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Numerical Investigation of a Pulse-Jet Filter Cleaning System Performance

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ABSTRACT: In this study, numerical simulation of a pulse-jet filter cleaning system is conducted and its performance is investigated under pre-defined conditions. In the first step, 3D simulation of the system from a high pressure tank to the filter inlet is performed and the output is used as the input of second step. In the second step, simulation is performed for filters with inlet mass flow rates calculated from the previous step. To validate the model, the results are compared to experimental data showing acceptable agreement. The results show that regardless of the valve type, the cleaning pulse generates after 0.5 s and suddenly decreases afterward. No shock or choking is observed in the system. Another interesting result is the induced flow, generated after the nozzles, which increases the filter inlet mass flow rate. In addition, the axial distribution of the filter outlet flow is not uniform, degrading from inlet to outlet. Finally, a complete parametric study is performed to investigate the effect of the tank pressure on the pressure difference in the filter which is an important index in the cleaning performance analysis.

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1. Introduction

Pulse-jet cleaning is one of the most effective methods for separation of solid particles from a gas stream. In this system, the cleaning gas is supplied from a high-pressure tank, passing through some nozzles before entering into the inner part of the filters. The flow of the cleaning gas from inner to outer region of the filter, sheds the cake of the dust over the filter surface. Here, some of the numerical studies relevant to the subject, are reported. Kurose et al. [1] numerically investigated the pulse-jet cleaning of ceramic filters applicable in the high temperature and pressure. The numerical study was performed on the fluid stream flowing through a ceramic filter. Li et al. [2] numerically analyzed the pulse-jet cleaning of ceramic filters by applying boundary conditions on the nozzles inlet. Dang et al. [3] investigated the maximum pressure over the filter numerically, modeling the flow in one filter. Anderson et al. [4] studied a low-pressure pulse-jet cleaning system. They analyzed the effect of nozzle design on the system performance. S. Chen and D. R. Chen [5] numerically studied the cleaning gas flow inside one filter. The characteristics of the cleaning gas flow as well as the cleaning pulse were applied as the boundary conditions. Chen et al. [6] investigated the effect of filer pleat shape on the performance of a pulse-jet cleaning system. They observed the best performance with a trapezoidal pleat.

In this study, the transient compressible flow of a cleaning gas is numerically investigated in a pulse-jet cleaning system. Considering all the components of the system and also analyzing the effect of the tank pressure on the pressure difference of the filter, are the novelties of the present study.

2. Mathematical Modeling

In the present study, the high pressure nitrogen gas exists in a tank at a temperature and pressure of 45℃ and 1450 kPa, respectively. By opening the valve for a pre-defined period, the cleaning gas is discharged into the main tank (low-pressure tank) which holds the filters. The temperature and pressure of the dirty gas in the low-pressure tank are 150℃ and 470 kPa, respectively.

The governing equations including the continuity, momentum and energy are given in Eqs. (1)-(3).

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_i}\left(\rho u_i\right)=0 \tag{1}$$

$$\frac{\partial \rho u_i}{\partial t}+\frac{\partial}{\partial x_j}\left(\rho u_i u_j\right)+\frac{\partial p}{\partial x_i}=\frac{\partial}{\partial x_j}\left(\tau_{ij}+\tau_{ij}^R\right)+S_i \tag{2}$$

$$\begin{aligned}\frac{\partial \rho H}{\partial t}+\frac{\partial \rho u_i H}{\partial x_i}=\frac{\partial}{\partial x_i}\left(u_j\left(\tau_{ij}+\tau_{ij}^R\right)+q_i\right)+\frac{\partial p}{\partial t}\\ -\tau_{ij}^R\frac{\partial u_i}{\partial x_j}+\rho\varepsilon+S_i u_i+Q_H\end{aligned} \tag{3}$$

where, H is the stagnation enthalpy, S_i is a volumetric force, Q_H is a source/sink term, τ_{ij} is the shear stress tensor

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and q_i is the flux of heat diffusion in the fluid.

Two transport equations are also solved for the turbulence kinetic energy and dissipation of the turbulence energy (ε) as Eqs. (4) and (5).

$$\frac{\partial \rho k}{\partial t}+\frac{\partial}{\partial x_i}(\rho u_i k)=\frac{\partial}{\partial x_i}\left(\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right)+S_k\,; \qquad S_k=\tau_{ij}^R\frac{\partial u_i}{\partial x_j}-\rho\varepsilon+\mu_t P_B \tag{4}$$

$$\frac{\partial \rho \varepsilon}{\partial t}+\frac{\partial}{\partial x_i}(\rho u_i \varepsilon)=\frac{\partial}{\partial x_i}\left(\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_i}\right)+S_\varepsilon\,; \qquad S_\varepsilon=C_{\varepsilon 1}\frac{\varepsilon}{k}\left(f_1\tau_{ij}^R\frac{\partial u_i}{\partial x_j}+\mu_t C_B P_B\right)-C_{\varepsilon 2} f_2\frac{\rho\varepsilon^2}{k} \tag{5}$$

3. Numerical Method

All the components of the system including the high- and low-pressure tanks, connecting pipes, distributor, nozzles and filters are discretized by using structured and unstructured meshes as shown in Fig. 1.

The SIMPLE algorithm is used for the pressure-velocity coupling. The discretization of the pressure, density, momentum, energy and turbulence equations are second order. The calculations are performed by using a node of 16-core processor with a speed of 2.3 GHz and a 16 GB RAM. A relative residual of 10^{-6} was selected as the convergence criterion.

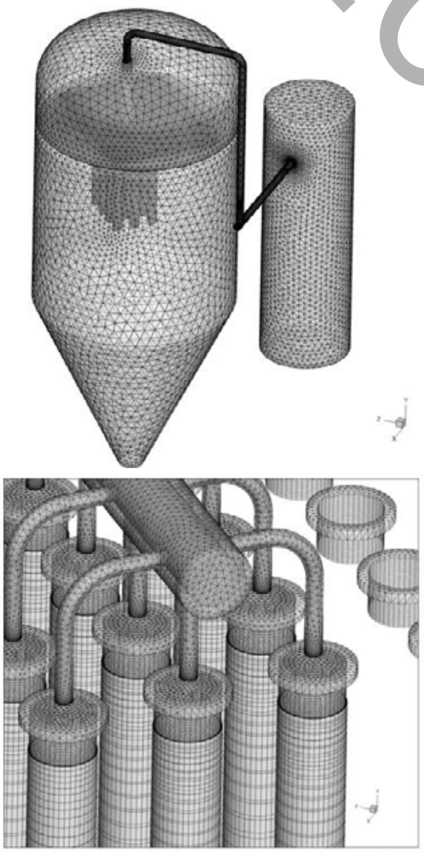

Fig. 1. The computational domain and the corresponding unstructured grid in different parts of the system

4. Results and Discussion

The experimental results of Anderson et al. [4] is used for the validation, showing excellent agreement with the results of the present study as shown in Fig. 2.

In Fig.3, the variations of the mass and temperature of the gas inside the high-pressure tank, are given. The interesting result of this figure is the slight oscillation of the mass and temperature at the discharge ending. The mass and temperature have reached their minimum value and then, enhanced and stabilized.

In Fig. 4, the temporal behavior of the mass flow rates at the inlets of two selected nozzles and the corresponding filters, are given. When the high-speed flow exits the nozzles, the Venturi effect is created and as a result of a static pressure drop, the stagnant gas round the filter inlet is sucked into it. This is the reason of higher inlet mass flow rate of in the filters with respect to the corresponding nozzles.

In Fig. 5, the radial velocity distributions along the filter length in the middle layer of filter at different times,

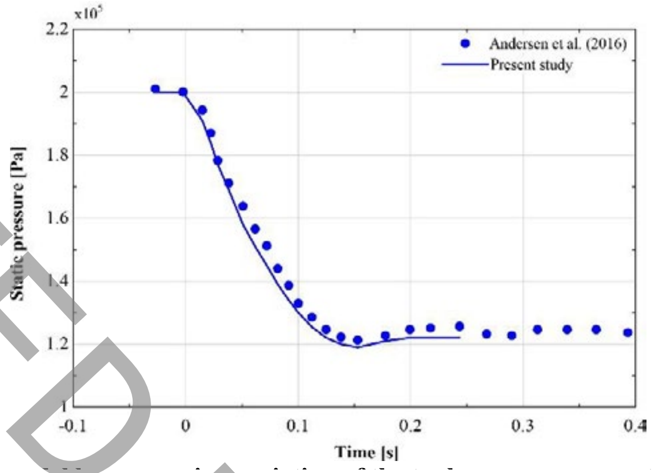

Fig. 2. Validation of the present model by comparing variation of the tank pressure versus time with the results of Andersen *et al.* [4]

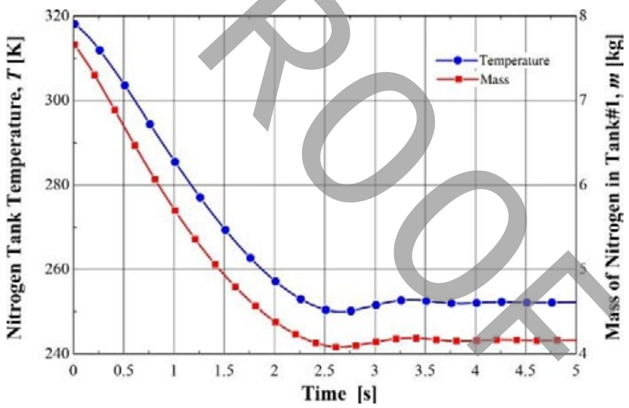

Fig. 3. Variation of the static temperature and mass of the remaining gas inside the tank versus time

are presented. The filter is a metal filter with porosity and permeability of 70% and 1.602×10^{-13} m^2, respectively.

In Fig. 6, the effect of pulse pressure on the pressure difference between inner and outer surface of the filter is investigated. By increasing the pressure of the high-pressure tank, the pressure difference is enhanced. In all cases, after a sudden rise in the pressure difference, it has remained nearly constant for a period of time. According to the experimental observations, the main cleaning occurs in this period.

5. Conclusion

In this study, a numerical investigation of a pulse-jet cleaning system was performed. The results revealed, after 0.5 s from the valve opening, the pulse pressure which is used for the cleaning is generated and then vanished rapidly. The distance between the nozzle and filter inlet, made a Venturi effect which enhanced the mass flow rate flowing into the filter by sucking the stagnant gas around the inlet. In addition, analysis of the distribution of the radial velocity along the filter, revealed that the distribution is not uniform. It seems that the on/off time of the valve, nozzle outlet and filter inlet positions, pressure difference between the tanks and the geometry of the filters have considerable effects on the performance of the system, and must be considered in the parameter selections.

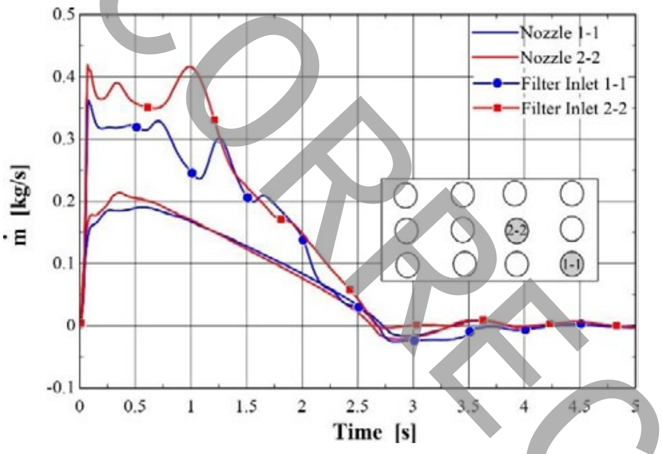

Fig. 4. Variation of the mass flow rates of nozzles and inlet sections above the filters 1-1 and 2-2

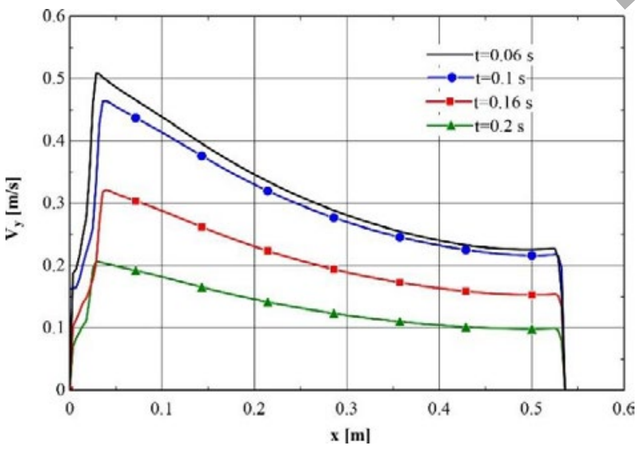

Fig. 5. Radial velocity distribution along the filter length in the middle layer of filter at different times

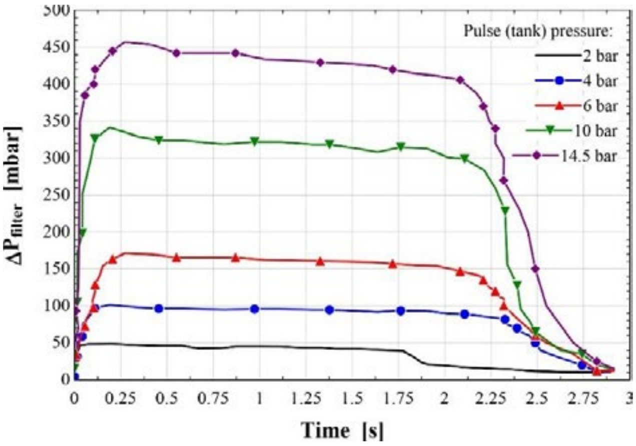

Fig. 6. A parametric analysis of effect of tank pressure on the pressure drop in the filter

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