NUMERICAL SIMULATION OF GAS-SOLID TWO PHASE FLOW IN BAGHOUSE DUST COLLECTORS WITH A LOW ENTRY

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The computational fluid dynamics (CFD) commercial software, FLUENT5.0, has been applied to predict the gas-solid two-phase flow in a baghouse dust collector and its ameliorated type. The mechanism lead to bag failure for the prototype was exposed. Numerical results show that the flow field is improved by means of using larger inlet pipe and arranging blunts in the hopper.

INTRODUCTION

Filter dust collector is widely used for high-efficiency separation of fine dusts from industrial gas streams. Baghouses, compared to cartridges, account for more than 80% of all filter dust collection systems in use today[1]. With more stringent pollution control requirements and the need of high value dust recovery, the proper design of baghouse is more critical than ever. Croom[2] and Moore et al.[1] suggested some fundamental guidelines on baghouse design, including the filter medium, dust recovery method, velocity through the equipment, optimum sizing, etc. Croom[3] reviewed some new developments in filter dust collection. Their studies, however, focus on the averaged characteristics and quite qualitative. Few work of the baghouse flow field has been published. The sizing and specifying of baghouse still greatly relies on experience and experimentation.

The present work devoted to predict the gas solid two-phase flow in a poorly designed baghouse dust collector using for lead oxide dust elimination in a kinescope factory, with the aid of commercial CFD software FLUENT5.0. Flow mechanism leading to bag failure was exposed. Design optimization was carried out further.

PHYSICAL MODEL AND NUMERICAL DETAILS

Simulation domain of the prototype baghouse

The upper section of the prototype baghouse is a cuboid of 4.57m long, 1.83m wide and 2.75m high. The hopper is 1.4m high, with a shrinking end of 3.7m long, 0.4 m wide. 180 suspended vertical filter bags are packed in 20 rows in the upper section. The filter bag is a 2.5m long cylinder with diameter of 0.16m. Inlet pipe is located at the narrow side of the hopper. A shutter is amounted to the end of the inlet pipe to direct the stream 45° downward. Fig.1 shows the simulation domain. Only half part of the baghouse was included for symmetry. Every two rows of filter bags in the domain are simplified into a cuboid of the same length. The cross section area of the cuboid equals the sum of the filter bags, which results in that the total area of longitudinal flow passages unchanged.

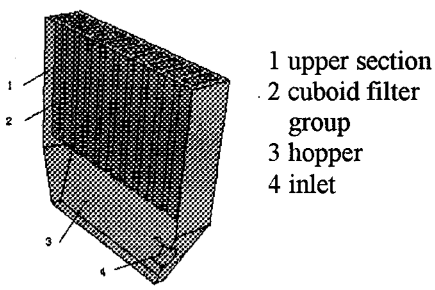


Fig. 1 Simulation domain of the prototype baghouse

Physical model

Gas phase flow were simulated using the $k-\varepsilon$ model[4], while particle trajectories were computed in a Lagrangian frame of reference. Two-way coupling was used to incorporate the effect of the discrete phase trajectories on the continuum. The inertia, drag force and gravity were considered in the particle motion equation, which is shown below,

$$\frac{du_{p,i}}{dt} = \frac{18\mu}{\rho_p d_p^{\ 2}} \frac{C_D \mathrm{Re}_p}{24}(u_i - u_{p,i}) + g_i(\rho_p - \rho)/\rho_p$$

The drag coefficient, C_D, was computed using the formula given by Morsi and Alexander[5]. Darcy's law was used to model the filter medium:

$$\Delta p = -\frac{\mu}{\alpha} v \cdot \Delta m \text{, or } v = -c \cdot \Delta p$$

where, v is the filtration velocity, c may be called apparent permeability which has been modified as follows to account for the difference of the filter area between the cuboid filter group and the real bags,

$$c' = \frac{A}{A'} \cdot c$$

where, c' is the real apparent permeability of filter media. Uniform velocity profile was imposed at the inlet. At the outlet, pressure (equal to zero) boundary condition was selected.

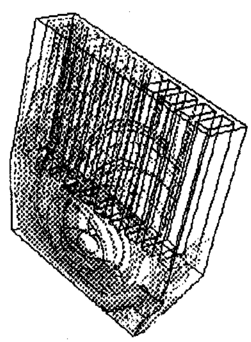
Numerical details

Discretization of the simulation domain was performed by using unstructured grid technique. The gas phase governing equations were solved by means of a control volume method. SIMPLEC algorithm was used to resolve the coupling between velocity and pressure. The second order upwind scheme was selected. For particle trajectory calculation, trajectory equation and particle motion equation were integrated by stepwise over discrete time steps.

RESULTS AND DISCUSSION

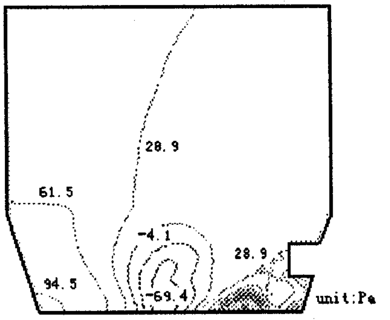
Flow characteristics in the prototype baghouse

The two-phase flow in the prototype baghouse was simulated under different inlet flowrates and filter media permeability. Fig.2 depicts fluid particle trajectories. Gas stream is injected into the hopper in the direction of 45° downward. Two vertexes are formed. The small one is below the inlet. The large one occupies nearly all the intermediate zone of the hopper, which repress the upward flow. Gas stream moves forward along the floor, turning upward to the rear bags at the far end. Then from the rear, the stream flows back to the front, with gas passing through the filter medium into the bags on the way.



Q_{inlet}=17660m^3/h, c'=2.69e-4m^{2}s/kg
Fig. 2 Trajectories of fluid particles in the prototype baghouse

The pressure contours in symmetry are plotted in fig.3. There are a high-pressure zone near the impact point and low-pressure zones around the center of vertexes. The pressure in the rear is higher, indicating higher filtration velocity for the rear bags.



Q_{inlet}=17660m^3/h, c'=2.69e-4m^{2}s/kg
Fig. 3 Velocity contours in symmetry of the prototype baghouse

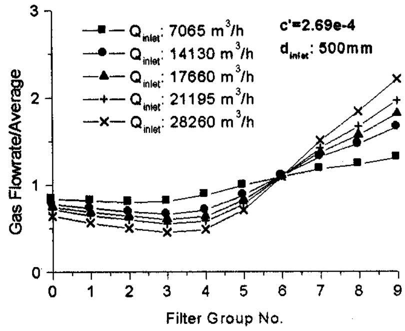
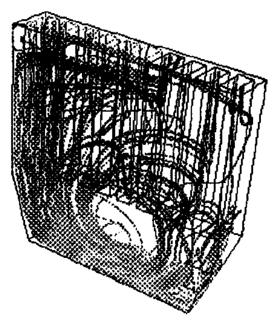


Fig. 4 Gas flowrate through each filter group of the prototype baghouse

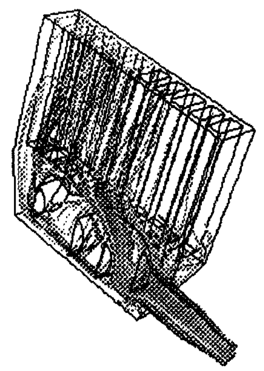
Fig.4 shows the non-dimensional gas flowrate through each cuboid filter group under different inlet flowrates, which reveal a minimum near the front (3#) and a maximum at the rear (9#). The nonuniformity of the flowrate distribution is more prominent for high inlet flowrate. The cause of the nonuniformity lies in the nonuniform pressure field.

Fig.5 depicts solid particle trajectories. It is quite similar to that of the fluid particle. There are fewer trajectories in the vertex center for the centrifugal effect. The quantity of particles accumulated on each filter group was also investigated. The intermittent filter groups catch more dusts.



Q_{inlet}=17660m^3/h
c'=2.69e-4m^{2}s/kg
Fig. 5 Trajectories of solid particles in the prototype baghouse

Flow characteristics in the improved baghouse



Q_{inlet}=17660m^3/h, c'=2.69e-4m^{2}s/kg
Fig. 6 Trajectories of fluid particles in the improved baghouse

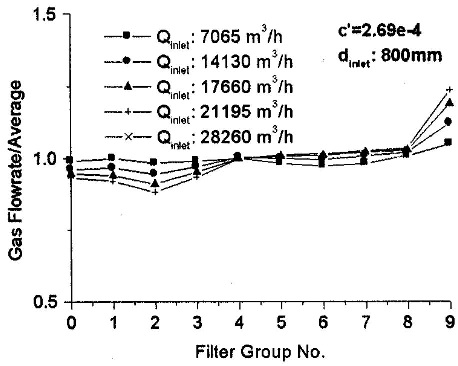


Fig. 7 Gas flowrate through each filter group of the improved baghouse

We proposed an improving scheme to ameliorate the baghouse flow field by using larger inlet pipe (its diameter increased from 0.5m to 0.8m) and arranging four blunts in the hopper. The two-phase flow in the improved baghouse under the same cases was simulated. Fig.6 shows the fluid particle trajectories. The recirculation flow with vertex in the prototype baghouse has been changed into a three streams pattern directed by the blunts. Parallel flow within the filter groups is formed. The numerical results also show a uniform pressure field in the upper section. Fig. 7 reveals the gas flowrate through each filter groups under different inlet flowrates. The uniformity of the flowrate distribution is greatly improved. The solid particle trajectories are similar with that of the fluid particle.

Comparison of the pressure loss through the baghouses

Fig. 8 compares the total pressure loss through baghouse between the improved and the prototype. The pressure loss is reduced by about 60% for the improved. It may be explained as that, owning to the elimination of vertexes, the turbulence dissipation is greatly decreased.

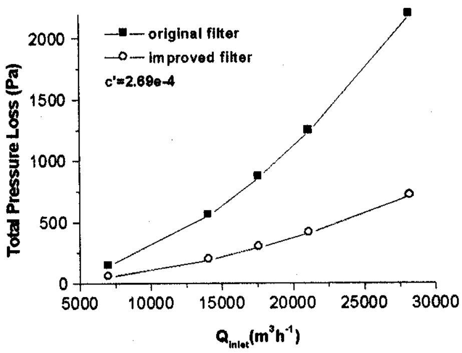


Fig. 8 Comparison of the total pressure loss through bag house between the improved and the prototype

Discussion

Filtration velocity, which is calculated by dividing the volumetric flowrate by the filter cloth area, is the starting point in baghouse design. Greater filtration velocity results in higher operating pressure dorp and increased energy costs. It would also cause more fine particles to penetrate the filter medium into bags. Can velocity is another vital factor. It is established as the velocity in flow passage between filters within the baghouse. If this is too high, the dust tends to remain in suspension within the system and only small portion of the bag is actually used for dust cake buildup. This condition places higher energy consumption on the system and reduces filtration efficiency. Croom[2] suggested the method to specify the limits of the two key factors.

The design of the prototype baghouse included two hypothesizes, one is that the filtration velocity is uniform between all the bags, the other is that uniform upward flow is formed within the bags. As the numerical results illustrated above, these two does not consist with the real condition. The filtration velocity for the rear filter group may exceeds 200% of the average. Cross flow is formed within the bags. It should be pointed out that the cross passage area is less than 1/4 of the parallel passage area. So at the rear, can velocity may exceeds the threshold by several times. Further more, rapid cross flow would cause bag vibration, which augment bag failure. In the overhaul of the prototype filter, it was found that the rear bag tends to be damaged at its root and large quantity of fine dust accumulation inside it occurs. The observation conforms to our analysis quite well. As to the improved baghouse, with uniform pressure field and parallel flow within the bags being formed, the filtration velocity and can velocity are balanced and reduced to an acceptable level.

CONCLUSION

The following conclusions were drawn from present investigation:

(1) A recirculation pattern with vertexes is formed in the prototype baghouse. The pressure field is nonuniform, resulting in higher filtration velocity for the rear

filter group. Gas stream flow through the cross passage within the bags from the rear to the front. The can velocity exceeds several times over its threshold at the rear. The too high filtration velocity and can velocity could augment bag failure, which were observed frequently in its overhaul.

(2) By using large inlet pipe and arranging blunts in the hopper, the recirculation flow in the original structure has been changed into a three streams pattern directed by blunts. The pressure field is quite uniform and the filtration velocity variation is within −10%~20%. Parallel flow within the filter groups is formed. In most area of the upper section, the can velocity is less than the threshold. The total pressure loss through the bag house is reduced by about 60%.

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