Review of technologies for low-quality solid fuel gasification

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Abstract. The article discusses World’s current status of surface coal and other resources gasification technology. Examples of existing and planned gasification plants efficiencies up to the year 2022 along with the use of syngas for chemical resources production and distribution of plants are given. The SGT (SES Gasification Technology) gasification technology where produced syngas is used for energy production is described.

1. Introduction

Recent agreements within European Union member states impose further reduction of CO₂ emissions. In December 2017 new legislation establishes binding annual greenhouse gas emission targets for Member States for the period 2021–2030. These targets concern emissions from most sectors not included in the EU Emissions Trading System (EU ETS), such as transport, buildings, agriculture and waste. The national targets will collectively deliver a reduction of around 40% in total EU emissions from the sectors covered by 2030 compared with 1990 levels. The Regulation on binding annual emission reductions by Member States from 2021 to 2030 (Effort Sharing Regulation) adopted in 2018 is a part of the Energy Union strategy. It sets national emission reduction targets for 2030 for all Member States, ranging from 0% to 40% from 2005 levels. The national targets are based on Member States’ relative wealth. According to the agreement, Poland has to decrease non-ETS emissions by 7%. Additionally, European Commission as part of its proposal for a new Electricity Regulation, the European Commission proposes to introduce an Emission Performance Standard (550 g CO₂/kWh) for generation capacity participating in capacity mechanisms. Worth mentioning is the fact that a highly efficient ultra-supercritical coal power plant does not meet the emission standard below 750 g per 1 kWh [1].

Other restrictions of European Commission include decarbonisation, namely phasing out coal as a source of Energy generation. Poland has prolonged these restrictions until 2021. According to the Polish Electricity Association introducing 550 Emission Performance Standard will increase the cost of energy for end-users by approximately 300 million Euros between 2017 and 2040. It will be the consequence of building new power plants fueled by natural gas [2].

One of the solutions of this problem is the gasification technology where solid (coal, biomass, waste) or liquid (oil) fuel is converted into synthesis gas. Synthesis gas is composed mainly of hydrogen and carbon monoxide which are the products of incomplete combustion of fuel. Oxidants in this process are mainly air or oxygen and the choice of the oxidant for the process depends on the fuel
reactivity, designation of the end-product and gasifier type. Often, steam is used to regulate the temperature of the process. Molecular disintegration of the feed in the gasifier allows for the separation of impurities such as: sulfur, lead, mercury, etc. It also allows to separate a pure stream of CO$_2$ which can be further stored or utilized (eg. converted to synthetic fuel).

Gasification technology is known for many years since the first Lurgi gasifier was patented in 1887. Interest in gasification technology has been changing with coal and oil price variations. The higher the price of oil the higher the interest in coal gasification. Various hydrocarbons or biomass could be converted into ammonia, methanol or hydrogen products.

Currently, the development of gasification technology is focused on the production of process gas, which is used in chemical synthesis methods and for electricity generation. According to experts [3,4] the use of gasification in the so-called polygeneration systems, combining the production of electricity and chemical products from coal, mainly motor liquid fuels, methanol or hydrogen is the most attractive option for gasification.

2. Development of gasification technology

Development of gasification technology results in the construction of new installations and gasifiers. Table 1 shows the number of operating, under construction and planned gasification projects and number of gasifiers [5–8]. Figures 1 and 2 are a graphical representation of data given in Table 1.

**Table 1.** Number of operating, under construction and planned gasification projects and gasifiers from 1999 to 2018 [5–8].

| Year | Operating projects/gasifiers | Under construction projects/gasifiers | Planned projects/gasifiers |
|------|-----------------------------|--------------------------------------|---------------------------|
| 1999 | 128/366                     | n/a                                  | 33/48                     |
| 2001 | 131/409                     | n/a                                  | 32/59                     |
| 2004 | 117/385                     | n/a                                  | 38/66                     |
| 2007 | 144/427                     | n/a                                  | 10/34                     |
| 2010 | 192/405                     | 11/17                                | 37/76                     |
| 2013 | 234/618                     | 61/202                               | 98/550                    |
| 2016 | 356/863                     | 108/322                              | 134/685                   |
| 2017 | 379/938                     | 131/348                              | 146/734                   |
| 2018 | 451/1074                    | 129/355                              | 135/667                   |

**Figure 1.** Number of operating gasification projects from 1999 to 2018 [5–8].
Over the last years the cumulative capacity of projects has increased, particularly after 2010 (see Figure 3). Currently, the cumulative capacity is approximately 200 000 MWth of synthesis gas and it should reach 425 000 in 2022.

Synthesis gas is produced from various feedstocks where the most common resource is the hard coal. It is reflected in the number of operating projects and the capacity of installations (Figure 4). Coal has the largest share in the production of synthesis gas among all gasification installations and the number of coal gasifiers had the largest growth in 2017 and 2018. When looking at the number of projects under construction and planned, this trend will continue in 2021 and 2022 [7,8].
Synthesis gas is used in manufacturing of various products. The majority of it is consumed in petrochemical industry where ammonia, methanol, liquid fuels and hydrogen are produced. It is also used for electricity generation. In Figure 5 consumption of syngas in 2017 and 2018 by application is shown [7,8]. The highest growth in consumption is observed in production of liquid fuels and ammonia.

Capacity of operating, in construction and planned gasification installation differs depending on the region where Asia is the region with the largest capacity of installations. The dominance is clear for both operating as well as under construction and planned installations (see Figure 6) [8].
3. Forecasts of gasification technology development in Poland

Currently in Poland there is no operating gasification installation of industrial capacity fueled by coal. There are many efforts to develop such installation [2]. One installation is planned near Kedzierzyn-Kozle in southern Poland. According to the estimation it should consume up to 900 000 tons of hard coal per year and cover 15% of national needs for ammonia and methanol. Two large companies: Tauron and Grupa Azoty have signed a letter of intent to erect an installation in 2021-2022 with estimated budget of 400-600 mln Euros. Economic analysis are still being carried out. Another initiative has been developed between ENEA capital group and coal company BOGDANKA where IGCC plant fueled by coal is planned to be constructed in 2020-2023. Feasibility study is being carried out currently.

EnCoal Gasification Sp. z o.o. is another company that intends to introduce an American SGT - SES Gasification Technology in Poland. Research has been carried out for several years and it appears that this technology would be particularly economically efficient taking into account polish market conditions. Various researchers from Institute for Chemical Processing of Coal, Central Mining Institute and experts from TAURON Wytwarzanie have verified the concept and its application. The SGT technology has been chosen for retrofitting 200 MW boilers in TAURON [9].

On November 9th 2017 American Synthesis Energy Systems Inc. from Houston and polish EnCoal Gasification Sp. z o.o. established Joint Venture named SES EnCoal Energy in Warsaw. This company will have exclusive rights for the SES Gasification Technology (SGT) in Poland [9].

4. Benefits of SGT (SES Gasification Technology)

The SGT is the development of U-GAS® technology which was originally developed by Gasification Research Institute in Chicago. The U-GAS® gasification technology was piloted, demonstrated, and commercially operated on a wide range of feedstocks including bituminous coal, sub-bituminous coal, lignite, biomass, coal char and wastes, and metallurgical coke. As SES began to commercially deploy the U-GAS® technology, the company advanced the technology through modifications that improve fuel utilization, plant efficiency, and cost competitiveness through an expanding intellectual property library – forming SES Gasification Technology. SES is a technological company publicly traded on
NASDAQ since 2007. SES has built and operated several SGT gasifiers in China [9] and has several other gasification projects under development.

Coal feedstock in SGT technology is gasified in innovative fluidized bed reactors under relatively low temperature ie. 840°C to 1100°C. This number is important taking into account the melting point of ashes for polish coals which is slightly above this value. Ash melting may result in reduced air circulation and decreases gasification efficiency. The higher the gasification temperature the more advanced heat protection of gasifiers is required, hence the construction costs are elevated. Pressure in SGT reactor varies from 3 to 40 bars and depends on the designation of synthesis gas. Efficiency of carbon conversion exceeds 85% where conversion into synthesis gas has an efficiency of 99.5%. Remaining 15% of unconverted carbon is converted into heat necessary to keep the process constant. Conventional gasifiers in SGT technology can handle from 200 to 1200 tons of feed per day. Modified gasifiers (under higher pressure) can handle up to 3000 ton per day. Another advantage of this technology is the fuel flexibility, ability to gasify a variety of different coals, biomass or waste. This is also valid for coals where the low quality coals can be used as a feed and this includes coal wastes and slurries (with high content of ash and sulfur). Even low quality coal materials with calorific value below 10 GJ/Mg can be used as a feed. For optimal efficiency a feed of 3500 kcal/kg (14.7 GJ/Mg) [10].

5. Example of SGT technology application

An interesting solution offered by SES company is the I-GAS gasification technology designed for electricity production where gas turbines are fueled by purified synthesis gas. Additional heat generated in the process is used in the steam turbine. Emission of greenhouse gases and other pollutants is comparable to installations fueled by natural gas. In Figures 7 and 8 Solar St Titan 130 by Caterpillar and GE LM2500 by General Electric are presented, respectively.

![View of Caterpillar Solar St Titan 130 gas turbine](image-url)

Figure 7. View of Caterpillar Solar St Titan 130 gas turbine [11].
Figure 8. View of General Electric LM2500 gas turbine [12].

Typical configuration of I-GAS gasification installation is presented in Table 2.

| I-GAS power capacity, MW | 40  | 80  | 160 |
|--------------------------|-----|-----|-----|
| Working pressure, bar    | 35-50 | 40-50 | 40-50 |
| No. of gasifiers, -      | 1   | 2   | 4   |
| No of gas turbines, -    | 2   | 2   | 4   |
| St Titan 130             |     |     |     |
| GE LM2500                |     |     |     |
| GE LM3500                |     |     |     |
| No. of steam turbines, - | 1   | 1   | 1   |

6. Conclusions

Abovementioned data indicate increasing interest in the gasification technologies in the World. The number of operating, in construction and planned gasification installation is growing along with the capacity of synthesis gas produced. Such installations can cover energy needs of cities as it commonly observed currently.

In case of Poland where energy mix is mostly based on coal gasification could provide a viable solution to the problem of emission limits. Remaining coal reserves which are relatively abundant could be used without harmful emission penalties. There are already few gasification solutions that could be introduced on the polish market and coal companies express interest in such technologies. Yet, decisions have not been undertaken for any industrial scale installation. Time is running and the following reasons should accelerate gasification on the market:

a) Poland will have to decrease GHG emissions (CO₂) in the transport, housing, agricultural, waste and forestry sector by 7% until the end of 2030 from 2005 levels. Additionally, European Commission proposes to introduce an Emission Performance Standard (550 g CO₂/kWh) for generation capacity participating in capacity mechanisms. These standards could be fulfilled with gasification installation fueled by coal and biomass or waste since part of emissions generated by alternative fuel (RDF – Refused Derived Fuel or biomass) is considered as carbon neutral, hence compliance with 550 g CO₂/kWh standard.

b) SGT technology presented in this article allows gasification of low-quality coals such as coal waste slurries either produced currently or deposited in impoundments with RDF [10].
c) Gasification technology enables separation of pure CO\textsubscript{2} stream which could be further utilized in CCU technologies (Carbon Capture and Utilization). This is a major advantage of gasification where CO\textsubscript{2} separation is much more efficient and economic than in case of conventional coal boilers.

Another breakthrough in the gasification technology is integration of gasifiers with fuels cells. This solution will provide compliance with 550 g CO\textsubscript{2}/kWh standard. Extensive research is being carried out in Japan such as EAGLE project coordinated by NEDO (New Energy and Industrial Technology Development Organization) where oxygen-blown coal gasifier is being tested [13].

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