Comparative technical and economic analysis of innovative methods for waste heat recovery from flue gases for boiler type BKZ 220-100

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Abstract. Two alternative schemes for waste heat recovery from flue gases of boiler type BKZ 220-100 in the Stepnogorsk TPP (Kazakhstan) are presented. The technical solutions are innovative because they create conditions for deep heat recovery even when using battery emulsifiers to purify the gas flow. A characteristic feature of the schemes is the purification of a small part (10-15%) of the stream by means of a bag filter and the mixing of the stream with the main gas flow consisting of moist gases after a battery emulsifier. An analysis and assessment of the technical and economic feasibility of the implementation of the two alternatives has been carried out.

1 Introduction

Waste heat recovery from flue gases of industrial and steam boilers is always a topical issue for industry and energy [10,14]. Each decrease in the flue gas temperature increases the rate of fuel use, reduces heat losses with the exhaust gases q_2 and directly affects the efficiency of the boilers [3,5,9,10, 19]. In addition to the direct benefits of fuel economy through heat recovery both the amount of harmful components and CO_2 emissions are reduced.

However, it should be noted that despite the undeniable advantages of waste heat recovery methods, there are sometimes insurmountable obstacles to the implementation of such projects. For example, the sulphur content of the fuel is essential [4] to the process – it determines the permissible limit temperature to which the gases can be cooled without causing condensation and low-temperature corrosion on the heating surfaces of the disposal facilities [3]. Sometimes there are energy schemes where it is difficult at first glance to assess the technical and economic feasibility of implementing a waste heat recovery system, especially when more than one technical solution is offered [5].

In the present work, a technical and economic analysis of two proposals for the utilization of waste heat from the exhaust gases of the steam generator BKZ 220-100F [7] in Stepnogorskaya TPP – Kazakhstan [4] is carried out.

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2 Problem description

At the Stepnogorskaya CHP, three steam generators of the BKZ 220-100F type are in operation. No. 5, 6 and 7), burning Ekibastuz coal [4, 7]. The average temperature of flue gases for the boiler No. 5 under consideration is very high, 183 °C, which leads to significant heat losses with the flue gases of up to 9 ÷ 9.5%. The average efficiency of boiler No. 5 does not exceed 84%, which gives grounds to look for opportunities to reduce the temperature of flue gases and thus increase boiler efficiency. It is also important to note that the existing emulsifier second generation [8] cleans the flue gases to a satisfactory degree and there is no reason at this stage to recommend a transition to another ash collection system. A significant disadvantage of wet ash collectors is their high-energy consumption for the circulation of flushing water. Due to the fact that humid gases after emulsifiers have a high relative humidity (in practice, 100%) heating of these is required before entering the pipe to prevent secondary condensation and subsequent sulfuric corrosion in the stack [3,6].

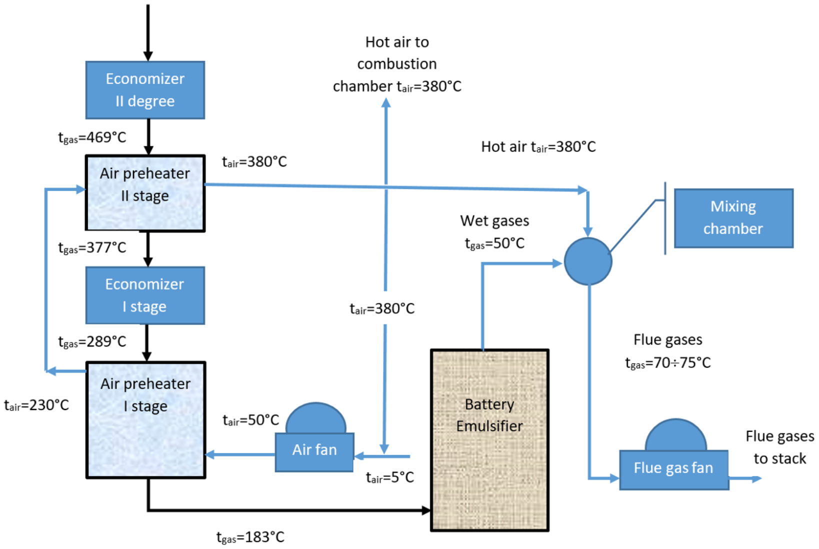


Fig. 1. Schematic diagram of the gas path after the steam generator with a battery emulsifier

A disadvantage of the presented scheme is the non-utilisation of the heat of the exhaust gases. With a high temperature of 183 °C, the gases after passing through an air preheater second stage enter a battery emulsifier which purifies the solid particles they contain. Thus, the potential from 183 to 125 °C is lost due to the wet method of gas purification used. Moreover, given that the gases purified in the emulsifier are wet (in practice their relative humidity is 100%), they should be heated additionally from 50 to 75 °C before entering the stack by mixing the flow of wet gases with part of the hot air after the air preheater 1 stage (air temperature is 380 °C). The diagram shows that the incoming air from the atmosphere is not heated by a steam heater, but this is done by mixing the outside air with part of the heated air after an air heater of the 1st stage (air temperature is 380 °C).

The preliminary assessment shows a high degree of heat loss, both with the heating air after the air heater 1st stage and with the unused potential of the flue gases before they enter the emulsifier.

3 The essence of the innovative method for waste heat recovery

There are two schemes for waste heat recovery from the exhaust gases, which create conditions for the elimination of the heating of the exhaust gases after the battery emulsifier [1], without using preheated air from a second stage air heater. These schemes will be analysed in detail to assess their technical and economic feasibility.

3.1. Description of the proposed method for heat waste recovery (variant 1)

The proposed method to improve energy efficiency provides for a more complete use of thermal energy of flue gases and the elimination of the need for additional heating in front of the stack. This can be achieved by directing a portion of the gas stream (11.5%) into a bag filter, keeping the same temperature, and then mixing this portion with the main stream (88,5% from the flue gas flow) in the existing mixing chamber to achieve the desired overall temperature.

The main flow of flue gases (88.5%) after the air heater at stage 1 enters an additional air heater-utilizer, with a heat output of 3019 kW. In it the temperature of the flue gases is reduced from 183 to 150 °C, while the captured heat is used to heat the outside air from 5 to 67 °C, which should enter the stage 1 air heater. The produced heat power is able to completely eliminate the old inefficient scheme of heating the air before the air heater. However, it should be noted that the additional air heater-utilizer should be made of thermosyphons to ensure a corrosion-free regime of its heating surfaces in the winter season [6]. After the air heater-utilizer the gases enter the existing battery emulsifier for wet purification of the gases. At the outlet of the emulsifier, the temperature of the gases is reduced to 55 °C at high relative humidity (100%). Therefore, before entering the stack, the gases are mixed in a mixing chamber, with the hot stream of purified gases coming from the bag filter. The temperature of the mixture (75 °C) is normatively determined by the condition to avoid secondary condensation of the gases in the stack.

The aerodynamic resistance of the bag filter, which will be connected in parallel with the emulsifier, does not differ from the resistance of the battery emulsifier, which will allow for the use of the existing exhauster without any changes.

Thus, several positive effects are simultaneously achieved:

- Energy consumption for heating flue gases with hot air is eliminated;
- Part of the heat energy of flue gases is recovered;
- Significant cleaning of gases from ash is carried out;
- Emulsifiers are unloaded, the volume of flush water directed to the ash dump is reduced, which reduces the load on the emulsifier and flush water pumps and theoretically makes it possible to reduce their power consumption (for example, by installing a frequency control when it is economically justified by the current prices and tariffs);
- If there is market demand and economically viable transportation opportunities, baghouse ash can be sold for use in construction, agriculture or other industries.

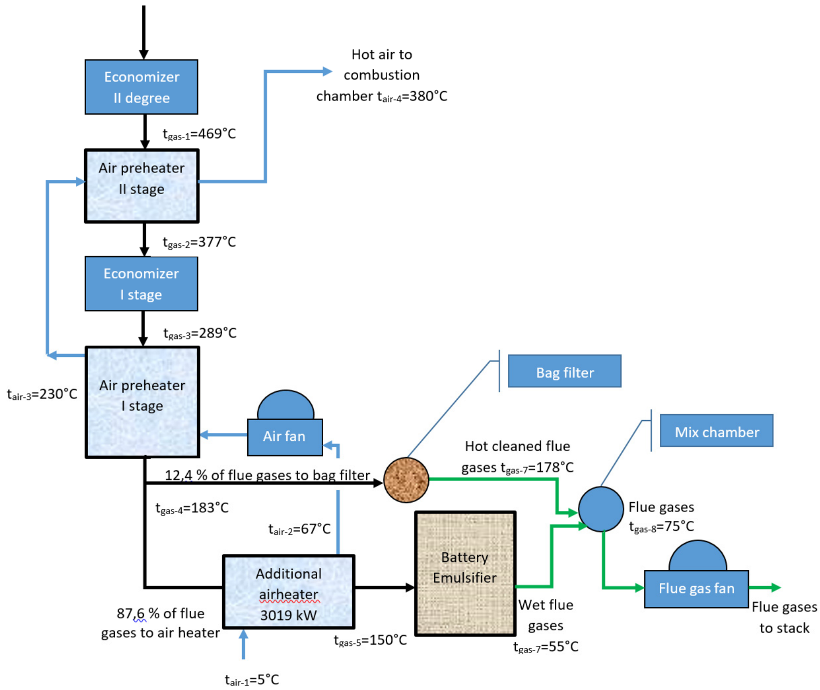


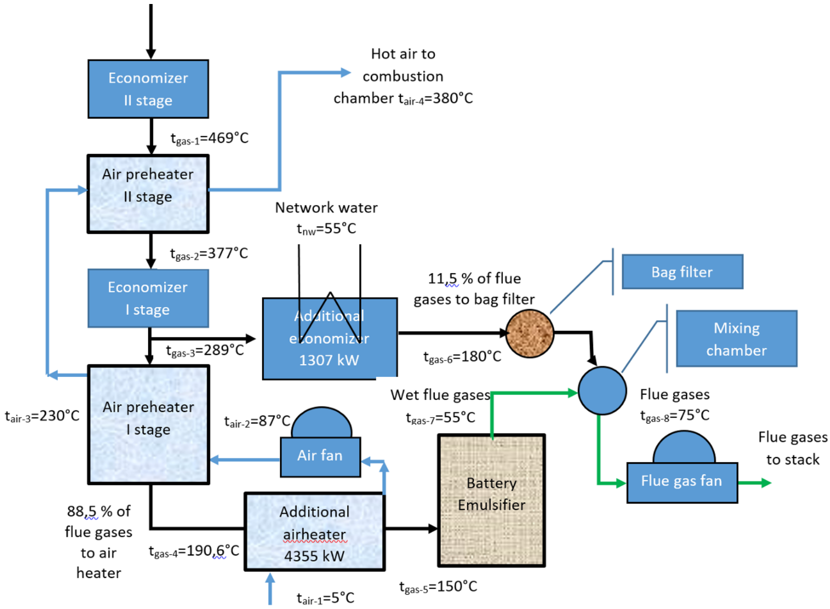
Fig. 2. Diagram of the gas path after installation of an additional air heater before battery emulsifier, including bag filter.

3.2. Description of the proposed method for heat waste recovery (variant 2)

The second option uses two energy-saving units: a water economizer and an additional air heater.

Some of the hot gases (11.5%) after the 1st stage economizer at a temperature of 289 °C are fed to an additional economizer with a heat output of 1307 kW, in which the gases are cooled down to about 180 °C and then enter a bag filter for gas purification. The economizer is supplied with network water with an initial temperature of 55 °C and a flow rate of 35 m^3 / h and is heated to 87 °C and is again fed to the district heating network. In order to comply with the permissible operating temperatures ($t<200$°C) of the gases before they enter the bag filter, the water flow in the economizer acts as a regulating factor in the various operating modes. The purified gases after the bag filter at a temperature of 178 °C enter a mixing chamber, where they are mixed with the wet and cooled to 55 °C gases after the battery emulsifier. The mixing temperature should be in the range of 72-75 °C to avoid secondary condensation in the chimney.

Due to the reduction of the gas flow (up to 88.5%) before the air heater 1st stage, the velocity of the gases in the tubular heat exchanger decreases and as a consequence the gas temperature increases from 183 to 190.5 °C. Under these conditions, the main gas flow will enter an additional thermosyphon-type air heater with a heat output of 4355 kW, where the gases will be cooled down to 150 °C before entering the battery emulsifier for purification. In this case, the air heater will heat the outside air from 5 to 87 °C and will replace the existing inefficient method for heating the outside air with hot air after a second stage air heater.



In Fig. 3 is a diagram illustrating the operation of the method for utilization of waste heat from gases.

Fig. 3. Diagram of the gas path after installation of economizer and a bag filter and additional air heater before battery emulsifier

4. Analysis of results

Numerical calculations have been performed with specialized software for calculation of energy steam generators in accordance with the widely used Normative method for calculation of boilers [18].

Table 1 presents data on the technical parameters for baseline, variant 1 and variant 2 of waste heat recovery.

Table 1. General technical parameters

Parameter/TPP	BKZ-220-100F baseline	BKZ-220-100F First variant	BKZ-220-100F Second variant
Average steam production, D_{av}, t/h (or water flow)	210	210	210
Average flue gas outlet temperature after economizer second stage, t_{fg}^{eco}, °C	289	289	289
Average flue gas inlet temperature after air heater first stage t_{fg}^{AH}, °C	183	183	190.6

Temperature of heated network water: Inlet, t'_w, °C Outlet, t''_w, °C	-	-	55 87.1
Network water flow, $\dot{m}$ m³/h	-	-	35.0
Estimated heating capacity of the additional economizer, Q, kW			1 307
Recovered heat of gases in additional economizer, Q_r, MWh/yr.	-	-	6 928
Recovered heat of gases in additional airheater, Q_r, MWh/yr.	-	16 004	23 090
Heat loss with flue gases after units implementation, q''_2, %	10.38	8.44	7.02
Flue gas temperature after Heat recovery and emulsifier, t_{em}, °C	55	55	55
Standard temperature of gases before entering the stack, t_{st}, °C	72-75	72-75	72-75
Required heat output for heating gases after the emulsifier, Q_{em}, kW	9 998	9 998	9 998
Flue gas flow via bag filter, m³/h	-	52 903	53 943
Flue gas flow via additional economizer, nm³/h	-	-	32 120
Flue gas flow via additional airheater, nm³/h	-	226 788	248 248
Boiler operation time, hours/year	5 302	5 302	5 302

The technical parameters are determined under real conditions, as the values are accepted as average for all boilers in 2020.

Full thermal calculations of the waste heat recovery units [11,12] (air preheater in combination with a bag filter and economizer) have been made, and the production, installation and commissioning costs have been estimated at European prices. The data from the calculations are presented in Table 2. The ecological payments that can be avoided as a result of the realised savings from coal are also estimated.

Table 2. Investments and fuel savings for different variants.

Parameters	**Variant 1**	**Variant 2**
Investment for the additional economizer, EUR	-	53 474
Investment for the back filter, EUR	61281	61281
Investment for the additional airheater, EUR	191250	255000

Total investment, EUR	252 531	369 755
Annual coal saving, t/year	6 981	10 662
Annual water savings, m^3/year	37 361	37 467
Price of coal, EUR/t	7.35	7.35
Price of technical water, EUR/m^3	0.134	0.134
Total savings, EUR/year	56 330	83 409
Savings due to harmful emissions reduction (based on the emission charge), EUR/year	5 092	7 776
Total cost savings and revenue, EUR/year	61 421	91 185
Specific savings, EUR/MWh	9.71	9.04

4.1. Comparative analysis of economizers for different schemes of waste heat recovery

The benchmarks for selection between both variants include [16]:

- Fuel savings;
- Payback period;
- Net present value;
- Internal Rate of Return;
- Specific savings;

One of the most important criteria for assessing the feasibility of an investment related to energy efficiency is the minimum investment per unit of energy saved (EUR / MWh) min. This criterion is characterized by a high degree of objectivity, especially in countries where the price of fuels is many times lower than those on the global market. According to the data in Table 1, it can be seen that Option 1 is superior in this criterion.

The analysis shows that the most economically viable is variant 1 in which the investment for 1 MWh of saved energy is 9.71 EUR. This assessment is complex and includes a complex dependence on several criteria: fuel price, operating time of the steam generator, exhaust gas temperature, average boiler load, etc.

4.2. Financial analysis

The results from the performed technical economic analysis are used to prioritize the two options proposed in Table 3.

Table 3. Estimated investments, savings, IRR, NPV, NPVQ and payback period

Variant of waste heat recovery method	Investment, EUR	Savings, EUR	IRR, %	NPV, EUR	NPVQ	PB, years
Variant 1 (see Fig.2)	252 531	61 421	20.6	274 089	1.09	4.11
Variant 2 (See fig.3)	369 755	91 185	21.0	412 060	1.11	4.05

This set of energy efficiency measures represents a CAPEX module, which can be used successfully by the company's management in making investment decisions [13,15,16].

In Table 2 the proposed measures (options) are prioritized based on their Internal Rate of Return (IRR) share. The following parameters are compared in the table:

- Annual net savings for the entire operational life of the project;
- Evaluation of the investment required for project implementation;
- Internal Rate of Return (IRR);
- Net Present Value (NPV);
- Net Present Value coefficient (NPVQ);
- Payback period.

The economic life has been set at 10 years for both options;

Real interest rate - set at 10% based on the conditions of bank financing in Kazakhstan; the inflation coefficient for 2020 according to data from the State Statistics Service of Kazakhstan is 6.9% [14];

The calculations have been obtained using the 'ENSI economy' v6 software product, with the results presented in Table 3.

The proposed prioritization scheme is strictly informative offering decision-makers a possibility to compare and select the most attractive option.

4.3. Environmental and other project benefits/impacts

The main environmental effect of installing waste heat recovery units (economizer with back filter and airheater) are the reduced CO_2 and NOx emissions [17]. The different options with included economizer, air heater and back filter are estimated to reduce coal consumption by 6981 to 10662 tons/year, CO_2 emissions from 10113 to 15445 t CO_2/year and NOx emissions from 44.9 to 68.5 t NOx/year, depending on the selected technology and equipment.

The project's environmental impacts for three investment options are summarized in Table 4.

Table 4. Environmental impacts

Option	**Units**	**Variant 1**	**Variant 2**
Coal savings	t/year	6 981	10 662
Emission factor for coal	tCO_2/t_{coal}	1.4486	1.4486
Decrease of CO_2 from saved coal	tCO_2/year	10 113	15 445
Decrease of SO_2 from saved coal	tSO_2/year	43.8	66.9
Decrease of NOx from saved coal	tNO_x/year	44.9	68.5

5 Conclusion

1. The proposed innovative waste heat recovery methods, comprising a combination of an additional air preheater and a bag filter or alternatively an additional economizer, air heater and a bag filter, is a topical option for steam generators and boilers using "wet methods" for flue gas purification (scrubbers, emulsifiers of the first and the second generation). Both options presented create excellent conditions for deep utilization of waste heat from the flue gases.
2. The conducted technical and economic analysis shows the expediency of the implementation of both options. There is a slight advantage of the second option in terms of simple payback period, NPV and NPVQ, but the difference is insignificant.

3. The realisation of the waste heat recovery units has high environmental impact and is estimated to reduce coal use from 6981 to 10662 tons/year, CO_2 emissions from 10113 to 15445 t CO_2/year and NOx emissions from 44.9 to 68.5 t NOx/year, depending on the selected boilers.
4. The conclusions drawn can be used by experts in the field when making an investment decision regarding the introduction of the relevant technologies in TPP and CHP.

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