A Novel Heat Recovery System for High Temperature and High Humidity Gas

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Abstract. Double phase change heat exchanger (DHEX) is used combining with steam ejector to build a new steam production. This convenient and efficient system can recover not only the sensible heat of high temperature and humidity gas but also the latent heat of water vapor. Simulation method has been adopted to achieve the vapor production quality under two kind of operating modes. The result indicates that through the new heat recovery system, the condensation latent heat of gas turns into the vaporization latent heat of vapor steam, and generates the steam at medium temperature and pressure.

Introduction

There is much high temperature and high humidity gas produced by industrial process or emitted directly, such as the production of butadiene [1], polyester [2], and diammonium phosphate [3]. Now most of them adopt cooling tower to release the heat to the atmosphere. This direct emission steam dropping on the equipment may lead to the facilities corroded. The corrosion threatens the safe operation of devices [4], and direct emission can cause a great waste on latent heat of vaporization. Convenient and efficient heat recovery system needs to be built to take advantage of latent heat and sensible heat in flue gas.

Through the studies on high temperature and high humidity gas heat recovery, a new system for heat recovery is developed, which jointly use double phase change heat exchanger (DHEX) and ejector. It is involved with a new steam generation facility.

Design of the System

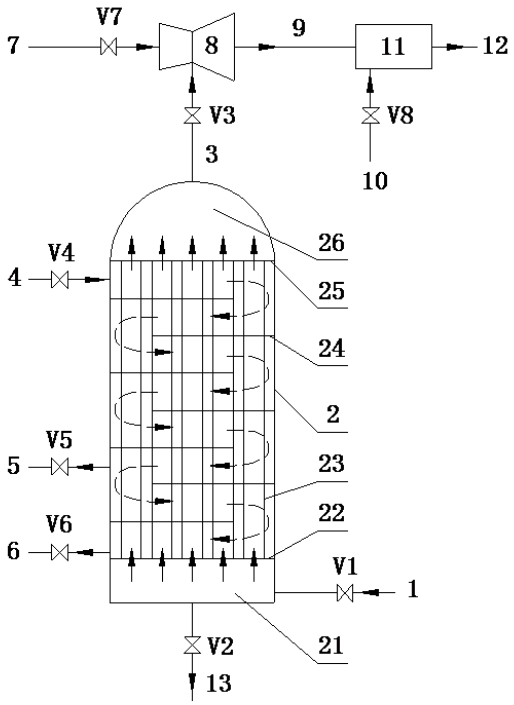
The new steam generation system contains water supply pipe, double phase change heat exchanger (DHEX), main steam pipe, high temperature and humidity gas pipe, low temperature and humidity steam pipe, condensate pipe, injection pipe, ejector, steam pipe, desuperheating water pipe, desuperheater, steam outlet pipe, and blow-off pipe. DHEX contains water separator, down tube plate, water evaporating tube, guide plate, up tube plate, as well as stream header.

Water supply pipe is linked up with the water separator of the DHEX. Valve V1 is installed on water supply pipe. Water evaporating tube is installed between up and down tube plates. Guide plate of flue gas is set out the water evaporating tube. Valve V4 is installed on the high temperature and humidity gas pipe. Flue gas enters into the DHEX from the high temperature and humidity gas pipe at the top. Flue gas flows from top to bottom with the action of guide plate out of the water evaporating. Valve V5 is installed on the low temperature and humidity gas pipe, and valve V6 is setup on the condensate pipe. Uncondensed steam is passed out from low temperature and humidity gas pipe, while the condensate is discharges from condensate pipe. Control the opening action degree of V6 to keep the liquid level of condensate between the low temperature and humidity gas pipe and condensate pipe, that can make the condensate do not discharge from the low temperature and humidity gas pipe, and the steam do not pass out from the condensate pipe.

Water from supply pipe first goes into the water separator, and flows into water evaporating tube later. After vaporizing, the steam goes up to steam header. Main steam pipe connects the steam header and ejector and there is a valve V3 on the main steam pipe. Injection pipe is connected with the ejector flow entrance. Between ejector and desuperheater, there is the steam pipe. Desuperheating water pipe is linked to desuperheater and valve V8 is set on it. At the exit of desuperheater there is steam outlet pipe. Valve V7 can control the vapor quality which is injected into the ejector. V8 can limit the quantity of desuperheater spray and adjust the steam parameter of steam outlet pipe according to the need.

Working Principle

High temperature and high humidity flue gas condensed in the DHEX. The heated water flowing into the DHEX evaporates and then goes to the steam header. The admission port of ejector links up with the header, so that the inlet pressure is the evaporating pressure of heated water flowing into the DHEX. As long as the inlet pressure is lower than the evaporating pressure and the condensing temperature of flue gas is higher than the vaporization temperature of heated water, the latent heat of condensation transfers to the heated water to make the water evaporate [5]. In ejector, evaporated water vapor mixes with the high pressure and temperature ejector flow, and becomes vapor steam at medium temperature and pressure. This process recovers the condensation latent heat of flue gas and turns it into the vaporization latent heat of vapor steam [6].

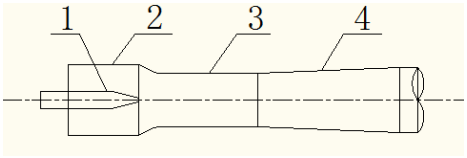


1. Water supply pipe 2. Double phase change heat exchanger (DHEX)
3. Main steam pipe 4. High temperature and humidity gas pipe
5. Low temperature and humidity steam pipe 6. Condensate pipe
7. Injection pipe 8. Ejector 9. Steam pipe 10. Desuperheating water pipe
11. Desuperheater 12. Steam outlet pipe 13. Blow-off pipe
21. Water separator 22. Down tube plate 23. Water evaporating tube
24. Guide plate 25. Up tube plate 26. Stream header

Fig. 1. Flowsheet of high temperature and humidity gas heat recovery

This steam production system is especially suitable for the flue gas with high temperature and

high humidity. The generating steam at medium temperature and pressure also can be used in other processes. Fig. 1 shows the ejector system.



1. working nozzle 2. receiving chamber 3. mixing chamber 4. diffusion chamber

Fig. 2. The constitution of ejector.

Simulation Process

Fig. 2 shows the constitution of ejector. Taking advantage of diffusion of turbulent jet, the ejector is a device that mixes two fluids with different pressures and energy exchange happens.

Before entering the device, working fluid has the high pressure. It flows into receiving chamber in a high speed. Because of the diffusion of turbulent jet, working fluid entrains the surrounding fluid to exchange the momentum. The low pressure fluid which has been sucked out is called ejection fluid. Working fluid mixing with ejection fluid in the mixing chamber to exchange the momentum and mass, balance the speed gradually in the process of flowing and pressure increasing often accompany during this time. The fluid coming out of the mixing chamber into the diffusion chamber, the pressure will go up because of the flow rate slowing down. In the diffusion chamber exit, mixed fluid pressure is higher than ejection fluid pressure.

Using thermodynamics theory, flow and heat transfer theory, ejector technology and computer software technology, to build model of this new system for heat recovery of gas with high temperature and high humidity, and study the operation condition through simulation method.

Ejector working comply with the following three basic laws [7][8][9][10].

The law of conservation of energy:

$$i_p + ui_H = (1+u)i_c \tag{1}$$

Where,

i_p——the enthalpy of working fluid before entering the device

i_H——the enthalpy of ejection fluid before entering the device

i_c——the enthalpy of mixing fluid after entering the device

u——the ejecting ratio

The law of conservation of mass:

$$M_C = M_P + M_H \tag{2}$$

Where,

M_C——the mass flow rate of mixing fluid

M_P——the mass flow rate of working fluid

M_H——the mass flow rate of ejection fluid

The theorem of momentum:

$$M_P W_{p1} + M_H W_{H1} - (M_P + M_H)W_3 = p_3 f_3 - \left(p_{p1} f_{p1} + p_{H1} f_{H1}\right) - \int_{f_3}^{f_1} p\, df \tag{3}$$

Where,

W_{p1}——working fluid speed on the mixing chamber inlet plane

W_{H1}——ejection fluid speed on the mixing chamber inlet plane

W_3——mixing fluid speed on the mixing chamber outlet plane

p_{p1}——static pressure of working fluid on the mixing chamber inlet plane

p_{H1}——static pressure of ejection fluid on the mixing chamber inlet plane

p_3——static pressure of mixing fluid on the mixing chamber outlet plane

f_{p1}——sectional area of working fluid in the mixing chamber

f_{H1}——sectional area of ejection fluid in the mixing chamber

f_3——sectional area of mixing fluid at the mixing chamber outlet

$\int_{f_3}^{f_1} p\,df$——impulse integral of the force acting on the mixing chamber wall between section 1-1 and section 1-3.

Fig. 3 shows that high temperature and humidity gas entering the DHEX from “flue gas”, turns into gas-liquid mixed flow “fgas 1” and then enters VSEP to separate the “liquid” and “fgas 2”. The “water” entering the DHEX becomes low pressure “vapor” going to “EJECT”. High temperature and pressure “steam” goes into “EJECT” with a high velocity and creates a low pressure area. “DHEX” is connected with the low pressure area of “EJECT” which makes a low pressure area in “DHEX” and evaporates the “water”. Under the effect of temperature difference, steam with high temperature and humidity condenses and releases the latent heat. This process transmits the heat from high temperature and humidity gas to low pressure steam generated from water. Steam at low pressure and high pressure mixes in “EJECT”, and goes to “MIX” as “new steam”. Moreover, desuperheating water flowing into “MIX” through “water 2” blends with “new steam” to meet the design steam parameters, and at last saturated steam discharges from “psteam”.

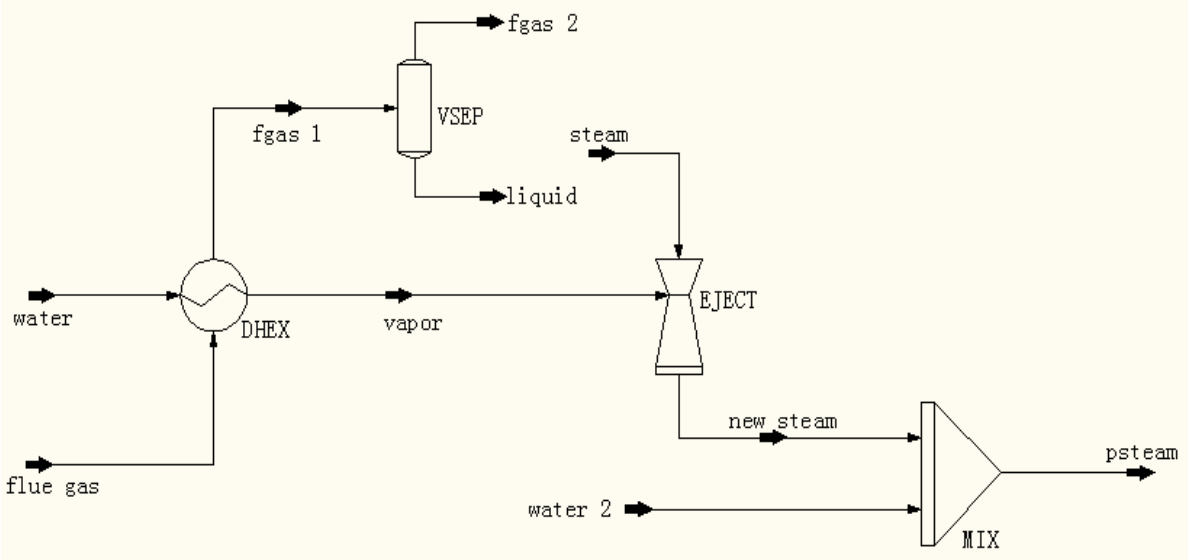


Fig. 3. Simulation flow diagram of high temperature and humidity gas heat recovery.

Simulation results

Table 1 shows two kinds of flue gas at different temperatures and water vapor contents. Table 2 shows the results of steam generation from the two flue gas. As for flue gas 1, there is 62.8 t/h saturated steam generated at 0.35 MPa by using 12.1t/h steam at 230^{o}C and 0.9MPa. In terms of flue gas 2, 43t/h of steam at 150^{o}C and 0.3MPa can generate 68.5 t/h of saturated steam at 0.15 MPa. These examples show the application of the novel heat recovery system, which is favorable to many high temperature and high humidity gases.

Table 1. The operation condition of flue gas

Flue gas	Temperature (^{o}C)	Pressure (MPa)	Gas component (%)						Flow (t/h)
			C_4H_6	NH_3	O_2	N_2	CO_2	water vapor	
1	180	0.25	12	0	0.3	20	2.7	65	78
2	130	0.11	0	0.01	6.35	63.39	5.22	25.03	100

Table 2. The results of steam generation

Flue gas	Steam	Vapor (t/h)	Water 2 (t/h)	Psteam
1	230^{o}C, 0.9MPa, 12.1t/h	50.5	0.2	62.8 t/h, 0.35 MPa
2	150^{o}C, 0.3MPa, 43t/h	25	0.5	68.5 t/h, 0.15 MPa

Conclusion

Combining double phase change heat exchanger (DHEX) and steam ejector can efficiently recover the sensible heat of high temperature and humidity gas and latent heat of water vapor. heat transfer temperature difference and rate have been controlled by adjusting the vapor pressure of DHEX through ejector. Cooling, condensing and undercooling of flue gas and heating as well as evaporating and overheating of water can be achieved in DHEX. This system using as a new steam production technology has the characteristics containing simple construction, convenient adjustment and effective energy-saving, etc.

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