DYNAFLOW
RESEARCH
GROUP.

CFD Analysis of the Header of a Finger-Type Slug Catcher

Frank M. Bos, Hans J. Bos

Abstract

The flow in the header of a finger-type slug catcher is analysed using CFD techniques. In order to design a high performance finger-type slug catcher, it is necessary that the fluid flow in the inlet header manifold is evenly distributed among the different fingers. Dynaflow performed a detailed flow analysis by means of Computational Fluid Dynamics using the proven OpenFOAM® code. Different configurations are defined and compared using the time-averaged mass flow at the finger inlets. The proposed configuration, using a variable pipe diameter, leads to a large misdistribution in time-averaged mass flow. A constant and increased pipe diameter was found to promote the mass flow balance. Additionally, by applying an extra split in the main header pipe, the equal flow distribution is significantly increased.

1. Introduction

The function of a (finger-type) slug catcher is the separation of gas and liquid under a variety of two-phase process conditions. The inflow conditions may range from steady stratified two-phase flow to highly unsteady slug flow where the slug catcher must be able to absorb sustained in-flow of large liquid volumes at irregular intervals.

The slug catcher receives a mixture of production gas and liquid condensate from the main pipeline into the slug catcher inlet header. In order to promote stratified flow in the fingers, the relatively high average flow velocity in the main pipeline needs to be reduced as much as possible in the slug catcher. This is achieved by increasing the total available cross-sectional area from the inlet cross-section to the combined cross-sectional area of all fingers. Figure 1 reflects the proposed configuration, where the area increment is done in two steps by means of an intermediate inlet manifold. The incoming two-phase mixture is distributed while flowing downwards through the downcomers over the different fingers. In the fingers, gravity acts as the driving force for liquid gas separation.

For optimal efficiency it is very important that the mass flow distribution along the finger pipes, see figure 1, is equally distributed. Analytically, this is the case. However, the flow through the manifold is unsteady, turbulent and subjected to viscous effects, like boundary and shear layers. It is important to assess the flow in the header manifold in detail, such that design modifications may be made, leading to a more uniform mass flow distribution along the fingers and down comers. Dynaflow successfully performed a detailed CFD analysis in order to understand the flow in the manifold and address some design modifications.

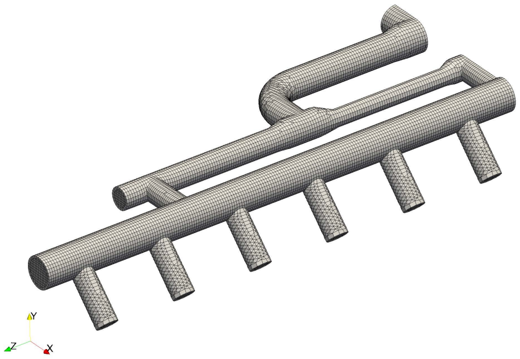

Figure 1: Computational mesh of the proposed configuration of the inlet header manifold.

2. Problem and Methods

The incompressuble, turbulent flow in the inlet header manifold is governed by the Navier-Stokes equations (Ferziger & Peric, 2002), given by:

$$\nabla \cdot \mathbf{u} = \mathbf{0}, \qquad (1)$$

and

$$\frac{\partial \mathbf{u}}{\partial t} + \nabla \cdot (\mathbf{u}\mathbf{u}) = -\frac{\nabla p}{\rho} + \nu \nabla^2 \mathbf{u}. \qquad (2)$$

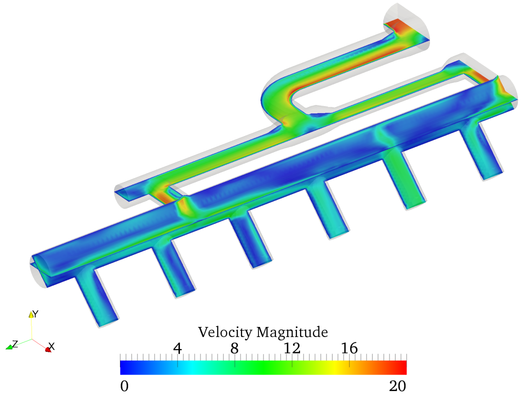

Figure 2: Velocity contours for the proposed header manifold configuration.

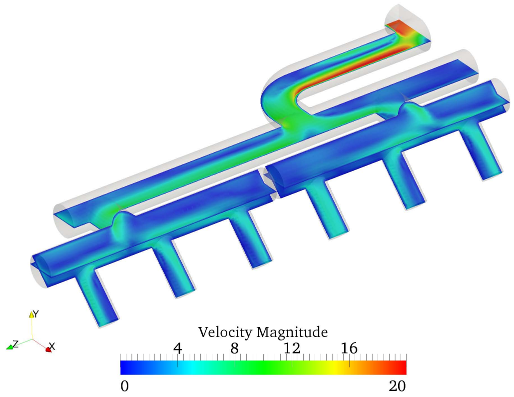

Figure 3: Velocity contours for the final modified header manifold configuration.

In order to solve the Navier-Stokes equations, a computational mesh is generated. Figure 1 shows the computational mesh, containing polyhedral cells, for the proposed design with variable pipe diameter. A symmetry plane is used through the middle of the header. In order to solve the Navier-Stokes equations, boundary conditions need to be specified for the inlet, the symmetry plane and the finger outlet boundaries.

At the inlet, the flow velocity is specified, while the gradient of the pressure is set to zero. Furthermore, at the symmetry plane, the flow velocity perpendicular to this plane is set to zero, no flow is possible through this plane. Additionally, the relative pressure at the outlet boundaries is set to zero, such that the flow velocity will be calculated accordingly. The time-averaged mass flow at the finger outlets is calculated by a multiplication of the gas density and the volume flux through these boundaries. The used mesh resolution was 50000 finite volume cells. The flow is solved using the open-source framework OpenFOAM®, which has been used extensively in industry (Jasak, 2009; Jasak & Tuković, 2004; Jasak et al., 2004; Weller et al., 1998).

In order to study the mass flow distribution along fingers, we considered a worst case with the largest gas flow velocity. The values used are U=18.7 m/s and ρ=15.331 kg/ m^3 for the inlet velocity and the reference density. This results in a mass flow of about 216 kg/s, which need to be distributed along 12 fingers. Therefore, in the ideal situation, a uniform distribution of the mass flow at the finger outlets of about 18 kg/s is obtained.

3. Results and Discussion

The variable pipe diameter causes accelerations in the flow, such that a large velocity variation occurs in the main header pipe. This is shown, using velocity contours, in figure 2. Different design modifications were studied in order to find a configuration with low velocities and equally distributed mass flow for the finger outlet boundaries. The final design configuration is shown in figure 3, which is characterised by an increase in pipe diameter in combination with an additional split in the main header pipe. It is shown that the velocities are lower and evenly distributed. Additionally, figure 4 shows the time-averaged mass flow at the finger inlet boundaries. The time-averaged mass flow varies around 18 kg/s with a deviation of 2 kg/s, which is considered to be a large improvement compared to the initial configuration. It should be noted that in all cases the erosion velocity occurs, especially in the first pipe before the bend. Therefore, material reinforcements may be necessary at these regions. The extra split in the main header pipe results in a more uniform distribution of velocity and mass flow accordingly. So, significant improvement is already made by applying an extra split in the main header pipe. Additional gain can be obtained by optimising the outer inlet pipe, towards

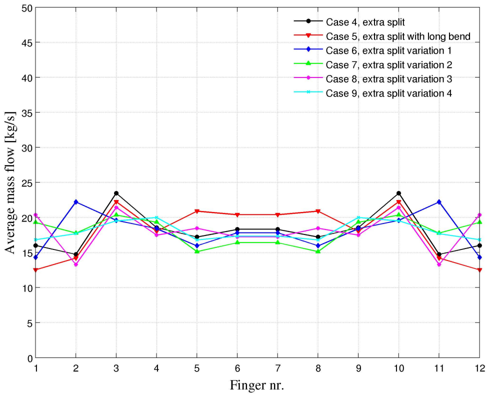

Figure 4: Time-averaged mass flow at the finger outlet boundaries.

the main header pipe.

4. Conclusions

Dynaflow successfully performed a CFD analysis of the inlet header manifold of the finger-type slug catcher using the open-source framework OpenFOAM®. The gas flow is solved for different configurations based on the initial design, which uses variable sizes of the piping. The mass flow at the finger inlets is highly misdistributed in the original design configuration. Almost backflow occurs at certain fingers. A design modification where the inlet header manifold has an increased and constant diameter improves the mass flow distribution significantly. The mass flow distibution in the inlet header manifold is further improved by applying a split in the main header pipe.

5. Bibliography

Ferziger, J. H. & Peric, M. (2002), *Computational Methods for Fluid Dynamics*, third edn, Springer-Verlag Berlin.

Jasak, H. (2009), Dynamic mesh handling in openfoam, *in* '47th AIAA Aerospace Sciences Meeting, Orlando', 2009-341.

Jasak, H. & Tuković, Z. (2004), 'Automatic mesh motion for the unstructured finite volume method', *Elsevier Science (submitted)*.

Jasak, H., Weller, H. G. & Nordin, N. (2004), 'In-cylinder CFD simulation using a c++ object-oriented toolkit', *SAE Technical paper 2004-01-0110*.

Weller, H. G., Tabor, G., Jasak, H. & Fureby, C. (1998), 'A tensorial approach to computational continuum mechanics using object-oriented techniques', *Computers in Physics*.