CFD ANALYSIS OF NON-NEWTONIAN FLUID PROCESSING PUMP

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June 26-30, 2016
11th OpenFOAM Workshop, Guimarães, Portugal

Keywords: *non-Newtonian fluids, Turbomachinery, Pumps, Moving mesh*

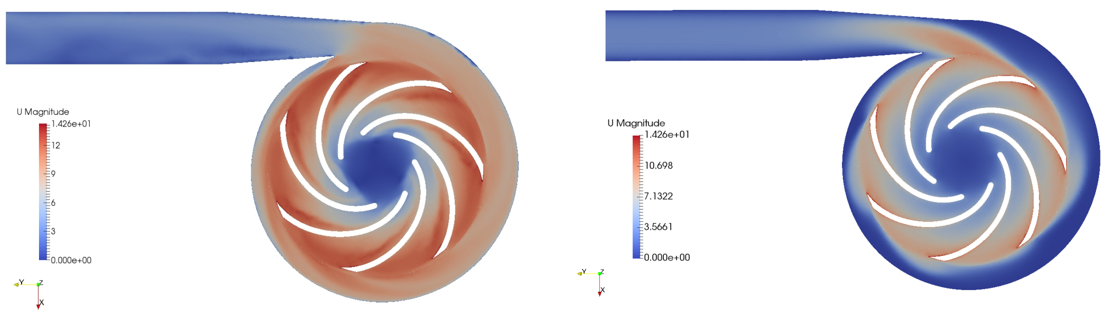
In this work the 3-D simulation of impeller and volute of a centrifugal pump is presented. The impeller involved in this work is semi-open. The main advantage of this kind of machines, as suggested by [1], is the efficiency which can be considered constant thanks to the clearance adjustment. In addition this kind of impeller is less likely to clog with solid bodies (important in case of slurry-processing). The open impeller has all the parts visible, so it is easier to inspect for wear and damages. Eventually it is lighter than a shrouded impeller and thus it can spin faster. The stress due to centrifugal force is indeed a limit for the speed of these machines.
The simulations have been carried out using OpenFOAM (v. 3.0.0). The numerical results in case of water operating pump have been compared to the experimental data and to the ones obtained with ANSYS-CFX, in order to evaluate the accuracy of the two software. The comparison have been made in the best efficiency point (i.e. volumetric flow rate of $1.09l/s$). The differences in the results obtained from a full unsteady simulation with moving mesh and a steady-state simulation with frozen rotor model are pointed out, showing a difference in the head of about 10% at the BEP.
Furthermore the performance variation in case of non-Newtonian fluids processing is presented. It is known that the performance of a centrifugal pump drops processing a viscous fluid [3]. Even so the behaviour during the pumping of non-Newtonian fluids has not been investigated so far. The differences in terms of overall performance are shown.
The non-Newtonian fluid has been modelled according to power law model as suggested by [2]. In that work the same model was used: the rheological analysis of the tomato paste produced in the plant was performed by the manufacturer of the pump. This model is available among the non-Newtonian ones implemented in OpenFOAM, and its formulation is:

$$\nu = k\dot{\gamma}^{n-1} \tag{1}$$

Where: ν represents the kinematic viscosity, τ_y is the yeld stress, k is the consistency index, $\dot{\gamma}$ is the shear strain rate and n is the viscosity index
The results of the rheological analysis, show good agreement with the power law model if the consistency index k is equal to $0.1764m^2/s$, considering a density for the tomato paste of $\rho = 1100kg/m^3$, and the viscosity index n is 0.326. Since the power Law model presents a singularity for zero shear strain rate and the apparent viscosity tends to zero for high value of the shear strain rate (tomato paste is a shear thinning fluid), is common practice to bound the values the viscosity can assume. The following rule is usually implemented:

$$\nu = \begin{cases} k\dot{\gamma}_{min}^{n-1} & \text{if} \quad \dot{\gamma} < \dot{\gamma_{min}} \\ k\dot{\gamma}^{n-1} & \text{if} \quad \dot{\gamma_{min}} < \dot{\gamma} < \dot{\gamma_{max}} \\ k\dot{\gamma}_{max}^{n-1} & \text{if} \quad \dot{\gamma} > \dot{\gamma_{max}} \end{cases}$$

In this case, as suggested by [2], the limits of $\dot{\gamma}_{min} = 10^{-4}s^{-1}$ and $\dot{\gamma}_{max} = 10^{7}s^{-1}$ are set. These limits provide the conditions of $\nu_{max} = 87.635m^2/s$ and $\nu_{min} = 3.378 \cdot 10^{-6}m^2/s$ respectively.
Both the performance in case of water (Newtonian fluid) and tomato paste (non-Newtonian fluid) are presented.
Since the viscosity of the tomato paste varies in a wide range, an a priori decision of whether the flow is laminar or not is not allowed. It is not possible to predict the machine Reynolds number for this application. For this reason a sensitivity analysis to the turbulence model have been carried out. The y^+ varies in a wide range, so a k-Omega SST model combined with a scalable wall function for the eddy viscosity has been used.
The post-processing of the result shows a viscosity ratio ν_t/ν maximum of 0.01. It is common practice for external flows to assume a flow to be turbulent if the eddy viscosity ratio is greater than 0.1. The results of this simulation show that the



(a) Newtonian fluid **(b) non-Newtonian fluid**

Figure 1: Midspan contour of absolute velocity

same threshold can be assumed for internal flows. If the pump operates with tomato paste, the flow is laminar since the eddy viscosity ratio is well below the assumed threshold. The pump characteristic when operating tomato paste has been obtained, comparing the results obtained in case of either laminar flow or turbulent flow with k-omega SST model.

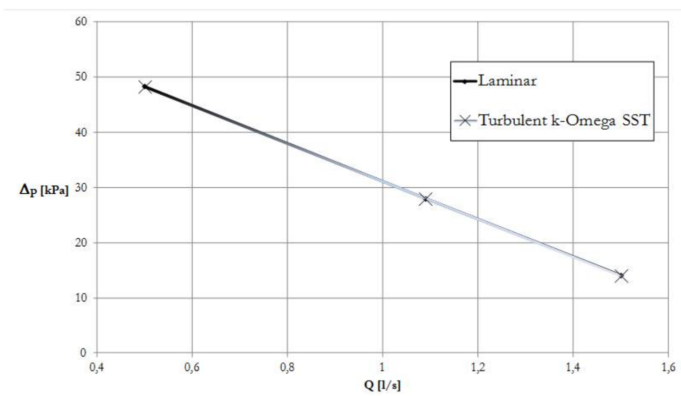


Figure 2: Characteristic curve comparison: laminar and k-Omega SST

Furthermore, the problems of the semi open impeller are investigated. If compared to a shrouded pump it has a lower efficiency due to the heavier tip leakage: the different behaviour of this critical detail depending on the nature of the processed fluid is shown.

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