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THE ECONOMIC POSSIBILITIES OF ELECTRICITY PRODUCTION FROM WASTE HEAT

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Development in the energy market motivates its participants to think about increasing the use of primary energy sources and thereby reducing energy costs. One of the options is the production of electricity from waste heat. The first part of the article is focused on the quantification of the theoretical potential of waste heat in terms from the energy balance of the Czech Republic. The second part focuses on the preparation of a business case that describes one of many real possibilities of the performance of investment in a device for the use of waste heat from industry.

Keywords: power production, waste heat

Introduction: Primary energy sources (PES) consumption, energy efficiency, estimation of the amount of waste heat

Table 1 summarises the consumption of coal and the natural gas in the Czech Republic. Coal and natural gas are the key primary energy sources (PES) in the CR. Power production consumes about 60%, industry about 16.5%. But industry is also an important consumer of the products of power production, the both heat and electricity.

There is a question of how effectively the primary energy sources are used, ie which values achieve the coefficient of fuel efficiency. This coefficient can be compiled as the ratio of produced energy for the batch of primary energy sources.

Considerations on the use of waste heat for reducing the demands of the national economy in primary energy sources must be based on the theoretical balance amount. The problem is the identification the potential of this source. Data on the amount of "waste" heat from the processes are not available. There are statistical reports of "only" final consumption of already-transformed energy, or PES inputs to each sector.

More-precise information can be obtained perhaps only from data on energy transformations. Statistics of production in large power plants and CHP plants of heat and electricity are provided in the following table, which was prepared based on data from the Czech statistical office, [1], [2], [3]. In the summary, the information on production electricity and the heat energy in Factory power production – stating that combined heat and power (CHP) has weakened the influence of balance data from 2010 because it significantly deviated from the average and statistics – is apparently inaccurate. This inaccuracy can be demonstrated. According to the calculation methodology, electricity production in these sources showed over 50% efficiency, which is unrealistic.

From Table 2, the efficiency of the conversions is obvious. In the production of electricity from coal, the primary energy is transformed with efficiency of around 31%, which corresponds to common experience. Table 2 also shows a well-known fact that the CHP significantly increases the efficiency of fuel use. In comparison with Table 1, it is clear that the effort to save PES must primarily target power production, particularly in the deployment of CHP.

Energy balance in CR Coal and natural gas	2009 PJ	2010 PJ	2011 PJ
Total consumption of coal and natural gas	1013.27	1111.45	1056.53
Of which			
statistical difference	-4.56	11.39	0.86
energetics of coal	557.68	587.63	594.25
energetic of natural gas	55.17	59.26	41.53
processes out of energetics	57.63	61.92	59.61
final consumption of coal	118.67	124.86	122.54
final consumption of natural gas	228.68	266.39	237.72
Consumption by sector	PJ	PJ	PJ
energetics	612.85	646.89	635.78
industry	167.25	179.69	176.35
others	233.17	284.87	244.4
	%	%	%
energetics	60.48	58.20	60.18
industry	16.51	16.17	16.69
others	23.01	25.63	23.13
Final consumption - industry	167.25	179.69	176.35
coal	86.18	84.2	88.06
natural gas	81.07	95.49	88.29
Transformed energy consumption-industry	100.81	108.11	109.14
heat	22.24	25.18	25.9
electricity	78.57	82.93	83.24

Tab. 1 – Energy balance in CR for coal and natural gas

Expanding or building new district heating systems faces strong legislative and economic difficulties. The interesting growth potential of cogeneration is the broad application of decentralised cogeneration. It is necessary to take into account the environmental aspects of the deployment in the locations, the power system operation, etc.

The degree of fuel efficiency reaches 44.35% for power production. The data do not include boiler plants without CHP. We can say that with respect to the orientation of energy as an industry specialised in efficient energy use, it is in theory possible as a very effective use of energy transformation.

On the other hand, the purpose of the use of energy in the industrial process is to ensure the functioning of the sub-process, minimising investment requirements for appliances, etc, not maximising the use of PES. Consequently, the waste heat from the technological processes furnaces and dryers is often emitted into the atmosphere at a temperature that is high from the perspective of power production, with a theoretically-lower fuel efficiency. It can be deduced that the degree of fuel efficiency in the industry will be lower than in power production. If we accept the consideration specified, it is possible to identify the minimum potential of "waste" heat that is produced by industrial factories and that is likely to appear as low-potential usable waste heat.

ENERGETIC BALANCE IN CR. COAL	PEZ		FUEL USE EFFICIENCY
2009 - 2011	PJ	GWh	%
Public energetic – power plants	343.3	95 357.4	33.71
Factory energetic – power plants	4.1	1 140.7	32.84
		weighted average	***33.70***
Public energetic – CHP	179.5	49 868.5	63.66
Factory energetic – CHP	52.1	14 466.7	48.88
		weighted average	***60.34***
TOTAL	579.0	160 833.3	44.35

EFFICIENCY OF ENERGY TRANSFORMATIONS	ELECTRICITY PRODUCTION		HEAT PRODUCTION		
		efficiency			efficiency
	GWh	%	TJ	GWh	%
Public energetic – power plants	32 143.0	33.71	0.0	0.0	0.00
Factory energetic – power plants	374.7	32.84	0.0	0.0	0.00
Public energetic – CHP	10 918.7	21.89	74 987.0	20 829.7	41.77
Factory energetic – CHP	4 932.0	34.09	7 700.5	2 139.0	14.79
	weighted average	**31.07**			

Tab. 2 – Energetic balance in CR, coal

Industry consumes 167.25 PJ PES directly and approximately 22.24 PJ in supplied heat. That is about 190 PJ of heat. For simplicity, electricity is not included in the account. We estimate the degree of fuel efficiency in the industrial processes (heat used to the specific activity, such as heating) similarly for energy to be 45%; the amount of waste heat from these processes can reach values of about 105 PJ. With the assumption that the lower limit value of the fuel efficiency is 20%, the quantity of waste heat will then be 152 PJ. The amount of waste heat from industry, which could be used to generate electricity, we can generally estimate at 120 PJ.

Regarding the structure of the heat source, with regard to note [4], the following is possible:

- Appreciable heat from products after processing;
- Appreciable heat from flue gas – furnaces, dryers;
- Appreciable heat from the cooling of technological processes;
- Appreciable heat from cooling water from compressor stations.

When using appreciable heat waste media and products, it is possible to obtain great amounts of heat for additional transformations. The re-use of heat in the same process is obviously technologically limited (direct recovery). An interesting possibility may be thermal cycles capable of utilising this heat to produce electricity, for example the Organic Rankine Cycle (ORC).

Electricity production in ORC

Details on features and technical development in the field ORC are readily available in the specialised press today. ORC devices work on the similar principle as conventional steam technology. Differences can be observed in the design and interconnection scheme of the device; this is mainly influenced by the nature of the used working fluid. In practice, the most common use lies in the area of refrigerants (R245fa, R134a), silicone oils and hydrocarbons (pentane, toluene, etc). Compared to water, working fluids offer an opportunity to use waste heat at low potentials, generally with temperatures higher than 100 ° C. The efficiency of devices for the recovery of waste heat without using combined heat and power production is in the range 5-11%.

Case study

An example of economic model installation of ORC may be the recovery of appreciable heat from the flue gas of a furnace for heating the blanks for pressing. The heat power output of furnaces reaches values around 1 MW; the outgoing flue gas temperature is around 400 ° C. The nominal efficiency of ORC device can think of 15.3%, excluding own consumption for heat dissipation to the atmosphere [5]. Operating electrical efficiency can be considered at the level of 12%. We consider the permanent usage 500 kW of heat; the unit will be operating electric power at 60 kW. The unit will operate 6,000 h/year from 10.8 TJ of waste heat, producing 360 MWh of electricity. The unit price is CZK 6 million.

A key factor is the selected funding model. An interesting alternative is a form of energy performance contracting (EPC), where the client payment is implemented as pay-per-kWh. It is a variant of the commonly-used business models, pay-per-click, pay-per-paper, etc. At the beginning of the relationship, the client will pay part of the price of the investment, deliver its waste heat to the device and buy the electricity according to defined price list. The cost of this electricity is designed to achieve the required saving by device for the client. It is necessary to correct the electricity prices during the lifetime of the investment horizon so that the client reaches a defined return on investment that guarantees him an EPC contractor. On the other hand, the price of electricity from the client will parametrically depend on the heat supplied to the ORC. It is necessary to restrict situations in which the client will not want to waste heat to supply the device for various reasons. All prices are given without VAT and at current prices.

In this model, the client pays once according to a contract for the EPC 40% of the units (CZK 2.4 million). The contract is concluded for 10 years. After the expiration, the client's deposit will be credited as the residual value of the device at the supplier and the unit becomes the client's property. The nominal growth rate of the electricity market (4.5% [6]) is considered, while the price of electricity from ORC is adjusted for inflation at 2.37% annually [7]. The market price of electricity in year 0 is considered CZK 3.9 /kWh, and for electricity from ORC it is considered to be CZK 2.8 /kWh. A nominal discount rate of 12% for the client is considered, which appears to be sufficient due to the very low risk of the project.

In the following figures there is a statement of cash flow (CF) in nominal and the discounted variants along with the development of electricity prices. In the first year, the client realised cost savings of purchased electricity of CZK 360 thousand, so a fair amount for the CF is CZK 2.04 million, not the expected CZK 2.4 million. Simple payback is set at four years, discounted reaches 5.5 years.

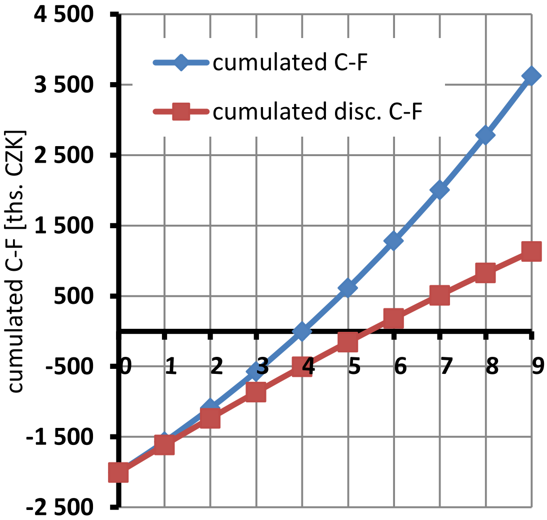

Fig. 1 – Cumulated CF

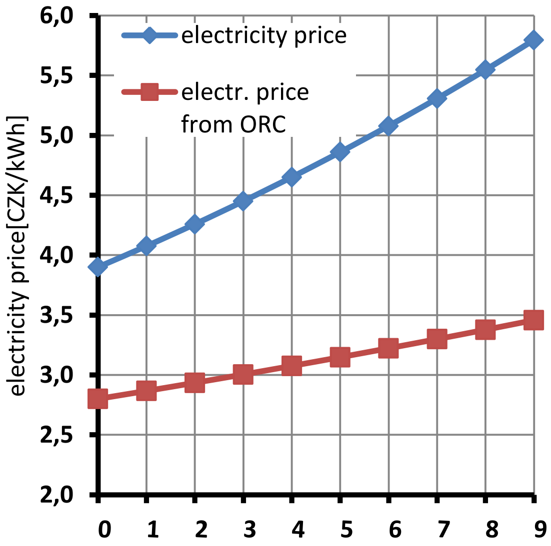

Fig. 2 – Electricity price

From the perspective of the EPC, the contractor is required to cover CZK 3.6 million investment in year 0. This is done using its own funds in the amount of 20%; the rest is commercial lending with an interest rate of 5%. The length of the loan is 8 years with a grace period of one year of principal. The real CF is about CZK 400 thousand/year; IRR reaches around 80%, and the contractor achieves a positive cumulative CF after the second year of the investment. These parameters provide an adequate reserve and profitability in terms of energy technology contractors. The contractor shall bear the cost of repairs and maintenance costs of CZK 250 thousand/year and the installation costs of CZK 600 thousand in year 0. The items were included in the CF.

Conclusion

The research balance in the Czech Republic indicates that power production is a key consumer of PES, with a high proportion of "waste" heat and it makes sense to deal with the intensification of CHP in the future. However, the current application of CHP shows a number of complications. In the future, it will probably be advantageous to consider decentralised CHP as an interesting alternative, of course, taking into account economic and ecological aspects of this development. Major consideration of the low-potential amount of waste heat led to the conclusion that we can expect potential of heat at 120 PJ in industrial production in the Czech Republic. This opens a significant scope for the application of technologies that can utilise this heat. At the theoretical level, around 11 thousand of pieces of ORC installation like the one described above could be applied, which would produce about 3.95 TWh of electricity.

One of the possible options for usage of the waste heat is the application of ORC technology within the EPC contract for 10 years with an integrated pay-per-kWh approach, which is inspired by similar business models from other business areas (pay-per-click, pay-per-paper). The paper demonstrates that it is possible to compile a suitable model for financing these investments with immediate effect for a client and an interesting return. It is shown that the choice of a discount rate of 12% of the investment for EPC client is feasible. It is obvious that the selected contractor model is economically viable with sufficiently-high IRR to allow it to be realised.

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