Method of Combined Heat and Electricity Generation Using Biogas and Coal-Water Slurries

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***Abstract*—Agroindustrial complexes are built in a technological and geographical binding to the sources of heat and electricity. In the absence of the possibility of connecting to the central distribution heat and power networks in the investment project, proposals are made for the construction of a source of heat and electricity on affordable fuel. An agricultural complex may be located in a remote area, for example, in a mountainous area, without access to natural gas. In this case, it is economically advantageous to deliver water-coal fuel to the agro-complex, and to receive biogas fuel from the production waste on the territory of the enterprise itself. The properties of biogas and coal-water fuel allow processing enterprises to generate heat and electricity autonomously.**

Keywords—agroindustrial complexes; heat; power; recycling

I. INTRODUCTION

Most of Combined Heat and Power Plants (CHPP) and boiler-houses get heat and electrical energy in steam boilers or steam-turbo-electrical generators. Sometimes gas turbine electrical generators are used for additional electric energy production [1-4]. Hot complete or incomplete-combustion products are extracted from gas turbine units and are partially cooled in own or general station heat exchangers. After that, gases, as a rule, are directed to waste heat boilers located near by CHPP. Building of adjoining complex to CHPP is accompanied by serious layout plan change, reconfiguring and reconstruction of steam and water pipes, high capital charges. To minimize them, boiler operating plants are used supplying them with gaseous products. Gaseous products are delivered to boiler plants from primary cooling system with temperature 600-700 K [5-7]. While utilization CHPP gets thermotechnical and economical giants:

$$\Delta q_{CHPP} = (q'_{CHPP} - q''_{CHPP}), \tag{1}$$

$$\Delta E_{CHPP} = f(\Delta q_{CHPP}), \tag{2}$$

where $q'_{CHPP}=f_1(T_{CHPP})$ is CHPP heat losses with flue-gas at temperature T_{fg}^{CHPP}, K, kW; $q''_{CHPP}=f_2(T_{fg}^{b})$ is boiler heat losses with flue-gas at temperature T_{CHPP}^{b}, K, kW [8-10].

Designed for certain thermal, gasdynamic, hydraulic performances and economic parameters existing boilers in most case are limited by their technical capabilities for effective utilization heat of combustion products from gas turbine electrical unit. Boiler plants can incur losses due to utilization [11,12]. That losses estimated like:

$$\Delta q_b = [(q''_2 - q'_2) + (q''_3 - q'_3) + (q''_4 - q'_4)], \tag{3}$$

$$\Delta E_b = \varphi(\Delta q_b), \tag{4}$$

Where q'_2 и q''_2, q'_3 и q''_3, q'_4 и q''_4 are boiler heat losses with leaving flue-gas; incomplete combustion heat losses and unburned fuel loss without and with discharge of combustion products, kW. Parameter Δqb depends on used fuel type, technology process and combustion system. This parameter is heavy vary: to reduce or exceed creating be CHPP desirable effects

$$(\Delta q_{CHPP} - \Delta q_b), \tag{5}$$

$$(\Delta E_{CHPP} - \Delta E_b), \tag{6}$$

Efficiency of combustion products discharge from CHPP to boiler's furnace is individual. Utilization technology is selected in accordance with forward estimate of existing boilers adaptive capability of using secondary source heat. Experience of designing and operation shows that heat utilization of combustion products interrelate with discharge gas ballast to furnace or boiler pass:

$$\alpha + \beta = \chi. \quad (1) \qquad (1)$$

$$V_{bl} = rV_b, \tag{7}$$

where V_{bl}, V_b are consumption of gas ballast and boiler's flue gases, nm^3 / s (normal cubic meter per second), r is equivalent proportion of flue gases, increasing heat losses with flue-gas flows pass to atmosphere from q'_2 till q''_2. If the gas recovery technology involves a gas recirculation, replacement of inert products from the gas-processing complex will take place with minimum losses $\Delta q_2=(q''_2-q'_2)$, kW [13,14]. Consider several examples of rational substitution.

II. Theoretical Part

Fig. 1 shows scheme of a steam boiler gas-air duct for burning fuel oil and natural gas with a flue gas recirculation system [4]. The main product of the boiler is a superheated steam. It is produced by flame combustion in a furnace 1 of liquid or gaseous fuel. Fuel is fed through wall-mounted burners 16 together with air heated in air heater 6. The feed water is heated in the economizer 3, evaporated in the waterwall tubes 4 of the furnace 1 and overheated in the superheaters 5 to form steam up to necessary parameters for the turbine operation. Boiler operating feature is a method of controlling superheated steam temperature at the output of superheaters 5 also changing the consumption of the mixture of flue gases and hot air. Hot air flows through the exhaust duct 11 into the nozzles 12 which located in the lower frontal part of the furnace 1 under the burners 16. Flue gases are taken from connective boiler duct 7 by the fans 10. Hot air is taken from the air channel 15, 17 which are located the air heaters 6.

An air additive allows to maintain the oxidizing environment in the near field. This reduces the activity of metal corrosion, soot formation and coking, manifested with low excess air in burners $\alpha_b \leq 1.05$, for the combustion of natural gas and fuel oil. The flue gas consumption and energy consumption of the blowing engines 10 can be minimized by adjusting the consumption of hot air additive which is regulated the temperature T_{ss} of the superheated steam. In the upper part of the furnace 1 nozzles 13 are installed before the superheaters 5 to reduce the temperature unevenness in the combustion products stream. In the nozzle 13 flue gases or a mixture there of with air are supplied. Separate and simultaneous operation of the lower and upper nozzles 12, 13 is possible. If a gas turbine electrical generator is installed at the CHPP, the boiler house will be equipped with a discharge duct 18. From the gas turbine electrical generator the products of complete combustion waste at the backpressure p_{CHPP} enter to the duct 18. Further along the exhaust duct furnace addition 19 products enter to exhaust duct recirculating flue gases 11 and upper nozzles 12, 13. Blowing engines 10 are off. They are in reserve.

Adjusting the temperature T_{ss} of the superheated steam is implemented by consumption of hot air additive at the constant of the supplied combustion products with a low oxygen content $O_2 \leq 4.0\%$. At a commensurate temperature level of gases behind the economizer at the point of recirculation gases extraction and behind the turbo-electric generator ($T_g \approx T_{CHPP}$ = 600-700 K), the T_{ss} deflections continue to be eliminated by the consumption of the hot air additive from the air duct 17. The cold air additive through the duct 20 is arranged in the duct 11 at a higher level of $T_{CHPP} >$ 700 K. The consumption of replacement combustion products should be commensurate with the consumption characteristics of the blowing engines 10 in the initial modes during normal operation of the boiler. The total number of boilers involved in the combined technology is

$$m \geq n + 1, \tag{8}$$

where n is the number of operating boilers,

V_{CHPP} and V_g are consumption gases behind gas turbines and boiler recirculation, nm^3 / s.

$$n = V_{CHPP} / V_g \tag{9}$$

If we take the working fraction of recirculating gases r = 0.30 – 0.35, at which the boilers $(q_2'' - q_2') \approx 0$, then the combustion products from the overbuild gas turbine-electric installations will receive combustion products with a consumption of V_{CHPP} [15-17],

$$V_{CHPP} \approx rV_b \approx V_b / 3, \tag{10}$$

where V_b is the flue gas consumption behind the boiler, nm^3 / s. The choice of the capacity of the overbuild power plant for the considered technology of combined generation of heat and electric energy at the project stage must be linked with organization of combustion products discharge. This means taking into account the possibilities of the existing boiler equipment of the CHPP. The supply of combustion products to the nozzles 12, 13 by the new technology is carried out due to the pressure (back pressure) of the gas turbine plants with the blowing engines 10. Such a method generates savings for own needs of CHPP ΔE_{CHPP}. The discharge of gases into the atmosphere is realized in common boiler flows by induced equipment (exhausters) 8 with an overload of V_b / 3 and an increasing in the energy consumption ΔE_{ie}. However $\Delta E_{ie} < \Delta E_{CHPP}$, the volume of combustion products cooled in the boilers up to $T_{fg} \approx 390 - 415$ K becomes smaller. The main effect of the integrated technology is the reduction of heat losses with outgoing flue gases Δq_{CHPP} [18-20].

$$\Delta q_{CHPP} = q'_{CHPP} - q''_{CHPP} \tag{11}$$

The project of transferring CHP to the new technology should provide for the emergency discharge of combustion products into the chimney, the estimated verification of the chimney for the production of additional flue gas volumes.

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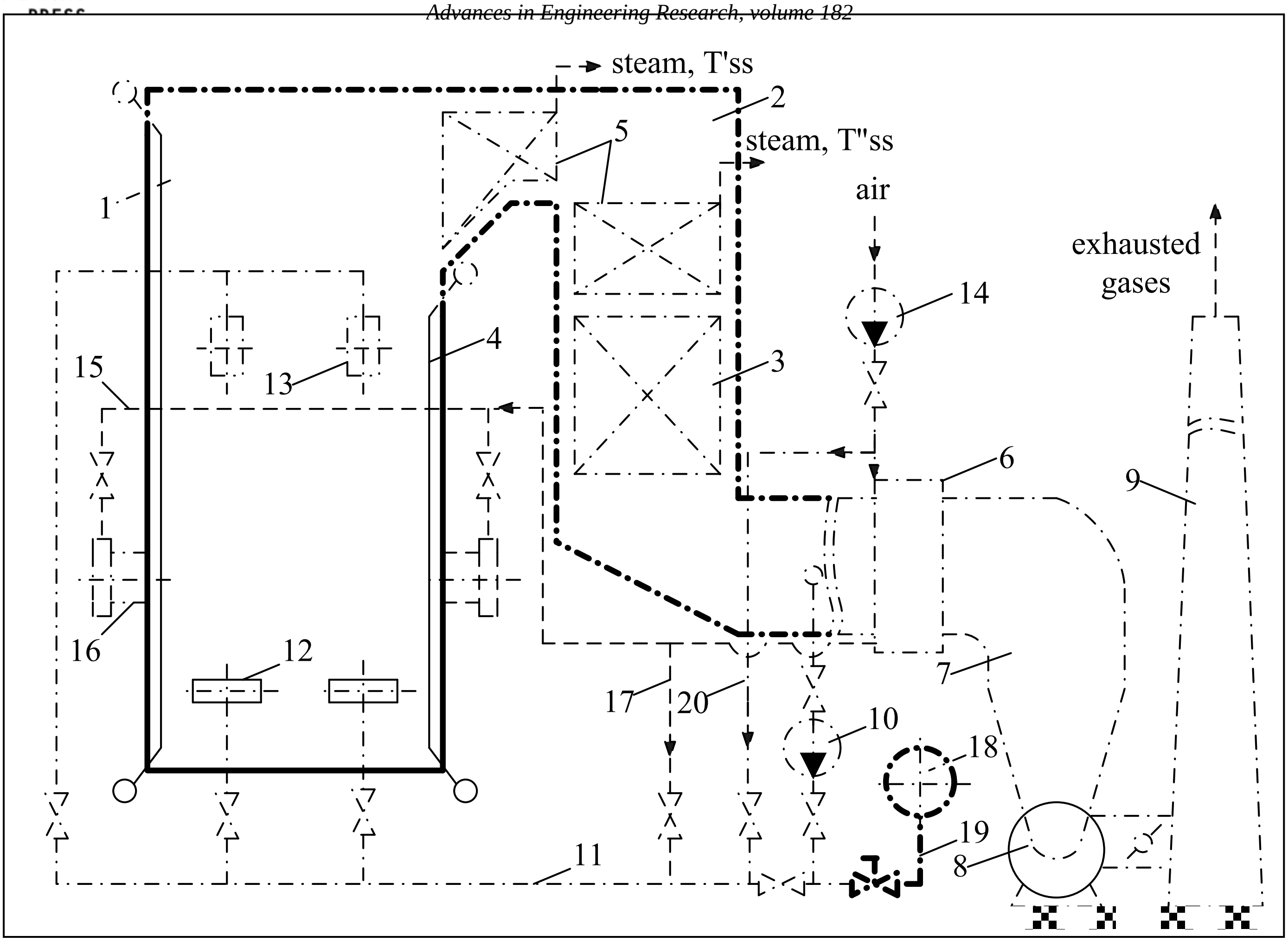

Fig. 1. Scheme of a steam boiler gas-air duct for burning fuel oil and natural gas with a flue gas recirculation system

In regions of the world with a shortage of natural gas, technologies are being introduced to extract shale gas, liquefied natural gas storage facilities and terminals are being built, and systems based on renewable energy sources are being developed. In such countries, high-tech technologies are being developed for pumping coal-water fuel and flaring coal-water suspensions in power steam generators of industrial enterprises and thermal power plants. Scientists approach the issue of choosing a fuel, first of all, from an economic point of view. For example, in China, a leader in the development of water-coal technologies, the Maoming CHP plant has been built and is operational. It is currently the largest in Asia and is based on a suspension preparation plant. An overview of the preparation processes and combustion technologies of coal-water suspensions is proposed. The authors also consider promising options for transportation of coal-water suspensions to consumers, their mixtures with surfactants and combustion catalysts. The rheological properties of coal are different, as well as the properties of solid and liquid inclusions in coal-water slurries. Additionally, it should be noted the results of computer simulation of the coal-water suspensions combustion process. The proposed technological developments take into account the specifics of the coal thermophysical properties and can be integrated into existing pulverized coal-fired power plants, or into individual block-based boiler houses. Such technologies can be applied in metallurgical production when using coal. Hydraulic calculation of the pressure transport system, as a rule, is performed at a given performance using solid, a known quality characteristic of the transported material and slurry and is reduced to the calculation and selection of the optimal concentration, optimum mode, diameter of the pipeline and determination of specific pressure losses to friction. There is an opinion that from the point of view of economic efficiency and hydrotransport, the concentration should be taken close to the limiting saturation of the slurry. In real hydrotransport flows, the ultimate saturation can be considered as such that the necessary mobility and hydrodynamic stability of the flow are preserved, ensuring its transport capacity with a satisfactory optimal energy intensity of the process, that is, when an unimpeded, cost-effective transfer of the solid phase is accomplished by a pressurized transport fluid flow. According to experimental data obtained by various authors and organizations during the transportation of coal slurries composed of coal with a particle size of 0-3 ... 0-1 mm and finely ground particles, the maximum saturation of the slurry depending on the quality characteristics of the transported material is 55-62% by weight. With this saturation, due to changes in the flow structure, slurries can sometimes acquire anomalous non-Newtonian properties. Therefore, based on the conditions of trouble-free operation of the hydrotransport system, the working concentration of coal slurry should be taken less than the limit. Biogas can be obtained on farms as well as large agro-complexes. The main equipment is the digesters for the production of gas, the main component of which is methane. The methane content in biogas varies from 10% to 40% depending on the degree of its enrichment. At the same time, at large plant-growing enterprises producing biogas may be the main asset, while the cost of the products produced from plants will decrease due to a decrease in energy costs for the company's own needs. Biogas can be used as an additional fuel not only for boiler houses, but also for gas piston units and for drying chambers, Fig. 1, 2, 3.

Biogas plant operates according to the following principle: the reactor is heated by warm water, the temperature of which is 60°C at the entrance to the reactor, and after the reactor about 40°C. The system is a network of heated tubes inside the wall of the reactor, or on its inner surface. As a result, in addition to agricultural fertilizers, biogas is obtained, which is stored in a gas storage tank, where the pressure and gas composition are equalized. From this tank, there is a continuous supply of biogas to a gas or diesel-gas heat and power generator, which produces thermal energy and electricity.

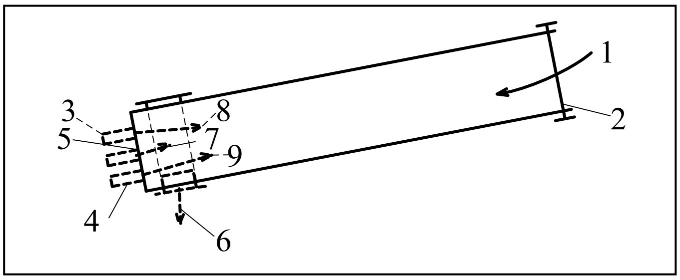

Fig. 2. Scheme of drying wet agromaterial: 1 – wet product (agromaterial), 2 – input window, 3 – natural gas supply nozzles, 4 – exhaust gas nozzles after the boiler, 5 – air nozzles, 6 – finished product, 7 - air flows, 8 – natural gas flows, 9 – exhaust gas flows

Using biogas plants as an additional fuel source for gas piston saves energy. The conditional scheme of such a power plant is shown in Fig. 3.

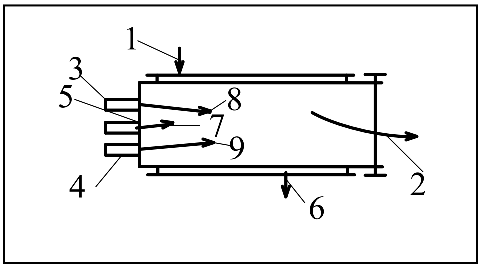

Fig. 3. Conditional operation scheme of a gas piston unit using biogas: 1 – coolant, 2 – exhaust gases, 3 – natural gas supply nozzles, 4 – biogas nozzles after the boiler, 5 – air nozzles, 6 – heated coolant, 7 - air flows, 8 – natural gas flows, 9 – biogas flows

The operation of such a plant is based on principles similar to those used in the cycle of an internal combustion engine. Here, biogas can be added as an additional fuel. This somewhat reduces the efficiency of the gas piston unit, but the benefit lies in the simultaneous production of both electrical and thermal energy. The latter is achieved by utilizing the heat of the heated body. Heat is transferred to the coolant: water or glycol. The lack of installation - increased oil consumption for moving mechanisms. All shortcomings are taken into account when choosing thermal equipment. Especially it concerns the choice of boiler units [23-25] and fuel [26-28].

III. Scientific Novelty

Operation principle of the agro-complex can be based on the use of flue gases heat of the boiler unit in drying chambers, for example, of the drum type. Similar installations are used for drying wet waste of animal and vegetable origin. The product obtained in the dryer is used for the manufacture of fertilizers, it can be stored for a long time in dry warehouses.

Scientific novelty lies in the combination of individual elements of technological schemes of agro-complexes and elements of energy-generating enterprises.

For the first time it is proposed to use the flue gases of the boiler unit for drying agricultural products, and as a fuel for heat and power plants in remote areas coal-water slurries and biogas produced at the agro complex itself.

IV. Application

There is practical application of the developed technological solutions in enterprises of the livestock and crop sector of agriculture, primarily for remote and hard-to-reach areas of mountainous terrain.

The efficiency of the agrotechnological complex can be increased by using energy-saving and innovative technologies [21, 22].

The application is also associated with the use of the proposed technology in the absence of available types of organic fuel combusted in the furnaces of boiler units [29-31]. Methods of burning fuel are different [32-34]. Coal-water fuel and biogas can be used as an addition. The latter is obtained at agrocomplexes, which reduces the cost of production.

The properties of biogas and coal-water fuel allow processing enterprises to generate heat and electricity autonomously [35,36]. Such a scheme for generating heat and electricity increases the reliability of the enterprise.

V. Conclusion

Economic expediency of using water-coal fuel at remote agro-complexes, and biogas fuel in the territory of the enterprise itself, should be calculated in investment projects based on the conditions for the implementation of environmentally friendly technologies.

Construction of a source of heat and electricity generation on affordable fuel for an agricultural complex in a mountainous area may be accompanied by the construction of a hydrotransport system of coal-water slurry.

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