Pressure drop in valve for different open flow areas

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Abstract. In any piping system different types of regulating components (valves) are used. To determine the pressure drop of the liquid in these components, it is necessary to know the exact values of the local loss coefficients, which depend on their design and manufacturer. The calculations of local loss coefficients of the valves are usually carried out according to engineering methods using design handbooks. However, the large design diversity of the valves does not allow an accurate assessment of the local loss coefficient for a particular product (using handbooks). There are two ways to solve this problem. The first way is experimental determination; the second is calculation using CFD modelling. This article presents the results of CFD simulation of the pressure drop of liquid through valves and a comparison with experimental data obtained from the thermal hydraulic test bench.

1. Introduction

At the Institute of Nuclear Physics and Engineering of the National Research Nuclear University MEPhI, a two-circuit thermal hydraulic stand (TGS) has been designed for the study of transient heat transfer processes. Primary objectives of installing TGS:

- collecting and storing of experimental data on hydrodynamic characteristics of single and two-phase flow;
- study of heat transfer in transient modes (from convective single-phase flow to under-developed boiling and from under-developed to developed boiling mode) in the working volume with mimics of fuel elements with forced and natural circulation of the coolant;
- development of systems for diagnosing and predicting transient heat transfer modes;
- creating a database for verification of prevailing thermal-hydraulic calculation codes;
- use for educational purposes.

An important component of the TGS is the valves, which are used to regulate the flow rate of the coolant in the TGS. In the stand, valves HEISSKRAFT (internal diameter 63 mm) are used. It is worth noting that the coefficient of local loss of the valve makes a significant contribution to the overall pressure drop of the TGS. During operation of TGS, valve can be at different open flow areas, while assessing the coefficient of local loss using engineering method gives significant error. For this reason, CFD simulations of the coolant flow in the valve at different open flow areas and comparison with experimental data were performed. Calculations were carried out with the help of CFD package STAR-CCM+ using different turbulence models: k-ε, k-ω SST and RSM.

2. Simulations

Figure 1 shows the three-dimensional mesh of the valve. Surface mesh generator with automatic surface correction to form a surface mesh and "polyhedral" volume mesh were used in STAR CCM+. The numerical solution of the Navier-Stokes equation, the laws of conservation of energy and mass is done considering "coupled flow". In the calculation, the density of water was considered constant at a 25°C. Regarding the boundary conditions: at the inlet of the valve, mass flow rate G was set and the outlet was set as atmospheric pressure.

Figure 2 presents the results of calculations of the velocity vector field in the longitudinal section of the valve at a flow rate of 0.875 kg/s (Re = 24000) using the k-ε turbulence model. The figure shows that stagnant areas are formed in the upper and lower parts of the valve with the appearance of characteristic vortices.

Figure 1. Volume mesh of the valve.

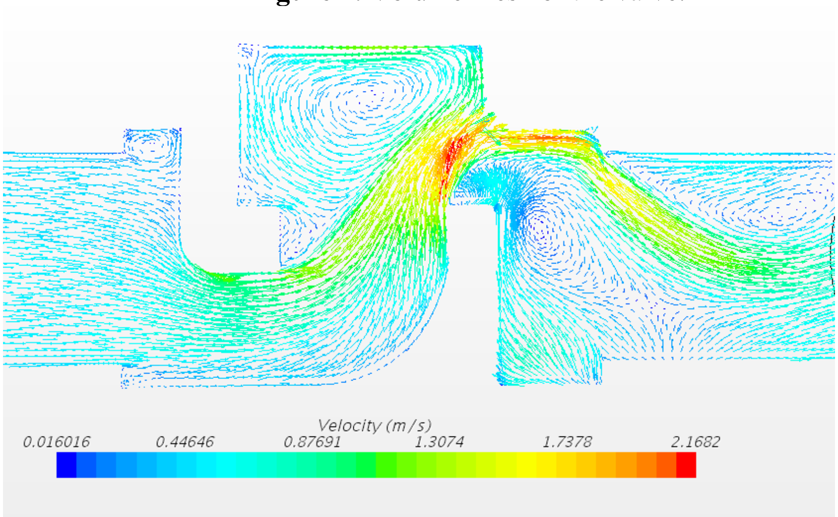

Figure 2. Results of calculations of the velocity vectors in the longitudinal section of the valve at a flow rate of 0.875 kg/s.

Similar calculations to determine the pressure drops were carried out for three flow rates (G = 0.875; 1.16; 1.54 kg/s). According to the results of calculations using the k-ε model, it was found that the coefficients of local loss do not depend on the flow rate, and its average value is $\xi \approx 19$. Figure 3 shows the dependence of the local loss coefficients with the valve opening. It is interesting to note that in the case of a half-open valve, the local loss coefficient is slightly less than in the case of a fully open valve. This is probably due to the design features of the valve. Similar calculations were performed for the half-open valve using k-ω SST and RSM turbulence models. The results of calculations for different models are shown in figure 4.

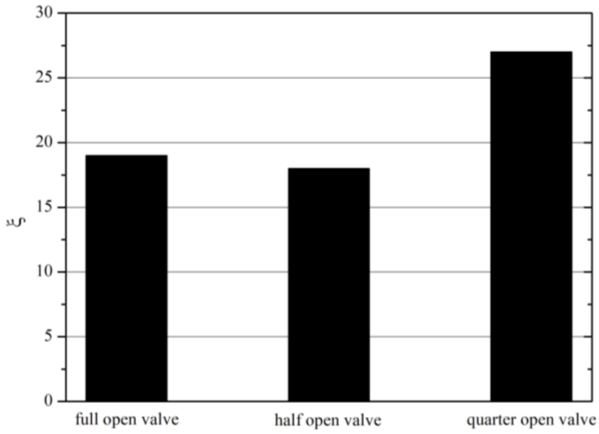

Figure 3. Values of the local loss coefficients at different valve opening using the k-ε turbulence model.

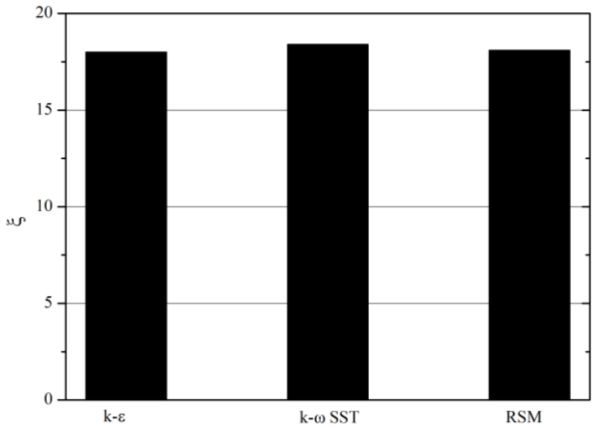

Figure 4. The results of the calculations of local loss coefficients of the half-open valve for different turbulence models.

As can be seen from figure 4, the calculations for different models give approximately the same local loss coefficients. Experiments on TGS were carried out to verify the obtained calculation results. In the experiments, the pressure drop between the precision pressure gauges P3 and P1 (figure 5) with an accuracy of ±1% (in the measuring range) was measured on the bench section. The coolant flow rate was determined with the help of ultrasonic flow meters of the same accuracy (not shown in figure 5). Figure 6 presents a comparison of the results of calculations for the k-ε model with experimental data.

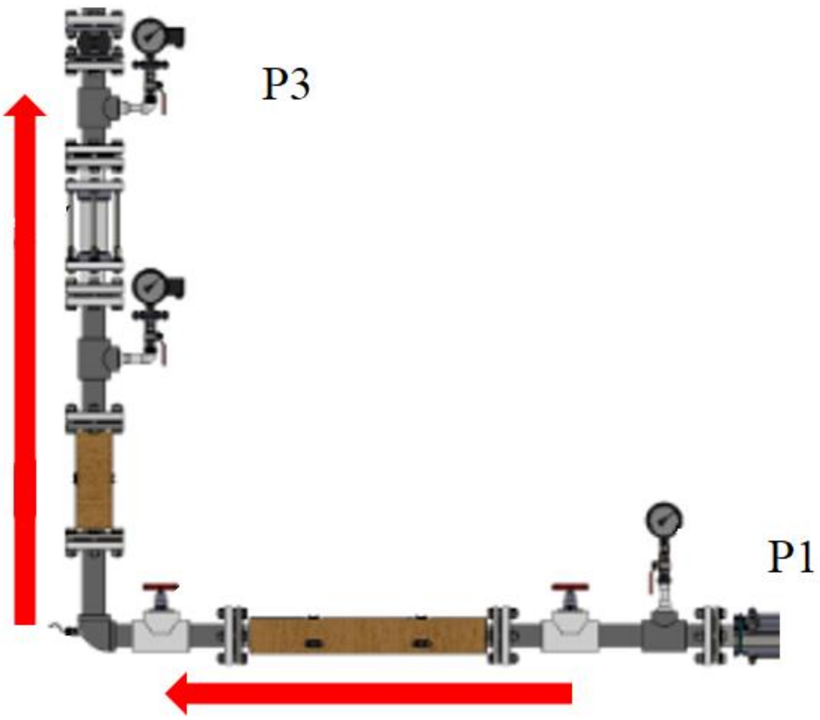

Figure 5. Part of the TGS corresponding to the experimental determination of pressure drop.

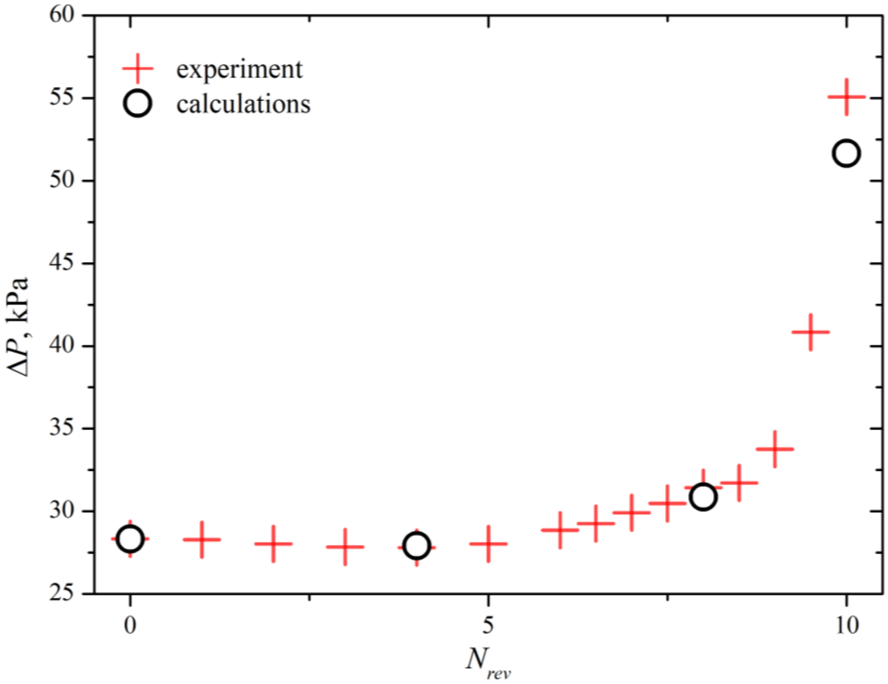

Figure 6. The dependence of the differential pressure P1-P3 with the number of revolutions of the handwheel of the valve: experimental data (circles) and calculation results (crosses).

As can be seen from the figure, the pressure drop in the hydrodynamic section of the TGS remains almost constant until the valve is half closed. In addition, the results of the calculations are in excellent agreement with the experimental data.

3. Conclusion

The results of CFD modelling are in good agreement with the experimental data. From the comparison of calculations and the experimental data, it is established that the valves used in TGS have much higher coefficients of local loss, than calculated with the engineering design handbooks [1, 2]. In addition, the simulation showed that with the decrease in the flow passage down to half of the maximum, coefficient of local loss remains almost constant. This circumstance, apparently, is connected with its design features. Comparison of calculations carried out using different models of turbulence showed that the most optimal for the calculation of the local loss of the globe valve is k-ε turbulence model. The results of calculations for the k-ε model differ slightly from those for the k - ω SST and RSM turbulence models. The advantage of k-ε model in comparison with other considered models is a high rate of convergence and low sensitivity to the initial approximation, which saves computing power.

References

[1] D.C. Rennels, H M. Hudson 2012 *Pipe flow: a practical and comprehensive guide* John Wiley & Sons

[2] I.E. Idelchik 1992 *Handbook of hydraulic resistances. Coefficients of local resistance and of friction* Mashinostroenie (in Russian)