TECHNICAL AND ECONOMIC ASPECTS OF WASTE HEAT UTILISATION

by

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The main aim of the following presentation is the comparison and evaluation of the conditions for waste heat utilisation in Germany and in Poland. This paper presents synthetically the results of economic analysis of the different technical variants. The employment of heat pumps and other heat transformers, respectively, can reduce the energy consumption, but using of those technical possibilities depends mainly on the economic aspects. The main parameters of the financial calculations were the energy and equipment costs but beyond it a number of other factors were also considered and compared, for example calculation interests, profit tax level and similar. Four different technical alternatives were analysed, it is using of absorption heat pump, compression heat pump, heat transformer (absorption), and a special combined system with gas motor to drive of heat pump compressor. The capital value as main result of the investigations is in Poland generally lower because of relatively high investment cost and lower energy prices compared to the situation in Germany and West Europe. The basis for the presented comparative analysis was an industrial project in Germany which effected in development of concepts for waste heat using.

Key words: *waste heat, case study, cost analysis, compression heat pump, refrigeration installation*

Introduction

The development of technical systems, equipment, and installations for low temperature heat transformation and use was very intensive in recent decades. The development of heat engineering made it possible to reduce primary energy consumption by low grade energy transformation and use on a higher temperature level – in comparison to conventional solutions. Low temperature energy sources amount to an enormous energy potential, which can be exploited in different branches primarily for heating, but also as a component of industrial energy supply systems, for example for the utilisation of "waste heat sources" (chemical industry, metallurgy, energy supply, food industry and similar). The economy of possible technical solutions determines their application in energy systems and constitutes the main object of the following analysis.

The main aim of the following analysis is the economic investigation of the possible technical solutions and comparison of the conditions in Germany and Poland. The analysis bases on a real project from an industrial energy supplying system in Germany. The conditions and results of the investigations will be compared with the situation on the Polish energy market.

Technical aspects of an industrial project as an example for low rate energy systems

The relevant project of the waste heat utilisation comes from the German food industry. The concept consists in the utilisation of low temperature waste heat from the existing refrigeration system and other heat sources (cooling systems of different machines like pumps, ventilators and others). Figure 1 shows the refrigeration installation (vapour-compression refrigeration cycle) with the installed refrigeration effect of about 1.5 MW and with "cold storage" capacity of ca. 40 10^6 kJ to compensate irregular daily requirements. The temperature level of the waste heat fluctuates between 35-45 °C.

Four different possibilities for waste heat utilisation [1-4 and others] from the refrigeration process and other possible sources were considered and analysed:
- low temperature heat use with a heat transformer; this is a relatively new technological development with different advantages related to the efficiency of low and middle temperature heat transformation, but there are no standardised technical installations on the market. That is why investment costs for this solution were only estimated on the basis of comparable absorption heat pump installations (fig. 2a),
- absorption heat pump with heat supply from the existing gas boiler (saturated steam) and ammonia-water as refrigerant (fig. 2b),
- compression heat pump (fig. 2c), and
- a combined solution with a compression heat pump and a gas motor for the drive of the heat pump compressor and the utilisation of low temperature heat from the refrigeration process and middle temperature heat from the gas motor process (fig. 2d).

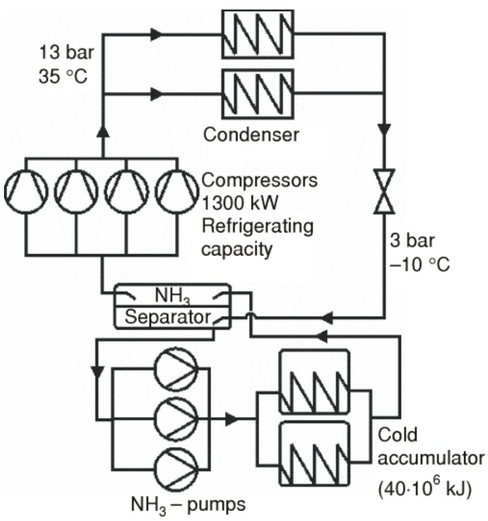

Figure 1. Refrigeration system

Figure 2 shows the appropriated technical alternatives in form of simplified circuit diagrams with the basic parameters.

More details about the technical aspects and economic framework of the project were published in other papers [5-8].

The following economic investigations consider only the relevant technical installations and disregard some details or parts of equipment, which are specific

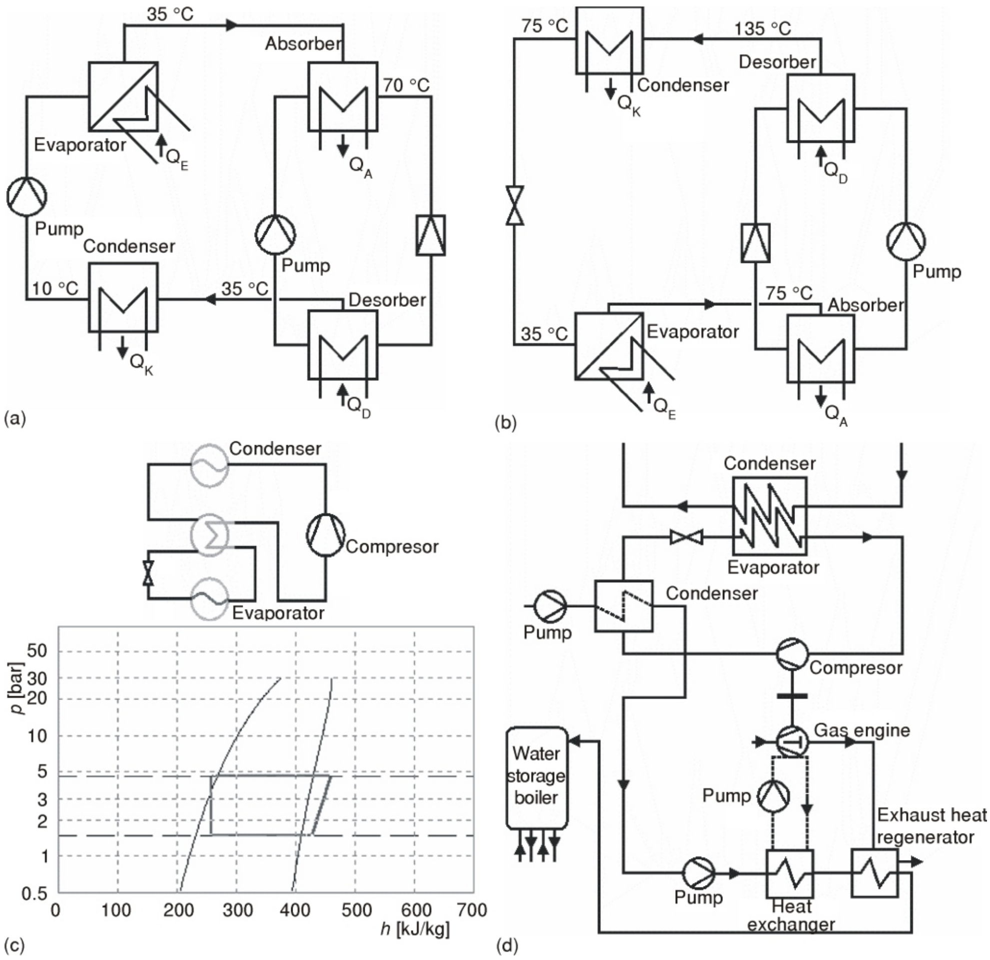

Figure 2. The analysed variants of waste heat utilisation
(a) heat transformer, (b) absorption heat pump, (c) compression heat pump, (d) combined system with gas motor

for the particular technological variants. For example the heat storage installation has not been considered. This part of the equipment would be important for the technical realization but for the comparative analysis was negligible.

Economic analysis procedure

The economic calculations base on the dynamic present-value-method [9] and the discount procedure for the conversion of expenditures and profits. Hence, eq. 1 is used for calculations the capital value:

$$C = (E - A)\frac{\left(1+\frac{P}{100}\right)^{n} - 1}{\frac{P}{100}\left(1+\frac{P}{100}\right)^{n}} - K_0 \tag{1}$$

The constant annual incomes were calculated as the saving of gas costs by the alternative heat supply from a gas boiler. The expenditures consider all exploitation costs including manpower costs. The investment capital (eq. 2) was reduced for the purpose of comparison only to the direct investment costs $K_{0_{\mathrm{dir}}}$:

$$K_{0_{\mathrm{inv}}} = K_{0_{\mathrm{dir}}}\left(1 + \sum_{i=1}^{n}\frac{\alpha_i}{100}\right) \quad (n = 7) \tag{2}$$

Neglecting the seven previously mentioned supplements simplifies the comparison and effects the results of the analysis only marginally. Complementing to the capital value method the following parameter was also determined – annuity and capital service value:

$$a = \frac{\frac{P}{100}\left(1+\frac{P}{100}\right)^{n}}{\left(1+\frac{P}{100}\right)^{n} - 1} \tag{3}$$

$$K_D = K_0\, a \tag{4}$$

In this way the most important factors of the economic evaluation were defined, which were the basis for the comparison.

Conditions for the comparison and representative results of the calculations

The main aim of the following calculations was the investigation of the effects of different parameters on the economic effect. The representative project was the basis for this analysis. In order to make the comparison realistic and to present an authentic example, the reference project was theoretically transferred to another energy market, which means from German to present Polish conditions. The starting parameters for the analysis of differences between German and Polish conditions were simplified to show the most important aspects and neglect irrelevant influences. Therefore, investment costs were supposed to be on the same level in both countries, because the major share of the total investment value was constituted by equipment costs. The share of staff costs was insignificant. Staff costs in Poland are essentially lower compared to the situation in Germany but, according to the relevant project, neither the share of these costs at the investment nor at the exploitation, affected the results of the investigations as regards general conclusions. The different staff costs were only estimated and considered by the fixing of the constant annual expenditures and their effect was a second rate quantity.

The most important factor of the economic analysis, calculations of expenditures and incomes was energy prices. There are big differences between German and Polish energy market with respect price level and the prices arrangement system. Because of this, the representative mean prices for the conditions of the relevant project were considered, which means for the heat performance in the order of 1.5-2.0 MW and comparable conditions regarding relevant industrial energy supply systems.

In tab. 1 and diagrams (figs. 3-8) are shown the present parameters of the four analysed technical alternatives depending on the most important economic parameters and as a comparison between German and Polish conditions.

Table 1. The mean parameter and results of the economic analysis (connected to the fig. 2 and eq. 1-4)

	Variants	K_0 [10^3 €]	K_D [10^3 €]	a	E [10^3 €]		A [10^3 €]		p [%]	n (a)	C [10^3 €]	
					D	PL	D	PL			D	PL
1	Heat transformer	82.1	7.9	0.096	21.0	16.3	11.8	8.5	5	15	21.7	–1.1
2	Absorption heat pump	75.5	7.3	0.096	25.8	17.9	20.0	13.7	5	15	–15.3	–31.9
3	Compression heat pump	45.7	4.4	0.096	23.2	16.9	18.4	13.0	5	15	4.1	–5.2
4	Combined system with gas motor	65.0	6.3	0.096	22.8	17.4	17.1	12.9	5	15	–5.8	–18.3

The graphs below illustrate the influence of variables: calculation exploitation period (fig. 3), calculation interest rate (fig. 4), gas prices (fig. 5), and electricity prices (fig. 6). From the developed sensitivity investigation result the economic implications of the changing energy prices only indirectly; it means the diagrams 5 and 6 illustrate the modifications of the capital value dependent to the varying (yearly constant) earnings and expenditures. In this simulation the gas and electricity prices vary in the range of 20% for gas and 30% for electricity.

In order to show the effect of energy prices on the economic results objectively and independently of other parameters, the results in figs. 7 and 8 are base on a reference

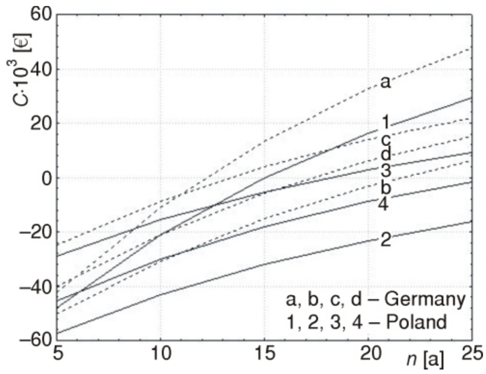

Figure 3. Influence of the exploitation period on the present value amount

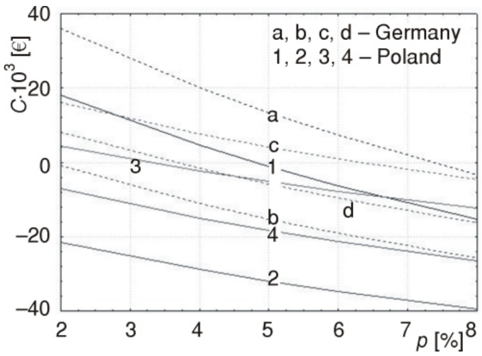

Figure 4. Influence of the calculation interest rate on the present value amount

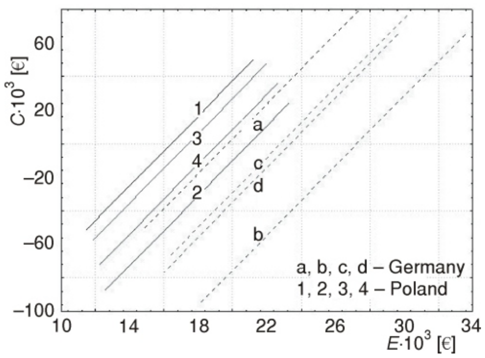

Figure 5. Influence of the variable gas prices in the range of 30% on the present value amount

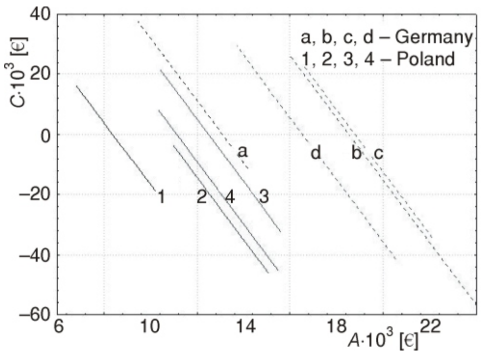

Figure 6. Influence of the variable electricity prices in the range of 20% on the present value amounting the range of 30% on the present value amount

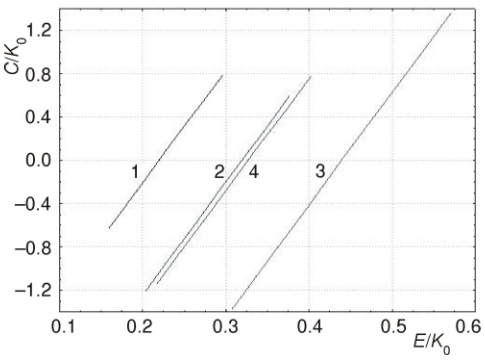

Figure 7. Influence of the variable gas prices connected to the reference dates (dimensionless co-ordinate system)

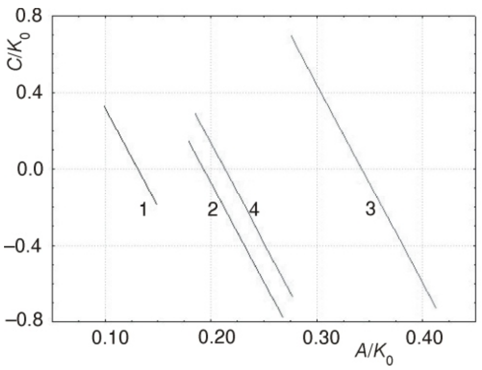

Figure 8. Influence of the variable electricity prices connected to the reference dates (dimensionless co-ordinate system)

projects. This means that the basis for the calculation was not made of parameters different in these two countries but of the mean values taken as a reference point. This way, both graphs illustrate the theoretic economic consequences without coupling with one of the analysed conditions. The capital value, incomes and expenditures are shown in figs. 7 and 8 as dimensionless in relation to the relevant investment capital.

Conclusions

The capital value of the regarding investments is generally lower in Polish conditions compared to the situation in Germany. It means that the same measures and technologies for the waste heat utilisation are in Germany more effective from the economic point of view. The economic equivalent of the waste heat is dependent on the technology and cost, but on the other hand the economic conditions cause the divergent assessment of different systems. The main reason for this conclusion is various gas prices, because the alternative heat source of the relevant comparative analysis was a conventional gas boiler. In case of using coal as an alternative fuel for heat production the differences between capital values would still be high. The influence of other parameters like electricity prices, personnel and exploitation costs, taxes and similar were much lower in comparison to the fuel cost of the reference heat source.

The results of project analysis show for the German conditions, that two technologies of waste heat using would be profitable, it means heat transformer and compression heat pump related to the standard economic parameter $P = 5\%$ and $n = 15$. The combined system with gas motor lie close by the null line of capital value (considering the uncertainty of both the data and used economic methods) and the absorption heat pump is for the relevant case evidently under this line. The comparison with the Polish conditions proves the same order of the analysed variants but the capital value is significantly lower. None of discussed technology cases lies in positive area of the mentioned values of P and n. The changing of economic conditions can make most of the relevant cases profitable but in the sphere of realistic economics and technical room to move there are not any new aspects.

The general conclusions are only connected with the concerning project and the four technical variants and can not be extrapolated to other areas (for example different temperature levels, technologies, special price conditions and others).

Nomenclature

A – yearly constant current expenditures, [€]
a – annuity, [–]
C – capital value, [€]
E – yearly constant earning, [€]
K_D – capital service value, [€]
K_0 – investment capital, [–]
$K_{0_{dir}}$ – direct investment costs, [–]

$K_{0_{inv}}$ – total investment costs, [–]
n – calculation depreciation period, [year]
P – calculation interest rate, [%]

α_i – supplements for interest, insurance, taxation, price sliding, inflation, putting into operation, own achievement and withdrawal, [–]

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