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Underground Storage of Natural Gas and its Economic Aspects

Erika Liptáková[1] ● Jozef Janko[1]

[1]*Department of Applied Mathematics and Business Informatics, Faculty of Economics, Technical University of Košice, Letná 9, Slovakia,*
erika.liptakova@tuke.sk

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Abstract: After oil and coal, natural gas is the third source of energy for the world economy and is widely used. Stable natural gas supplies continue to rely primarily on underground storage. The aim of this paper is to provide a basic quantitative analysis and basic economic view on the three most common methods of underground storage of natural gas, namely in depleted oil and gas fields, in aquifers and in salt caverns. The analysis focused on the capacity utilization of the selected storage types as well as on the calculation of the cash-flow and internal rate of return of the projects. Based on the results obtained, we can conclude that underground reservoirs created from aquifers are the most costly. The most lucrative variant are reservoirs created from depleted gas and oil fields, as the initial investment is the lowest compared to the other types. For fluctuations in consumption, reservoirs created from salt caverns are the most important, as they have the characteristic of a short delivery time and can react the fastest to market fluctuations.

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1 Introduction

In the 21st century, the use of various energy commodities has become an integral part of our lives. A huge number of products offered on the world's diverse markets exist thanks to energy commodities. We can include natural gas in this group. How natural gas is extracted, transported or stored is not a major concern for the end consumer. He is only interested in end consumption in order to be able to meet his needs.

As with other energy commodities, there is a certain type of hierarchical and necessary process for natural gas to be able to meet the consumer's needs. An important part of the handling of natural gas is its storage, which can be done through underground storage tanks.

The objective of this paper is to provide a basic quantitative analysis of three types of underground natural gas storage, namely, storage created from depleted oil and gas fields, storage from aquifers, and storage from salt caverns. The analysis will cover the capacity utilisation of each type of reservoir as well as an economic analysis of the internal rate of return of the projects for these types of reservoirs.

2 Underground storage of natural gas

Gas storage can compensate for seasonal fluctuations in gas demand by injecting gas into storage during the period when gas demand is lowest (summer) and storing it for withdrawal during the period when gas demand is highest (winter). Many storage facilities are also used to smooth short-term fluctuations in gas supply and demand. These variations can be intra-day, day-to-day or week-to-week, etc. Some facilities supply or withdraw gas at very short notice to balance the actual supply and demand requirements of their customers and to help maintain the integrity of the gas network.

Different types of storage facilities provide flexibility, with the distinction between medium and long term storage being particularly obvious. Each type provides a balanced portfolio of storage volumes capable of responding to different short and medium term seasonal system requirements. Mid-range storage allows for greater injection and withdrawal. Such facilities provide greater flexibility and a high degree of variation and are often operated in a different manner than long-term storage facilities [1].

The initial investment in underground storage is enormous. Costs are in the tens of millions of dollars and sometimes in the hundreds of millions of dollars.

Therefore, these investment costs need to be well managed in order to achieve the lowest annual cost over a long period of time. As with many other types of projects, the minimum investment may not always translate into minimum annual costs. The extent of flexibility to achieve optimal economic conditions will vary for underground storage tanks. It may sometimes be the case that the storage requirements and constraints of the chosen type of storage tank will be limited. In that case there will be little room for economic manoeuvre [2].

2.1 Types of underground storage

Stable natural gas supplies depend primarily on underground storage facilities. These help to offset seasonal fluctuations in demand and protect against gas supply disruptions. There are three types of underground gas storage facilities: [3]

- depleted natural gas fields,
- aquifer reservoirs,
- salt cavern reservoirs.

The first two store gas in natural porous layers (i.e. inside pore spaces in the rock). These storage facilities tend to have large amounts of storage capacity but relatively low gas injection and pumping rates. They are therefore suitable for seasonal gas storage.

Salt caverns tend to have relatively small amounts of storage capacity but high injection or pumping rates. They are therefore suitable for storage for peak loads or as trading tools for short-term arbitrage due to changes in weather or changes in demand (e.g. weekend demand versus weekday demand).

These storage tanks have several advantages, the main ones being the length of time they are able to store natural gas. In many cases, they are capable of storing it theoretically for up to millions of years.

In the following section, we describe the basic types of underground gas storage.

2.1.1 Storage in depleted gas and oil fields

Most of the underground storage is built from depleted gas fields. This is because of their proven ability to hold gas for long periods of time and also because of the usual presence of a large number of wells.

The behaviour of these areas is also known from the long history of exploitation. However, this does not necessarily mean that any gas or oil field that has been exploited in the past is suitable for underground storage. The main considerations regarding the suitability of a depleted gas field for conversion to underground storage are [1]:

- containment,
- size,
- reservoir characteristics,
- productivity and injectivity,
- water-bearing capacity,
- condensed original gas content,
- distance to existing infrastructure and market.

2.1.2 Storage in aquifers

An aquifer is a porous reservoir filled with water. By injecting gas into this type of reservoir, it can be converted into an underground gas storage tank. Once commissioned, the behaviour and operation of the plant is similar to that of gas storage tanks.

With this type of storage, there is more uncertainty as to the ability of the tank to contain the gas. In the case of aquifers, it is necessary to re-establish a protective layer that will provide the necessary properties for proper and efficient underground storage. Among other things, this requires special core analysis of field tests coupled with gas injection tests into the reservoir. The maximum pressure in many gas tanks is often limited to the original tank pressure. However, in the aquifer, the pressure must be higher than the original pressure in order to be able to inject any gas. In addition, there is often a lack of knowledge of reservoir characteristics and an adequate model due to the lack of existing wells and production history. All of this means that the lead time to create an underground storage reservoir in aquifers is longer than for depleted gas fields and that the initial cost is usually higher as well. [1]

2.1.3 Storage in salt caverns

The use of salt caverns as underground gas storage facilities depends on the presence of vast underground salt reserves at accessible depths. Large cavities can form in rock salt, which is only a few hundred metres below the earth's surface, to store gas and can be easily pumped out of boreholes.

There are a number of criteria that need to be considered to make a salt cave suitable for gas storage. These criteria include mainly [4]:

- sufficient size, volume;
- short- and long-term structural stability;
- limited volume reduction (wall convergence due to salt flow);
- safe storage of the stored material (no loss of gas).

3 Quantitative analysis of natural gas storage

For the purpose of the analysis, three types of reservoirs were selected in the USA, namely in the states of California, Illinois and Texas. These states contain reservoirs developed in gas and oil fields, aquifers and salt caverns. The analysis was carried out using data from 2010-2019, but it is important to note that underground reservoirs were already developed prior to this period, and it is now likely that the initial capital investment has been paid off and the projects are profitable.

A number of factors were taken into account in developing the analysis, namely:

- CAPEX – capital expenditures,
- OPEX – operating expenditures,
    - gas injection and pumping costs
    - gas storage costs
- Total gas capacity
- Base gas – the amount of gas required to be maintained in storage to maintain the efficiency of the deliverability of the reservoir,
- Working gas – the amount of gas that can be handled, traded,
- Injections – the amount of gas injected into the storage tanks,
- Withdrawals – the amount of gas withdrawn from storage,
- Price – the price of natural gas over the period 2010-2019,
- Storage type – depleted gas and oil fields, aquifers, salt caverns [5].

All calculations and graphical representations were created using MS Excel.

3.1 Characteristics of different types of underground gas storage

In the beginning of the quantitative analysis we will focus on the capacity characteristics of the reservoirs, namely:

- Total gas capacity;
- Base gas;
- Working gas;
- Working and base gas.

The data for the years 2010-2019 will be displayed graphically using a line chart, which will be complemented by a trend line of storage capacity utilisation.

3.1.1 Capacity utilization in depleted gas and oil fields

Data on underground reservoirs created from depleted gas and oil fields in the State of California were used for the analysis. Figure 1 shows the amount of storage capacity in the State of California from 2010-2019. Underground storage tanks created from depleted gas and oil fields are located in this area. They are known to be able to capture residual gas on their territory, thus reducing initial costs.

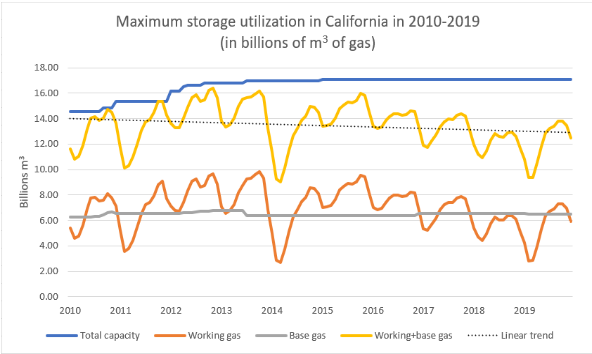

Figure 1: Maximum storage utilization in California in 2010-2019 (billions m^3 gas)
Source: Own calculations and processing according to [5]

The capacity of these underground reservoirs was expanded several times during the observation period. During the period under observation, the underground gas reservoirs created in depleted gas and oil fields needed approximately 40% of their total capacity to store the base gas necessary to maintain efficiency in pumping and injection. The remaining 60 % serves as storage capacity for working gas.

During the period under observation, the total amount of working gas and base gas combined has been gradually decreasing. The decreasing linear trend (dotted line) indicates a gradual reduction in the use of these storage tanks.

Even though the total storage capacity of the reservoirs has been expanding over the years, the amount of working gas in the reservoirs has been decreasing. This may be indicative of a number of factors, e.g. there may have been a shortage of gas on the market, or gas prices may have been high, or it may have depended on the weather. In any case, the analysed storage facilities did not use their full gas storage potential in the period under observation.

3.1.2 Capacity utilization in aquifers

We will describe the storage of natural gas in underground aquifers using the example of reservoirs in Illinois. Figure 2 captures the maximum storage capacity utilization from 2010-2019. We can observe the effect of seasonality – in the summer periods, working and base gas storage combined approached close to the maximum possible storage capacity and, conversely, in the winter periods, the working gas level in the reservoirs declined.

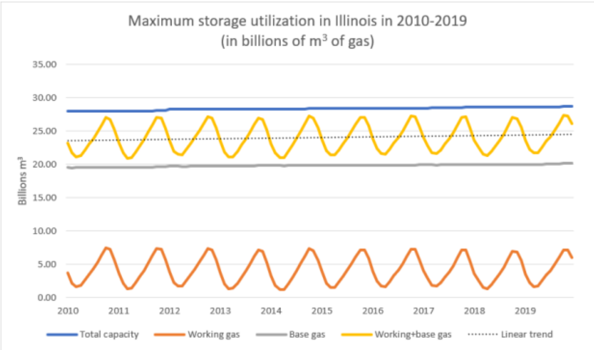

Figure 2: Maximum storage utilization in Illinois in 2010-2019 (billions m^3 gas)
Source: Own calculations and processing according to [5]

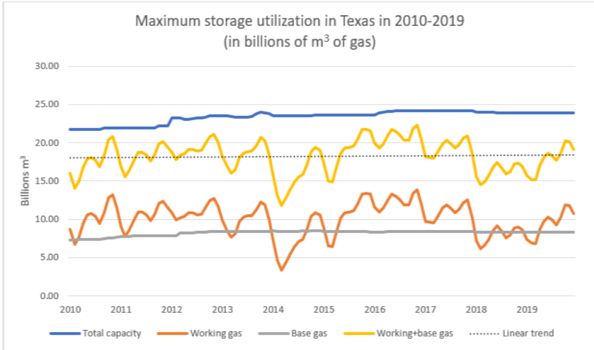

Figure 3: Maximum storage utilization in Texas in 2010-2019 (billions m^3 gas)
Source: Own calculations and processing according to [5]

We can note that reservoirs formed from aquifers need huge amounts of base gas to maintain reservoir efficiency. Almost 70 % of the reservoirs have to be made up of base gas in order to maintain the efficiency of these reservoirs as high as possible. This suggests that only around 30 % of the storage capacity can be working gas that has a real use for the population.

Figure 2 also shows a very slightly increasing linear trend in capacity utilisation (dotted line), which indicates a slight increase in working and base gas in storage, which is probably driven by the increase in total storage capacity over the observed period.

3.1.3 Capacity utilization in salt caverns

We selected underground natural gas reservoirs located in salt caverns in the state of Texas to illustrate the natural gas reservoirs located in salt caverns during the period 2010-2019. This type of reservoir stands out for its flexibility and allows for multiple injections and withdrawals of gas throughout the year. We can see this fact in the graph in Figure 3, where we can notice that the seasonality is not as pronounced as in the case of reservoirs created from aquifers. Although several bottoms are recorded at the turn of the observed years, and thus in the winter periods, similar situations can be seen during the summer periods of each year. Of course, these values do not reach such low numbers as in the colder months, but some activity is also observed during the summer periods.

The underground reservoirs we have observed, formed from salt caverns, need approximately 35% of the total capacity to store the base gas (see Figure 3). The remaining 65% is available for working gas storage. Thus, we can see that over the observed period there was still some margin and potential to store more working gas in the reservoirs.

Figure 3 also shows a very slightly increasing linear trend in the volumetric use of reservoir capacity in salt caves (dotted line). The trend shows a minimal increase over the observed period.

3.2 Analysis of the cash-flow and internal rate of return on investments in different types of underground gas storage facilities

Underground natural gas storage facilities are very costly projects that are expected to return on investment rather in the long term. As the initial costs are extremely high, it is not possible to assume a return on investment in the short or medium term. There are several ways of valuing these investments.

In our article, we calculate both the cash-flow and the internal rate of return of the projects for the construction and operation of the three types of underground natural gas storage mentioned above. The analyzed reservoirs were already built before the observation period 2010-2019, and most likely for some of them the initial costs are already paid off and some of them may even be moderately profitable at present.

IRR (internal rate of return) is a metric used in financial analysis to estimate the profitability of potential investments. IRR is a discount rate that makes the net present value (NPV) of all cash flows equal to zero in a discounted cash flow analysis. Generally speaking, the higher an internal rate of return, the more desirable an investment is to undertake.

The formula and calculation used to determine this figure are as follows [6]:

$$0 = NPV = \sum_{t=1}^{T} \frac{C_t}{(1 + IRR)^t} - C_0$$

where:
C_t – net cash inflow during the period t
C_0 – total initial investment costs
IRR – the internal rate of return
T – the number of time periods

The term cash flow refers to the net amount of cash and cash equivalents being transferred in and out of a company. A company's ability to create value for shareholders is fundamentally determined by its ability to generate positive cash flows [7].

When calculating the initial investment, we took into account: the type of storage tank, the total storage capacity in 2010 and the approximate valuation of the storage tank type.

The variables used in the cash-flow calculations are: total storage capacity, working gas volume, pumping volume, injection volume and gas price. All values have been converted to the relevant month from 2010 to 2019.

Costs and revenues are calculated as follows:

1. Revenue
   - Pumping volume × gas price
2. Costs
   - Total reservoir capacity × reservoir construction costs (depleted gas and oil fields);
   - Reservoir injection × injection rate;
   - Drawdown from reservoir × drawdown rate;
   - Storage in the reservoir × storage rate;
   - Expansion of total capacity × cost of reservoir expansion.

Figure 4 shows the cash flow of underground reservoirs in California, that is, reservoirs created from depleted gas and oil fields over the observation period 2010-2019.

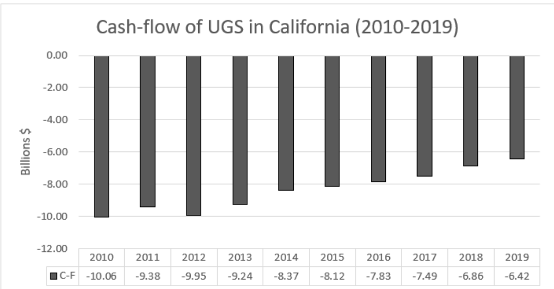

Figure 41: Cash-flow of UGS in California (2010-2019)
Source: Own calculations and processing according to [5]

Over the years, a gradual repayment of the initial costs of the underground storage tank construction is observable. With the exception of 2012, when up to three reservoir expansions took place, which significantly increased the costs in that year, the values have gradually approached the 0 mark. This threshold is indicative of the point at which the completed project enters the positive numbers, and therefore the initial investment is paid off and the reservoirs begin to generate a profit for the company.

The initial investment did not reach positive numbers during the observation period 2010-2019. However, it is likely that if we had chosen a longer time period, the project might already be in positive numbers.

We have also calculated the internal rate of return (IRR) on investment (ROI) in the project. For comparability, we expressed the IRR after five and ten years in the period:

- IRR after 5 years: -33.51 %
- IRR after 10 years: -13.80 %

The calculated values indicate that the project is not profitable. However, when calculating the value after ten years, we arrive at a value significantly closer to positive figures, which means that the project can move into positive figures in the next few years.

The construction and development of underground reservoirs in aquifer areas is more costly than in the case of depleted gas and oil fields and salt caverns. At the same time, this type of storage also has the longest development time, making it the least lucrative investment. Consequently, the high initial investment is also reflected in the payback period of underground gas storage projects.

Figure 5 shows the cash flow of underground storage projects in Illinois. In this case, the reservoirs were aquifers. The time period captured is 2010-2019.

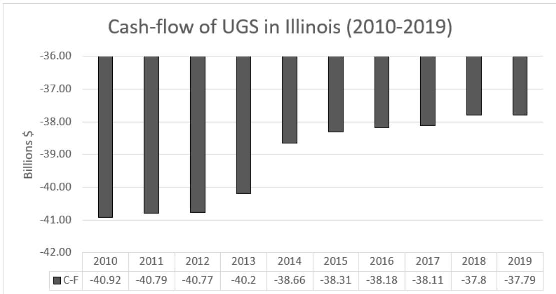

Figure 5: Cash-flow of UGS in Illinois (2010-2019)
Source: Own calculations and processing according to [5]

Underground gas storage formed from aquifers have the highest initial costs for both construction and capacity expansion. A large number of procedures and findings have to be carried out prior to actual construction. As can be seen in Figure 5, even after ten years, the initial investment has not been recouped and thus does not show a profit from this perspective. Over the years, the total capacity has expanded only marginally and therefore this has not been reflected in the year-on-year increase in debt.

For comparability, we have expressed the internal rate of return (IRR) after five and ten years over the period:

- IRR after 5 years: -43.23 %
- IRR after 10 years: -27.97 %

The values obtained speak to the fact that the project is not profitable. Even with a longer period, which for us was 10 years, the project is still far from being profitable for the companies. It is possible that if we were to consider a period twice as long, i.e. 20 years, perhaps the project would start to show a profit.

The cash-flow of underground gas storages created from salt caverns in the state of Texas is shown in Figure 6. We can observe that the project is still in negative numbers after ten years. However, it is important to point out that underground reservoirs created from salt caverns can inject and pump gas several times a year, which can generate more cash-flow in less time. Even though this project is still in negative numbers in the observation period, the difference between 2010 and 2019 is significant.

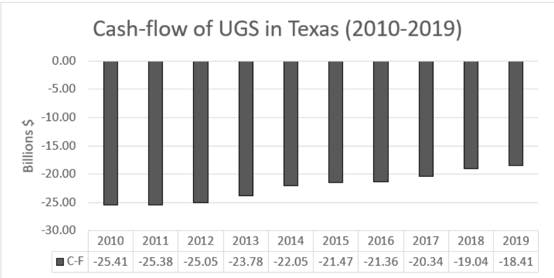

Figure 6: Cash-flow of UGS in Texas (2010-2019)
Source: Own calculations and processing according to [5]

Again, we have expressed the internal rate of return as in the previous cases, after five and ten years:

- IRR after 5 years: -35.78 %
- IRR after 10 years: -16.86 %

The values obtained show that the project is not profitable even after ten years. Just as in the shorter period, for us 5 years, so also in the longer period - 10 years, the underground reservoirs created from the salt caves do not show a profit. However, the flexibility of a higher number of injections and drawdowns over the course of a year can provide a faster return on investment.

Financially, these projects are more challenging than depleted gas and oil fields. The initial investment is very high, but the ability to inject and pump at shorter intervals leads to high annual gas turnover, which significantly reduces operating costs.

4 Discussion

From our analyses, we can say that the least costly and most geologically accessible and preferred form of underground natural gas storage are reservoirs created from depleted gas and oil fields. This form of storage is preferred by most of the world's leading natural gas producers. Initial costs are lower due to the proven ability to hold gas in the long term and the presence of a large number of existing wells. The projects are also financially relieved from exploration of the areas concerned. The suitability of these areas as storage areas is already known from history and so they do not need to be investigated in as much detail as other types of underground storage. The presence of natural gas that has never been extracted from these areas is one of the last advantages. In this case, this gas can act as a base gas, which is essential to maintain the efficiency of underground storage tanks for injection and pumping. In this way, savings can also be made in the injection of gas into the reservoirs, as only a fractional amount of gas needs to be injected.

Underground reservoirs created from depleted gas and oil fields need about 40% of the total capacity to store the base gas. Considering this hypothesis, this leaves roughly 60 % of the capacity to store working gas. This gas is injected into this type of reservoir during warm periods when the gas is not needed as much and pumped out during winter periods. This type of reservoir is suitable for long-term storage with a low deliverability rate when needed.

Although storage facilities in the State of California underwent an increase in their volumetric capacity during the 2010-2019 study period, we found a slight downward trend in the total amount of working and base gas. This speaks to the fact that utilization of these reservoirs has been slowly decreasing over the years and the reservoirs are not utilizing their full storage potential. For underground reservoirs created from depleted gas and oil fields, the return on initial investment appears to be the most acceptable option. Although the internal rate of return on initial investment did not translate into positive figures in the period under observation, the year-on-year change was observable and moved significantly closer to positive values.

The most financially expensive type of underground natural gas storage is aquifer storage. The initial investment is high because of the necessary tests that must be carried out before construction can begin. The characteristics of the terrain for gas storage must be reassessed. For this type of reservoirs, there are not enough wells existing from the past and the properties of these areas are not known as in the case of depleted gas and oil fields. These facts prolong the actual construction of underground storage tanks of this type and also push the initial costs into higher figures.

From our observation, we have concluded that underground reservoirs created from aquifers need large amounts of base gas. For the sustainability of injection and pumping efficiency, the base gas in reservoirs needs to account for up to 70 % of the total capacity. This finding detracts from the added value of this type of storage. For working gas, which can be realistically handled, only about 30 % of the total storage capacity remains.

Gas is injected into this type of storage during warm periods and pumped out during winter periods when market demand is highest. It is therefore a seasonal type of storage with a long deliverability period. The capacity of observed aquifer-derived storage in Illinois has varied minimally over the years. During warm periods when gas was injected into the reservoirs, the underground reservoirs reached near maximum capacity. The very slightly increasing linear trend shown shows that base and working gas are approaching maximum possible volume over time during the summer periods, thus using the reservoirs to near their full potential. Also for this type of reservoir we have expressed an internal rate of return on the initial investment. This was still in the very high negative figures after the observation period. The very high initial investment as well as the limited amount of working gas storage at the expense of the high base gas demand play the most important role. From our observation we can therefore conclude that this is the least economic form of gas storage.

Underground reservoirs created from salt caverns appear to be the most economically acceptable option for underground natural gas storage. The initial development costs are very high, as a lot of money needs to be spent on infrastructure development and modification of the underground space to exhibit the necessary characteristics to develop an underground storage facility.

After conducting an analysis on underground storage developed from salt caverns in the state of Texas, we concluded that this type of storage needs to be approximately 35 % filled with base gas to be able to maintain its efficiency. The remaining 65 % of the total capacity can be working gas.

The property that underground reservoirs formed from salt caverns are able to deliver gas in a short time interval makes them unique. This means that gas can be injected and pumped from the reservoirs several times a year. The ability to pump and inject multiple times a year generates a greater amount of cash flow than other types of reservoirs. Although the financial turnover is greater for this type, even for underground reservoirs created from salt caverns, we have not reached positive values for the internal rate of return on initial investment.

This type of reservoir also needs a relatively long period to show a profit. However, the ability to pump and inject gas several times a year speeds up the process, and this is a major economic advantage over other types of reservoirs. However, the market also needs reservoirs that can deliver volumes of gas to meet market demand throughout the year, which is precisely what underground reservoirs created from salt caverns are designed to do.

5 Conclusions

Natural gas has found its place among other energy-intensive minerals in the world's energy mix. The characteristic of liquefaction and subsequent gasification makes this commodity more versatile in the market compared to other energy sources. This characteristic has allowed the development of various types of processing, transport and storage.

The aim of this paper was to provide a basic quantitative analysis and basic economic view of the three most common methods of underground storage of natural gas, namely in depleted oil and gas fields, in aquifers and in salt caverns. The analyses focused on the capacity utilisation of the selected storage types as well as on the calculation of the cash-flow and internal rate of return of the projects.

Based on the results obtained, we concluded that underground reservoirs created from aquifers are the most costly.

The most lucrative variant of underground storage are reservoirs created from depleted gas and oil fields, as the initial investment is the lowest compared to the other types. However, these are seasonal reservoirs with a long gas deliverability period.

For fluctuations in consumption, reservoirs created from salt caverns are the most important, as they have the characteristic of a short delivery time and can react the fastest to market fluctuations.

In the observation period 2010-2019, none of the initial investments were recovered and all the projects observed were loss-making. However, progress was visible for all three types of storage tanks. In percentage terms, the most significant progress was seen for reservoirs created from salt caverns, as the ability to produce higher cash-flow values multiple times per year also results in higher returns. Noticeably lower initial construction costs were also observed for reservoirs created from depleted gas and oil fields. Reservoirs created from aquifers fared the worst, as high initial costs pushed returns into higher numbers.

Based on the analysis, it can be assessed that although these projects are very costly to implement, the initial investment will pay off in the long run. However, there are a number of factors to take into account when building new underground gas storage, such as the proven gas reserves remaining on the Earth.

The reference list

[1] EVANS, D. J., CHADWICK, R. A.: *Underground gas Storage: Worldwide experiences and future development in the UK and Europe.* 1st edition, London, Geological Society, 2009.

[2] FLANIGAN, O.: *Underground gas Storage facilities: Design and implementation*. 1st edition. Oxford, Gulf Professional Publishing, 1995.

[3] On natural gas and gas storage. Pozagas. [Online], Available: http://www.pozagas.sk/en/on-natural-gas-and-gas-storage, [29 Dec 2021], 2010.

[4] Underground Gas Storage Safety. Marcogaz. Technical Association of the European Natural Gas Industry. [Online], Available: https://www.marcogaz.org/publications/underground-gas-storage-safety/ [29 Dec 2021], 2019.

[5] US Energy, Information, Administration. Underground Natural Gas Storage by All Operators. [Online], Available: https://www.eia.gov/dnav/ng/ng_stor_sum_a_EPG0_sat_mmcf_m.htm [20 Dec 2021], 2021.

[6] FERNANDO, J.: What Is Internal Rate of Return (IRR)? [Online], Available: https://www.investopedia.com/terms/i/irr.asp [20 Dec 2021], 2021.

[7] HAYES, A.: What Is Cash Flow? [Online], Available: https://www.investopedia.com/terms/c/cashflow.asp [20 Dec 2021], 2021.

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Possibility Analysis of Pyrolysis Gas for Firing Pusher Furnace Heating

Magdalena Skrzyniarz[1] ● Monika Zajemska[1] ● Przemysła Rajca[1]

[1]Faculty of Production Engineering and Materials Technology, Czestochowa University of Technology, 19 Armii Krajowej Ave., 42-200, Czestochowa, Poland, magdalena.skrzyniarz@pcz.pl, monika.zajemska@pcz.pl, przemyslaw.rajca@pcz.pl

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Abstract : The article compares the possibilities of using natural gas, coke oven gas and gas from the pyrolysis of municipal solid waste RDF (refuse derived fuel) for pusher furnace heating at the department of the rolling mill of one of the national steel mills. Taking into account the high calorific value of the pyrolysis gas, an economic assessment of the above-mentioned venture was made, with particular emphasis on the benefits associated with its use in the metallurgical industry. The analysis takes into account the prices prevailing on the market in 2019.

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1 Introduction

The gaseous fuels used in the steel industry are natural gas, coke oven gas and blast furnace gas. The consumption of natural gas in the industrial sector is constantly growing, which is closely related to the decline in the demand for coal, resulting from increasingly restrictive European Union regulations regarding the improvement of air quality. Moreover, in order to ensure reliable supplies of natural gas, the transmission networks in our country are constantly developing. The greater use of natural gas compared to fuel oil or LPG is encouraged by the lower price, lack of need for tanks and, above all, residue-free combustion. On the other hand, coke oven gas is one of the process gases which, in its raw form, due to the presence of undesirable components such as tar, ammonia, benzene hydrocarbons or hydrogen sulphide, requires multi-stage treatment. As far as gas management is concerned, about 50 % of the total amount is used by coking plants for their own purposes, e.g. for firing coke oven batteries or generating process steam, while excess gas, due to the obligation to manage it, is sold outside. At present, a practical and economical solution is to use the surplus gas in the rolling mill department for firing heating furnaces. In addition to the demonstrated advantages of replacing natural gas with coke oven gas, there are also disadvantages. One of them is the increased risk of poisoning by carbon monoxide, which is a fuel component. On the other hand, the gaseous fuel obtained in the blast furnace process is blast furnace gas. The production volume of the aforementioned gas is 1,200 to 2,000 $m^3.t^{-1}$ of pig iron, and additionally, it has a calorific value in the range of 2.7-4.0 $MJ.m^{-3}$; therefore, after cleaning it from process dust and enriching it with coke oven or natural gas, blast furnace gas is often used as a gas fuel in the steel industry. Moreover, if modern burners or preheating of the combustion air are used in blast furnace blast heaters, this gas can also be used without enrichment. Pyrolysis gas is also noteworthy, which is a product of the pyrolysis of biomass, municipal waste or tires. The composition and calorific value of the said syngas depend on the physicochemical properties of the charge, as well as the process temperature. The calorific value of pyrolysis gas obtained from biomass ranges from 10-15 $MJ.m^{-3}$, from municipal waste about 15 $MJ.m^{-3}$, and in the case of tires even above 50 $MJ.m^{-3}$, thanks to which it can be used for the production of electricity and heat, superheated steam or other fuels. The aforementioned premises encourage the use of the said gas as fuel in the steel industry [1–7].

During the hot rolling process, it is important to heat the steel charge to the appropriate rolling temperature, i.e. between 1050 and 1300°C, as well as to ensure its even distribution. In domestic hot rolling mills, natural gas-fired pusher-type heating furnaces are most often used, and also, if possible, a mixture of coke oven gas and blast furnace gas or coke oven gas only. The advantage of the aforementioned furnaces is their high efficiency, low consumption of thermal energy, and the possibility of heating the charge to high temperatures. However, their main disadvantage is the impossibility of simultaneous heating of the charge with different cross-sections, resulting from the differences in the charge movement speeds [8,9].

2 Possibilities of using pyrolysis gas for firing metallurgical heating furnaces

This article provides an economic assessment of the use of pyrolysis gas for firing heating furnaces. The pusher-type furnace described in [10] was analysed. The device is fired with natural gas or coke oven gas and is divided into three zones:

- heating 1073 K – 1373 K,
- heating 1373 K – 1623 K,
- equalizing 1423 K – 1553 K.

The considered furnace is divided into six control zones and equipped with 105 control burners located on the ceiling and side walls [9,10].

Table 1 summarizes the calorific value and chemical composition of gaseous fuels used for firing the above-mentioned heating furnace versus pyrolysis gas.

Table 1 Calorific value and chemical compositions of selected gaseous fuels

	Units	Natural gas[11]	Coke oven gas[11]	Pyrolysis gas[12]
LHV	[MJ. m^{-3}]	34.43	17.5	22.8
CH_4	[%]	97.1	25	32.9
H_2	[%]	-	58	29.4
C_mH_n	[%]	1.7	3	7.2
N_2	[%]	1.1	4	-
CO_2	[%]	0.1	2.5	13.2
CO	[%]	-	7	11.3
O_2	[%]	-	0.5	-
Other	[%]	-	-	6
Price for 1000 m^3	[PLN]	1400**	410**	300*

* estimated gas price; ** prices valid in 2019

As can be seen from the above data, natural gas is characterized by a high content of methane (over 97 %) and trace amounts of hydrocarbons, nitrogen and carbon dioxide, as well as a high calorific value of 34.43 MJ.m^{-3}. On the other hand, coke oven gas is characterized by an almost twofold lower calorific value, a high hydrogen content of 58 %, and a significantly lower methane content (25 %). Its composition also includes carbon monoxide at the level of 7 % and traces of other components. Taking into account the syngas from the pyrolysis of RDF, it is possible to notice the almost 1/3 methane content in the fuel composition, a high content of hydrogen (29.4 %) and carbon monoxide (11.3 %), as well as the highest hydrocarbon content among the above-mentioned gases, at the level of 7.2 %. Additionally, the calorific value of the said gas is 5.3 MJ.m^{-3} higher than in the case of coke oven gas. On the other hand, pyrolysis gas produced from RDF in one of the national thermal waste conversion plants has a 11.2 MJ.m^{-3} higher calorific value than coke oven gas, which encourages its wider use as a gas fuel in the steel industry [11,12].

3 Economic aspect of using pyrolysis gas for energy purposes

Taking into account the high calorific value of the pyrolysis gas, an economic analysis was made of the use of the said gas for firing a pusher-type furnace, compared to the currently used fuels. Table 2 shows the consumption of the analysed gaseous fuels depending on the efficiency of the heating device.

Table 2 Consumption of selected gaseous fuels depending on efficiency of pusher furnace [10]

Furnace efficiency [t.h^{-1}]	20	40	60	80
Furnace power [MW]	10.41	18.22	26.03	33.84
Consumption of natural gas [m^3/h]	1047	1832	2618	3403
Consumption of coke oven gas[m^3/h]	2063	3609	5157	6704
Consumption of pyrolysis gas [m^3/h]	1581	2766	3953	5139

As can be seen from the above data, the consumption of the above-mentioned gaseous fuels was determined for the efficiency of a pusher-type furnace in the range of 20 to 80 t.h^{-1} and power in the range of 10.41 to 33.84 MW. To estimate the consumption of coke oven gas and pyrolysis gas instead of natural gas, the so-called conversion factor for the conversion of natural gas to coke oven or pyrolysis gas is described by Equation (1):

$$n = \frac{Wd_{gz}}{Wd_{gza}} \tag{1}$$

where:
Wd_{gz} - calorific value of natural gas MJ.m^{-3},
Wd_{gza} - calorific value of substitute gas MJ.m^{-3}.

The determined value of the above-mentioned the coefficient is 1.97 for coke oven gas and 1.51 for pyrolysis gas. By analysing the consumption of the above-mentioned of gases and their prices, the costs of 1 hour of operation of a pusher-type furnace were compared (Figure 1).

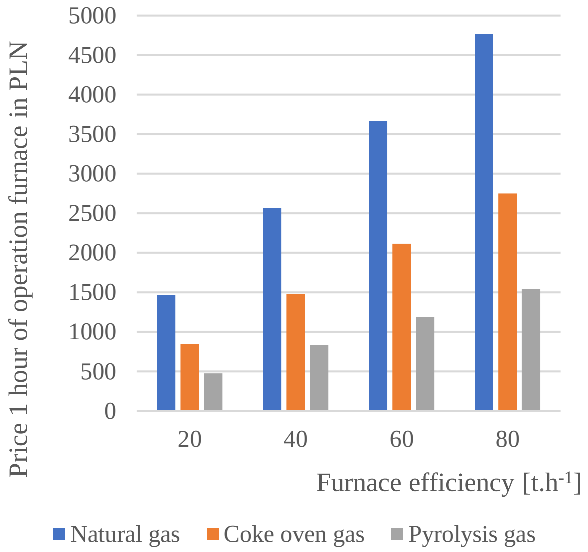
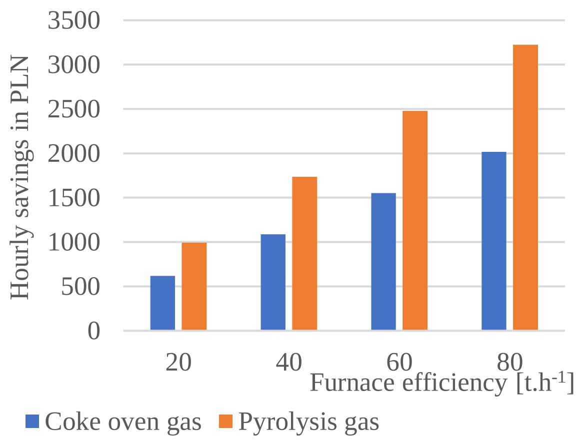


Figure 1 Comparison of price of 1 hour of furnace work for various gaseous fuels

Savings, both hourly and daily, resulting from the use of coke oven and pyrolysis gas instead of natural gas are presented in Figure 2.



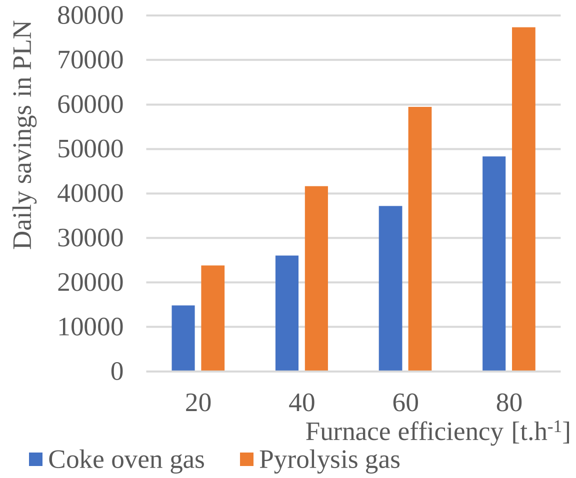


Figure 2 Economic effects of using coke oven gas and pyrolysis gas

With the above data in mind, there are significant benefits to using pyrolysis gas instead of natural gas. The greatest savings result from the use of syngas from the pyrolysis of RDF, from 992 PLN.h^{-1} with a furnace capacity of 20 t.h^{-1} to even 3222 PLN.h^{-1}, with a capacity of 80 t.h^{-1}. These savings are respectively 372 PLN.h^{-1} (with a capacity of 20 t.h^{-1}) and 1207 PLN.h^{-1} (with a capacity of 80 t.h^{-1}) higher than in the case of coke oven gas. Real savings for rolling mills in relation to 1 ton of heated slab, resulting from the replacement of natural gas with the above-mentioned gases are summarized in Figure 3.

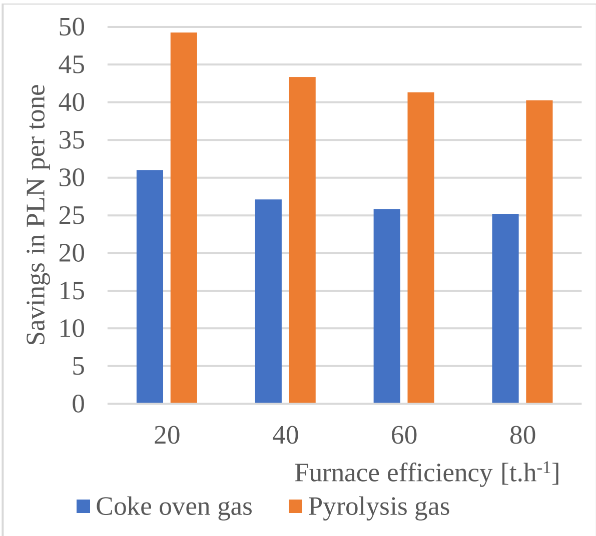


Figure 3 Savings for rolling mill in relation to heated slab

By analysing the above data, an increase in savings in relation to the heated charge was found in the range from 25.19 to 31.00 PLN.t^{-1} in the case of coke oven gas and 40.28 to 49.60 PLN.t^{-1} by using pyrolysis gas, along with a decrease in the efficiency of the pusher-type furnace.

4 Conclusions

In the face of the intensive optimization of production processes and reduction of incurred financial outlays, there is an opportunity to increase the competitiveness of the analysed rolling mill, thanks to the use of pyrolysis gas for firing a pusher-type furnace. With an annual steel production volume of 500,000 t, savings will amount to 20.140 million PLN; thus, it is possible to consider the construction of an RDF pyrolysis installation in the vicinity of the rolling mill. Nevertheless, it is necessary to take into account the costs of building a fuel supply pipeline, the costs of modernizing the gas-air installation of the furnace, including the modernization of the burners. At present, to supply a furnace with a capacity of 20 t.h^{-1}, approximately 12 modules must be installed in the pyrolysis installation, each of which produces approximately 130 m^3 of syngas per hour. Taking into account the capabilities of the above-mentioned installation, about 40 modules are needed to generate the amount of pyrolysis gas necessary to power a pusher furnace with a capacity of 80 t.h^{-1}. Currently, the installation is at the research and development stage; nonetheless, the high calorific value of the obtained syngas encourages its further improvement, as well as wider use of the said gas fuel. In addition, pyrolysis gas may contribute to a lower consumption of natural gas, which will allow diversification of the fuel and energy sources in our country, and will also bring tangible economic benefits.

The reference list

[1] CZAJCZYŃSKA D., NANNOU T., ANGUILANO L., KRZYZYŃSKA R., GHAZAL H., SPENCER N., JOUHARA H.: Potentials of pyrolysis processes in the waste management sector, *Energy Procedia*. Vol.123, pp. 387–394, 2017.

[2] Foundation Institute for Sustainable Development, Natural gas as a support for a low-emission economy, 2015.

[3] KALISZ S., PRONOBIS M., BAXTER D.: Co-firing of biomass waste-derived syngas in coal power boiler, *Energy*, Vol. 33, pp. 1770–1778, 2008.

[4] MACHOWSKA H.: The coke industry in terms of environmental protection, *Proceedings of ECOpole*. Vol. 5, 2011.

[5] OLKUSKI T., SZURLEJ A., JANUSZ P.: Implementation of the energy policy in the area of natural gas, *Energy Policy Journal*. Vol. 18, pp. 5–18, 2015.

[6] WIELGOSIŃSKI G.: Review of waste thermal processing technology, *Nowa Energia*, Vol. 1, 2011.

[7] RAJCA P, ZAJEMSKA M.: Possibilities of using pyrolytic gas to heat metallurgical reheating furnaces, *Hutnik*, Vol. 85, pp. 421–423, 2018.

[8] ZIELI K., KLIMCZYK A.: Fundamentals of manufacturing and processing technology, *Akademia Górniczo-Hutnicza Im Stanisława Staszica w Krakowie*, pp. 1–27, 2015.

[9] ZAJEMSKA M.: Numerical modeling of the chemical composition of exhaust gases in heating furnaces, *Monografie Nr 37*, Czestochowa University of Technology, Częstochowa, 2013.

[10] ZAJEMSKA M., MAROSZEK A.: Profitability analysis of the use of coke oven gas for firing metallurgical heating furnaces, *Monografie Nr 48*, Czestochowa University of Technology, Częstochowa, 2015.

[11] WU D., ZHANG A., XIAO L., BA Y., REN H., LIU L., Pyrolysis Characteristics of Municipal Solid Waste in Oxygen-free Circumstance, *Energy Procedia*, Vol. 105, pp. 1255–1262, 2017.

[12] RIMÁR M., SHMYHOL D.: Issues in the Field of Municipal Waste Management, *Advance in Thermal Processes and Energy Transformation*, Vol. 4, No. 2, pp. 31-36, 2021.

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