Multiple Orifice Technique for Pressure Drop in Compressible Pipe Flows

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1. Introduction
Flow through devices such as an orifice, nozzle, venturi, diffuser and bend has been of great interest to designers of flow systems. These devices are often used to change pressure, velocity or direction of fluid flow, and therefore could be regarded as flow control devices. The orifice as a flow control device is of practical importance as it is simple to design and manufacture and is also cost effective. Orifice has a device, which is better understood as an instrument for measurement of flow rates in a flow system. There have been systematic investigations of the effects of Reynolds number, heat transfer and geometry on the effectiveness (discharge coefficient) of orifice for flow measurements. However, the effect of compressibility on orifice effectiveness is not fully understood. There is no knowledge based on the use of orifice as a control device in compressible flow systems.

The objective of this work is to investigate the effectiveness of an orifice in producing pressure drops and the effect of compressibility on the pressure drop by CFD approach.

2. CFD Analysis
Computations using the mass-averaged implicit Navier-Stokes equations were applied to the axisymmetric pipe flows operating at a moderate pressure ratio. The governing equations were discretized in space using a finite volume differencing formulation. The standard k-ε turbulence model was employed to close the governing equations. Numerical calculations were carried out for some combinations of the multiple orifice configurations.

Figure 1 shows the entire computational domain of the double orifice flow field. The pipe has a diameter of 2R. The flow direction is from left towards right of the pipe. The domain extends about 4R back from the first orifice, which has an opening area of πr₁²(A₁), and about 10R downstream away from the second orifice which has an opening area of πr₂²(A₂). The heights of the two orifices were changed to make different values of A₂/A₁. The interval (l) between orifices was changed in range of l=0.5R to 4.0R, but the pipe length (L) downstream of the second orifice was kept constant for all the present computations.

The static pressure (Pₛ) at the exit of pipe was kept constant 101.3 kPa and the air temperature at the inlet was kept 300 K. Adiabatic, no slip wall and symmetry conditions were assumed on the pipe walls and the axis of the pipe, respectively. The total pressure (Pₜₚ) at the inlet of the pipe was changed to give different values of Pₜₚ/Pₛ, which will be used as the operating pressure ratio.

3. Results and Discussion
From the relationship between the orifice interval and the total pressure drop across the orifice system, it was found that the total pressure drop did not depend on the orifice intervals and was much smaller compared with higher pressure ratio. In this case, the total pressure drop would be caused by the viscous dissipations which largely generate between the orifices.

For the effect of the orifice area ratio on the total pressure drop in double orifice pipe flow, the total pressure drop showed a peak value at A₂/A₁=1.0 and then had a minimum value at A₂/A₁=2.0 before increasing with a further increase in the orifice area ratio. For the double orifice system to reduce the pressure level of an exhaust gas, it was desirable to use the high orifice area ratio above 2.5. From both the data of Pₜₚ/Pₛ = 8.0 and 20.0, the total pressure drop characteristics was nearly the same. This implies that the present CFD data could be used for the operating pressure ratios higher than those applied to the present study.

Figure 2 represents the relationship between the total pressure drop and the operating pressure ratio. The orifice interval and the orifice area ratio are constant by 2.5 and 1.0 respectively. The total pressure drop rapidly increases when the operating pressure ratio increases from 1.5 to 4.0, but there is no remarkable difference with the number of orifice applied. The total pressure drop remains nearly constant for the further increase in the operating pressure ratio.

The triple orifice system leads to a little larger pressure drops, compared with the single and double orifice systems. The total pressure drops for Pₜₚ/Pₛ >4.0 are more than two times those for Pₜₚ/Pₛ =1.5. The present CFD data show that the orifice systems, which have been applied to incompressible flow regime to date, can not be used for the high operating pressure ratio flows. Compressibility effect is the main reason for this difference.

4. Concluding Remarks
Numerical calculations were carried out for some combinations of the multiple orifice configurations. As a result, the orifice interval did not strongly affect the total pressure drop, but the orifice area ratio more than 2.5 led to higher pressure drops, when compared with the orifice area ratios below 2.5. The total pressure drop rapidly increased in the range of the operating pressure ratio from 1.5 to 4.0, but it did not depend on the operating pressure ratio.