CFD BASED STUDY AND OPTIMIZATION OF MANIFOLD SYSTEMS

Dr. A. P. Senthil Kumar[1], N. Jagadeesh[2], Dr. S. Janaki[3]

[1]*Assistant Professor, Department of Mechanical Engineering, PSG College of Technology, Coimbatore- 641004. Tamil Nadu, INDIA.*
[2]*Research Scholar, Department of Mechanical Engineering, PSG College of Technology, Coimbatore-641004. Tamil Nadu, INDIA.*
[3]*Professor, Department of Mechanical Engineering, Akshaya College of Engineering and Technology, Coimbatore-641109. Tamil Nadu, INDIA.*

---***---

Abstract*:- Flows in manifolds are of great importance in quite diverse fields of science and technology, including IC engines, fuel cells, sprayers, solar collectors, micro channels, porous infiltration and irrigation etc. Theory of flow distribution and pressure drop is crucial to predict process performance and efficiency of manifold systems. The performances of the manifold systems are greatly depending on how the fluid gets evenly split by the manifold to the lateral ports. This study deals with the design and optimization of manifold systems for even flow split in lateral ports. A CFD based optimization technique is carried out for the process of optimization and study.*

Key Words**—Manifold systems, Optimization, NLPQL, Adaptive Single Objective.**

1. INTRODUCTION

The flow in manifold systems is extensively encountered in many industrial processes including IC engines, chemical [1–3], biomedical [4, 5], mechanical [6–8] and civil and environmental engineering [9–11]. The uniformity of the flow distribution in manifold system often determines efficiency, durability and cost of the units. There are two common structures of manifolds used for flow distributions: consecutive [1–11] and bifurcation [12, 13].

A fractal bifurcation structure assumes that the fluid behaves tree-like where the channels at the last level have the smallest length and diameter, in the bifurcation structure the reaction channels are usually the longest. The bifurcation structure is usually a good design in the lack of channel dimensional variations. It is the only one where flow distribution does not change for different flow rates at high Re. However, the equi-partition is greatly depending on manufacturing tolerance and port blockage. Furthermore, when a large number of ports, a large pressure drop is likely due to turning loss and it is also more complex to design and fabricate. Therefore, it is inappropriate for those cases where additional pressure losses become important.

A consecutive manifold consists of multiple ports with constant cross-sectional area. In a consecutive manifold the main fluid stream entrances a manifold and branches continuously along the manifold. This kind of manifolds is the most commonly used flow distributors due to their clear advantages of simplicity and less pressure drop over bifurcation structures. This means the greatest potential to reduce development and manufacturing cost and accelerate design and manufacturing cycle. However, using a consecutive manifold, a key question which arises in the design of such units is a possibility of the severe flow mal distribution problems. Some ports may be starved of fluids, while others may have them in excess, which reduces system performance and efficiency. It is a key to predict the performance and efficiency of various manifold configurations so that high efficiency and cost reduction can be achieved through an optimal geometrical structure. This paper discuss on how much does design of manifold affects the flow distribution and optimization manifold system for even flow split. There are three approaches to study pressure drop and flow distribution in a manifold: computational fluid dynamics (CFD) [14], discrete models [7] and analytical models [2].

Analytical model is also called the continuous model in which flow is considered to be continuously branched along a manifold. It has been shown intuitively, as well as mathematically, that the continuous manifolds are limiting cases of the discrete manifolds [2]. In mathematical viewpoint, the fluid mechanical principles in a continuous manifold lead to a differential rather than a difference equation in a discrete one. Furthermore, an explicit analytical solution can directly be converted to one solution of discrete systems. For these reasons, the continuous models are also fundamentals of different discrete models. The basic problem with discrete model is without the knowledge of flow coefficients, pressure recovery and other factors it is difficult to go with analytical method.

Discrete model is also called network model. In a discrete model, a manifold is represented as a network of multiple junctions traversed by the fluid flow. Then, mass and momentum conservation equations can be build at each junction. Finally, a set of difference equations is solved by means of an iteration program. Because of its relatively simplicity this approach has been used by many researchers.

The CFD is a detailed approach in which modelling has potential to resolve real-world 3-D engineering structures. The pressure drop and flow distribution can be predicted using this approach without the knowledge of flow coefficients, such as the friction and pressure recovery coefficients. Hence CFD approach is most accurate approach when comparing all the three approaches.

2. MANIFOLD DESIGN STUDY

Several manifold studies has been carried out to find how the design of manifold systems affects the flow distribution in manifold systems.

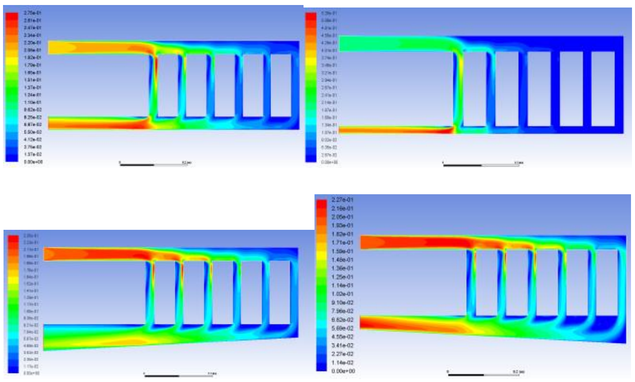

Fig-1: Velocity contour of different of manifold geometry

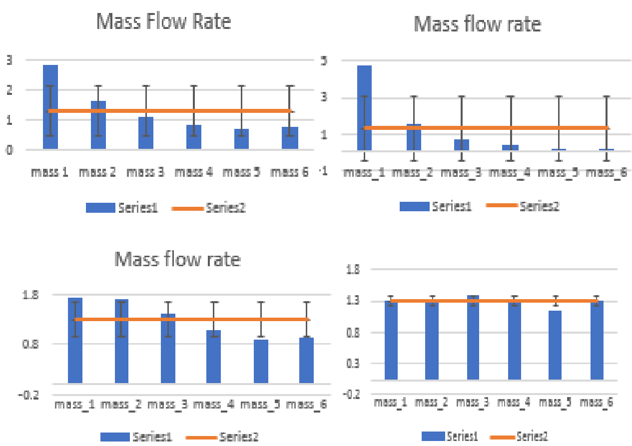

Fig-2: Mass flow split for different manifold modification

The results shows that the flow distribution is greatly affected by the design of the manifold systems by finding the right dimensions of the manifold system we can able to get the flow distribution of even flow split using optimization.

3. OPTIMIZATION

The optimization process of NLPQL-nonlinear programming by quadratic lagrangian method is used for the process of optimization, four variables are selected as design variables im_1, im_2, om_1, om_2 all has a baseline value of 40 mm.

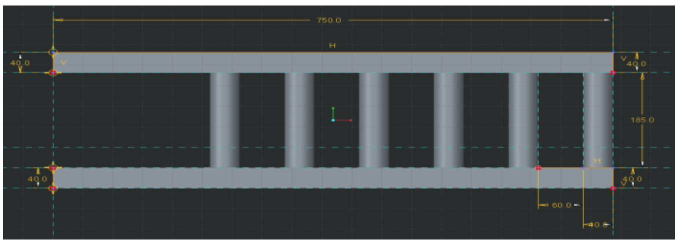

Fig-3: Baseline CAD geometry of manifold system.

Before optimization the CFD study of baseline design is done for the boundary conditions of inlet mass flow rate 0.32 kg/s and outlet pressure of 0 Pa.

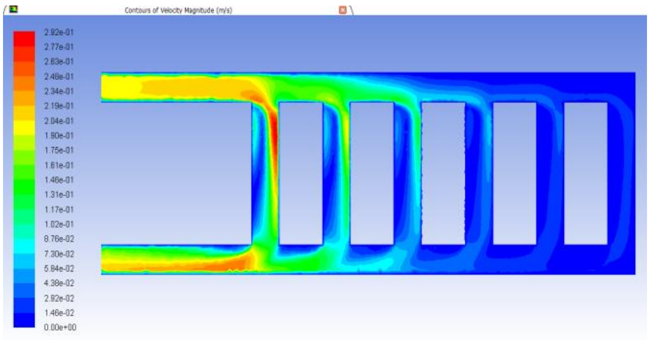

Fig-4: Baseline velocity contour

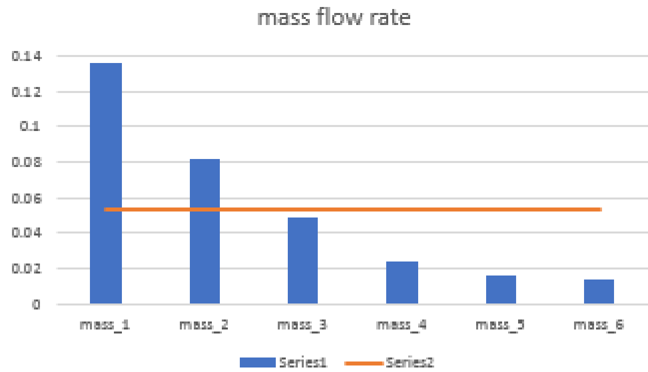

Fig-5: Baseline mass flow split in (Kg/s).

The result shows that the mass flow split of the baseline design is bad and has higher misdistribution. To optimize the manifold design to get even flow split a parameter is considered as an objective function which could be a measure of misdistribution in lateral ports, Standard deviation of the mass flow split is considered as a output parameter for optimization, lower the standard deviation more uniform the flow. The standard deviation of mass flow split for the baseline design is 0.048.

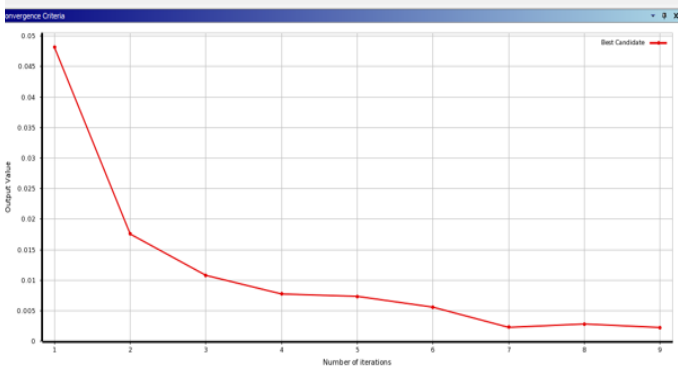

Fig-6: Optimization objective function history

The above figure shows that optimization iteration history of output variable in our case the standard deviation of the mass flow split.

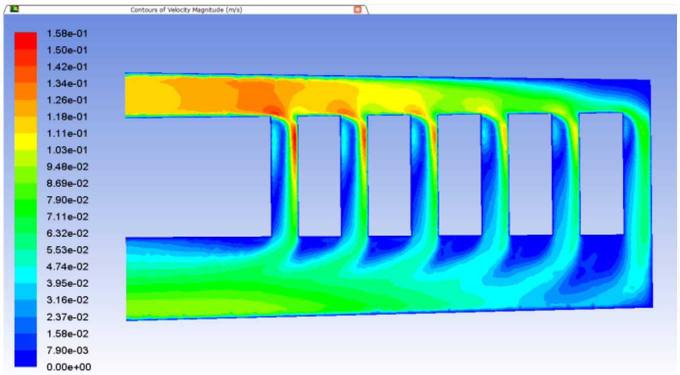

Fig-7: Velocity contour of optimum design.

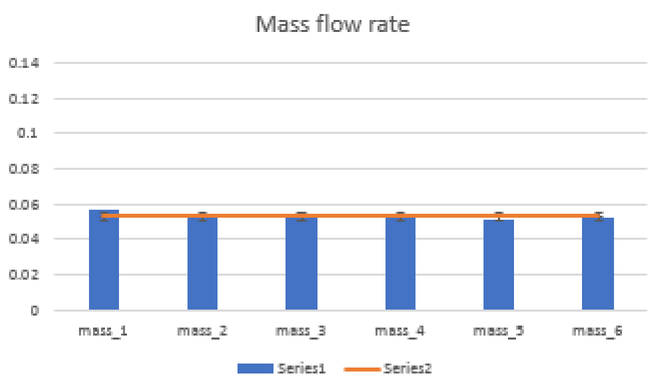

Fig-8: Mass flow split of optimum design.

From the optimized result it can be clearly seen that the flow misdistribution is greatly reduced. The optimized design has a standard deviation of 0.0022. The optimization algorithm came up with the optimized dimensions of 71.3mm, 50.4mm, 130mm, and 111.5 mm for im_1, im_2, om_1 and om_2 respectively. The result clearly shows that the flow misdistribution can be completely controlled by the design of manifold even without affecting the dimensions of port.

4. CONCLUSION

From the study it can be clearly observed that the flow distribution is greatly affected by the design of manifold. By finding the right dimensions of the manifold the flow misdistribution can be eliminated completely. The optimization process is carried out in a sophisticated automated way of connecting different tools together. CFD is a time consuming and computationally expensive process using it for optimization multiplies its time consumption and computational expensiveness. Further study in the advancement of optimization using CFD models has to be done to do optimization in a smarted way such that minimum number of CFD evaluation is required for optimizing the design so that computational expensiveness and time consumption for optimization can be reduced.

REFERENCES

[1] R.L. Pigford, M. Ashraf, Y.D. Mlron, Flow distribution in piping manifolds, Ind. Eng. Chem. Fundam. 22 (1983) 463 471.

[2] J.Y. Wang, Z.L. Gao, G.H. Gan, D.D. Wu, Analytical solution of flow coefficients for a uniformly distributed porous channel, Chem. Eng. J., 84 (1) 1–6.

[3] N.S. Hanspal, A.N. Waghode, V. Nassehi, R.J. Wakeman, Development of a predictive mathematical model for coupled stokes/Darcy flows in cross-flow membrane filtration, Chem. Eng. J. 149 (2009) 132–142.

[4] F. Kamisli, Laminar flow of a non-Newtonian fluid in channels with wall suction or injection, Int. J. Eng. Sci. 44 (2006) 650–661.

[5] F. Kamisli, Second law analysis of a disturbedflowin a thin slit with wall suction and injection, Int. J. Heat Mass transfer. 51 (2008) 3985–4001.

[6] R.A. Bajura, Amodel for flow distribution in manifolds, J. Eng. Power 98 (1971) 654–665.

[7] Z.Q. Miao, T.M. Xu, Single phase flow characteristics in the headers and connecting tube of parallel tube platen systems, Appl. Thermal Eng. 26 (2006) 396–402.

[8] J.Y. Wang, G.H. Priestman, D.D. Wu, A theoretical analysis of uniform flow distribution for the admission of high energy fluids to steam surface condenser, J Eng. Gas Turbine Power 123 (2) (2001) 472–475.

[9] H.T. Chou, H.C. Lei, Outflow uniformity along a continuous manifold, J. Hydraulic Eng. 134 (9) (2008) 1383 1388.

[10] A.A. Anwar, Friction crorrection factors for center pivots, J Irrig. Drain. Eng. 125 (5) (1999) 280–286.

[11] A.A. Anwar, Adjusted factor Ga for pipelines with multiple outlets and outflow, J Irrig. Drain. Eng. 125 (6) (1999) 355–359.

[12] C. Amador, A. Gavriilidis, P. Angeli, Flow distribution in different micro reactor scale-out geometries and the effect of manufacturing tolerances and channel blockage, Chem. Eng. J. 101 (2004) 379–390.

[13] H. Liu, P.W. Li, J.V. Lew, CFD study onflow distribution uniformity in fuel distributors having multiple structural bifurcations of flow channels, Int. J. Hydrogen Energy 35 (2010) 9186–9198.

[14] M. Heggemann, S. Hirschberg, L. Spiegel, C. Bachmann, CFD simulation and experimental validation of fluid flow in liquid distributors, Trans IChemE, Part A, Chem. Eng. Res. Design 85 (A1) (2007) 59–64.

[15] O. Tonomura, S. Tanaka, M. Noda, M. Kano, S. Hasebe, I. Hashimoto, CFD-based optimal design of manifold in plate fin micro devices, Chem. Eng. J. 101 (2004) 397–402.