Analysis of Energy Conservation on Thermal Plasma Medical Waste Treatment System

Xing Wang[1, a], Xiaomin Qin[1, b], Leilei Zhao[1, c], Tingqi Yan[1, d], Peng Zheng[1, e] and Yuwei Dai[1, f]

[1]School of Mechanical and Electronic Engineering, Shandong University of Science and Technology, Qingdao, 266590, China.

[a]wangxinglearner@163.com, [b]2315685822@qq.com, [c]979574131@qq.com, [d]837885467@qq.com, [e]1419508741@qq.com, [f]824998408@qq.com

Abstract

In this paper, the thermal plasma medical waste treatment system was improved. The fume afterheat of the system was recycled by regenerative heat exchanger preheat the waste and gasification agent, which can save the energy cost, reduce the power consumption of inductively coupled plasma torch and improve the energy utilization efficiency. With the comprehensive consideration of the heat transmission by conduction, convection and radiation among the high-temperature air, the wall and the medical waste in the rotary heater, the one-dimension heat transfer model was built, and the energy conservation equation and the heat transfer coefficient of conduction, convection and radiation were concluded. The total heat of the waste obtained in preheater and the percentages of each part were calculated. It can be shown that 17% - 28.8% of the power consumption of inductively coupled plasma torch could be reduced by preheating the medical waste with afterheat.

Keywords

Regenerative heat exchanger; rotary heater; thermal plasma medical; fume afterheat; energy conservation.

1. Introduction

Medical waste is produced in the whole process of medical activities, carrying a large number of pathogenic microorganisms. If discharged or treated improperly, it will cause water, air, soil pollution, and even endanger human health. At present, the treatment of medical waste at home and abroad mainly includes direct incineration, pyrolysis incineration, plasma and other methods[1].The traditional direct incineration has the advantages of simple way and low cost, but it has many disadvantages ,for instance, dioxin in the furnace is not completely decomposed, the dust content in the flue gas is high, and the residue needs landfill treatment. The pyrolysis incineration method can incinerate waste materials after pyrolysis, which improves the treatment efficiency and reduces the dust content of flue gas. However, the problem of dioxin emission has not been properly solved[2].Thermal plasma treatment technology has extremely high temperature, meanwhile,dioxins are thoroughly decomposed into small molecules in the furnace, incineration ash is melted into harmless glass body [3].It's efficiency is high and the way of treatment is flexible [4]. However, because the technology uses expensive electricity as the main source of energy, in many cases, this economic drawback has become a major obstacle to the development of thermal plasma technology . In order to solve this problem and meet the requirement of energy saving, this paper improves and designs the waste heat utilization system of thermal plasma medical waste treatment device, which uses waste heat of flue gas to preheat garbage and gasifier, so as to achieve the purpose of energy saving and reduction.

2. Energy saving analysis

2.1. Current Situation of Medical Waste

Medical waste mainly consists of cotton swabs, gauze, syringes, packaging bags, and tested samples. Medical waste contains a lot of organic matter and water content, which is easy to corrupt and produce malodor. It is a good place for the breeding of flies, rats and other microorganisms, and has great harm. The water content of medical waste varies from 20% to 40% in different places[5].. When these moisture is completely vaporized by plasma torch (i.e. electric energy) and further heated to high temperature above 1600℃, the power consumption is extremely high. However, if the water is preheated and evaporated into steam in advance by other methods, the electric consumption of the heating process can be greatly reduced by avoiding the latent heat of vaporization of the water in the main combustion chamber with high energy consumption (the latent heat of vaporization of water is much higher than the sensible heat). The device uses waste heat recovery to obtain high temperature air to preheat garbage directly, to raise the temperature of garbage, and to reduce the electric energy needed in the drying stage. According to the analysis of heat source, it can be concluded that after preheating medical waste, on the one hand, the heat required in the gasifier and melting furnace is reduced, and the energy is retained as much as possible in the combustible gas after reaction, thus the calorific value of the combustible gas is increased. On the other hand, the power consumption of plasma torch is greatly reduced.

2.2. Heat Transfer Mechanism of Rotary Waste Preheater

The complex heat exchange process takes place in the rotating preheater. There are not only direct heat exchange process but also regenerative heat transfer process between waste material and high temperature air and flue gas. Considering heat conduction, convection and radiation heat transfer between high temperature air, preheater wall and waste material, a one-dimensional axial heat transfer model is established[6]. Specific heat transfer paths include the following heat transfer processes: convection and radiation heat transfer between high temperature air and garbage material; convection and radiation heat transfer between high temperature air and the inner wall of bare preheater; radiation heat transfer between bare inner wall and garbage material layer; heat conduction between garbage material and contact wall surface; heat conduction between inner and outer wall of preheater; pre-covering insulation layer;The heat dissipated from the wall of the heater through radiation and flow to the environment.

2.3. One-Dimensional Axial Heat Transfer Model

According to the heat transfer process, a one-dimensional steady-state model is established along the axis length of the waste preheater. Firstly, the following simplified assumptions are made:

(1) The temperature of air, waste material and wall is uniform in each axial position of waste preheater, ignoring the circumferential and radial heat transfer;

(2) Insulation of the inlet and outlet section of waste preheater;

(3) The heat released by high temperature air is the heat source;

(4) The preheater is in steady state;

(5) The air side surface of the material is flat.

(6) There is no energy accumulation in the wall of the preheater.

The conservation formula of air energy is as follows:

$$-\sum m_a c_{pa}\frac{dT_a}{dz} = h^c_{a\to ew}A_{ew}(T_a - T_w) + \varepsilon_{a\to ew}\sigma A_{ew}(T_a^4 - T_w^4) +$$
$$A_{ws}h^c_{a\to ws}(T_a - T_{mw}) + \varepsilon_{a\to ws}\sigma A_{ws}(T_a^4 - T_{mw}^4)$$

The energy conservation formula for garbage material is as follows:

$$\sum m_{mw} c_{pmw}\frac{dT_{mw}}{dz} = h^c_{a\to ws}A_{ws}(T_a - T_{mw}) + \varepsilon_{a\to ws}\sigma A_{ws}(T_a^4 - T_{mw}^4) +$$
$$A_{cw}h^c_{cw\to tw}(T_w - T_{mw}) + \varepsilon_{ew\to ws}\sigma A_{ws}(T_w^4 - T_{mw}^4)$$

In the formula: h^c—Convective heat transfer coefficient,W/(m^2·K);

A—The measure of area,m^2;

T—Thermodynamic temperature,K;

ε—Emissivity of an object;

σ—Stefan-Boltzmann constant, commonly known as the blackbody radiation constant, is a natural constant with a value of 5.67×10^{-8}W/(m^2·K^4);

l—Length along the axis;

c_P—Constant pressure specific heat capacity, kJ/(kg·K).

Corner marks: mw-medical waste material; tw-wall contact material; cw-covered kiln wall; ws-material surface; ew-exposed kiln wall; a-high temperature air; w-inner wall; sh-outer wall; e-external environment. The sign "→" in the subscript indicates the heat transfer path between the two; z—the direction of the preheater shaft length.

2.4. Calculations of Various Heat Transfer Coefficients

Convection heat transfer coefficient between high temperature air and material surface:

$$h^c_{a\to ws} = 0.46\frac{\lambda_a}{D}Re_D^{\ 0.535}Re_w^{\ 0.104}f^{-0.341}$$

In the formula: $D_e = D[\pi - \varepsilon + \sin(2\varepsilon)]/(\pi - \varepsilon + \sin\varepsilon)$;

$$Re_D = \rho_a v_a D_e/\mu_a,\ Re_w = \rho_a \omega D_e^{\ 2}/\mu_a.$$

f —Resistance coefficient, $f = (1.82\lg Re_D - 1.62)^{-2}$;

μ_a—Viscosity of high temperature aerodynamic, kg/(m·s);

v_a—Velocity of high temperature air,m/s.

Convection heat transfer coefficient between waste material and the interior wall of contact preheater:

$$h^c_{cw\to tw} = \frac{11.6\lambda_{mw}}{D\varepsilon}[\frac{\omega R^2\varepsilon}{30\alpha_{mw}}]^{0.3}$$

In the formula: λ_{mw}—Thermal conductivity of materials,W/(m·K);

D—Internal diameter of rotary preheater,m;

R—Internal radius of rotary preheater,m;

ε—Half filling angle of medical waste material,rad;

ω—Rotary speed of rotary preheater,s^{-1};

α_{mw} —Thermal diffusivity of medical waste,m^2/s;

Radiation heat transfer in rotary preheater mainly includes radiation heat transfer between high temperature air and surface of medical waste , radiation heat transfer between high temperature air and surface of bare preheater, radiation heat transfer between bare wall and surface of medical waste, radiation heat transfer between external wall and environment. The emission coefficients are respectively:

$$\varepsilon_{a\to ws} = \frac{\varepsilon_a \varepsilon_{ws}[1+\kappa(1-\varepsilon_a)(1-\varepsilon_{ew})]}{1-U}$$

$$\varepsilon_{a\to ew} = \frac{\varepsilon_a \varepsilon_{ew}[1+\kappa(1-\varepsilon_a)(1-\varepsilon_{ws})]}{1-U}$$

$$\varepsilon_{ew\to ws} = \frac{\varepsilon_{ws}\varepsilon_{ew}(1-\varepsilon_a)}{1-U}$$

In the formula: κ —Ratio of surface area to exposed inner surface area of medical waste.

$$U=(1-\varepsilon_a)(1-\varepsilon_w)(\kappa(1-\varepsilon_a)(1-\varepsilon_{ws})+(1-\kappa)$$

$$\kappa = \frac{\sin\varepsilon}{\pi-\varepsilon}$$

3. Model Calculation Results and Analysis

The test equipment is a rotary preheater with inner diameter of 0.8m, outer diameter of 1.2m and length of 6m. The mixture of high temperature air and flue gas flows counter-flow with medical waste inside the preheater. In the experiment, high temperature air with different temperatures is injected into the preheater, the average inner wall temperature and the temperature of the refuse material are recorded, and the physical parameters obtained from the temperature are brought into the formula. Then the percentage of the total heat of each part is calculated as shown in Figure 1, and the total heat of the refuse material in the preheating stage is shown in Figure 2.

When the operation is stable, the wall temperature of rotary preheater and the temperature of medical waste remain basically unchanged. As the heat transfer between high temperature air and medical waste is the main heat transfer mode of the system, the convection and radiation heat transfer between high temperature air and medical waste account for more than 90% of the total heat transfer, and the heat transfer ratio between bare wall and covered medical waste is less than 10%. Because the radiation heat transfer is proportional to the fourth power of temperature, when the temperature of high temperature air and medical waste increases, the radiation heat transfer resistance between high temperature air and medical waste decreases, and the proportion of radiation heat transfer in total heat transfer increases. With the increase of high temperature air temperature, the heat gained by medical waste in the preheating stage is also greatly increased. When the high temperature air temperature is between 850℃ and 1050℃, the total heat obtained from medical waste is equivalent to 17%-28.8% reduction in the power consumption of plasma torch.

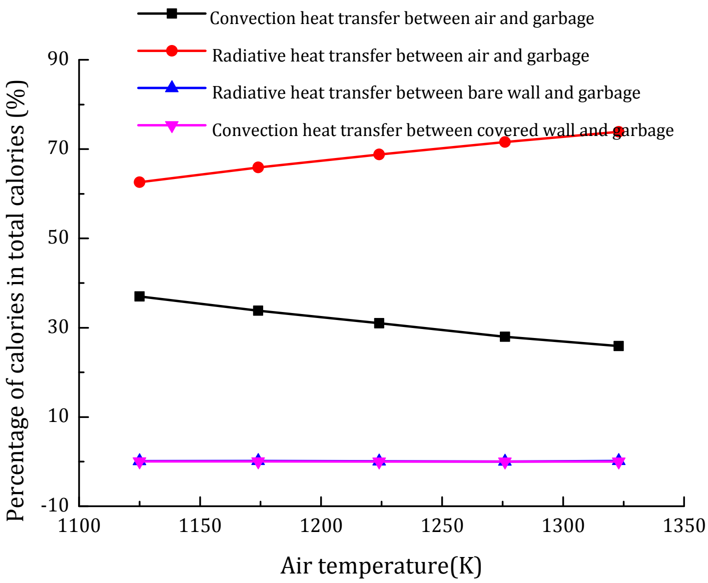

Fig 1. The percentage of the amount of heat to the total heat at different air temperatures

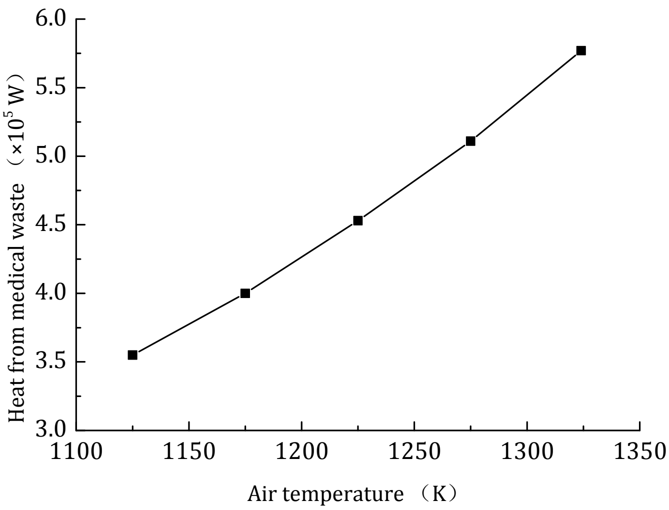

Fig 2. The heat medical waste obtained at different air temperatures

4. Conclusion

(1) There is a complex heat exchange among high temperature air, wall and garbage in the preheater. Based on the existing research, this paper establishes a one-dimensional heat transfer model and concludes the energy conservation equation and convection, heat conduction and radiation heat transfer coefficient.

(2) Medical waste is not only harmful, but also has high water content. The treatment of plasma system will consume a lot of electric energy. This paper calculates that using waste heat of flue gas to preheat medical waste will reduce the power consumption of plasma torch by 17%-28.8%.

(3) To promote energy saving and emission reduction, it is necessary to promote the combination of waste heat utilization technology and process energy saving, analyze energy supply and demand from the whole process system, and optimize the process system and its corresponding waste heat utilization technology.

References

[1] Chen Min, Yang Hongcai. Current status of disinfection technology for medical waste [J]. Chinese Journal of Disinfection, 2016,33, (2): 171-174.

[2] Hang Pengzhi, Zhou Shuping, Gong Yesheng. Design of pyrolysis process for centralized treatment of medical waste [J]. China Environmental Protection Industry, 2004 (s1): 92-95.

[3] Chu J P, Hwang I J, Tzeng C C, et al. Characterization of vitrified slag from mixed medical waste surrogates treated by a thermal plasma system[J]. Journal of Hazardous Materials, 1998, 58(1–3):179-194.

[4] Chu J P, Hwang I J, Tzeng C, et al. Characterization of vitrified slag from mixed medical waste surrogates treated by a thermal plasma system [J]. Journal of Hazardous Materials, 1998, 58 (1-3): 179-194.

[5] Shao Qiang. Plasma technology and its application in "three wastes" treatment [J]. Petrochemical safety and environmental protection technology, 2007, 23, (6): 51-55.

[6] Gao Yuan, Pan Sihong, Qu Yanping, et al. Present situation and Treatment Countermeasures of medical waste in Zhengzhou [J]. Environmental Health Engineering, 2003, 11 (2): 77-80.

[7] Shen Chunyan, Zhai Yong, Yin Hongchao. Mathematical model of gas-solid two-phase flow and heat transfer in rotary kiln [J].Energy Saving, 2013, 32(1): 26-30.