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Clean technologies

UTILIZATION OF WASTE HEAT OF FLUE GASES

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Abstract. The contact economizers systems (CES) for utilization of the waste heat of flue gases obtained by burning of natural gas in boilers, dryers, and gas turbines are described and their advantages and shortcomings are discussed. Many installations of this type, developed by the authors team, are already in operation in Bulgaria. The quantity of the utilized heat from the exit flue gases is between 12 and 43% of the heat entering with the fuel in the installation burners. CO_2 emissions are reduced with the same percent. The emissions of NO_x decrease up to 3.8 times.

Keywords: waste heat utilization, contact economizers, boilers, dryers, gas turbines, NO_x removal.

AIMS AND BACKGROUND

The utilization of flue gases heat exhausted from the biggest fuel consumers such as steam and water heating boilers, dryers, and gas turbines offers a possibility for essential decreasing of the green-house gases emissions. The contact economizers systems (CES) developed by the authors team are especially appropriate for solving this problem, particularly when natural gas is burned. The purpose of this paper is to spread the information for these systems, their advantages and shortcomings, and especially for increasing of the energy efficiency and reduction of green-house gases emissions.

UTILIZATION OF WASTE HEAT FROM BOILERS FLUE GASES

The main waste heat quantity of these flue gases, especially when natural gas is burned, is the condensation heat of their water vapours contents. The stoichiometric amount of these vapours is 2.25 kg per kg of burned methane. The CES used for utilization of this heat are first and second generation.

First generation contact economizer system. The name "contact economizer" means that the heat transfer in this type of apparatus is done by direct contact. For this reason the maximum temperature, from thermodynamic point of view, to which water can be heated in these systems, does not reach the bulb temperature of the flue gases. In most of boilers burning natural gas, the bulb temperature is usually about 60°C.

The temperature to which pure water can be economically heated is about 55-56°C. The technological scheme of a first generation system[1,2] is presented in

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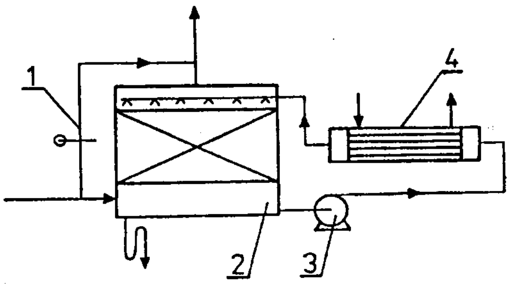

Fig. 1. Technological scheme of a first generation CES

Fig. 1. The flue gases from the boiler are scrubbed with circulating water in the packing of the contact economizer 2. The heated water is transported by pump 3 to the heat exchanger 4, where pure water is heated. After that, the re-circulating water is returned to the liquid distributor of the contact economizer 2. The condensed water vapours in the apparatus 2 are evacuated through a hydro-locking device. A part of the flue gases can bypass the contact economizer (line 1).

At initial temperature of flue gases 120-130°C, the maximum quantity of utilized heat is up to 13% of the heat produced in the boiler. At 190-200°C flue gases temperature, the amount of utilized heat is up to 16%. This heat can be used for warming water before the chemical purification, feed water for the boilers and for district heating network. Such a kind of installation designed by the authors team, operate with 7 boilers in Bulgaria.

Second generation contact economizers systems. In all cases of utilization of waste heat using contact economizer systems, it is necessary to have enough cold water to be warmed. When the condensers and heat-distribution network are well maintained, they demand relatively small feeding with cold water, i.e. they are small consumers of the heat that can be utilized by the first generation contact economizer systems. An enormous consumer of flue gases waste heat is the cooled water returning in the heating station through the district heating network. In the heating plants of Western Europe, its temperature is about 45°C, while in the ex-socialist countries it is about 55°C. For heating of this water to about 63°C, contact economizers system second generation was developed[2-4]. The technological scheme of these systems is presented in Fig. 2. The flue gases from the boiler 1 enter the contact economizer 4. Here they are cooled heating the circulating water. The warmed circulating water is fed by pump 9 in the heat exchanger 10, where the central heating water is heated. After that, the circulating water is returned to the contact economizer 4. The flue gases, partially cooled in contact economizer 4, enter the contact economizer 5. Here they are additionally cooled during the contact with circulating water fed by the pump 8. The water heated in the contact economizer 5 enters the distributor of the column 3 and flows down over the packing. Here it heats and humidifies the air (fed by the fan 7) used for burning the fuel in the boiler 1. After passing the contact economizer 5, the flue gases are thrown out in the air. If there is a gas fan, they pass through it in their way to the chimney. The system is mounted in parallel to the existing flue gases duct con-

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necting the boiler and the chimney. The condensed water vapors from contact economizers 4 and 5 are evacuated through hydro-locking devices not shown in Fig. 2.

For mean annual temperature of the air 11°C and returning circulated heating water with temperature 55°C, the flue gases are cooled to about 40°C. More than 60% of their water vapours contents are condensed. Using these systems, the quantity of the utilized heat is 12-13% from the heat obtained in the boiler. Because of decreasing of the flame temperature by adding of water vapours with the air, the NO_x emissions are reduced up to 3.8 times.

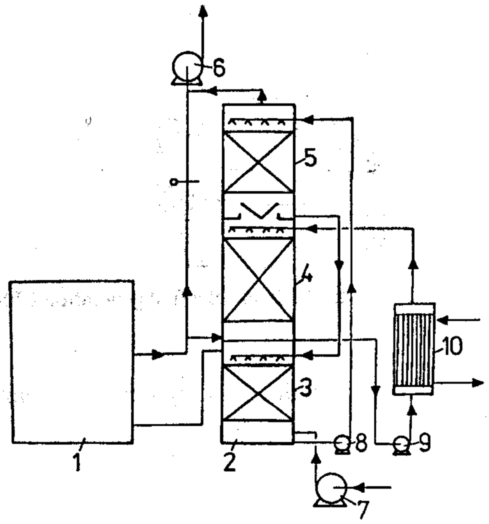

Fig. 2. Technological scheme of second generation CES

Second generation contact economizer systems designed by the author's team, operate with 2 boilers in Bulgaria.

Comparison between ribbed-pipe heat exchangers and contact economizers systems. Heat exchangers for indirect heating are also largely used for utilization of the flue gases waste heat. From this type of apparatus, especially appropriate are the heat exchangers with ribbed pipes. The best among them, from economical point of view, are iron pipes with aluminum ribs, pressed on the pipe using a special technology[5]. An important advantage of these apparatuses is that they are able to heat the water to a temperature higher than the bulb one. The contact economizers are quite better for utilization of the condensation heat. A more circumstantial comparison between the two types of apparatuses shows that when the difference between the hot flue gases and the heated water is larger than 48°C, more effective from economical point of view are the ribbed pipes. When this difference is lower, more effective are the first generation contact economizers systems. This was the reason for development of a new system named contact economizers system of third generation[6], which gathers the advantages of both systems, eliminating their disadvantages.

The comparison between the ribbed-pipes heat exchanger and second generation contact economizers systems shows that the latter are able to utilize 3.27 times more waste heat (if the temperature of the flue gases after the boiler is 120°C).

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INCREASE OF THE ENERGY EFFICIENCY OF DRYERS USING CONTACT ECONOMIZERS SYSTEMS

The quantity of the heat thrown out from the dryers with the flue gases is usually very high. Unfortunately, the bulb temperature of these gases is not enough high to provide a simple possibility to utilize the waste heat for warming the plant. Generally, it is impossible to find other consumers of this heat. For resolution of the problem for increasing of the flue gases bulb temperature without increase of the humidity of the dried material, re-circulation of the flue gases and additional increase of their exit temperature was offered[7,8]. The preliminary calculations with a new calculating method showed that although the rise of the flue gases exit temperature, the fuel consumption is decreased. The new method was used in the reconstruction of an industrial dryer for production of ceramic powder by drying ceramic suspension. The industrial investigations show that the fuel consumption for the drying process decreases with 15.6%. The water vapours concentration in the flue gases was 52%, the bulb temperature – 82.5°C. The quantity of the heat, which can be utilized for warming the plant, is up to 80% from the heat produced in the burner of the dryer installation. The real quantity of the utilized heat was 1 MW, which was enough to heat the plant halls. For this reason the entire increasing of the installation energy efficiency was only 43%.

GAS-STEAM TURBINES WITH CONTACT ECONOMIZERS SYSTEMS

The existing gas turbines have a very important disadvantage – they operate with large air excess in the burning chamber, which is necessary to regulate the inlet flue gas temperature of the turbine. This large excess leads to increasing of NO_x concentration in the flue gases and also to strong reduction of the water vapours concentration in them. The air compressor uses about 66% of the energy produced in the turbine. That is why the energy efficiency of the turbine is only about 38%. Because of low water vapours concentration in the flue gases, it is practically impossible to use contact economizer systems for utilization of their waste heat. The problem can be solved[9] replacing the air excess with steam produced in the boiler for cooling the flue gases after the turbine. In this way the water vapours concentration of the flue gases can reach more than 50%, which gives the possibility to use the waste heat utilized in a simple contact economizer system, for warming of district heating water.

The technological scheme of the new cycle, for a *N*-staged turbine, in a variant for district heating plants is presented in Fig. 3.

Air required for the fuel burning enters turbo compressor block 2, which is divided into N stages, by means of gas pipe1. Between the stages of the compressor, heat exchangers 3, respectively 3′ to 3^{N1-1}, are connected in order to reduce the energy needed for compression. In the case of district heating plants, it is supposed to cool these heat exchangers by means of district heating water that allows

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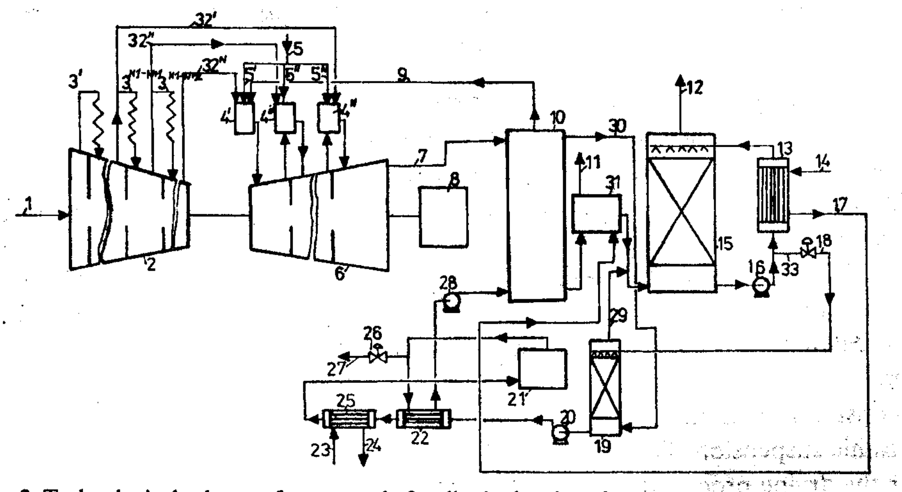

Fig. 3. Technological scheme of a new cycle for district heating plants

increasing the thermodynamic efficiency of the installation. This, as well as the condensation of a part of the water steam obtained at the fuel burning, allows the coefficient of thermodynamic efficiency for these installations to be higher than one. The air from the compressor block enters combustors 4, respectively from 4′ to 4^N of gas-steam turbine 6, where fuel, e.g. natural gas, is also passed. Water steam is also transferred to combustor 4′, whereas flue gases, cooled in the previous stages of the turbine, are passed to the combustors 4″ to 4^N. The mechanical energy produced in the turbine moves electrical generator 8 and compressor block 1. After the turbine, the gas-steam mixture enters boiler 10, where it is cooled, and enters the heat exchanger 31 with ribbed pipes. The gas-steam mixture cooled to about 100 °C enters the contact economizer 15 after which the finally cooled flue gases are thrown out into the atmosphere by means of stack 12. The flue gases are cooled in the contact economizer by circulating water passed through heat exchanger block 13 by means of pump 16. The heat exchanger block is cooled by district heating water entering the apparatus through pipe 14 and leaving it by means of pipe 17. The water condensate obtained is passed through valve 18, which regulates the level in the economizer. Then, the condensate enters deairator 19, constructed as a packed bed column, where carbon dioxide and oxygen are removed. The deairation is performed by means of steam passed from boiler 10 through line 30. The gas-steam mixture obtained in the deairator is passed through pipe 29 and is mixed with the flue gases before their entering contact economizer 15. The condensate, treated in the deairator, enters heat exchangers 22 and 25 by means of pump 20 and is cooled to the working temperature of ion exchange block 21. After this block, water is again heated in heat exchanger 22, thus cooling the hot water condensate. The heated water enters boiler 10 where it evaporates and becomes overheated. The overheated water steam enters combustor 4. If the heat

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of the gas-steam mixture is not enough, in order to provide the steam required, boiler 35, which could be heated by coal burning, is also connected.

The thermodynamic study of the new type of installation[10] shows the following advantages of the new technology:

- 52% of the fuel energy can be transferred in electrical energy at initial pressure in the turbine equal to 30 bar;
- the overall thermodynamic efficiency of the installation, calculated on the basis of lower calorific value of the fuel, at 30 bar initial pressure, is up to 104%;
- about 50% of the water vapour obtained by burning of natural gas can be obtained as pure water.

The decreasing of the air consumption for the new installation leads to 7.53 times reduction of the energy used in the compressor and 2.35 times increasing of the power of the turbine, for a given power on the axe of the electrical generator.

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