ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0003

Study on Heat Transfer Performance of a Combined Type Roller Cold Slag Machine

Boquan Liao, Qingzhong He, Tao Peng, Yucong Liu

School of Mechanical Engineering Sichuan University of Science & Engineering in China, 644000, China.

Abstract

Based on the advantages of the traditional drum type cold slag machine, a kind of combined tandem roller water-cooled slag machine is designed.Using the ANSYS thermal analysis module, heat-solid and heat-flow coupling methods are used to carry out heat transfer analysis of high temperature slag and cooling water.The results show that the slag temperature from 1000 ℃ to slag temperature about 135 ℃, its thermal efficiency is 0.84, and cooling effect is obvious; 30 ℃ cooling water from import export heats up to 76 ℃, and the waste heat utilization ratio is 0.287. This type of cold slag machine can be combined in series according to different working conditions. Compared with the same level drum slag cooler, this innovative structure has the advantages of small size and light weight on the premise of ensuring heat exchange performance.

Keywords

Combined type roller cold slag machine, High temperature slag, Cooling water, Heat-solid coupling, Heat - flow coupling.

1. Introduction

With the continuous deepening of the national industrial green development plan, in the completion of the expected task of reducing the proportion of coal-fired power generation energy structure by another 30%, the circulating fluidized bed boilers above 300 MW have unique characteristics due to their combustion efficiency and energy saving and emission reduction. It is listed as one of the major technical equipment to encourage development. In order to ensure the safe and stable operation of circulating fluidized bed coal-fired boilers, and at the same time make full use of the residual heat of high-temperature slag and reduce the discharge of pollutants from ash powder, topics such as the cooling of high-temperature slag and the utilization of waste heat resources have received increasing attention . At present, when the slag cooler commonly used in circulating fluidized bed coal-fired boilers ensures heat transfer and continuous operation with material balance, once the stability of the circulating fluidized bed boiler changes, there are often phenomena such as limited heat exchange efficiency and ash powder clogging, thereby affecting the operation of the circulating fluidized bed boiler[1-4].

The drum type cold slag machine has the advantages of stable and reliable operation due to its simple structure and controllable balance of materials and heat exchange. It can be applied to the cooling of slag at different temperatures and has been widely used[5-6]. However, related researches on heat transfer characteristics, heat exchange efficiency, and material balance in the drum-type slag cooler mainly rely on experience and calculation of heat balance[7-8]. The team represented by Tsinghua University Li Jinjing et al[9], Huazhong University of Science and Technology Zhuang Yu et al.[10], North China Electric Power University Liu Pingping[11] achieved good results in the heat transfer analysis and experimental research of the drum type cold slag machine , It is of great significance to

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0003

promote the heat transfer of the ash and slag of the drum type cold slag machine, improve the slag capacity and stabilize the operation. This paper focuses on the heat transfer performance of a new type of drum type cold slag machine with a combined series structure to verify the effectiveness of the new type drum type cold slag machine structure and heat exchange efficiency design.

2. Determination of main design parameters and establishment of three-dimensional model

2.1 Main structural features

Compared with the traditional roller slag cooler, the combined roller slag cooler adopts a series combined cold slag heat exchange cylinder structure, which can flexibly connect the number of heat exchange cylinder groups in series according to the working conditions and adjust the flow or flow rate of cooling water , While maximizing the recovery of high-temperature slag waste heat to achieve cooling requirements, low-temperature and low-volatile dust slag is obtained in the closed volume, which reduces the pollution of dust particles and has greater economic and social benefits.

The structural innovation of this type of drum slag cooler lies in the series combination to form a heat exchange cylinder. In the horizontal horizontal rotation installation, the slag inlet is set at the high end and the slag outlet is set at the low end. When the high temperature slag enters the prismatic cold slag tube Due to the action of the polygonal body, the slag rolling motion in the prism is much greater than the sliding motion, which reduces the wear on the inner surface of the prism and improves the service life. It has the characteristics of flexible heat exchange cylinder combination, wide application range, high heat exchange efficiency, small friction on the slag cooling surface, compact structure, small size and light weight.

2.2 Main design parameters

The main design parameters of the combined drum cold slag machine are shown in Table 1.

Table 1 main design parameters of combined type roller slag cooler

Design Parameters	value	unit
Number of combined series	4	group
Effective calculation length of slag machine	3.2	m
Slag inlet temperature	1000	℃
Slag outlet temperature	≤170	℃
Slag cooling capacity	1-2	t/h
Cooling water inlet temperature	30	℃
Cooling water outlet temperature	≤90	℃
Cooling water	3-6	t/h
Drum speed	5	rad/s
pressure	650	Pa

2.3 The establishment of the geometric dimensions and three-dimensional model of the combined drum cold slag machine

In order to study the heat exchange performance of the combined drum slag machine, under the premise of being as consistent as possible with the actual operating conditions of the slag machine, 4 groups were selected as the reference group for series connection, of which the geometric dimensions of the single group of drums are shown in Figure 1. On this basis, the three-dimensional assembly

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0003

phantom of the combined roller cold slag machine is established using Solid Works three-dimensional modeling software as shown in Figure 2.

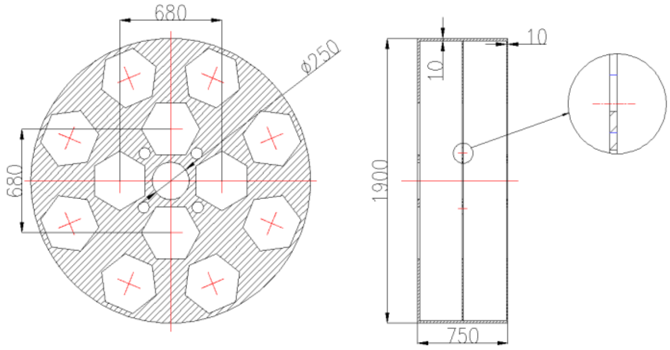

Fig.1 Geometric dimensions of single roller

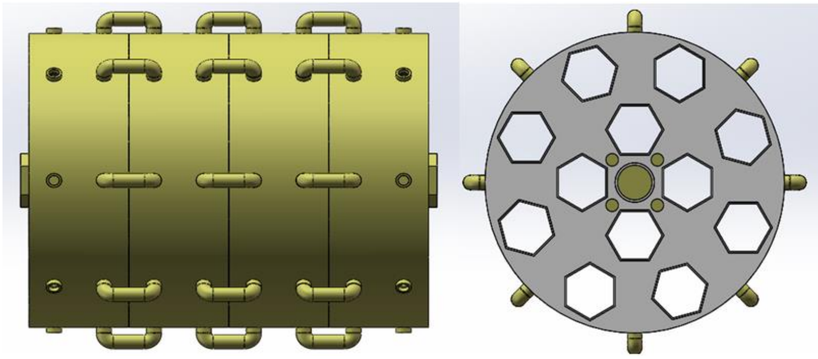

Fig. 2 Three-dimensional model of combined roller slag cooler

3. Heat transfer performance analysis

When the high temperature slag enters the cold slag tube in the cold slag machine, the ash will transfer a large amount of physical heat carried by itself to the cold slag tube wall in the cold slag machine, releasing most of the heat, and then the tube wall The heat on the surface is transferred to the surface of the drum of the slag machine through heat conduction, and a large amount of heat is absorbed under the effect of heat convection of the cooling water to achieve the effect of cooling and cooling[12].

3.1 Heat transfer analysis of high temperature slag

In the actual working process of the cold slag machine, there is mainly contact heat exchange between the high-temperature slag and the wall surface of the cold slag tube covered by it; the radiative heat exchange between the high-temperature slag and the wall of the uncovered cold slag tube; the air is not covered by the slag The heat transfer between the wall surface of the cold slag tube and the heat transfer between the high-temperature slag and air; the convection heat exchange between the wall surface of the cold slag tube and the cooling water in the roller channel; the heat dissipation on the outer surface of the roller[13-14]. In the analysis, the following assumptions and simplifications of the model need to be made: the slag movement in the cold slag tube is consistent, and it is assumed that the temperature distribution of the furnace in each cold slag tube is the same in the axial direction; each cold slag is under the difference between high and low temperatures The difference in thermal expansion coefficient of the tube is very small, and the average thermal expansion coefficient can be used instead; the air in the main cylinder can be considered to be relatively static due to the slow flow of the air, so the convection heat exchange of the air can be ignored; the temperature difference

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0003

between different media is far Far greater than the temperature difference of the axial medium, the heat of the ash is mainly absorbed by the cooling medium, and the axial heat transfer is ignored[16].

3.1.1 Establishment and division of grid model

According to the size of the main barrel of the combined cold slag machine, the Solid Works professional modeling software is used to create a 3D model of its assembly, and further pass the interference check to ensure that the assembly is free of interference, and save it as STEP format for import Go to the mesh module of the workbench platform to perform grid division. The grid model is shown in Figure 3. The number of nodes is 770440 and the number of nodes is 1381057.

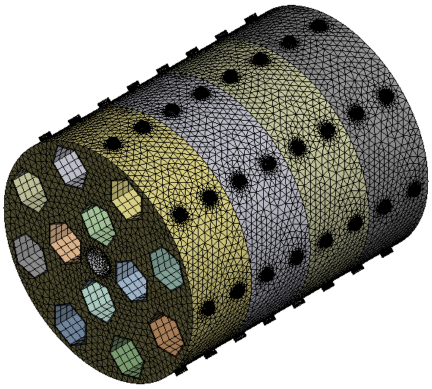

Fig.3 Grid heat transfer model of slag

3.1.2 Setting and solving of physical boundary conditions

A high-temperature slag of about 1000 *°C* is attached to the inlet end of the drum of the cold slag machine. This simulation calculation uses 1000 *°C* for the calculation simulation; a large amount of cooling water is attached to the drum, of which the initial temperature of the cooling water is 30 *°C*. For forced convection heat exchange, according to the structural characteristics of the slag cooler and the layout characteristics of the cold slag pipe, the convection heat transfer coefficient is 5000 $W/(m^2{\cdot}°C)$. The material of the roller is nickel-chromium steel, the heat transfer rate is 70 $W/(m^2{\cdot}°C)$, and the solution calculation is performed to obtain the axial temperature distribution of the slag in the main barrel of the cold slag machine. As shown in Figure 4, the corresponding path is obtained through a custom path Slag temperature change curve, as shown in Figure 5.

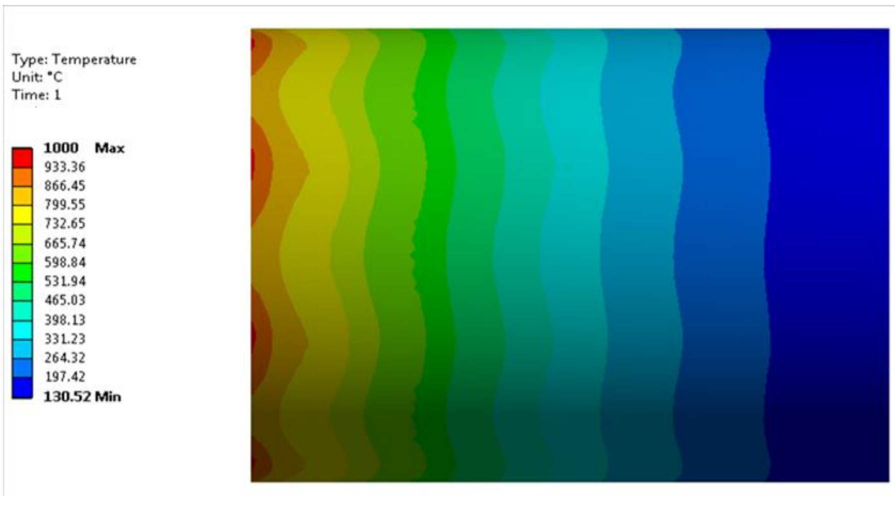

Fig. 4 The slag temperature distribution on overall axial path

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0003

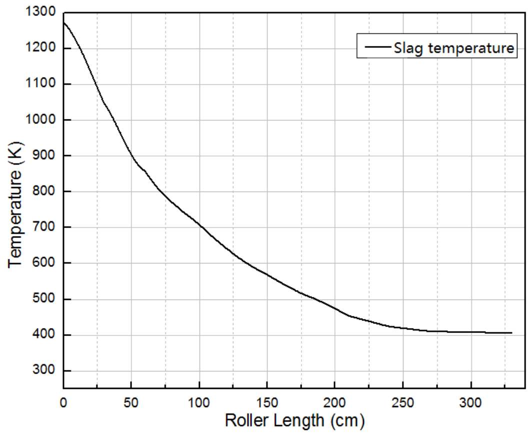

Fig. 5 Temperature variation curve of slag axial path

It can be seen from Figures 4 and 5 that after cooling, the slag has a large temperature gradient in the drum. Because the cooling water temperature is lower at the inlet, the cooling rate of the slag machine inlet is faster. With the operation of the slag machine and the increase in the temperature of the convective cooling water, the slag cooling rate gradually decreases and reaches the outlet. The cooling rate tends to be gentle. The high-temperature slag is continuously cooled from the inlet end to the outlet end, and gradually decreases from the inlet end of 1273 K to the outlet end of 413 K, indicating that the convection cooling effect of the slag cooler is obvious.

3.2 Heat transfer analysis of cooling water

On the basis of slag heat transfer analysis, the heat flow coupling analysis method is used to extract the flow channel model, mesh division, medium attribute setting, apply boundary conditions and solve the cooling water temperature of the combined drum slag cooler finite element model. The distribution cloud diagram is shown in Figure 6, the temperature of the middle symmetry plane is shown in Figure 7, and the temperature change of the end face is shown in Figure 8: (a)-(h), where the main parameters are set as follows: the temperature of the inlet end of the cooling water is 30$°C$ Normal temperature water, the pressure is 0.6 Mpa.

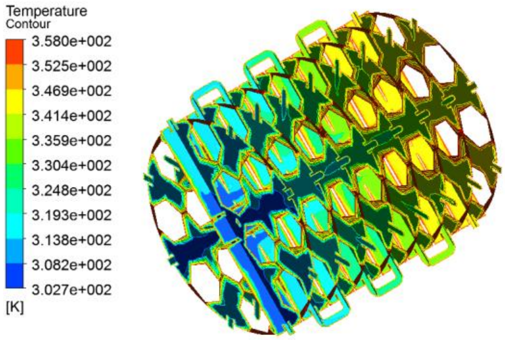

Fig.6 Cooling water overall temperature distribution nephogram

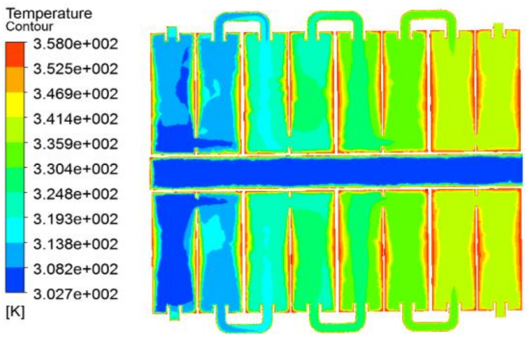

Fig.7 axial temperature distribution of cooling water

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0003

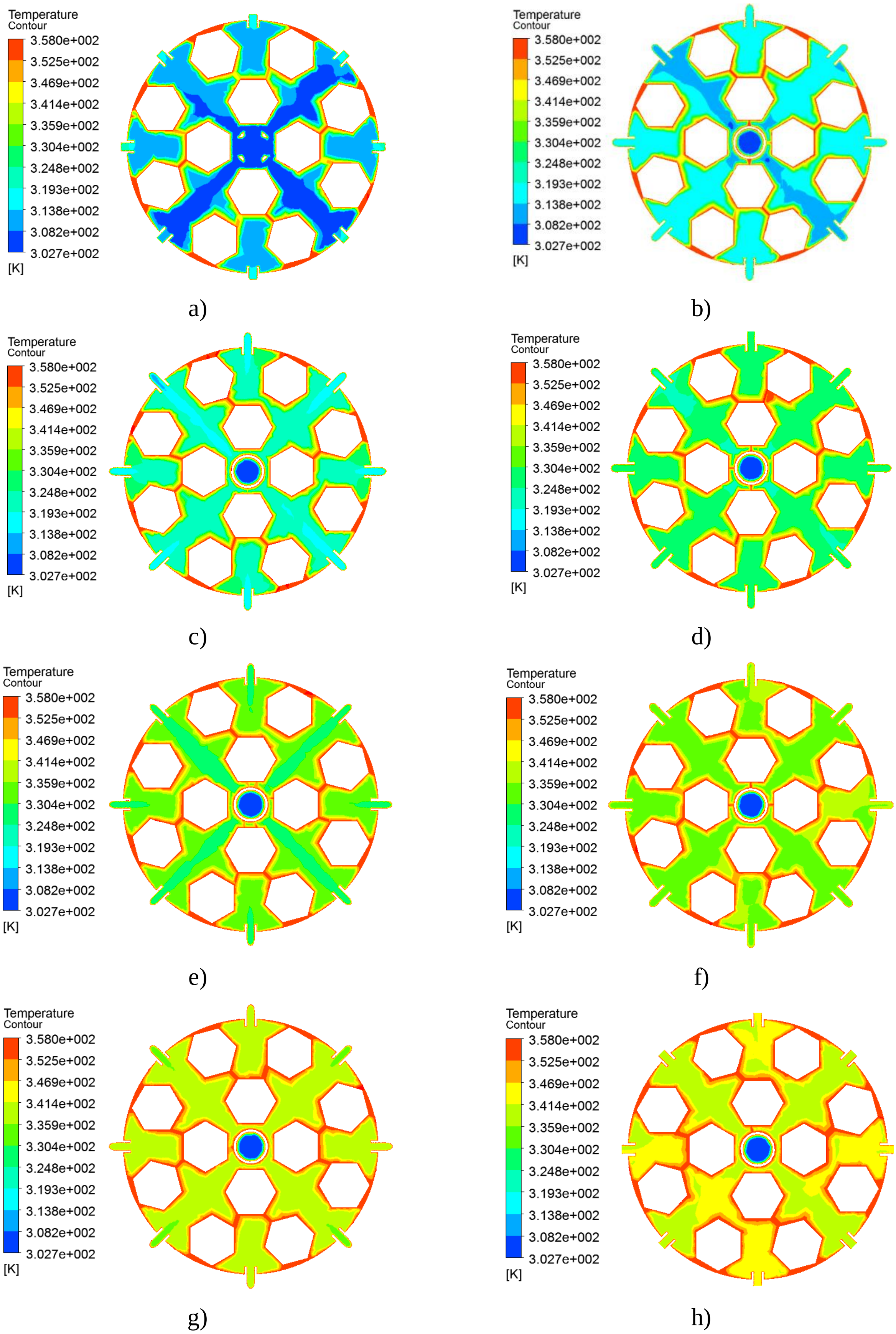

Fig.8 End temperature of each combined unit

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0003

According to the analysis results of the temperature change of the cooling water in the axial direction and the radial direction, it can be obtained that the temperature of the cooling water gradually increases and the overall temperature rises, gradually increasing from 303 *K* (30 °*C*) to 350 *K* (76 °*C*), which is consistent with the cooling of the slag machine Claim. The cooling water flows into the drum of the cold slag machine through the middle hollow shaft. Because there is no convection heat exchange, the temperature of the cooling water in the central shaft remains basically unchanged. With the operation of the cold slag machine and the temperature of the slag in the cold slag machine The temperature difference between the cooling water and the slag gradually decreases, and the temperature of the cooling water gradually becomes gentle.

Through the heat transfer analysis of the high-temperature slag in the combined drum cold slag machine, that is, the slag gradually decreases from the inlet of 1273 *K* (1000 °*C*) to the outlet of 408 *K* (135 °*C*), and the heat flow analysis of the cooling water, that is, the cooling water gradually from the inlet 303 *K* The temperature is raised to 350 *K* (76 °*C*) at the outlet, all of which meet the design requirements of the combined drum cold slag machine. At the same time, in order to make the analysis results more intuitive, the results of the two types of heat transfer analysis are further fitted into curves to obtain the temperature change curve of the slag and cooling water in the axial direction, as shown in Figure 9. It can be seen from the temperature change curve of slag and cooling water that high temperature slag will release a large amount of physical heat in a short time after entering the main barrel of the slag cooler, and forced convection heat exchange with the cooling water to achieve a rapid cooling process, and with the The operation of the slag cooler and the influence of convection heat transfer reduce the slag temperature, and the final slag temperature stabilizes at around 408.15 *K*. At the same time, the cooling water temperature rises and finally stabilizes at about 350 *K*. With the temperature difference between the slag and the cooling water Reduced, the slag cooling and cooling water heating basically reached the dynamic heat exchange balance.

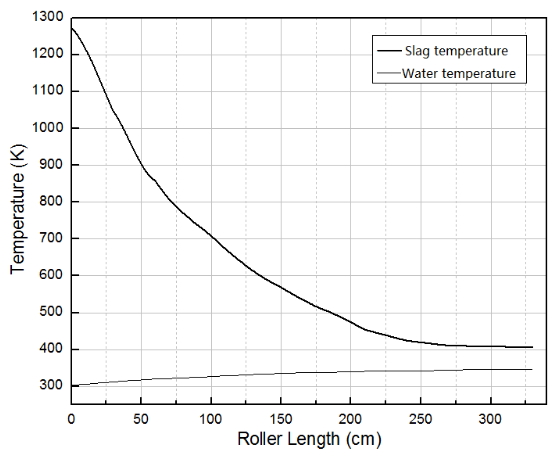

Fig.9 Curves of axial temperature of cooling water and slag

3.3 Energy efficiency analysis of combined roller cold slag machine

According to the calculation results of the cooling water and slag temperature field and the related design parameters of the combined drum slag machine, in order to more intuitively express the thermal efficiency and effective waste heat utilization rate of the combined drum slag machine, through the calculation formula and calculation results It is further fitted into a correlation curve [17], as shown in Figures 10 and 11.

It can be seen from the above figure that the heat exchange efficiency of the combined drum slag cooler varies in different slag discharge temperature ranges. The slag temperature is calculated to be around 135 °*C*, the heat exchange efficiency is 0.84, and the cooling water temperature increases To

ISSN: 2414-1895
DOI: 10.6919/ICJE.202009_6(9).0003

about 76 *°C*, the remaining heat utilization rate is 0.287. Therefore, under the premise of ensuring the safe operation of the cold slag machine equipment, when raising the temperature of the cooling water, there is an effective way to improve the utilization of the residual heat and energy efficiency of the cold slag machine.

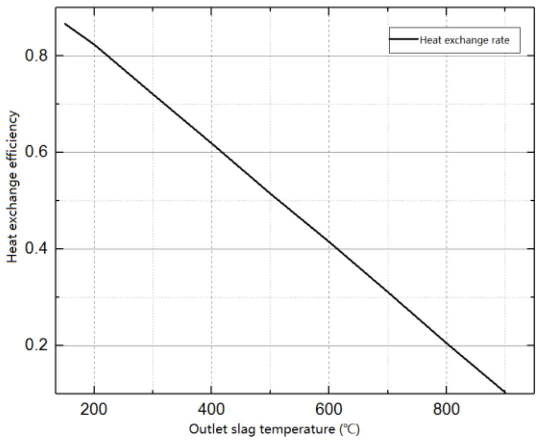

Fig.10 Heat transfer efficiency diagram

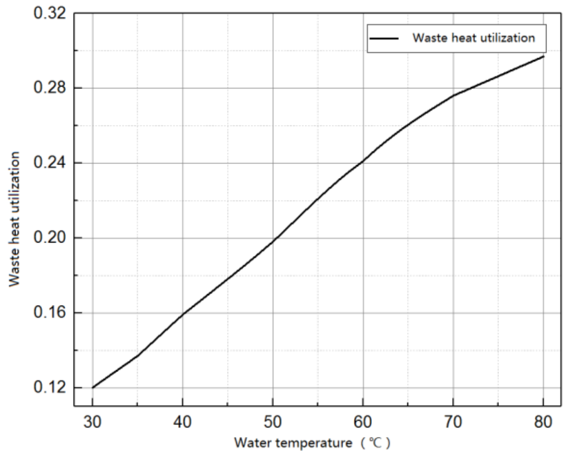

Fig.11 Waste heat utilization efficiency diagram

4. Conclusion

1) Axial heat transfer analysis of the high-temperature slag in the slag cooler to obtain the temperature change of the slag from the inlet end to the outlet end, as the evaluation standard of the heat transfer and cooling performance of the combined drum slag cooler, the result table shows the temperature of the slag outlet end It is basically stable between 135*°C*-150*°C*, which meets the cooling requirements of the drum slag cooler.

2) The heat flow coupling method was used to analyze the convective heat transfer of the internal cooling water of the combined drum slag cooler, and the temperature change of the cooling water was obtained. The results showed that the temperature of the cooling water outlet was basically stable at about 76 *°C*. With the temperature difference between the slag and the cooling water The reduction of the final, basically reached the dynamic heat balance.

3) The energy efficiency of the combined drum slag cooler is analyzed, and the heat exchange efficiency is 0.84 and the waste heat utilization rate is 0.287, which provides a strong theoretical basis for the structural design, heat transfer and energy efficiency analysis of the slag cooler.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0003

References

[1] QIAN Zhiyong, ZHU Yunpeng, XIONG Tihua etal. Analysis and improvement of operation problem of fengshui combined cold slag of large CFB boiler [J]. China Power, 2006, 39(4):52-55.

[2] SHU Maolong, CHEN Jihui, LU Xiaofeng et al. Investigation on Fluidized Bed Bottom Ash Coolers in Large-Scale CFB Boilers[J].Power System Engineering, 2007 23(2).

[3] LI Sen, CEHN Lei, FAN Guiru,etal. Circulating fluidized bed boiler cold slag coking reason analysis and prevent method [J]. Power system engineering, 2008,24(2):29-33.

[4] WANG Xin, ZHANG Zhi. Problems and treatment measures of wind water combined slag cooler in circulating fluidized bed boiler [J]. thermal power generation, 2008, 37(4):40-42.

[5] ZHANG Haiquan. Characteristics and application of roller cold slag machine[J]. technology and equipment, 2011 5.

[6] WU Lang, Discussion on the main tube structure of the drum water cooled slag cooler [J]. technology and innovation, 201412.

[7] ZHANG ZHongli, ZHEN Liguo, Heat balance calculation of FSG geomantic cooling roller slag cooler [J]. coal engineering, 2003, (12):55-56.

[8] LIU Kun. Analysis and calculation of heat transfer model of 300MWCFB boiler drum slag cooler, [J], thermal power generation, 2010, 01 (39).

[9] LI Jinjing, WANG Wei, YANG Shi et al. Experimental study on heat transfer characteristics of drum slag[J]. Power System Engineering, 2009 25(1):11-13.

[10] ZHUANG Yu, CEHN Hanping, YANG Huanping etal. Onedimensional heat transfer simulation of roller type cold slag machine [J]. Journal of power engineering, 2011,7 (31).

[11] LIU Ping, ZHOU Tao. Research on heat transfer process of slag slag in circulating fluidized bed boiler [J]. thermal power generation, 2011,10.

[12] HE Xiaoyang. Heat transfer model and numerical simulation of circulating fluidized bed boiler[D]. Huazhong University of Science and Technology, 2007.

[13] JIA Jiandong. Study on the slag movement and heat transfer analysis of the roller cooler[D]. North University of China, 2016.

[14] LIU Boqian, LIU Huaiwei, TAN Peilai et al. Study on the heat transfer process of the roller cold slag machine[J]. Xuzhou engineering journal, 2014 29(2).

[15] Si X, YANG H, Wu Y, et al. Heat transfer in the rotary ash cooler with residual char combustion considered[J]. Fuel Processing Technology, 2012, 94(1):61-66.

[16] ZHUANG Yu. Study on the slag movement and heat transfer analysis of the roller cooler[D].Huazhong University of Science and Technology,2011.

[17] LI Jianfeng, LV Junfu, LI Bin.Energy and efficiency analysis ash cooling equipment of 300 MW circulating fluidized bed unit[J], 2011 17(4).

[18] Yang M. Numerical study of the characteristic influence of the helically coiled tube on the heat transfer of carbon dioxide[J]. Applied Thermal Engineering, 2016, 102:882-896.