Environmentally Friendly Organic Rankine Cycle Technology Based on Improved Absorption Refrigerating Machine

Osintsev K.V.
Power Engineering Department
South Ural State University
Chelyabinsk, Russia
osintcevkv@susu.ru

Dudkin M.M.
Power Engineering Department
South Ural State University
Chelyabinsk, Russia
dudkinmm@susu.ru

Prikhodko Iu.S.
Power Engineering Department
South Ural State University
Chelyabinsk, Russia
npuxogiko@yandex.ru

Kuskarbekova S.I.
Power Engineering Department
South Ural State University
Chelyabinsk, Russia
sulpan2006@rambler.ru

Abstract – **The purpose of the work is the development of environmentally friendly technology of heat recovery from condensation of water vapor at a constant partial pressure of the outgoing flue gases in contact heat exchangers with a passive nozzle at thermal power plants running on natural gas, and the use of solar heaters in the block structure of an absorption refrigerating machine. Using contact heat exchangers can reduce greenhouse gas emissions. Greenhouse gas is harmful to the environment. Using solar heaters can improve the efficiency of the Li-Br absorption refrigerating machine. Ways to improve the efficiency of industrial enterprises are different. One of the main ways is to use renewable energy for heat recovery. In addition, the use of renewable energy sources reduces emissions of harmful greenhouse gases into the atmosphere.**

Keywords—organic Rankine cycle; exchanger, agroindustrial complex; greenhouse gases

I. INTRODUCTION

Agricultural and processing enterprises of various purposes assume the presence of thermal power personnel. The main devices for producing steam and hot water are steam and water boilers operating with a nominal capacity during the heating period. The efficiency of boilers decreases in the summer season. Boilers produce significant amount of greenhouse gases harmful to the environment in winter season. In this paper, it is proposed to improve the energy efficiency of boilers. Also it is proposed to improve the environmental situation in agrocomplexes. In this situation, the Rankine organic cycle is used to increase efficiency [1-4]. Technologies that increase boiler and thermal power plants efficiency are known. These technologies are based on the use of heat pumps and absorption chillers. Problems of efficiency and resource conservation arise in the production of agromaterials and agricultural products. For example, in the production of fertilizers based on nitrogen and phosphorus in chemical plants requires a significant amount of thermal, electrical energy and cold. Thus, the agro-industrial complex and the chemical industry need resource-saving and environmentally friendly technologies [5-8].

II. PROBLEM RELEVANCE

Problems of energy saving and resource saving exist in enterprises of various industries, including the production of heat and electricity. The power plants are equipped with steam boilers, steam turbines and gas turbines. The most modern trend is the construction of steam-gas units for supercritical parameters. The efficiency of stations with such installations is close to 55%. However, ways to improve the efficiency of power units operating on natural gas have not yet been exhausted. Development and application of energy technologies combining existing energy systems using organic fuel and environmentally friendly technologies of using heat of condensation of water vapor from flue gases at a certain partial pressure are becoming topical. The work is devoted to study of intensification of heat transfer processes in convective smoke ducts. The results of the study will allow one to reduce gas consumption, to increase the share of non-conventional and renewable energy sources and to reduce the amount of harmful emissions into the atmosphere. The high content of carbon oxides, nitrogen and sulfur in the atmosphere leads to the formation of acids. Acids together with precipitation fall to the ground and are absorbed by groundwater [9-11]. As the experience of operating thermal power plants using the organic Rankine cycle shows, additional equipment pays off within 5-6 years when it is introduced into the system of technical water supply and heat supply.

III. Comparison with Analogues

There is a method of using exhaust gases heat from a fire-tube boiler, according to which the boiler unit is divided into three work areas. A heat exchanger and a water jacket are used for cooling. The invention improves the maintainability, but has drawbacks – reducing the efficiency of the condensation part of boiler due to the impossibility of the heating systems to operate at return network water temperature below 40°C, as well as frequent replacement of the heat exchanger pipes [12-14]. Outdoor condensing boiler is known, equipped with hydro-thermally insulated casing. The invention increases the efficiency of the boiler during a power outage, but has drawbacks – the impossibility to use the boiler for industrial purposes, as well as the high specific cost of heat generation [15-17]. Wall condensing boiler Logomax plus GB172i is known. The invention is compact, ergonomic and highly efficient. However, it should be noted drawbacks - the inability to use the boiler in an industrial enterprise due to low parameters of the heat carrier, as well as the high specific cost of heat generation [18-20]. Water condensing boiler Bosch Condens 5000W is known. It is floor boiler with the ability to connect multiple units in a cascade scheme. It should be noted ergonomic quality and high efficiency of the device. The disadvantage of this device is the use of expensive materials and automation, which affects the final cost of the heat energy received [21,22]. There is a method of using the heat of exhaust gases after gas turbine power generators. The heat recovery boiler can be used with any energy parameters, both for producing hot water and steam. The advantage of the invention is to improve the technical, economic and environmental characteristics of the unit as a whole. The disadvantage is the incomplete use of the heat of condensation of water vapor at a constant partial pressure of flue gases [23].

In standard vapor compressor refrigeration units of non-absorption type, designers use refrigerants, including ones that are harmful to the environment.

The operation principle of the vapor compression unit is as follows. The compressor pumps out working agent vapors from the evaporator at pressure P_0 and compresses them to pressure P_c. Compressed steam enters the condenser, where it undergoes saturation under the influence of an upper heat source and then condenses at a temperature T_c. In this case, the upper heat source is heated from temperature T_u' to temperature T_u''.

The pressure and temperature of the agent decrease when it is throttled in a pressure reducing valve with a transition to a wet steam state. The liquid phase enters the evaporator and boils at a temperature T_0 due to the heat supplied from the lower heat source. Lower heat source with temperature T_l' enters the evaporator for cooling. It lowers its temperature to T_l'' by giving heat to the boiling agent in the evaporator.

The boiling point T_0 and condensation point T_c of the working agent directly depend on the temperature of the lower T_l and the upper T_u heat sources:

$$T_0 = T_b - \Delta T_0^{mid}\ , \qquad (1)$$

where ΔT_0^{mid} = 2–4 degrees for immersed liquid (water) evaporators.

The condensing temperature of the working agent Tc depends on the temperature and the flow rate of the heated carrier, which supplied to the condenser.

$$T_c = T_{uc}'' + (4\ldots5). \qquad (2)$$

Air heating in air condensers is carried out within 4 - 5 degrees.

Agents for which $P_0 \geq 0.1$ MPa (in order to avoid suction of atmospheric air) are selected according to the tables of saturated vapors of working substances and according to the found boiling point T_0. Those agents are selected to provide the condensation process for which $T_{cr} > T_c + (20\ldots25)$.

It is need to strive to ensure minimum values T_{lc}, P_c, $\Delta P = P_c - P_0$, P_c/P_0 when choosing an agent. Preference is given to an agent with a maximum coefficient of parameters, for which $P_c/P_0 \leq 12$. In addition, the agent is subject to the requirements of thermal stability, explosion safety, incombustibility, non-toxicity, low cost. All other things being equal, preference is given to a working agent having the highest maximum allowable concentration (threshold limit value, TLV) and the lowest toxic hazard ratio $K_{t.h.}$.

The proposed absorption chillers on the principle of action are very different from freon. Here the main components are two substances, easily separated and easily absorbent. Such chillers practically do not require electricity, or the consumption of electricity tends to zero.

Flow diagrams of thermal power plants with embedded renewable sources of thermal energy are known. Solar energy stored in the air, soil or water is used by heat pumps to heat the house and heat the water. The use of solar energy becomes even more efficient if a solar collector is paired with a heat pump. Water heating by a flat solar collector will be perfectly combined with a heat pump regardless of the selected source of energy extraction by a heat pump (air, geothermal, water). Solar collector is a device for collecting thermal energy emitted by the sun. The solar collector heats the heat carrier to heat the house and for needs of the hot water system in contrast to the solar panels used to generate electricity. Modern solar collectors can heat water to the boiling point even in negative temperature conditions. The principle of operation of the heating system with solar collectors and heat pump is as follows. The heat of radiation is transferred by the solar collector to the heat carrier, which can be water or brine (NaCl), during the hours of sunshine. The heat carrier heated in the solar collector is cooled in the heat pump evaporator and returns to the storage tank for subsequent heating. At night and overcast hours, water or brine passes through the bypass line, bypassing the solar collector, to reduce heat losses. The coolant evaporates, and the vapor enters the compressor due to the heat transferred from the solar collector in the evaporator. Compressed refrigerant vapor with temperature 80-85ºC provide heating of the coolant of primary circuit. Heated, for example, up to 65ºC, the heat carrier enters the storage tank Then the heat carrier goes to residential buildings in the micro district.

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IV. Scientific Novelty

The scientific novelty of the work lies in the comprehensive study of theoretical and practical problems associated with the integration of the principles of using renewable and traditional energy sources. Scientific results: analysis of theoretical studies of condensation process of water vapor from flue gases and recommendations for the further development of research; methods of thermodynamic and exergy calculations based on balance of the amount of energy when utilizing water vapor condensation heat at a outgoing flue gases constant partial pressure; extension of the theory of condensation heat transfer in relation to solar collectors, heat exchangers installed behind the power units of thermal power plants.

V. Description of the Proposed Technology

Consider an installation that implements the method of flue gases absorption in a contact heat exchanger with subsequent heating [24,25], Fig.1. The outgoing flue gases 1 after the steam overheater of the boiler unit with the natural circulation of the steam-water medium enter the descending duct with convective heating surfaces. The feed water is heated in economizer. Feed water enters the boiler unit after the thermal treatment system.

The heated feed water 2 enters the boiler drum. Atmospheric air 3 is injected in the air heater 4 by a fan. The heated air 4 is sent to the fuel supply system, the burner device or directly into the furnace, depending on the type of fuel being burned and the fuel preparation system. In convective surfaces, flue gases are cooled to a temperature 110-140 ºC. Cooled to this temperature, the gases are sent to a convective heat exchanger with a passive nozzle. In the heat exchanger, flue gases pass through a passive nozzle into which cooled water is sprayed from the nozzles 5 connected to the pipeline system from the upper part of the heat exchanger. The water sprayed by the nozzles 5 reacts with the components of the flue gases. Part of triatomic gases, first of all, CO_2, besides NO_x and SO_x adsorbed by water and flows into the lower part of the heat exchanger. Gas-saturated water through pipeline system is sent to an advanced absorption Li-Br refrigeration machine (Li-Br absorption refrigeration machine, 6). A distinctive feature of Li-Br absorption refrigeration machine-C 6 is the presence of heating unit which use solar radiation. Heating elements 7 Li-Br absorption refrigeration machine -C 6 summarized in one block 8. Gas-rich water is heated in compartment 9. Element 7 is installed in compartment 10 of water heating. The compartment 10 is heated by solar radiation. The upper part of the compartment 25 may be made of a convex or concave parabolic shape.

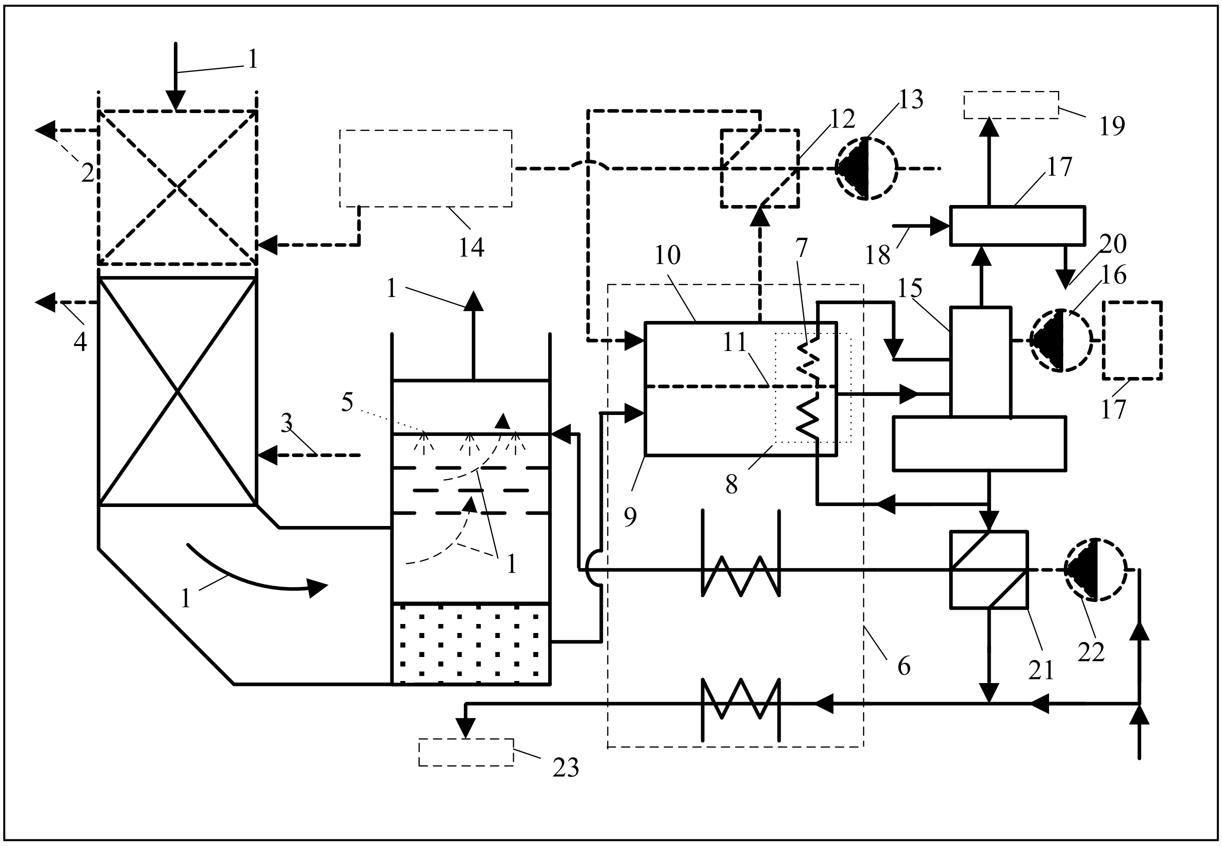

Fig. 1. Installation using a combined greenhouse gas capture technology (designations are given hereinafter)

The compartments 9 and 10 are separated by a partition 11. In the heating unit 8, thermally treated feedwater circulates. The water heated in compartments 10 is sent to heat exchangers 12 of the chemical water treatment unit. Initial water is pumped over through the chemical preparation unit by the pump 13 and sent to the thermal preparation unit 14. Unit 14 includes the main deaerator and heat exchangers. From block 14 feedwater is sent to the economizer of boiler unit. The circulating water cooled in block 8 is directed to an auxiliary deaerator 15 consisting of a deaeration column 30 and a tank. A solution of monoethanolamine is injected into the deaerator 15 by a dosing pump 16 from the tank 17 for better desorption of CO_2. Vapor from deaerator 15 is sent to the tank 17, which is injected with a solution of calcium chloride, necessary for the separation NO_x and SO_x. Gases are removed from the tank 17 and sent to the separation unit 19.

The mixture of the obtained materials 20 is removed from the tank 17 for processing. Thermally treated water from the tank is divided into two streams. Stream is sent to the heat exchangers 21 of the raw water preparation unit pumped by the pump 22. After the heat exchangers 21, the water must be cooled in the evaporator of Li-Br absorption refrigeration machine 6. The initial water is mixed with water after the heat exchangers 21. The mixture of flows is sent to the absorber of Li-Br absorption refrigeration machine 6. Heated in Li-Br absorption refrigeration machine 6 water is sent to the heat pump.

VI. Application

Application could be formulated in follow sentences. Recommendations for optimizing flue gas parameters for steam boilers and gas turbines can be obtained as a result of the study. At the same time, boiler units can operate on various types of fuel, including coal-water slurries [26,27]. Recommendations can also be obtained for reducing the consumption of natural gas for the power unit subject to the implementation of technology of heat recovery condensation of water vapor. Further work will help clarify recommendations for the compilation of regime maps steam boilers and gas turbines, power unit management. The article also creates the prerequisites for a development of concepts for the use of solar collectors [28] and heat exchangers behind the power units of thermal power plants running on natural gas. The application of results of this research may be associated with the use of the proposed solutions at compressor stations of chemical and metallurgical plants to obtain associated compressed components from the flue gases of the boiler unit. At the same time, the boiler unit can work as part of an energy unit, or as part of a production boiler house that produces overheated and saturated steam for the needs of the complex. Use of chillers and heat pumps saves resources, thereby reducing the cost of products manufactured at the plant. Agrocomplexes always use hot water or steam, therefore the proposed technological solutions are also valid for agricultural enterprises. The properties of Li-Br absorption refrigerating machine make it possible to use them in various industries. For example, the proposed technological scheme can be used at thermal power plants. The scheme allows reduce heat loss and increase the thermal efficiency of the entire power plant.

In addition, the application of the technological scheme is associated with the use of equipment to reduce harmful emissions into the atmosphere. In this case, this technological scheme is useful for large industrial cities with complex environmental conditions.

VII. Conclusion

Schemes for utilization of the heat of condensation of water vapor have been developed. With their use, the principles of introducing and managing reliable and environmentally friendly technologies can be created. These principles should be based on the use of combined-cycle plants described in the work. Various agricultural and processing industries need the presence of qualified personnel to maintain heat and power generating equipment. The main heatcarriers are steam and hot water produced in steam and hot water boilers that provide nominal capacity during the heating period.

Agricultural and processing complexes of various purposes assume the presence of attendants in the field of heat and power engineering. The main devices for producing steam and hot water are steam and water boilers operating at a nominal capacity during the heating period. The efficiency of boilers decreases in the summer season. Boilers produce significant amount of greenhouse gases harmful to the environment in winter season. The paper shows that it is possible to increase the energy efficiency of boilers and improve the ecological situation in agricultural complexes using devices for obtaining technological energy carriers – steam and hot water [29,30,31]. The use of technological solutions in thermal power plants associated with the use of low-potential and solar energy allows to regenerate part of the heat lost in the thermodynamic cycle, which increases the efficiency of the technical water supply systems of the steam turbine installation and heat supply due to the preheating of water by heat pumps and solar collectors. The degree of efficiency of the proposed technological solutions depends on the performance of the boiler unit and on the quality of steam, which can be saturated and overheated. The technology of using the exhaust gases heat and the separation of individual components from these gases can be used in various industries, both in the agro-industry and in the chemical industry using innovative energy-saving methods and devices. In conclusion, it is necessary to note the reliability of the proposed technological scheme in terms of the materials used. Currently, the production technology of construction materials is associated with the use of bimetallic materials and metals with anti-corrosion coating. To collect acidic condensate and pipelines of this condensate, modern innovative materials should be used. The application of the proposed technologies should be accompanied with the development of devices operating on the organic Rankine cycle. The trend towards the use of the organic Rankine cycle is confirmed by the research of scientists from European Union countries. In addition, it is possible to use micro turbines, which will increase the efficiency of the proposed technology.

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