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The heat recovery equipment design of the primary furnace/exhaust gas: coil heat exchanger

Біріншілік жанған/қолданған газдан шыққан жылуды утилдеу құралын жобалау

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Мақалада сызықты регрессия көмегімен есептелген ASPEN бағдарламасынан алынған параметрлердің қасиеттері берілген. Үрімші қаласындағы петрохимиялық компаниясында жылуды утильдеу құралдың есептеулері EXCEL бағдарламасы көмегімен орындалған. Есептеулер бойынша қолданған газдың температурасы 175 ºС-тен 150 ºС және 90 ºС-қа дейін төмендеген.

В статье дан параметр свойства, взятый из большой выборки данных программы ASPEN, рассчитанный с помощью линейной регрессии. Расчет оборудования по утилизации тепла для петрохимической компании г. Урумчи выполнен с помощью программы EXCEL. Расчет показал, что температура отработанного газа снизилась с 175 ºС до 150 ºС и 90 ºС.

The primary reformer in Urumqi Petrochemical Company fertilizer plant ammonia plant in the second section was designed by TECNOMONT and manufactured by KIRCHNER, which had radiation section and convection section. Combustion reaction was occurred in radiation section and the fuel for the combustion was natural gas, waste gas, refining gas and synthesis purge gas, combustion improver was fuel turbine exhaust gas and the methane-steam transforming reaction was occurred in reformer tube with the heat released by the combustion reaction. The products of combustion was mixed with another fuel turbine exhaust gas well in the bottom of convection section, and then enter in convection section to recovery heat. There are six groups of convection section coil, from top to bottom boiler feedwater coil and feed gas preheating coil and preheating coil and mixing feed coil and air preheating coil and overheating coil respectively, and after recovering heat stack gas was discharged by means of induced draft fan. The temperature of the conversion furnace gas was higher, the actual exhaust gas temperature is about 247 ºC. Because of their large capacity of discharge and high temperature the recovery efficiency is higher, thereby the secondary pollution of the atmosphere which was caused by the drain of high temperature gas could be reduced.

Compared with the tube heat exchanger, the coil heat exchanger has been extensive attention because of its fast heat transfer rate and its high heat transfer coefficient [1]. And because of its compact structure, high heat transfer coefficient the coil heat exchanger is widely used in power generation, nuclear industry, manufacturing, waste heat recovery systems, refrigeration and food industries. Therefore since 1974 the coil heat exchanger has been studied extensively at home and abroad [2]. The coil was designed with Excel software in this article to recover the waste heat emissions which was used to heat up the water for civilian.

1 Design models

1.1 Model of convective heat transfer coefficient in the tube [3]

Convection heat transfer coefficient in the tube: $\alpha_1 = C\alpha_{11}$ $\alpha_{11} = 0.023\frac{\lambda}{d_1}\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4}$.

For liquid $C = 1.2$, $\mathrm{Re} = \frac{d_1 u_2 \rho_c}{\mu_c}$, $\mathrm{P}_r = \frac{C_{pc}\mu_c}{\lambda_c}$.

1.2 External heat transfer coefficient model [4]

Mixed gas heat transfer coefficient outside the coil [4]: $\alpha_2 = 0.87\frac{\lambda}{D_e}\mathrm{Re}^{0.63}\,\mathrm{Pr}^{\frac{1}{3}}$, $\mathrm{Re} = \frac{D_e u_1 \rho_h}{\mu_h}$, $\mathrm{P}_r = \frac{C_{ph}\mu_h}{\lambda_h}$.

1.3 Model of logarithmic mean temperature difference [5]

For the coil heat exchanger which the cooling water baffled over four in the tube [5]: the average temperature difference is calculated based on counter-current: $LMTD = \Delta t_m = \dfrac{(T_1 - t_2) - (T_2 - t_1)}{\ln\dfrac{T_1 - t_2}{T_2 - t_1}}$.

1.4 Overall heat transfer coefficient and heat transfer area model based on the coil outside surface area

Overall heat transfer coefficient [6]: $\frac{1}{K} = \frac{1}{\alpha_1} \times \frac{d_2}{d_1} + R_1 + \frac{t_s d_2}{\lambda_s d_m} + R_2 + \frac{1}{\alpha_2}$.

Heat transfer area: $A = \frac{Q}{K\Delta t_m}$.

1.5 Pipe size design model [7]

Determination of the number of coil parallel group number *m*: $m = \frac{4V}{\pi d_1^{\,2} u_2}$.

Coil length: $L_t = \frac{A}{\pi d_2}$; Each coil length: $L = \frac{L_t}{m}$.

Length of each hose pipe: $l = \sqrt{(\pi Dc)^2 h^2} \approx \pi Dc$; coil turns: $n = \frac{L}{l}$; the distance between inner and out: $Pt = 2.5d_2$ the vertical distance between up and down ring: $Sc = 1.6d_2$. The total coil height: $Lc = (n-1)Sc$.

1.6 Calculation model of fluid pressure drop in pipe [8]

The single-phase flow friction inside coil is larger than straight, but the calculation also used the straight tube pressure drop formula and factor to corrected, that is $\Delta P = f\rho\frac{L}{d_1}\frac{u^2}{2}$ Pa.

Laminar flow: $\mathrm{Re} \le 40\sqrt{\frac{Dc}{d_1}}, \frac{f}{f_0} = 1$; $40\sqrt{\frac{Dc}{d_1}} \le \mathrm{Re} \le 2000\sqrt{\frac{Dc}{d_1}}$, $\frac{f}{f_0} = 0.288^{0.36}\left(\frac{d_1}{Dc}\right)^{0.18}$, which the straight pipe friction factor is $f_0 = \frac{64}{\mathrm{Re}}$. Tolerance: $\mathrm{Re} = 1.5\times10^4 \sim 10^5$, $\frac{f}{f_0} = 1 + 0.075\,\mathrm{Re}^{\frac{1}{4}}(\frac{d_1}{Dc})^{0.5}$, which straight pipe friction factor: $f_0 = \frac{0.3164}{\mathrm{Re}^{0.25}}$.

1.7 The efficiency of heat exchanger [9]

Heat exchanger efficiency E is defined as:

$$E = \frac{\text{the actual heat transfer capability}}{\text{the largest possible heat transfer capability in theory}} = \frac{Q^t}{Q^t_{\max}}$$

$$Q^t_{\max} = (GCp)_{\min}(T_1 - t_2);\ Q^t = (GCp)_{\min}(t - T)_{\max}.$$

In this design, $(GC_p)_1 < (GC_p)_2$, therefore: $E = \dfrac{T_1 - T_2}{T_1 - t_2}$.

2 Design conditions

2.1 Design conditions

The parameter needed in the design process and the known condition was shown in tables 1, 2:

Table 1

The design condition of cold and hot fluids

Parameter	Hot fluids stack gas	Cold fluids water
Mass flow (kg/h)	273500	Undetermined
Inlet temperature (K)	175	25
Outlet temperature (K)	To be determined	90
Pressure (kPa)	60	101.3

Table 2

Composition of flue gas

Composition of flue gas	Mole fraction (y)
O_2	0.064
N_2	0.744
CO_2	0.054
H_2O	0.138
$\sum y$	1

2.2 Setting outlet temperature of flue gas

Setting basis of the final exit flue gas temperature should be that the temperature is 5~10 ºC of its dew point temperature higher.

The determination of dew temperature model: water-vapor partial pressure $P_{H_2O} = y_{H_2O}P$, P — total pressure of flue gas (kPa).

The relationship of dew temperature and saturated vapor pressure within the range 1.0<p<10.0:

$$t_d = 17.074 \ln P_{H_2O} + 5.3544.$$

In this design the flue gas flow was large, the size of the coil exchanger can not satisfy the request under the condition that the dew point was 5~10 ºC higher, so the flue gas outlet temperature was set to 150 ºC.

2.3 Determination of cold fluid mass flow

According to heat balance equation, the cold fluid flow: $Q = W_h c_{ph}(T_1 - T_2) = W_c c_{pc}(t_1 - t_2) + Q_L$ (heat loss was calculated according to 15 percent of the released heat)

2.4 Calculation model of the hot and cold fluid property parameter

In this design the property parameter of the flue gas and water exported from the software ASPEN PLAS was regressed by the empirical equation between the both of these property parameter such as density, viscosity, thermal conductivity and heat capacity [10] by Excel.

2.4.1 Determination of the property parameter of heat fluids(flue gas)

Qualitative Temperature: $T_m = \dfrac{T_1 + T_2}{2}$.

Flue gas specific heat (J/kg K): $C_{ph} = 0.1928T_m + 1028.8$.

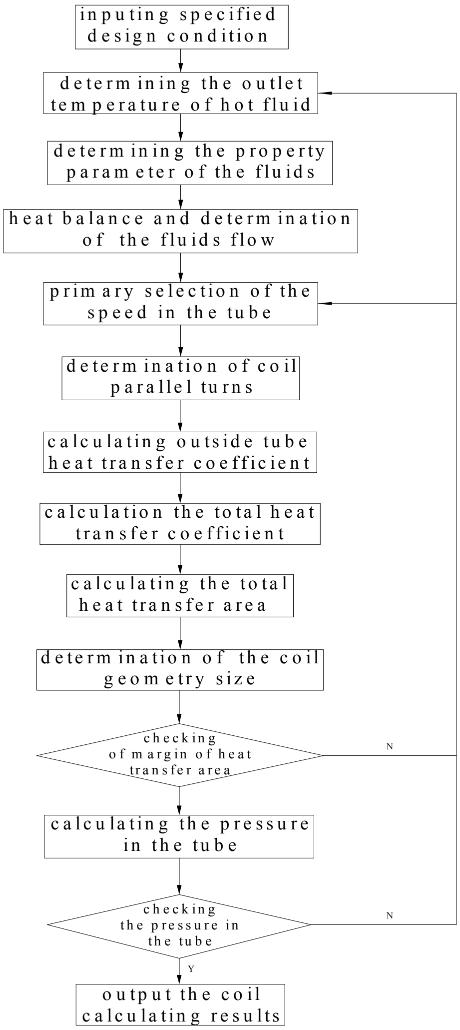

Fig. 1. Calculating process of design

Flue gas density (kg/m^3): $\rho_h = -0.0012T_m + 0.9808$.

Flue gas viscosity (Pa·s): $\mu_h = 4E - 08T_m + 5E - 06$.

Flue gas thermal conductivity (w/m K): $\lambda_h = 7E - 05T_m + 0.0028$.

2.4.2 Property parameters of cold fluid (water)

Qualitative Temperature: $t_m = \dfrac{t_1 + t_2}{2}$.

Water specific heat (J/kg K): $C_{pc} = 6.8837T + 1790.6$.

The density of water (kg/m^3): $\rho_c = -0.9932T + 1289.9$.

Water viscosity (Pa·s): $\mu_c = 7E + 10T^{-6.611}$.

Thermal conductivity of water (w / m K): $\lambda_c = 0.0011T + 0.2877$

3 Design Process

In this article taking Excel as calculated tool, various parameter of flue gas and water needed was regressed to obtain, the heat transfer coefficient and heat transfer area was calculated by Excel. The whole design process was shown in figure 1.

4 Calculation results of design

4.1 Calculation results of technical parameter and structure size of the coil exchanger

Table 3 shows the constructure size and process parameter of coil heat exchanger which was designed by Excel.

Table 3

Design results of coil heat exchanger

Design parameter	Sign (unit)	Design value
Systematic heat load	Q(W)	2.09×10^6
Cold fluids flow	Wc kg/s	6.73
The average heat transfer temperature difference	Δt_m	103
Tube heat trandsfer coefficient	α_1(W/m^2.K)	5343
Outside tube heat transfer coefficient	α_2(W/m^2.K)	175
The total heat transfer coefficient based on tube surface area	K(W/m^2.K)	77.4
Heat transfer area required	A_d(m^2)	261
Number of coil parallel group	m	3
Design of coil turns	n_p	70
Design of coil length	Ltp(m)	1800
Coil height	Lc	6.72
Actual single tube heat transfer area	A_d(m^2)	305
Actual of margin of heat transfer area	ξ	0.17
Pressure drop in tube	Δp(Pa)	2611

Conclusion

Three groups of ∅ 60×3 mm, 80 ring coils should be taken parallel, so the furnace exhaust gas emissed with 10 ºC decresed, and the heat can be used to heat 6.73 kg/s, 25 ºC water to 90 ºC which can be used civilian, which played a role in energy conservation.

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