Qozonlarning aylanuvchi regenerativ havo isitgichlarini zanglash va ifloslanishdan himoya qilish

Sagdulla K. Ismatxodjaev[1], Nadir A. Zaxidov[2], Xayrulla S. Isaxodjayev[3]

[1] PhD, prof., Toshkent davlat texnika universiteti, Toshkent, 100095, O‘zbekiston; isk1934@mail.ru https://orcid.org/0009-0003-5165-0601
[2] Elektr va elektronika muhandislari instituti a'zosi, Ingersoll, N5C, Kanada; nzakhidov@gmail.com
[3] PhD, dots., Toshkent davlat texnika universiteti, Toshkent, 100095, O‘zbekiston; x.isaxodjayev1965@yandex.ru https://orcid.org/0000-0003-1616-7203

Dolzarbligi: oltingugurtli mazut yoki gaz yoqilg‘ilari yoqilishi jarayonida gaz-mazut qozonlarining regenerativ havo isitgichlarida korroziya va ifloslanishni kamaytirish maqsadida, odatda, havo isitgichlarning sovuq uchiga beriladigan havoni oldindan isitish usuli qo‘llaniladi. Bu havo isish jarayoni ko‘pincha bug‘ turbinasidan olinadigan bug‘ bilan ta’minlanadigan kalorifer qurilmasi yordamida amalga oshiriladi.

Qozon ish samaradorligidagi yo‘qotishlarni minimallashtirish va o‘tkir o‘zgaruvchan yuklama sharoitida korroziya hamda ifloslanish darajasini me’yoriy chegaralarda ushlab turish uchun, havoni oldindan isitish haroratini boshqarish zarurati paydo bo‘ladi. Shunga qaramay, mavjud standart sxemalar kalorifer qurilmasidan isituvchi bug‘ kondensatini chiqarishda ikki fazali muhit oqimining ishonchli gidrodinamik rejimini ta'minlay olmaydi. Bu esa, bug‘ning pastki kondensat yig‘uvchi kameralariga kirib ketishining oldini olish imkonini bermaydi.

Ushbu maqolada bizning tadqiqotlarimiz asosida ishlab chiqilgan va patent olish uchun taklif etilgan avtomatik boshqaruv tizimi – bug‘li kalorifer qurilmasida havoni oldindan isitish haroratini boshqarish tizimi haqida ma’lumotlar taqdim etiladi. Shuningdek, bug‘ kondensatini chiqarish tizimida gidrozarbalarning oldini oluvchi qurilma va 160 MVt quvvatli TGM-94 gaz-mazut qozoni uchun kalorifer qurilmasining yangi oqim sxemasi keltirilgan.

Maqsad: oltingugurt saqlovchi yoqilg‘ilar, jumladan tabiiy gaz va mazutni birgalikda yoki alohida yoqishda energetik qozonlardan foydalanish samaradorligi va ishonchliligini oshirish.

Usullari: energetik qozonlar va ularning ish rejimini avtomatik boshqarish tizimlarini optimallashtirish nazariyasi va amaliy usullaridan foydalanilgan. Ushbu usullar oltingugurt saqlovchi yoqilg‘ilarni birgalikda yoqish sharoitida qo‘llanilgan.

Natijalar: tabiiy gaz va mazutni birgalikda yoqishda TGM-94 turidagi qozonlarga yangi texnologiya va ish rejimini avtomatik boshqarish tizimini joriy etish bo‘yicha o‘tkazilgan tadqiqot natijalari keltirilgan.

Kalit so'zlar: Kalorifer, boshqaruv tizimi, korroziya (zanglash), oqim sxemasi, gidrotiqinlar, ifloslanish, regenerativ havo isitgichi.

For citation: S.K. Ismatxodjaev, N.A. Zaxidov, X.S. Isaxodjayev. Rust and pollution protection of the rotating regenerative air - heaters of the boilers. Scientific and technical journal of Problems of Energy and Sources Saving, 2025, no. 4, pp. 45-51.
https://doi.org/10.5281/zenodo.18459750

Received: 05.04.2025
Revised: 19.04.2025
Accepted: 09.04.2025
Published: 27.12.2025

Защита вращающихся регенеративных воздухоподогревателей котлов от коррозии и загрязнения

Сагдулла К. Исматходжаев[1], Надир А. Захидов[2], Хайрулла С. Исаходжаев[3]

[1] PhD, проф., Ташкентский государственный технический университет, Ташкент, 100095, Узбекистан; isk1934@mail.ru https://orcid.org/0009-0003-5165-0601
[2] Член Института инженеров электротехники и электроники, Ингерсолл, N5C, Канада; nzakhidov@gmail.com
[3] PhD, доц., Ташкентский государственный технический университет, Ташкент, 100095, Узбекистан; x.isaxodjayev1965@yandex.ru https://orcid.org/0000-0003-1616-7203

Актуальность: в процессе сжигания серосодержащих мазутов или газообразных топлив в газомазутных котлах с целью снижения коррозии и загрязнения в регенеративных воздухоподогревателях (РВП) обычно применяется предварительный подогрев воздуха, подаваемого на холодную сторону воздухоподогревателя. Этот процесс нагрева воздуха, как правило, осуществляется с помощью калориферной установки, питаемой паром, отбираемым от турбины.

Для минимизации потерь эффективности работы котла и поддержания уровня коррозии и загрязнения в допустимых пределах при резких изменениях нагрузки котла возникает необходимость регулирования температуры предварительного подогрева воздуха. Однако существующие стандартные схемы отвода конденсата нагревательного пара из калорифера не обеспечивают надежного гидродинамического режима двухфазного потока в указанных условиях и не исключают проникновение пара в нижние камеры сбора конденсата.

В данной статье представлены сведения о разработанной на основе наших исследований и предложенной к патентованию автоматической системе управления температурой предварительного подогрева воздуха в паровом калорифере газомазутного котла. Кроме того, рассмотрены устройство, предотвращающее гидроудары в системе отвода парового конденсата, и новая схема потока калориферной установки для газомазутного котла ТГМ-94 мощностью 160 МВт.

Цель: повышение эффективности и надежности эксплуатации энергетических котлов при совместно-раздельном сжигании серосодержащих видов топлива, в том числе природного газа и мазута.

Методы: использовании теории и методы практический оптимизации эксплуатации энергетических котлов и их систем автоматического регулирования режимных параметров при совместном сжигание серосодержащих топлива.

Результаты: приведены результаты исследований серийного внедрения новый технологии и системы автоматического регулирования режимных параметров котлов ТГМ -94 при совместном сжигании природного газа и мазута.

Ключевые слова: Калорифер, система управления, коррозия, схема потока, гидрозатворы, загрязнение, регенеративный воздухоподогреватель.

Rust and pollution protection of the rotating regenerative air - heaters of the boilers

Sagdulla K. Ismatkhodzhaev[1], Nadir A. Zakhidov[2], Xayrulla S. Isakhodjayev[3]

[1] PhD, prof., Tashkent State Technical University, Tashkent, 100095, Uzbekistan; isk1934@mail.ru https://orcid.org/0009-0003-5165-0601
[2] Member of IEEE, Ingersoll, N5C, Canada; nzakhidov@gmail.com
[3] PhD, ass. prof., Tashkent State Technical University, Tashkent, 100095, Uzbekistan; x.isaxodjayev1965@yandex.ru https://orcid.org/0000-0003-1616-7203

Relevance: in order to reduce corrosion and pollution of regenerative air-heaters in gas and mazut boilers during the combustion of sulfurous oil or gas fuels, it is common practice to preheat the air supplied to the cold-end packages of the air-heaters. This air preheating is typically achieved using a calorifier unit, which is fed by steam extracted from turbine take-offs.

To minimize boiler efficiency losses and to keep corrosion and pollution levels within permissible limits under conditions of rapidly varying boiler loads, it becomes necessary to regulate the temperature of the preheated air. However, the standard existing layouts for removing heating steam condensate from the calorifier unit do not ensure a reliable hydrodynamic regime for two-phase flow under such conditions. They also fail to prevent steam from entering the condensate-collecting lower chambers.

This paper presents the results of our research on the development and implementation of a patentable automatic control system for regulating the air preheating temperature in the steam calorifier unit of gas-and-mazut boilers. Additionally, it introduces a specially designed device to eliminate hydraulic shocks in the steam condensate removal system and proposes a new flow diagram for the calorifier unit in the TGM-94 gas-and-mazut boiler of a 160 MW power unit.

Aim: to improve the efficiency and reliability of power boiler operation during combined or separate combustion of sulfur-containing fuels, including natural gas and fuel oil.

Methods: theoretical approaches and practical methods of optimizing the operation of power boilers and their automatic control systems under combined combustion of sulfur-containing fuels were used.

Results: the results of studies on the serial implementation of a new technology and an automatic control system for operational parameters in TGM-94 boilers during combined combustion of natural gas and fuel oil are presented.

Keywords: Terms -Calorifier, control system, corrosion, flow diagram, hydro-seals, pollution, regenerative air- heater.

1. Introduction

The burning of sulfur-containing liquid and gaseous fuels in the gas-and-mazut boilers brings to formation of corrosion-generating dangerous components, in particular, sulfuric anhydride SO_3 in the furnace gases. The sulfuric anhydride in interaction with water steam existing in furnace gases produces vapor of sulfuric acid H_2SO_4. This vapor condensing on relatively cold packages of stuffing of the rotating regenerative air-heaters $(RRAH)$ with the temperature of the wall t_{wall}^{RRAH} lower, than dew-point temperature of combustion products $t_{d.p.}^{H_2SO_4}$, brings to sulfur-acid corrosion of metal of stuffing. Simultaneously, the process of pollution of $RRAH$ by products of corrosion and sediments produced by interaction of the condensed sulfuric acid and not burnt organic and mineral parts of fuel is intensified. As a result, the aerodynamic resistance of air and gas duct grows up, working load of the boiler falls down due to the draught shortage, the temperature of outgoing gases rises, service life of RRAH and its heat-transfer efficiency decrease. Above mentioned brings down the efficiency and reliability of the boiler and power unit as a whole. The analysis of experimental data shows, that the temperature of the lower edge wall of cold packages of rotating regenerative air-heaters with counter-current movement of heat-conductors can, with sufficient accuracy, be determined by temperature of cold air at the inlet of $RRAH$ $t_{c.a.}$ and temperature of outgoing *gases* $t_{o.g.}$[1]:

$$t_{wall}^{RRAH} = 0{,}5\left(t_{c.a.} + t_{o.g.}\right) - 5\ . \qquad (1)$$

From here it follows that maintenance of the wall temperature, required by the terms of limitation of corrosion and pollution, will be possible or by increasing the temperature of *RRAH* incoming air by means of pre-heating [2]; as well as by re-circulation of hot air [2], [3]; or by increasing the temperature of outgoing gases by means of bypassing part of cold air round *RRAH* [4]. In the present time one of the most effective ways to reduce sulfur-acid corrosion and pollution of *RRAH* , is preheating of air by low-temperature steam from turbine in energetic steam calorifier units (ESCU) before supplying this air into the *RRAH* [5].

2. Methods and materials

Proposed automatic control system for regulation of preheating air temperature. ESCU working on thermal stations, in most cases, are not equipped with automatic systems for regulation of the temperature of air preheating with ability to operate in all working conditions of the boiler. As a result, during the systematic and casual fluctuations of the contents of sulfur in fuel, working load of boiler, surplus of air in the fire-chamber, consumption ratio of jointly-separately burnt mazut and natural gas, temperature of feeding water, it occurs that pollution and corrosion of *RRAH* increase and boilers work with non-optimal temperatures of outgoing gases. The offered technical solutions [6], [7] do not solve these problems. Moreover, schemes of pipelines put into practice for the removal of heating steam condensate from calorifier do not provide reliable hydrodynamic conditions of two-phase medium flow and cannot exclude the penetration of steam into the condensate collecting lower chambers, resulting in hydraulic shocks arising in the system of condensate removal [8].

Present article contains the results of elaboration and research of all-regime automated energetic steam calorifier unit, equipped with automatic control system for the temperature of air preheating [9] and with reliable device for steam condensate removal [10], implemented on gas-and-mazut boilers TGM-94 of 160 MW power units (Fig. 1).

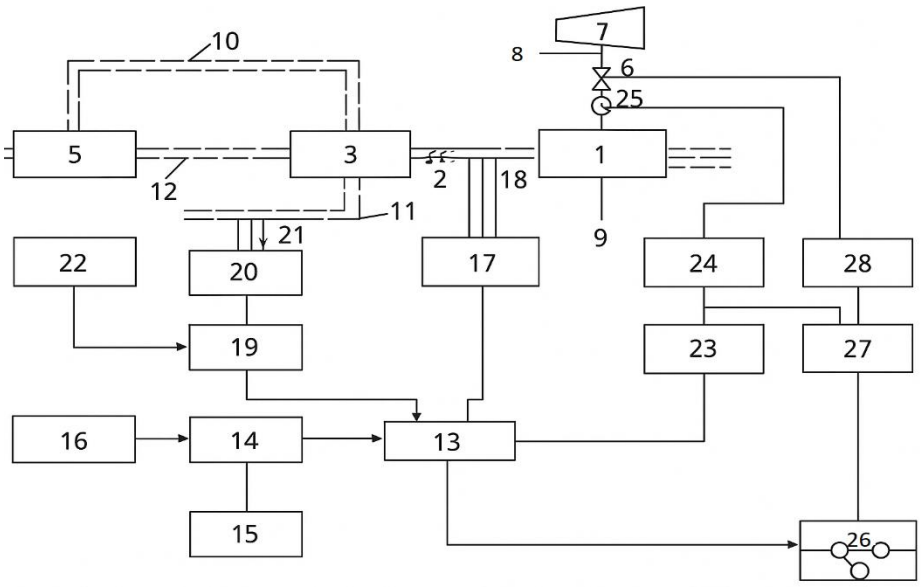

Fig. 1. Automatic control system for the temperature of air preheating

1 - calorifier unit (ESCU); 2, 4 - air ducts; 3 - rotating regenerative air-heaters (*RRAH*); 5 - boiler fire-chamber; 6- heating steam regulator; 7- turbine; 8 - low-potential take-off of turbine, and other consumers of steam; 9 - condensate; 10, 11 - gas ducts; 12 - fuel supply; 13 - regulator; 14 - summator; 15 - master controller; 16 - competing device; 17, 19, 20 - data separators for minimal signals; 18,21 - preheated air and outgoing gases thermometers; 22- outgoing gases upper limit controller; 23- differentiator; 24,25 - steam consumption secondary and primary flow-meters; 26 - relay; 27 - comparing device; 28 - steam maximum consumption controller.

In contradistinction to offered earlier technical solutions [6], [7], the automatic system for regulation of the temperature of air preheating [9], offered by authors operates steady in different working conditions of the boilers owing to introduction into the regulator the forestall impulse of steam consumption to *RRAH*, minimal signals, introduction of the computing device for automatic adjustment of controller for various cleaning methods of *RRAH* stuffing, joint and separate burning of natural gas and mazut, as well as taking into account the restrictions for consumption of steam to the calorifier and other consumers, temperatures of outgoing gases. Thus, the reliable work of exhaust fan is pro-

vided in case of inadmissible increases of outgoing gases temperatures that can take place when the heating surfaces of boilers are heavily polluted and during the emergency shut-downs of one of air-heaters.

Investigation of static and dynamic behaviors of energetic steam calorifier unit. For the estimation of static and dynamic properties of ESCU tests have been carried out on working boiler TGM-94 (Gas-Mazut boiler) of 160 *MW* power unit equipped with three *RRAH* with CO-110 type calorifer sections (Tables 1,2)

Table 1. Transfer function parameters of the calorifer unit on the channel "$Q_{st} - t_{c.a.}$"

Working load of boiler, MW	Heating steam flow changes Q_{st} > kg/s	Air temperature changes after calorifier $_t$ $t_{c.a.}$ °C	Transfer factor of the object K_0, °C/(kg/s)	Dead time τ_0, s	Time constant T_0, s	Fuel
1	2	3	4	5	6	7
154	3,05-3,61	55,2-60,0	8,64	108	666	mazut
	3,61-3,05	66,1-56,1	-18,0	60	480	mazut
155	3,05-3,61	61,5-66,0	8,1	96	672	gas
	3,01-3,05	66,0-62,3	-6,66	42	462	gas
120	2,36-2,77	58,5-64,1	12,96	156	762	mazut
	2,77-2,36	64,1-58,5	-9,58	120	860	mazut
156	3,05-3,61	63,5-69,0	9,9	84	1098	gas
	3,61-3,05	69,0-65,6	-6,3	96	528	gas

Table 2. Transfer function parameters of radiators unit and boiler on channel "$Q_{st} - t_{c.a.}$","$N - t_{o.g.}$"

Working load of boiler, *MW*	Heating steam flow changes Q_{st}, kg/s	Flue gases temperature changes $t_{o.g.}$, °C	Transfer factor of the object K_0, °C/(kg/s)	Dead time τ_0, s	Time constant T_0, s	Fuel
1	2	3	4	5	*6*	7
155	3,05-3,61	161-163	3,6	144	336	gas
	3,61-3,05	163-161	-3,6	84	288	gas
154	3,05-3,61	159-161	3,6	174	384	mazut
	3,61-3,05	161-159	-3,6	84	264	mazut
105-157*	3,05-3,75	150-171	30,24	180	1560	Gas-66,9% mazut-33,1%

The parameters of transfer functions of the calorifiers unit on channels "$Q_{st} - t_{c.a.}$", "$Q_{st} - t_{o.g.}$" and "$N - t_{o.g.}$" have been determined by following approximation:

$$W(p) = \frac{k_0}{T_0 p + 1} \cdot e^{r_0 p} . \quad (2)$$

It is established that transfer function factors of the calorifier unit on the channel "$Q_{st} - t_{c.a.}$" depend on loading of the power unit, i.e., on consumption of air passing through the calorifier.

Thus, for low working loads of power unit the transfer factors rise owing to increase of heat transmission from steam to air and for high loads they decrease. The same is true for the outgoing gases temperatures, but under high loads the factors of transfer are 1,5 — 2,0 times lower in comparison with factors of transfer by air and under low loads they have equal order of values.

Results of analysis of experimental data show, that the optimal condition for heating of air in calorifiers (not lower than 70°C - according to the requirement of technical operation norms) in various combinations of natural gas and mazut consumptions and rather close values of cold air and outgoing gases temperatures, was set at the levels of steam consumption 3,61 - 3,75 kg/s. The temperature of air on air-heaters inlet was 70,1 - 70,4°C, temperatures of outgoing gases were 171 - 173°C, and the outside air temperatures was 16 - 20°C. The temperatures of air on the air-heaters inlet can be raised to 85°C and higher, and hydraulic shocks in the condensate removal system will be excluded even in case of penetration of some amounts of steam if the condensate removal device, submitted in Fig. 2, c will be used.

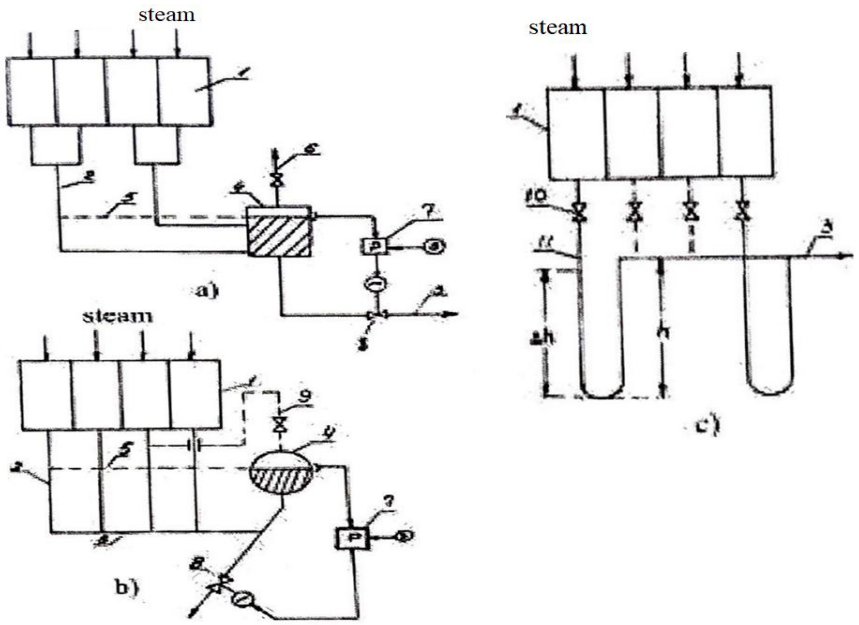

Fig. 2. Condensate low diagrams.
a) Standard layout; b) Device by Japanese patent No.5 8-44931;
c) Proposed condensate removal device;
1 - groups of calorifier sections; 2 – down take pipes; 3 - general condensate duct; 4 - expansion tank; 5 - level of condensate in expansion tank and drainage pipes; 6 - air-valve; 7 - regulator; 8 - regulating valve; 9 - leveling line; 10 - slide-valve; 11 – hydro seal

3. Results and discussion

New device for heating steam condensate removal. In contrast to the condensate removal devices, generally used at Thermal Power Plants [5] (Fig. 2,a) or to the device by Japanese patent [11] (Fig. 2,b), proposed condensate removal device, successfully implemented on the boilers TGM-94 of 160 *MW* power units and consisting of calorifier sections groups in the shape of U-type water-seals [10,11] (Fig. 2,c) works reliably even without automated control of condensate level in the expansion tanks.

In the offered device the inlets of the calorifier sections groups are connected to low-potential take-off of turbine and the outlets by the side-valves and water-seals are connected to general condensate removal line. Condensate is removed to the drainage tank of power unit or to the low-pressure heaters.

The basic requirement to the offered device for removal of heating steam condensate is to maintain the steady work of water-seals with maximal steam consumption through the calorifier when it is required to ensure the maximal heating of air. This requirement will be met if the sum of pressure of steam and water mixture and its high-speed pressure does not exceed the sum of leveling pressure of water column in water- seal and pressure of water in general condensate line. To meet this requirement the diameters of water-seal pipes should be determined by the following inequality:

$$D_{in}^2 > \frac{4Q_{st}^{max}}{\pi n} \cdot \frac{V'(1-x)+V''x}{\sqrt{\frac{20,4g}{\gamma_{mix}}(\Delta P_{lev}+P_w-P_{mix})}}; \quad (3)$$

where π=3,14; g =9,8lm /s^2; Q_{st}^{max} - maximal steam consumption though calorifier unit, kg/s; D_{in} - internal diameter of pipes, mm; n - number of water-seals; V', V''-specific volumes of water and saturated steam in the saturation line under the absolute pressure P_{mix}, kg/m^3; P_{mix} - absolute static pressure of steam and water mixture at the outlet from the groups of calorifier unit sections, MPa; ΔP_{lev}-maximal leveling difference of pressure in the water-seal, MPa; P_w - absolute static pressure of water after water- seal in general condensate line, MPa; x - mass steam content of the flow in water-seal, relative units.

Modified flow diagram of the calorifier unit. The reconstructed thermal scheme of the calorifier unit of TGM-94 boiler of 160 MW power unit is given on Fig. 3.

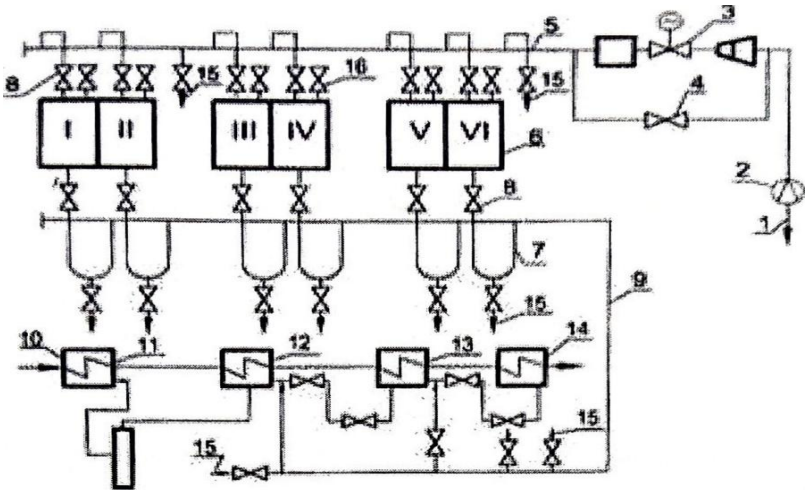

Fig. 3. Reconstructed thermal scheme of calorifier unit of the boiler TGM-94 of 160MW power unit

1 - supply of steam from V-take-off of turbine; 2 - flow-metering disk; 3 - regulating valve; 4 - bypass valve; 5 - supply of steam to groups of section; 6 - groups of calorifier unit sections; 7 – hydro seals; 8

- slide-valve; 9 - general condensate duct; 10 - feeding water; 11-14 - LPH 1, LPH 4;15 - drainages; 16 - air-valves

ESCU of the boiler consists of six groups of CO-110 type calorifier sections, three sections forming a group. By the project ESCU is fed with superheated steam from V(fifth)-take-off of turbine with 0,45 MPa pressure and 320°C temperature, in operation these parameters are lower. In addition, steam-consumption regulating valve with bypass slide-valve and steam flow-meters are installed on the line of steam supply. Two groups of calorifier sections set in one line with the direction of air movement are connected to each of three $RRAH$. The air is supplied to $RRAH$ from top to bottom and the fuel gases are supplied from bottom to the top.

4. Conclusion

The device for removal of steam and water mixture and condensate has six water-seals, one for each group of sections. The condensate removes from the general condensate line to the steam area of LPH-2 (Low Pressure Heater) and to the line of cascade drainage removal from LPH-4 to LPH-3. Such scheme allows to adjust the optimal working conditions of calorifier unit to meet the requirement of steady condensate removal, taking into account the maintenance of maximal efficiency of work of power unit as a whole.

On complete opening of steam consumption regulating valve and bypass slide-valve and 155MW working load of power unit, the air in ESCU is heated to 85°C and higher with the average temperature of 13 °C after blowing fans. Heating steam condensate is steady removed to the thermal scheme of the power unit at the temperature not exceeding 85-90°C. Hydraulic shocks in the condensate removal line are absent. The elaborated principal of calorifier units' automation can be implemented on all operating and designing gas-and-mazut boilers burning sulfur containing liquid and

gaseous kinds of fuel.

REFERENCES

1. R.B. Akhmedov, and L.M. Tsirulnikov. “Technology of gas and mazut burning in steam generators.” -L.: “Nedra”, 1976, 272 pp.

2. V.A. Lokshin, S.N. Tulin, T.V. Abramova, and V.N. Fomina. Guiding instructions for designing and operation of energetic calorifers with wire loop fins. -M.: SPO Soyuztechenergo, 1981, 43 p.

3. T.S. Dobryakov, V.K. Migay, V.S. Nazarenko, I.I. Nadyrov, and I.I. Fedorov Air-heaters of boiler units L.: “Energy”, 1977, 184 p.

4. A.S. Gonoboblev, I.A. Avdeev, O.G. Panasovskiy, and M.I. Rudoy About the method of protection of RRAH and gas ducts of TGMP - 204 boiler from low-temperature corrosion. Energetic, 1984, Xs 11, p. 12.

5. I.S. Mysak, I.A. Kuskov, M.T. Kruk, and I.M. Duda. Recommendations on the improvement of gas- mazut boilers' RRAH of 300 mw power units and their operation regimes under conditions of abrupt - variable schedule of loads of Thermal Power Station (Trial of Lukoml Steam Power Station). M.: SPO Soyuztech energo, 1989, 62.

6. Authorship certificate Ns 1216421 (USSR). Method of regulation of temperature of air behind the calorifier . S.S. Karaban, V.V. Pazukhin, and N.P. Virkovskiy // B.I., 1986, .N°9.

7. Authorship certificate Xel 578416 (USSR). Method of regulation of temperature of air behind the calorifier . A.N. Grechaniy, B.I. Pasko / B.I., 1988, N°26.[8] V.A. Lokshin. Formation of free level steam straight - tube heat exchangers. Thermoenergetics, 1974, Noll p.46-49.

8. Patent of the Republic of Uzbekistan N 4793. Method of automatic regulation of the temperature of air behind calorifer . S.K. Ismatkhodjaev, N.A. Zakhidov / B.I. RUz, 1997, N°4.

9. Patent of the Republic of Uzbekistan N 4232. Device for condensate removal from steam heat - exchangers . S.K. Ismatkhodjaev, Sh. A. Abdullaev, O.G. Ertcenkin, N.A. Zakhidov and O.A. Panov / B.I. Ruz, 1997, Nal.

10. Development of a mathematical model of a direct evaporative cooling device in air conditioning systems.Kh.S. Isakhodjayev, I.A. Toshpulatov. //Problems of energy and sources saving. №86. 2024 y. 123.

11. Methods for utilizing waste heat from a rotary clinker kiln. Kh.S. Isakhodjaev, Y.U. Abdullabekov. //Problems of energy and sources saving №85 2024 y.123.