Heating And Air-conditioning Technology For Radiant Heat Recovery In Kiln Wall Of Cement Plant

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ABSTRACT

There is a large amount of energy waste in the cement production process, in which the waste of rotary kiln heat and the waste of high temperature exhaust gas at the kiln tail are the most serious. Therefore, the full and reasonable utilization of this waste heat resource is an important measure to improve the utilization degree and energy efficiency of waste heat, effectively reduce the heat pollution caused by waste heat emission to the environment, and protect the ecological environment. It is of great significance to realize energy conservation and emission reduction and regional sustainable development. The strategic goals are extremely important. At present, the waste heat mainly used by cement plants is the high-temperature flue gas at the kiln head and kiln tail, and there are few cases of recycling the radiant heat of the kiln tube wall. Therefore, based on the data provided by a cement plant in Shandong Province, China, a set of waste heat recovery equipment for the rotary kiln of a cement plant is designed. According to actual needs, a suitable lithium bromide absorption refrigeration unit and heat exchanger are selected to determine the waste heat utilization plan in winter, summer and transition season and make economic analysis.

1. INTRODUCTION

Energy resources are the foundation of energy development. As a national basic industry, the cement industry belongs to the high-energy manufacturing industry, which is the most serious area with low production capacity and high pollution. As a major energy consumer, the cement industry has become a bottleneck in the development of coal, electricity and pollutant emissions.

Cement producers are big energy hogs and emit a lot of heat. The waste heat resources of cement kiln mainly come from three production stages: raw material pre-decomposition (pre-decomposition furnace), clinker firing (rotary kiln), clinker cooling (clinker cooler). Energy waste mainly includes: 1) exhaust gas from preheater at the end of kiln, 2) exhaust gas from grate cooler at kiln head, 3) heat dissipation on the surface of kiln barrel, 4) used for drying the heat generated by raw material grinding. Among them, the high-temperature flue gas is mainly produced in the kiln head and the kiln tail, which contains a large amount of dust. As an important part of cement production equipment, rotary kiln accounts for more than 85% of the energy consumption of the whole production line (Han, 1996).

At present, the low temperature waste heat is used to generate electricity in the cement industry, which reduces the power consumption of cement production while utilizing the waste heat resources, achieves self-sufficiency in the electric energy in the cement production process, and reduces the production cost of cement. The external surface temperature of rotary kiln barrel is up to 250-350℃, and the heat directly discharged into the atmosphere can be up to 7-12% of the total heat consumption of cement production (Shen, 2016). The heat loss on the outer surface of rotary kiln accounts for about 12% of the total energy loss of cement production line, and 56.3-66.3% of the surface heat loss of cement production line. In addition, the outlet flue gas temperature of rotary kiln is between 250 ℃ and 400 ℃, and its outlet flue gas energy accounts for 19.5 ~ 32.6% of the total energy consumption of cement production (Yin, 2018). Thus it can be seen that the main equipment of the above three processes have the potential of saving energy and reducing consumption.

Zhu *et al*. (2001) was proposed in 2001 by high temperature period in rotary kiln surface set water jacketed devices to surface heat recovery methods, then some researchers have designed various kinds of surface heat recovery unit. According to the surrounding area of the surface of the rotary kiln, divided into semi-closed collector and totally enclosed collector.

Zhang *et al*. (2012) et al. carried out a preliminary optimization design for the semi-enclosed collector, using convective fin tube instead of the existing conventional circular tube, and setting a convective window on the shell. Wang *et al*. (2013) designed a fully enclosed collector. The heat exchange tube beam is arranged along the axial direction of the kiln body to make the best use of the surface heat dissipation. Japan has been interested in the waste heat of cement plants for a long time. More than 30 years ago, two sets of waste heat units were put into operation in Gifu cement plant, which were used to recover the waste heat of gas exported by cooling machines (Zhong *et al*., 1990). Nearly 70% of the new dry cement production lines in Japan are equipped with waste heat power generation, and the operation is stable and the power generation efficiency is high. More than 43% of the power consumption comes from waste heat power generation, which is in the world's leading level of waste heat recovery technology (Tahsin *et al*., 2005). On the basis of energy flow analysis of rotary kiln, Mirollli *et al*. (2007) points out that the main heat loss of the new dry cement production line is: exhaust gas at the outlet of the preheater, exhaust air from the grate cooler, convection and radiant heat on the surface of the rotary kiln. Relevant research shows that the amount of heat dissipated from the barrel surface of cement rotary kiln is considerable and it has high recycling value. Recurrent corporation in the United States has developed a waste heat recovery system for steam turbines using a mixture of ammonia and water as the working medium, with a capacity of 50 ~ 60kWh/t per ton of waste heat generated from clinker (Wu *et al*., 1993).

Taken together, the cement waste heat resource is enough, though some are used, but can be a great potential for development, therefore, sufficient and reasonable utilization of the waste heat resources, increase the degree of cement plant of cascade utilization of waste heat and energy utilization, can effectively reduce the emissions of waste heat thermal pollution to the environment, is one of the important measures to protect the ecological environment, the construction resource conservation society and environment friendly society, to realize the sustainable development of energy conservation and emissions reduction and regional strategic target has the extremely important significance.

2. OVERVIEW OF WASTE HEAT

Taking two cement production lines of 5000 t/d as an example, the surface temperature of rotary kiln barrel is generally around 300 ℃. Due to the long barrel of rotary kiln, the temperature of each section varies greatly during the calcining process of cement clinker. According to the different changes of materials in rotary kiln, the new dry rotary kiln is divided into transition zone, firing zone and cooling zone. The temperature of transition zone is low, and the temperature of firing zone is basically above 300 ℃. The cooling zone temperature drops. The firing zone of the barrel temperature is the highest, the average temperature is 300 ~ 350 ℃, the length of the rotary kiln about 1/8

~ 1/9 of the length of the barrel. Therefore, when designing the installation position of heat exchanger, the clinker firing section of kiln body should be preferred. The heat loss of cement rotary kiln barrel is

$$\phi = \alpha_T A_1 (T_R - T_E) \quad (1)$$

ϕ ——The total heat transfer, W

α_T —— Comprehensive heat transfer coefficient, W/m^2 K

A_1 —— External surface area of rotary kiln barrel, m^2

T_R —— Rotary kiln barrel surface temperature, K

T_E —— Outdoor ambient temperature, K

When the diameter of the cement rotary cellar barrel is D=4 m and the length L=60 m, the surface emission rate of the kiln barrel is 0.8, the average surface temperature of the barrel is calculated by T_R =300 ℃, the outdoor environment temperature is 20℃, and the outdoor wind speed is 1.5m/s, the known data is put into the equation to obtain: ∅=4 MW. It can be seen that in the case of no recovery of waste heat from the surface of rotary kiln, the heat loss on the surface of the pit barrel is still large, so the recovery potential of waste heat on the surface of the pit barrel is considerable.

3. DESIGN OF WASTE HEAT RECOVERY DEVICE

3.1 Structure of Waste Heat Recovery Unit

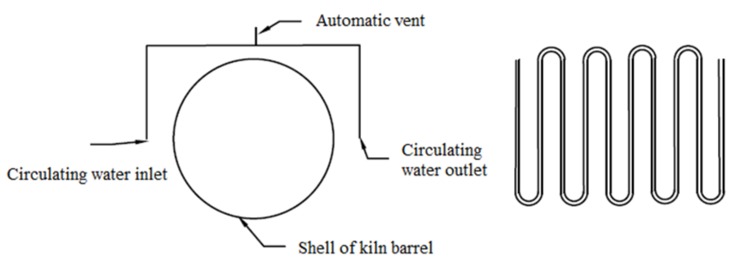

Figure 1: A waste heat recovery device of rotary kiln

By consulting literature and analyzing the structure of rotary kiln, it is found that a waste heat recovery device of rotary kiln is shown in Figure 1. The waste heat recovery device semi-surrounds the rotary kiln, and the overall device is rectangular, and the internal collecting pipe is arranged in a snaking pattern. The waste heat device has a small area surrounding the rotary kiln, and the waste heat cutting device is rectangular, which is not conducive to the uniform heating of the water in the collecting tube, and the serpentine arrangement. There is a distance between the collecting tubes, and the volume of the water used by the waste heat recovery device is not large enough.

It is found that the heating surface of the waste heat recovery device has a reasonable circular arc structure, and the covering area is more than 1/2, so that the different areas of the collector are close to the surface of the cylinder, and the heat transfer area is expanded, which is conducive to radiation heat transfer. In addition, the actual engineering test results show that there is no significant change in the temperature of kiln barrel before and after using the waste heat recovery device, and there is no adverse effect on the process operation of the kiln. The collecting tubes are still serpentine, reducing the distance between them and making the collector more capable of heating water.

The design diagram of the improved waste heat recovery device is shown in Figure 2.

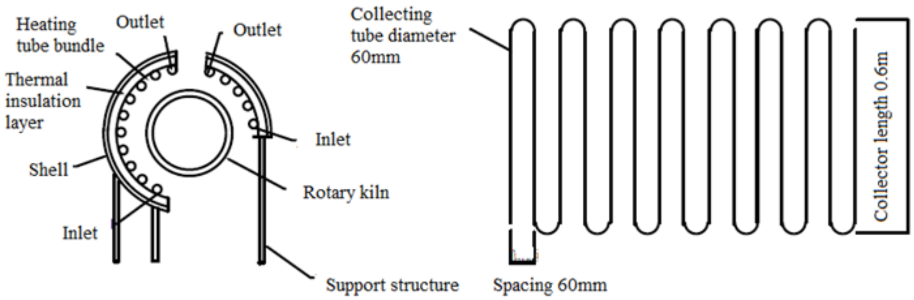

Figure 2: The diagram of waste heat recovery device

The overall waste heat recovery device is a circular arc, which is composed of outer shell, insulation layer and collector bundle. The collector can be set on the movable steel support structure, which can be adjusted at any time, so as to facilitate the overhaul and maintenance of the collector. The collector surrounds 3/4 of the area of the kiln barrel. Under the condition that the surface temperature scanning monitor and the cooling fan of the kiln barrel are set on the same side, the unenclosed area can be used as the surface temperature scanning monitoring area and the cooling blower area of the kiln barrel.

3.2 Design and Calculation of Waste Heat Recovery of Kiln Barrel

Hypothesis: rotary kiln running stable and uniform surface temperature, Set the hot water tube wall temperature is uniform, Ignore the rotary kiln shell, hot water pipe and air gap of convective heat transfer, Rotary kiln shell and the heating device is the radiation heat transfer between the two diffuse gray surface of the closed cavity radiation heat transfer.

The thermal resistance analysis of waste heat recovery device is shown in Figure 3.

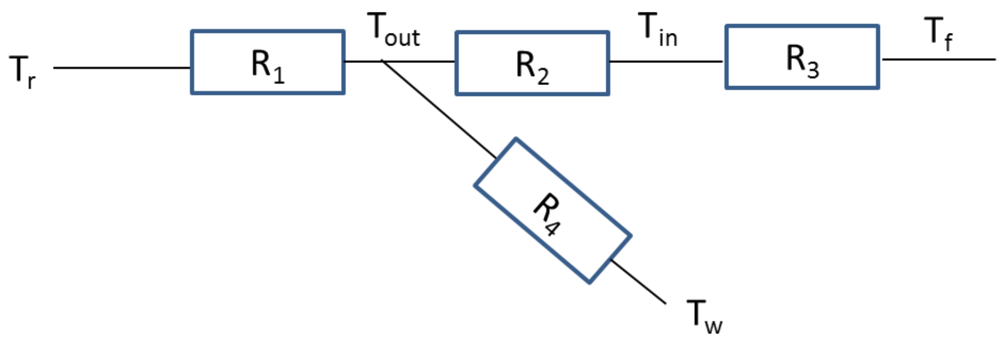

Figure 3: Thermal resistance analysis of waste heat recovery device

Where T_r is the temperature of rotary kiln, T_{out} is the external surface temperature of collecting tube, T_w is the shell surface temperature, T_{in} is the surface temperature of hot water collecting tube, and T_f is the temperature of the water inside the collector.

The relevant thermal resistance is calculated as follows:

$$R_1 = \frac{1}{\frac{1}{\varepsilon_1} + (\frac{1}{\varepsilon_2} - 1)\frac{A_1}{A_2}} \tag{2}$$

R_1- Radiant heat transfer resistance between tube and hot water collector in cement rotary kiln,

A_1- External surface area of rotary kiln, m^2

A_2- Surface area of hot water collecting pipe of heat exchanger body participating in heat exchange, m^2

ε_1- Emissivity of rotary kiln barrel,

ε_2- Emissivity of hot water collector.

$$R_2 = \frac{n}{\frac{1}{2\pi\lambda l}\ln\frac{r_{in}}{r_{out}}} \tag{3}$$

R_2 - The thermal resistance of the wall of a hot water collector, K/W
n- Number of collecting tube roots,
λ- Heat conductivity of collector tube, W/m•K
l- Length of single hot water collector, m
r_{in}- Inner diameter of hot water collecting pipe, m
r_{out}- Outer diameter of hot water collecting pipe, m.

$$R_3 = \frac{1}{n\pi l h_m r_{in}} \tag{4}$$

R_3- Convection heat transfer resistance between inner wall of water pipe and water, K/W
h_m- Convective heat transfer coefficient between inner wall and water of hot water collecting pipe, W/m^2•K

$$R_4 = \frac{2\pi l}{\frac{\ln\frac{d_2}{d_1}}{\lambda_1} + \frac{\ln\frac{d_3}{d_2}}{\lambda_2}} \tag{5}$$

R_4-Heat conduction resistance of insulation layer and steel shell, K/W;
d_1- Insulation inner diameter, m;
d_2- Outer diameter of insulation layer, m;
d_3- Outer diameter of steel shell, m;
λ_1- Thermal conductivity of insulation layer, W/m•K;
λ_2- Thermal conductivity of steel shell, W/m•K;
l- Heat collector length, m
The mathematical model of heat exchanger is as follows:
Radiant heat transfer between rotary kiln and collector tube:

$$\varnothing_1 = \frac{\sigma A_1}{R_1}(T_r^{\,4} - T_{out}^{\,4}) \tag{6}$$

Through the heat conduction of the wall of the hot water collector：

$$\varnothing_2 = \frac{n}{R_2}(T_{out} - T_{in}) \tag{7}$$

Convection heat transfer between the inner wall of the hot water collecting pipe and the water:

$$\varnothing_3 = R_3 \nabla T_m \tag{8}$$

Mean temperature difference ∇T_m calculation:

$$\nabla T_m = \frac{T_1 - T_2}{\ln\frac{T_{in} - T_2}{T_{in} - T_1}} \tag{9}$$

Heat gain from water：

$$\varnothing_4 = mc_p(T_1 - T_2) \tag{10}$$

Heat conduction of the enclosure through the insulation layer：

$$\varnothing_n = R_4(T_{out} - T_w) \quad (11)$$

When the system is in thermal equilibrium, there is the following relationship:

$$\varnothing_1 = \varnothing_3 = \varnothing_4 \quad (12)$$

$$\varnothing_1 = \varnothing_2 + \varnothing_n \quad (13)$$

Its surface temperature is constant at 573K, its surface is oxidized steel surface, and its emissivity is 0.8. Calculation of heat transfer area of the recovery device: the length of the hot water collecting pipe of the recovery device is 0.6 m and the shape is 3/4 circular arc.

Taking winter heating as an example, the inlet water temperature is set to 70 ℃ and the outlet water temperature to 95 ℃. The surface occurrence rate of galvanized welded steel tube with hot water collecting tube was 0.37. The shell temperature of the heat collector is 323 K.The steel plate shell is made of low-alloy steel plate with a thickness of 50mm ($\lambda 1$＝36.7 W/(m•K)). The insulation layer is made of slag wool (λ_2＝0.58 W/(m•K)).

The outer diameter of hot water collecting pipe of heat collecting device is 60 mm. Length of hot water collection pipe: the length of each section of hot water collection pipe is 0.6 m in measured length of each section of rotary kiln. The distance between the heat collector and the rotary kiln is 0.1 m. The insulation layer thickness is 0.1 m.

Assuming that the inside of the hot water collector pipe is fully developed by laminar flow, the convective heat transfer coefficient between the inner wall of the hot water collector pipe and the water is independent of Reynolds number. Under the condition of constant wall temperature, N_u = 3.66. Check the dimension table of welded zinc steel pipe used for low-pressure fluid transportation to get the steel pipe with the outer diameter of 60 mm and the wall thickness of ordinary steel pipe is 3.5 mm, h_m＝46.54 W/(m^2•K). Comprehensive recoverable heat: 1.98 MW. According to the design, the inlet temperature of the water is 70 ℃ and the outlet temperature is 95 ℃. Combined with the recyclable residual heat, the flow rate of the water is 67885 kg/h, namely 67.885 m^3/h.

4 COMPREHENSIVE APPLICATION SCHEME OF WASTE HEAT RECOVERY OF ROTARY CYLINDER

4.1 Recovery and Utilization of Waste Heat from Rotary Cylinder in Summer

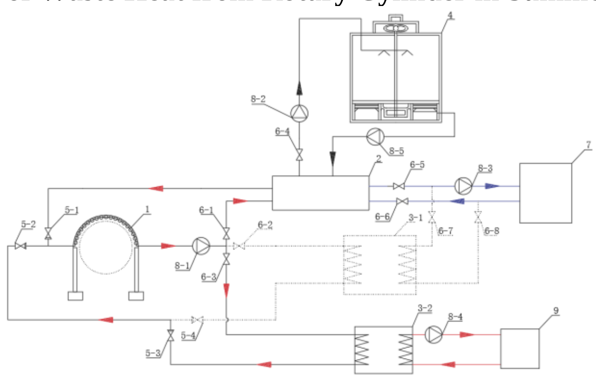

Figure 4: Waste heat recovery and utilization scheme of rotary cylinder in summer

1- Kiln drum wall waste heat recovery device 2- Lithium bromide absorption refrigerating unit 3- Water-water heat exchanger 4- Cooling tower 5- Check valve 6- Switch valve 7- Client fan coil 8- Water pump 9- Bath end device

As shown in Figure 4, during the summer in order to meet the demand of cooling and washing, the rotary cylinder outer radiant heat by waste heat recovery unit for heat recovery kiln wall, filling the deionized water in the device to prevent internal scale, with deionized water as a dielectric absorption wall lateral radiant heat temperature reached 95 ℃, after close 5-4, 6-2, 6-7, 6-8 valve, open the 6-1, 6-3 valves, using 8-1 pump to drive the hot water, hot water by the valve to lithium bromide absorption refrigerating unit as driving heat source, refrigerating machine produced by cooling water pump to the cooling tower, After cooling by cooling tower, the water is sent to 2-lithium bromide absorption refrigeration unit by water pump. The cold water generated at 7 ℃ is driven by water pump and transported to the user's fan coil tube. After the release of cold water, the return water at 12 ℃ is generated. The hot water is transferred to the water-water heat exchanger, and the generated hot water is transferred to the bathing water terminal device to provide bathing water.

4.2 Waste Heat Recovery and Utilization Scheme of Rotary Cylinder in Winter

As shown in Figure 5, the winter when the valve 5-1,6-1,6-5,6-1 closure, with 8-1 pump drive hot water, hot water valve by 6-2 to water - water heat exchanger, fan coil of hot water is hot water to clients through 6-3 to 3-2 valve, water - water heat exchanger by using hot water pump 8-4 to 9 - washing terminal devices, provide bath water.

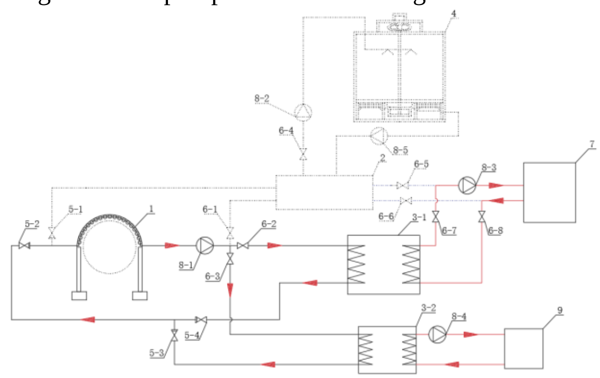

Figure 5: Waste heat utilization scheme of rotary cylinder in winter

1- Kiln drum wall waste heat recovery device 2- Lithium bromide absorption refrigerating unit 3- Water-water heat exchanger 4- Cooling tower 5- Check valve 6- Switch valve 7- Client fan coil 8- Water pump 9- Bath end device

4.3 Recovery Plan of Waste Heat from Rotary Cylinder in Transition Season

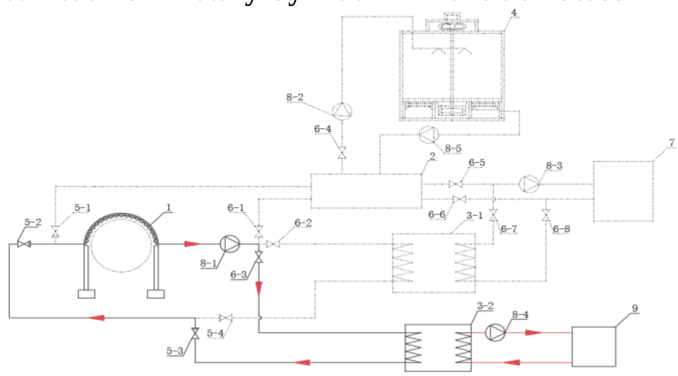

Figure 6: waste heat utilization scheme of rotary cylinder in transition season

1- Kiln drum wall waste heat recovery device 2- Lithium bromide absorption refrigerating unit 3- Water-water heat exchanger 4- Cooling tower 5-Check valve 6- Switch valve 7- Client fan coil 8-Water pump 9- Bath end device

As shown in Figure 6, in the transition season, valves 5-1, 6-1, 6-2 and 5-4 are closed, and hot water is driven by 8-1 pump. Hot water is transferred to 3-2 water-water exchanger through 6-3 valve.

5 ECONOMIC BENEFIT ANALYSIS OF WASTE HEAT WASTE HEAT UTILIZATION ON CYLINDER SURFACE

Taking a production line with a capacity of 5000 t/d clinker in Shandong province as an example, generally speaking, the surface temperature of rotary kiln barrel is about 30 0 ℃ and its diameter is up to 4.8 m. The length of the tube is 74m, and the length of the radiant heat exchanger is about 50m. Since the emittance of the tube material is within 0.8 range, the heat absorption of the ring heat exchanger can be calculated as 1.98 Mw, and the heat provided by the heating pipeline after the water-water heat exchanger is 1.39 Mw. On the basis of recovery of waste heat by means of waste heat recovery device on the surface of high temperature cylinder of rotary kiln and the utilization of hot water lithium bromide unit, such combination device can basically effectively meet the annual cold and heat load and domestic water demand of some office building areas.

(1) coal saving in heating season:

The heating demand area of a cement factory in Shandong has 9000 m^2, according to the heat of 100W per square meter, the heat of 900 kW is needed, the calorific value of pulverized coal is 20910 kJ/kg, the boiler thermal efficiency is 70%, the need to burn coal is 0.252 t/h, Shandong heating season cycle in 4 months, by burning 12 hours a day calculation, can save 362.88 t of coal every year. The price of coal is 600 yuan /t, saving 217,728 yuan.
(2) energy saving in cooling in summer:
The cooling capacity of cement plant in summer is of 900kW. If screw chiller is selected, the power consumption per hour is 186 degrees. The industrial power consumption in Shandong province is about 0.6 yuan/degree.
(3) coal consumption in four seasons bathing province:
It has about 600 employees, every employee every time probably wash bath water to 20 L, the heat capacity of the water is 4.2 kJ/kg ℃, 50 ℃ water bath heating, each about 4200 kJ heat, the total quantity of heat of 2520000 kJ, pulverized coal calorific value 20910 kJ/kg, boiler thermal efficiency is 70%, every time a bath in coal consumption is 172.2 kg, bath times throughout the year, according to each person 300, year-round bathing in coal consumption is 51660 kg, price 600 yuan/t, so the bath cost savings totaled 30996 yuan.
(4) Annual benefit: 21.7+12.0+3.1= 368,000 yuan

6 CONCLUSION

This paper has completed the analysis of the waste heat resources of cement plant. Although it can not change the cost of cement production, it can achieve the purpose of energy saving without affecting the production of cement plant, and reduce the pollution caused to the environment in the process of cement production to some extent. At the same time, if the heating and cooling can be achieved, due to the large production capacity of the cement plant, the waste heat generated, therefore, the heating and cooling area can be provided will be very large, on the other hand, the need to provide heating and cooling part of the coal consumption and electricity consumption.

NOMENCLATURE

ϕ	The total heat transfer	(W)
α_T	Comprehensive heat transfer coefficient	(W/m^2 K)
A_1	External surface area of rotary kiln barrel	(m^2)
T_R	Rotary kiln barrel surface temperature	(K)
T_E	Outdoor ambient temperature	(K)
R_1	Radiant heat transfer resistance	(–)
A_2	Surface area heat exchanger	(m^2)
ε_1	Emissivity of rotary kiln barrel	(–)
ε_2	Emissivity of hot water collector	(–)
R_2	The thermal resistance of the wall of a hot water collector	(K/W)
n	Number of collecting tube roots	(–)
λ	Heat conductivity of collector tube	(W/m•K)
l	Length of single hot water collector	(m)
r_{in}	Inner diameter of hot water collecting pipe	(m)
r_{out}	Outer diameter of hot water collecting pipe	(m)
R_3	Convection heat transfer resistance between inner wall of pipe and water	(K/W)
h_m	Convective heat transfer coefficient between inner wall and water	(W/m^2•K)
R_4	Heat conduction resistance of insulation layer and steel shell	(K/W)
d_1	Insulation inner diameter	(m)

d_2	Outer diameter of insulation layer	(m)
d_3	Outer diameter of steel shell	(m)
λ_1	Thermal conductivity of insulation layer	(W/m•K)
λ_2	Thermal conductivity of steel shell	(W/m•K)

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