The finite time thermodynamics analysis and the energy-saving optimization of the coil organic heat transfer material heater

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Received 2 August 2014, www.cmnt.lv

Abstract

According to the problems as low efficiency, aging of organic heat transfer material and frequent accidents in the operation of the coil organic heat transfer material heater, with the finite time thermodynamics, this paper studies the actual processes including combustion process, flow and heat transfer process, considers the irreversible factors as combustion condition, the fuel characteristics, flow resistance and heat transfer temperature difference, derives the calculation formula of energy loss for three processes and to determine the minimum energy loss. Based on this, this paper proposes energy-saving optimization strategy and gives examples, the results accord with the analysis. In design and operation, the outlet flue gas temperature of furnace, flue gas temperature and flow velocity of hot oil are important.

Keywords: the coil organic heat transfer material heater, finite time thermodynamics, energy loss, energy-saving optimization

1 Introduction

Nowadays, the coil organic heat transfer material heaters are widely used in industrial processes in which indirect heating under high temperature is needed. Compared with traditional vapour heating, the organic heat transfer material heating has many advantages such as high temperature under low pressure, without heat loss of condensation, high efficiency of heating system, but the most important is the energy-saving effect by 35~45% theoretically. However, in the operation of the coil organic heat transfer material heater, there are still some problems as low efficiency, aging of organic heat transfer material, frequent accidents, and so on. For the heater, there exist three processes, which occur at the same time. These processes are the combustion process of fuel, the flow process of oil and the heat transfer process between the flue gas and oil. These processes are irreversible with the irreversible factors such as the fuel, combustion condition, flow resistance and heat transfer temperature difference. The more irreversible of the process, the great the entropy generation, and the great the energy loss, this means the waste of energy. Thus, in this paper, the energy loss in the coil organic heat transfer material heater is analysed, the measures to reduce the energy loss are studied, and furthermore the energy-saving optimization strategy is obtained.

In the operation of the coil organic heat transfer material heater, the energy flow is shown in Figure 1.

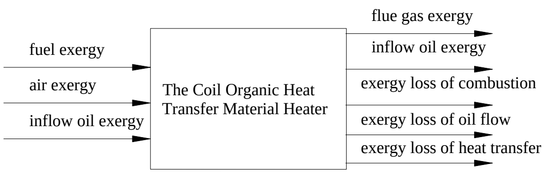

FIGURE 1 The energy flow in the coil organic heat transfer material heater

2 The finite time thermodynamics analysis of combustion process

The combustion process of fuel is an intensive chemical reaction, and the reaction heat released depends on the types of fuel and chemical reaction conditions directly. According to the thermodynamics principles, the combustion is irreversible. For this process, the entropy generation indicates the irreversible degree of the process, and the energy loss indicates the energy loss in the process. The more irreversible the process, the greater the entropy generated, and the greater the energy losses.

Combustion process occurs in the furnace, fuel and air entering the furnace, mixing and burning, and producing flue gas. The furnace is a control volume system, the media in and out the system are fuel, air and flue gas. However, as the energy flow of the furnace, besides the energy of fuel, air and flue gas, there exists energy loss.

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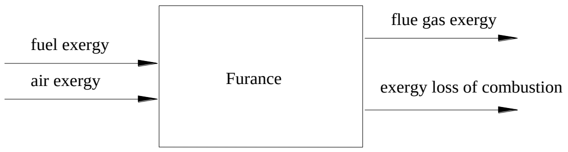

FIGURE 2 Energy flow of adiabatic combustion in furnace

Assume the combustion process is adiabatic, the energy flow of the process is shown in Figure 2. The energy entering the system are the fuel energy and the air energy, the energy leaving the system is the flue gas energy, besides, there exists energy loss caused by the irreversibility of combustion and the energy balance equation of combustion is as following [1].

$$E_{x,f}+E_{x,a}=E_{x,g}+E_{x,l}\,. \tag{1}$$

From Equation (1), the energy loss can be calculated as following:

$$E_{x,l}=E_{x,f}+E_{x,a}-E_{x,g}\,. \tag{2}$$

The energy loss can be obtained by determining the other terms in the energy balance equation.

2.1 FUEL ENERGY

The fuel energy is the energy entering the system with fuel, which consists of chemical energy $\left(E_{x,f,ch}\right)$ and physical energy $\left(E_{x,f,ph}\right)$. Because $E_{x,f,ch}\gg E_{x,f,ph}$, the $E_{x,f}\approx E_{x,f,ch}$. For chemical energy, the standard state is 1 atm, 25°C. For gas fuel, the chemical energy can be obtained with theory formula, and for solid and liquid fuel, the experienced formulas are used to obtain the chemical energy because of their complex component.

2.1.1 Gas fuel energy

The standard chemical energy of gas fuel can be obtained with following Equation (2), (3):

$$\begin{aligned}E^0_{x,f}&=-\Delta G^0_n+\sum n_jE^0_{x,j}-\sum n_{O_2}E^0_{x,O_2}=\\&-(\Delta H^0_f-T_0\Delta S^0_f)+\sum n_jE^0_{x,j}-\sum n_{O_2}E^0_{x,O_2}\end{aligned}\,. \tag{3}$$

When the environmental state is different with standard state, the temperature must be corrected.

2.1.2 Liquid fuel energy and solid fuel energy

The standard chemical energy of solid fuel and liquid fuel can be obtained with following Equation:

$$\begin{aligned}E^0_{x,f}=&\,34218.87[C]+21.97[N]+116702.76[H]+18260.357[S]-13278.593[O]+24114.107[F]+11759.425[Cl]+\\&5038.791[Br]+2897.42[I]-(298.15)(0.71768)m_{a,h}+0.6276[O]+32792.8[C]+141791.11[H]+16019.49[S]-\\&17723.842[O]+18607.798[F]+7493.126[Cl]+2853.363[Br]+1401.054[I].\end{aligned} \tag{4}$$

2.2 FLUE GAS ENERGY

The flue gas energy consists of chemical energy and physical energy. The chemical energy can be omitted because of the fixed components of flue gas in engineering applications. And, for flue gas, the physical energy is dominant. The standard chemical energy of solid fuel and liquid fuel can be obtained with following equations:

$$E^g_{x,ph}=\sum x_i[(H_g-H^0_g)-T_0(S_g-S^0_g)]\,, \tag{5}$$

$$E^g_{x,ph}=\int\sum x_ic_{pi}dT-T_0\int\sum x_ic_{pi}\frac{dT}{T}\,. \tag{6}$$

2.3 ENERGY LOSS IN COMBUSTION

From Equation (2), the energy loss can be obtained with fuel energy, air energy and flue gas energy.

2.4 THE ENERGY LOSS OF TYPICAL FUELS

2.4.1 Basic assumptions

For simplification, consider following assumptions: the quantities of solid fuel, liquid fuel and gas fuel are 1 kg, 1 kg, and 1 m^3; the environmental state is standard state, so the air energy is zero; the combustion is adiabatic, the temperature is theoretical combustion absolute temperature; the combustion is completed combustion without excess air coefficient; the function of specific heat capacity is [2]:

$$c_{pm}=a_0+a_1\times10^{-3}T+a_2\times10^{-6}T^2\,. \tag{7}$$

2.4.2 Typical fuels

The solid fuel is bituminous coal (AII), theoretical combustion absolute temperature is 1767 K/1494℃, the flue gas volume is 5.43 m^3 with 1 kg fuel, $Q_{net,v,ar}$ is 18726.4 kJ/kg.

The characteristics of bituminous coal (AII) are shown in Table 1.

TABLE 1 Matter fraction of solid fuel (%)

C_{ar}	H_{ar}	O_{ar}	N_{ar}	S_{ar}	W_{ar}	A_{ar}	V_{daf}
47.53	3.56	6.95	0.9	0.33	10.33	30.4	28.8

The liquid fuel is light diesel oil (0#), theoretical combustion absolute temperature 2128 K/1855°C the flue gas volume is 11.587 m^3 with 1kg fuel, $Q_{net,v,ar}$ is 42914.7 kJ/kg.

The characteristics of light diesel oil (0#), are shown in Table 2.

TABLE 2 Matter fraction of liquid fuel (%)

C_{ar}	H_{ar}	O_{ar}	N_{ar}	S_{ar}	W_{ar}	A_{ar}
85.55	13.49	0.66	0.04	0.25	0	0.01

The gas fuel is pyrogenous coal gas, theoretical combustion absolute temperature 1959 K/1868℃, the flue gas volume is 4.28 m^3 with 1 m^3 fuel. The function of specific heat capacity is:

$$c_{pm} = a_0 + a_1 \times 10^{-2} T \,. \quad (8)$$

The characteristics of pyrogenous coal gas are shown in Table 3.

TABLE 3 Volume fraction of gas fuel (%)

	H_2	N_2	CH_4	NH_3
x_i	66.0	21.0	9.0	4.0
a_0	29.08	28.882	19.874	27.55
a_1	-0.1918	-0.1570	5.0242	2.5644

2.4.3 The energy loss of typical fuels

With the data and formula above-mentioned, the energy loss of combustion with typical fuels is shown in Table 4.

TABLE 4 Energy loss of combustion with different fuels

	Solid Fuel	Liquid Fuel	Gas fuel
Fuel energy	20339.65 kJ/kg	45427.1 kJ/kg	10892.9 kJ/m^3
Flue gas energy	9130.68 kJ/kg	27628.87 kJ/kg	9103.37 kJ/m^3
Energy loss	11208.97 kJ/kg	17798.23 kJ/kg	1789.53 kJ/m^3
Energy loss ratio	55.1%	39.2%	16.4%

2.5 NOTATION

The following terms are used in equations above-mentioned:

$E_{x,f}$ – fuel energy;
$E_{x,a}$ – air energy;
$E_{x,g}$ – fuel gas energy;
$E_{x,l}$ – energy loss;
$E_{x,f,ch}$ – chemical energy;
$E_{x,f,ph}$ – physical energy;
$E^0_{x,f}$ – standard chemical energy of gas fuel;
ΔG^0_n – Gibbs function;
$n_j, E^0_{x,j}$ – the mole number and chemical energy of resultant according to 1 kmol fuel;
n_{O_2}, E^0_{x,O_2} – the mole number and chemical energy of O_2 needed for 1 kmol fuel;
ΔH^0_f – standard reaction enthalpy;
x – the matter fraction of elements;
$m_{a,h}$ – the matter fraction of ash;
T – combustion temperature;
T_0 – environment temperature;
c_{pm}– specific heat capacity;
a_0 and a_1 – constants.

2.6 ANALYSIS OF ENERGY LOSS WITH THREE TYPICAL FUELS

For gas fuel, liquid fuel and solid fuel, the energy loss ratio is 16.4%, 39.2% and 55.1%. The energy loss is relatively great in combustion, and the energy utilization ratio is relatively low. The effect factors include the combustion condition and the fuel characteristics.

2.6.1 The effect of combustion condition-temperature

As shown in Equation (2), under certain environmental state, the fuel energy is constant, and the energy depends on the flue gas energy directly. As flue gas energy increases, the energy loss reduces. From Equations (5) and (6), flue gas energy depends on the combustion temperature. The higher the temperature, the great the flue gas energy. The combustion temperature of solid fuel is lower than that of the liquid fuel and gas fuel in the example, and the energy loss ratio is greatest.

2.6.2 The effect of fuel characteristics-component

The flue gas energy also depends on the quantity of flue gas produced by combustion, and the quantity of flue gas depends on the component of fuel directly. The solid fuel and liquid fuel has the same elements, but different matter fraction, especially on the C and H, which results in the different quantity of flue gas. In this example, the matter fraction of C is 85.55% and 47.53%, in liquid fuel and solid fuel, the matter fraction of H is 13.49% and 3.56%, thus the energy loss ratio of solid fuel is higher than that of liquid fuel.

2.6.3 The effect of fuel characteristics-existing form of flammable substances in fuel

In the combustion, the flammable substances in solid fuel and liquid fuel must separates out firstly, which causes excess energy consumption, thus the energy loss ratio of solid fuel and liquid fuel is higher than that of gas fuel.

3 The finite time thermodynamics analysis of flow and heat transfer process

In the operation of the coil, organic heat transfer material heater, the hot oil flows in tubes and absorbs heat. When the temperature of hot oil increases to specified temperature, the hot oil leaves boiler and enters the heat consumers. That means the flow process and heat transfer process occurs at the same time. The model of the flow and heat transfer process of hot oil in tubes is shown in Figure 3.

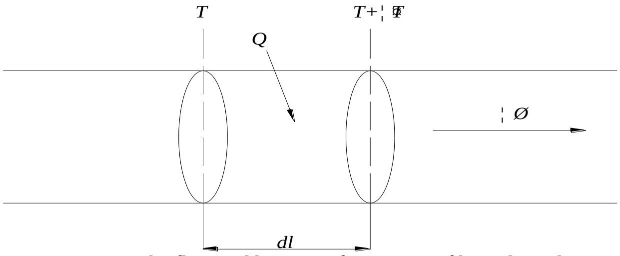

FIGURE 3 The flow and heat transfer process of hot oil in tube

Figure 3 shows the flow and heat transfer process of m kg hot oil in tube. Set Infinitesimal length be *dl*, set the heat absorbed per unit tube length be *Q*, the temperature of hot oil increases from *T* to *T*+Δ*T*, the velocity of hot oil in the tube be *ω*. Because of the flow resistance and the temperature difference in heat transfer, the flow and heat transfer process is irreversible, and the entropy generation can be obtained with follows:

$$dS_g = mds - \frac{Qdl}{T+\Delta T}. \quad (9)$$

According to the thermodynamic relations, considers the relationship between enthalpy change and heat in isobaric process, obtains the entropy change in the process shown in Equation (10).

$$ds = \left(\frac{Q}{m} - \frac{1}{\rho}\frac{dp}{dl}\right)\frac{dl}{T}. \quad (10)$$

Combined Equations (9) and (10), obtains the entropy generation per unit length shown in Equation (11).

$$S_g = \frac{m}{\rho T}\left(-\frac{\Delta p}{l}\right) + \frac{Q\Delta T}{T^2\left(1+\frac{\Delta T}{T}\right)}. \quad (11)$$

Considers time factor *τ*, obtains the entropy generation ratio per unit length shown in Equation (12).

$$S_g^\tau = \frac{\frac{m}{\rho T}\left(-\frac{\Delta p}{l}\right) + \frac{Q\Delta T}{T^2\left(1+\frac{\Delta T}{T}\right)}}{\tau}. \quad (12)$$

When *τ*→0, the entropy generation ratio per unit length is shown in Equation (13).

$$S_g^\tau = \frac{m}{\rho T}\left(-\frac{\Delta p}{l}\right) + \frac{Q\Delta T}{T^2}. \quad (13)$$

The energy loss ratio per unit length is shown in Equation (14).

$$L = S_g^\tau T_0 = \left[\frac{m}{\rho T}\left(-\frac{\Delta p}{l}\right) + \frac{Q\Delta T}{T^2}\right]T_0. \quad (14)$$

From Equation (13), the entropy generation ratio consists of two parts, the first part is entropy generation ratio of dissipation effect which caused by the flow resistance, the second part is entropy generation ratio of potential difference which caused by the temperature difference in heat transfer. The flow resistance and temperature difference are the irreversible factors of the flow and heat transfer process. The entropy generation ratio of dissipation effect depends on the type of hot oil, the flow pattern, physical parameters, structure and operation of the coil organic heat transfer material heater. The entropy generation ratio of heat transfer with temperature difference depends on heat transfer coefficient, heat transfer area, mean exothermic temperature and mean endotherm temperature.

3.1 THE ENERGY LOSS RATE OF DISSIPATION EFFECT

From Equation (14), the energy loss ratio can be obtained based on the entropy generation ratio and the environment temperature. From Equation (13), obtains the entropy generation ratio of dissipation effect shown in Equation (15).

$$S_g^\tau = \frac{m}{\rho T}\left(-\frac{\Delta p}{l}\right). \quad (15)$$

From fluid mechanics, the entropy generation ratio and energy loss ratio of dissipation effect are related to the on-way resistance *λ*, Reynold number Re, viscosity *υ*, velocity *ω* and pipe diameter *d*, as shown in Equations (16) and (17).

$$S_g^\tau = \frac{m}{\rho T}\left(-\frac{\Delta p}{l}\right), \quad (16)$$

$$L = S_{g,f}^\tau T_0 = \frac{\lambda}{d}\frac{\varpi^2}{2T}T_0 = \frac{\lambda \upsilon^2 \mathrm{Re}^2}{2Td^3}T_0. \quad (17)$$

From Equation (17), energy loss ratio *L* is the function of *λ*, *ω*, *d* and *T*. Among these parameters, *λ* depends on the Re, and the Re is related to the *υ*, *ω* and *d*. In engineering, when a heater puts into practice, the pipe diameter is determined, that means the energy loss ratio of dissipation effect mainly depends on the viscosity and velocity. Viscosity *υ* depends on the type of hot oil. The influence of temperature is on the viscosity. So the comprehensive influence of viscosity and velocity can be considered with constant pipe diameter.

The following example is a comparison among three types of hot oil (YD-300, XD-300, L-Q300), calculation conditions: *L*=1 m, *d*=45 mm, *k*=0.046 mm. The example is about the influence of viscosity and velocity on the energy loss ratio. The results are shown in Figures 4-6.

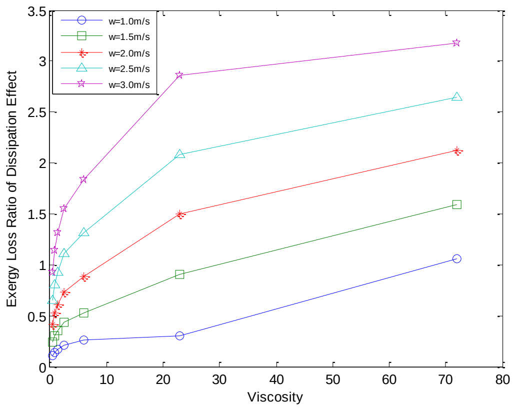

FIGURE 4 The influence of viscosity and velocity for XD-300

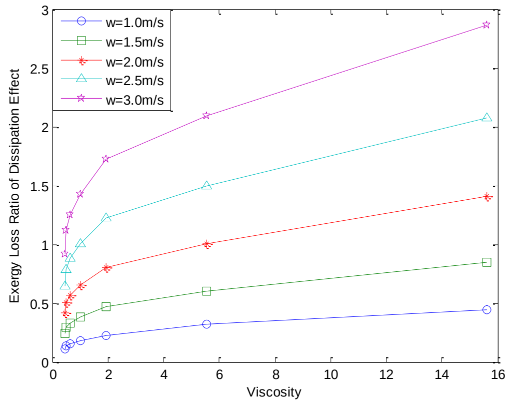

FIGURE 5 The influence of viscosity and velocity for YD-300

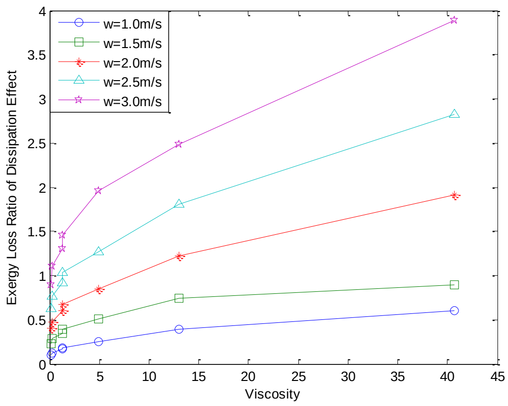

FIGURE 6 The influence of viscosity and velocity for L-Q300

Figures 4-6 show the influence of viscosity and velocity on energy loss ratio of dissipation effect. The influence is similar for the three types of hot oil. With the increase of temperature, viscosity decreases, and the energy loss ratio of dissipation effect decreases, on the other hand, with the increase of velocity, the energy loss ratio of dissipation effect increases. In operation, the organic hear transfer material experiences temperature rising stage and normal operation stage. In the temperature rising stage, because of the great variation of hot oil viscosity, the influence of viscosity on energy loss ratio of dissipation effect is larger than that of the velocity. However, in the normal operation stage, the viscosity is basically steady, and the influence of velocity is dominant. For different type of hot oil, the variation range is different, so the temperature range in which the viscosity and velocity is dominant in part is different. Thus, in operation, the type of hot oil must be considered to decrease the energy loss ratio of dissipation effect and the velocity must be controlled to avoid overheat.

3.2 THE ENERGY LOSS RATE OF HEAT TRANSFER WITH TEMPERATURE DIFFERENCE

The hot oil absorbs heat from flue gas in the coil organic heat transfer material heater. To simplify the analysis, mean temperature is adopted, high temperature flue gas releases heat at mean exothermic temperature, and hot oil absorbs heat at mean endotherm temperature. The heat released is equal to that absorbed.

According to the thermodynamic theory, the energy loss ratio of heat transfer with temperature difference in isolated system is as follows [5, 6]:

$$L^{\tau} = T_0 \Delta S^{\tau}_{\text{iso}} = \frac{T_0 \Delta S_{\text{iso}}}{\tau} = \frac{T_0 Q\left(\dfrac{1}{T_{\text{Lm}}} - \dfrac{1}{T_{\text{Hm}}}\right)}{\tau} = KT_0\left(T_{\text{Hm}} - T_{\text{Lm}}\right)\left(\frac{T_{\text{Hm}} - T_{\text{Lm}}}{T_{\text{Hm}} T_{\text{Lm}}}\right). \quad (18)$$

From Equation (18), as the environment temperature is determined, the energy loss ratio mainly depends on heat transfer coefficient, heat transfer area, mean exothermic temperature and mean endotherm temperature. When the structure and medium of the organic heat transfer material heater are determined, the energy loss ratio only depends on mean exothermic temperature and mean endotherm temperature. To obtain smallest energy loss, the mean endotherm temperature must be near to the mean exothermic temperature, thus the irreversible degree of heat transfer with temperature difference is small, and so does the energy loss. The following is an example of energy loss ratio calculation, the type of the organic heat transfer material heater is QXS0.93-280/260-Y. The fuel is 0# light diesel oil, and different mean exothermic temperature and mean endotherm temperature are adopted. The results are shown in Table 5.

TABLE 5 Energy loss of heat transfer with temperature difference

Name	Symbol	Unit	Value 1	Value 2
Flue gas temperature	Θ_{py}	°C	380	300
The outlet flue gas temperature of furnace	Θ_{ll}	°C	938	800
The inlet temperature of heat transfer oil	T_{l1}	°C	260	260
The outlet temperature of heat transfer oil	T_{l2}	°C	280	280
Low thermal value	Q^{y}_{dw}	LJ/kg	42914.7	42914.7
The mean endotherm temperature	T_{lm}	°C	270	270
The mean exothermic temperature	T_{hm}	°C	618	486
Energy efficiency	$\eta_{ex.B}$	/	32.9	34.9
Energy loss ratio	L		67.1	65.1

3.3 NOTATION

The following terms are used in equations above-mentioned:
dl – Infinitesimal length
Q – the heat absorbed per unit tube length
T – temperature of hot oil
ΔT – temperature increase
ω – velocity of hot oil in the tube
s – entropy generation
L – energy loss ratio
λ – on-way resistance
Re – Renold number
υ – viscosity
d – pipe diameter
k – heat transfer coefficient
F – heat transfer area
T_{Hm} – mean exothermic temperature
T_{Lm} – mean endotherm temperature

4 The energy-saving optimization strategy of the organic heat transfer material heater based on finite time thermodynamic analysis

Based on the finite time thermodynamic analysis on the irreversible processes, the main influencing factors of combustion process, flow process and heat transfer process are obtained. By analysing these factors, the energy-saving optimization strategy can be achieved in design and operation management.

4.1 DESIGN

4.1.1 Determination of Design Parameters

In the design of the coil organic heat transfer material heater, the design parameters related to combustion and heat transfer with temperature difference are the outlet flue gas temperature of furnace and flue gas temperature. The design parameters related to flow process is velocity of hot oil.

1) Determination of the outlet flue gas temperature of furnace. The outlet flue gas temperature of furnace is a parameter reflecting the heat operation capacity in furnace. Too lower the outlet flue gas temperature of furnace can cause the lower reaction temperature, which causes less flue gas energy, increases the energy loss and energy loss ratio of combustion, and reduces the energy utilization efficient. However, the reduction of the outlet flue gas temperature of furnace can reduce the mean exothermic temperature, decrease the energy loss of heat transfer process with large temperature difference, and improve the transfer efficiency of energy. So in order to determine an appropriate outlet flue gas temperature of furnace, it is necessary to consider the two aspects in design. However, in actual design process, the determination of the outlet flue gas temperature of furnace is experiential, and lacks theoretical basis. Thus sets energy loss as evaluation index, obtains function relationship between the total energy loss of irreversible processes and the outlet flue gas temperature of furnace. Setting this functional relationship as objective function, the outlet flue gas temperature of furnace can be optimized, and provides theoretical basis for the determination of the outlet flue gas temperature of furnace.
2) Determination of flue gas temperature. The flue gas temperature is the temperature of flue gas emitted into the environment. The flue gas temperature affects the energy loss of heat transfer with temperature difference. The higher flue gas temperature means the higher mean exothermic temperature, and the more the energy loss; the lower flue gas temperature means the lower mean exothermic temperature, and the less the energy loss. However the flue gas temperature must be higher than the outlet temperature of heat transfer oil. The temperature difference determines the area of heating surface and affects the cost of equipment directly. However, in actual design process, the determination of the flue gas temperature is experiential, and lacks theoretical basis. Thus sets energy loss as evaluation index, establishes function relationship between the total energy loss of irreversible processes and the flue gas temperature. Setting this functional relationship as objective function, the flue gas temperature can be optimized, and provides theoretical basis for the determination of the flue gas temperature.
3) Determination of flow velocity of hot oil. In determining the flow velocity of hot oil, two aspects must be considered. One is the energy loss caused by the higher velocity, the other is the overheat of hot oil caused by the lower velocity. Besides, the higher velocity means large circulation pump, which causes further waste of energy. Thus, the determination of flow velocity must base on the flow pattern of the hot oil in tubes. The appropriate velocity means that the flow pattern of hot oil in tubes is turbulence without too large Re.

4.1.2 Design of structure

In design of structure, the related parts include the determination of the ratio between radiant heating surface and convective heating surface, and arrangement of assistant heating surface. Based on the analysis above-mentioned, the ratio between radiant heating surface and convective heating surface can be described with the outlet flue gas temperature of furnace. Besides, the component of fuel affects the capacity of flue gas energy, and the reaction temperature in furnace affects the production of flue gas. Thus, the optimization on the ratio between radiant heating surface and convective heating surface can be achieved at the basic of the optimization on the outlet flue gas temperature of furnace with the characteristics of fuels. Because higher flue gas temperature can cause larger energy loss, the waste heat recovery devices should be adopted for flue gas. The increased cost of devices can be evaluated with economic analysis.

4.2 OPERATION MANAGEMENT

Based on the analysis above-mentioned, the optimization on the operation management can be carried out from following aspects:

1) Implementing the real-time monitoring on the outlet flue gas temperature of furnace and the flue gas temperature in order to avoid the increase of energy loss caused by large temperature difference in heat transfer.
2) Prohibiting the change of design fuel optionally in order to avoid the increase of energy loss of combustion caused by the change of flue gas energy with different fuels.
3) Implementing the real-time monitoring on the combustion in order to avoid the increase of energy loss of combustion caused by the combustion instability under lower reaction temperature.
4) Implementing the real-time monitoring on flow pattern to avoid the increase of energy loss of flow process caused by the higher velocity of hot oil, besides avoid the overheat of hot oil at too lower velocity.

5 Conclusions

1) Studies the combustion process based on the theory of finite time thermodynamics, compares the energy loss of different fuels, analyses the influencing factors on energy loss of combustion.
2) Studies the flow process and heat transfer process based on the theory of finite time thermodynamics, compares energy loss at different mean exothermic temperature and mean endotherm temperature, compares the energy loss of different types of hot oil, analyses influencing factors of the flow process and heat transfer process.
3) On the basis of this analysis, proposes the energy-saving optimization measures on design and operation management of the coil organic heat transfer material heater, and specially points out that in the design process, objective function can be constructed with the energy loss as evaluation index to determine the outlet flue gas temperature of furnace and the flue gas temperature, and provides theoretical basis for the determination of design parameters.

Acknowledgments

This paper supported by the National Natural Science Foundation of China "Experimental research on the characteristic of flow and heat transfer in organic thermal fluid" (51346007).

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