Раздел 3. «IT-технологии, энергетика, автоматизация и вычислительная техника»

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Use of under-furnace devices behind the rotary kiln of the limestone burning shop of JSC «Qarmet»

The study is devoted to increasing the efficiency of waste heat recovery units of rotary kilns in the limestone burning shop of JSC Qarmet by introducing under-fire devices. The solution is aimed at eliminating the problems of reduced steam production caused by fluctuations in temperature and flow rate of exhaust gases from the rotary kiln. The possibility of using a fuel oil substitute (FOS) as a fuel for the under-fire device is considered, which will significantly reduce operating costs. Calculations are made of the volumetric flow rates of the main gas flows of the heat recovery unit and their temperatures under various operating modes. The technical and economic analysis showed that the modernization will increase the steam production of waste heat boilers by 20% with minimal capital investment. The expected payback period is about two years. The results confirm the technical and economic feasibility of the proposed solution.

Key words: utilization plant, fuel oil substitute, under-furnace device; rotary kilns; lime-kiln production; recirculation; exhaust gases; furnace operating modes.

Introduction

In recent years, new ways of intensifying heat exchange devices and industrial furnaces operating on organic fuel have become very important. The need for this is due to the following factors:

- irreversible depletion of natural fuel resources and the resulting increase in fuel prices;
- increase in industrial emissions of fuel combustion products into the atmosphere, which entails deterioration of the environmental situation and the occurrence of a thermal effect.

The use of secondary energy resources (SER) significantly reduces the negative impact on the environment by reducing harmful emissions into the atmosphere. In addition, in some cases, the use of SER allows increasing the productivity of process units or extending their working cycle [1].

The consumption of industrial steam by consumers of any metallurgical production varies greatly both by season and within months, days and even hours. Steam receipts from utilization units using exhaust gases from heating and kilns also change during the day (hours). Thus, if the amount of raw materials heated in the furnaces at the moment exceeds the production needs for one reason or another, then the amount of fuel burned in the furnaces is sharply reduced. Accordingly, the steam capacity of the waste heat boilers installed behind these furnaces is greatly reduced. During routine repairs of industrial equipment, which can last from several hours to several days, the steam capacity of the waste heat boilers drops practically to zero. Such a decrease in productivity greatly affects the balance of production steam throughout the entire enterprise [2].

Therefore, to ensure reliable, uninterrupted steam supply to consumers, it is absolutely insufficient to balance the enterprise using average values of expenses and receipts for a month, and especially for a year, but it is necessary to take into account the actual schedules of steam consumption during a month, day, hour. The steam balance must converge in any, even short, period of time.

Almost all enterprises in various industries have consumers of industrial steam for whom interruptions in the steam supply or a sharp decrease in its supply, as well as a decrease in pressure, are unacceptable. For these consumers, a decrease in steam pressure, and, consequently, the temperature in the heat exchangers, can sharply reduce the productivity of the plant for the main technological product and even suspend the flow of the technological process. In this case, the quality of the product may decrease and even its spoilage is observed. A decrease in steam pressure in the system of general plant steam pipelines is observed when there is insufficient steam supply to it. Auxiliary mechanisms operating on steam may not ensure the operation of the technological unit that they service [3]. Unbalances in production steam arise largely due to uneven steam output from waste heat recovery units, therefore, one of the ways to maintain the steam balance across the plant is to equalize the steam output of the waste heat recovery units. For most waste heat recovery units, such equalization can be achieved by so-called under-stoking, i.e. by burning fuel in the waste heat recovery units [4]. Usually, the waste heat recovery boiler is heated by the exhaust gases of a process unit, for example, a heating furnace. When the flow rate and temperature of the exhaust gases decrease for one reason or another, the steam output of the waste heat recovery boilers decreases accordingly. It can be increased to the required (previous) value by burning fuel in the under-stoking unit and mixing hot gases from the under-stoking unit with the exhaust gases from the furnace. Under-stoking can ensure the nominal steam output of the waste heat recovery boilers even when the furnace is stopped, and even exceed it. In both cases, additional steam is obtained by burning fuel, as in conventional industrial or peak boiler houses. Accordingly, the efficiency of using a sub-stoker is determined by the efficiency with which the additional fuel is used, as well as the annual number of operating hours of the sub-stoker device [5].

The efficiency of the waste heat recovery unit can be significantly increased by using gas recirculation. Mixing in recirculated gases taken from the flue after the waste heat boiler allows the temperature of gases after the under-fire device to be reduced to approximately 850 °C. With this operating scheme, the use of heat from the fuel burned in the under-fire device increases to 0.8 - 0.87 with the furnace stopped. If the furnace operates with a reduced, counter-design productivity, and the nominal steam capacity of the waste heat boilers is maintained by the under-fire, then the utilization factor of the fuel burned in the under-fire device is somewhat lower than with the furnace stopped. Thus, the use of the under-fire with recirculation allows the steam capacity of waste heat recovery units to be equalized with fairly good energy indicators. The economic indicators of the under-fire are high, since the cost of the additional steam obtained due to it is determined mainly only by the fuel component and the cost of feed water. Indeed, the additional capital costs of the under-stoker and the recirculation system amount to only a few percent of the capital costs of the utilization units. Therefore, the cost of steam additionally obtained at the utilization units due to the under-stoker is significantly lower than the cost of steam from special peak steam boilers.

The use of a sub-stoker allows increasing the steam capacity of the installed waste heat boilers by approximately 20% above the nominal value. If the exhaust gases from the furnace did not provide the nominal steam capacity of the installed waste heat boiler, then the sub-stoker can provide it [6]. The problem of reducing steam capacity is also relevant for the waste heat boiler installed behind the rotary kiln in the lime burning shop of JSC QARMET. Fluctuations in the temperature and flow rate of the exhaust gases from the furnace lead to unstable operation of the waste heat recovery unit, which reduces the efficiency of steam generation and can negatively affect the technological processes of the enterprise. In this regard, this paper analyzes the possibility of upgrading the system by installing a sub-stoker. The main goal of the proposed solution is to ensure the stability of the waste heat boiler steam capacity, minimize fluctuations in steam supply and increase the efficiency of fuel use by optimizing the operation of the heat recovery unit [7].

Methods and materials

In this paper, the main research method is a comprehensive analysis, including the study of literary sources, a review of scientific publications and regulatory documents related to the operation of waste heat recovery units and under-fire devices. This allowed us to identify the main trends, problems and promising areas for the development of these technologies.

Additionally, mathematical modeling methods were used to predict the operating parameters of the system and assess the impact of various factors on the heat recovery process. Engineering calculations included calculating the volumetric flow rates of gas flows, determining temperature conditions and calculating the required amount of fuel to ensure stable operation of the waste heat boiler.

In addition, a technical and economic analysis was carried out to assess the effectiveness of the proposed solution. This approach allowed us to objectively assess the feasibility of upgrading the waste heat recovery unit and justify its technical and economic efficiency.

Results and discussion

To ensure stable operation of the furnace device, it is advisable to use the same fuel that is used in the main process unit - the rotary kiln. In this case, the furnace operates on fuel oil and its substitute (FOS).

FOS is a fairly expensive type of fuel, which makes its use less economically viable. In addition, its efficient combustion requires preliminary preparation - heating and supply of steam as a companion, which reduces the viscosity of the fuel oil, facilitating its atomization and subsequent combustion. These additional technological processes increase operating costs and complicate the fuel supply system.

In this regard, it is proposed to use a fuel oil substitute (FOS) as the main fuel for the furnace device. This type of fuel has similar energy characteristics, but is more affordable and economically viable. Its use allows to significantly reduce the cost of steam production, which has a positive effect on the overall cost of heat energy. Additionally, the use of FOS in the under-fire device simplifies the fuel supply process flow chart, since it does not require significant costs for preliminary heating and mixing with steam. Thus, the transition to FOS contributes not only to the reduction of operating costs, but also to the increase in the efficiency of the entire utilization plant, which ultimately ensures a significant economic effect and a reduction in the payback period for modernization [8].

The calculation determined the volumetric flow rates of the main gas flows of the heat recovery unit and their temperatures under various operating conditions. The required flow rates of the heat recovery unit for the under-fire device under the corresponding conditions were also determined. The following typical operating conditions of the furnace were considered.

Mode No. 1 – forced: exhaust gases outlet $V_g^b = 54000$ nm^3/h; exhaust gas temperature $t_g^0 = 850$ °C.

Mode No. 2 – nominal: exhaust gas outlet $V_g^b = 47000$ nm^3/h; exhaust gas temperature $t_g^0 = 800$ °C.

Mode No. 3 – the furnace does not work: exhaust gases outlet $V_g^b = 0$ nm^3/h; exhaust gas temperature $t_g^0 = 0$ °C.

The calculation of gas flows was based on the joint solution of a system of two equations: the equation of the material balance of flows converging at one node and the equation of the energy balance of these flows. In general, the system of equations will have the form:

$$\begin{cases} V_{hb}^{/} = V_g^b + V_g^{uhd} + V_g^r \\ V_{hb}^{/} \cdot h_{hb}^{/} = V_g^b \cdot h_g^b + V_g^{uhd} \cdot h_g^{uhd} + V_g^r \cdot h_g^r \end{cases}$$

where $h_{hb}^{/}, h_g^b, h_g^{uhd}, h_g^0$ - are enthalpies of gas flows, respectively, in front of the waste heat boiler, coming from the furnace, the under-fire device and recirculation gases.

To simplify the calculations, in all the options under consideration, the temperature of the gases in the firebox is taken to be equal to $t_g^{uhd} = 1400$ °C. We accept the temperature of gases for recirculation $t_n^b = 230$ °C.

The general calculation scheme for the heating of a waste heat boiler installed behind a rotary kiln is shown in Fig. 1.

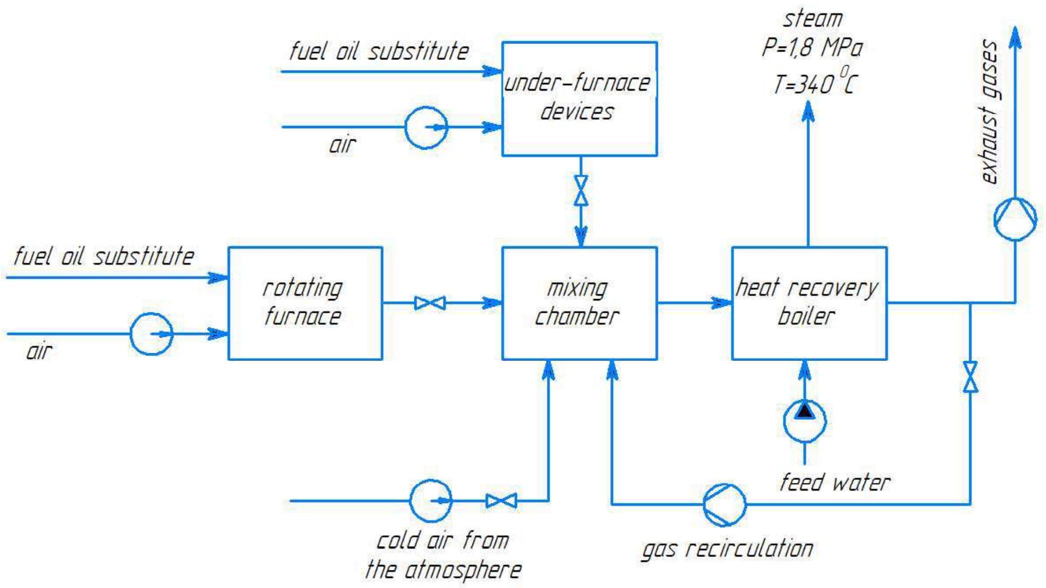

Figure 1 – Diagram of gas flows of a waste heat boiler with a furnace device

It is advisable to consider installing a vertical cylindrical cyclone furnace as a sub-firebox. This type of furnace operates on the cyclone principle, in which fuel combustion is carried out in a special chamber with intensive swirling of the air flow. High-speed gas movement ensures turbulent mixing of the fuel and oxidizer, which contributes to more complete and efficient combustion. Cyclone furnaces have a number of significant advantages. They are characterized by a high degree of fuel combustion, which allows for the maximum use of its energy potential. Intensive heat exchange in the combustion chamber helps to increase the combustion temperature and reduce the number of unburned residues. This is especially important when using alternative fuels, such as fuel oil substitute (FOS). Another important advantage is the relative simplicity of the design and operation of such units. Unlike traditional fireboxes, cyclone furnaces require less maintenance, since they have virtually no moving parts subject to wear. This helps to reduce maintenance costs and extend the service life of the equipment [9].

The calculations performed showed that the under-fire device will be able to provide the required amount of flue gases. The required calculated fuel consumption (FOS) of the under-fire device at the maximum peak mode of the KU-60 is taken from the calculation of gas flows and is $B_{fuel} = 1152,5$ kg/hour or 0,32 kg/sec. Three normalized high-pressure nozzles FVD-400 with double atomization are installed as a combustion device [10]. Compressed air with an excess pressure of 5 atmospheres and saturated steam with an excess pressure of 6 – 6,5 atmospheres can be used as an atomizer. The specific amount of compressed air is 1,3 kg/kg of liquid fuel, and saturated steam is 1 kg/kg of liquid fuel. Nozzle boxes of type A (with straight pipes) and type B (with pipes for air supply at an angle of 75° to the nozzle axis) are used. For a given throughput according to FOS, nozzle box No. 7 of type A corresponds. The geometric dimensions of the combustion chamber are determined by geometric construction depending on the calculated length of the fuel combustion flame. The required overall dimensions of the sub-firebox are as follows: internal diameter - 2600 mm, height - 6.5 m (see Fig. 2).

The lining of the firebox is made in two layers: the first layer is 230 mm thick chrome-magnesite, the second layer is 230 mm thick dinas lightweight. Between the firebox body and the lining is 10 mm thick asbestos cardboard. The seam between the masonry is 5 mm. The total thickness of the lining is $\delta_{ФУТ} = 230 + 230 + 10 + 5 = 475$ mm.

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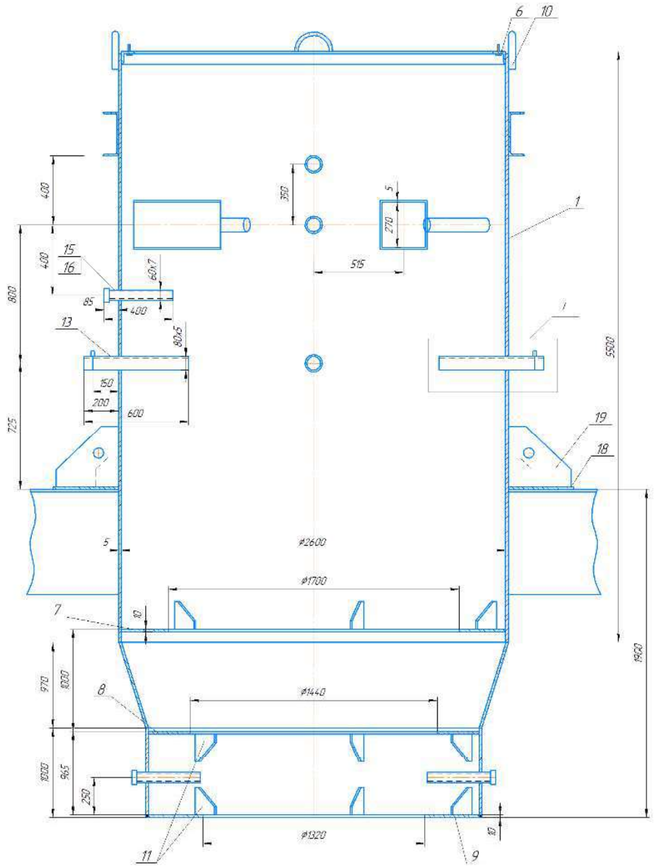

Figure 2 – General view of the under-fire device

Conclusion

The study examined the possibility of increasing the efficiency of the waste heat boiler installed behind the rotary kiln in the lime burning shop of JSC QARMET by introducing a furnace. The main problem identified in the work is the decrease in the steam capacity of the waste heat boiler, which negatively affects the technological process. To solve this problem, it is proposed to use a vertical cylindrical cyclone furnace as a furnace. The analysis showed that cyclone furnaces have a number of advantages, including a high fuel combustion coefficient, the ability to use various types of energy sources, as well as relatively low operating costs. It is proposed to use a fuel oil substitute (FOS) as the main fuel for the furnace, which is not inferior to traditional fuel oil in its energy characteristics, but is a more economical option. This will significantly reduce the cost of generated steam and increase the profitability of production. The application of the proposed solution will ensure stabilization of the waste heat boiler operation, increase of its productivity and reduction of energy costs. Additionally, a positive environmental effect will be achieved due to more complete combustion of fuel and reduction of harmful emissions into the atmosphere. Thus, the introduction of a furnace device based on a cyclone furnace is a rational and economically justified measure aimed at increasing the efficiency of the waste heat recovery unit and improving overall production indicators.

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О.Н.Онищенко, С.Н. Камарова, Г.Г.Жабалова, О.А. Денисова

«Qarmet» АҚ күйдіргіш цехының айналмалы пешінен кейінгі пештің астын қыздыру құрылғыларын пайдалану

Зерттеу «Qarmet» АҚ әктасты күйдіру цехының айналмалы пештерін кәдеге жарату қондырғылары жұмысының тиімділігін арттыруға арналған. Температураның ауытқуынан және пештен шығатын газдар шығынынан туындаған бу өндірісінің төмендеу проблемаларын жою шешімдеріне бағытталған. Қыздыру мазутын алмастырғышты (ҚМА) жану құрылғысы үшін отын ретінде пайдалану мүмкіндігі қарастырылған, бұл қолданыс шығындарды едәуір төмендетуге мүмкіндік береді. Жылуды кәдеге жарату қондырғысының негізгі газ ағындарының көлемді шығындары мен олардың әртүрлі жұмыс режимдеріндегі температуралары есептелді. Техникалық-экономикалық талдау көрсеткендей, бұл жаңғырту минималды капитал салымдарымен кәдеге жарату қазандықтарының бу өнімділігін 20%-ға арттыруға мүмкіндік береді. Болжамды өтеу мерзімі шамамен екі жыл. Нәтижелер ұсынылған шешімді қолданудың техникалық және экономикалық орындылығын растайды.

Түйін сөздер: кәдеге жарату қондырғысы, қыздыру мазутын алмастырғыш, жану құрылғысы; айналмалы пештер; әк-күйдіру өндірісі; рециркуляция; шығатын газдар; пеш жұмысының режимдері.

О.Н.Онищенко, С.Н. Камарова Г.Г.Жабалова, О.А. Денисова

Использование подтопочных устройств за вращающейся печью цеха обжига известняка АО «Qarmet»

Исследование посвящено повышению эффективности работы утилизационных установок вращающихся печей цеха обжига известняка АО «Qarmet» за счет внедрения подтопочных устройств. Решение направлено на устранение проблем снижения паропроизводительности, вызванного колебаниями температуры и расхода отходящих газов от вращающейся печи. Рассмотрена возможность использования заменителя топочного мазута (ЗТМ) в качестве топлива для подтопочного устройства, что позволит значительно снизить эксплуатационные затраты. Произведены расчеты объемных расходов основных газовых потоков теплоутилизационной установки и их температур при различных режимах работы. Технико-экономический анализ показал, что модернизация позволит увеличить паропроизводительность котлов-утилизаторов на 20% при минимальных капитальных вложениях. Предполагаемый срок окупаемости около двух лет. Результаты подтверждают техническую и экономическую целесообразность применения предложенного решения.

Ключевые слова: утилизационная установка, заменитель топочного мазута, подтопочное устройство; вращающиеся печи; известково-обжиговое производство; рециркуляция; отходящие газы; режимы работы печи.

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