

A CFD modeling investigation for structure optimization of a rotary steam tube dryer

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Abstract. This paper presents an optimized structure to improve the performance of rotary steam tube dryer by assembling the so called ‘Y’ shape flights. A verified CFD model, which was developed and validated in the previous work, was employed to verify the optimized structure by the comparisons of concentration distribution, velocity distribution and heat transfer coefficient. The simulation results showed that assembling ‘Y’ shape flights in a rotary steam tube dryer is an effective approach to increase material filling ratio and heat exchanging area. The optimized construction is able to reduce the wear of the material to the tube surface, due to the low maximum particle velocity. The optimized structure yields a uniform particle velocity distribution and high average surface heat transfer coefficient of tubes which is about ten times of that without flights.

1. Introduction

Drying is an indispensable but high energy consumption operation in the iron-making plants. Different from the direct heating drying, which is popularly applied at present, the indirect heating drying does not require drying medium (such as air) to bring the drying required heat into the dryer, but by indirect heat exchange to provide heat for the evaporation of water. The exhaust gas discharged from the dryer is almost pure water steam or solvent vapour. Therefore, indirect heating drying method is of the advantages of less exhaust gas emission, high energy utilization rate and easy recovery of exhaust heat and solvent.

Rotary steam tube dryer is one of the most typical representatives of indirect heating dryer. However, despite its decade’s application in industry, including in the iron-making plants as one of the coal moisture control facilities, its drying performance has not been significantly improved, because the internal structure has not optimized. One of the obvious defects of this structure is caused by the low filling rate of internal material. Usually the material filled in a rotary steam tube dryer is less than 22%. As a result, the heat exchange area is not fully utilized because of the low proportion of the material immersed tubes. Another evident shortcoming is reflected by low average heat transfer coefficient. The reason is due to that a part of the material at the bottom of the cylinder is stationary to the heat exchange tubes. The installation of suitable flights seems to be one of the efficacious approaches to improve the performance of rotary steam tube dryer [1].

The objective of this work is to optimize the structure of rotary steam tube dryer for the goal of performance improvement.



2. Analysis of Heat Transfer

A rotary steam tube dryer is reformed from the traditional direct heating rotary dryer by installing steam tubes in its chamber, as shown in figure1 and figure2. Generally, there is no flight inside the chamber. Usually, water steam flows through the tubes to provide required drying heat. The material in the drying chamber rotates with the tubes and contacts the outer wall of the heating tubes to obtain the heat needed for drying. The movement of material particles includes lifting, rolling, falling and so on. Experimental observation found that during the stable operating stage, the material particles will form a stable crescent area on the cross section of the dryer cylinder, as shown in figure3 and figure4.



Figure 1. Photo of rotary steam tube dryer

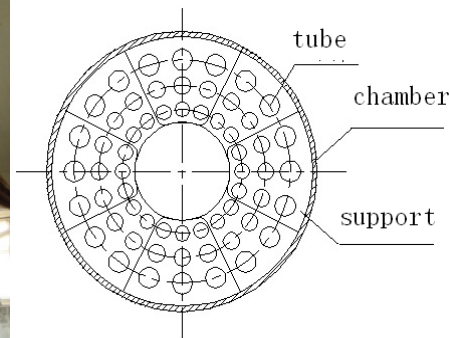


Figure 2. Cross section diagram

When the heating tube is immersed by the material layer, the heat transfer presents the following processes:

- At first, heat transfers from the heat source (such as water steam) inside the tube to the inner wall of the heating tube by means of condensation or convection.
- Then, heat transfers from the inner wall to the outer wall of the heating tube by means of heat conduction.
- Finally, heat transfers from the outer wall of the heating tube to the material layer near to the wall by means of convection, collision contact and radiation.

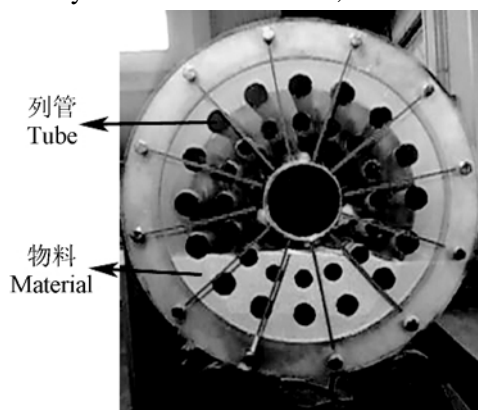


Figure 3. Material particles distribution at static state

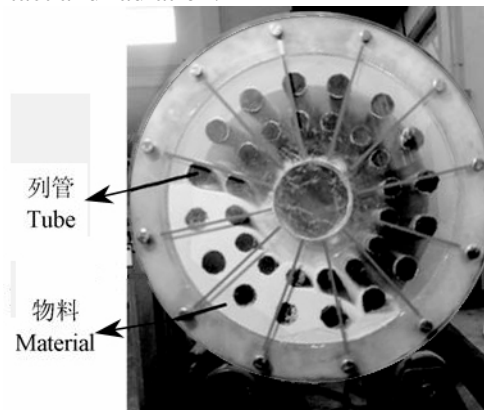


Figure 4. Material particles distribution at stable state

Meanwhile, as the dryer rotating and particles mixing in the material layer, hot particles transfer heat to cold particles by radiation and contact. As soon as a particle obtains heat, the heat transfers from the surface to the interior by heat conduction.

Investigation showed^[3] that, in the above heat transfer processes, main transfer resistance takes place between tubes' outer wall and material, which accounts for more than 95% in total.

When a steam tube is immersed by gas phase, which usually consists of waste vapor and air, the heat transfer occurs between gas and tube surface. Generally, this is a small part comparing to the heat transferred to material.

Obviously, the way to increase the drying ability of rotary steam tube dryer includes two approaches:

- To keep the relative movement between heating tubes and material particles.
- To increase the area proportion of particles immersed tubes.

A set of suitable flights is likely able to fit such intentions [1,2], because the flights can be used to disperse material particles to the circumference of chamber, and keep particles sprinkling with chamber rotating. Taking the existing design into consideration, this paper proposes a unique flight, so called 'Y' shape flight, to match the requirements. The 'Y' shape flights are uniformly distributed around the inner side of cylinder, as showed in figure5.

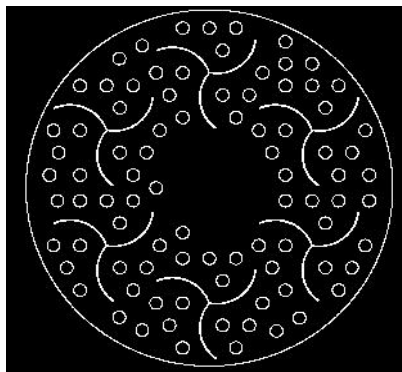


Figure 5. Geographical model of rotary steam tube dryer with 'Y' shape flights.

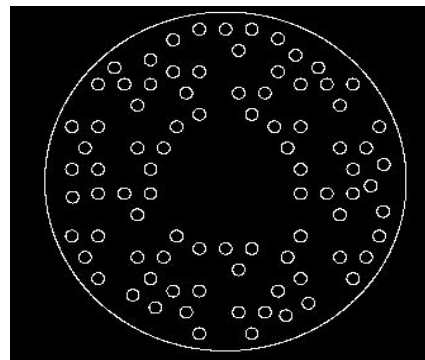


Figure 6. Geographical model of rotary steam tube dryer without flight

Comparing to the traditional right angle flight, a set of suitable 'Y' flights is able to transport material particles from one flight to another, so as to distribute material particles to the circumference of chamber. Meanwhile, as the flight moving with the chamber rotating, it keeps particles filling and discharging alternatively. As a result, the material particles keep a relative movement to the near tubes.

3. CFD Mode

In order to validate the optimized structure, a CFD model which was verified in our previous work^[4,5,6], was employed to simulate the flow and heat transfer processes. This model consisted of mass conservation equation, momentum conservation equation and energy conservation equation. The turbulence was defined as laminar. The Eulerian model was adopted to describe the multiphase flow. While, the tubes and chamber were defined as the moving walls which rotates around the axis of cylinder with an angular velocity of 6 rpm.

A rotary steam tube dryer with a diameter of 2m and with 60 heating tubes was selected as the simulation object. A two-dimensional geometric model, showed in figure 3, was carried out to simulate the particles' movement state at a cross-section, which reflects the heat and mass transfer processes in the whole dryer.

The geometric model was meshed by triangle, which carried out about 600 thousands cells.

A traditional rotary steam tube dryer model without flight was also developed, shown in figure6, so as to compare the differences on the performances.

The unsteady solver with a time step of 0.1s was defined to show the variations of velocity and particle concentration distributions corresponding to the operation duration.

All the simulations kept the material particles filling ration by 50%. The coal particles which used in iron-making plants were taken as the raw material.

4. Results and Analysis

Figure 7 shows the concentration distributions, when the particles movement is stable. It was observed that the interface between the particle and the gas phases in Figure 7 is obviously higher than that in Figure 8, and the concentration in Figure 8 is lower than that in Figure 7. This indicates that the material particles can be effectively dispersed around the cylinder's wall by the 'Y' shape flights. Consequently, the contact area between the heating tube and the material can be increased by assembling 'Y' shape flights.

The material filling ratio in a rotary dryer is mainly dependent on the flights holding material amount and the height of retaining ring which is generally as high as the most inner tubes position. So, the high material filling ratio set in this paper is improper in engineering cases. However, because of the flight ability of holding and dispersing particles, the material filling ratio is able to be increased by assembling flights. Preliminary estimation showed that for the case of without flight, the filling ratio is about 20%; while for the case of installed 'Y' shape flights, the ratio is about 40%.

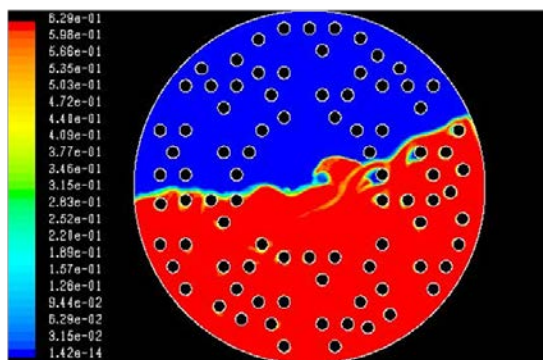


Figure 7. Concentration distribution without flights.

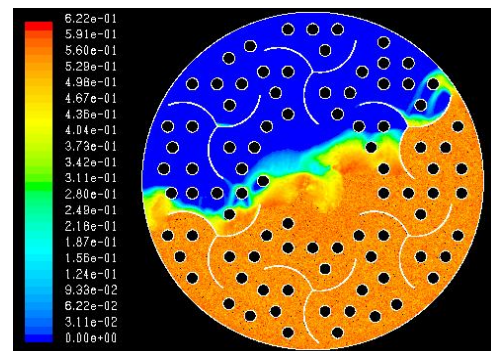


Figure 8. Concentration distribution with "Y" flights

Despite the maximum velocity is up to 10.7 m/s in Figure 9, which shows the particle velocity distribution in the rotary steam tube dryer without flight, the particles in the bottom area are almost static, as Figure 10 zoomed. It was also found that the velocities are not uniform. While, if a rotary steam tube dryer is assembled with 'Y' shape flights, the particle velocities are much uniformly distributed, though the maximum velocity is as low as 2.1 m/s, as it was showed in Figure 11. This feature leads to a pair of advantages: enhance heat exchange between particles and heating tubes; because of the low particle velocity, the wear of the material to the tube surface is significantly reduced. It was also found that in the bottom area, as it was showed in Figure 12, the particles keep significant relative movement to the tubes. This conducts such a consequence that all the particle immersed tubes are of well heat transfer condition.

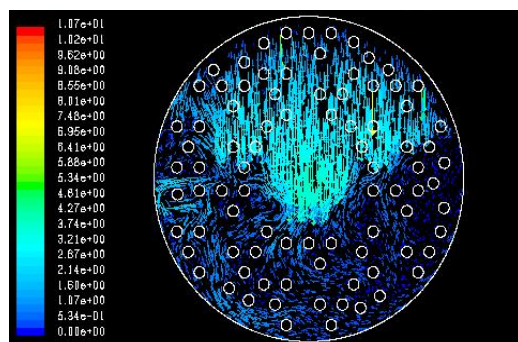


Figure 9. Velocity distribution on the whole section of the case without flight.

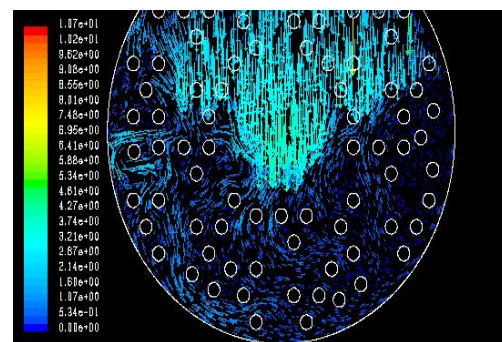


Figure 10. Velocity distribution zoomed in bottom of the case without flight.

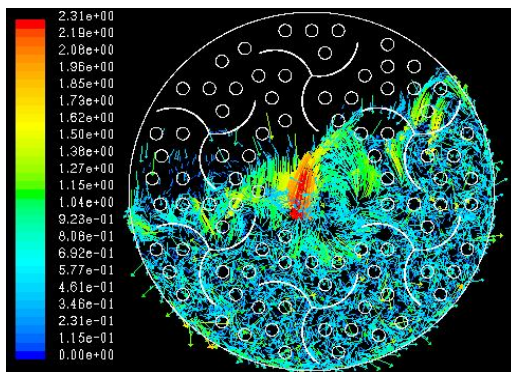


Figure 11. Velocity distribution on the whole section of the case with “Y” shape flights

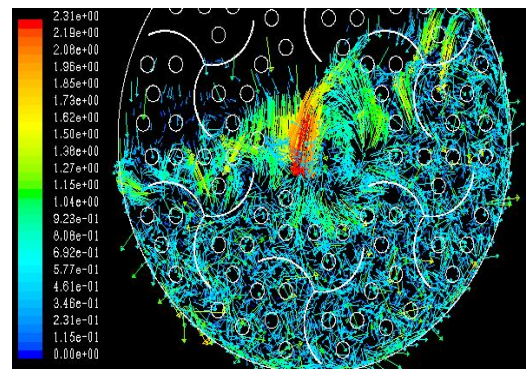


Figure 12. Velocity distribution zoomed in bottom of the case with “Y” shape flights

5. Conclusions

Rotary steam tube dryer is one of the most typical representatives of indirect heating dryer. There are two main ways to increase the drying ability. One is keeping the relative movement between heating tubes and material particles. This work conducts following results:

- Assembling ‘Y’ shape flights in a rotary steam dry is an efficient approach to increase material filling ratio and heat exchanging area.
- The optimized structure is able to reduce the wear of the material to the tube surface, due to the low maximum particle velocity.
- The optimized structure yields a uniform particle velocity distribution and high average surface heat transfer coefficient of tubes.

A more optimized structure is to be carried out by investigating the influence of the dimension of flights.

Acknowledgments

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References

- [1] Daya R N, Prabir B and Bishnu A Investigation into overall heat transfer coefficient in indirectly heated rotary torrefier *International Journal of Heat and Mass Transfer* **102** (2016) 64–76
- [2] Pan Y K, Wang X Z and Liu X D 2006 *Modern Drying Technology* vol **2** (Beijing: Chemical Industry Press)
- [3] Yue Y F, Sun Z X and Liu Y Z Research on heat transfer coefficient of rotary steam tubedryer *Petrochemical Equipment* in chinese 2008 **37**(1) 8-11
- [4] Wu J, Li X Y and Liu X D Development on CFD model of indirect heating rotary tube dryer *Petrochemical Equipment* 2007 **10**(57) 25-27
- [5] Zhao H M, Xing Z L, Li J, Li X Y, Liu F X and Xiao P M 2010 *Proc. of the 5th National Gypsum Technology Conf. and Exhibition (Jinan)* pp11-6
- [6] Wu J 2014 Ph.D thesis *Analysis and Experimental Research on Heat Transfer Process in an Indirect-heating Tube Rotary Dryer* (Jian: Shandong University)