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Technical-econmical evaluation of CHP plant fed with methane from hard coal bed

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Abstract

The arguments supporting the development of cogeneration (CHP), among others based on methane from coal bed, are discussed in the presented paper. The resources of methane from coal beds are characterised and the prognosis of the CHP development are presented. The technical analysis of selected CHP plant basing on the regulations included in the Polish energy law has been carried out. The detailed economic analysis proved the profitability of application of the methane from coal bed as a fuel for CHP plants. It has been demonstrated that the important factor deciding of this profitability is the support system based on certificates for high efficient cogeneration. It has been also demonstrated that the further increase of the CHP efficiency is possible thanks to the realisation of tri-generation.

Keywords: Cogeneration, Methane from coal bed, Economic analysis

1. Introduction

The The main aims of the Polish energy policy [1] include among others:

1. improvement of the energy efficiency,
2. increase of the energy security,
3. decrease of harmful impacts of energy sector on the natural environment including the decrease of green house gasses (GHG) emissions.

Application of CHP units represents one of the possible way to realise the aim 1 and 3 that additionally are in accordance with the rules of the 3x20 Package. The energy savings in CHP units and furthermore the decrease in emission of harmful substances are directly the results of elimination of part of irreversible processes in CHP unit in comparison to the separate production of heat and electricity [2, 3]. These advantageous effects can be even demonstrated by means of simplified analysis without the necessity of performance of advanced thermodynamic evaluations. The illustrative example of such simplified analysis is presented in Fig. 1, that presents the comparison of primary energy consumption in separate production of heat and electricity consisting of power plant with the energy efficiency $\eta_{E,el} = 0.4$ and in boiler house with energy efficiency $\eta_{E,c} = 0.85$ with the cogenerated production on CHP plant with the energy efficiency $\eta_{E,CHP} = 0.8$. The power to heat ratio has been assumed on the level of $\sigma = E_{el}/Q = 1.0$. The power to heat ratio on the level of 1.0 can be achieved for example in CHP plants based on internal combustion engines.

In the simplified example presented in Fig. 1 the primary energy saving amount to:

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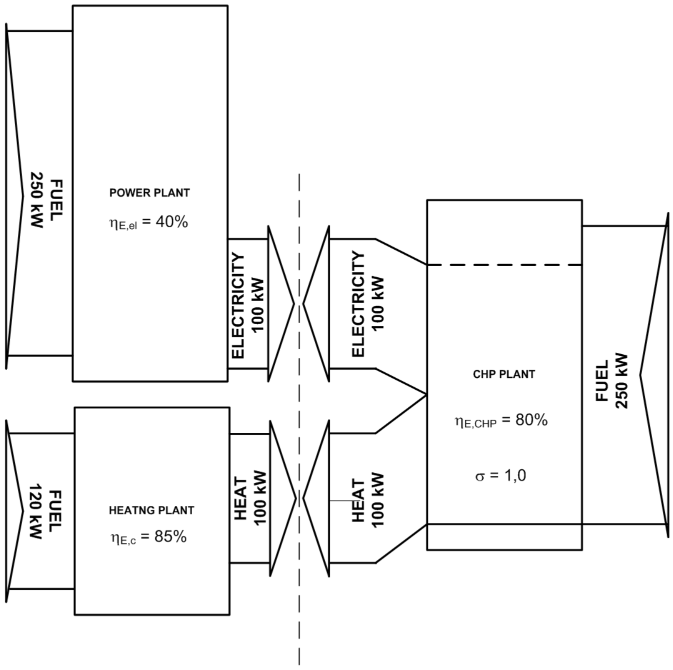

Figure 1: Primary energy savings due to the realisation of combined heat-and-power (CHP) generation

$$\Delta E_{ch} = E_{ch,r} - E_{ch,CHP} = (E_{ch,EL} + E_{ch,c}) - E_{ch,CHP} \\ = 250\,kW + 120\,kW - 250\,kW = 120\,kW,$$

what corresponds with the relative savings of primary energy on the level of about 32%. The same magnitude of CO_2 emission decrease can be expected.
The CHP systems as analysed in Fig. 1 belongs to the group of distributed energy systems and are localised directly at the consumer of heat and electricity. For this reason in such cases the decrease of distribution losses as well as improvement of energy security can be expected. Both effects represents the additional arguments for application of local CHP units.

Polish energy policy [1] ensures the financial supporting mechanisms for commercial activities aiming to the realisation of assumption of the energy policy. Among others theses mechanisms support the high efficient cogeneration [4, 5]. It can be regarded as the additional economic income and can improve significantly the economic profitability of CHP installations. In other words investment in cogeneration beside the profits in the form of primary energy savings and in the decrease of environmental impacts leads also to economic support by means of so-called certificates. These certificates are entitled to these CHP units that fulfilled some requirements resulting from the Polish energy law [4, 5]. Stimulation of the development of CHP technology by means of supporting mechanisms is mentioned in Polish energy policy till the year 2030 as one of the priority towards sustainability and improvement of energy efficiency. It can be expected that these mechanisms will be in force in the next decades and will be the effective encouragement for investment in CHP and will results in decrease of investment risk in this case.

Among variety of different solutions of CHP units [3, 6–9] there is an option of CHP based on internal combustion engines and fired with methane extracted from coal bed mine during the hard coal exploitation [7]. This group finds the additional support for support in the form of the assumption included in Polish energy policy [1]. These assumptions are as follows:

- it is expected that maximum amount of the methane released during coal exploitation will be usefully utilised as primary energy source,
- Polish resources of coal will be representing the role of important stabilizer in the domestic energy balance and will be playing the important role from the point of view of energy security.

The mentioned arguments additionally confirmed the purposefulness of the investment in the CHP units based on the methane from coal mines. Additionally the utilisation of the mentioned primary energy is important from the point of view of the structure of Polish energy mix in which the demand on the natural gas are covered by means of import mainly from one eastern direction. Also the increasing prices of imported natural gas can be deciding factor on the economic profitability of the CHP units combined with the extraction of methane from coal mines. The utilisation of the methane from coal mines are possible thanks to exploitation of surface producing wells. The actual level of utilisation of methane from coal bed as well as the future potential are illustrated by means of data included in the Table 1. Basing on the data presented in the Table 1 it can be concluded that there is relatively high potential for usage of the methane from coal bed. Additionally it can be observed that the actual level of extraction of methane is significantly lower than the proved reserves. It would assure the long term energy security of CHP installation fired with the methane from coal mines. Additionally, also the prognosis of development of CHP sector is the argument supporting the investment in the discussed CHP units. The Table 2 presents after [1] the potential of the development of CHP technology in Poland in the horizon of the year 2030.

Due to the Polish energy policy [1] the generation of electricity in high-efficient cogeneration will be decreasing from the level of 24.4 TWh in the year 2006 up to 47.9 TWh in the year 2030. The planned in 2030 share of electricity from the high-efficient cogeneration amounts to 22%. For sure in this amount there is a place for cogeneration based on internal combustion engines fired with methane from coal mine bed.

2. Characteristic of the investigated CHP plant

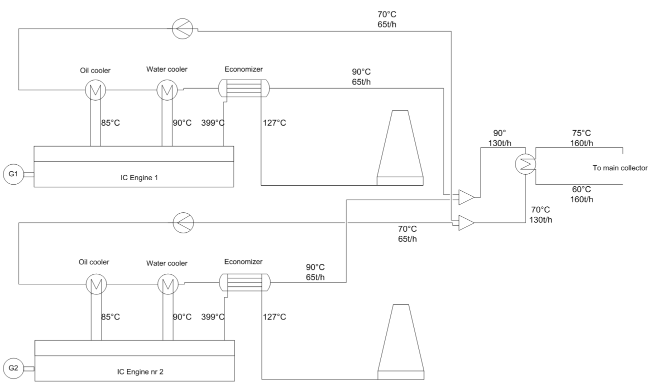

Figure 2: Scheme of the analysed CHP plant

The simplified scheme of the analysed CHP plant based on internal combustion engines fired with methane from coal mine bed is presented in Fig. 2.

In the analysed CHP plant two internal combustion engines are installed. The main parameters characterising the investigated CHP plant are summarised in Table 3.

The presented nominal parameters are available in the case of firing the engine with the methane from coal bed. It has been assumed that in the case of natural gas usage the attainable indices are at least at the same level.

Table 3: Nominal parameters of the analysed CHP plant

Parameter	Unit	Value
Electric power	MW_{el}	2.806
Heat power	MW_t	2.958
Total efficiency	%	86.5
Electric efficiency	%	42.1
Heat efficiency	%	44.4
Power to heat ratio		0.95

3. Evaluation of high-efficient cogeneration

Due to the current Polish energy law regulations [4, 5] and due to the EU Directive [10], the evaluation of the high-efficient cogeneration deciding if the CHP unit is granted with certificates is based on two criterions:

1. index of primary energy saving (PES),
2. energy efficiency of the CHP plant η_{CHP}.

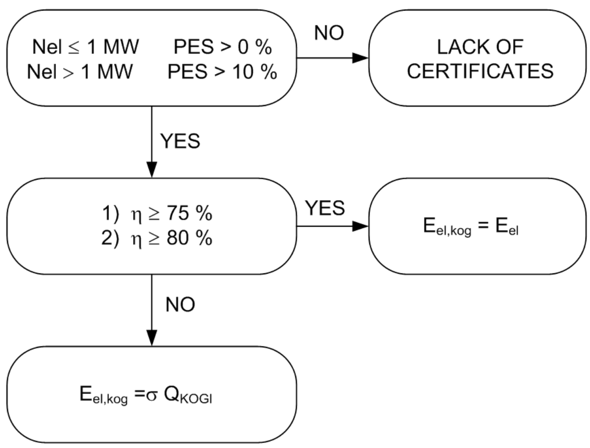

Figure 3: Evaluation algorithm of high-efficient cogeneration

The simplified scheme of the evaluation algorithm of high-efficient cogeneration is presented in Fig. 3.

Index (PES) is expressed as the difference in primary energy consumption in the case of separate production of heat and electricity $E_{ch,r}$ (power plant and heating plant) and consumption of primary energy in the cogenerated process $E_{ch,CHP}$:

$$(PES) = \frac{E_{ch,r} - E_{ch,CHP}}{E_{ch,r}} = 1 - \frac{E_{ch,CHP}}{E_{ch,r}} \quad (1)$$

Due to [4] the partial efficiencies are defined as follows:

- electric efficiency:

$$\eta_{el,CHP} = \frac{E_{el,CHP}}{E_{ch,CHP}} \tag{2}$$

where:

$E_{el,CHP}$ amount of electricity generated in cogeneration,

$E_{ch,CHP}$ consumption of chemical energy of fuels burdening the production of heat and electricity in the cogeneration process,

- thermal efficiency:

$$\eta_{c,CHP} = \frac{Q_{CHP}}{E_{ch,CHP}} \tag{3}$$

where Q_{CHP} denotes the production of useful heat in cogeneration.

After introduction of partial efficiencies defined by (2) and (3) into Eq. (1) the formula for (PES) calculation can be expressed as follows:

$$(PES) = 1 - \frac{1}{\frac{\eta_{c,CHP}}{\eta_{ref\,c}} + \frac{\eta_{el,CHP}}{\eta_{ref\,e}}} \tag{4}$$

where:

$\eta_{ref\,c}$ reference thermal efficiency of heat production in separate generation process, [%],

$\eta_{ref\,e}$ reference electric efficiency of electricity production in separate generation process, [%].

The reference efficiencies have to be assumed due to the regulation [4]. For the internal combustion engine they are as follows:

in the case of natural gas as a fuel: $\eta_{ref,c} = 90.0\%$, $\eta_{ref,el} = 52.5\%$,

in the case of methane from coal bed: $\eta_{ref,c} = 80\%$, $\eta_{ref,el} = 35.0\%$.

The energy efficiency of CHP plant is defined as follows:

$$\eta_{E,CHP} = \frac{E_{el,CHP} + Q_{CHP}}{E_{ch,CHP}} \tag{5}$$

In the case of CHP equipped with the internal combustion engine it is required that the energy efficiency calculated by means of Eq. 5 has to be higher than $\eta_{gr} = 80\%$. If this condition if fulfilled the whole amount of the generated electricity is granted by the certificates. Otherwise, when the efficiency is lower than 80% the amount of certificated electricity is calculated as a function of the power to heat ratio:

$$E_{el,CHP} = \sigma Q_{CHP} \tag{6}$$

The power to heat ratio σ should be determined basing on the registered data from CHP measurement system. If the determination of σ is not possible by means of the registered measurements its value is assumed basing on the regulations included in [4]. In the case of CHP based on the internal combustion engine it should be assumed as $\sigma = 0.75$. The results of example calculations of the complete set of indices deciding on the qualification of CHP in the group of high-efficient cogeneration is included in the Table 4.

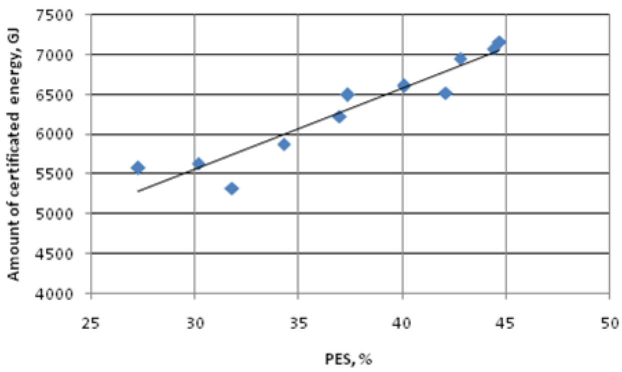

Figure 4: Dependence between certified energy and PES index

In the considered case the average yearly efficiency of the CHP unit is equal to $\eta_{E,CHP} = 78.6$ and is higher than the minimum level of 75%. For this reason all the production of electricity in cogeneration with heat will be granted with certificates. Otherwise it should be determined using the Eq. 6. Such situation can be observed in the investigated CHP plant between January and April. However, despite the required minimal efficiency is not fulfilled almost all the generated electricity would be certificated as the $\sigma \approx 1$ Fig. 4 presents the dependence between the amount of certificated

electricity and the index PES. It can be observed that in the face of apparently lack of dependence between amount of certified energy and PES index (regulation [4] requires only to fulfil the the following constrain $(PES) > 10\%$) such dependence exist. It is the result of indirect dependency of PES index on the power to heat ratio σ, and this factor mainly decides on the amount of granted certificated.

3.1. Economic evaluation of considered CHP plant

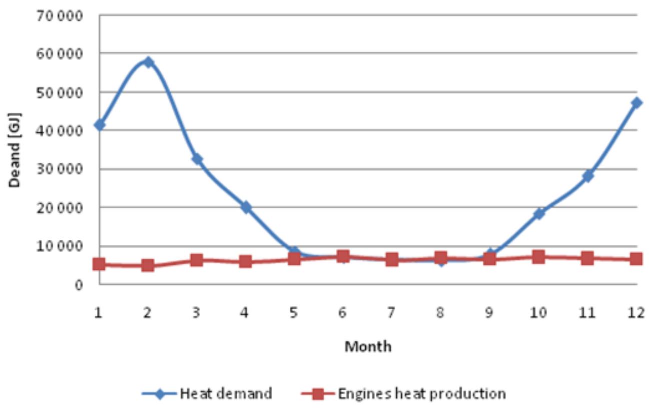

Figure 5: Comparison of heat production in CHP engines and the total demand for heat

The assessment of the engines' power as well as economic analysis have been done for the assumed yearly demand for useful heat. In the cases in which the engine works in the cogeneration model (electricity and heat generation) the work of engines was fitted to the basic demand for heat. The comparison of heat production in CHP engines and the total heat demand has been presented in Fig. 5.

Table 5: Assumptions for economic analysis

Item	Unit	Value
Average price of selling electricity	zł/MWh	213
Average price of heat	zł/GJ	23
Average price of cold agent	zł/GJ	80
Unit price of certificate substitute (yellow certificate)	zł/MWh	128.8
Unit price of certificate substitute (purple certificate)	zł/MWh	59.16
Price of electricity selling (including yellow certificates)	zł/MWh	341.80
Price of electricity selling (including purple certificates)	zł/MWh	272.16

For the economic analysis the total investment expenditures has been assumed at the the level of I_0 =11 500 000 zł (cogeneration mode) and I_0 =16 500 000 zł (tri-generation mode). The additional assumptions for economic analysis have been summarized in the Table 5.

Table 6: Results of economic analysis of cogeneration and trigeneration plant

Variant	Support with certificates	SPB, years	NPV (10 year), mln zł
COGENERATION			
Methane from coal bed	YES	2.44	17.473
Methane from coal bed	NO	2.73	14.413
Natural gas from net	YES	9.80	-3.975
Natural gas from net	NO	-	-20.498
TRIGENERATION			
Methane from coal bed	YES	2.33	27.022
Natural gas from net	YES	7.22	-2.451

Additionally it has been assumed that the total price of natural gas from PGNiG is at the level of 1.55 zł/m^3. The price of methane from coal mine bed is dependent on the agreement between the owner of the CHP plant and the coal mine. In the presented work it has been assumed that the price of methane from coal mine is 0.23 zł/m^3. The results of economic analysis are summarised in the Table 6.

The results of economic analysis shown that in the case of firing the CHP with cheap fuel, eg. methane from coal bed, the system is profitable in both variants—with and without certificates. Additionally the pay-back period is relatively short—2.4 years with and 2.7 years without certificates. The relatively high price of the natural gas form the network causes that the pay-back time is significantly increasing and in the case without certification can be even non profitable. In the case of trigeneration fired with methane from coal mine the pay-back period is about 2.3 years and it can be concluded that the introduction of trigeneration in the case of cheap fuel doesn't lead to significant economic improvement in comparison with the cogeneration system. The other conclusions are observed in the case of the CHP system fired with expensive gas fuel. In this case the introduction of trigenration shorten the pay-back period to 7.2 years and the investment becomes profitable.

4. Summary and conclusions

In the presented work the technical-economical analysis of selected CHP unit has been carried out. Additionally the case of trigenartion mode has been analysed. In the case of trigeneration mode the engine supplies with heat the adsorption chiller. It leads to increase of the period of full cogeneration and furthermore in this case all the generated electricity can be supported with certificates. The obtained results of economic analysis show that pay-back period in the case of CHP fired with the methane from coal bed and with the support by purple certificates for electricity is below 3 years. Relatively high profitability of this variant results from the low price of the methane while the fuel cost is the main position in the cash flows of the considered cogeneration system. It has to be stressed that the main positions in the cash flows in all considered cases are: income from selling heat, electricity, certificates and cold carrier. In all analysed cases the variant without support by certificates for high-efficient cogeneration has been taken into account. The lack of certificates has only a little influence on the economic profitability in the case of CHP fired with methane from coal mine. In the mentioned case the pay-back period increased only by about half a year. It is the additional confirmation of the features resulting from the analysis CHP solutions and confirmation of low investment risk in the case of lack of existence of supporting mechanism. Furthermore, it has been assumed that the analysed CHP system is fired with the natural gas from the national gas grid. It results first of all in the increase of fuel price by about 7 times. Finally this case under assumption of support by yellow certificates results in the pay-back period of about 10 years. When the lack of certification in the case of natural gas is assumed the investment become not profitable. Next cases assumed the possibility of increase of the time of full cogeneration by means of realisation of the tri-generation process with additional production of cold carrier in the adsorption chiller. In the case of CHP fired with the methane from coal bed the pay-back period is shorten by half a year and the investment become even more profitable. In general, it can be concluded that the CHP mode with expensive natural gas is low profitable (case with yellow certificates) or even non-profitable (case without support by certificates). The main risk is assigned to the existence of certificate supporting system as well as to the price of natural gas. In the case of Polish structure of primary energy this price can be not stable as about 70% is imported from one direction. Also the certificate system apparently is not stable. The obligation for buying and write off in the case of yellow certificates expired by the year 2012. Additionally CHP units fired with natural gas are still granted with these certificates. It would results in surplus of yellow certificates at the marked and finally to very low price of this certificates. As was proved in the paper the certificate system plays dominant role in the economic account of CHP fired with natural gas. For this reason the described situation would finally lead to the significant decrease of development of CHP fired with natural gas from grid.

Acknowledgments

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Table 1: Resources of methane from coal bed, mln m^3 [7]

Item	Extractable resources		Industrial	Emission	Extraction
	balanced	unbalanced	resources		
Proved reserves (48)	85 860.41	22 642.95	3 486.37	169.78	272.70
- in exploitation area (29)	25 895.25	1 847.72	2 316.83	169.78	272.69
- outside exploitation area (19)	59 965.16	20 795.23	1 169.54	–	0.01

Table 2: Prognosis of the CHP development in Poland [1]

	Year					
	2006	2010	2015	2020	2025	2030
	Gross demand for electricity, TWh					
	147.7	128.7	140.1	156.1	180.3	201.8
	Gross installed power, MW					
CHP—hard coal	4845	4950	5394	5658	5835	5870
CHP—natural gas	704	710	810	873	964	1090
CHP—industrial. hard coal	1516	1411	1416	1447	1514	1555
CHP—industrial. natural gas	51	50	63	79	85	92
CHP—industrial. other fuels	671	730	834	882	896	910
CHP—solid biomass	25	40	196	623	958	1218
CHP—biogas	33	74	328	802	1293	1379

Table 4: Results of analysis of high-efficient cogeneration

	$E_{ch,CHP}$	Q_{CHP}	$E_{el,CHP}$	σ	$\eta_{el,CHP}$	$\eta_{c,CHP}$	$\eta_{E,CHP}$	(PES)
Month	GJ	GJ	GJ	-	%	%	%	%
I	16 290.31	5 203.00	5 574.53	1.07	34.2	31.9	66.1	27.3
II	14 533.75	4 891.00	5 322.28	1.09	36.6	33.6	70.2	31.8
III	16 097.81	6 174.00	5 879.99	0.95	36.5	38.3	74.8	34.3
IV	16 290.31	5 779.00	5 635.66	0.97	34.6	35.5	70.1	30.2
V	16 242.19	6 408.00	6 222.45	0.97	38.3	39.4	77.7	37.0
VI	16 266.25	7 229.00	7 077.54	0.98	43.5	44.4	87.9	44.4
VII	16 073.75	6 318.00	6 621.96	1.05	41.2	39.3	80.5	40.1
VIII	16 194.06	6 721.00	6 957.15	1.03	43.0	41.5	84.5	42.8
IX	16 170.00	6 479.00	6 610.16	1.02	40.9	40.1	81.0	40.1
X	16 121.88	6 974.00	7 159.65	1.03	44.4	43.2	87.6	44.7
XI	15 616.56	6 674.00	6 523.25	0.98	41.8	42.7	84.5	42.1
XII	16 603.13	6 433.00	6 494.80	1.01	39.0	38.7	77.7	37.4
Year	192 500.00	75 283.00	76 079.39	1.01	39.5	39.1	78.6	38.2