International Journal of Control and Automation
Vol.8, No.8 (2015), pp.1-8
http://dx.doi.org/10.14257/ijca.2015.8.8.01

Based On FLUENT Simulation Analysis of Vertical Heat-Carrier Heating Device

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Abstract

Heat-carrier heating device is an important part of biomass pyrolysis oil equipment. In particular, the application of vertical heat-carrier heating device can improve the rate of biomass pyrolysis. In this article, we will analyze the vertical carrier heating device based on FLUENT software and model the temperature field and velocity field of hot gas and carrier so as to draw a conclusion that the final temperature of carrier can reach approximately 840K which can meet the biomass pyrolysis process temperature. Meanwhile, the movement of carrier is very smooth without any stoppage thus laying a solid foundation for the improvement and optimization of the device.

Keyword: *Heat-Carrier Heating Device; Vertical; FLUENT*

With the rapid growth of world population and the development of technology, energy shortage becomes more and more serious so that the new energy came into being. As one of the most promising new energy, biofuel is characterized by high cost performance, low price and renewability, which can effectively solve the problems of agricultural and forest waste and environmental pollution to a certain extent. [1] Thus, research on biomass pyrolysis oil equipment has great economic and environmental significance. Since the carrier heating device is an important part of the biomass pyrolysis oil equipment, we mainly focus on the study of vertical carrier heating device in this article.

Not only does the vertical carrier heating device need to reach the process temperature through heating, but also to complete the heat transfer process and separation process of hot gas and carrier. Since the design of the device is really difficult and there is no clear specification and industry Standard Reference, we try to provide a new way of design for the vertical carrier heating device through simulation model of heat transfer and the movement of carrier based on FLUENT.

1. The Structure and Working Principles of Vertical Carrier Heating Device

1.1 The Structure of Vertical Carrier Heating Device

In order to make the carrier reach the needed temperature of the next process, the vertical carrier heating device passes heat to the carrier through the joint movement of hot gas and carrier. It mainly consists of burner, vertical bed, feeding device, carrier buffer, peephole, hot gas outlet, carrier outlet, cover and insulation layer. The overall structure is shown in Figure 1.

ISSN: 2005-4297 IJCA

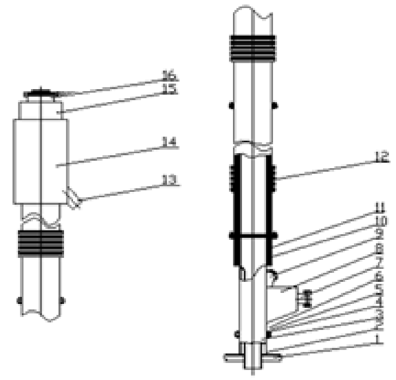

Figure 1. The Structure of Vertical Carrier Heating Device

1. Burner 2. Inner tube of vertical bed 3. Fluidized pipeline 4. Hex Bolts 5. Homemade flange 6. Hex nuts 7. Peephole 8. Feeding device 9. Feeding tube 10. Outer tube of vertical bed 11. Insulation layer 12. Bellows 13. Carrier outlet 14. Carrier buffer 15. Hot gas outlet 16. Cover

1.2 The Working Principles of Vertical Carrier Heating Device

The vertical carrier heating device can make the carrier reach a certain temperature by heat transfer between the hot gas and the carrier. The main working principles are explained as followings. The hot gas which is generated by the burner comes into the heating device at a high speed through the inner tube of the vertical bed, drives the carrier which comes from the feeding device to move upwards along the vertical bed. When the lift of carrier given by the hot gas equals the gravity of carrier, the carrier will move at a constant speed along with the hot gas. As it moves to the inlet of the vertical bed pipeline, the sudden expansion of the diameter leads to a slow-down of the hot gas and the carrier and then the diameter enlarges again at the carrier buffer so that the hot gas and the carrier move upwards again at the same speed with it passing by the inlet of the vertical bed pipeline. Finally, it enters the carrier outlet in free fall through the baffle under the buffer while the hot gas also moves to the next process through the hot gas outlet. During this process, heat transfer is carried out.

2. The Model Establishment of Vertical Carrier Heating Device

2.1 The Parameters of the Main Structure and the Building of Three-Dimensional Model

The main structural parameters of the vertical carrier heating device in this study are as follows: the diameter of the inner tube is 377mm; the diameter of the outer tube is 692mm; the overall height of the vertical bed is 23.26m; the height of the inner tube is 2.3m; the height of the carrier buffer is 2.6m; the thickness of the insulation layer is 100mm. According to the structure and the parameters in this article, the three-dimensional simulation model of the vertical carrier heating device is shown in Figure 2.

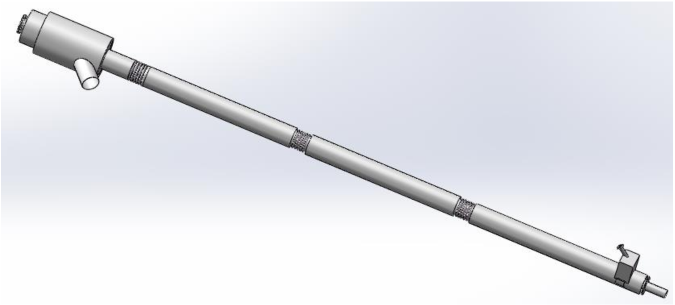

Figure 2. The Three-Dimensional Structure of the Vertical Carrier Heating Device

2.2 Mathematical Description

The theory of this device mainly depends on the fluid characteristics such as heat convection and the heat-flow coupling calculation based on hydrodynamics and heat transfer. In order to meet the fluid characteristics and the heat transfer performance, continuity equation, momentum equation and energy equation are established [2].

Continuity equation:

$$\frac{\partial \rho}{\partial t}+\frac{\partial \rho u}{\partial x}+\frac{\partial \rho v}{\partial y}+\frac{\partial \rho w}{\partial z}=0$$

Momentum equation:

$$\rho\frac{\partial u}{\partial \tau}+\rho u\frac{\partial u}{\partial x}+\rho v\frac{\partial u}{\partial y}+\rho w\frac{\partial w}{\partial z}= f_x-\frac{\partial \rho}{\partial x}+\mu(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2})$$

$$\rho\frac{\partial v}{\partial \tau}+\rho u\frac{\partial v}{\partial x}+\rho v\frac{\partial v}{\partial y}+\rho w\frac{\partial v}{\partial z}= f_y-\frac{\partial \rho}{\partial y}+\mu(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2})$$

$$\rho\frac{\partial w}{\partial \tau}+\rho u\frac{\partial w}{\partial x}+\rho v\frac{\partial w}{\partial y}+\rho w\frac{\partial w}{\partial z}= f_x-\frac{\partial \rho}{\partial z}+\mu(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2})$$

Energy equation:

$$\rho c_p\frac{\partial t}{\partial \tau}+\rho c_p u\frac{\partial t}{\partial x}+\rho c_p v\frac{\partial t}{\partial y}+\rho c_p w\frac{\partial t}{\partial z}=\lambda(\frac{\partial^2 t}{\partial x^2}+\frac{\partial^2 t}{\partial y^2}+\frac{\partial^2 t}{\partial z^2})$$

In the formula, u、v、w means the velocity of the fluid from x, y, z direction; f_x、f_y、f_z represents the component force from x, y, z direction which the fluid per unit mass is received; ρ is the density of the fluid; p is the surface force aroused by the viscosity of the fluid and the hydrostatic pressure; u means the fluid viscosity coefficient; λ is the thermal conductivity of the fluid.

2.3 The Model Grid Division and Boundary Conditions

To ensure the accuracy of the simulation results, the model should be simplified based on the structural characteristics of the device. Moreover, we use the structured grid to divide the model with a total number of 994,088. The overall grid and the local grid division are shown in Figure 3[3].

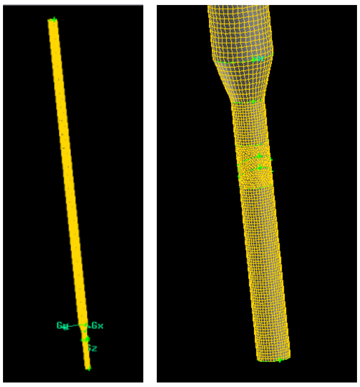

Figure 3. The Grid Division of the Vertical Carrier Heating Device

In FLUENT simulation process, it is essential to establish correct physical parameters of materials [4]. FLUENT mainly sets up physical parameters for fluid and solid, including density or molecular weight, heat capacity, viscosity, mass diffusion coefficient, thermal conductivity, kinetic theory parameters and so on. The boundary conditions are shown in Table 1.

Table 1. Boundary Settings

Physical Quantities	Unit	Parameter
Gas inlet velocity	m/s	19.3
Gas inlet temperature	K	1070
Gas outlet reflux turbulence intensity	--	5%
Gas density	kg/m2	1.225
Gas heat capacity	J/kg·K	1006.43
Gas heat transfer coefficient	W/m·K	0.0242
Gas viscosity coefficient	--	1.7894×10^{-5}
Carrier density	kg/m2	1700
Carrier heat capacity	J/kg·K	800
Carrier heat transfer coefficient	W/m·K	0.46
Mixed heat transfer coefficient	W/m·K	0.0454
Carrier inlet velocity	m/s	1.98
Carrier inlet temperature	K	400

3. Simulation Results and Analysis

3.1. The Selection of the Relaxation Factor

When we try to solve the linear algebraic equations which are obtained from the discrete control equations, the relaxation factor is introduced to change the rate of dependent variable [5].

$$\frac{a_p}{\alpha}\Phi_p = \sum a_{nb}\Phi_{nb} + b + (1-\alpha)\frac{a_p}{\alpha}\Phi_p$$

In the formula, α is the relaxation factor; when $\alpha > 1$, it is over relaxation; when $\alpha < 1$, it is under relaxation.

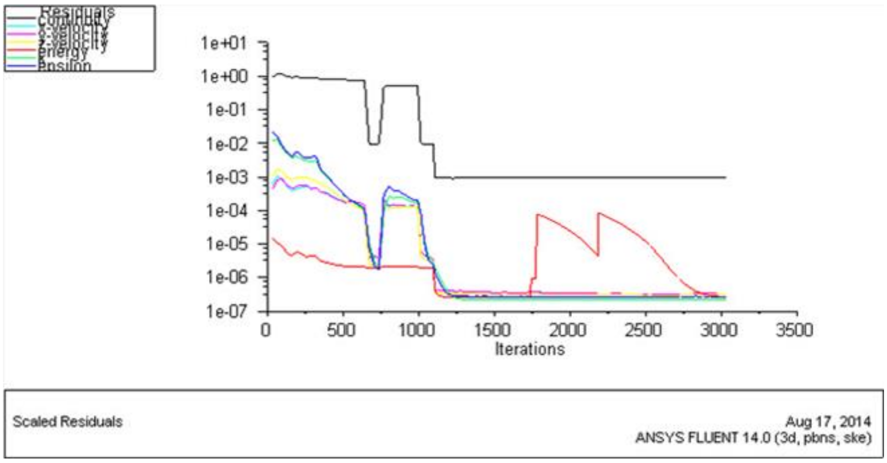

Figure 4. Residual Convergence Curves

Generally we use underrelaxation to solve nonlinear problems. Since the gas-solid coupling belongs to the typical nonlinear model and the convergence rate slows down when the relaxation factor decreases, small relaxation factor is favorable for convergence calculation.

During the simulation process, the relaxation factor in FLUENT is set to 0.2, and the residual convergence curves are shown in Figure 4. We can find that all the residual values fluctuate around a certain value respectively in the iteration process. After 3,000 times of iteration calculation, the values suddenly change and converge to 1x10-7. Therefore, the relaxation factor we chose is appropriate for the convergence requirements.

(2) Analysis on the Temperature Simulation Results of Hot Gas and Carrier

The simulation results of gas temperature are shown in Figure 5, and its temperature change curves are shown in Figure 6; the simulation results of carrier temperature are shown in Figure7, and its temperature change curves are shown in Figure 8.

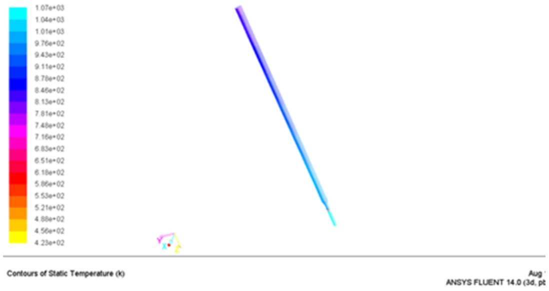

Figure 5. The Temperature Field Distribution of Hot Gas

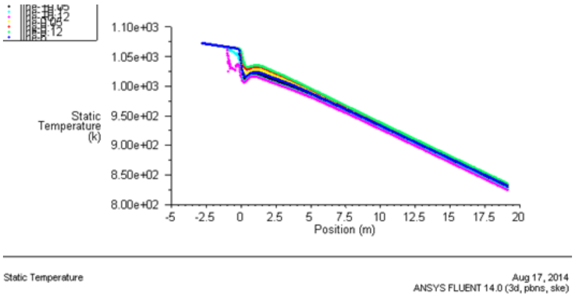

Figure 6. The Temperature Change Curves of Hot Gas

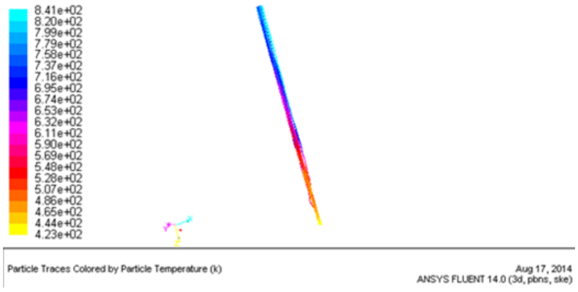

Figure 7. The Temperature Field Distribution of Carrier

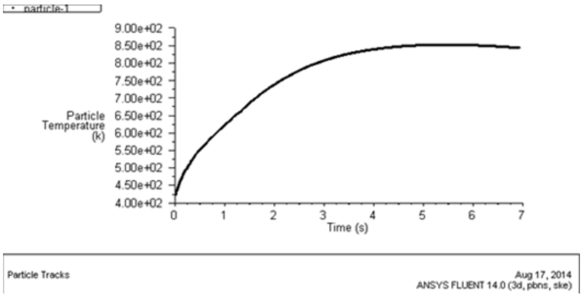

Figure 8. The Temperature Change Curves of Carrier

By Figure 5 and Figure 6, we can find that hot gas enjoys the highest temperature of 1070K at the vertical bed gas inlet. With the rise of gas, its temperature drops gradually and decreases to 850K at the gas outlet. By Figure 7 and Figure 8, the temperature of carrier is about 400K at the carrier inlet. During the process of carrier rising which is driven by the gas, the temperature of carrier gradually increases and eventually reaches about 840K. Thus the results have shown that the final temperature of hot gas basically equals that of carrier and also have indicated that hot gas transferred heat to carrier. Meanwhile, as shown in Figure 8, the temperature of carrier goes up quickly to the required processing temperature which means the high efficiency of the device.

(3) Analysis on the Velocity Simulation Results of Hot Gas and Carrier

The velocity simulation results of hot gas are shown in Figure 9, and its velocity change curves are shown in Figure 10; the velocity simulation results of carrier are shown in Figure 11, and its velocity change curves are shown in Figure 12.

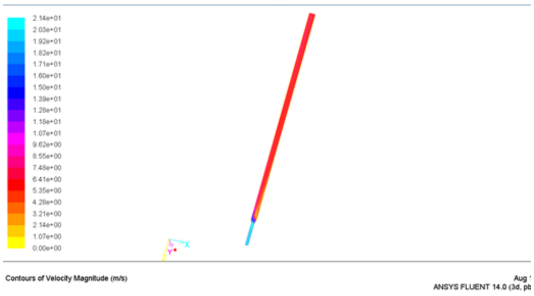

Figure 9. The Velocity Field Distribution of Hot Gas

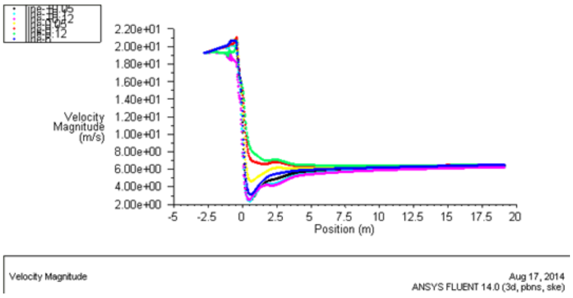

Figure 10. The Velocity Change Curves of Hot Gas

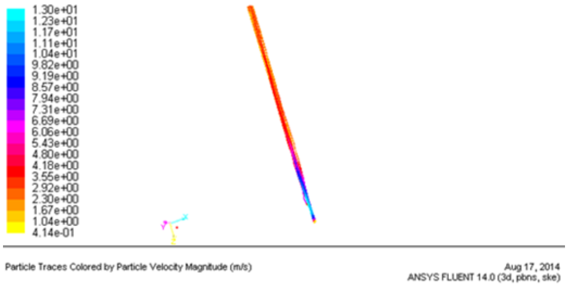

Figure 11. The Velocity Field Distribution of Carrier

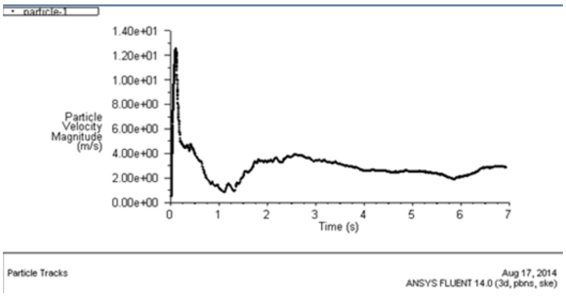

Figure 12. The Velocity Change Curves of Carrier

By Figure 9 and Figure 10, we can find that hot gas comes into the vertical bed at a speed of 19.3m / s, slows down dramatically at the junction of the outer tube and inner tube due to the sudden enlarging of the outer tube diameter, and rises in uniform motion at a speed of 5m / s ultimately. By Figure 11 and Figure 12, the velocity of carrier climbs sharply within 0.5s because the carrier meets the high-speed gas when it enters the vertical bed. Furthermore, the velocity change of carrier is as same as the gas since the rise of carrier is lifted by the gas. Then at the junction of the outer tube and inner tube, the velocity of carrier also decreases rapidly owing to the same reason. With the rise of carrier, its velocity tends to be 3.5m / s when the gravity of carrier equals its lift given by the hot gas.

4. Conclusion

The establishment of three-dimensional model and the grid division for the carrier heating device is based on FLUENT. We have achieved the visualization of numerical simulation to a certain extent. The conclusions drawn from the simulation results are explained as followings:

(1) The vertical carrier heating device enjoys an advantage of high efficiency for heating. The total heating process only takes about 4s. Since a little temperature difference between carrier and gas is relatively acceptable when they leave the vertical

bed, high thermal efficiency and fine heat transfer is proved. It will benefit the reduction of the energy consumption and the improvement of working efficiency for biomass pyrolysis oil device.

(2) The movement of gas and carrier is very smooth without any block. The reasonable velocity change can effectively promote the upward movement of carrier driven by gas, and allow a certain initial speed of gas and carrier when leaving the vertical bed which is in favor of separation.

Acknowledgements

Supported by "the Fundamental Research Funds for the Central Universities" (2572014CB28)

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