Numerical simulation of the dryer drum radiation area using coupled CFD and DEM methods

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Abstract. This article investigates the use of coupled computational fluid dynamics (CFD) and discrete element methods (DEM) to simulate the heat transfer by thermal radiation in the material containing zone of an aggregate drum dryer for hot mix asphalt production. A 250mm long material containing zone structure was selected. For the asphalt binder to properly coat the aggregate, the aggregate must be completely dry. This process is accomplished in a counter-flow drum heated by a burner with the flights attached inside the drum walls to facilitate heat transfer. The materials containing drum area was tested and simulated, and the material temperature rise and drum temperature were obtained, with an error of less than 5% from the experimental results, indicating that the simulation is feasible. The results of the study show that the best heat radiation effect is achieved with a semi-contained flight; the material temperature increases and then decreases as the output increases. The flame diameter increases by 1.5 times, the heat radiation effect is enhanced. The preliminary results may provide some guidelines for operating the dry drum efficiently and designing drum to control quality of material mixes and save energy.

1. Introduction
With the rapid development of computer computing power, simulation through the use of computer software is becoming an important means of validating theoretical models. And simulation is particularly advantageous in cases where the experimental requirements are very demanding [1-3]. Therefore, in recent years, many researchers at home and abroad have used computer simulation of the heat and mass transfer process of material particles in the drying cylinder to replace difficult and expensive experiments, and achieved good result [4-5].

Tsuji et al. [6] in Japan carried out numerical simulation of gas-solid two-phase flow in horizontal pipelines, and the research results showed that in the fluidized bed with low particle phase density, the hard-ball model could obtain the basic experimental results. Wu et al. [7] established the CFD-DPM coupling numerical analysis model under the three-dimensional unstructured grid framework, and introduced in detail the method for accurate calculation of particle volume in the process of low-density two-phase flow and the method for improving the coupling calculation efficiency. Haifang Wen [8] used coupled computational fluid dynamics (CFD) and discrete element method (DEM) to simulate the motion and heat transfer of aggregates in a simple drum. The effects of aggregate particle size, drum speed and flight on the variation aggregate temperature, and the effect of fluid temperature on thermal efficiency were investigated. The results show that small particles are more susceptible to heat than large particles. The determination of the optimal drum speed requires consideration of the particle motion model and the residence time in a realistic inclined drum.
Because the movements of gas and solid are basically relatively independent, the heat transfer process in the drying cylinder does not belong to the traditional gas-solid two-phase flow category, so using the secondary development port of the existing software to consider the heat and mass transfer characteristics of the drying cylinder comprehensively and get more realistic simulation results is the difficulty of this paper's research\textsuperscript{[9]}. The subject of this article is to study the application of this coupling called the EDEM CFD coupling for FLUENT to simulate the thermal radiation of the material in the aggregate dryer.

2. Thermal radiation
Thermal radiation is the way in which an object transmits energy outwards in the form of electromagnetic waves. Radiation due to temperature is called thermal radiation\textsuperscript{[10]}. The emission of thermal radiation by an object is the conversion of the object's thermal energy into radiant energy, while the absorption of radiant energy by an object is the conversion of radiant energy into thermal energy. According to the fourfold law of radiation, as the temperature rises, the radiant force increases sharply. At the same time, radiation has a directional, perpendicular to the surface of the object in the direction of the maximum radiation energy, parallel to the surface of the material in the direction of the minimum radiation energy. The material absorbs the heat radiation and at the same time emits it outwards.

The fundamental law of heat conduction is expressed as:

\[
q = -\lambda \frac{dt}{dx}
\]

Where \(\Phi\) is the heat conductivity, \(\lambda\) is the thermal conductivity, \(t\) is the temperature and \(x\) is the coordinate on the thermal conductivity surface.

3. Simulation and experiment

3.1. Geometry
The main body of the drying drum of the asphalt mixing plant is a slightly inclined and rotating cylinder, which is subject to both high temperature heating and conveying equipment. The material zone of the drying drum is the area where the aggregates are heated to working temperature. In order for the fuel to burn fully, the aggregate in this zone moves forward without blocking the flame and cannot form a material curtain. Due to the high combustion temperature at one end of the burner the flight section is generally T-shaped, its structure is arranged as in Fig. 1, and the two wings of the flight can make the aggregate stay in it, which not only avoids the direct contact between the aggregate and the flame, reduces the loss of incomplete combustion caused by the fuel being stuck down by the aggregate, but also protects the cylinder wall, reduces the heat loss through the cylinder wall and the deformation caused by the high temperature baking drum.

![Fig.1 Schematic diagram of bearing area structure](image-url)
The shape of the flight is box-shaped structure, the drying cylinder rotates when the flow of materials in the flight box along the wall of the cylinder surrounded by a week. This reduces the heat loss caused by the heat dissipation of the cylinder wall and enables the heat to be fully transferred to the material while at the same time reducing the damage caused by the high temperature to the drying cylinder wall. Three different material-containing flights were studied, with the flight structure shown in Fig. 2. Flight 1 is a fully contained flight, flight 2 is a semi-contained flight and flight 3 is a less contained flight.

3.2. Parameters setup

Parameters of DEM are set as shown in Table 1. Parameters of CFD are set as shown in Table 2.

| DEM parameters                  | Value   |
|---------------------------------|---------|
| Contact Model                   | Hertz-Mind |
| Geometry Poisson’s Ratio        | 0.3     |
| Particle Density (kg/m³)        | 2500    |
| particle Diameter (mm)          | 40      |
| Particle Poisson’s Ratio        | 0.25    |
| Particle Shear Modulus (Pa)     | 1.38e+07|
| Geometry Shear Modulus (Pa)     | 7.5e+1  |
| Particle-Particle Coefficient of Restitution | 0.181 |
| Particle-Static Friction Coefficient | 0.2   |
| Particle-Sliding Friction Coefficient | 0.19  |
| Geometry Density (kg/m³)        | 7800    |
| DEM Time Step (s)               | 0.00025 |

| CFD parameters                  | Value   |
|---------------------------------|---------|
| Flame Diameter (mm)             | 240     |
| Initial Temperature of Material (K) | 423  |
| Flame Thermal Radiation Coefficient | 0.25  |
| Flame Temperature (K)           | 1473    |
| Heat Transfer Model             | Natural convection |
| CFD Time Step (s)               | 0.05-0.25 |
3.3. Result and discussion

A comparison of the material temperatures obtained from the simulation of the 30kg material radiation zone and the experimentally measured material temperatures is shown in Table 3.

| Flight type | Experiment (K) | Simulation (K) | Error (%) |
|-------------|----------------|----------------|-----------|
| Flight 1    | 430.4          | 440.6          | 2.37      |
| Flight 2    | 431.5          | 445.2          | 3.17      |
| Flight 3    | 430.6          | 438.6          | 1.86      |

The error between the simulation and the experimentally measured data is kept within 5%, because in the actual test there are deviations due to differences in the material moisture content and filling rate. Therefore, the actual situation can be reached gradually by setting suitable boundary conditions. The values of the other measurement points are similar to the simulation results, indicate the simulation results basically reflect the real influence process of the heat radiation in the material containing area of the drying drum and the simulation parameters were reasonably set.

According to Fig. 3 and Fig. 4, the cylinder wall temperature of flight 3 is the lowest and the temperature of the material is the highest, indicating that the best heat radiation effect is achieved by using the structure of flight 3. Aggregate containing less material will lead to insufficient convective heat exchange between the stone and the flue gas, the flue gas takes away too much heat, causing difficulties in heating up the stone and low drying cylinder output. However, if the aggregate contains too much material, it will destroy the flame shape and also lead to too low an exhaust temperature, causing dew inside the bag filter and affecting the dust removal effect. Therefore, when working with drying cylinders in practice, it is necessary to select aggregates of reasonable quality, better design alignment and shape of flights could be largely benefit to the aggregate heating.

![Fig. 3](image-url)
3.4. The effect of flame diameter on the material and wall temperature

The material mass is 30 kg, the flame diameter is increased from 240mm to 360mm, and the simulation values are shown in Table 4. The temperature distribution and material distribution are shown in Fig. 5.

Table 4 Simulation results of changing flame diameter are compared

| Flame diameter (mm) | Material temperature (K) | Wall temperature (K) |
|---------------------|--------------------------|----------------------|
| 240                 | 445.2                    | 417                  |
| 360                 | 457.5                    | 458                  |

Flame diameter increased by 50%, material temperature increased by 50%, thermal radiation effect
increased significantly. Drum wall temperature increased by about 10%. Since the required space volume of combustion is basically fixed, when the flame diameter is increased and the length is correspondingly shortened, the temperature field of the drum moves forward and the thermal radiation intensity in the material containing area increases.

4. Conclusions
Through the above analysis, the following conclusions can be drawn:

1. The internal situation of the drying drum part of the movement and temperature distribution is not easy to observe, and for the complex, CFD-DEM coupling technology for dynamic simulation, to achieve the visualization of the internal structure. The study shows that the model can better predict the temperature of the material particles and the change of the wall temperature during the drying process.

2. Comparison of the effect of different flight configurations on the heating effect under variable material quality conditions shows that the best heating effect is achieved with semi-contained flight, and the best heating effect is achieved with semi-contained flight, which provides a theoretical basis for further optimization of the material-containing zone structure parameters.

3. The effect of flame diameter on thermal radiation was studied. The thermal radiation effect of different flame diameters was compared, and the temperature rise of the material was obvious when the flame diameter increased.

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References
[1] Mikio Sakai, Yusuke Shigeto, Gytis Basinskas, et al. Discrete element simulation for the evaluation of solid mixing in an industrial blender[J]. Chemical Engineering Journal, 2015, 279: 821-839.
[2] Tao Fan, Malin Liu, Huaqing Ma, et al. DEM simulation for separating coated fuel particles by inclined vibrating plate[J]. Powder Technology, 2020, 366: 261-274.
[3] Andrew Hobbs. Simulation of an aggregate dryer using coupled CFD and DEM methods[J]. International Journal of Computational Fluid Dynamics, 2009, 23(2): 199-207.
[4] Xuejiao Liu, Jieqing Gan, Wenqi Zhong, et al. Particle shape effects on dynamic behaviors in a spouted bed: CFD-DEM study[J]. Powder Technology, 2020, 361: 349-362.
[5] Giulio Dondi, Andrea Simone, Valeria Vignali, et al. Numerical and experimental study of granular mixes for asphalts[J]. Powder Technology, 2012, 232: 31-40.
[6] Tsuji Yutaka, Morikawa Yoshinobu, Tsuji Tanka, et al. Numerical simulation of gas-solid two-phase flow in a two-dimensional horizontal channel [J]. International Journal of Multiphase Flow, 1987, 135(5): 671-684.
[7] Chunliang Wu, Abdallah Berrouk, Nandakumar Kandakumar. Three-dimensional discrete particle model for gas-solid fluidized beds on unstructured mesh[J]. Chemical Engineering Journal, 2009, 152(2-3): 514-529.
[8] Haifang We and Kun Zhang. Simulation of aggregates heating in asphalt plants[J]. Journal of Engineering Mechanics, 2014, 239 19-28.
[9] Meihua Chen, Haifeng Lu, Yong Jin, et al. Experimental and numerical study on gas-solid two-phase flow through regulating valve of pulverized coal flow[J]. Chemical Engineering Research and Design, 2015, 155: 1-11.
[10] Xiangqi Wang, Arun Mujumdar. Heat transfer characteristics of nanofluids: a review[J]. International Journal of Thermal Sciences, 2007, 46(1): 1-19.