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Experimental and Numerical Analysis of a Non-Newtonian Fluids Processing Pump

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Abstract

Centrifugal pumps are used in many applications in which non-Newtonian fluids are involved: food processing industry, pharmaceutical and oil/gas applications. In addition to pressure and temperature, the viscosity of a non-Newtonian fluid depends on the shear rate and usually is several orders of magnitude higher than water. High values of viscosity cause a derating of pump performance with respect to water. Nowadays, pumping and mixing non-Newtonian fluids is a matter of increasing interest, but there is still lack of a detailed analysis of the fluid-dynamic phenomena occurring within these machines. A specific design process should take into account these effects in order to define the proper pump geometry, able to operate with non-Newtonian fluids with specific characteristics. Only few approaches are available for correcting the pump performance based on the Hydraulic Institute method.

In this work, an experimental and numerical campaign is presented for a semi–open impeller centrifugal pump elaborating non-Newtonian fluids. An on-purpose test bench was built and used to investigate the influence on pump performance of three different non-Newtonian fluids. Each pump performance test was accompanied by the rheological characterization of the fluid, in order to detect modifications of the rheological phenomena and allow a proper Computation Fluid Dynamics (CFD) modeling. The performance of the machine handling both Newtonian and non-Newtonian fluids are highlighted in relation with the internal flow field.

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Keywords: centrifugal pump, semi-open impeller, non-Newtonian fluids, pseudoplastic, CFD

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Introduction

Non-Newtonian fluids are characterized by a non-linear relation between shear stress and shear rate and, for time independent non-Newtonian fluids the apparent viscosity, defined as the ratio between the shear stress and shear rate values, depends on the local shear rate value [1]. For this reason, Non-Newtonian fluids are able to exhibit values of apparent viscosity higher than those of water viscosity. Therefore, when centrifugal pumps are used with non-Newtonian fluids their efficiency, head and shaft power are altered. The knowledge of non-Newtonian fluid effects on the pump performance is fundamental in the design process as well as in the pump choice (manufacturers provide pump performance curve obtained with water as operating fluid). In literature, there is a lack of experimental data about centrifugal pumps handling non-Newtonian fluids, and even less about numerical simulations of centrifugal pumps which process non-Newtonian fluids. Experimental tests of centrifugal pumps handling non-Newtonian fluids are reported for example in [2 – 9].

Some authors have proposed methods for estimating the performance of centrifugal pumps with non-Newtonian fluids [2, 3, 7]. These methods asses a representative value of viscosity of non-Newtonian fluids to be used in the Hydraulic Institute Method, which is specific for predicting the performance of pumps handling Newtonian fluids having a viscosity higher than water. Recently, CFD has been used to evaluate the performance of centrifugal pumps with non-Newtonian fluids but the number of applications is limited. In [10] an analysis of the performance and flow structures of two open impeller centrifugal pumps, operating with tomato paste (non-Newtonian), water and many Newtonian fluids is carried out. Other two relevant works are reported in [11], in which the internal flow of an open impeller pump is analyzed by using different volutes, and in [12] which presents a study on the laminar/turbulent transition inside an open impeller pump. In [13] the flow characteristics within a shrouded centrifugal impeller were investigated highlighting the different phenomena occurring with water and with non-Newtonian fluids. In [14] a comparison between the performance of two pumps operating with non-Newtonian fluids was obtained by means of CFD simulations and by applying the estimation methods reported in literature. In this case, the performance of the pumps with non-Newtonian fluids, calculated by numerical simulations, are not compared with experimental data.

In this paper, the results of experimental tests, conducted with non-Newtonian fluids on a small centrifugal pump [14, 15], will be presented to highlight the differences in performance with respect to the data obtained with water. The rheological behavior of non-Newtonian fluids was experimentally analysed by means of a rotational rheometer. Subsequently, CFD simulations were performed with the same fluids used throughout the experiments, with the aim of evaluating the differences between experimental and numerical results.

Pump description

The experimental tests have been carried out on an electric motor driven centrifugal pump of small size characterized by specific speed n_{sQ} equal to 18 rpm·m$^{3/4}$/s$^{1/2}$, and designed to work at 2900 rpm. The electric motor has a nominal power of 0.37 kW. The pump is characterized by a semi-open type impeller with a diameter of 95.5 mm with seven blades. The pump was designed for operating with dirty water (industry or agriculture applications). The maximum diameter of the solid bodies is equal to 4 mm. Figure 1 shows the pump volute and impeller.

Experimental test rig

The experimental test rig allows an accurate measurement of the mass flow processed by the pump through to

Nomenclature

H	Head [m]	k	Consistency index [Pa·s^n]
η	Efficiency [%]	n	Viscosity index [ ]
Q	Volumetric flow rate [l/min]	$\dot{\gamma}$	Shear rate [s^{-1}]
n_{sQ}	Kinematic specific speed [rpm·m$^{3/4}$/s$^{1/2}$]	ϑ	Tangential coordinate [°]
ρ	Density [kg/m^3]	Vu	Tangential component of absolute velocity [m/s]
T	Temperature [°C]		