Study on Separation Efficiency of Dehydration Equipment with Corrugated Plates

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Abstract. The complex problem on two-phase flow field in the dehydration equipment with corrugated plates is presented in the paper. The influence factors on dehydration effect were found by the numerical analysis on the gas-liquid two-phase flow field and droplets’ mechanical behavior in the dehydration equipment with corrugated plates while changing the structure parameters and operating conditions. Experiment on the separation efficiency and limit gas speed of dehydration equipment was carried out by changing the plate spacing, droplets diameter and spraying water flow. The results show that the dehydration equipment has the highest dehydration efficiency and minimum resistance loss when the distance between the plate is 15 mm, the droplets’ average diameter is 160 μm, and the spraying water flow is 0.89 m³/h. While the limit gas speed is affected by the plate spacing, droplets diameter and spraying water flow. The optimal limit gas speed is 3.7 m/s considering the correlative factors of dehydration efficiency and resistance loss comprehensively. The numerical simulation results agree well with the experimental results. It provides a guide for the industrial design of the dehydration equipment with corrugated plates.

Introduction

Natural gas, coal gas and other gas fuels are used more and more widely in industry. However, moisture in gas fuels will directly affect its combustion efficiency[1-3]. Gas dehydration technology plays an important part in the utilization of gas fuels[4-6]. Moisture in natural gas not only reduces the calorific value of the gas, but also dissolves acidic gases such as H₂S which causes serious corrosion of the gas service equipment[7]. Therefore, natural gas must be dehydrated before it can be transported and utilized. Blast furnace, converter and coke oven gas are important energy in the iron and steel enterprises. Many enterprises use combined cycle power plant (CCPP) generation technology to make use of them. However, water in the gas will have many problems in CCPP. Firstly, acidic substances are easily dissolved in the gas containing mechanical water. They will make the coating of gas turbine blades corroded and cause the blades to crack and break[8]. It will seriously affect the service life of gas turbine. Secondly, the mechanical water will vaporize while the gas is burning. It will consume a part of calorific value of the gas and reduce its thermal efficiency. Finally, the mechanical water in the gas contains phenol, tar and other components, which will condensate and discharge during the transportation process and cause environmental pollution. Therefore, the mechanical water content in the gas entering the CCPP must be less than 5mg/m³.

At present, there are many dehydration technologies used for gas fuel, such as wire mesh and cyclone dehydration device. They can’t meet the requirements of industrial application the operation because the dehydration efficiency is very low and the energy consumption is very high. The corrugated plates dehydration device can efficiently remove the mechanical water in the gas and has little resistance loss[9-11]. However, its dehydration efficiency and resistance are greatly affected by the operation conditions[12,13]. The optimum structure parameter and limit gas speed are found from the experiment which can give a guidance for the industrial application.
Computational Model and Experimental Principle

Computational Model

As shown in Fig. 1, the gas makes curvilinear motion in the corrugated plates dehydration equipment. Some part of droplets moves along the original direction under the action of inertial force, they will be captured by the plate wall and form a layer of water film. These droplets will be separated from the gas flow finally. The other part of the droplets moves along with the gas flow trace and passes through the gas passage. These droplets will flow out from the gas passage eventually.

Based on the two-phase flow model, motion of the gas phase and the droplet phase are considered. Equation of motion for the gas flow field is solved in Euler coordinate system, and particle trajectory model is used to solve the motion of droplet phase in Lagrange coordinate system. Droplets are mainly affected by the following forces in the gas flow, such as viscous resistance, false mass force, pressure gradient force, lift force and gravity. Compared with the difference of each force, it is found that the droplets are mainly subjected by viscous resistance in the gas flow field.

As shown in Fig. 2, the computing grid model of the corrugated plates dehydration equipment was established by using FLUENT pre-processing software GAMBIT. The geometric parameters of the corrugated plates are as follows: the length of corrugated plate $l$ is 380 mm; the length of the collected hook $h$ is 50 mm; the angle of curved plate $\theta$ is 34º; and the distance between plates $d$ is 15 mm. For the corrugated plates with hooks, the unstructured mesh should be adopted because of its complex structure. In this unstructured grid, the number of elements and nodes is not fixed, and the location of nodes can’t be named in a fixed way. Although the unstructured grid is complex, it has great adaptability and can treat the boundary better. In order to improve the accuracy of calculation, the grid spacing is divided into 1mm, 0.55mm and 0.2mm. A total of 8680 grids are generated.

Experimental Principle

As shown in Fig. 1, Gas containing droplets passes through the curved passage consisting of continuous corrugated plates, the droplets will be separated from the gas because of inertia force. Some droplets are collected by the collected hooks at the turning point. The uncollected droplets flow
with the gas and are gradually collected at the subsequent turning point. The water will be dehydrated from the gas at last.

As shown in Fig. 3, Water in the tank 1 is pressurized and ejected from the nozzle 3. The water pressure and flow rate can be adjusted by the regulating valve 2. Droplet sizes of the nozzle under different water pressure were measured by a DP-02 laser particle size analyzer. The DP-02 laser particle size analyzer consists of generating laser 4, laser receiver 5 and computer 6. Before testing, the laser generator and receiver should be aligned so that the focus point of the generating laser is just on the center ring of the receiver. The center part of droplets from nozzle 3 should pass through the light path as far as possible because the spraying droplets from this are uniform and stable. A professional analysis software is installed on Computer 6 to get the droplets size test report.

![Figure 3. Measurement system of droplets’ diameter.](image)

**Results of Simulation and Experimental**

**Trajectory of Droplets in Corrugated Plates**

Fig. 4 shows the trajectory of droplets in dehydration units with collected hooks and without it. It is obvious that the collected hooks have great influence on the vortex of the gas flow field. From the two-phase flow theory, it can be considered that the droplets follow the motion of gas and the velocity is the same as it. When droplets enter the collected hooks area, on the one hand, the boundary layer separation phenomenon causes the formation of vortex, this will promote separation of droplets from the gas, but on the other hand, the resistance loss will increase. For the dehydration units without collected hooks, the inertia force of droplets is greater than that with hooks, but there is no vortex at the turning corner. The droplets will be brought out by the gas flow due to little change of motion direction, and its dehydration effect will significantly reduce.

![Droplets’ trajectory in dehydrator with collected hooks](image)

![Droplets’ trajectory in dehydrator without collected hooks](image)

**Figure 4. Motion trajectory of droplets in curved plate.**

**Influence of the Plate Spacing**

Fig. 5 shows the dehydration efficiency of corrugated plates under different plate spacing. The separator efficiency reaches the maximum when the plate spacing is 15 mm. and it reduces with the plate spacing when it is more than 15 mm. The reason is that the smaller plate spacing, the more vortices generated in the gas flow passage. And the droplets will have great probability to move to the plate wall. Meanwhile, When the plate spacing increases, the gas velocity at the gas passage will increase, the volume of entrainment droplets will increase too. A large number of droplets will not be
moved to the wall until they are directly taken out of the dehydrating units. Therefore, the distance between the plates should not be too large. The best plate spacing should be 15mm. As shown in Fig.5, With the same plate spacing, the dehydration efficiency of the corrugated plates with collected hook is obviously higher than that of without it. The reason is that the dehydration efficiency increases with the vortex generated by the collected hook. The adhesive force of water film on the plate wall will increase too, so the secondary entrainment of droplets can be effectively avoided.

![Figure 5. Dehydration efficiency at different plate spacing.](image)

Influence of the Droplets’ Diameter

The droplets’ average diameter of the nozzle used for the dehydration experiment is 10–270 μm. They were measured by a DP-02 laser particle size analyzer. It can be seen from Fig. 6(a), the dehydration efficiency increases with the droplets’ diameter at the beginning, but it decreases when the droplets’ size is more than 160 μm. The reason is that the large size droplets can maintain its original direction and speed of motion preferably because their motion are greatly influenced by inertia force. The larger droplet diameter is, the worse dripping property of droplets is. Therefore, larger droplets are easily separated from the gas flow. Nevertheless, When the larger droplets collide with the plate wall at a relatively high speed, they will spatter easily. These secondary droplets produced by splash will return to the gas. Finally, the dehydration efficiency is reduced. Therefore, when the average droplets’ diameter is 160 μm, the dehydration efficiency is the highest without considering the loss of resistance.

![Figure 6. Influence of the droplets’ diameter.](image)
Fig. 6(b) shows that the limit gas speed of droplets under different droplets diameter. The limit gas speed is that of the dehydration efficiency reaches the maximum. When the droplet size is 160 μm, the limit gas speed reaches 3.7 m/s. When increasing or decreasing the plates spacing, the limit gas speed will decrease. but its variation range is not large, so the effect of droplets’ diameter on the limit gas speed is not obvious.

**Influence of the Water Flow**

The spraying system of the dehydration test platform adopts a regulating valve to control its flow and pressure, and different spraying flow can be obtained by changing the types of nozzles in the spraying area before the corrugated plates. The gas moisture content at the inlet of the corrugated plates will changes with the water flow. The flow rate of the spray system was measured by a flowmeter, and the moisture content at the inlet of the corrugated plate was measured by gravimetric method. Table 1 shows the flow rate and inlet moisture content which were measured at different sets of tests. Fig. 7 shows the relationship between the dehydration efficiency affected by the change of cross section gas speed at different water flow. In Fig. 7, it can be seen that the dehydration efficiency increases with the water flow rate, but when the water flow rate is too large, the dehydration efficiency begins to decrease significantly, and the value is even less than 70% while it works at a high gas speed.

<table>
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<th>Test number</th>
<th>1#</th>
<th>2#</th>
<th>3#</th>
<th>4#</th>
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<td>0.74</td>
<td>0.89</td>
<td>1.70</td>
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<td>inlet moisture content/(g/m³)</td>
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<td>6.12</td>
<td>9.58</td>
<td>13.46</td>
</tr>
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The reason is that the water film on the wall of the corrugated plates dehydration device will thicken with the increase of water flow. The dehydration efficiency will be improved for the increase of droplets adhesion in a certain range of flow rate. However, when the water flow is too large, the water film is too thick to fall down normally. It is even possible to produce overlapping phenomena similar to “bridging”. A large number of secondary droplets will be formed and the dehydration efficiency will be reduced significantly when the droplets pass through the channel of the dehydration device at a high cross-section gas speed. Meanwhile, it could exceed the capacity of the curved plate dehydration unit because the processing capacity of the collected hook is limited when the water flow rate is too large. Therefore, the dehydration effect is the best when the water flow rate is 0.89 m³/h.

![Figure 7. Dehydration efficiency at different water flow.](image)

As shown in Fig. 9, the limit gas speed decreases with the increase of water flow. For the same type of dehydration device, as long as the liquid-gas ratio in the gas flow remains unchanged, the limit gas speed will doesn’t change. The shear force of the gas on the droplets is large and the liquid film will break into a large number of secondary droplets at the same time when the liquid-gas ratio is large.
The dehydration efficiency will decrease greatly for the formation of secondary droplets. So the limit gas speed becomes smaller simultaneously. Generally, the main factors affecting the limiting wind speed are not only plate spacing, droplets diameter and water flow, but also the shape, angle and width of the dehydration plate.

![Graph showing limited gas speed at different spraying quantity.](image)

**Conclusion**

Through the numerical simulation and experiment on the corrugated plates dehydration equipment, the effect of gas-liquid two-phase flow field on dehydration performance under different structures and operating parameters was investigated. Conclusions are drawn as follows: The distribution of gas flow field in the dehydration equipment with collected hooks and hook free are completely different. The plate with hooks is easier to realize the gas liquid separation after the droplets enter the collected hook. Reducing the plate spacing can effectively improve the separation efficiency of corrugated plates. The best plate spacing obtained by the experiment is 15 mm. The dehydration efficiency increases with the droplets diameter. When the droplet diameter is 160 μm, the maximum dehydration efficiency is 93%, and the limit gas speed is 3.7 m/s. The dehydration efficiency and the limiting gas speed are greatly affected by the water flow rate. When the water flow rate changes from 0.38 m³/h to 1.70 m³/h, the dehydration efficiency increases from 74.1% to 93.4%, and the limiting gas speed decreases from 3.7 m/s to 3 m/s.

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**References**


