GENERAL ECONOMIC MODEL FOR UTILIZATION OF WASTE HEAT FOR THE PRODUCTION OF ELECTRICAL ENERGY AND HEAT SUPPLY

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Abstract

Industrial processes consume large quantities of fuel and electricity that ultimately produce heat, much of which is typically wasted to the atmosphere. Re-using of this waste energy within manufacturing process is the optimal solution. Within is a research project PITAGORAS co-funded by the European Commission framed into the “FP7 - Smart Cities program” a large scale pilot plant has been built and commissioned for production of electricity (ORC technology) and heat for central heating system of a town. This contribution describes the general economic evaluation of return on investment for similar technology within the steel industry in Czech Republic.

Keywords: Metallurgy, waste heat, ORC technology, central heating system, economic model

1. INTRODUCTION

Most waste-heat-recovery devices transfer heat from a high-temperature effluent stream to a lower-temperature input stream. Waste heat can also be utilized by using hot gases to produce steam through a turbine, to generate electricity. Particularly in the metallurgical industry with high energy consumption there are many possibilities to use these “green” technologies [1].

Within is a research project PITAGORAS a large scale pilot plant has been built and commissioned for production of electricity (ORC technology) and heat for central heating system of a town. The aim of the paper is to develop a general economic model for evaluation of return on investment for similar technology within the steel industry in Czech Republic.

2. TECHNICAL PARAMETERS OF THE PROJECT PITAGORAS

In the frame of the European funded PITAGORAS project (FP7, Smart Cities Programme) a large scale pilot plant based on ORC technology has been built and commissioned for electricity and heat production using waste heat from fumes of an electric arc furnace (EAF) in a steel mill in Brescia (Italy). The plant was successfully commissioned on October 2016 and has a recovery potential of 9.1 MW_t and produces electricity in summer (1.800 kW_e) and district heat in winter (10MW_t).

Figure 1 shows a block diagram of the demo plant in Brescia. The source of the waste heat to be recovered is the flue gas from the electric arc furnace installed at the steel mill. The flow rate of the flue gas varies over the course of the batch operation of the furnace. During the melting phase about 100.000 Nm³/h are available, during the tapping phase this flow rises to about 150.000 Nm³/h while the temperature drops to about 300 °C. The flue gas temperature averages to about 500 °C. This hot flue gas is then led into the waste heat recovery unit, designed and installed by Tenova S.p.A., where it is cooled down to about 200 °C by evaporating water and creating saturated steam as an energy carrier.

The steam produced is then fed into a steam accumulator with a volume of 150 m³, which serves as a buffer storage to equalize the fluctuations in the steam production caused by the batch operation of the EAF to guarantee optimal operation of the downstream processes.

Further usage of the steam depends on the time of the year: during summer periods (mid-April to mid-October) steam is used to power a water-cooled ORC-Module, designed and installed by Turboden S.p.A., for electrical power generation with a nominal power of 1.8 MW_e to partially cover the electric own demand of the steel mill. During the winter periods (mid-October to mid-April) the steam is fed to two heat exchangers with a nominal power of 10 MW_t in order to provide heat to the district heating system of the city of Brescia operated by a2a energia S.p.A. This mode of operation has been considered the most appropriate and efficient taking into account the specific boundary conditions of the plant as well as the heat delivery contract with a2a energia.

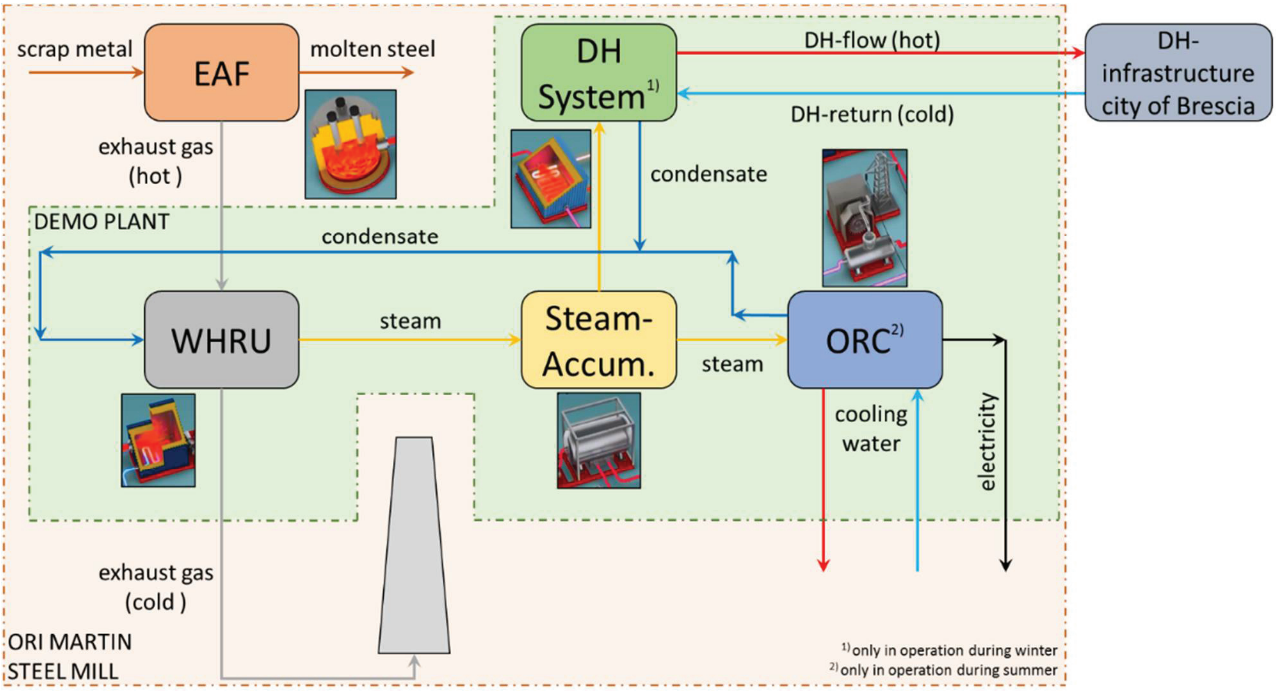

Figure 1 Concept scheme of the whole process

3. GENERAL ECONOMIC MODEL FOR EVALUATION OF RETURN ON INVESTMENTS

Based case studies for steel producers in the Czech Republic [2] and Slovakia [3] the general economic model for evaluation of return investments was created. This economic model provides the first approximation of a simple return on investment for potential investors. The model is primarily designed for metallurgical industry within the Czech Republic nevertheless it can also be used in other EU countries.

The economic model for the simple return on investment counts with two variants. Namely option A (only electricity generation) and option B (electricity generation and heat for district heating). This economic model consists of two parts. The first part defines the technical and production parameters. In the second part there is a model and calculation of a simple return on investment with respect to the ORC project.

Table 1 defines the average annual technical parameters of ORC project. First, with a steam boiler and steam accumulator input power is defined. The result of these parameters is the output power, which is actually the input power for the ORC device for the production of only electrical energy (option A) and for the production of electricity and heat (variant B). Based on this efficiency we obtain different values of output power for both variants. Average annual electricity production and average annual heat production (for both options) is calculated from the output power and the volume of annual operating hours.

Table 1 The average annual technical parameters of an investment within the ORC project

Specification of the technical and production parameters of the investment			**Unit of measure**	**Option A** Only production of electricity	**Option B** Production of electricity + heat	**Row**
WHRU + Steam Accum.	Installed power	Input	MW_t	12.36	10.36	1
		Efficiency	%	70	70	2
		Output	MW_t	8.65	7.25	3
	Operating hours of the year		Hours	8 400	8 400	4
	Annual output		MWh_t	72 660	60 900	5
ORC production of electricity	Installed power	Input	MW_t	8.65	7.25	6
		Efficiency	%	19.42	19.31	7
		Output	MW_e	1.68	1.40	8
	Operating hours of the year		Hours	8 400	8 400	9
	Annual output		MWh_e	14 112	11 760	10
ORC production of heat	Installed power	Input	MW_t	-	7.25	11
		Efficiency	%	-	47.59	12
		Output	MW_t	-	3.45	13
	Operating hours of the year		Hours	-	4 800	14
	Annual output		MWh_t	-	16 560	15

Table 2 Economic model of simple return on investment within the project ORC

Specification of the technical and production parameters of the investment		**Unit of measure**	**Option A** Only production of electricity	**Option B** Production of electricity + heat	**Row**
Total construction and machinery investment expenses		**Thous. €**	**5 500**	**5 200**	16
Average annual revenues and savings from operating investments	Annual savings on the purchase of electricity	MWh_e	14 112	11 760	17
		€/MWh_e	80	80	18
		Thous. €	1 129	941	19
	Annual revenues from heat sales	MWh_t	0	16 560	20
		€/MWh_t	0	19.1	21
		Thous. €	0	316	22
	Annual savings on emission allowances for CO_2	tCO_2/MW_eh	1.6	1.6	23
		Tons	22 579	18 816	24
		€/t CO_2	13	13	25
		Thous. €	294	245	26
	Total annual revenue and savings	**Thous. €**	**1 423**	**1 502**	27
Average annual expenditure on operating an investment	Annual maintenance costs	Thous. €	20	20	28
	Annual operating expenses	Hours	400	400	29
		€/Hour	15	15	30
		Thous. €	6	6	31
	Annual costs - other direct costs	Thous. €	4	4	32
	Total annual operating expenses	**Thous. €**	**30**	**30**	33
Average annual cash flow from the operation of the investment		**Thous. €**	**1 393**	**1 472**	34
Simple return on investment		**Years**	**3.95**	**3.53**	35

Defined values | Assumed values | Calculated values

Table 2 shows an example of an economic model for calculating a simple return on investment (for both options A and B). Firstly, the total construction and machinery “investment costs” are defined. Subsequently, calculations of the average annual revenues, savings in investment and operation of average annual expenditure on operating investments are made for both options (A and B). Based on the difference of these values, the average annual Cash Flow is calculated from the operation of the investment within both variants. The result of this table is the calculation of a simple return within variants A and B.

Under the term Defined values we mean values of the input parameters, which are defined within a specific investment project. Under the term Assumed values we mean values which were already defined or calculated. Formulas used in the economic model are described below.

Calculation of output power for rows 3, 5, 8 a 13:

$$OP = IP \times E \tag{1}$$

OP - Output power (MW), *IP* - Input power (MW), *E* - Efficiency (%)

Annual electricity production - row 10:

$$APe = OPe \times H \tag{2}$$

APe - Annual electricity production (MWh_e), *OPe* - Output power electricity from ORC (MW_e), *H* - Operating hours of the year (hours)

Annual heat production - row 15:

$$APt = OPt \times \mathrm{H} \tag{3}$$

APt - Annual heat production (MWh_t), *OPt* - Output power heat from ORC (MW_t), *H* - Operating hours of the year (hours)

Calculation of the annual savings for the purchase of electricity - row 19:

$$ASe_{€} = APe \times PRe \tag{4}$$

$ASe_{€}$ - Annual savings for the purchase of electricity (Thous. €), *APe* - Annual electricity production (MWh_e), *PRe* - Price of electricity (€/MWh_e)

Calculation of annual revenue for heat sales - row 22:

$$ARt_{€} = APt \times PRt \tag{5}$$

$ARt_{€}$ - Annual revenue for heat sales (Thous. €), *APt* - Annual heat production (MWh_t), *PRt* - Price of heat (€/MWh_t)

Calculation of annual emissions of CO_2 - row 24:

$$APco_2 = APe \times Mco_2 \tag{6}$$

$APco_2$ - Annual production of CO_2 (tons), *APe* - Annual production of electricity (MWh_e), Mco_2 - Specific content of CO_2 per produced MWh of electricity- row 23 (tCO_2/MWh_e)

Calculation of annual cost savings for emission allowances for CO_2 - row 26:

$$ARco_{2€} = APco_2 \times PRco_2 \tag{7}$$

$ARco_{2€}$ - Annual revenue for emission allowances for CO_2 (Thous. €), $APco_2$ - Annual production of CO_2 (tons), $PRco_2$ - Price of emission allowances for CO_2 (€/tCO_2)

Average total annual revenue and savings from operating an investment - row 27:

$$AAR_{€} = ASe_{€} + ARt_{€} + ARco_{2€} \tag{8}$$

$AAR_€$ - Average total annual revenue and savings from operating an investment (Thous. €), $ASe_€$ - Annual savings for the purchase of electricity (Thous. €), $ARt_€$ - Annual revenue for heat sales (Thous. €), $ARco_{2€}$ - Annual savings for emission allowances for CO_2 (Thous. €)

Calculation of annual expenses for operating the investment - row 31:

$$AE_€ = Ch \times HR \tag{9}$$

$AE_€$ - Annual expenses of operating the investment (Thous. €), Ch - Capacity of hours needed for annual service operation of the investment (hours), HR - Hourly rate of operating the investment (€/hour)

Average total annual operating expenses of the investment - row 33:

$$AAE_€ = AM_€ + AE_€ + AC_€ \tag{10}$$

$AAE_€$ - Average total annual operating expenses of the investment (Thous. €), $AM_€$ - Annual maintenance costs - row 28 (Thous. €), $AE_€$ - Annual expenses of operating the investment (Thous. €), $AC_€$ - Annual expenditure on other direct costs - row 32 (Thous. €)

Average annual Cash Flow from operating an investment - row 34:

$$AACF_€ = AAR_€ - AAE_€ \tag{11}$$

$AACF_€$ - Average annual Cash Flow from operating an investment (Thous. €), $AAR_€$ - Average total annual revenue and savings from operating an investment (Thous. €), $AAE_€$ - Average total annual operating expenses of the investment (Thous. €)

Calculation of simple return on investment - row 35 [4]:

$$RI = TE_€ / AACF_€ \tag{12}$$

RI - Simple return on investment (years), $TE_€$ - Total construction and machinery investment expenses - row 16 (Thous. €), $AACF_€$ - Average annual Cash Flow from operating and investment (Thous. €)

4. DISCUSSION

The proposed general economic model defines the basic conditions for calculating the economic return on investment in this technology (waste heat utilization for production of electricity and heat). This model serves for a quick and simple calculation of the simple return on invested funds based on variable input conditions.

If the results of this general model are acceptable, it may proceed to a more detailed processing of input and output information. Consequently, the dynamic methods of investment evaluation (mainly calculation of the discounted return time, net present value and internal yield percentage) can be applied. Conversely, if the calculated payback time is unacceptable it makes no sense to go into dynamic methods because these results will always be worse due to the discounted value of the investment funds [5].

For the overall evaluation of the investment project it is very convenient to work with more investment options. Then we can compare and choose technically and economically the best option [6]. Variants A and B in **Tables 1 and 2** is an example of this procedure.

In order to define the benefits, it has to be stated that in the case of power generation the situation is simple. This power generation replaces the purchase of electricity so that the annual contribution is based on the annual electricity produced at the purchase price of the electricity (In **Table 2** is calculated the price of 80 €/MWh_e). More complicated is the situation of heat production, especially with the appreciation of the heat produced in this way. For this case **Table 2** shows the price of 19.1 €/MWh_t based on the sales price of heat purchased by the heat distributor. This condition occurs when the thus generated heat cannot be efficiently consumed directly by the investor or a potential end user, i.e. if there is enough waste heat that is already consumed in a process and also to heat water.

In case whereas the heat produced would replace heat purchased (or by direct heat and water production by standard technologies) then the heat produced could be valued by the heat supplied by the distributor (which is approximately 70 €/MWh_t or more). Alternatively, the heat produced in this way could be valued as a result of replacing the consumption of primary sources for its production (electricity or natural gas) which also comes at around € 70/MWh_t.

In this case the heat production would be valued at 70 €/MWh_t instead of the original 19.1 €/MWh_t, then the return on investment would be reduced to 2.25 years compare the original 3.53 year.

5. CONCLUSION

Within the PITAGORAS project a large scale ORC plant has been built and commissioned. It is one of the few installations in Europe which couples electricity production by an ORC unit with heat delivery to a DH network. The presented economic model shows that, in the case of application within the Czech Republic, the return period of the investment could range from 3.5 to 4 years. This successful pilot project can inspire many of metallurgical plants not only in the Czech Republic but also in other EU countries.

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PITAGORAS

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