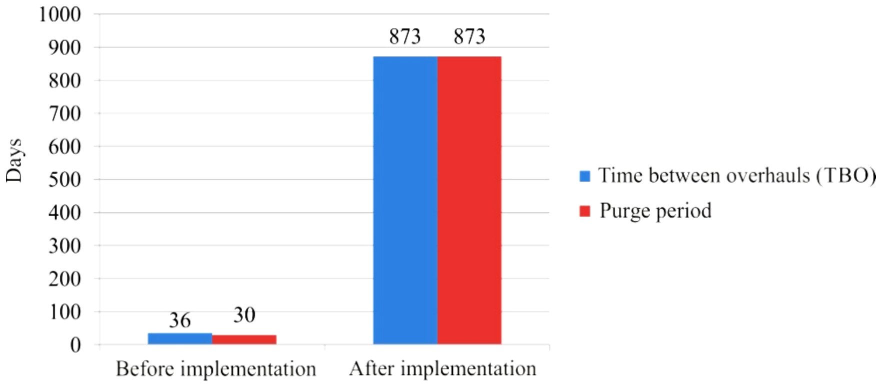

Fig. 7. The results of pilot testing of heating cable on wells of Udmurtia oilfields.

Despite existing power consumption, these units pay for themselves due to drop in expenses on prevention from APRD and its removal. The expenses decrease due to reducing of some workovers and income for incremental oil production resulting from TBO increase. Results of implementation of heating cable lines on oilfields are demonstrated in table 6. The number of workovers caused by APRD decreased by 35 - 40 times after installation of heating cable lines. The use of this technology allowed full rejection of dewaxing of downhole equipment by hot oiling treatment.

Tab. 6. Results of implementing heating cable lines.

Well №	**Before implementation**		**After implementation**	
	The number of workovers caused by APRD	**The number of flushings for APRD removal**	**The number of workovers caused by APRD**	**The number of flushings for APRD removal**
1	3	12	0	0
2	7	12	1	0
3	1	12	0	0
4	7	12	2	0
5	1	12	0	0

Summary

Thermal methods of prevention from APRD are based on maintenance of the temperature of oil flow with the use of heating cable. During operation, the cable heats the internal or external surface of tubing string which, in turn, heats the fluid that moves through the string to the temperature equal or exceeding the temperature of deposition formation. After the implementation of this equipment, dewaxing well treatment was not required. This technology is applicable in the removal of APRD formed, provided the calculation of the heating current and the operating time of the heating cable, especially for melting the deposits on the tubing walls.

The increasing exploitation of wells of complicated stock makes it important to understand the mechanism of wax deposition and the methods available to prevent and remediate wax deposits in different systems. This often involves the use of thermal treatment to deliver a fit for purpose wax control and management strategy suitable for a particular development. The thermal technology relates to oil and other industries associated with the production, transport and storage of oil (condensate), and can be used to remove and prevent asphalt, resin and paraffin deposits (ARPD) in wells, oilfield equipment and the bottom hole formation zone, the oil storage tanks.

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Principles of computer simulation design for the needs of improvement of the raw materials combined transport system

Martin Straka[1], Andrea Rosová[1], Radim Lenort[2], Petr Besta[3] *and* ***Janka Šaderová[1]***

This article is focused on computer simulation design for raw materials transportation. The creation of a simulation model of the combined transport system for the raw materials transportation has its own problematic parts. In general, these are parts, which represent transport nodes, i.e. parts of the system in which raw materials are reloaded from one vehicle to another. The given operations are in practice dependent on the preparedness of all transportation means, which participate in it. To locate operations of reloading of the raw materials from one vehicle to another and the check of the preparedness of the vehicles of the reloading in the simulation system is more demanding because it is necessary to take into consideration several aspects, such as an existence of a vehicle with raw materials, an existence of a vehicle to which it is to be reloaded, a suitable freeloader, and so on. The article focuses on defining a procedure and correct steps at the creation of the simulation computer model of the combined raw materials transport system in the EXTENDSIM simulation system based on specific data from a real transport system. As is clear from the proposed procedure of the creation of the combined raw material transport system, as a check element of the transport system preparedness, it is suitable to use the "Gate" block and its features in the EXTENDSIM simulation system. As transpires from the results of simulation of the combined raw material transport system, about 322,000 tons of raw materials at 90-96% with the use of all vehicles is transported during the year.

Key words: *computer simulation, EXTENDSIM, combined transport system, raw materials, improvement.*

Introduction

Successful realisation of transportation of millions of tons of raw materials with the use of different types of transportation depends on many factors. It is important to effectively set the logistic activities, such as loading, material transfer and unloading, effectively use technical resources and minimisation of delay and reconstruction times. It is not easy to design such a system due to time and distance reasons. That is why a suitable instrument for effective setting and testing such systems focusing on raw material transportation appears to be the use of computer simulation. The quality of the output and data depends on the quality of the realised analysis and a correct procedure, verification, validation and realisation of the simulation model. What procedure is better for designing such a system is not clear. That is why the article focuses on defining a procedure and correct steps at the creation of the simulation computer model of the combined raw materials transport system. An instrumentality of the computer simulation will be the EXTENDSIM system. The consequence of the steps is however usable for whatever simulation system and project of freight transport.

Activities closely tied to material flow can proceed simultaneously with the material flow, they can follow the material flow, or even against the material flow (Straka, 2010; Drastich, 2017). The problematics of identification of the common signs during designing combine transport systems with the help of particular simulation systems is in general significant and important, what is proved - among others - by general interest to the solved problematics of many other authors and designers. Some general principles are necessary to consider in the design and analysis of the material flow, for example a classification of the states, a system, cell or workstation and tips on how to define other possible alternative material flow scenarios (Delgado Sobrino et al., 2013; Pacana et al., 2014; Malindzakova et al., 2015). From the point of view of the mining activity and consequential treatment of raw materials, it is necessary to evaluate such activity very sensitively and thoroughly and emphasise the living environment. According to the authors Burchart-Korol et al. (2016), Witkowski and Kiba-Janiak (2012) and Khouri et al. (2017), life cycle assessment is important for the environmental evaluation of mining operations, which enables assessment of the factors that are both directly and indirectly affecting the environment and are associated with the production of raw materials and energy used in processes. It is clear from the above mentioned that solving a combine raw material transport system with the help of simulation systems has such higher importance because it enables us to set and propose a system in such activity to remove many important inadequacies (Grujic et al., 2011).

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According to the authors Straka et al. (2017), in the same way as the company gradually goes through different stages of development, so can the means of simulation modelling adapt to the requirements of any given development stage. Similarly, as a house is gradually being constructed so the simulation models can be built from specific blocks, objects, components and other tools within the simulation systems. The current possibilities of the computer simulation approach enable us to mimic the real processes of logistic production activities as well as of the actual production and transportation.

Literature review

The use of computer simulation for solving systems that are complicated, dangerous, tricky, in a phase of the prototype, unavailable, expensive and so on, became inevitable. From the point of view of the administration of the transport systems in time, it is mainly dynamical systems and dynamical simulation. According to the authors Zemanová, Botek and Strachotová (2017), Straka (2017) dynamic simulation is a powerful tool for optimising processes within the company. The meaning of computer simulation and the correct setting of the entire combine transport system is also important from the point of view of the effective management of the transfer of millions of tons of raw materials. Effective management of the provision of raw materials at the raw materials reloading point shall save costs of the transport itself and does not saturate a general transport network (Besta et al., 2016; Folega and Burchart-Korol, 2017). The computer simulation is one of the stable instruments for the implementation of internal and operational costs. Contemporary enterprises are constantly looking for new methods and solutions (including simulation) that allow their competitiveness to be increased and help them to improve the quality of decision-making and reduce the time and cost of the processes (Saniuk et al., 2014). Computer simulation and simulation software can be used in many branches. According to the authors Botek (2005), Dupláková, Knapčíková et al. (2017) and Straka et al. (2018), it is possible to use simulation software in the manufacturing plants. They are using the simulation software for cutting, milling, drilling, planning, assembly, manufacturing, management. It is possible to use the simulation software during the production of composite materials in the simulation of material flows.

According to the authors Taušová et al. (2017) and Wittenberger et al. (2012), the mining industry is in constant development on every continent. The reason is increasing demand for raw materials. The acquisition of mineral raw materials is the most important part of the mining industry, which produces raw materials worth hundreds of millions of euros per year in Slovakia alone. It is related to and increases the importance of the transport of raw materials.

European transport policy has undergone significant transformations both taking into account its range as well as implementation instruments since 1957. Contemporary conditions of the social and economic situation determine the existence of wide interactions between objectives of the strategy Transport 2050 and other European Union policies, like environmental and cohesion policy or support of research and innovations. In this situation, the efficient coordination of both programming (simulation too), as well as implementation instruments of these policies, has become a fundamental challenge (Straka and Malindzak, 2009; Drejerska, 2011; Kiba-Janiak, 2017). The Central and Eastern European region has grown dynamically over the past decade, starting its development even before the accession of many of the leading economies to the European Union. Infrastructure shapes mobility. No major change in transport will be possible without the support of an adequate network and more intelligence in using it (Hricová, 2017).

According to the authors Straka et al. (2016), logistics as a cross-sectional area in companies, including those with chemical production, aims to combine the material, spatial and temporal differentiation of the production and consumption in the liaison positions between the single economic subjects logically and cost-effectively. However, it is important to realise that a pragmatic delimitation of logistics characterises its mission narrowed to the sub-areas of the logistics system primarily for supply, storage or transport.

Analysis of the evaluated combined transport system

To enable the composition of a complex simulation model of the raw materials transport system activity, it is necessary to prepare and realise a thorough analysis of the transport system elements. The activity of the objective transport system can be classified as a flexible connection between the source of the raw materials and the point of their industrial using. The whole raw materials transport system consists of several parts. The first part of the system is created by the railway freight transport. The second part of the system is a loader, which withdraws raw materials from the freight wagons and reloads them to the trucks. The next part of the transport system is created by the instruments of the freight transport that carry out the loaded raw materials to the place of their processing. The last part of the freight system is created by the road infrastructure.

The input flow is created by thousands of tons of the delivered raw materials by means of the railway transport resources. The raw materials are loaded from the wagons with the help of a loader to the arrived trucks, which carry out them to the raw materials dumping place that serves for the industrial usage.

The following findings result from the system analysis of the transport system activity:

- Annually, about 322,000 tons of raw materials are transported by the railway.
- Transported raw materials come through several levels of transportation. The first level of transportation is created by the transport of raw materials from the place of mining by means of railway freight transport. Transfer of raw materials with the help of instruments for loading and unloading creates the second level of transportation. The third level of transportation is created by the road freight transport to the place of destination and processing the raw materials.

From the point of view of the general activity of the raw materials transport system, it is necessary to remember some following findings and parameters:

- One train consists of tens of freight wagons.
- The second level of transportation of the raw materials consists of one loader with a shovel capacity of 0.86 ton.
- The third level of transportation is created by three trucks. One truck has a capacity of 7.8 tons.
- The loader needs 4 minutes for the loading of one truck.
- The truck will overcome the road to the dumping place of raw materials by 1.75 minutes.
- One full wagon contains 70 tons of raw materials, what represents loading about of 9 pcs of trucks.
- Provided all vehicles be loaded, the train and the loader have to wait for returning back empty vehicles.
- When the train is unloaded, the vehicles and the loader have to wait for the addition of the following train loaded by raw materials.
- An addition of one wagon takes approximately of 1.5 minutes.

The composition of a formalised and block scheme for raw materials transport

Raw materials transportation and the activity of the entire transport system has its parameters, limitations and a precise sequence. Based on the information mentioned above and the analysis of the transport system activity, it is possible to compose its formalised scheme (Fig. 1). The formalised scheme represents the whole transport system with its elements and interconnections. Elements of the system create separate parts and levels of transportation and transport operations with raw materials.

The composed formalised scheme creates a very important base for the creation of the simulation system itself. Particular parts of the formalised scheme are consequently replaced by appropriate blocks of a specific simulation system. The creation of the simulation model consists of two parts. The first part is represented by a block scheme of a corresponding simulation system (Fig. 2) and the second part is the simulation model itself with the realisation of the research for the sphere of transportation of raw materials and the logistics (Fig. 3).

The composition of the block scheme as source materials for the simulation model itself is important for the preparation of data and information that are necessary for the setting of separate blocks of the simulation model.

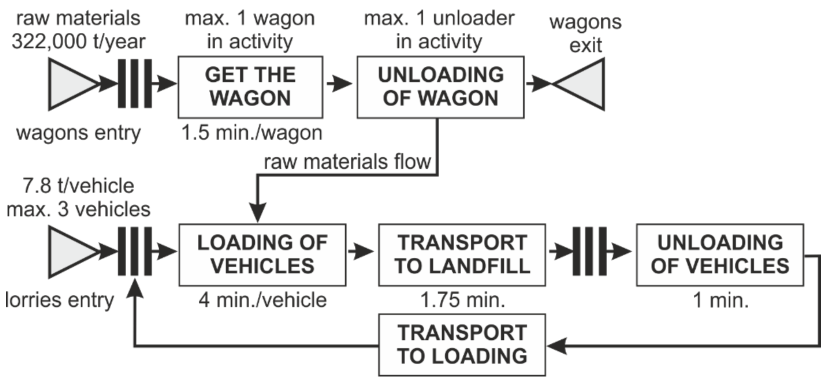

Fig. 1. Formalised scheme of the combined transport system of the raw materials traffic.

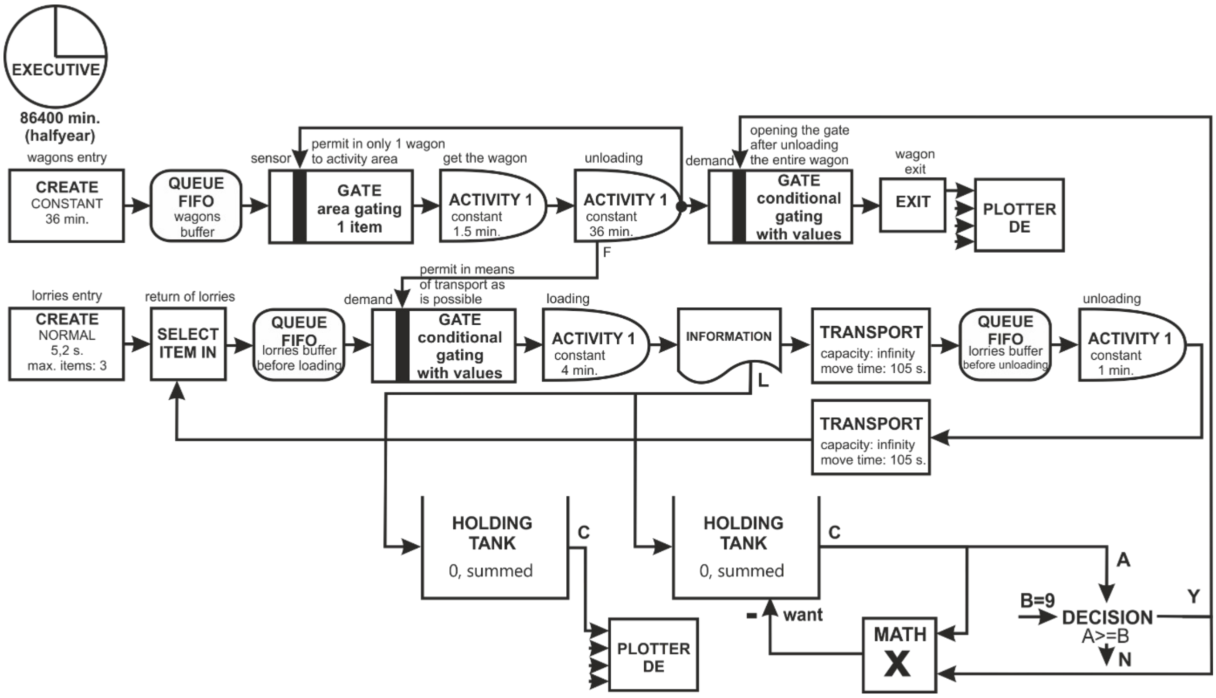

Fig. 2. Block scheme of the combined transport system of the raw materials traffic.

Proposal for a simulation model of the combined raw materials transport system

It is clear from the statistical data obtained from the operation of the raw materials transport system that the transfer of raw materials to a railway-reloading centre is approximate of 322,000 tons of raw materials annually. As is clear from the detailed data analysis, about 0.613 tons of raw materials is delivered by the railway every minute.

From the point of view of the creation of the simulation model itself and covering the activity of the entire transport system, two parts are very important:

1. The train with raw materials is added and is not empty, but all trucks are loaded, i.e. they realise transportation to the dumping place of raw materials or are on the way.
2. The trucks are prepared for loading, but the train is after unloading, and it is necessary to wait up for the addition of the next train full with raw materials.

In both cases, a lost time has to occur in part of the transport system, which is just physically unavailable.

Another interesting thing from the point of view of the creation of the simulation model of the evaluated transport system is that a dynamical element under the general name of "request" represents coming transport means. From the first entry, these are generated wagons, and from the second entry, these are generated cargo vehicles.

The given state from the point of view of the creation of the simulation model of the whole transport system, it is necessary to imitate in a concrete simulation system so that it corresponds to the activity the evaluated real system, what is not easy in many simulation systems.

Parts of the simulation model are characterised by the availability of blocks that are connected with junctions, which uniquely determine the direction of the flows. Their position, icon and a block name, blocks connectors, junctions, dialogue boxes with operands and flows define basic characteristics of particular blocks of the model. Each used block occupies a certain place, a position in the simulation model, which represent a real evaluated system. The blocks themselves represent certain parts of the processes or operations from which the model of the evaluated real system itself is created. Icons and names of the blocks are illustrative images of the blocks with their precise unique name that describe their basic function. Each block has its unique icon and its unique name that expresses its basic usage within the models. The block named „Create" represents generating entries of requests (waste in tons) to the model; the block named „Queue" characterises the creation of series of requests, with an entry into the series, including its leaving. The block named „Exit" represents an output from the model according to the requests that will input into the block.

Connectors of the blocks are parts of the icons that enable connection of the blocks between each other, whereas a rule has to be observed that it is necessary to connect only input connectors with output connectors. By connecting the connectors of two different blocks, a logical sequence of blocks corresponding to a real system and the base of origination of the flow of requests and values is created. The connection of the blocks between each other will provide the creation of flows and invoke their control and check. The connection of the blocks has to represent a real sequence of the blocks as well as in the examined system. By connection of two blocks via their connectors, a junction will be created (a doubled or simple line), which unequivocally encloses a sequence of the blocks and a direction of the flow of the requests and values. Dialogue boxes and operands represent specific items, features of the blocks, which are characteristic for separate blocks and necessary for the activity of separate blocks. In case of the opening the dialogue box of the block, specific parameters and features of the block will be displayed, which can be or have to be set for the concrete block.

As far as dynamic elements in the simulation model are represented by the requirements of „Wagon“ and „Truck“ type, etc., generators of inputs will be adapted to the given conditions.

Parameters of the generation of the entry of wagons into the modelled transport system of the first entry generator named „Create1-Wagons entry“ are set to the distribution function with a division of „Constant“ of 36 min. The given setting will ensure the insertion of one wagon full of raw materials into the examined transport system.

Parameters of the generation of the entry of trucks into the modelled transport system of the second generator of entry named „Create2-Vehicles entry" are set to the distribution function with a division of „Normal“ 5±2 seconds; the maximum number of the generated requests is adjustable to the value of 3. The given setting will ensure insertion of at the most of 3 trucks into the examined transport system in the given time division. As far as the raw materials dumping place is close to the loading point for the trucks within the whole system, three trucks are enough.

From the point of view of modelling a procedure of the entire train via the raw materials reloading centre, the connection of „Queue1-Gate1-Activity1-Activity2-Gate2-Exit“ blocks will follow up.

The „Queue1“ block represents an accumulator, i.e. auxiliary track, to which it is possible to place eventual next incoming wagons with raw materials.

The „Gate1“ block provides a check or an incoming wagon that has been already fully unloaded. If the incoming wagon has not yet been unloaded, then the „Gate1“ block will not let go the next wagon for unloading. Provided the incoming wagon has been already fully unloaded, the „Gate1“ block will let go the next wagon for unloading.

The consequence „Activity1“ block represents an addition of the wagon to the place of unloading, what standardly lasts 1.5 minutes. That is why the block is set to a delay with the „Constants“ segmentation of 1.5 minutes. At the same time, no other wagon can be unloaded.

The next „Activity2“ block represents unloading of raw materials from separate wagons. Unloading of a whole wagon takes approximately 36 minutes. That is why the block is set to a delay with the „Constants“ segmentation of 36 minutes.

The „Gate2“ block provides a check whether the wagon is already fully unloaded in the raw materials unloading position. If the wagon is not yet fully unloaded, then the „Gate2“ block of the wagon will not let it go the stands and unloading of raw materials. Provided the wagon is fully unloaded, the „Gate2“ block will let the wagon leave the transport system via the „Exit“ block. The „Gate2“ block is informed of the full unloading of the wagon via the „Decision“ block provided the condition be met that the given wagon maintained at least 9 pcs of trucks, what represents a discharge of one full wagon.

The „Exit“ block enables the unloaded wagons to leave the whole examined transport system.

From the point of view of modelling the activity of the road cargo transportation depending on the need of loading, driving-away and unloading of raw materials on a closely situated raw materials dumping place, a connection of „Select Item In-Queue2-Gate3-Activity3-Information-Transport1-Queue3-Activity4-Transport2“ blocks gets on.

The „Select Item In“ block serves for the security of the position of the incoming trucks into a queue in front of the loader of raw materials.

The „Queue2“ block represents a queue of the unattended non-loaded trucks, which wait in a queue for loading.

The „Gate3“ block provides a check whether there is available a wagon with accessible raw materials. If present, a wagon is not added, and trucks are prepared for loading, then the „Gate3 block will not let the next truck go to the attendance, for the loading with raw materials. If a wagon with raw materials is available, then the „Gate3 block will allow in the next truck for the loading with raw materials.

The „Activity3" block represents loading of the vehicles with raw materials from separate wagons. The loading of one truck lasts approximately 4 minutes. That is why the block is set to a delay with the „Constants" segmentation of 4 minutes.

The „Information" block serves for the sending information about the serviced trucks via the connector „L" to the „Holding Tank" block, which consequently summarises the number of the serviced trucks, for the needs of assessment of the condition for the check of wagon unloading.

The „Transport1" block represents a way as a multi-channel servicing equipment. It is the way, which has to be overcome from the station of loading to the enterprise mine of raw materials. Any number of trucks may be in the way at the same time. There are three trucks in our system. The truck will overcome the way by 105 seconds. Therefore the block in the „Travel time" item is set to „Move time" of 105 seconds.

The „Queue3" block represents a queue of the unattended non-unloaded trucks, which wait in a queue for unloading in front of the enterprise mine of raw materials.

The „Activity4" block represents unloading, emptying the trucks in the enterprise mine of raw materials. The unloading, emptying one truck lasts approximately 1 minute. That is why the block is set to a delay with the „Constants" segmentation of 1 minute.

The „Transport2" block represents a way as a multi-channel servicing equipment. It is the way, which has to be overcome from the enterprise mine of raw materials to the station of loading for trucks, i.e. the way back to the station. Any number of trucks may be in the way at the same time. The truck will overcome the way by the same time of 105 seconds. Therefore the block in the „Travel time" item is set to „Move time" of 105 seconds. The closure of the cycle of the trucks is being realised by the entry connector of the „Select Item In" block.

The prepared block scheme of the model of activity of the combined transport system represents an inactive part of the computer simulation model itself. An application of the block scheme in a particular simulation model comes on, thanks to which the inactive part will become an active computer simulation system. The result of the active part of the realisation of the simulation model is data representing the present state of activity of the combined transport system. By modification of parameters and examination of other effects to the created simulation model, it is possible to define recommendations and improvements of the activity of the combined raw materials transport system.

The simulation model of the combined transport system consists of blocks (Fig. 3) representing separate parts, operations within the transport system (addition, withdrawal, unloading, loading, transportation). Each block of the simulation model has its own meaning and substantiation. Not all operations can be modelled with one corresponding block, but several blocks have to be used in a sequence, which corresponds with a real activity of the combined transport system. No less important part of the entire simulation model is the thorough setting of parameters of the simulation model as it results from the analysis, the formalised and block scheme.

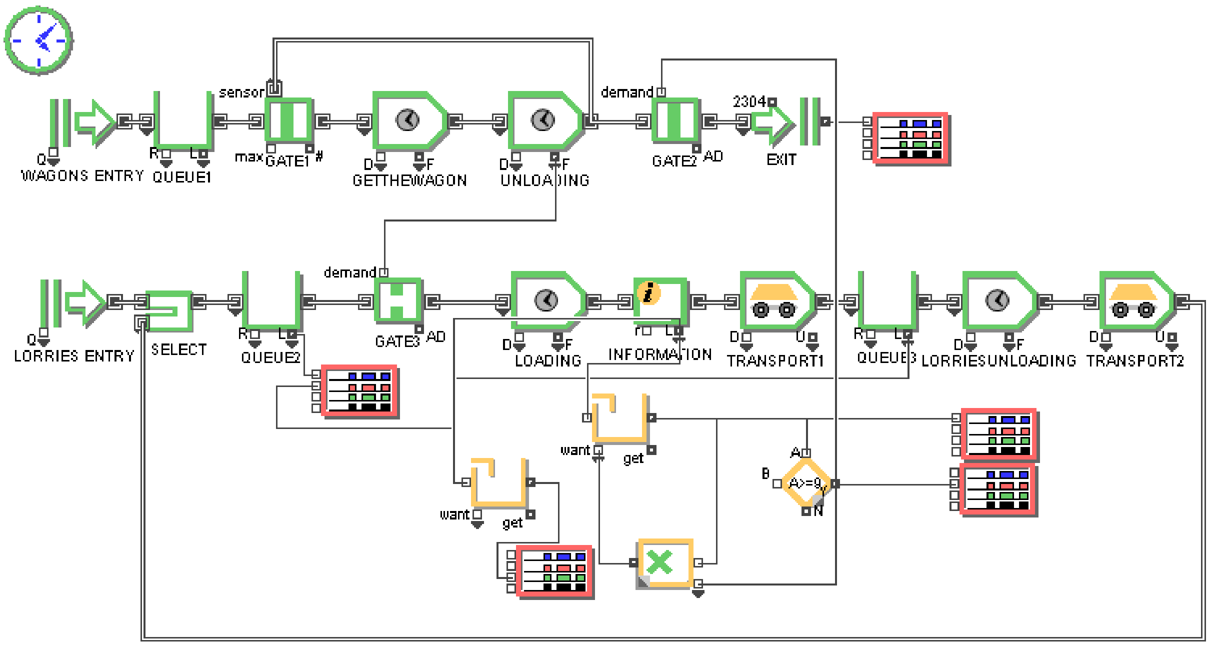

Fig. 3. The simulation model of the combined transport system of the raw materials traffic.

Settings of the simulation model of the combined raw materials transport system

To put blocks on the modelling area of a particular simulation system is no problem. The problem is to give a logical sequence for the connection of the blocks and set the parameters of the blocks so that they correspond to the real factual system.

The „Create1 Wagons Entry-Queue1-Gate1“ blocks (Fig. 4), represent driving-in the wagons with the loaded raw materials. In case of occupation of the railway, a position on which another wagon with raw materials is just being unloaded, the next incoming wagon will remain in a queue of waiting for non-unloaded wagons, full of raw materials.

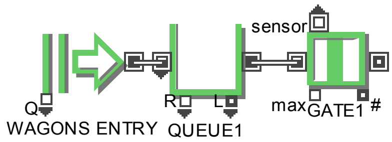

Fig. 4. Blocks „Create1 Wagons Entry-Queue1-Gate1“.

For the provision of the entry of the incoming loaded wagons to the reloading place of raw materials, it is necessary to set a distributing function according to the parameters recorded in the block scheme of the model (Fig. 5).

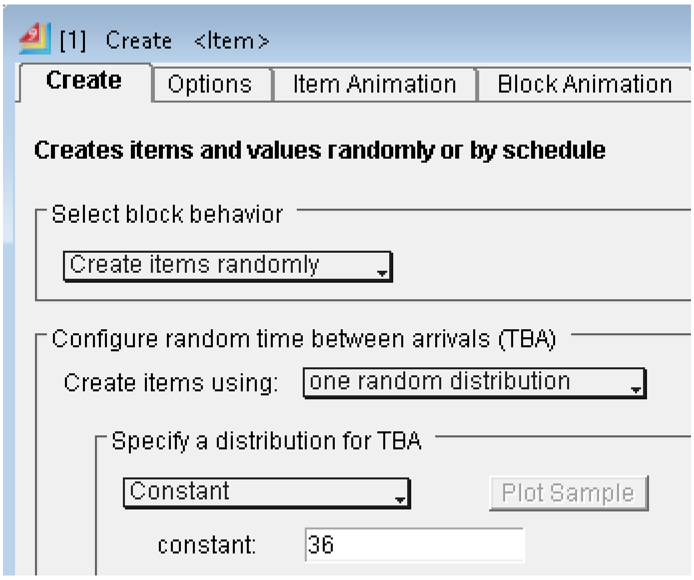

Fig. 5. Dialogue of the block „Create1-Wagons Entry“ and its setting according to the requirements of the simulation model.

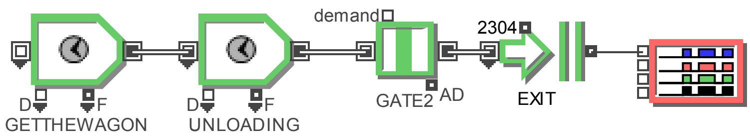

Fig. 6. Blocks „Activity1 GetTheWagon-Activity2 Unloading-Gate2- Exit“ and „Plotter“.

The „Activity1 GetTheWagon-Activity2 Unloading-Gate2-Exit“ blocks (Fig. 6) and „Plotter“ which represents ad addition of the wagons, their unloading, leaving the system and simulation data recording. The „Activity2-Unloading“ block represents unloading of the incoming loaded wagons. In the block, it is necessary to set parameters of the duration of wagons unloading (Fig. 7) according to the analysis and according to the data in the block scheme.

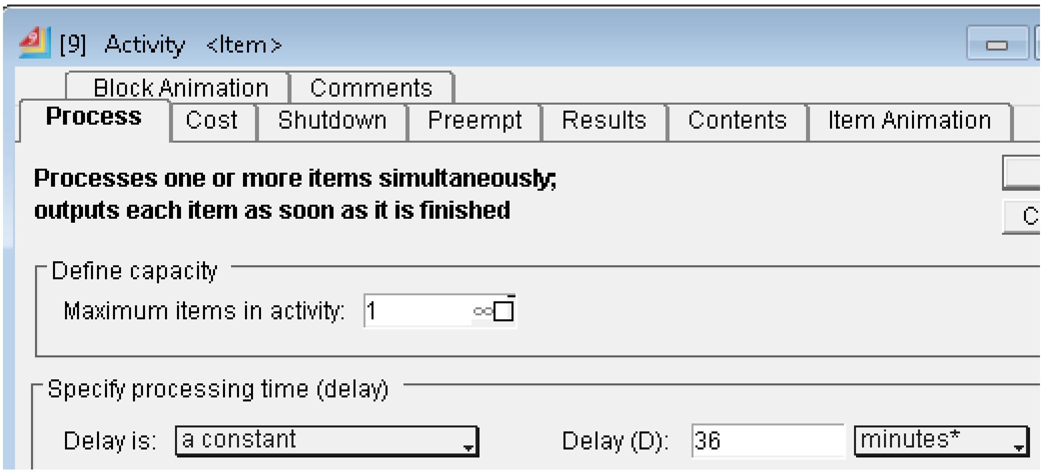

Fig. 7. Dialogue of the block „Activity2-Unloading", which represents the duration of the unloading of the wagons.

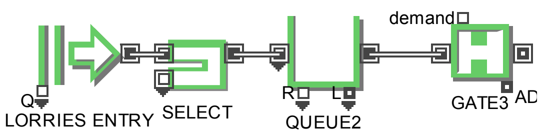

Fig. 8. Blocks „Create2 Trucks Entry-Select Item In-Queue2-Gate3".

The „Create2 Trucks Entry-Select Item In-Queue2-Gate3" blocks (Fig. 8) represent driving-in the trucks into the combined transport system. In case of occupation of the position of loading of the trucks by another truck, the next incoming truck will remain in a queue of the waiting non-loaded trucks.

For the provision of the entry of the incoming empty trucks to the reloading place of raw materials, it is necessary to set a distributing function according to the parameters recorded in the block scheme of the model (Fig. 9).

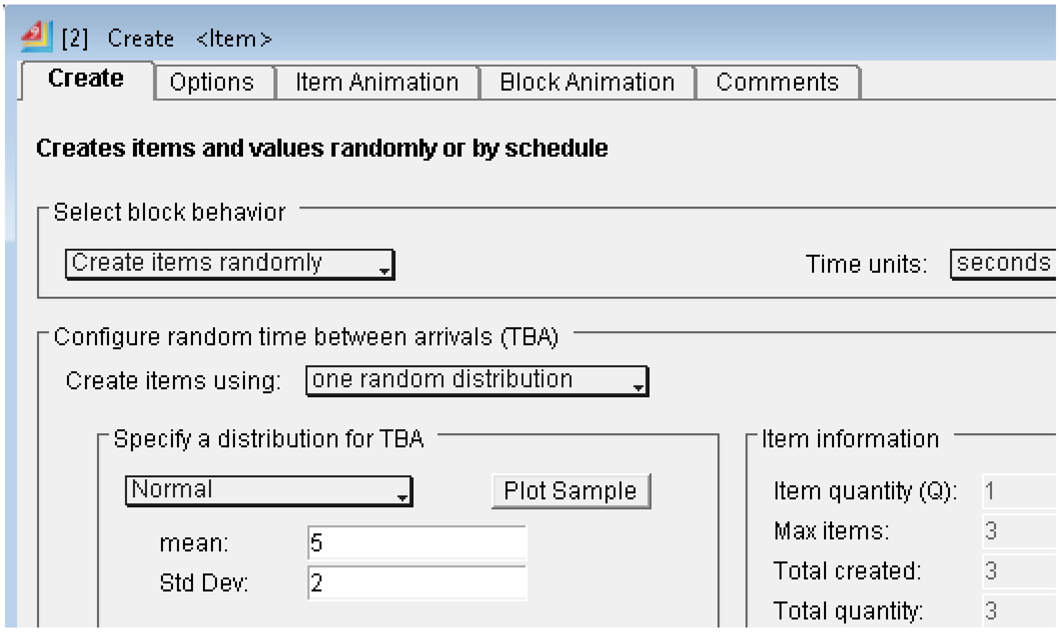

Fig. 9. Dialogue of the block „Create2-Trucks Entry" and its setting according to the requirements of the simulation model.

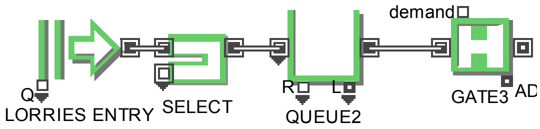

Fig. 10. Blocks „Activity3 Loading-Information".

The „Activity3 Loading-Information" blocks (Fig. 10) which represent driving-in the trucks, their loading and sending information about a number of the loaded trucks to the next parts of the system depending on the needs of the control of the course of the simulation model. In the block, it is necessary to set parameters of the duration of trucks loading (Fig. 11) according to the analysis and according to the data in the block scheme.

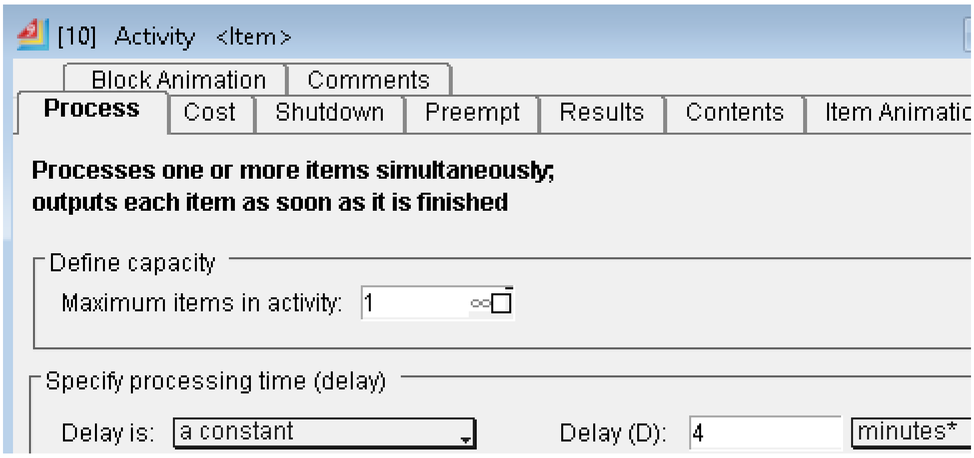

Fig. 11. Dialogue of the block „Activity3-Loading", which represents the duration of the loading of the trucks.

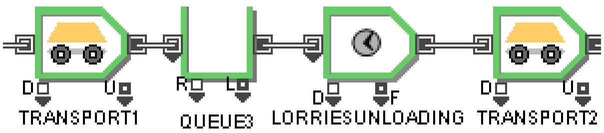

Fig. 12. Blocks „Activity3 Loading-Information".

The „Transport1-Queue3-Activity4TrucksUnloading-Transport2" blocks (Fig. 12) which represent a transfer of the loaded trucks to the place of unloading, sequencing the trucks into a queue of the waiting non-unloaded trucks, the realisation of unloading of the trucks and their return to the place of loading with the next raw materials. In the block, it is necessary to set parameters of the duration of the transfer of the loaded and the return of emptied trucks („Transport1" and „Transport2") (Fig. 13) as well as the duration of unloading of raw materials in the mines of the company („Activity4TrucksUnloading") (Fig. 14) according to the analysis and depending on the data in the block scheme.

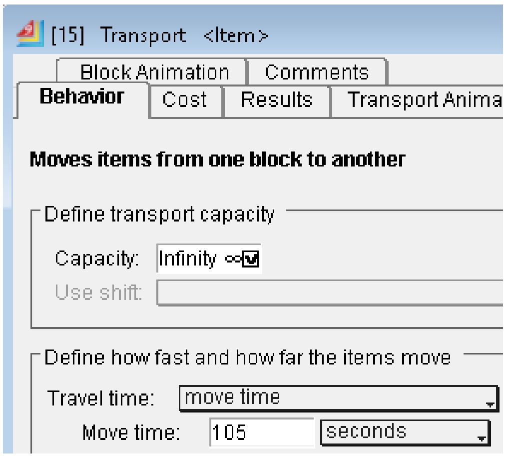

Fig. 13. Dialogue of the blocks „Transport1" and „Transport2", which represent overcoming the distance.

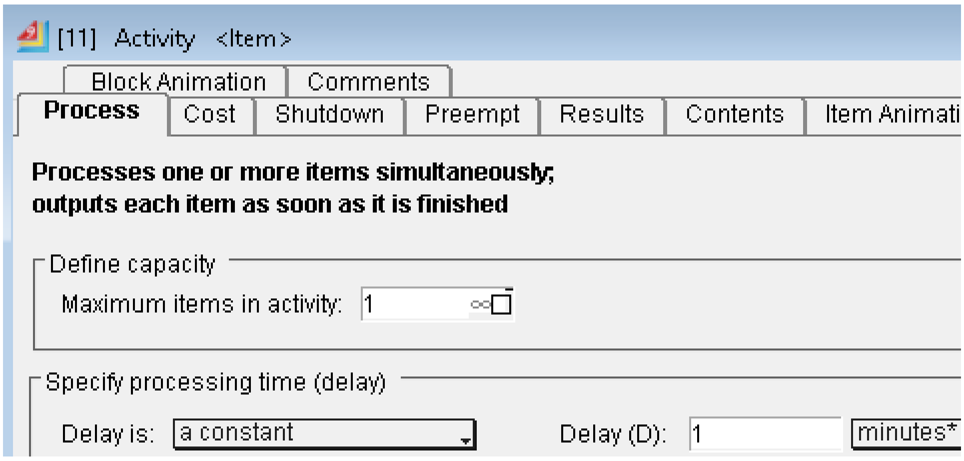

Fig. 14. Dialogue of the block „Activity4-Unloading“, which represents the duration of the unloading of the trucks.

Results and conclusion

After setting the simulation model, its usage goes on for the aim of examination of the activity of the combined raw materials transport system. The benefit of the computer simulation is also that it is possible to examine states, which could not be possible in reality or would not be possible from the point of view of the safety of the examined system. The simulation simulates the activity of the system during half of the year and its workdays, i.e. 86,400 minutes. The entry of one element into the system represents driving-in 70 tons of raw materials.

As it is clear from the results of the simulation, the combined transport system during half of the year will convey approximately 2304 of loaded wagons, what represents 322.560 tons of raw materials for the whole work year (Fig.15).

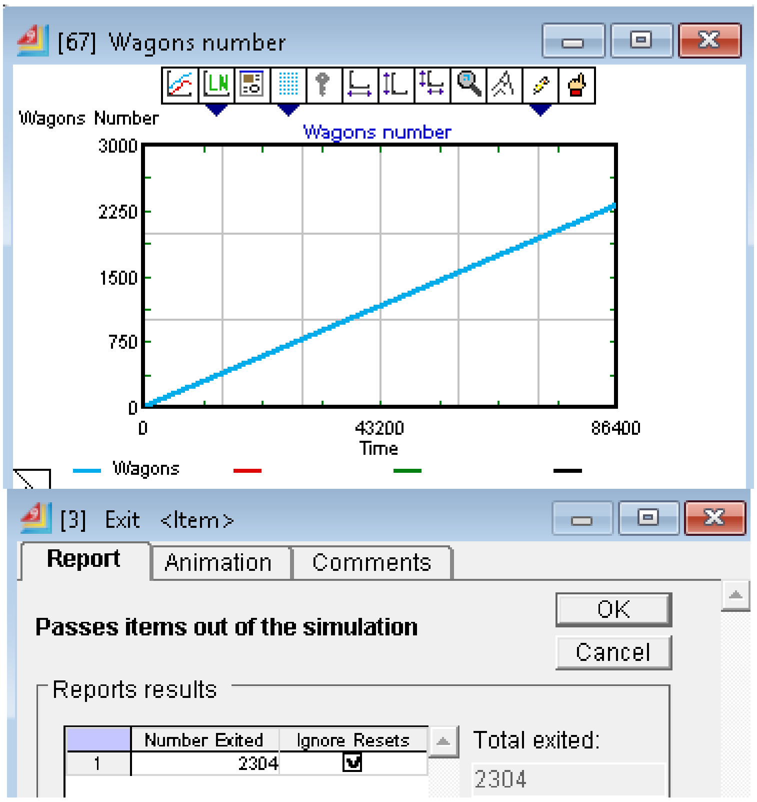

Fig. 15. The number of serviced, emptied wagons for the half a year.

Based on the examination of different settings of the combined transport system (Fig. 16), it is possible to say that three trucks with a capacity of 7.8 tons are enough for the entire provision of the activity of the combined transport system. While provisioning parallel unloading of several wagons at the same time, it is possible to increase the performance of the entire combined raw materials transport system several folds.

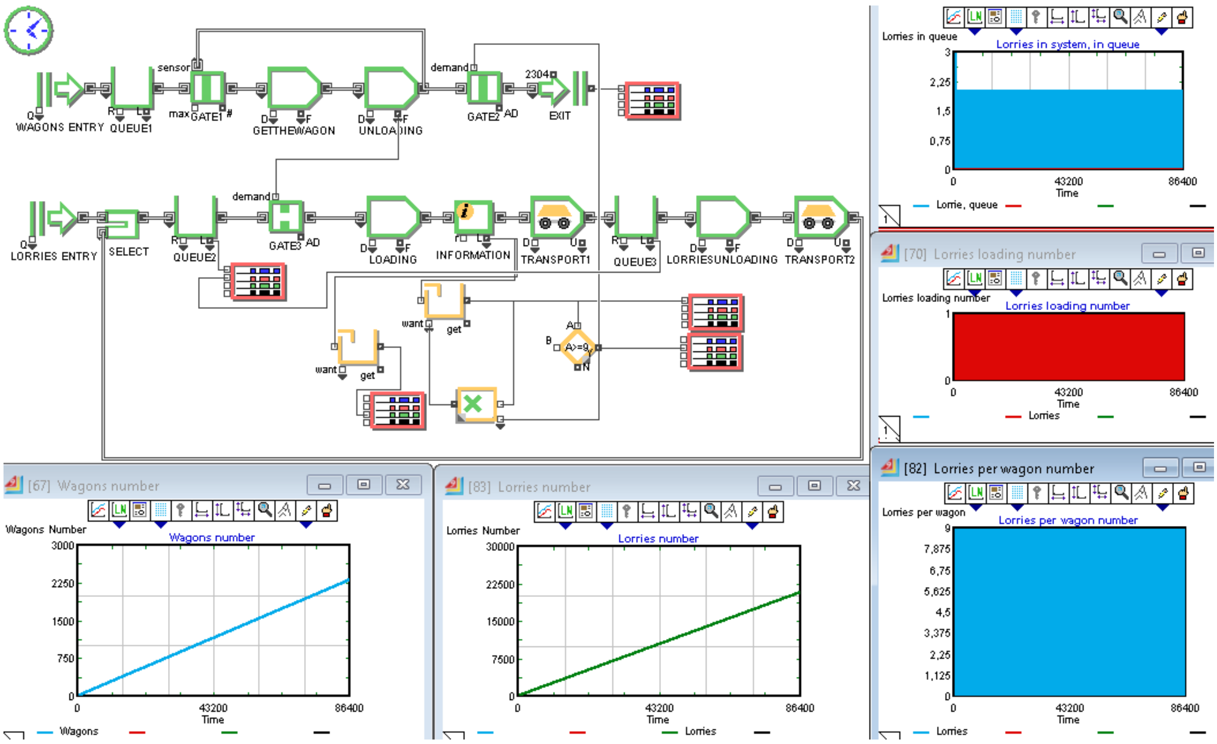

Fig. 16. The overall simulation model of the combined transport system for the transport of mineral resources.

Acknowledgements: *The submitted paper is a part of the projects " Implementation of innovative instruments for increasing the quality of higher education in the 5.2.52 Industrial Engineering field of study" KEGA 030TUKE-4/2017, funded by the Slovak Cultural and Education Grant Agency and "The specific university research of Ministry of Education, Youth and Sports of the Czech Republic no. SP 2018/109 investigated at VSB-Technical University of Ostrava".*

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The possibility of increasing the efficiency of temperature distribution control in reheating furnaces

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The concepts of creating the uniform temperature distribution in the reheating facilities equipped with high-effective regenerators have been considered in the present work. Uniformity of the temperature in the working space of reheating furnaces favours the removal of the local high-temperature three-dimensional zones in the furnace. This causes increasing the quality of metal heating, decreasing waste of metal, harmful gas-like ejections (including nitrogen oxides) with flue gases and improving conditions of the lining exploitation of the heating facilities.

High-temperature preheating of the combustion air predetermines the low consumption of the fuel in furnaces and the deep utilisation of the heat of furnaces gases. It is proposed to bring off the maintenance of the uniform temperature distribution in reheating furnaces at the expense of the new distributed three-dimensional practice of burning fuel.

Organisation of the new practice of fuel combustion is connected with special conditions of mixing fuel and air, recirculation and reverse of the furnace gases. Three dimensional (volumetric) fuel combustion is ensured by the modern design of burners equipment at the expense of the structural parameters of a burner and working space of the furnace, the arrangement of the fuel combustion facilities, duct openings of flue gases and gas dynamic characteristics of the furnace gases. Solutions for ensuring volumetrically distributed fuel burning for the main types of reheating facilities: several types of reheating pits, various types of batch and continuous reheating furnaces.

Keywords: *heating furnaces, temperature, combustion*

Introduction

The torch way of burning remains as the most widespread practice in furnaces using the gaseous fuel in the present time. This practice is notable for the simplicity of regulation of heat power and heat escaping in the furnace.

Technological processes of raw processing include many processes of transfer, accumulation and transformation of mass, energy and momentum (Terpák, Dorčák and Madula, 2007).

In consequence of the concentrated heat supply and removal of the fuel smoke at the torch burning of the preconditions arise to the appearance of the non-uniform temperature distribution and heating of metal. In zones at high temperatures formation of the "thermal" NOx is intensified. These phenomena are redoubled in the presence of the high-temperature heating-up of the burning air.

Investigations on operational parameters of afterburning chambers included in metallurgical thermal equipment have been presented in the source (Gil, Rozpondek and Bialik, 2014). The effects of temperature and modernisation within the firing system on concentrations of nitrogen oxides and carbon oxide have been analysed.

Uniformity and standard character of heating in furnaces are reached by recirculation and reverse of furnace gases, pulsed heating, separate, by the periods of heating, feed of the fuel, rocking of the burner, changing the direction of the torch, multistage combustion of the fuel and other ways (Gubinskiy, 2005; Shults, 1995; Gubinskiy and Lu Chzhun, 1995). In the source (Gubinskiy and Lu Chzhun, 1995) and the works by A.V. Kavaderov and Y.P. Ivantsov, the locality of the external heat exchange is described. According to this principle, the heating of the charge is determined with radiation and convection from gas volumes located in immediate proximity to the surface. In accordance with this principle, attainment of uniformity in heating of the charge in the furnace is brought off by the rational control of gases movement ensuring heat transfer to the local sections of metal and lining.

In high-temperature heating furnaces, as well as in low-temperature chamber heat furnaces (LTCF), the optimization of the schedule of gas movement in the furnace of the burners, the way of removal of the flue gases, external and internal recirculation of the flue gases, employment of impulse burners (Revun and Zinchenko, 2006) and other practices bringing combustion nearer to volumetric one. "Questions of using the volumetric

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combustion of the fuel in LTCF are still demanding their design solution and technological grounding" (Revun and Zinchenko, 2006).

Using the volumetric fuel combustion leads to changes of condition for the local heat transfer to metal and lining in different points. The absence of concentrated heat forces, which are the most brightly expressed for the torch practice of fuel combustion, leads to the situation when the whole of the surface of the metal to be heated is under the equivalent condition of heating. There is no stagnant zones or metal being in zones of stagnation. The volumetric burning of the fuel can be arranged by regulated intermixing of the burning reagents. Heat transfers and combustion processes are described by the authors (Ferstl and Masaryk, 2011; Rimár and Fedák, 2014; Varga et al., 2013)

In contribution (Durdán and Kostúr, 2015; Durdán and Kostúr, 2006), a proposal of the system for indirect measurement temperatures in the underground coal gasification (UCG) process is presented. A two-dimensional solution results from the Fourier partial differential equation of the heat conduction was used for the calculation of the temperature distribution in the real coal seam. An algorithm of queue burning movement for modelling the boundary conditions in gasification channel was created.

The objective of the work (Lazić et al., 2011) was to investigate the essential features of radiation and convection heat transfer in the chamber furnace heated with roof flat-flame burners and conventional side-fired torch burner. The effect of change in the furnace chamber height on the heat transfer rate in the furnace enclosure, particularly on the heat flux onto the heated material, was determined numerically and experimentally.

Experimental evolution of heat flux distribution in a reheating aluminium furnace with a pair of regenerative burners was conducted in the study (Zhang and Deng, 2017). Reheating furnace with regenerative system has been widely applied in the non-ferrous metal industry due to its great advantages, such as high energy efficiency, low pollutant emission and high production yield.

Combustion of the fuel with air at the regulated intermixing

The methods for changing the torch length by way of regulating the quality of intermixing the fuel with oxidiser are known. They are: the pulsed way of burning the fuel; periodical change of the torch direction and the dynamic characteristics of the torch and other practices trained on the change of conditions for external heat exchange. The proposed practices only bring the regime of fuel combustion closed to volumetric one, as the torch in these practices is present at certain stretches of time or in the definite point of the furnace working space.

The practice of multi-stage fuel burning is the nearest to the volumetric burning. Only a part of the air necessary for the complete combustion of the fuel is conveyed to the burner, and the rest is carried along the trajectory of movement of the furnace gases. With the more step introduction of air and gradually complete combustion of the fuel, the longer flame is achieved under conditions that are close to the volumetric combustion. Such burning is practised on a large scale in the boiler equipment. In industrial furnaces, the burning of fuel by stages was connected with the necessity of organising the low-oxidising and oxidising free heating of steel before metal forming. It is also noted in the literature (Shults, 2005) that the burning of fuel by stages allows shortening ejections of the nitrogen oxides by 20-80% and creating a low-oxidising atmosphere in the working space of a furnace.

- *Method for calculating emissions of nitrogen oxides*

Basic studies of nitrogen oxides were performed by Zeldovich J.B. in 1947 (Zeldovich, J.B., Sadovnikov, P.P and Frank-Kameneckiy, D.A, 1947). According to J.B. Zeldovich content (amount) of NOx in the combustion products is determined: the temperature of the flame and the resulting combustion products; the content of the oxidising agent in the gases and other factors.

In the Shults L. A. (2005) work, the following relationships were used to determine the concentrations of nitrogen oxides in fuel combustion products:

$$[NO] = 0.24\ 10^{10} K_g\ K(O_2)\ K(\varepsilon)\ K_v\ exp\left[\frac{35\ 000}{T_{k_1}^{0.25}\ T_{k_2}^{0.5}\ T_n^{0.25}}\right] \qquad (1)$$

where the following variables are used:

K_g - coefficient reflecting the type of burner. $K_g=0.5\text{-}3.5$. For turbulent burners $K_g=1$

$K(\varepsilon)$ - coefficient depending on the optical density of the combustion products

$K(\varepsilon)=0.3\text{-}1.0$;

K_v - concentration coefficient. $K_v = \frac{V_\alpha}{V_{\alpha=1}}$, V_α - specific (measured) amount of exiting flue gases from calculations of fuel combustion stoichiometry, $V_{\alpha=1}$ - standard flue gas outlet;

$K(O_2)$ – a coefficient dependent on the oxygen content of the combustion products. With excess air greater than one $K(O_2) = (0.7 + O_2)^{0.5}$;

T_{k_1} - standard calorimetric temperature *(*K*);*
T_{k_2} - calorimetric flame temperature *(*K*);*
T_n – the temperature of the flue gases leaving the furnace (K).

- *Low oxidation atmosphere in furnaces*

Combustion of hydrocarbon fuels (which contain carbon and hydrogen compounds, for example, natural gas) provide the following components of CO-carbon (carbon monoxide) and H_2 (gaseous hydrogen) which are formed in two- and multi-stage combustion.

The amount of such reducing gases (CO and H_2) and their ratio to total combustion oxidising gas (CO_2 and H_2O) depends on the coefficient of the amount of air used to burn the hydrocarbon fuel.

With sequential fuel combustion in the first stage, the 45-60% of the air required by air stoichiometry is supplied. The remainder of the air, with a slight excess (up to 5-10%), is fed to the second or further stages of combustion.

This achieves a triple effect of reducing the emissions of nitrogen oxides:

- The specific concentration of oxidising gases(CO_2 and H_2O); decreases
- The specific concentration of reducing gases (CO and H_2) increases ;
- The temperature in the combustion zone decreases.

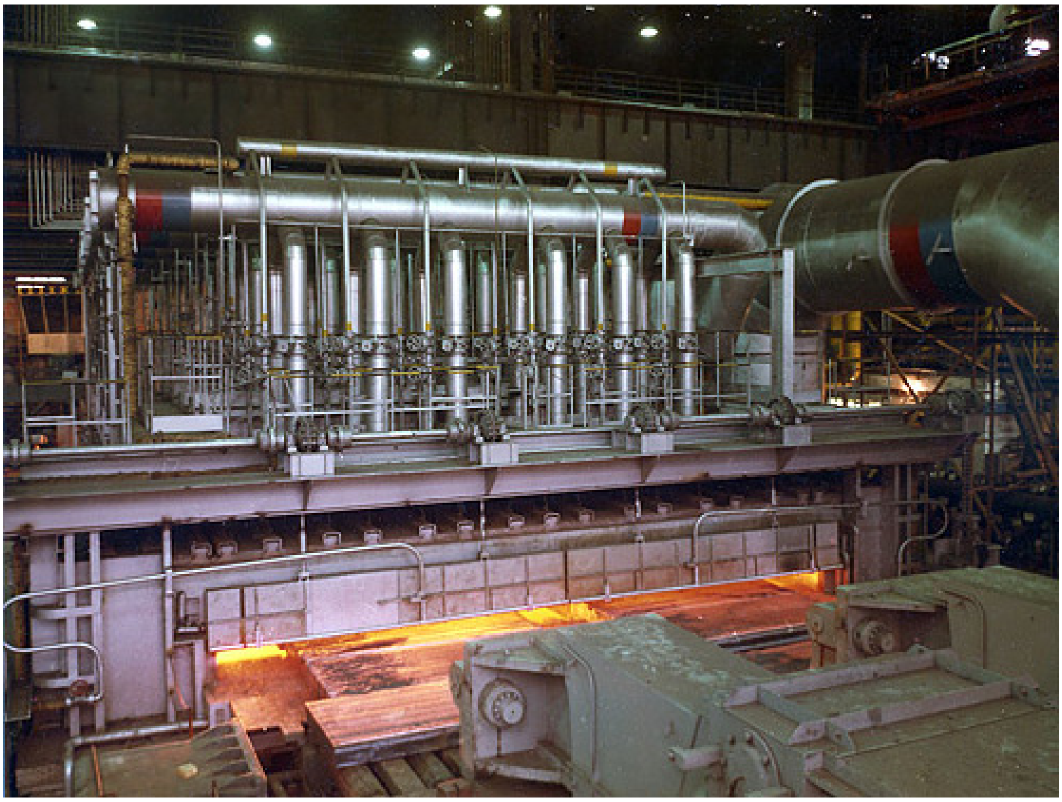

Fig. 1. View of the pusher furnace.

The work (Shults, 2005) shows that "stretched" in time burning in the working space of the heat engineering equipment is achieved by dispersion of the lead-in air by the length of torch, as well as by deregulating the work of burners, layers of burners or burners of different zones of burning open to each other as to gas dynamic and connected mutually, in accordance with coefficient of air consumption. The realisation of the fuel burning by stages in practice is entailed with some difficulties. A bulky system of pipelines, additional blocking and regulating accessories and complication of the system of automatic equipment, the unsolved question about the organisation of multistage schedule of burning at the variable heat power of burners, which is connected with carrying out the heat process, put limitations on using the given practice in heating furnaces.

A typical example of the use of temperature distribution control in reheating furnace is the pusher furnace, which is shown in Fig. 1.

Regulated (specified) intermixture of the burning reagents and distributed fuel burning in heating furnaces with high-temperature preheating of the combustion air

The organisation of volumetric fuel burning by means of the specified regulated intermixture of the burning reagents, when fuel in the working space of the furnace is burning on all the length of the trajectory of the furnace gases movement without creating local high-temperature zones, could become alternative to the stage combustion.

To the recent time, slowed intermixture of the fuel with air was not widespread in industrial furnaces. Traditional burners do not assure the complete intermixture of the fuel with air. The unsatisfied intermixture of the burning reagents leads to creating so-called physical under burning and over expenditure process in heating furnaces equipped with recuperates or operated without heat utilises. The situation is different in the furnaces with regenerators. If the complete combustion of the fuel is organised before leaving the flue gases from the packing of regenerators, the released chemical heat with a high coefficient of regeneration will return back to the furnace with heated air. The only condition is the complete combustion before leaving the packing of regenerators. When the combustible components of the fuel are burnt in the regenerator, the nozzle does not exceed 2-3% at 10% underburning of the fuel in the furnace. This is ensured by a high degree of recovery (regeneration) of the heat of flue gases (up to 80%) in modern ball regenerators and regenerative burners.

The presence in the volume zone of the burning of the fuel-air mixture with temperature exceeding the temperature of fuel ignition at the expense of high-temperature air heating in the modern regenerators makes possible burning at any quantity of oxygen.

The heat escape can be distributed along all the trajectories of moving the furnace gases at the expense of regulated intermixing fuel and air. In the view of the distributed burning, the low oxidising atmosphere is created in the furnace, the local high-temperature zones disappear, the uniformity of metal heating is improved and the quantity of harmful ejections during the burning.

Organization of distributed volume fuel combustion in heating furnace equipped with high-efficient regenerators (or in other words “volume-regenerative practice of fuel combustion”) is ensured at the expense of dividing the flows of fuel and air in burners facility and assuring the dynamic characteristics of the gas-air streams, which guarantee the specific quality of mixing the reagents of burning. Due to the choice of number, geometric characteristics and mutual arrangement of gas nozzles, flue gases openings in regenerators and other structural parameters of the furnace and its elements, the conditions are created for regulated mixing of fuel and air.

Gas-dynamic characteristics of furnace gases

1. The speed of the motion and dimensionless speed of the motion.

Stability of the flame and combustion process in the furnace depend on the velocity of reactants. If the velocity of reactants exceeds the flame speed, the flame will begin to move in the direction of the reactant flow. This would extinguish the flame and result in uncombusted fuel. This condition is known as a liftoff. If the reactants have a velocity much lower than the flame speed, the flame moves opposite the direction of the reactant flow. This condition is known as a flashback (Semikin, Averin and Radchenko, 1965).

2. Consumption pulse of jets and flows.

In the paper (Semikin, Averin and Radchenko, 1965), it was shown by I.D. Semikin “that the decisive influence in the determination of the length of turbulent flame at fuel burning has the ratio of the mass flows of the air and gas”.

By analogy with the notion of the thermal heat capacity of the flow (W_t/K), the notion of consumption pulse had to be introduced (or the notion of consumption quality of the medium motion (H)).

$$I_{med} = \rho_{0med} \frac{V_{0med}^2}{f_{med}} \left(1 + \frac{t_{med}}{273}\right) \qquad (2)$$

where

$V_{0\,med}$ – volumetric consumption of the medium (fuel, air, flue gases) under n.c. (normal conditions), m^3/s;

f_{med} – the area of section for passage of the medium (section of the gas nozzle for fuel, or section of the canal for flue gases and so on), m^2;

t_{med} – the temperature of the medium, °C;

$\rho_{0\,med}$ – density of the medium under the n.c., kg/m^3.

It is possible to judge which reagent in the fuel-air flow is the key by the ratio of the motion quantity of one reagent to the general pulse of fuel *(lower index f)* and air *(lower index a)*.

$$\Delta I = \frac{I_f}{I_f + I_a} = \frac{\frac{\rho_{of}}{f_f}\left(1+\frac{t_f}{273}\right)}{\frac{\rho_{of}}{f_f}\left(1+\frac{t_f}{273}\right)+\rho_{oa}\frac{L_n^2}{f_a}\left(1+\frac{t_a}{273}\right)} \quad (3)$$

The difference of pulses of burning reagent by the value, which does not exceed 10-15%, assures the minimal interaction of jets and the slowed regulated mixing of the fuel and high-temperature air.

3. The kinetic energy of jets to be consumed.

The kinetic energy of burning reagent related to the second consumption of reagents shows to what extent the energy potential of these gases can be transformed into rectilinear or recirculating motion of the combustion gases*(lower index s)* with *Vs* and kinetic energy to be consumed (Yeromin, 2012)

$$E = \frac{\rho_0\, \overline{w}_0^2\, V_0}{2}\left(1+\frac{t}{273}\right)^2 \quad (4)$$

where
ρ_0 – density under n.c., m/s;
V_0 – volumetric consumption of the heat-transport medium under n.c., m^3/s.

Using the notions of the consumed kinetic energy of furnace gases allows expressing the energy balance of medium circulation as equality of presented power of circulation and power of furnace gases consumed for their motion along the specified trajectory in the form of expression.

$$\frac{\rho_f\, \overline{w}_0^2}{\rho_f\, \overline{w}_s^2\, v_s} + \frac{\rho_f\, \overline{w}_a^2\, L_n}{\rho_s\, \overline{w}_s^2\, v_s} - 1 = \sum_{i=1}^{i} \lambda_{eqi}\, \frac{L_{av\, i}}{d_{eqv\, i}}\, K_{rec}^3 \quad (5)$$

where
λ_{eqv} – coefficient of the energy losses at the circulating motion of gases in the *i*-th section;
L_{av} – the average length of the motion trajectory of the furnace gases in the *i*-th section, m;
d_{eqv} – equivalent diameter of the middle section of the flue gases flow in the *i*-th section in the furnace, m;
K_{rec} – the multiplicity of the flue gases recirculation;
i – the number of the section of the trajectory of the furnace gases motion;
v_s – the specific output of combustion gases during burning, m^3/m^3.

4. The energy of furnace gases circulation

The kinetic energy of furnace gases, which is spent for circulation in one second (energy of circulation *N*, W_t) is equal to the kinetic energy of the flow of flue gases introduced to the furnace, minus the kinetic energy of the flow of flue gases leaving the furnace through the flue gases ducts (Yeromin and Gubinskiy, 2011).

$$\mathbf{N} = \frac{\rho_f\, \overline{w}_f^2\, v_f\left(\frac{T_f}{273}\right)^2 + \rho_a\, \overline{w}_a^2\, v_a\left(\frac{T_a}{273}\right)^2 - \rho_s\, \overline{w}_s^2\, v_s\left(\frac{T_s}{273}\right)^2}{2} = \quad (6)$$

$$= \frac{\rho_f\, w_f^3\, F_f\left(\frac{T_f}{273}\right)^2 + \rho_a\, w_a^3\, F_a\left(\frac{T_a}{273}\right)^2 - \rho_s\, w_s^2\, F_s\left(\frac{T_s}{273}\right)^2}{2}$$

where
F_f, F_a, F_s are the passage section of the gas nozzle, air ducts and flue gases ducts, m^2.

5. and 6. The specific energy of circulating in dimensional and dimensionless representation.

The quantity of kinetic energy in 1m^3 of furnace gases is called the specific energy of circulated N_{sp} (Yeromin and Gubinskiy, 2011) expressed in the form:

$$N_{sp} = \lambda_{eqv}\, \frac{L_{av}}{d_{eqv}}\, K_{rec}^3\, \frac{\rho_s\, \overline{w}_s^2}{2}\, \frac{T_s}{273} \quad (7)$$

$$N_{sp} = \frac{\rho_f\, \overline{w}_f^2\, V_f\left(\frac{T_f}{273}\right)^2 + \rho_a\, \overline{w}_a^2\, V_a\left(\frac{T_a}{273}\right)^2 - \rho_s\, \overline{w}_s^2\, V_s\left(\frac{T_s}{273}\right)^2}{2\, V_s\left(\frac{T_s}{273}\right)} \quad (8)$$

Eq. 7 and Eq. 8 allow determining the gas-dynamic characteristics of furnace gases ensuring the specified multiplicity of recirculation and the length of trajectories of these gases motions in the working space of the furnace.

It is easy to judge about the range of the furnace gases flow in the furnace by the specific energy of circulation in dimensionless form.

7. The multiplicity of recirculating the furnace gases.

According to the opinion of the professor V.I. Gubinskiy (Gubinskiy and Lu Chzhun, 1995), “in the practice of designing furnaces, one needs taking into account and using the active part of conditions of gases circulation and the fuel burning. As opportunities for gases motion control with the purpose of equalisation of the temperature in the furnace working space can serve the internal and external recirculations as well as the reverse of the furnace gases. The final evaluation and the choice of schedules for gas circulation and burning fuel can be done by way of calculating the conjugate temperature distributions of openings, metals and refractories of the furnace”.

The multiplicity of recirculation K_{rec} to be found from the equation of energy balance including pressure losses on all the sections of the trajectories of furnace gases motion from a burner to the flue gases ducts. This equation for the energy of circulation has the next dimensional form:

$$K_{rec} \sqrt[3]{\frac{\rho_f\ \overline{w}_f^2\ V_f \left(\frac{T_f}{273}\right)^2 + \rho_a\ \overline{w}_a^2\ V_a \left(\frac{T_a}{273}\right)^2 - \rho_s\ \overline{w}_s^2\ V_s \left(\frac{T_s}{273}\right)^2}{\lambda_{eqv} \left(\frac{T_s}{273}\right)^2 \sum_{i=1}^{i} \left(\frac{L_{av\,i}}{d_{eqv\,i}}\ \rho_{s\,i}\ \overline{w}_{s\,i}^2\ V_s\right)}} = \tag{9}$$

$$= \sqrt[3]{\frac{2\ N_{sp}}{\lambda_{eqv} \frac{T_s}{273} \sum_{i=1}^{4} \left(\frac{L_{av\,i}}{d_{eqv\,i}}\ \rho_{s\,i}\ \overline{w}_{s\,i}^2\right)}}$$

The increase of the heating efficiency in reheating furnaces

Flame combustion of fuel

Flame combustion of fuel (Fig. 2) is characterised by:

1. concentrated heat input,
2. non-uniform temperature distribution and low quality of metal heating,
3. intensive NOx formation,
4. formation of the scale,
5. durability and melting of the lining, especially under the high temperatures.

Uniformity of temperature distribution in furnaces can be achieved with the help of controlled air-fuel mixing (impulse method, variable consumption of reagents, change of direction and dynamic flame characteristics, gradual fuel combustion, slow mixing of reagents).

Fig. 2. Flame combustion of fuel.

Distributed fuel combustion in the volume

The organisation of volume fuel combustion requires adjustment of the furnace and burner design construction parameters such as:

1. gas nozzles and ducts for combustion air supply,
2. flue gases openings (number, layout, geometric parameters),

3. mixing angle of reagents streams,
4. mutual layout of: burners, flue gases openings, metal in furnace and others.

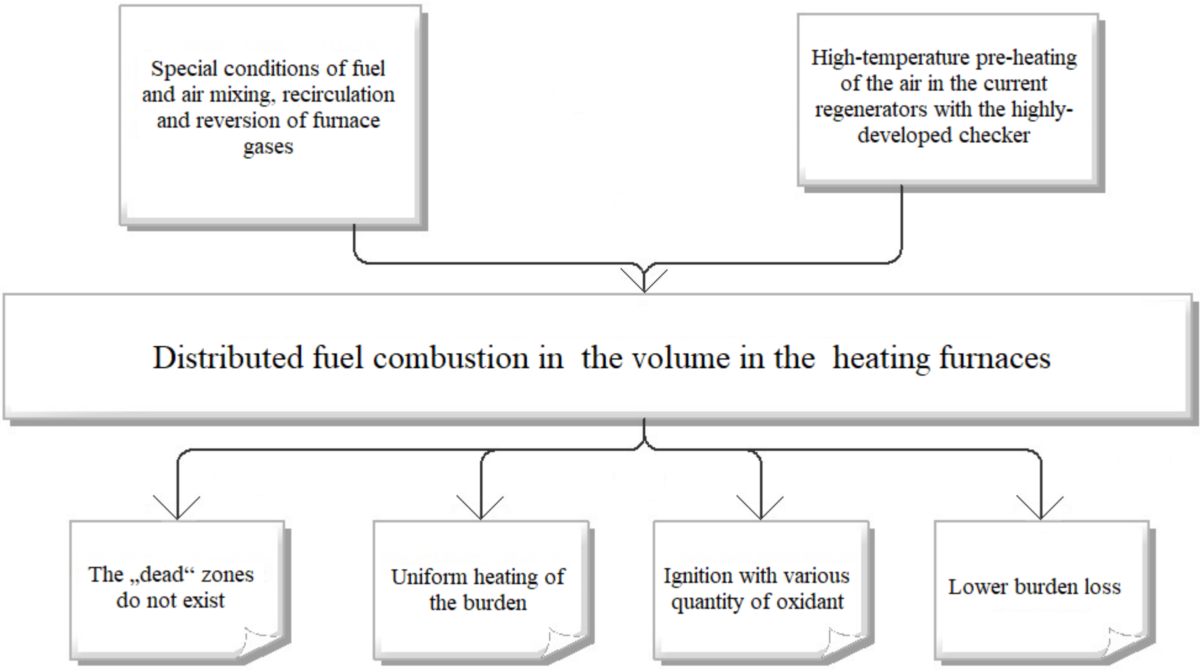

Fig. 3. Distributed fuel combustion in the volume.

Utilisation of the regenerative heating shaft

The practical benefits of distributed volume fuel combustion and efficient temperature distribution control are shown for the application of a regenerative heating shaft. The indicators of the work of the reheating furnace (Fig. 4) before the reconstruction and after reconstruction are presented in Tab. 1.

Fig. 4. View of the ingot reheating furnace.

Tab. 1. Indicators of the work of the heating furnace to the reconstruction and after reconstruction.

Indicator	Dimension	Heating method	
		Recuperative	Regenerative
Type of fuel	-	**mix gas**	**mix gas**
Calorific value (Higher heating value)	MJ/m^3	8,2	8,2
Maximum fuel consumption	m^3/h	2100	1500
Maximum air consumption	m^3/h	10000	5000
Maximum heat output	MW	4,87	3,48
Mass of charge	t	120	120
Lining volume in recuperator or regenerator	m^3	31,75	0,75
Temperature of ingots	°C	900 - 950	900 - 950
The temperature of preheating air	°C	do 600	do 1100
Coefficient of fuel utilization	%	50	75
Specific fuel consumption for batch heating	kg/t	18	12
Average specific fuel consumption (cold run)	kg/t	25,3 – 28,4	30,3
The amount of scale per 1t of metal per year	kg	10,9 – 12,8	8,4 – 9,35

Conclusions

It is possible to organise distributed volumetric fuel combustion in the regenerative furnaces by means of ensuring gas-dynamic characteristics of the furnace gases, their reverse and recirculation, and by structural parameters of the furnace elements. Uniform temperature distribution in the working space of a furnace, formed as a result of distributed volumetric fuel combustion in reheating furnaces equipped with high-effective regenerators, predetermines: uniformity heating of ingots considering the height and the length of the working space (Yeromin, Gubinskiy and Sibir, 2007), decreasing the quantity of harmful ejections and creating the low oxidizing atmosphere in the working chamber of the furnace.

At present, increasing the energy efficiency of thermal aggregates is one of the pillars of the energy policy not only of the EU *(European Union, 2018; Europarl.europa.eu, 2018)* but also of global interest. Addressing these issues contributes to meeting these declared environmental policy goals and reducing the impact of global warming.

The European Commission has also subscribed to the conclusions of the Paris Conference on Climate Change held in December 2015 (COP2l), which confirmed that the way to "clean energy" is irreversible (Klepáč, 2016).

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Assessment of valuation methodology for land properties with mineral deposits used in Poland

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Land properties with mineral deposits are the specific good whose valuation is an extremely demanding task. The difficulty in evaluating such properties is associated with attributes that go beyond the catalogue of typical market value influencing factors, attributable to land properties. The valuation is also affected by the fact that properties with mineral deposits are evolving as the investment processes progress. Following the example of world standards, the Code for the Valuation of Mineral Assets POLVAL has been in force in Poland since 2008. It creates substantive grounds for the valuation, and these grounds have been attempted to be assessed in this publication. Part of the research involves the assessment of the methodology used in Poland for the valuation of land properties with mineral deposits using the SWOT/TOWS analysis. In the analysis, three strengths and three weaknesses of the valuation procedure have been used, as well as three opportunities and three threats associated with the expected future events that may affect the valuation procedure. As a result of the conducted analysis, it turns out that the methodology used in Poland for valuation of land properties with mineral deposits has great potential, but it should be restructured to overcome potential future threats. The Authors also state that the SWOT/TOWS analysis is not the best way to assess the valuation methodology, but it could be used for its preliminary assessment.

Keywords: *geological and mining assets, SWOT/TOWS analysis, valuation methodology, land properties with mineral deposits, Code for the Valuation of Mineral Assets POLVAL*

Introduction

Although mining is one of the oldest industries, the valuation of geological and mining assets is relatively recent. The value of these assets may be determined for their sale, carrying out a merger or acquisition, specifying the minimum price under a tender procedure, conducting transactions on terms other than market terms, court proceedings, expropriation or insurance claims (Roscoe, 2002).

Many countries have introduced the codes regulating valuation of geological and mining assets. For the mining industry, the need to understand the factors affecting the value of real estate with mineral deposits, and the ability to effectively and consistently evaluate investments and facilities associated with their mining is essential (Lilford and Minnitt, 2002).

It is commonly believed that the first code devoted exclusively to the valuation of geological and mining assets was the code VALMIN introduced in Australia in 1995 (Uberman, 2014). The version which is currently in force was adopted on 29 February 2005 and is called the VALMIN Code 2005 (2005). Soon after, in 1999, Canada began work on the CIMVal Code (2003), which was adopted in February 2003. Both were recommended by relevant capital market authorities for use by mining companies. Then, in 2008, the SAMVAL code (2008) was developed in South Africa. In the US, the USMinval code became the subject of discussion, still functioning as a proposal, but has never become legally binding (Zielińska, 2017).

In 2005, as a result of the publication of the Interpretative Note No. 14 “Valuation of Properties in the Extractive Industries”, geological and mining assets have also become subject to International Valuation Standards. As a result of the review carried out as part of a special project aimed at improving all valuation standards, a decision was made to withdraw this Interpretative Note in February 2010, and in June 2011, a project aimed at its improvement and updating was launched. It is expected that it should be re-issued in the revised version.

Poland has also had a specialised code for the valuation of geological and mining assets since 2008. Established in 2006, the Polish Association of Mineral Asset Valuation developed and published the Code for the Valuation of Mineral Assets POLVAL in 2008. Following the example of foreign codes, it creates substantive grounds for the valuation of all geological and mining assets, including mineral deposits associated with land properties. The current version is recommended for use since January 1, 2017 (2017).

Following the European law, we divide mineral deposits in Poland into those subject to mining property right and real estate ownership right. Pursuant to the Act on Geological and Mining Law (Act, 2011), the assets of hydrocarbons, hard coal, methane occurring as accompanying mineral, lignite, metal ores with the exception of bog iron ores, native metals, ores of radioactive elements, native sulfur, rock salt, potassium salt, potassium-

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magnesium salt, gypsum and anhydrite, precious stones regardless of their place of occurrence, are covered by mining property right. The mining property also includes deposits of therapeutic waters, thermal waters and saline. In addition, the mining property includes parts of the rock mass outside of geospatial boundaries of land properties, especially those located within the boundaries of the maritime areas of the Republic of Poland. The mining property right is a separate property right vested solely in the State Treasury. The remaining mineral deposits, not mentioned above, are covered by the land ownership right. The further part of this study is devoted to this group of deposits.

Material and Methods

The research involved the evaluation of the methodology used in Poland for the valuation of land properties with mineral deposits using the SWOT/TOWS analysis. For this purpose, the assessed procedure was described, the analysis factors and their weights were determined, and the relationships between them were identified.

The methodology used in Poland for the valuation of land properties with mineral deposits

Land properties with mineral deposits are the specific good. Their uniqueness associated with attributes that go beyond the catalogue of typical market value influencing factors, attributable to land properties, gives a special character to the valuation process. Hence, there is a need to analyse a number of specific conditions affecting the value of this type of real estate. The source of knowledge about the market characteristics of specific real property is the field inspection and the documents allowing to determine the status and intended purpose of this real estate (Tab.1.). The status of the real estate should be understood as the state of development, legal status, technical and utility status, level of equipping with technical infrastructure devices, as well as the condition of the property surroundings, including its size, character and degree of urbanization of the locality where the property is situated (Act, 1997).

Tab.1. Documents used for valuation of land properties with mineral deposits.

Documentation of real properties	Documentation of mineral deposits	Documentation of mineral extraction
– study of conditions and directions of spatial development of the commune, – local land use plan, – real estate cadastre.	– geological documentation of deposit, – deposit information sheets, – local land use plan of the mining area, – deposit development plan, – environmental impact assessment, – deposit mining license, – mining plant operation schedule, – survey and geological documentation of deposit, – design and cost documentation of land reclamation.	– lease agreements, – water law permits, – permits for decommissioning of components, including logging of trees, – Minutes of inspection of District Mining Offices, – balance sheet and profit and loss account, – list of tangible fixed assets of mining plants together with their balance sheet values.

Based on the analysis of the documents listed in Table 1, as well as field inspection, market recognition in economic and supply-demand terms, the real estate valuer analyses a number of specific conditions affecting the value of the property with a mineral deposit. Their classification has been prepared in the form of a diagram illustrated in Fig. 1.

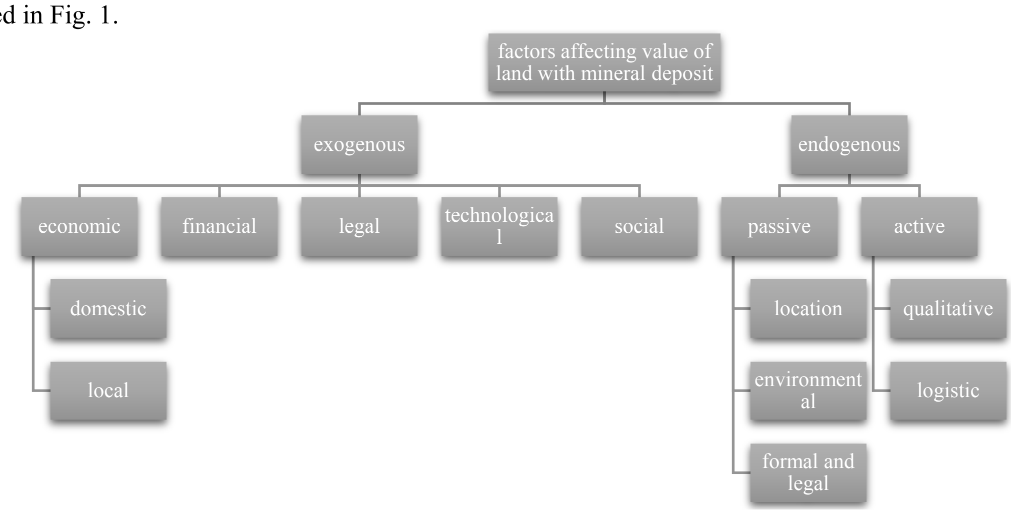

Fig. 1. Classification of factors affecting the value of land with mineral deposit..

External factors constitute the socio-economic background of the type of real estate being valued. They were divided into five groups: economic, financial, legal, technological and social. The economic aspect should be considered on a macro (i.e. domestic) and micro (i.e. local) scales. Domestic factors are associated with the country's economic situation, inflation, unemployment, public wealth or the market index. The factors typical for a specific location include the supply-demand situation considered on two levels: the real estate market with mineral deposits and the mineral deposit itself, including the sale price, investment conditions, or competition and development predictions. However, attention should be paid to the variable boundary between the macro and micro parameters. Depending on the type and size of the deposit, local factors should also be considered on a macro scale. Financial factors refer to the possibility of financing the real estate and the mining process. The legal group includes all the regulations regarding the real estate, mineral deposit and mining process in the light of the existing legal regulations. Technological factors are mainly related to the mining process and relate to the technology being used. Demographic situation, lifestyle, etc., were included in the group of exogenous social factors.

The catalogue of endogenous factors was divided into the passive, existing group, concerning mainly parameters related to the real estate with a mineral deposit, and the active group associated with the exploration and mining processes. In the passive group, the following factors were distinguished:

- **location factors** related to accessibility, location with respect to output markets, other deposits, mines, watercourses and surface water reservoirs in the context of reservoir water discharge, groundwater intake in the context of the possibility of water supply for technological and sanitary purposes, various types of development in the context of operating nuisance, both for the existing and future developments, comfort of life, safety and human health,
- **environmental factors** related to the type of land use, including permanent and temporary conversion of land to non-agricultural and non-forestry use, location with respect to legally protected areas, the impact of investments on the environment, e.g. logging of trees, water pollution, small-particle air pollution, noise,
- **formal and legal factors** covering the legal status of the real estate and its designation, the intended land use in the planning documents such as the local land use plan or, if there is no plan, in the study of conditions and directions of spatial development of the commune, and in the local land use plan for the mining area (if it has been prepared), the right to geological information, environmental conditions resulting from the relevant decisions, mining conditions established in the deposit mining license, findings contained in the mining plant operation schedule, findings resulting from other significant documents related to the extraction of the deposit, such as land lease agreements, water law permits, operating fees for extraction of minerals.

The active group includes these factors that may change as a result of changes in the surroundings or progress of the mining process. They were divided into:

- **qualitative factors** referring to the category of deposit exploration, quality of the mineral, thickness and type of the overburden, presence of increments, liquid rock inserts etc., the ratio of the thickness of the overburden to the thickness of the deposit, recoverable, industrial and operational resources, deposit abundance, other geological and mining conditions, including hydrogeological conditions, etc.,
- **logistic factors**, especially those related to accessibility of transport routes, road condition and related tonnage and cubic limitations, including limitations established on road culverts, bridges, overpasses, etc., accessibility for heavy equipment, availability of technical infrastructure (electricity, water, etc.).

Market analysis in the aspect of the factors mentioned above is a key element in the valuation process of the property with a mineral deposit. Based on its results, the real estate valuer chooses the right valuation approach and technique. The Polish legislation allows for the use of two approaches to valuation of the property with a mineral deposit: comparative approach and income approach (Regulation, 2004). Additionally, as part of good practice, at the stage of the mining plant decommissioning and land reclamation, it is possible to use a mixed approach (Standard, 2017). As the investment process progresses, we distinguish three stages of mining, with the following valuation approaches recommended (Standard, 2017):

1. The stage after exploration and documenting a deposit – the comparative approach.
2. Providing access and extraction of a deposit – the income approach, and in the case of suspended extraction – the income approach or the comparative approach.
3. Mining plant decommissioning and land reclamation – the comparative or mixed approach using the decommissioning costs method and the residual method.

The comparative approach is recommended at each stage of the investment process. According to the definition, it consists in the comparison of the real estate being the subject of valuation whose attributes are known, with comparable properties that were subject to real estate transactions and for which transaction prices, transaction conditions and attributes are known (Regulation, 2004). The formal and legal significance for the assessment of the applicability of the comparative approach to the valuation of the real estate with mineral deposits is the assessment of meeting the requirements formulated for the concept of "comparable properties", which is comparable to the real estate being the subject of valuation due to its location, legal status, intended purpose, manner of use and other market value influencing factors (Act, 1997). For the real estate with a mineral deposit, the group of other market value influencing factors includes the factors shaping the value of the deposit, which in the case of comparable properties must be of the same type, have similar abundance and geological structure. The variety of value influencing factors for the property with a mineral deposit, determining the degree of their similarity, limits the application of the comparative approach. According to the Authors, the difficulty of valuation of the property with a mineral deposit increases with the progress of the investment process. With the progress of the mining process, new documents are collected that are a source of additional information about the real estate and about the deposit itself. Each stage of the investment process has a different type of real estate, although the subject of the valuation is still the same – the property with a mineral deposit. The property with a mineral deposit is evolving with the progress in the investment processes: most frequently from the agricultural land at the prospecting stage, through the investment real estate at the stage of exploration and providing access, to the operating real estate at the extraction stage. Decommissioning of the mining plant and land reclamation restores the original character of the property, and often imposes a new use to it, for example, recreational one. Therefore, it is necessary to change the method of valuation depending on the investment stage. The Authors of this research paper suggest that the selection of the valuation method should closely correlate with the stage of the investment process, i.e. with an exploration of the deposit. For the first two stages of the project, which include prospecting for an exploration of the deposit, the comparative and cost approaches are proposed, which have been omitted in the valuation of the property with a mineral deposit in the current legal status. Depending on the progress of works, at the stage of the legal and physical preparation of the deposit for extraction, it is recommended to apply the comparative, cost or income approach. During the extraction stage, the income approach is suggested, and in the last, decommissioning stage, the mixed approach is recommended (Fig. 2).

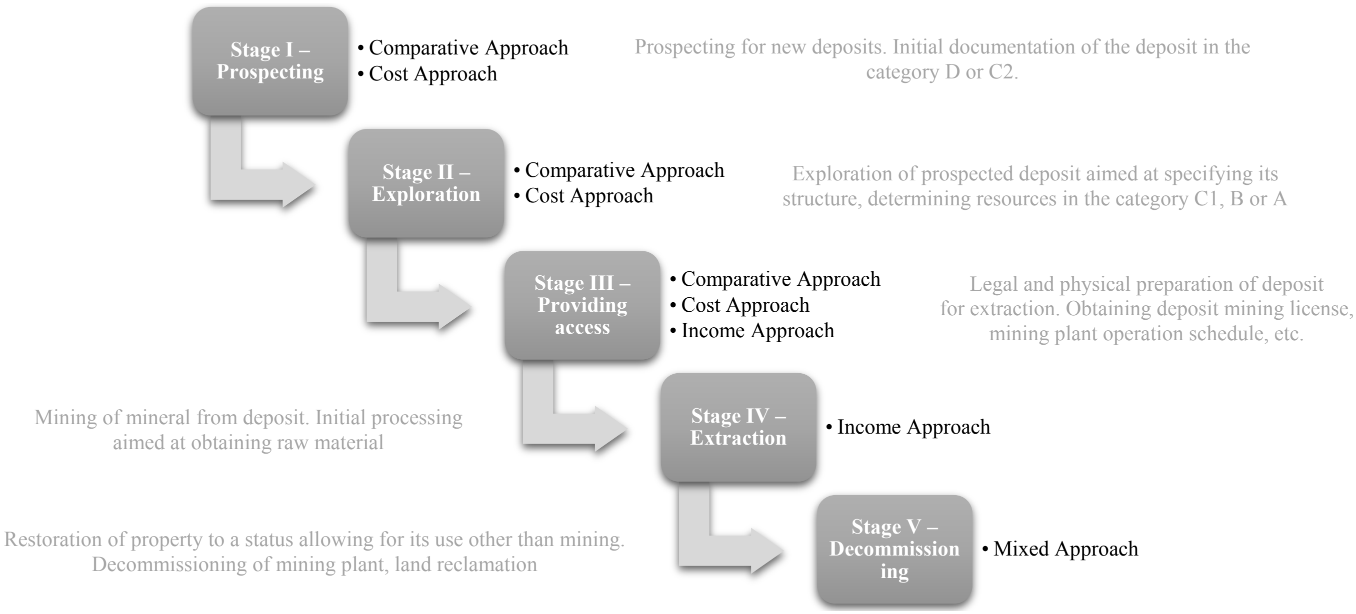

Fig. 2. Stages of the progress of the investment process with the recommended valuation approach.

A – The mineral deposit is explored to the extent allowing for current planning and extraction at the highest possible exploitation of the deposit. The error in estimating the average values of the deposit and resource parameters in individual blocks cannot exceed 10%.
B – The boundaries of the deposit are defined in a more specific way based on exploratory workings or geophysical surveys specially made for this purpose. The error estimating the average values of the deposit and resource parameters cannot exceed 20%.
C1 – The boundaries of the mineral deposit are defined based on the data from exploratory workings, natural exposures or geophysical surveys. The error estimating the average values of the deposit and resource parameters cannot exceed 30%.
C2 – The boundaries of the mineral deposit are defined based on the data from workings, natural exposures or geophysical surveys. The error estimating the average values of the deposit and resource parameters cannot exceed 40%.
D – The boundaries of the mineral deposit, its geological structure and expected resources are determined based on the existing, available geological data, especially isolated workings or natural exposures. The error estimating the average values of the deposit and resource parameters cannot exceed 40%.

The proposed division is a kind of generalisation of the investment process. In practice, we often deal with the staging of the investment. The property is divided into investment fields at various stages of development, and therefore, the use of a single valuation approach for the whole property is very restricted. It is necessary to apply a few approaches at the same time and to analyse the documentation from individual stages of development. Although the valuation of the real estate, carried out in the first three stages of the investment process and the last one, does not bring on too many problems, the determination of the operational value during the extraction stage goes beyond the typical procedure. Therefore, the further part of this research study is devoted to the determination of the market value of the operating real estate.

The market of land properties with mineral deposits is limited and inactive, both in terms of transaction prices and rents, especially during the extraction stage. Hence, the valuation methods in the income approach should be limited to the profit method. In this method, income from real estate, which is equivalent to rental income, is defined as part of the income from a business activity conducted on a given property by a typical, average user. In this case, the source of information about the amount of income from the real estate is the market data from the valued property. The income from the real estate is calculated based on the user's operating income, less the user's operating costs and operating expenditures. The scheme for the valuation of the property with a mineral deposit in the income approach, by the method of profits, is illustrated in the diagram in Figure 3.

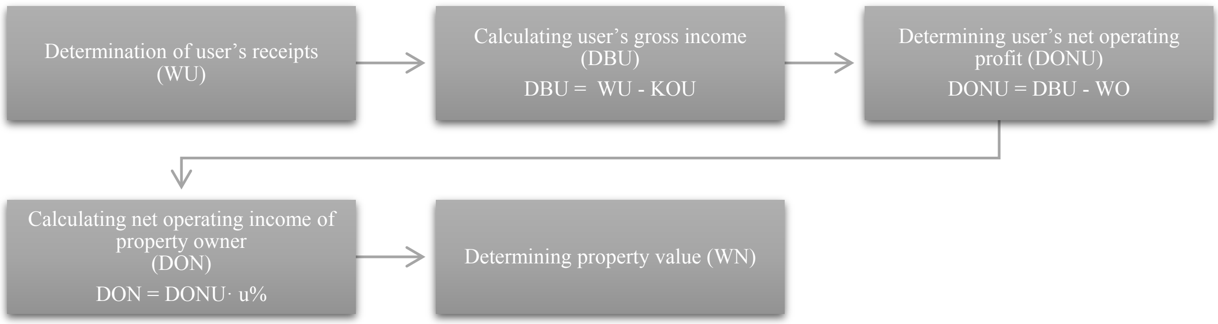

Fig. 3. Flowchart of a procedure in property valuation in the income approach, in the method of profits.

WU – is determined from the operating activity conducted on the property; DBU – is the difference between user's receipts and user's operating costs (KOU) which are all the expenses related to the running of business and which condition the expected receipts, including purchase of goods, materials, services, staff wages, costs related to replacement of fixed assets and equipment, advertising costs, etc.; DONU – corresponds to the user's gross income reduced by operating costs (WO) of annual expenses of property maintenance borne by the owner, for example, property taxes, fees for perpetual usufruct etc.; DON – is defined as the property owner's share u% in the user's net operating income.

The value of real estate is determined by capitalisation of DON or its discounting. The use of capitalisation is justified on the assumption of fixed income in the long-term which, with reference to the property with a mineral deposit and ongoing mining process, seems to be too much of a simplification. With the progressing mining works, the level of knowledge about the structure and quality of the deposit is increasing, which is reflected in the variability of the income. The predicted volatility should be reflected in the valuation process by using the technique of discounting income streams. The market value of the property (WN) estimated in the income approach, by the profit method, with the technique of discounting income streams, is expressed by Formula (1).

$$WN=\frac{DON_1}{(1+r_d)^1}+\frac{DON_2}{(1+r_d)^2}+\ldots+\frac{DON_n}{(1+r_d)^n}+\frac{RV}{(1+r_d)^n} \qquad (1)$$

where according to Formula (2):

$$RV=\frac{DON_n}{R}=\frac{r\cdot net\ operating\ income}{capitalization\ rate} \qquad (2)$$

where:
RV – residual value of the subject of valuation,
n – the number of years of prediction period,
DON_1, DON_2, …, DON_n – net operating income in subsequent prediction periods,
R – capitalisation rate,
r_d – discount rate.

The capitalisation rate (R) is an indicator of the economy of a specific (valued) real estate. It results from the relationship between net operating income obtained from the property which is the most similar to the one being valued, and transaction prices of comparable properties which have been sold. Therefore, each property has its own market capitalisation rate resulting from its attributes.

The discount rate (r_d) is also an indicator of the economy of a specific property. It is equal to the capitalisation rate adjusted for the risk resulting from the real estate market, related to the risk from other long-term investments.

Both rates can be determined in an alternative manner based on quoted financial market parameters, where the natural diversity of property attributes is included in the partial risk factor. The values of risk factors of investing in the valued property are therefore derived from its market characteristics. In the case of real property with a mineral deposit, the risk decreases with the progress of the investment process.

According to the Authors of this research paper, the described valuation procedure most closely reflects the physical and economic complexity of a property with a mineral deposit. The limitation in its application results from the lack of an active rent market for comparable properties with mineral deposits, based on rents calculated relative to the share in the operator's profits. In this paper, it is proposed that the share (u%) in the operator's profits is determined by the heuristic method based on the opinions and assessments of different people, not just experts. Preliminary research carried out in the form of brainstorming, based on a free exchange of views in a group of people selected with respect to their knowledge of the analysed problem, indicate a 15-20% share of the owner in the operator's profits. The group claimed that this level would meet the financial expectations of the property owner and is high enough for the owner of the property to resign from running a business on their own.

SWOT/TOWS analysis as a method of assessing procedures in property management

SWOT/TOWS analysis is a popular heuristic technique used for organising and analysing information. By definition, it is the process of studying the internal and external environments of the organisation, based on which it is possible to infer about the best development strategy of this organisation (Ghazinoory et al., 2011). Initially, the use of SWOT/TOWS was associated with the management of enterprises and formulating strategies for them (Weihrich, 1982). Later, however, the analysis was also used in such fields as agriculture (Baudino et al., 2017), health (Van Durme et al., 2014), tourism (Qian, 2017), environmental protection (Gao et al., 2017) and many more.

SWOT/TOWS has also been used in real estate management to determine the strategy of the future of the real estate cadastre (Polat et al., 2017), to assess the marine cadastre development strategy (Dawidowicz and Źróbek, 2014), for the methods of port resource management (Dawidowicz et al., 2017), for the analysis of legal methods of protecting agricultural land (Pawlikowska et al., 2017) and to determine the directions of spatial development of cities (Bieda and Brzozowska, 2017). That is why the Authors decided to attempt to assess the above-described procedure for valuation of land properties with mineral deposits using this specific method. The analysis was carried out in four stages, as described in (Obłój, 2001):

1. Determination and description of the factors that have either a positive or negative impact on the proper conduct of the valuation procedure for land properties with mineral deposits. The current conditions of the procedure were recognised as Strengths (S) and weaknesses (W), and opportunities (O) and threats (T) – the expected future events which may affect the assessed valuation procedure.
2. Assigning significance to individual factors through the determination of weights, which was performed based on a survey conducted in a group of 11 experts in the field of mining, deposit extraction and property valuation. The task of the respondents was to rank the presented factors from the most important to the least important ones. The respondents evaluated the validity of a given factor using the Tilgner five-point scale (Babbie, 2008): 1 point – no impact of the factor, 2 points – low impact, 3 points – average impact, 4 points – significant impact and 5 points – maximum impact. The weights (W_{Ci}) were defined by converting the results obtained in the questionnaires using Formula (3).

$$W_{Ci}=\frac{p_i}{\Sigma p_i}, \tag{1}$$

where p_i represents the arithmetic mean of the values assigned by the respondents to the i-th factor.
The values have been rounded up to 5%.

3. Analysis of interrelations between the selected factors by marking their relationship as strong – “2”, weak – “1”, or non-existent – “0”. The relationships between the factors were identified by answering eight questions (Fig. 4).

SWOT:

• does a strength allow a given opportunity to be used?
• does a strength allow a given threat to be eliminated?
• does a weakness limit the possibility to use a given opportunity?
• does a weakness intensify the risk associated with a given threat?

TOWS:

• does an opportunity strengthen a given strength?
• does an opportunity allow a given weakness to be eliminated?
• does a threat eliminate a given strength?
• does a threat emphasize a given weakness?

Fig. 4. The questions leading to the identification of relationships between SWOT/TOWS factors.

4. Selection of one of the four strategies that will allow assessing the methodology for the valuation of land properties with mineral deposits (Fig. 5).

Aggressive	Conservative	Competitive	Defensive
• strengths and related opportunities prevail	• strengths and related weaknesses prevail	• weaknesses and related opportunities prevail	• weaknesses and related threats prevail

Fig. 5. Strategies that are feasible as a result of SWOT/TOWS analysis.

Results

In the performed SWOT/TOWS analysis, the three highest rated factors from each category were used. The strengths and weaknesses of the valuation methodology applied in Poland for land properties with mineral deposits, the opportunities and threats that have been observed for this methodology, as well as their weights, are presented in Table 2.

Tab. 2. Factors of the analysis.

No.	Weight	Internal factors	No.	Weight	External factors
-	**1,00**	**Strengths (S)**	**-**	**1,00**	**Opportunities (O)**
S1	0,40	mineral deposits are usually well-documented; therefore, property valuers receive full information about the property being valued	O1	0,35	state policy supports the extraction of minerals; therefore the market of land properties with mineral deposits has a chance to develop
S2	0,40	method of valuation depends on the degree of real estate investment, so the value resulting from the valuation process accurately reflects the state of the property	O2	0,35	conducted geological research may lead to exploration of new mineral deposits and thus to the development of the market of land properties with mineral deposits
S3	0,20	there is a standard for the valuation of land properties with mineral deposits, as a result of which such valuations are carried out in a uniform manner	O3	0,30	the valuation standard may lead to legal regulation of valuation procedures for land properties from mineral deposits
-	**1,00**	**Weaknesses (W)**	**-**	**1,00**	**Threats (T)**
W1	0,45	real estate valuer has limited access to documentation about properties comparable to the one being valued, and therefore their selection is hindered	T1	0,50	real property with mineral deposit is constantly evolving resulting in increased difficulty of valuation as the mining process progresses
W2	0,35	a poorly-developed market of real properties with mineral deposits may hinder valuation in the comparative approach, and no information about rents – in the profit approach	T2	0,25	staging of investment on land properties with mineral deposits may hinder their valuation
W3	0,20	the standard for valuation of land properties with mineral deposits is not a provision of law	T3	0,25	the strong correlation between the variable value of land properties with mineral deposits and the market value of the mineral

The interrelations between the factors contained in Table 2 are presented in Tables 3 (relationships in the SWOT analysis) and 4 (relationships in the TOWS analysis).

Tab. 3. SWOT analysis of interrelationships.

	O1	O2	O3	T1	T2	T3
S1	0	1	0	2	2	1
S2	0	1	1	2	2	0
S3	1	0	2	2	2	1
W1	0	2	1	2	2	2
W2	0	1	0	1	2	1
W3	1	0	2	0	0	0

Tab. 4. TOWS analysis of interrelationships.

	S1	S2	S3	W1	W2	W3
O1	1	1	0	0	2	0
O2	2	0	0	0	2	0
O3	0	0	2	1	0	2
T1	2	2	2	2	2	0
T2	1	2	1	2	2	0
T3	1	1	1	2	2	0

The cumulative summary of the SWOT/TOWS analysis is presented in Table 5, while the results of the strategic analysis and selection of the strategy in Table 6.

Tab. 5. Summary of the results of SWOT/TOWS analysis.

	Results of SWOT analysis		**Results of TOWS analysis**		**Summary of SWOT/TOWS**	
Combination	The sum of interactions	The sum of products	The sum of interactions	The sum of products	The sum of interactions	The sum of products
Strengths [S]/ Opportunities [O]	12	3.55	12	4.00	18	5.60
Strengths [S]/ Threats [T]	28	9.60	26	9.15	54	18.75
Weaknesses [W]/ Opportunities [O]	14	4.30	14	4.55	28	8.85
Weaknesses [W]/ Threats [T]	20	1.25	24	8.80	44	10.05

Tab. 6. Results of the strategic analysis and strategy selection.

	Opportunities [O]	**Threats [T]**
Strengths [S]	Aggressive strategy	Conservative strategy
	Number of interactions	Number of interactions
	24	54
	Weighted number of interactions	Weighted number of interactions
	7.55	18.75
Weaknesses [W]	Competitive strategy	Defensive Strategy
	Number of interactions	Number of interactions
	28	44
	Weighted number of interactions	Weighted number of interactions
	8.85	10.05

The cumulative summary (Tab. 6) contains the sums of the relationship from Tables 3 and 4 and the sums of products of weights and these relationships. They achieve the highest values for the conservative strategy. This means that the methodology used in Poland for the valuation of land properties with mineral deposits has great potential, but it should be restructured to overcome potential future threats.

Discussion

Valuation of land properties with mineral deposits is an extremely difficult task. In order to carry it out properly, it must be based on reliable source materials and a well-described procedure. Therefore, the Authors of this research paper attempted to evaluate the methodology used for the valuation of land properties with mineral deposits using the SWOT/TOWS analysis.

Although the Authors consider the described procedure for valuation of land properties with mineral deposits to be good, they hoped that the results of the conducted evaluation would allow identifying these elements of the procedure that should be improved. However, according to the Authors, the conclusions drawn from the SWOT/TOWS analysis are not entirely satisfactory. The highest values of interactions and weighted interactions between the factors of the analysis require pointing to the conservative strategy according to which the valuation method should be improved. This means that the methodology used in Poland for the valuation of land properties with mineral deposits has great potential, and possible changes should prevent the occurrence of the contingent future risk. According to the Authors, Polish legislation should allow access to full documentation of deposits for properties comparable to the one being valued, in the first place.

The results of the performed analysis were undoubtedly influenced by the fact that very few factors were identified to carry out the analysis. The Authors' approach to describing strengths, weaknesses, opportunities and threats was also important. Strengths and weaknesses are attributes of the current valuation procedure, and opportunities and threats are expected future events. If, however, the internal factors were considered to be strengths and weaknesses, and the external factors were considered to be opportunities and threats, or if the factors dependent on the creators of the procedure were considered to be strengths and weaknesses, and the objective factors on which they did not have direct causative influence were considered to be opportunities and threats, the results of the analysis would certainly be different.

Thus, it turns out that although the SWOT/TOWS analysis may not be the best way to assess the valuation methodology when determining its factors, it is possible to identify its sensitive elements. It is therefore suggested to use the proposed method for the preliminary assessment of the procedures related to real estate valuation (also for properties with mineral deposits). According to the Authors of this study, an interesting research topic could be the SWOT/TOWS analysis carried out for the global valuation procedures for land properties with mineral deposits.

***Acknowledgements**: This work is financed from the funds for science, no 11.11.150.006, realised at AGH University of Science and Technology, Faculty of Mining Surveying and Environmental Engineering, Department of Geomatics, allocated for the year 2018.*

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Use of mining FREIGHT Cableway in urban mobility as a part of an integrated transport system

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Due to the extensive economic activities in urban areas, many European cities face multiple problems related to or caused by transport and traffic. Traffic infrastructure in cities and beyond will cease capacitively and qualitatively. This situation can be addressed by building infrastructure with compatible integrated transport systems. The article presents the possibilities of using the route of a high-speed suspended cableway originally intended for the transport of magnesite from the mine Bankov for processing into the former thermal operation in Ťahanovce in urban mobility. The basis of the article is the methodology of designing a personal cableway with capacity and strength calculation. City outbuildings in Kosice are currently expanding beyond the city centre to its periphery, which also changes user needs. Residents demand a new culture of urban mobility. Meeting these needs together with the need to increase the share of green public passenger transport requires a fundamental change in order to provide traffic closer to the sources and the destination of the roads. By using the route of the former mining cableway, a new conveyor system of the suburban cable car would be created. This system could be integrated into the integrated transport system of the city of Kosice. At the end of the article is a case study on the integration of a personal cableway into the integrated transport system of the city of Kosice as an effective and environmentally-friendly alternative to improving mobility in the city.

Keywords: *mining, cableway, transport, city logistics, smart city, urban mobility*

Introduction

The interplant transport of mineral raw materials plays an important role in the mining process carried out in mining companies (Andrejiova, 2015). An important part of this transport is a rope system. Rope systems offer high security, which is confirmed by statistics. This high safety is of course without further consideration, as the rope itself is a redundant element. The rope consists of a large number of wires. The individual wire breaks only affect the boundary length of the rope. Wire fragments and corrosion inside the rope can be detected by diagnostics, thus eliminating the rupture of the rope. Prediction of fatigue fractures diffusion on the cableway haul rope is described by Peterka (Peterka, 2016). Non-destructive testing of steel wire rope analyses Peterka (Peterka, 2014). Testing methods of steel wire ropes are described in the paper Krešák (Krešák, 2012). The special mechanical features of the device are conventional and tested, drives and braking systems. These are still multiple backed up and independent of each other. Rope transport systems do not endanger the environment, they have lower power consumption and cause only minor shocks. Optically do not get the impression of the surroundings because the wires consist of high-strength wires. Therefore, cableways have at least some of the means of transport that are connected with the ground.

In 2010, 73 % of European citizens lived in urban areas. This percentage is expected to increase to over 80% by 2050. As urban population growth, as expected to increase dramatically (Cohen, 2006) in the following years, it is necessary to find solutions for accommodating huge influxes of citizens in a way that is socially, economically and environmentally sustainable (Angel et al., 2011). Improvement of living conditions, working conditions and continual improvement quality of human capital can be achieved by social innovation. Social innovations in the context of a smart city allow achieving sustainable development, which in these days could ensure a higher quality of life (Jurenka, 2016). At the present moment, there is deep uncertainty concerning the strategies and policies that can effectively implement principles of sustainability within urban systems and how these can be measured and monitored (Robinson, 2004). In the attempt of providing a structured answer to these interrogatives, Morelli et al. (2016) present a methodology developed for investigating the modalities through which ICPs and KCPs contribute to the achievement or urban sustainability. Results suggest that ICPs and KCPs efficacy lies in supporting cities achieve a sustainable urban metabolism through optimization, innovation and behavior changes (Morelli, 2016). Feliu et al. (2010) show how city logistics approaches can meet the goals of Sustainable Development. In order to define the notion of sustainable city logistics, the main aspects of each

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sphere of sustainable development, respectively economic, environmental and societal, have been investigated. The main aspects of each sphere are described in order to unify the concept of sustainability related to city logistics (Feliu et al., 2010). Key success factors for city logistics from the perspective of city management were applied by Kiba-Janiak (2016).

However, due to the extensive economic activities in urban areas, many European cities face multiple problems related to or caused by transport and traffic. Social transformation has rapidly increased mobility levels, and the growth of private car use has been accompanied by increased urban sprawl and commuting, whereas public transport networks in many cases have not expanded at the same rate (European Commission, 2017). The number of alternatives to road transportation is nowadays still increasing, as well as the quality of these technologies (Široký, 2014). Life in the city and the areas directly adjacent to cities is becoming more and more burdensome (Cheba et al., 2015). Individual transport in Europe to 2030 increases by 40% according to the forecast (Marasova, 2010). Urban integrated mobility aims to slow down or stop the trend of rapidly increasing urban intensity in cities. Increasing individual transport, congestion, exhaust gas generation, noise, reduced security are the negative impacts of individual transport. These impacts also greatly affect mass transit. In the longer term, the development of transported passengers shows that there is a year-on-year decline in public transport between 3 % and 10 % (Ondruš and Dicova, 2011).

The basic parameter of choice for the means of transport is the time of shipment. Luminous signalling delays reach values in the range of 10-30 % of the total delay, therefore, the shorter the time of shipment will be the more attractive the mass passenger transport will become. (Kupčuljaková, 2011; Kalašová and Kupulčiaková, 2012) Optimising urban mobility is now very important for the scientific community. Neuenfeldt in his study identifies the scientific context of urban public transport management (Neuenfeldt, 2016).

Traffic infrastructure in cities and beyond will cease capacitively and qualitatively. This situation can be addressed by building infrastructure with compatible integrated transport systems. Making attractive public and non-motorized transport with social security everywhere and a natural choice for journeys in urban agglomerations is also one of the goals of the strategic plan for the development of transport infrastructure of the SR until 2030. (Strategic plan for the development of transport infrastructure of the SR until 2030, 2016). Cableways can become an efficient urban transport system between urban areas. Many places are characterised by this type of mobility.

For the city of Naples, it is also presented a new project for a ropeway between the two famous museums: the Archeological Museum, which is located inside the inner city, and the Capodimonte one which is at the top of the hill of Capodimonte inside the well-known area of the royal palace. For the two biggest Italian cities, there are two ropeways designed. In Milan, the cable car will link urban areas along a path that includes interchanges and stations in major urban hubs, starting from the airport. Cable car in Rome will cross the river Tevere in order to connect two large districts of the city: the EUR and Magliana, historically split by the barrier river" (Fistola, 2011).

Analysis of the problem

Design of a personal cableway along the route of a former freight cableway from Bankov mine to the housing estate of Ťahanovce and its integration into the integrated transport system of Košice is the main objective of this contribution. In addition to ensuring urban mobility, the personal cableway should have sport and recreational significance with the smallest impact on the environment and would enable the development of the city of Košice. An important aspect of the ecological transport policy in Košice is the limitation of passenger car transport. Integrated transport system (ITS) is one way to make better use of bulk passenger transport in cities and regions while making it more attractive to its users. The aim of this system is not only to combine and intermodal use of available transport capacity in the public passenger transport of the region but using state-of-the-art progressive transport technologies to make this mode of transport high-quality, attractive and environmentally friendly. The Kosice Integrated Transport System is designed to provide the aforementioned program tasks for public passenger transport in the conditions of the city of Košice and the Košice self-governing region.

The current state of the original mining freight elevator

Bankov Hill is the historically popular relaxing place of Košice. The mining of magnesite and its subsequent processing began in Banks in the 1950s. However, mining has disrupted this original recreational function of the site. An industrial complex with a ropeway was built in this area, which served to transport magnesite to a treatment plant in Ťahanovce. The mining was stopped in 1995 for environmental reasons. Since then, this industrial complex has been destroyed. After the mining, there was a 120 m deep crater. Of the original cableways, there is currently only a cableway from the thermal service of Ťahanovce (Anička) to the mine of Bankov. It is a costly cableway that was built in 1964 and is now in a desolate state. There are only carrier ropes, supports, tension weights in the return station and the power station building.

Design of a personal cableway along the route of a former freight lift for the transport of magnesite

Ropeways in Slovakia are mainly used for cultural and recreational purposes. Rope transport allows the transport of persons to higher positions during the summer and winter season. Linking the cable transport to the integrated transport system would have a sport-recreational significance, a positive impact on ensuring the necessary transport of people with the least impact on the environment and allowing the development of the city. Suburban tourism is a subsystem of recreational tourism. It is a recreation that is organised in a suitable recreation area, near towns, industrial and residential agglomerations. Recreation is not only a passive relaxation but also emphasises active participation in the interest of multiplying the effect of a favourable environment on a person.

Methods of calculation and results

Planning of a personal cableway

The process of designing not only a personal but also a cableway can be briefly summarised in these steps:

1. Carry up the geodetic terrain measurements.
2. Carry up the longitudinal section of the terrain.
3. Division of the track into powered sections and track sections.
4. Mark the support points.
5. Determine the height of the struts so that the safety clearance is left below the load rope.
6. Calculation of the tow rope.
7. Determination of the nominal load capacity of the ropes from the service life.
8. Determination of maximum permissible strain of ropes according to safety factor *k*.
9. Calculation of the weight of the tensioning weights for each track section.
10. Calculate the angles of the ropes on the supports and plot them into a clear plan. If an angle is unfavourable, the height of the support will change.
11. Calculation of the overload of the loaded rope to check the safe height of the cabin over the terrain.
12. Determination of the lift of the tensioning weights.
13. Static conversion of stations, supports and protective devices.

Before the inclusion of the current overhead cableway, it is necessary to change the cable car to the passenger lift, that is to say, the city's cableway. For the processing of the infrastructure project, the technical parameters of the personal suspended cableway are defined at the beginning. The length of the cableway course is to be divided into sections (A, B, C) due to the unevenness of the track and the obtaining of relevant results.

Calculation of the section length on the map

Now we divide the route of the cableway to the required number of sections depending on the terrain.
The created new sections are called: section A, section B and section C.

The inclination angle of the section is calculated based on Eq. 1:

$$tg\alpha_X = \frac{h_X}{LX} \text{ [-]}. \quad (1)$$

Calculation of the actual length of the section is as (Eq. 2):

$$L\acute{}_x = \frac{L_X}{cos\alpha_X} \text{ [-]}. \quad (2)$$

Tab. 1. Given and calculated parameters.

	Horizontal projection of the length of the section L_X [m]	**Segment elevation h_x [m]**	**Inclination angle of section α_x [°]**	**Actual length of section L'_x**
Section A	724	10	0,79	724
Section B	1292	120	5,30	1298
Section C	403	31	4,39	404
Total	2419	-	-	2426

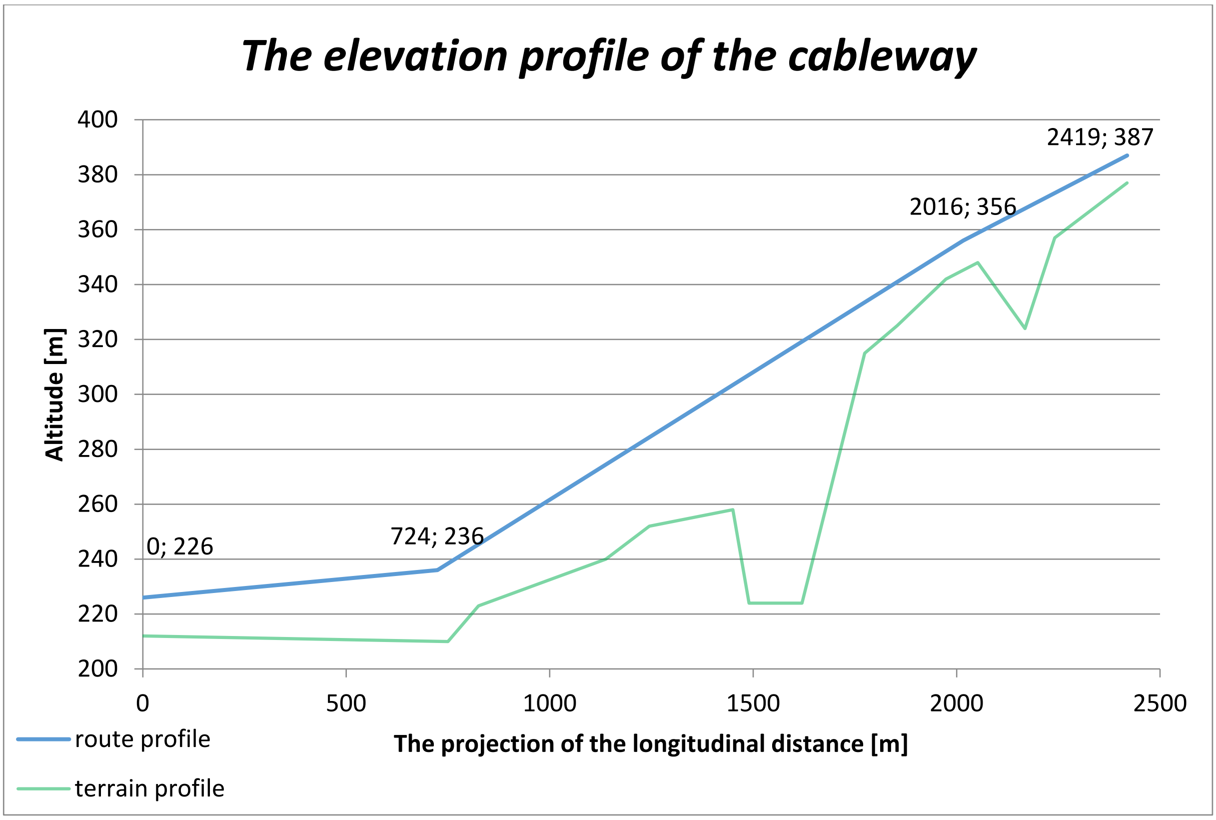

Fig. 1. The elevation profile of the designed suburban passenger cableway.

Capacitive calculations

The hourly transport capacity of the cableway can be determined by the relationship

$$P = 1{,}1\frac{P_C}{T_C} = 1{,}1\frac{1440}{12} = 132\ [t.h^{-1}]. \tag{3}$$

where:

P - is the hourly capacity of the cableway [$t.h^{-1}$]

P_C - is the required transport amount per day [$t.day^{-1}$]

T_C - the number of hours of operation of the cable car; 12 [hours]

1,1 - is the coefficient of transport inequality; 1,1 [-]

The operation time, in that case, will be 12 hours during 2 work shifts. The number of people per hour is stated as 1200 people/hour considering the weight of 1 person 100kg. The speed of the cableway according to STN 27 3200 will be 4 $m.s^{-1}$. According to the same standard, we can choose the next higher cableway performance as P = 160 $t.h^{-1}$.

The number of cabins that must pass from the lower station to the upper station of the cableway per hour n_v shall be calculated:

$$n_v = \frac{1000.P}{m} = \frac{1000.160}{1000} = 160\ [pcs]. \tag{4}$$

where

m - useful load carrying capacity; 1000 [kg]

The time interval between the cabins is calculated as:

$$t = \frac{3600}{n_v} = \frac{3600}{160} = 22{,}5\ [s]. \tag{5}$$

Distance between cabins on route l is:

$$l = v.t = 4.22,5 = 90\ [m]. \quad (6)$$

The calculated distance of the cabins by Eq. 6 is as 90 m.
The number of cabins n_x can be calculated according to Eq. 7

$$n_X = \frac{L'_X}{l}\ [-]. \quad (7)$$

Tab. 2. Calculations on the number of cabins.

	Actual length of section *L'x* [m]	**Distance between cabins on route *l*** [m]	**Cabin no. n_x** [pcs]
Section A	724	90	8
Section B	1298		15
Section C	404		5
Total	2426	-	28

Calculation of the haul rope

In order to determine the appropriate rope structure and check the safety of the haul rope, we have to calculate:

- a weight suspended on the rope,
- resistances against the movement of cabins – for full cabins side,
- resistances against the sheaves and cable wheels taking into account pull T_{min},
- pull on haul rope and motor power.

The weights weighing on the rope are determined from the results obtained by the calculations above.

For the side of the full cabin

$$m_{pl} = n\,.(M_v + m) = 28.(635 + 1000) = 45780\ [kg]. \quad (8)$$

where:

n – no. of cabins
M_v – the weight of the empty cabin; 635 [kg] (according to the manufacturer's prospectus)
m – useful load carrying capacity

For the side of the empty cabin

$$m_{pr} = n\,.\,M_v = 28 \times 635 = 17780\ [kg]. \quad (9)$$

Calculation of the haul rope

$$m_l = q_l\,.(2.L'_{A+B+C} + L_Z) = 2,8.(2\,.\,2426 + 250) = 14285,6\ [kg]. \quad (10)$$

where:

q_l - is the nominal weight of the haul rope, [kg.m^{-1}] (choose from 0,5 to 3 kg.m^{-1})
L_Z – backup length of the rope (it is required to wrap the cable wheels in the drive and return station - estimate) [m].
$2.L'_{A+B+C}$ – the actual length of the cableway route for both cabin sides [m].

A static load of the rope *Fs*:

$$Fs = g.\left(m_{pl} + m_{pr} + m_l\right) = 9,81.(45780 + 17780 + 14285,6).$$
$$Fs = 763665,34\ [N]. \quad (11)$$

The calculated cross-section of the rope is calculated from a known equation

$$N = Fs.b = S\,.\,R_m\ [N]. \quad (12)$$

so that

$$S = \frac{F.b}{R_m} = \frac{76366.5}{1770} = 215{,}72\ [mm^2]. \tag{13}$$

where:

N - is the load of the rope [N],
F - static load of the rope [N],
S - a nominal cross-section of the rope [mm²],
R_m - tensile strength [N.mm^{-2}],
b - the safety of the rope [-]

where F = 76366 N and is calculated as a 10% from total static load Fs.
(Note: 10% is selected because of the way of a load of the haul rope|
b = 5 by STN 27 3205, article 47
R_m = 1770 N.mm^{-2} by ON 27 3201, article 7, letter *b*.

Furthermore, according to the CASAR catalogue, we use the rope with the following parameters for our cableway. For the purpose of the suburban passenger cableway, we select the following rope:

Casar Stratoplast M 22 8x26 EPIWRC 1770 B zZ

Cross section of the rope S = 227,5 mm^2
Rope diameter d = 22,0 mm
Nominal weight of the haul rope q_l = 2,01 kg.m^{-1}
Load capacity of the rope N = 402,6 kN

The basic and smallest pull of the haul rope is selected according to ON 27 3202 as follows:
$T_o = T_{min}$ = (600 až 1000).g.q
$T_o = T_{min}$ = 900.9,81.2,01 = 17746,3 N
The weight is 1,81 t.

The following rule applies to the choice of tow rope: ON 27 3201, no. 7., letter b. The rated wire strength is 1570 or 1770 MPa. The rope must always be mutilated and evenly wound.

Resistance against cabin movement

The route of the cableway is divided into sections A, B and C thus for each section we have to calculate the resistance against the movement of the cabins separately.

$$Rv = g.L'\left(\frac{M_{v+m}}{l} + q_l\right)(\mu.cos\alpha + sin\alpha)[N]. \tag{14}$$

where:

R_V – is the resistance against cabin movement
μ - coefficient of rolling resistance when riding a cabin on a cable in a closed circuit [-]
g - Earth gravity acceleration [m.s^{-2}]
M_V – the weight of the empty cabin [kg]
m – a mass of people [kg]
q_l – the Nominal weight of the haul rope [kg.m^{-1}]
£ - the slope of the route of the relevant section of the cableway [°]

Calculations for the cabin sides
Full cabin side, direction up
Section A:

$$R_{VA} = g.L_A'\left(\frac{M_{v+m}}{l} + q_l\right)(\mu.cos\alpha_A + sin\alpha_A).$$
$$R_{VA} = 9{,}81.724.\left(\frac{635+1000}{90} + 2{,}01\right).(0{,}01.cos0{,}79° + sin0{,}79°). \tag{15}$$
$$R_{VA} = 7102{,}44.(20{,}18).(0{,}0238) = 3411{,}19\ [N].$$

Section B:

$$R_{VB} = g.L'_B\left(\frac{M_{v+m}}{l} + q_l\right)(\mu.cos\alpha_B - sin\alpha_B).$$

$$R_{VB} = 9{,}81.1298\left(\frac{635+1000}{90} + 2{,}01\right)(0{,}01.cos5{,}3° + sin5{,}3°). \quad (16)$$

$$R_{VB} = 12733{,}38\,.\,(20{,}18).(0{,}1023) = 26286{,}97\ [N].$$

Section C:

$$R_{VC} = g.L'_C\left(\frac{M_{v+m}}{l} + q_l\right)(\mu.cos\alpha_C + sin\alpha_C).$$

$$R_{VC} = 9{,}81.404\left(\frac{635+1000}{90} + 2{,}01\right)(0{,}01cos4{,}39° + sin4{,}39°). \quad (17)$$

$$R_{VC} = 3963{,}24.\,(20{,}18).(0{,}0865) = 6918{,}11\ [N].$$

Total resistance is as following:

$$RVplh,A,B,C = RVA + RVB + RVC = 36616{,}27\ [N]. \quad (18)$$

Full cabin side, direction down

Section A:

$$R_{VA} = g.L_A'\left(\frac{M_{v+m}}{l} + q_l\right)(\mu.cos\alpha_A - sin\alpha_A).$$

$$R_{VA} = 9{,}81.724\left(\frac{635+1000}{90} + 2.01\right)(0{,}0045.cos0{,}79° - sin0{,}79°). \quad (19)$$

$$R_{VA} = 7102{,}44.\,(20{,}18).(-0{,}009288) = -1331{,}22\ [N].$$

Section B:

$$R_{VB} = g.L'_B\left(\frac{M_{v+m}}{l} + q_l\right)(\mu.cos\alpha_B - sin\alpha_B).$$

$$R_{VB} = 9{,}81.1298\left(\frac{635+1000}{90} + 2{,}01\right)(0{,}0045cos5{,}3° - sin5{,}3°). \quad (20)$$

$$R_{VB} = 12733{,}38.\,(20{,}18).(-0{,}0878) = -22561{,}05\ [N].$$

Section C:

$$R_{VC} = g.L'_C\left(\frac{M_{v+m}}{l} + q_l\right)(\mu.cos\alpha_C - sin\alpha_C).$$

$$R_{VC} = 9{,}81.404\left(\frac{635+1000}{90} + 2{,}01\right)(0{,}0045.cos4{,}39° - sin4{,}39°). \quad (21)$$

$$R_{VC} = 3963{,}24.(20{,}18).(-\,0{,}072) = -5758{,}43\ [N].$$

Total resistance is as following:

$$R_{Vpld,A,B,C} = R_{VA} + R_{VB} + R_{VC} = -\,29650{,}7\ [N]. \quad (22)$$

Empty cabin side, direction up

Section A:

$$R_{VA} = g.L_A'\left(\frac{M_v}{l} + q_l\right)(\mu.cos\alpha_A + sin\alpha_A).$$

$$R_{VA} = 9{,}81.724\left(\frac{635}{90} + 2{,}01\right)(0{,}01cos0{,}79° + sin0{,}79°). \quad (23)$$

$$R_{VA} = 7102{,}44.(9{,}07).(0{,}0238) = 1533{,}18\ [N].$$

Section B:

$$R_{VB} = g.L'_B\left(\frac{M_v}{l} + q_l\right)(\mu.cos\alpha_B - sin\alpha_B).$$

$$R_{VB} = 9{,}81.1298\left(\frac{635}{90} + 2{,}01\right)(0{,}01cos5{,}3° + sin5{,}3°). \quad (24)$$

$$R_{VB} = 12733{,}38.(9{,}07).(0{,}1023) = 11814{,}81\ [N].$$

Section C:

$$R_{VC} = g.L'_C\left(\frac{M_v}{l} + q_l\right)(\mu.cos\alpha_C + sin\alpha_C).$$

$$R_{VC} = 9{,}81.404\left(\frac{635}{90} + 2{,}01\right)(0{,}01cos4{,}39° + sin4{,}39°). \quad (25)$$

$$R_{VC} = 3963{,}24.(9{,}07).(0{,}0865) = 3109{,}38\ [N].$$

Total resistance is as following:

$$R_{VprhA,B,C} = R_{VA} + R_{VB} + R_{VC} = 16457{,}37\ [N]. \quad (26)$$

Empty cabin side, direction down
Section A:

$$R_{VA} = g.L_A'\left(\frac{M_v}{l} + q_l\right)(\mu.cos\alpha_A - sin\alpha_A).$$

$$R_{VA} = 9{,}81.724\left(\frac{635}{90} + 2{,}01\right)(0{,}0045os0{,}79° - sin0{,}79°). \quad (27)$$

$$R_{VA} = 7102{,}44.(9{,}07).(-0{,}009288) = -598{,}32\ [N].$$

Section B:

$$R_{VB} = g.L'_B\left(\frac{M_v}{l} + q_l\right)(\mu.cos\alpha_B + sin\alpha_B).$$

$$R_{VB} = 9{,}81.1298\left(\frac{635}{90} + 2{,}01\right)(0{,}0045cos5{,}3° - sin5{,}3°). \quad (28)$$

$$R_{VB} = 12733{,}38.\ (9{,}07).(-0{,}0878) = -10140{,}18\ [N].$$

Section C:

$$R_{VC} = g.L'_C\left(\frac{M_v}{l} + q_l\right)(\mu.cos\alpha_C - sin\alpha_C).$$

$$R_{VC} = 9{,}81.404\left(\frac{635}{90} + 2{,}01\right)(0{,}0045cos4{,}39° - sin4{,}39°). \quad (29)$$

$$R_{VC} = 3963{,}24.\ (9{,}07)\ .\ (-0{,}072) = -2588{,}15\ [N].$$

Total resistance is as following:

$$R_{VprdA,B,C} = R_{VA} + R_{VB} + R_{VC} = -\ 13326{,}65\ [N]. \quad (30)$$

In order to calculate force on the drum F_{ob} and the engine power, we have to select the most unfavorable case, i.e. movement of full cabins up and empty cabins down. The formula to calculate force on the drum will be:

$$F_{ob} = R_{Vplh,A,B,C} + R_{Vprd,A,B,C} = 36616{,}27 - 13326{,}65 = 23289{,}62\ [N]. \quad (31)$$

Drive power of the estimated transmission efficiency η = 70% is calculated as:

$$P = \frac{F_{ob}.v}{1000.0{,}7} = \frac{23289{,}62.4}{1000.0{,}7} = 133{,}08\ [kW]. \quad (32)$$

Based on the calculations, the Siemens engine type 1LG4313-4IMV1 with a power of 152kW and 400V supply is selected from the catalogue.

Results discussion

Design of the use of a personal cableway in tourism

From the ropeway, there will be only supports on which new roller batteries will be installed. On supports, it will need to perform NDT tests to determine their status and then perform maintenance. The boarding station can be located in the Anička area, next to the beach swimming pool Ryba, which would help the development of suburban tourism.

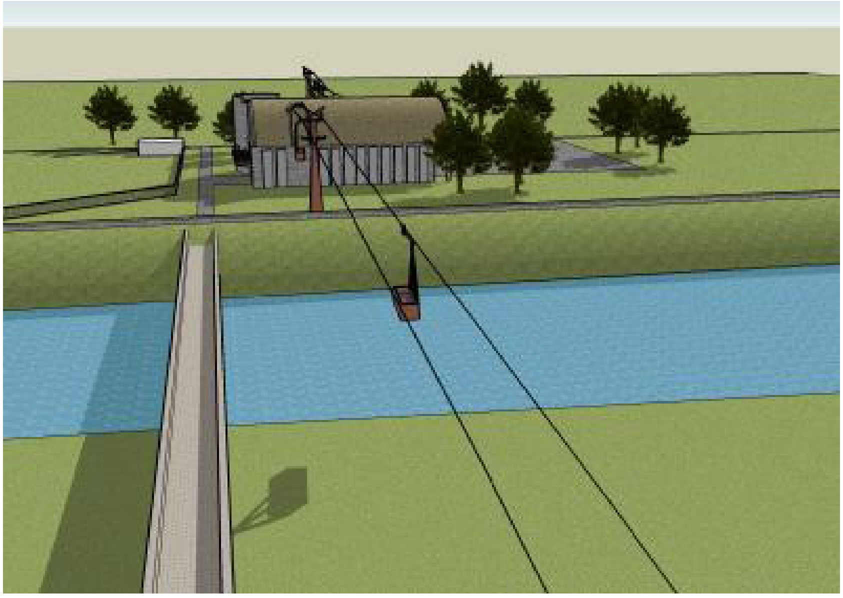

Fig. 2. View of the planned cableway and the Anička station (Balog et al.,2010).

Parking cars can be on land between Anička and route II. the class of Košice - Kysak, under the Podhradová settlement. At the boarding station, a return and tensioning system of the cableway can be placed, and at the same time, a museum devoted to the history of mining and freight cable transport of raw materials in Košice. The exit station of the cableway will be in the area of the amphitheatre, on the mine of Bankov in the places of the former building station and the hopper. The exit station can be a cableway drive, a restaurant, and a garage carriageway. The station can be directly connected to the building of the amphitheatre. In the building of the exit station, there could also be the start-up station of the cableway at the Kamenný Hrb in the future. (respectively Alpínka). A new cableway to the Jahodná through the Kamenný Hrb will be connected to the reconstructed cableway (resp. Alpínka), where it will be necessary to build a station to continue the cableway towards Jahodná and towards Alpínka and Kavečany – Hrešná. Presumed transport capacity of the individual cableway to the Alpínka and the cableway to the zoo in Kavečany will be around 1200 persons/hour and a cableway to Kamenný hrb – Jahodná around 600 persons/hour. Based on statistical data, it is reported that Bankov would visit 340,000 tourists each year, Jahodná 100 000 tourists and Kavečany (ZOO and Hrešná) 180 000 tourists.

From the market offer, one can choose the Sigmacabins, which meets the requirements of modern cable systems. Reliability and comfort of these cabs were appreciated by passengers in New York (USA), Rio de Janeiro (Brazil) and Medellin (Colombia) (Sotomayor, 2013). It is adapted to mountain conditions, but also to urban conditions as well as fun parks. Cabs provide a "standard" level of comfort with a wide opening of the doors. The cabin has glass plates and offers a nice view of the countryside.

Proposal to integrate a personal cableway into integrated urban mobility

City outbuildings in Košice are currently expanding beyond the city centre to its periphery, which also changes user needs. Residents demand a new culture of urban mobility. Meeting these needs together with the need to increase the share of green public passenger transport requires a fundamental change in order to provide traffic closer to the sources and the destination of the roads. By using the route of the former mining cableway, a new conveyor system of the suburban cable car would be created. This system could be integrated into the integrated transport system of the city of Košice.

The basic principles of the Kosice integrated transport system are based on the use of the transport capacities of all types of public passenger transport (train, bus, urban) within the common transport system - integrated. Figure 3 shows the design of an integrated transport system in Košice (Šarák, 2011).

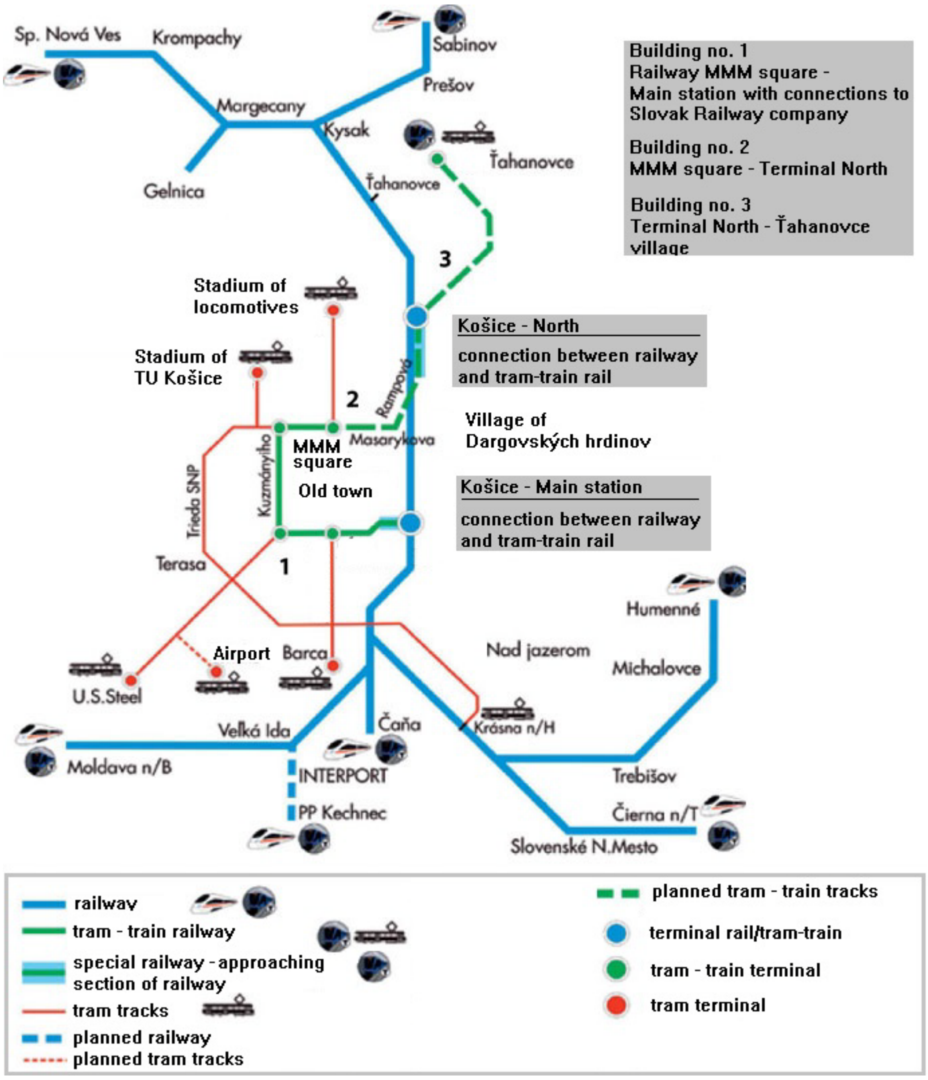

Fig. 3. The integrated transport system in the city of Košice.

The planned cableway for tourism will be able to connect other cableways in the Anička area, for example, from the settlement Furča and Bankov locality from the settlement KVP. These cableways could also serve as a means of public transport. At the same time, there is the possibility to integrate this transport system into the integrated transport system Košice in Terminal Sever-Ťahanovce (Figure 4).

Fig. 4. Terminál Sever- Ťahanovce (Šarak, 2011).

Terminal Sever – the settlement of Ťahanovce, is referred to as the Construction in the framework of the technical and technological solution of the construction of the Integrated system of Košice designated as Building 3 and budget costs amount to 31.4 million euros. The construction will be included in the OPD planning period 2014 – 2020. The track is to lead direct rail traffic from the city centre to the Ťahanovce settlement with 23,000 inhabitants. The tram-train system should also be used to directly connect the settlement with the US Steel and Kechnec industrial centres and the regions. The track is new construction of a double-track line with a length of 2.80 km and follows the building no. 2 (Terminal Sever – Peace Marathon Square (Košice Old Town)). The first part of the new building, 1.3 km long, is located on a separate building. The Section at the Ťahanovce settlement runs in the separate middle class of the American Class. The track will use tram-trains and trams, and five stops will be placed on it. Interestingly, the track will be 317 m long after the estacade. The ongoing process of project preparation for three buildings and their financing from the OPD gives the assumption that the planned objectives can be realised. It is very important to secure the necessary funds in the current OPD relocation process and to set up the OPD 2014-2020 (Šarak, 2011).

Conclusion

The city's overall transport strategy includes a proposal for the principles of transport subsystems in line with the overall transport strategy and sustainable mobility principles. The visions and objectives of the transport development and transport infrastructure of the city of Košice are aimed at reorganising transport and adding infrastructure for walking, cycling, mass and individual car transport. On the basis of the outputs from the analytical part, a proposal for the overall transport strategy of the city was prepared for the target period of 2030 with the stages 2020 and 2025, and also with a view to 2040. The development of transport from the point of view of the current territorial development of the city, focusing on the tasks of the new territorial plan of the city of Košice, characterises the authors Iglódy and Kolesárová (Iglódy and Kolesárová, 2015). The new territorial plan should be approved in 2017, and valid should be at least until 2040. In this proposal, sports and recreation are being proposed at the Anička and Allsport Area; a new idea is the placement of sports and recreational functions in Bankov area, which seems to be appropriate considering the location in relation to the city and the forest park. The proposed city cableway could also have an end station in the existing loading station of the suspended cableway in mine Bankov area.

Obtaining financial resources for the construction of the city lane would be possible from the Operational Program Integrated Infrastructure, in which more than $ 320 million is earmarked to support public transport itself in cities or from the Integrated Regional Operational Program to support bus transport, integrated transport, non-motorized transport and so- soft measures (on non-motorized transport, including cableway transport, is allocated 24 million €) (Dekánek, 2015).

The integration of the city cableway into the public transport system in Košice would make it possible for public transport to make an attractive choice and part of a lifestyle. Taking advantage of the current heavy-duty cableway would not only make it easier to improve urban mobility, but also a more efficient use of the recreational potential of the territory and the development of tourism in Košice. This activity will increase the share not only in income growth but also in total employment in the region.

***Acknowledgements**: This article is the result of the project Supported by the Scientific Grant Agency (VEGA) of the Ministry of Education of the Slovak Republic and the Slovak Academy of Sciences, Grant No. VEGA 1/0384/16 - Static ropes and their ends -possibility of the technical condition evaluation by a mean of nondestructive testing.*

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Environmental performance in OECD countries: A non-radial DEA approach

Beata Gavurova[1], ***Kristina Kocisova***[2], ***Marcel Behun***[3] and ***Miriam Tarhanicova***[4]

Data Envelopment Analysis (DEA) has become popular in performance measurement in the environmental area because it can provide a synthetic standardised performance index when pollutants are appropriately incorporated into the traditional DEA framework. Existing studies on the application of DEA to measure the environmental performance often follow the concept of a radial efficiency. In this paper, we use the non-radial and non-oriented DEA approach (SBM model) with undesirable output under the condition of constant rerun to scale. Since the slacks-based model (SBM model) integrates all the slacks in inputs and desirable outputs into a whole, the result can provide some standardised composite index with a higher discriminating power for modelling environmental performance. We apply the SBM model to measure environmental performance in OECD countries during the 1995-2014 period. We can see that the environmental performance of OECD countries as a whole has improved from 1995 to 2014. As the most efficient countries, we considered France, Italy and Switzerland, which were efficient during the wholly analysed period. On the other hand, the lowest efficiency was in countries like the Czech Republic, Hungary, Poland, and Slovakia. The highest progress obtained the Lithuania, where the efficiency score increased from 10.17 % in 1995 to 26.22 % in 2014. The biggest fall is evident in the case of Portugal, where the efficiency score fell from 40.8 % in 1995 to 29.55 % in 2014.

Key words: *Data Envelopment Analysis (DEA), Environmental performance, Undesirable outputs, Non-radial model, OECD countries*

Introduction

Numerous studies across all different industries explore the measurement of efficiency in many fields of activity. The choice of the analysis applied in these studies depends on their focus. While the focus of some studies is on the product or the production process, other studies focus on plant, companies or industrial sector (Kalb, 2010; Rajnoha, Lesníková, 2016). The regional analysis of the environmental effects as many benchmark studies introduce is still beneficial. According to the study by Wang, Lu, Wei (2013) for most Chinese regions, they did not recommend to increase or maintain their current scales of production. Alternatively, they should pay more attention to technology innovation of energy efficiency improvement. China has enormous energy conservation and emission reduction potentials. Study of Li, Fang, Yang, Wang, Hong (2013) proves that fiscal decentralisation and technology progress can increase environmental efficiency overall while economic scale and the regional difference can also influence the efficiency.

First attempts to measure the efficiency of economic units were based on the application of the efficiency indexes with a weighted average of inputs compared to a weighted average of outputs. The most known superlative index numbers are the Tornquiest-Theil-translog index and Fischer Ideal index (Tornquist, 1936). As the problems with the circularity and characteristic appearance, it is not recommended to do the multilateral comparative analysis of the time series data. Even though, the study of Caves, Christensen, Diewert (1982) shows that indexes are adequate for multilateral comparison using cross-section data and panel data. These indexes are not widely used in developing empirical comparative methods (Knight, Rosa, 2011). The disadvantage of the superlative multilateral indexes is that they rely on the fact, the price of the products is always positive (Pittman, 1983). In a study by Diewert (1979) the index number theory is divided into three approaches: statistical, the test approach and the functional approach. The functional approach helps to understand better and decide whether the usage of indexes is implemented appropriately or not. The study of Samuelson Swamy (1974) appertain to the functional approach, deals with the relationship between index techniques and the functions of production and utility.

Author (Farrell, 1957) in his study of farmers technical and price efficiency emphasises that measuring the productive efficiency should have some practical background. According to his study, it is more reasonable to compare the firm with the comparable firms than to compare firm with the theoretically efficient ideal that is

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hard to reach. The emphasis of his study is on the importance of using more than one input. The problems of characteristic and circularity are avoided.

Environmental issues have become an inseparable part of everyday life and are an indispensable tax on the comfort that most of the world today can afford. These problems affect all the environmental compartments, i.e. water, air, soil, and biota, and is not even a person exempt. The environmental efficiency index may be used to decide whether the economic agent is environmentally efficient (Rajnoha et al., 2017). Färe, Grosskopf, Lovell, Pasurka (1989) propose the development of a hyperbolic graph efficiency approach, which seeks the maximum simultaneous uniform expansion for the desired outputs and contraction for the inputs and undesirable outputs. This study is the modification of Farrell approach. It takes into account the study of Pittman (1983) that informs about the necessity of dividing the outputs into desirable and undesirable outputs. When analysing the environmental effects of firms, different environmental performance indicators may serve to analyse and identify the lagers and the leaders. As the conclusion of the study Färe, Grosskopf, Tyteca (1996) affirms, the adoption of tradeable permits would imply considerable differences among companies. The indicators that provide information about environmental performance would be a useful tool to gather the information for public decision-makers about the new policy that should be implemented to be more eco-efficient. The other approach towards environmental performance indicators is mathematical programming. The study of Seiford, Zhu (2002) evaluates the relative efficiencies and inefficiencies of similar organisational units (DMUs) by using Data Envelopment Analysis (DEA). Identification of efficient frontier allows bettering deciding whether the increasing level of output or decreasing the level of inputs is needed to improve the performance of DMU. As the term envelope says, the data are enveloped by the piecewise linear frontier in such a way that the radial distances to the frontier are minimised (Kulshreshtha. Parikh, 2002). As the methodology of measuring the efficiency differs, the results obtained from analysis differs too. In Färe et al. (1996) the comparison of Jaggi and Friedman model to environmental performance indicator on the same dataset was made. Models show significant divergence, caused by different ways of dealing with undesirable outputs. Two main non-parametric methods for the environmental performance analysis is data envelopment analysis (DEA) and free disposal hull (Yagi, Fujii, Hoang, Managi, 2015). DEA enables to do the simulation of the effect of any regulatory standard on production and provides the information about all lower and upper limits beyond which production is impossible (Charnes, Cooper, Rhodes, 1978). Two competing approaches to efficiency are a stochastic frontier estimation and DEA (Zaim, Taskin, 2000; Reinhard, Lovell, Thijssen, 2000). Data envelopment analysis is widely used to study the efficiency of energy industries, particularly in the mining industry (Kulshreshtha, Parikh, 2002; Tsolas, 2011; Vaninsky, 2006; Wossink, Denaux, 2006; Halkos, Tzeremes, 2009; Sueyoshi, Yuan, Goto, 2017; Murty, Kumar, Paul, 2006; Zaim, Taskin, 2000; Reinhard et al., 2000; Welch, Barnum, 2009; Zofío, Prieto, 2001; Zhou, Poh, Ang, 2016). Seiford, Thrall (1990) compare the mathematical programming to the regression approach of modelling DEA. The regression approach is criticized because of its „only" residuals side and the absence of the judgement on efficiency – it is not possible to identify the sources of inefficiency and the influence of the outliers is noticeable. The only requirement for the DEA is a single observation (for each input and output) per DMU. It may cause sensitivity to variable selection, model specification, and data errors. One of the methodologies to analyse the environmental efficiency is a non-radial and non-oriented Data Envelopment Analysis (DEA), namely the SBM model. According to (Mardani, Zavadskas, Streimikiene, Jusoh, Khoshnoudi, 2017) DEA is used mostly to explore the energy efficiency. Papers that do analysis while using DEA are based on areas: environmental efficiency, economic and eco-efficiency, energy efficiency issues, renewable and sustainable energy, water efficiency, energy performance, energy saving, integrated energy efficiency etc.

In the context of environmental performance measurement, the assumption used by traditional DEA models that all the outputs should be maximised is not appropriate when undesirable outputs are also generated as the by-products of the desired outputs in the production process. By the global environment conservation awareness, undesirable outputs of productions and social activities, for example, air pollutants and hazardous wastes, are being increasingly recognised as dangerous and undesirable. Thus, the development of technologies with less undesirable outputs is an important subject of concern in every area of production. Färe et al., (1989) presented one of the methods how the undesirable outputs could be involved in the evaluation. This method, based on the concept of weak disposable reference technology, also called the environmental DEA technology, has been adopted in environmental performance measurement for example in study of Reinhard et al., (2000); Zaim, Taskin, (2000); Zaim (2004); Zofío, Prieto, (2001); Zhou, Ang, Poh, (2006, 2008); Zhou, Poh, Ang, (2007).

This paper aims to apply the non-radial and non-oriented DEA model (SBM model) with undesirable outputs to measure environmental performance in OECD countries during the period from 1995 to 2014. We organised the remainder of the paper as follows. The next section deals with methodology issue and present data used in the analytical part of the paper. Then we present the results of the analysis. The last section concludes the study.

Methodology and data

DEA was first applied to the public sector, specifically to estimate the efficiency of schools, without information on prices. This formulation is known as the CCR (Charnes et al., 1978) The CCR model should not be used in many situations. In 1984 the BCC model was introduced as the extension of the CCR model and included even the situation when the returns to scale at different points on the production frontier are increasing/constant or decreasing (Ray, 2004). Difference between CCR and BCC model is that in the BCC model the assumption of a variable return to scale is used. Classification of DEA models is as follows: radial and oriented, radial and non-oriented, non-radial and oriented, non-radial and non-oriented. Oriented means that the model is input or output oriented, while radial means that the primary concern of model is proportional reduction/enlargement of inputs and output. We can use the bootstrap DEA with repeat sampling of correlation estimation to analyse the small data sample (Song, Zhang, Liu, Fisher, 2013). Most studies about the application of DEA to environmental performance evaluation follow the concept of the radial efficiency measures. According to (Zhou et al., 2007) using radial efficiency measures often leads to the case where a lot of evaluated production units (countries or individual companies) have the same efficiency score of 1 and hence the difficulty in ranking the environmental performance of these production units only based on their efficiency scores. Since non-radial efficiency measures have a higher discriminating power when evaluating the efficiency of production units, the non-radial DEA models seem to be more effective in measuring environmental performance. In the case of environmental performance evaluation, it is also necessary to extend the traditional non-radial DEA models into the case where undesirable outputs exist.

Consider a production process in which desirable and undesirable outputs are jointly produced. Assume that $\mathbf{x} = (x_1, \dots, x_n)$, $\mathbf{y^g} = (y_1^g, \dots, y_n^g)$ and $\mathbf{y^b} = (y_1^b, \dots, y_n^b)$ denote the vectors of inputs, desirable outputs and undesirable outputs respectively. The production teghnology can then be conceptually described as $P = \{(\mathbf{x}, \mathbf{y^g}, \mathbf{y^b}): \mathbf{x}\text{ can produce }(\mathbf{y^g}, \mathbf{y^b})\}$. In order to reasonably model a production process that produce both desirable and undesirable outputs, the following two assumptions are imposed on *P* by Färe et al. (1989):

1. Outputs are weakly disposable, i.e. if $(\mathbf{x}, \mathbf{y^g}, \mathbf{y^b}) \in P$ and $0 \le \theta \le 1$, then $(\mathbf{x}, \theta\mathbf{y^g}, \theta\mathbf{y^b}) \in P$. This assumption states that the proportional reduction in desirable outputs and undesirable outputs is possible.
2. Desirable outputs and undesirable outputs are null-joint, i.e. $(\mathbf{x}, \mathbf{y^g}, \mathbf{y^b}) \in P$ and $\mathbf{y^b} = 0$ imply that $\mathbf{y^g} = 0$. This assumption indicates that the only way to eliminate all undesirable outputs is to end production process.

Although the production technology *P* has been well-defined conceptually, it can not be directly used in the application. In the DEA scope, as described in Färe et al. (2004), *P* can be characterised by the piecewise linear combination of the observed data.

Suppose that there are *n* DMUs (decision-making units) each having three factors: inputs, desirable outputs and bad (undesirable) outputs, as represented by three vectors $x \in R^m, y^g \in R^{s_1}$, and $y^b \in R^{s_2}$. We define the matrices X, Y^g, and Y^b as follows. $X = [x_1, \dots, x_n] \in R^{m\times n}$, $Y^g = [y_1^g, \dots, y_n^g] \in R^{s_1\times n}$, and $Y^b = [y_1^b, \dots, y_n^b] \in R^{s_2\times n}$. We assume $X > 0, Y^g > 0$, and $Y^b > 0$ (Cooper et al., 2007).

We can define the production possibility set

(*P*) by $P = \{(x, y^g, y^b) \mid x \ge X\Upsilon, y^g \le Y^g\Upsilon, y^b \ge Y^b\Upsilon, \Upsilon \ge 0\}$, where $\Upsilon \in R^n$ is the intensity vector (Cooper et al., 2007). Since *P* is formulated in the DEA framework, as argued by Färe et al. (2004), it could be termed as the environmental DEA technology. Notice that the above definition corresponds to the constant return to scale technology when undesirable outputs are considered.

A $DMU_o\ (x_o, y_o^g, y_o^b)$ is efficient in the presence of undesirable outputs if there is no vector $(x, y^g, y^b) \in P$ such that $x_o \ge x$, $y_o^g \le y^g$ and $y_o^b \ge y^b$ with at least one strict inequality. By this definition, we can modify the non-radial and non-oriented SBM model as follows:

SBM-Undesirable

$$\rho^* = min \frac{1 - \frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{io}}}{1 + \frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{ro}^g} + \sum_{r=1}^{s_2}\frac{s_r^b}{y_{ro}^b}\right)} \tag{1}$$

Subject to

$$x_o = X\Upsilon + s^- \tag{2}$$

$$y_o^g = Y^g\Upsilon - s^g \tag{3}$$

$$y_o^b = Y^b\Upsilon + s^b \tag{4}$$

$$s^- \ge 0, s^g \ge 0, s^b \ge 0, \Upsilon \ge 0$$

The vector $s^- \in R^m$ and $s^b \in R^{s_2}$ correspond to excess in inputs and bad outputs, respectively, while $s^g \in R^{s_1}$ expresses shortage in good outputs. The objective function (1) is strictly decreasing with respect to $s_i^- (\forall i)$, $s_r^g (\forall r)$ and $s_r^b (\forall r)$ and the objective value satisfies $0 < \rho^* \leq 1$. Let an optimal solution of the above program be $(\Upsilon^*, s^{-*}, s^{g*}, s^{b*})$. Then the DMU_o is efficient in the presence of undesirable outputs in and if $\rho^* = 1$, i.e., $s^{-*} = 0$, $s^{g*} = 0$, and $s^{b*} = 0$ (Cooper et al., 2007).

Note that the set of constraints on undesirable outputs (4) in the model (1) can guarantee that DMU has now been a competent practitioner in pure environmental performance. Therefore, model (1) can be used to evaluate the economic inefficiency of DMU by a slacks-based efficiency measure ρ^* after its pollutants are adjusted to their minimal levels. The slack variables could be used to identify and estimate the causes of economic inefficiency.

If the DMU_o is inefficient, i.e. $\rho^* < 1$, it can be imporved and become efficient by deleting the excesses in inputs and bad outputs, and augmenting the shortfalls in good outputs by the following projection (Cooper et al., 2007):

$$\widehat{x_o} \leftarrow x_o - s^{-*} \tag{5}$$

$$\widehat{y_o^g} \leftarrow y_o^g + s^{g*} \tag{6}$$

$$\widehat{y_o^b} \leftarrow y_o^b - s^{b*} \tag{7}$$

If a DMU has a larger ρ^* than another DMU, then it has a better environmental performance than the other. Obviously, the index derived from the model (1) can provide an objective way for decision makers and environmental analysts to quantify and compare the environmental performance of different firms or entities (Zhou et al., 2007).

We decide to apply the non-radial and non-oriented DEA model (SBM model) with undesirable outputs. Through the model, we can calculate the environmental performance of selected countries in the OECD from 1995 to 2014. In this study, we employed the primary energy consumption (PEC) as input. The only desirable output is a gross domestic product (GDP). As the undesirable outputs (also called pollutants) are considered carbon dioxide (CO2), sulphur oxides (SOx) and nitrogen oxides (NOx) emissions. The number of input (*m*) and output (s) variables was set up according to the essential condition of DEA model that the number of variables should be lower than one-third of the analysed production units (*n*), i.e. ($m+s$)<n/3. In our sample of analysed countries (22) it means, that the number of variables should be lower than 7. The reason why we decide to use only five variables is that with the increasing number of input and output variables the efficiency score of analysed production units increase and much more production units are considered efficient.

Tab. 1. Summary statistics for 22 OECD countries in 1995-2014.

	PEC (ton per one labour person)	**GDP (USD per one labour person)**	**NOx (ton per one labour person)**	**SOx (ton per one labour person)**	**CO_2 (ton per one labour person)**
Minimum	2.8528	11013.01	0.01418	0.0004	0.0001
Maximum	19.2262	171012.04	0.11416	0.2113	0.0062
Average	8.0217	71886.57	0.05235	0.0360	0.0016
Standard deviation	3.1759	36221.82	0.01985	0.0364	0.0014

Source: Prepared by authors

As the countries involved in the analysis have different size, we decided to standardise them. As the tool for standardisation, we used the value of labour force in individual countries. We divided all variables involved in the analysis by the value of labour force which eliminates the size differences between the countries. We collected the data on environmental variables from OECD Environmental Data (OECD Statistics, 2017), Statistical Review of World Energy (World Energy, 2017), and the data about the labour force from the World Bank database (World Bank, 2018) Table 1 gives the descriptive statistics of the data involved in the analysis expressed on one labour person in the specified countries.

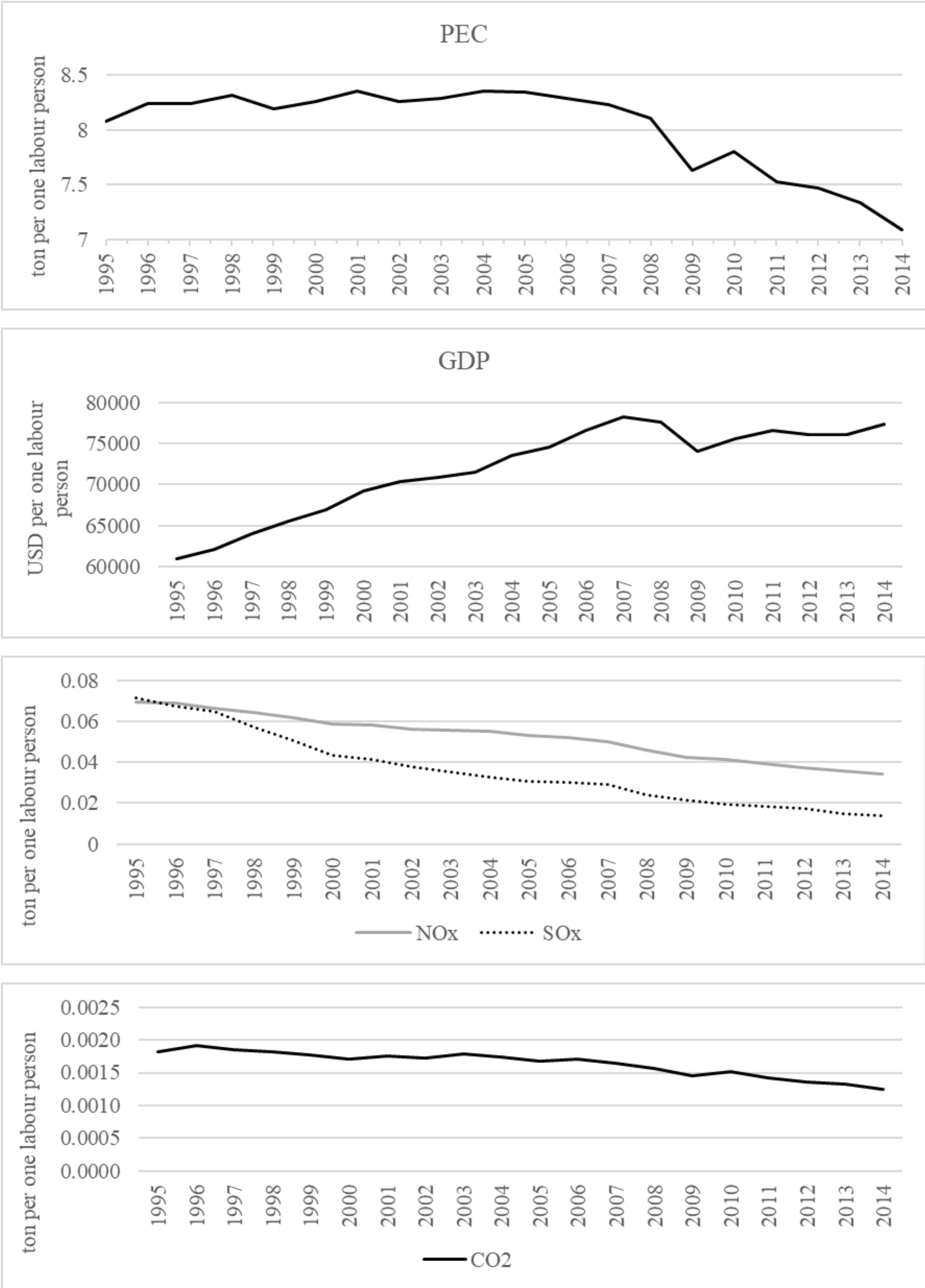

Fig. 1. The development of input and output variables, OECD average. Source: Prepared by authors

Figure 1 displays the development of variables, average values for all countries during the wholly analysed period. As can be seen according to the average values the primary energy consumption significantly decreased since 2005. The decrease can also be seen in the case of the production of undesirable outputs: carbon dioxide (CO_2), sulphur oxides (SOx) and nitrogen oxides (NOx). On the other hand, the gradual increase can be monitored in case of GDP expressed in constant prices of 2010. The gradual increase was shortly interrupted by the financial crisis, which hit all countries around the world after 2007.

Results

The correlation matrix of inputs and outputs was calculated to see if there was a significant relationship between the input and output variables. Table 2 shows the results of the analysis. All the correlation coefficients in the table are below 0.71, which indicate that a significantly high correlation does not exist between input and the output variables. It indicates that DEA analysis could be used as one of the conditions of the DEA model is that the input and output variables should not be highly correlated.

Tab. 2. Correlation matrix of input and output variables.

	PEC (ton per one labour person)	GDP (USD per one labour person)	NOx (ton per one labour person)	SOx (ton per one labour person)	CO_2 (ton per one labour person)
PEC	1				
GDP	0.704279	1			
NOx	0.456997	0.201574	1		
SOx	-0.31383	-0.53904	0.371496	1	
CO2	0.362085	0.265264	0.479356	-0.01957	1

Source: Prepared by authors

On the other hand, the value of correlation coefficient between input and output variables should not be equal or close to zero. The value close to zero indicates that the input has no impact on the output variable, which signalises that the model is not adequately specified. In our sample, the value of correlation coefficient between input (PEC) and output variables (GDP, NOx, SOx, and CO_2) is always higher than 0.31, which indicate that our input variable can influence the development of output variables. This way the underlying conditions have been met, and therefore the DEA model may be used.

Tab. 3. Environmental efficiency for 22 OECD countries in 1995-2014.

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Austria	0.4679	0.4564	0.4794	0.4787	0.4920	0.4888	0.4888	0.4570	0.4464	0.4364
Belgium	0.2932	0.2685	0.2873	0.2796	0.2993	0.3075	0.3075	0.2914	0.2794	0.2783
Czech Republic	0.1497	0.1451	0.1497	0.1515	0.1679	0.1635	0.1635	0.1546	0.1508	0.1502
Denmark	0.5677	0.4656	0.5632	0.5901	0.6415	0.7107	0.7107	0.6662	0.6073	0.6439
Finland	0.2648	0.2504	0.2782	0.2803	0.2998	0.3138	0.3138	0.2922	0.2740	0.2777
France	1	1	1	1	1	1	1	1	1	1
Germany	1	1	1	1	1	1	1	1	1	1
Greece	0.3694	0.3582	0.3776	0.3576	0.3774	0.3770	0.3770	0.3648	0.3646	0.3667
Hungary	0.1655	0.1547	0.1718	0.1748	0.1852	0.2009	0.2009	0.1978	0.2014	0.2042
Ireland	0.4151	0.4077	0.4496	0.4439	0.4735	0.4948	0.4948	0.4962	0.5239	0.5318
Italy	1	1	1	1	1	1	1	1	1	1
Lithuania	0.1017	0.0945	0.1160	0.1135	0.1372	0.1462	0.1462	0.1366	0.1430	0.1449
Netherlands	0.3534	0.3405	0.3797	0.3893	0.4218	0.4258	0.4258	0.3957	0.3901	0.3703
Norway	0.3839	0.4220	0.4385	0.4225	0.4207	0.4525	0.4525	0.4095	0.4538	0.4447
Poland	0.1185	0.1152	0.1300	0.1395	0.1522	0.1724	0.1724	0.1658	0.1647	0.1666
Portugal	0.4080	0.3999	0.4267	0.3974	0.4064	0.4092	0.4092	0.3825	0.3697	0.3671
Slovakia	0.1148	0.1169	0.1317	0.1323	0.1342	0.1314	0.1314	0.1272	0.1372	0.1425
Spain	0.6228	0.6156	0.5925	0.5915	0.5963	0.5742	0.5742	0.5587	0.5683	0.5564
Sweden	0.3154	0.3129	0.3316	0.3256	0.3549	0.3767	0.3767	0.3752	0.3965	0.3693
Switzerland	1	1	1	1	1	1	1	1	1	1
Turkey	0.4786	0.4552	0.4699	0.4733	0.4667	0.4599	0.4599	0.4399	0.4538	0.4710
United Kingdom	0.6111	0.5910	0.6492	0.6644	0.7210	0.7077	0.7077	0.7453	0.7892	0.8161
Average	0.4637	0.4532	0.4737	0.4730	0.4885	0.4960	0.4960	0.4844	0.4870	0.4881

Source: Prepared by authors

The non-radial and non-oriented DEA model (SBM model) with undesirable outputs under the assumption of a constant return to scale is applied to calculate the environmental efficiency of 22 OECD countries from 1995 to 2014. We specified the weight of each undesirable outputs (CO2, SOx, and NOx) as 0.33, which implies that the reduction of these undesirable outputs has the same degree of importance. Table 3 and Table 4 shows the obtained SBM efficiency scores of evaluated countries. It is evident that the environmental performance of OECD countries as a whole has been improved from 1995 to 2014. It should be stated that the higher the value of efficiency, the more efficient the country is. A country is efficient if its efficiency value is 1. If the value is lesser than 1, the country is not efficient and can improve its outputs to be efficient by learning from the efficient countries. The efficient countries that inefficient country references can be determined from a linear programming model.

Tab. 4. Environmental efficiency for 22 OECD countries in 1995-2014.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Austria	0.4070	0.4240	0.4264	0.4352	0.4452	0.4110	0.4148	0.4219	0.4281	0.4161
Belgium	0.2680	0.2747	0.2672	0.2700	0.2931	0.2677	0.2738	0.3010	0.2983	0.3023
Czech Republic	0.1507	0.1584	0.1598	0.1718	0.1769	0.1635	0.1577	0.1662	0.1681	0.1676
Denmark	0.6419	0.5957	0.6020	0.6374	0.6652	0.6118	0.6068	0.7046	0.6844	0.6672
Finland	0.2958	0.2848	0.2849	0.3031	0.3048	0.2713	0.2817	0.3029	0.3075	0.2964
France	1	1	1	1	1	1	1	1	1	1
Germany	1	1	1	1	0.9350	0.9154	0.9131	0.9028	0.8453	0.8405
Greece	0.3431	0.3506	0.3390	0.3550	0.3555	0.3306	0.2849	0.2903	0.2985	0.2982
Hungary	0.1882	0.1988	0.1921	0.1990	0.2072	0.1925	0.1885	0.2094	0.2275	0.2216
Ireland	0.5043	0.5259	0.5099	0.4999	0.5372	0.5221	0.5385	0.5708	0.5990	0.6111
Italy	1	1	1	1	1	1	1	1	1	1
Lithuania	0.1594	0.1791	0.1730	0.1811	0.1708	0.2226	0.2116	0.2296	0.2608	0.2622
Netherlands	0.3471	0.3630	0.3556	0.3783	0.3788	0.3480	0.3414	0.3696	0.3837	0.3835
Norway	0.3706	0.4130	0.3682	0.3684	0.3979	0.3882	0.3516	0.3448	0.3753	0.3434
Poland	0.1574	0.1614	0.1648	0.1717	0.1881	0.1726	0.1674	0.1846	0.1888	0.1889
Portugal	0.3417	0.3537	0.3430	0.3647	0.3584	0.3319	0.3151	0.3472	0.3171	0.2955
Slovakia	0.1343	0.1514	0.1701	0.1759	0.1868	0.1741	0.1726	0.1920	0.1889	0.1966
Spain	0.5561	0.5704	0.5426	0.6037	0.6279	0.6331	0.5940	0.5729	0.6044	0.5695
Sweden	0.3521	0.3957	0.3799	0.3885	0.4095	0.3788	0.3650	0.3828	0.4383	0.3813
Switzerland	1	1	1	1	1	1	1	1	1	1
Turkey	0.4935	0.4549	0.4107	0.4160	0.3815	0.4018	0.4064	0.4120	0.4609	0.4197
United Kingdom	0.8286	0.8357	0.8577	0.8725	0.8809	0.8744	1	0.8923	0.8960	1
Average	0.4791	0.4860	0.4794	0.4906	0.4955	0.4823	0.4811	0.4908	0.4987	0.4937

Source: Prepared by authors

We can see that only three countries were marked as efficient during the wholly analysed period. In the case of France, Italy and Switzerland the relation of inputs, outputs and undesirable outputs within the evaluation set able them to be marked as efficient with environmental efficiency score equal to one. The efficiency score equal to one can also be seen in the case of Germany from 1995 to 2008, but then the environmental efficiency started to decrease. Also, the United Kingdom can be considered environmental effects, but only in 2011 and 2014.

The progress between the first and last analysed year can be seen in case of Belgium (3.09 %), Czech Republic (11.97 %), Denmark (17.52 %), Finland (11.92 %), Hungary (33.89 %), Ireland (47.42 %), Netherland (8.51 %), Poland (59.46 %), Slovakia (71.23 %), Sweden (20.88 %), and United Kingdom (63.64 %), while the highest progress is evident in the case of Lithuania, where the efficiency score increased from 10.17 % in 1995 to 26.22% in 2014 (increase by 157.84 %). The fall is evident in the case of seven countries: Austria (-11.07 %), Germany (-15.95 %), Greece (-19.28 %), Norway (-10.55 %), Spain (-8.55 %), Turkey (-12.30 %), and the biggest fall is evident in case of Portugal, where the efficiency score falls from 40.8 % in 1995 to 29.55 % in 2014 (decrease by 27.57 %).

Besides determining the efficiencies of the countries, our approach can also provide the benchmarks for the inefficiency countries to be efficient. As our model is non-oriented, if the evaluate country intents to achieve efficiency, the country can reduce its inputs and reduce its undesirable outputs while increasing its desirable outputs simultaneously. For ease of illustration, we take only the year 2014 as an example. The countries expected inputs and outputs and corresponding incensement or decrements (in percentage form) of the current inputs and outputs are shown in Table 5.

These benchmarks provide the targets for OECD countries´ local governments to balance the development of economic growth and environmental protection. For example, in Slovakia intends to be efficient within the analysed group of countries, it should reduce its the primary energy consumption to the value 1.62996 ton per one labour person (reduction by 71.44 %) and reduce its considered carbon dioxide (CO_2) emissions by 86.72 %, sulphur oxides (SOx) emission by 97.33 % and nitrogen oxides (NOx) emissions by 87.62 %.

We must take in interpreting the results of this paper some limitations of DEA models. Thus far we have employed a technique in capturing environmental performance in selected OECD countries using the SBM methodology. We should be aware that the results of DEA techniques show relative efficiency depending on the collected sample. This fact results from the fact that all efficiency estimations of decision-making units are affected by how we sample the DMUs since the efficient frontier line is drawn from the given sample. Therefore, including other countries into the sample would have brought different results. The panel data over the years for multiple countries can also show intertemporal changes in efficiency and technology development separately using Malmquist index, which should be part of our future research.

Tab. 5. Benchmark of the 22 OECD countries to be efficient in 2014.

	PEC (ton per one labour person)		GDP (USD per one labour person)		NOx (ton per one labour person)		SOx (ton per one labour person)		CO_2 (ton per one labour person)	
	Projection	**Change** [%]	**Projection**	**Change** [%]	**Projection**	**Change** [%]	**Projection**	**Change** [%]	**Projection**	**Change** [%]
Austria	4.22604	-44.94%	92880.81	0.00%	0.00998	-70.92%	0.00115	-65.37%	0.00068	-57.59%
Belgium	4.57400	-59.17%	100528.31	0.00%	0.01080	-72.40%	0.00125	-85.20%	0.00074	-52.77%
Czech Republic	1.83038	-75.77%	40228.46	0.00%	0.00432	-86.40%	0.00050	-97.90%	0.00030	-83.07%
Denmark	5.25016	-12.06%	115389.07	0.00%	0.01240	-68.47%	0.00143	-62.87%	0.00085	-59.57%
Finland	4.18117	-57.90%	91894.60	0.00%	0.00988	-81.13%	0.00114	-92.91%	0.00068	-78.12%
France	7.86094	0.00%	90938.58	0.00%	0.02866	0.00%	0.00531	0.00%	0.00014	0.00%
Germany	6.59842	-10.23%	85875.14	0.00%	0.02872	0.00%	0.00497	-40.81%	0.00021	0.00%
Greece	2.27006	-57.43%	49891.70	0.00%	0.00536	-89.14%	0.00062	-97.52%	0.00037	-69.88%
Hungary	1.40055	-68.38%	30781.48	0.00%	0.00331	-87.52%	0.00038	-93.63%	0.00023	-75.02%
Ireland	5.25060	-16.19%	115398.73	0.00%	0.01240	-64.32%	0.00143	-83.82%	0.00085	-74.65%
Italy	5.77855	0.00%	80398.91	0.00%	0.03111	0.00%	0.00516	0.00%	0.00021	0.00%
Lithuania	1.34516	-61.59%	29564.14	0.00%	0.00318	-91.16%	0.00037	-96.77%	0.00022	-91.06%
Netherlands	4.32043	-52.09%	94955.30	0.00%	0.01020	-57.29%	0.00118	-63.43%	0.00070	-28.85%
Norway	7.66107	-55.03%	168376.34	0.00%	0.01810	-69.00%	0.00209	-65.58%	0.00124	-51.13%
Poland	1.32502	-73.64%	29121.59	0.00%	0.00313	-92.04%	0.00036	-99.17%	0.00021	-46.07%
Portugal	1.94407	-58.63%	42727.23	0.00%	0.00459	-85.81%	0.00053	-94.22%	0.00031	-59.84%
Slovakia	1.62996	-71.44%	35823.65	0.00%	0.00385	-87.62%	0.00044	-97.33%	0.00026	-86.72%
Spain	3.91178	-31.50%	59237.88	0.00%	0.01926	-49.66%	0.00312	-71.96%	0.00022	0.00%
Sweden	4.61601	-53.87%	101023.42	0.00%	0.01106	-57.82%	0.00129	-68.07%	0.00074	0.00%
Switzerland	6.00229	0.00%	131919.41	0.00%	0.01418	0.00%	0.00164	0.00%	0.00097	0.00%
Turkey	2.27265	-46.91%	35815.46	0.00%	0.01014	-62.94%	0.00300	-96.00%	0.00014	0.00%
United Kingdom	5.69015	0.00%	79750.98	0.00%	0.02873	0.00%	0.00920	0.00%	0.00019	0.00%

Source: Prepared by authors

Conclusion

The literature on production frontiers is further extended and modified to measure environmental performance in addition to capturing efficiency at the decision-making unit level. The primary methodology to analyse environmental efficiency is a non-radial Data Envelopment Analysis (DEA) that fulfils the fundamental role of modelling undesirable outputs in environmental performance measurement. DEA can easily handle different situations depending on the user targets. Discussion of some proposed methods indicates that they have certain shortcomings when the materials balance condition is applicable. The existence of particular regulatory constraints established by the authority poses new questions on the reasonable limits between which the constraint must be set. Since there are no globally agreed-upon targets for CO_2 reductions, institutional aspects of the industry should be integrated into any attempts to apply our findings in an actual policy setting. Climate change is among the direct environmental challenges. Still, too little progress has been made to mitigate its effects. However, dramatic progress is possible when measurement and management practices align. When dealing with undesirable output production, it is important to note whether all type of gas generation should be compared to efficient production processes or compared to environmentally inefficient processes. A surveillance system is required which would increase the cost of regulation at the aggregate level. Another requirement is the management of environmental and economic performance through the development and implementation of appropriate environment-related accounting systems and practices. The question that remains open is how it is possible to quantify efficiency scores that reflect the ability of firms to produce desired output with the lowest undesirable production and how standards definitions can be explicitly introduced into this analytical framework. The results of the analysis provided in previous sections show that the correlation does not exist between input and the output variables. As the correlation coefficient between input (PEC) and output variables (GDP, NOx, SOx, and CO_2) was always higher than 0.31, an input variable can influence the development of output variables and so, it indicates that DEA analysis could be used. In general, there are substantial economic gaps between the European countries. While wealthy highly developed countries as France, Switzerland or Germany produce the highest levels of climate emissions but still invest in the green innovation, the Eastern part of Europe seems to be behind them. The analysis provided in this research admits that there also exist the differences between the European countries even in the environmental field. Countries of varying economic development have divergent climate emissions trajectories.

Acknowledgement: *The research behind this paper was supported by research project VEGA 1/0794/18.*

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Multivariate Granger Causality among Oil prices, Gold prices, and KSE100: Evidence from Johansen Cointegration and GARCH Models

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The purpose of the research study is to examine the effect of changes in crude oil prices (COP) and gold prices (GP) and the long-run relationship of equity returns of KSE100 index. We have considered the sample period from January 1, 2010, through June 30, 2016, the KSE100 index daily data was obtained from the website of Pakistan stock exchange, and for COP and GP, we used the Yahoo Finance website. We employed descriptive statistics, correlation analysis, unit root test (ADF), multivariate cointegration, Granger causality, and ARCH & GARCH (1,1) time series models to perform the analysis.

Results of the study revealed an average daily return of stock prices is 9.85% with the volatility of 0.4676. Correlation analysis showed a significant negative association amidst equity returns, and crude oil and gold prices. By employing Johansen cointegration, we concluded that there is no long-run association has been observed amidst the equity returns, and crude oil and gold prices. The Granger causality test suggested one-way causation from COP to KSE100 at 5% level. The ARCH and GARCH (1,1) results revealed a cogent impact of COP on the returns volatility of KSE100 index.

Key words: *gold price, crude oil prices, KSE100 index, Johansen cointegration, ARCH & CARCH, Granger causality*

Introduction

Stock Markets are the barometer of the economic health of the economy and long-run sustainability. During the last decade, the stock markets and economies have witnessed massive upheavals and tremors. The unpredictable fluctuations in equity returns are trailed by reduced growth rates in an economy, as highlighted by Wei and Guo (2016) and Bhowmik (2013). Ma et al. (2016), and Engle and Patton (2001) have the view that financial asset prices do not evolve independently, so, it is likely that other factors might have enclosed vital evidence for the volatility of equity returns. Once we know which variables affect the volatility in the stock market, we can formulate strategies or policies to control these variables. Stock indices and returns are always being a great interest for arguments and association of stock indices with macroeconomic variables, and it is one of the most examined subjects for researchers and financial experts around the globe. This research measures the relationship among oil, gold and stock returns with exceptional reference to KSE100 index. The oil price showed a cogent impact for predicting prices of several industrial, and entrepreneurial costs, which eventually paved the way to determine the stock prices. Oil prices also influence almost every sphere of economy one way or the other. The oil price has become rationale fluctuation in earning capability of industrial and corporate concerns in an economy. More specifically the escalation in oil prices may cause a decline in earning capabilities of businesses concerns and/or vice verse. Rational evidence supports the stochastic association between stock and oil prices in an economy (Ghorbel & Souissi, 2016; Broadstock et al., 2016).

According to previous literature, there are several macroeconomic variables, which are responsible for the variation of equity returns, and changes in gold, and oil prices. These variations are imperative for investors' point of view. Numerous studies have been carried out to establish the association between gold prices and other economic indicators. According to Khan et al. (2016), Azar (2015), Toraman et al. (2011), Topcu (2010), Ghosh et al. (2004), Tully and Lucey (2005), and Koutsoyiannis (1983) gold is not a local product, therefore, the prices of gold influence the rate of exchange, oil prices, inflation, rate of interest, and equity returns etc. Since the dollar is used for the trade of gold, therefore, prices of gold directly influence the US policies; similarly, crude oil prices also affect the important variables and overall economy of the country. Same as other macroeconomic indicators for instance rate of inflation and interest, oil prices, and gold prices affect the equity returns (Raza et al., 2016; Najaf et al., 2016; Cheung et al., 1998; Gong & Mariano, 1997; Fama, 1981).

Mardini and Ali (2016) and Hu et al. (2016) have studied an association amidst oil prices and equity returns. They have concluded a positive and significant relationship between equity returns, economic growth, interest rate, and oil prices. It is an accepted fact that the financial markets play a cogent role in country's

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sustainable economy. This is also an important to comprehend that the variation in oil prices may cause changes in cost of doing business that indirectly hampers the inflation and interest rate, which further affect the equity returns of the business firms (Yurtkur et al., 2016; Naifar & Dohaiman, 2013; Driesprong et al., 2008; Pollet & Wilson, 2010). Similarly, crude oil is a backbone of the economy of any country. However, oil importing and oil exporting countries display different impacts while the crude oil prices increase or decrease. It is also observed that the variation in crude oil prices affects the rate of exchange, the rate of inflation, interest rates, and the equity returns (Broadstock et al., 2016; Wasseja, 2015; Hardouvelis, 1987). Sadorsky (1999), Nejad et al. (2016), and Levine (2003) have studied the impact of crude oil prices on the equity returns of the financial markets of Japan, the United States, the UK, and Canada. They have concluded a definite relationship between stock returns of these markets and crude oil prices; they established that the oil price is a major determinant for the sustainability of the economy and financial markets.

The objective of the research study

The research study aims to investigate the extent of linkages between crude oil and gold prices changes with the equity returns of KSE100 index. Another important objective of the research paper is to examine the causal association between the variations of crude oil and gold prices, and their impact on the returns of the Pakistan Stock market (KSE100). We have also taken care of gold and oil supply and demand factors and their impact on equity returns in the undertaken study. The analysis presumes to investigate the degree of relationship among gold, crude oil prices and KSE100 returns by utilizing Johansen cointegration, ARCH & GARCH (1,1), and Granger causality techniques. Another imperative point of the undertaken research study is to examine the effect of volatilities of the oil prices and gold prices on the equity returns of KSE100 index.

Significance and novelty of the research

The novelty and significance of the undertaken research study are multifarious. In recent past KSE100 index has witnessed incredible expansion and performance. Such exceptional performance of KSE100 distinguishes the market from its neighboring regional markets; this foundation has multiplied the significance of this study. Hefty developments are also observed in crude oil, and gold prices worldwide in general and Pakistan in particular. This has necessitated re-examining the association amidst equity returns, and crude oil prices and gold prices. The findings of this study will provide valuable investment decision input to the investors of a stock market. Numerous research paradigms are there, which confirmed oil and gold prices are the important variables that influence the equity returns. Hence the findings of this study are anticipated to provide valuable foundations to the stock investors. We have used high frequency (daily) data of the equity prices, and crude oil and gold prices for this research study that is more reliable while investigating an association amongst the economic indicators.

Gold trading markets in Pakistan

In Pakistan, there is a commodity market widely known as Pakistan Mercantile Exchange (PMEX), which further includes trade items of gold and commodities of variant nature. PMEX is actively offering services its target audience using e-sources 24-hours marketing and transactional services. The core commodities traded in the PMEX are crude oil, silver, and gold. There is a number of different contracts related to each commodity. There are eight contracts of gold, namely: mini-gold contracts, 100 gram, gold kilo, 100 *TOLA*, 50 *TOLA*, gold 1 *TOLA*, gold 100 ounces, and gold 1 ounce.

International crude oil prices

The spot prices of several barrels of oil are measured through crude oil prices, either Brent Blend or West Taxes Intermediate. Sometimes NMEX future and OPEC basket prices are also quoted. In Pakistani context, it can be easily observed that the cost of doing business and cost of production both in agriculture and manufacturing process is directly linked to the crude oil prices because of the oil importing country. As the economy of Pakistan mainly draws its substance from agrarian and textile products and the production cost in the identified segments are heavily influenced by the change in the prices of oil and gas. The prices of crude oil segregated according to its grade, which depends on the specific gravity and contents. The major classification is known as the sour crude oil, heavier, and lighter crude oil, etc.

Pakistan Stock Exchange (PSX)

Karachi stock exchange came into existence since September 18, 1947; at that time it was the sole equity market in Pakistan. It was a great milestone for KSE when it was announced one of the best financial markets in the world in 2002. The year 2016 was the great year for KSE when it regained the emerging market status once again. According to the internationally reputed financial magazine, Bloomberg has announced the 3rd best performing equity market for the year 2014 amongst other 10 markets. There was a transformation in Pakistani equity markets, and Pakistan stock exchange has come into existed since January 11, 2016, and other two markets, for instance, LSE and ISE have been merged into KSE and renamed it Pakistan stock exchange (PSX). PSX is regarded as one of the largest equity markets of South Asia. PSX comprises of 654 listed companies with total market capitalization of USD72 billion as of July 2015 and now reached up to USD120.5 billion in 2016 (Pakistan stock exchange, 2016).

The residue of the research paper is composed as: Segment 2 outlines the significant financial literature on the connection between crude oil prices, gold prices, essential economic factors, and capital markets. Segment III defines the empirical framework and estimation techniques. Segment IV consisted of estimations and results of the research study. However, Segment V comprises of discussions and conclusion.

Substantiation from previous literature

The association amidst equity returns and economic indicators is one of the most important subjects for financial experts and researchers around the globe for several decades. The results of previous literature are mixed, for instance in favor of equity returns or the other way around. The debate on the effect of crude oil and gold prices on equity returns is also ongoing. Previous literature regarding the subject matter is rich and diversified, and all the important equity markets observed different effects at distinctive time periods and circumstances.

Literature: Oil prices and Equity prices

Business entities are the leading determinants of the economy if the business organizations perform well then the equity prices of these companies also increase. The organizational financial performance also depends on the crude oil prices; so, in this way, the price of crude oil has an indirect effect on equity prices of a particular firm and sector. According to Clare and Thomas (1994), the crude oil price shocks are major elements for the policy makers of a country. According to Basher and Sadorsky (2006) increase in oil prices increases in the rate of interest, which leads to an increase in inflation and the expense of doing business then eventually equity prices will decrease. Similarly, Park and Ratti (2008) examined fourteen countries and concluded a cogent negative association amidst the prices of crude oil and equity prices except for Norway (it is an oil exporting country). According to Faff and Brailsford (1999), there is a cogent effect of prices of crude oil on equity prices. Lee et al. (2012) had a significant research study on G7 countries and examined the effect of crude oil prices on composite indices. Outcomes of the research study revealed a significant impact of crude oil prices on the equity returns of these stock markets. However, that impact was varied sector-to-sector and country-to-country. The impact of crude oil prices shocks on the equity markets also depends on the nature of a country's position; the impact of oil prices is dissimilar for oil exporting and oil importing countries. The economy, which is the oil exporting country, the effect of oil prices has a cogent positive effect on the equity market; however, in a case of oil imports, the stock returns have a negative effect (Wang et al., 2013). Arouri et al. (2012) have examined the important equity markets of Europe and concluded a significant volatility spillover impact between equity prices and crude oil prices in the case of Europe.

Basher and Sadorsky (2006) have carried out an important study; they examined the impact of crude oil prices and the emerging markets and concluded that the declines in oil prices exerted a significant affirmative effect on equity prices of the emerging markets. Mardini and Ali (2016), Ghorbel and Souissi (2016) and Hu et al. (2016) have concluded the same positive association. According to Gisser and Goodwin (1986), Burbidge and Harrison (1984) and Darby (1982) there is an inverse association amidst crude oil prices and real activity for oil importing economies. Ansar and Asghar (2013) revealed a positive association among CPI, crude oil prices, and KSE100 returns. Abdalla et al. (2012) concluded that the fluctuations in crude oil price led to an increase in equity returns' volatility. Nandha and Faff (2008), Nejad et al. (2016), Miller and Ratti (2009), Broadstock et al. (2016), and Jones and Kaul (1996) also concluded an inverse association amidst crude oil prices and equity prices of emerging and developed stock indices of the world. According to Ramos and Veiga (2010), it is not necessary that decreases in the price of oil have a definite increase in equity prices. Previous research studies for instance Cunado and Perez de Garcia (2005), Bec and Gaye (2016), Kilian (2009), Albulescu et al. (2016), and Hamilton (1983, 2003) have concluded an affirmative and cogent causal association between crude oil prices, and specific economic indicators for instance inflation, GDP and equity returns of developed markets.

Literature: Gold prices and Stock returns

The gold price is also considered another important economic factor that measures the health and sustainability of the economy of a country. There is a common perception that gold price becomes bullish when the outlook of an economy downward and the financial market are found bearish, the policymakers struggle to instigate any exposition and there is uncertainty over future trends (Chen & Faff, 1998; Khan et al., 2016; Arouri et al., 2015; Wang et al., 2010). The other factors contribute to increasing the prices of gold include a weak currency, the increase in inflation rate, and decreases in interest rate in the long run. According to Raza et al. (2016) and Najaf et al. (2016) this a universal fact that gold prices and stock returns have an inverse relation. It is a known fact when gold prices decrease; investors move to equity markets for better returns. On the other hand, when an economy goes down, and equity markets turn towards negative then investors stepping in the metal markets in order to secure their investments (Azar, 2015; Nguyen et al., 2012). The Gold tends to be an asset in a physical form that provides hedging versus exchange rate, the rate of inflation, economic downturns and political uncertainty (Baur & Lucey, 2010; Capie et al., 2005; Mahdavi & Zhou, 1997; Worthington & Pahlavani, 2007). According to Soytas et al. (2009) there is an established correlation and volatility dynamics but associated with risk management hedge, but Coudert et al. (2007) concluded a negative or null affiliation amidst equity returns and gold prices in recessionary periods. According to Hillier et al. (2006), a week relationship existed between equity returns and gold returns that suggest gold prices can deliver divergent profits for equity portfolios. Baur and Lucey (2010) and Tully and Lucey (2005) established a constant time-varying association between gold returns and equity returns.

Wang et al. (2010) have examined the equity returns of stock indices of the China, Japan, the United States, and Germany, and gold prices. They established a long haul association amidst gold prices and equity returns except for the United States; they report the null association existed in the case of the US. According to Shahzadi and Chohan (2011), the relationship amidst equity prices of KSE100, and crude oil and gold prices found negative in case of Pakistan. Similarly, Kaliyamoorthy and Parithi (2012) have concluded a direct association amidst stock returns, and gold returns. Nguyen et al. (2012) investigated the impact of stock prices on the United States, the UK, Singapore, Thailand, Japan, Malaysia, Indonesia, and the Philippines, and the gold prices. They concluded an inverse association amidst the prices of gold and equity returns for most of the considered indices. According to Narang and Singh (2012) causal association amidst equity returns of the Indian markets and gold prices has not been established. According to Pritchard (2010) and Moore (1990) when equity markets decline than the price of gold increases, thus they concluded an inverse relationship between equity returns and gold returns. Lawrence (2003) concluded a weak association amidst equity returns and gold prices. However, that relationship behaves differently in the presence of other macroeconomic variables. Bhunia and Mukhuti (2013) investigated the association between equity returns of BSE and NSE and gold price; they concluded a null causal relationship between gold prices and equity returns. According to Baig et al. (2013), gold prices do not influence the KSE100 returns. Smith (2001) also concluded the same findings in the case of the United States.

Material and methods

Data collection

For this research study, the daily data of gold prices, crude oil prices, and KSE100 index have been acquired for the period from January 1, 2010, to June 30, 2016. For the similar selected time period, the data of prices of crude and gold prices have been downloaded from the Yahoo Finance website, and the data of KSE100 index is taken from the official website of Pakistan stock exchange.

Estimation techniques

The estimation techniques, we used for the undertaken research for instance correlation and descriptive analysis, Augmented Dickey-Fuller unit root test, Multivariate Johansen cointegration, ARCH and GARCH (1,1) econometric models, and Granger causality technique.

Returns of KSE100 index

From the Eq. (1) as follows, it is evident that we have taken the differences of natural log values for the calculation of KSE100 returns:

$$KSE100_{(t)} = \ln\left(C_t / C_{t-1}\right) \quad (1)$$

where: in Eq. (1) the term "KSE100 t" refers for the returns of KSE100 equity prices in "*t*" period of time, though, "*C t*" and "*C t*-1" are represented for the returns of equity prices of KSE100 of current daytime "*t*" and previous day period of time "*t*-1".

Returns of gold prices (GP)

From the Eq. (2) as follows, it is obvious that we have taken the differences of natural log values for the calculation of the returns of gold prices:

$$GP_{(t)} = \ln\left(GP_t / GP_{t-1}\right) \quad (2)$$

where: in Eq. (2) the term "*GP t*" refers for the returns of gold prices in "*t*" period of time, though, "*GP t*", and "*GP t*-1" represented for the returns of gold prices for the current daytime "*t*", and previous day period of time "*t*-1".

Returns of crude oil prices (COP)

From the Eq. (3) as follows, it is apparent that we have taken the differences of natural log values for the calculation of crude oil returns:

$$COP_{(t)} = \ln\left(COP_t / COP_{t-1}\right) \tag{3}$$

where: in Eq. (3) the term "*COP t*" mentions for the returns of crude oil prices in "*t*" period of time, though, "*COP t*", and "*COP t*-1" represented for the returns oil prices for the current daytime "*t*" and previous day period of time "*t*-1".

Augmented Dickey-Fuller testing approach

This is mandatory to transform time series data into stationary series to precede further analysis. Thus, the first objective to examine the unit root in the considered data series, therefore, we employed the Augmented Dickey-Fuller (1979, 1981) unit root test, which is an extensively used method worldwide. The mathematical form of the equation could be expressed as follows:

$$\Delta y_t = \alpha_0 + \alpha_1 y_{t-1} + \sum_{i=1}^{n} \alpha \Delta y_t + e_t \tag{4}$$

where: in Eq. (4) the term 'y_t' represents for data time series in '*t*' time period, whereas, an optimal number of lags known as '*n*', and 'e_t' shows the white noise error in data time series, and the term '*α*' is considered as constant.

Johansen cointegration approach

It is generally; assume that if the affiliation of considered variables is stationary in a linear arrangement, then the taken variables are to be said cointegrated, though, it is not mandatory for a specific individual variable that has to be stationary. It is a possibility of long-haul equilibrium condition for integrating affiliation amongst the variables; however, in a short run, the variables are not dependent on each other. We have employed a time series model like Johansen multivariate cointegration approach to establishing the long haul association amongst the variables (Johansen, 1988, 1991; Johansen & Juselius, 1990). In Eq. (5) we incorporated '*n*' number of variables, which were non-stationary, and considered the VAR method with '*p*' lags. The equation could be written as follows:

$$\Delta y_t = \mu + \Delta_1 y_{t-1} + \ldots\ldots\ldots\ldots + \Delta_p y_{t-p} + \varepsilon_t \tag{5}$$

where: in Eq. (5) the term 'y_t' represented for (n_{x1}) vectors, however, 'ε_t' is known as the white noise error in the data time series. We have assimilated the variables in orders in Eq. (6), and then the mathematical expression could be written as follows:

$$\Delta y_t = \mu + \eta y_{t-1} + \sum_{i=1}^{n-1} \tau_t \Delta y_{t-1} + \varepsilon_t \tag{6}$$

where: in Eq. (6) $\eta = \sum_{i=1}^{p} \mathrm{A}_{i-1}$ and $\tau_t = \sum_{j=i+1}^{p} \mathrm{A}_j$

Johansen (1988, 1991, 1995), and Johansen and Juselius (1990) have developed the time series approach like multivariate Johansen cointegration. Thus, we have employed this approach to single out the values of cointegrating vectors. The aim of the exercise of this time series approach is to identify the two statistical tests, in which first test statistics is regarded as the *λ*-trace; this test statistics examines the void assumptions of considered time series. To investigate if the distinctive number of cointegrating vectors are equivalent to the '*p*' probability with respect to the unrestricted assortment *p* = *r*, thus the mathematical representation could be written as follows:

$$\lambda_{trace}(r) = -T \sum_{i=r+1}^{n} \ln\left(1 - \hat{\lambda}_{r+1}\right) \tag{7}$$

where: in Eq. (7), the term '*T*' represents for operative clarifications numbers, and *λr* + 1 is recognized as the predictable Eigenvalues from the matrix. Though, the Eq. (8) is denoted for Maximum Eigenvalue, and can be expressed as follows:

$$\lambda_{\max}(r, r+1) = -T \ln\left(1 - \hat{\lambda}_{r+1}\right) \tag{8}$$

where: the Eq. (8) examined the invalid suppositions whether there is '*r*' cointegrating vectors in relationship according to the theory of option, which signifies "*r* + 1" cointegrating vectors.

The Granger causality analysis

According to the time series approach, the Granger (1969) causality, it is essential to demonstrate and examine whether one variable can forecast another variable in different data time series. According to Goebel et al. (2003), this causality test is based on multiple linear regression techniques. Several research studies have been carried out on the basis of F-statistics residuals. According to Chen et al. (2009), the authorized trail coefficients can be used in order to execute T-test at group level statistics. MacFarlin et al. (2009) have explained the negative trail coefficients as an inhibitory outcome. Since we consider two data series "*X*" and "*Y*" then a pairwise test could be expressed as follows:

$$Y_t = \sum_{n=1}^{p} A_n X_{(t-p)} + \sum_{n=1}^{p} B_n Y_{(t-p)} + CZ_t + E_t \tag{9}$$

$$X_t = \sum_{n=1}^{p} A'_n Y'_{(t-p)} + \sum_{n=1}^{p} B'_n X'_{(t-p)} + C'Z_t + E'_t \tag{10}$$

where: in Eq. (9) & Eq. (10) '*X*' and '*Y*' denoted for two data series in the "*t*" period of time, if 'X_{t-p}' & 'Y_{t-p}' are known for these two data series for the time period "*t - p*" in "*p*" numbers of lagged time orders. If (A_n) & (A_n') represented for two authorized trailed measurements, and then (B_n) and (B_n') are called autoregression models, in which we take '*Zt*' as covariables at time period '*t*'.

The GARCH model

This method is used to evaluate the model volatility; this model has proposed by Bollerslev (1986) and termed as "Generalized Autoregressive Conditional Heteroskedasticity" or simply GARCH approach. This model is the up gradation of ARCH model. Since the ARCH model has the limitations to take the dynamic pattern in the case of conditional volatility, moreover, ARCH model cannot be used when the constraints are too large. Therefore, in order to avoid these limitations, we can use a GARCH model, in which conditional volatility is to be taken as a one-period future approximation for the variance. The conditional variance is depending on its own past lagged values, the most commonly used form of GARCH is known as the GARCH (1,1) model:

$$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \alpha_2 \sigma_{t-1}^2 \tag{11}$$

The interpretation of the Eq. (11) is that the existing tailored variance σ_t^2 is known as the function of long-term weighted average value, and it depends on α_0, tailored variance during the past first lag (α_0, σ_{t-1}^2), and volatility evidence during the past time (α, ε^2_{t-1}). Moreover, the coefficients should satisfy the condition of $\alpha_0 > 0$, $\alpha > 1$, and $\alpha_2 \geq 0$, in order of $\sigma_t^2 \geq 0$. If add lagged ε_t^2 on both sides of the Eq. (11) and moved σ_t^2 on the right side of the Eq. (11) then GARCH (1,1) could be written as ARMA (1,1) for squared errors:

$$\varepsilon_t^2 = \alpha_0 + \left(\alpha_1 + \beta_1\right)\varepsilon_{t-1}^2 + \left(\nu_t - \beta_1\right)\nu_{t-1} \tag{12}$$

where: in Eq. (12): $\nu_t = \varepsilon_t^2 - \sigma_t^2$

The GARCH (1,1) model is known to be the stationary in variance if the following condition will be met:

$$\alpha_1 + \beta_1 < 1$$

Therefore, in this case, the unconditional variance of 'ε_t' is to be considered a constant and then the expression can be expressed as:

$$\operatorname{var}\left(\varepsilon_t\right) = \frac{\alpha_0}{1-\left(\alpha_1 + \beta_1\right)} \tag{13}$$

where: in Eq. (13) the variance is to be said a non-stationary when the unconditional variance of 'ε_t' is not expressed in the following case:

$$\alpha_1 + \beta_1 \geq 1$$

If the following condition persists then it means there is unit root in the variance, and as integrated GARCH or IGARCH:

$$\alpha_1 + \beta_1 = 1$$

Estimation and results

Descriptive analysis

According to the results of Table 1, it is evident that the average returns of KSE100 are 9.85 % with the volatility of 0.4676, which shows that the risk trade-off is the highest in a case of KSE100 returns. The returns of gold prices are also significant, i.e., 7.21 % with the least volatility of 0.1476. The reason for the low volatility of gold prices is because of the reason that the prices of gold remained stable during that period of time. Results of the Jarque-Bera test showed that data time series does not follow the normality; the probability is less than 0.05 in all the cases, which validate the results of non-normality of the series.

Tab. 1. Descriptive analysis.

Descriptive Statistics	**LGP**	**LKSE100**	**LCOP**
Mean	7.2114	9.8518	4.3482
Median	7.1748	9.8131	4.4842
Maximum	7.5436	10.5656	4.7356
Minimum	6.9573	9.1302	3.2661
Std. Dev.	0.1476	0.4676	0.3315
Skewness	0.3843	-0.0181	-1.2029
Kurtosis	4.9294	4.3950	6.2883
Jarque-Bera	117.02	173.65	395.56
Probability	0.00	0.00	0.00
Observations	1617	1617	1617

Correlation analysis

Table 2 shows the significant negative (-0.558) correlation between stock returns and gold returns in the considered sample period that demonstrated an inverse association amidst KSE100 returns and prices of gold. It is anticipated that if stocks return increase, then gold returns decrease or vice versa. It can be concluded that the investors are very much rationale to the downfall of any market. Thus, they switch their investments from respective markets whenever they experience any downfall in the economy. It is also noted a cogent but negative correlation (-0.564) amidst crude oil prices, and equity prices, which shows a long run business activities felt decline due to the indirect effect of inflation because of oil price increases, and subsequently that also hampers the share values of the companies. Finally, correlation analysis shows a significant positive relation (0.568) amidst crude oil and gold prices as shown in Table 2.

Tab. 2. Correlation analysis.

Variables		**KSE100 index**	**Gold Prices**	**Crude oil Prices**
KSE100 index	Pearson Correlation	1	-.558**	-.564**
	Sig. (2-tailed)		.000	.000
	N	1617	1617	1617
Gold Prices	Pearson Correlation	-.558**	1	.568**
	Sig. (2-tailed)	.000		.000
	N	1617	1617	1617
Crude Oil Prices	Pearson Correlation	-.564**	.568**	1
	Sig. (2-tailed)	.000	.000	
	N	1617	1617	1617

Homoscedasticity Tests (Inferential Statistics)

For inferential analysis and to identify the homoscedasticity in data series, we employed Bartlett's (1937), Levene's and Brown-Forsythe tests. The results of the tests exhibited that considered data series followed the pattern of non-normality. The p-value is less than 0.05 for all three tests. Therefore, it is concluded that there is no homoscedasticity among the variables and data series, and our taken three variables have shown a non-normality pattern as well (Table 3).

Tab. 3. Inferential analysis.

Method	Df		Value	Probability
Bartlett	2		1797.86	0.0000
Levene	(2, 4848)		1503.85	0.0000
Brown-Forsythe	(2, 4848)		1051.00	0.0000
Category Statistics				
Variable	Count	Std. Dev.	Mean Diff.	Median Diff.
LKSE100	1617	0.4676	0.4326	0.4321
LGP	1617	0.1476	0.1267	0.1231
LCOP	1617	0.3315	0.2670	0.2389
All	4851	2.273487	0.275435	0.264704
Bartlett weighted standard deviation: 0.341714				

Stationary and non-stationary graphs

The first column of Figure 1 shows the trends observed by stock returns, gold prices, and oil prices over the time period. This is also evident from the following graphs of Figure 1; the stock returns have inclination trend throughout the time period. On the contrary, the series of gold and crude oil prices observed a positive trend and later turns into a negative trend, which depicted for the presence of unit roots. In order to formally investigate unit roots, we employed unit root test (ADF) in the next section. The left-hand side of Figure 1 exhibited the series are non-stationary at level; however, the second column of Figure 1 displayed a stationary pattern at first difference.

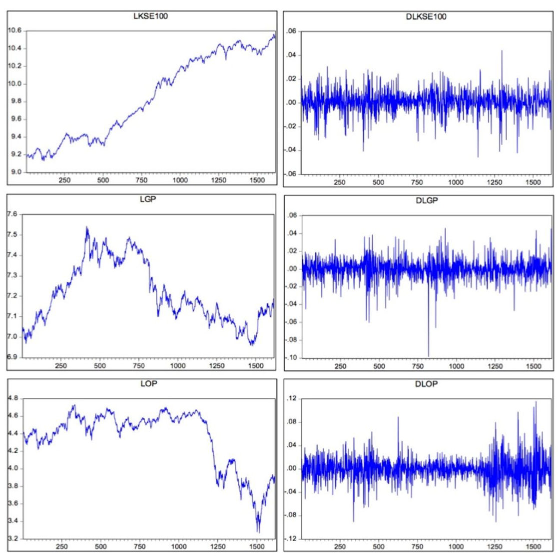

Fig. 1. Stationary and non-stationary Series.

Augmented Dickey-Fuller (ADF) techniques

Outcomes of Table 4 demonstrated that all the data series for instance returns of KSE100, crude oil prices, and gold prices have unit root at level; therefore, we used Augmented Dickey-Fuller approach, and check the unit root. The outcomes of Table 4 exhibited that the data series are non-stationary at the level, however, at first difference data series transformed into stationary form.

Tab. 4. Augmented Dickey-Fuller stationarity test.

Variables	Augmented Dickey-Fuller test statistic				Test critical values		
	At Level		At 1st Difference		1% level	5% level	10% level
	t-Statistic	Prob.*	t-Statistic	Prob.*	t-Statistic	t-Statistic	t-Statistic
LGP	-1.8057	0.3780	-41.2722	0.0000	-3.4318	-2.8621	-2.5671
LCOP	-0.8884	0.7923	-41.7273	0.0000	-3.4318	-2.8621	-2.5671
LKSE100	-0.3841	0.9094	-36.1019	0.0000	-3.4318	-2.8621	-2.5671

**MacKinnon (1996) one-sided p-values.*

VAR Lag Order Selection Criteria

Since we have already investigated the orders of integration or the data series are transformed into stationary for equity returns of KSE100, crude oil, and gold prices. The next step is to identify the appropriate lags length before employing cointegration approach. We employed lag length criteria of selection that follows the Akaike (1973) information criterion (AIC), which demonstrated lags 0 and lags 1 for considered data time series as exhibited in Table 5.

Tab. 5. VAR lag order criteria: DLKSE100 DLGP DLCOP.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	14169.83	NA	0.00	-17.62	-17.61*	-17.61
1	14188.61	37.47	4.41e-12*	-17.63260*	-17.59	-17.61769*
2	14194.12	10.98	0.00	-17.63	-17.56	-17.60
3	14203.95	19.52	0.00	-17.63	-17.53	-17.59
4	14211.04	14.07	0.00	-17.63	-17.50	-17.58
5	14222.09	21.89*	0.00	-17.63	-17.47	-17.57
6	14226.45	8.61	0.00	-17.62	-17.43	-17.55
7	14234.70	16.28	0.00	-17.62	-17.40	-17.54
8	14238.64	7.76	0.00	-17.62	-17.37	-17.52

** denotes lag order selection criterion*
AIC: Akaike information criterion

Multivariate Johansen cointegration for LKSE100, LGP, and LCOP

Since ADF test demonstrated that the KSE100 returns, crude oil and gold prices data series are stationary at first difference. Thus, the Johansen multivariate cointegration technique could be employed. In order to find a lag length of LKSE100, LCOP, and LGP, we used the Akaike information criteria to determine the appropriate lags, i.e. 0 and 1 as identified in the previous section. Outcomes of Table 6 demonstrated that there is no evidence of cointegrating vectors amongst the data series; hence, we have established that there is no long haul association amidst equity returns of KSE100 and crude oil and gold prices in the considered time period. This conclusion further substantiated by the values of trace and maximum Eigen tests because of both trace statistics and Max-Eigen statistics < Critical value, and corresponding probabilities are also higher than 0.05.

Tab. 6. Cointegration test for LKSE100, LCOP & LGP.

Unrestricted Cointegration Rank Test (Trace)				
Hypothesized		**Trace**	**0.05**	
No. Of CE(s)	**Eigenvalue**	**Statistic**	**Critical Value**	**Prob.****
None*	0.0065	17.0387	29.7971	0.6372
At most 1	0.0036	6.5059	15.4947	0.6357
At most 2	0.0004	0.6932	3.8415	0.4051
Unrestricted Cointegration Rank Test (Maximum Eigenvalue)				
Hypothesized		**Max-Eigen**	**0.05**	
No. Of CE(s)	**Eigenvalue**	**Statistic**	**Critical Value**	**Prob.****
None*	0.0065	10.5328	21.1316	0.6936
At most 1	0.0036	5.8127	14.2646	0.6374
At most 2	0.0004	0.6932	3.8415	0.4051

Max & Trace tests show no traces of cointegration vector at 0.05 levels
** Indicates rejection of the null hypothesis at 0.05 level*
*** MacKinnon-Haug-Mitchelis (1999)-p-value*

Granger causality test results

For the identification of causality and direction between the pair of variables, we employed the pairwise test of Granger causality. We have selected Lag 1 and lag 2 to know the better understanding of the causality. The results of Table 7 exhibited the unidirectional causality between DLKSE100 and DLCOP from crude oil prices to KSE100 index in lag 1 and Lag 2 at 5% level. However, unidirectional causality existed between DLKSE100 and DLCOP does not mean to carry change in other variables. Basically, in time series causality is unavoidable for the drive of variables (Awe, 2012).

Tab. 7. Results of Pairwise Granger Causality

Lags: 1			
Null Hypothesis:	**Obs.**	**F-Statistic**	**Prob.**
DLGP does not Granger cause DLKSE100	1615	0.9415	0.3320
DLKSE100 does not Granger cause DLGP		0.1797	0.6717
DLOP does not Granger cause DLKSE100	1615	13.3069	0.0003
DLKSE100 does not Granger cause DLCOP		0.4700	0.4931
DLOP does not Granger cause DLGP	1615	0.0479	0.8268
DLGP does not Granger cause DLCOP		0.0069	0.9340

Lags: 2			
Null Hypothesis:	**Obs.**	**F-Statistic**	**Prob.**
DLGP does not Granger cause DLKSE100	1614	1.1386	0.3205
DLKSE100 does not Granger cause DLGP		0.0666	0.9355
DLOP does not Granger cause DLKSE100	1614	7.1274	0.0008
DLKSE100 does not Granger cause DLCOP		0.1920	0.8254
DLOP does not Granger cause DLGP	1614	0.2012	0.8178
DLGP does not Granger cause DLCOP		2.3859	0.0923

Conditional Volatilities

Figure 2 exhibited that both patterns of time series confirmed the volatility-grouping occurrence, which indicates that significant variation leads to other massive changes, and small variations tend to follow minor variations. This hallmark indicates the possible spillover effects in returns and volatility among the stock returns, oil prices changes, and changes in gold prices. Hence, in this situation, GARCH type models are the preferred choice of methodology for these kinds of data time series (Francq & Zakoïan, 2010). Therefore, it is observed from Figure 2 both series behave like the same ways suggesting GARCH (1,1) instead of a higher order of ARCH in all three series.

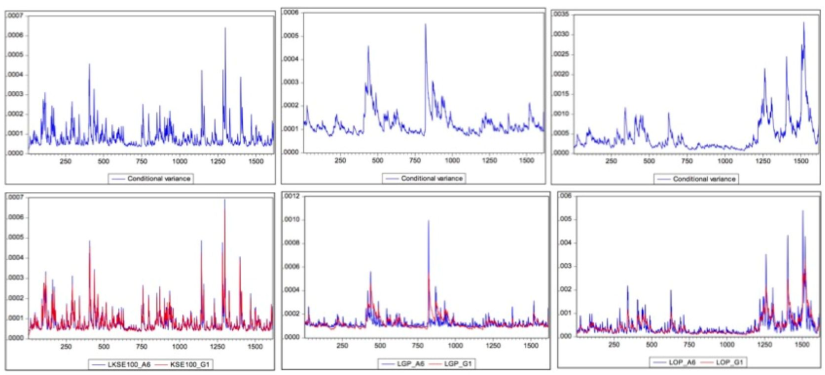

Fig. 2. Conditional Volatilities in both series

Testing for Heteroscedasticity in residual (ARCH-LM test)

Conditional heteroscedasticity in residual is the pre-condition for using the GARCH (1,1) model. Therefore, we employed ARCH-LM test to check the conditional heteroscedasticity in residuals. Engle (1982) has developed ARCH-LM test; according to the results of Table 8, there are no traces of heteroscedasticity in residuals for all the time series ($F>4$ & $p<0.05$). It is further demonstrated from the results that there is significant evidence of ARCH effects for all time series at lags 3 and lags 6. This suggested that the GARCH type model is the preferred choice in order to investigate the spillover of the volatility amidst equity returns, and gold and crude oil prices.

Tab. 8. Testing for Heteroscedasticity (ARCH-LM test.

LKSE100 Series (for Lag 3 & Lag 6)			
F-statistic	11.89494	Prob. F(3,1608)	0.0000
Obs*R-squared	34.99694	Prob. Chi-Square (3)	0.0000
F-statistic	7.966101	Prob. F(6,1602)	0.0000
Obs*R-squared	46.61468	Prob. Chi-Square (6)	0.0000
LGP Series (for Lag 3 & Lag 6)			
F-statistic	11.558174	Prob. F(3,1608)	0.0198
Obs*R-squared	34.672568	Prob. Chi-Square (3)	0.0074
F-statistic	10.908028	Prob. F(6,1602)	0.0062
Obs*R-squared	11.4166	Prob. Chi-Square (6)	0.0263
LCOP Series (for Lag 3 & Lag 6)			
F-statistic	30.27119	Prob. F(3,1608)	0.0000
Obs*R-squared	86.17277	Prob. Chi-Square (3)	0.0000
F-statistic	17.65408	Prob. F(6,1602)	0.0000
Obs*R-squared	99.78922	Prob. Chi-Square (6)	0.0000

Testing for Heteroscedasticity in residuals (White Test)

White (1980) test is the next step to validate the heteroscedasticity in residuals; according to the results of Table 9, there are no traces of heteroscedasticity in residuals because probabilities are less than 0.05. According to the results, it is indicated that ARCH is not present at lag 1; however, presented at lags 3 and lags 6 suggesting GARCH (1,1) is an appropriate model for LKSE100, LGP, and LCOP series.

Tab. 9. White Test-Dependent variable: WGT_RESID^2.

LKSE100 Series (for Lag 3 & Lag 6)				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
WGT_RESID^2(-3)	0.0830	0.0249	3.3358	0.0009
WGT_RESID^2(-6)	0.0647	0.0251	2.5808	0.0099
LGP Series (for Lag 3 & Lag 6)				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
WGT_RESID^2(-3)	0.0275	0.0247	2.1035	0.0270
WGT_RESID^2(-6)	0.0387	0.0253	2.5274	0.0127
LCOP Series (for Lag 3 & Lag 6)				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
WGT_RESID^2(-3)	0.1641	0.0246	6.6703	0.0000
WGT_RESID^2(-6)	0.0798	0.0252	3.1676	0.0016

The GARCH (1,1) Analysis

The GARCH (1,1) test has been applied after checking for heteroskedasticity. Table 10 exhibits the results of GARCH (1,1) approach in terms of variance and means equations, in which we used a maximum likelihood technique. Table 10 showed the different diagnostic parameters, the results of mean equation depicted that DLCOP influences the stock to mean returns ($p < 0.05$), however, there is no influence of DLGP on the returns of equities as exhibited by the Panel A in Table 10. Results of the ARCH and GARCH evaluate the conditional variances of macroeconomic variables such as gold price, and oil price. An outcome of the GARCH (1,1) approach shows the influence of equity returns' shocks on prevailing volatility die out with the passage of time. The coefficients α and β established a short run dynamics of the subsequent volatility data series.

Outcomes of Panel-B in Table 10 showed that three parameters of the variance equation namely the intercept (C), the squared returns of the first lag ARCH (α). However, the GARCH (β) is referred for the first lag of conditional variance. Both coefficient ARCH (α) and GARCH (β) are affirmative that indicate a lag of squared returns and lagged conditional variance exerted a cogent effect on conditional variance. It is further established that ARCH and GARCH effects have significant positive effects on stock returns. However, both ARCH and GARCH effects have evidence of volatility on KSE100 returns; this elaborates that there is a volatility grouping in Pakistan stock exchange. The positive values of ARCH and GARCH effects are in line with the previous literature (Engle, 1982; Bollerslev, 1986).

Tab. 10. Results of the GARCH (1,1) approach.

The Panel A: the mean equation				
Variable	**Coefficient**	**Std. Error**	**Z-Statistic**	**Prob.**
C	0.1690	0.1095	1.7159	0.2101
DLGP	0.0559	0.0592	2.5438	0.0156
DLCOP	0.1563	0.0277	5.6393	0.0000
The Panel B: the variance equation				
C	0.0000	0.0000	3.0695	0.0021
ARCH (α)	0.0847	0.0111	7.6058	0.0000
GARCH (β)	0.9092	0.0114	80.0741	0.0000
R-squared	0.0008	Mean dependent var.		-0.0003
Adjusted R-squared	0.0002	S.D. dependent var.		0.0211
S.E. of regression	0.0211	Akaike info criterion		-5.1621
Sum squared resid	0.7164	Schwarz criterion		-5.1454
Log-likelihood	4173.40	Hannan-Quinn criter.		-5.1559
Durbin-Watson stat	2.05	$\alpha + \beta < 1$		0.9938

Results of Table 10 also exhibited the long-term perseverance because the summation of parameters ARCH (α), and GARCH (β) is lower than one that indicates a long memory process. It is further observed from the sum of coefficients ($\alpha + \beta < 1$) that demonstrated an unconditional variance is stationary, and there is a mean-reverting variance process. A high value of $\alpha + \beta$, thus, it implies a 'long memory', which is again a property of the return series used in this study as the value of $\alpha + \beta$ in the GARCH estimation is very close to one (Walter, 2014; Carter et al., 2008). Since the coefficient α is significantly lower than the β coefficient that demonstrates that past volatility affects the volatility of KSE100 index and large β demonstrates that the shocks of volatility to the conditional variance take a longer period to die out.

Discussion

The undertaken research study examines the relationships amidst KSE100 equity returns and variation in oil and gold prices. The descriptive analysis showed significant stock returns with high volatility. Correlation analysis showed a significant negative relationship between equity returns, and crude oil and gold prices. The results of our study are very much consistent with the outcomes of previous literature such as (Azar, 2015; Nguyen et al., 2012; Shahzadi & Chohan, 2011; Pritchard, 2010; Moore, 1990; Sadorsky, 2004). Outcomes of Johansen multivariate cointegration approach exhibited no long haul association amidst equity returns of KSE100, and crude oil and gold prices. Similarly, previous studies also concluded the same results ((Raza et al., 2016; Najaf et al., 2016; Nguyen et al., 2012; Pritchard, 2010; Baur & Lucey, 2010). Results of Granger causality indicated a unidirectional causality from crude oil prices to equity returns in Lags 1 and 2. These results are also inclined with previous literature (Bhunia & Mukhuti, 2013; Kaliyamoorthy & Parithi, 2012). The results of GATCH (1,1) estimates showed that crude prices affect the volatility of stock returns of KSE100 index. Hence, GARCH (1,1) results are also in line with the previous literature such as (Raza et al., 2016; Khan et al., 2016; Najaf et al., 2016; Toraman et al., 2011; Topcu, 2010; Ghosh et al., 2004).

Conclusion

The correlation showed an inverse association between equity prices and gold prices, this confirmed the postulates if stocks return increase then gold returns decrease or vice versa. It can be concluded that the investors are very much rationale to the downfall of any market. Thus they switch their investments from respective markets whenever they experience any downfall. It is also concluded a cogent but negative correlation amidst equity returns and oil prices, which explains the long run business activities experienced a decline due to the indirect effect of inflation because of oil price increases, and subsequently, that also hampers the share values of the companies. The returns of the KSE100 index are significantly higher but with higher volatility as compared to the gold returns. It is further concluded from the results of this research that there is a short-run association between equity returns, and oil and crude prices, but did not conclude any long-haul relationship amongst the variables. It is also concluded that the unidirectional causality existed between equity prices and oil prices, the direction of this causality is from oil prices to equity returns in lags 1 and 2. The GARCH (1,1) also confirmed the Granger causality results and demonstrated that there is a cogent and positive impact of oil prices on equity returns of KSE100. Hence, it is finally concluded that because of an oil importing country, the oil prices have a significant impact on equity prices of KSE100 index and long-haul sustainability on the Pakistani economy.

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