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Effects of non-Newtonian fluid on centrifugal blood pump performance ☆

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Abstract

A 2:1 scaled-up model of the Kyoto-NTN magnetically suspended impeller centrifugal blood pump developed by Kyoto University, Japan, is tested using aqueous Xanthan gum solution and water as working fluids, respectively. It is found that the pump head rise with the solution is lower than that with water at same flow rate when the pump operates at low rotor speeds; at high rotor speeds, however, the pump will generate a higher head for the solution than for water at the same flow rate, and a maximum difference of 7% is detected. Data comparison indicates that water does not accurately model the head vs. flow rate characteristics of the prototype pump, and aqueous Xanthan gum solution of 600 ppm produced results best simulating the performance of the prototype pump.

Keywords: Centrifugal blood pump; Aqueous Xanthan gum solution; Rheological property; Pump performance; Similarity law

1. Introduction

Blood pump is a ventricular assist device (VAD) [1], which can entirely or partly replace the pump-action of natural heart. It plays an important role in the treatment of cardiovascular disease, and can significantly improve survival rate and the quality of life of patients with severe congestive heart failure.

To develop a blood pump with excellent hydrodynamics and biocompatibility, the flow pattern within the impeller passages and the clearance gap between the impeller and the volute of the pump should be examined carefully, and the test of a model pump is a must in the entire process of development. However, its characteristics, such as celerity clot and opacity, prevent blood from being used in the pump test with large volume [2–5], blood substitute fluids have to be sought for the test instead.

Most of the researchers use Newtonian fluids such as water, a mixture of water and glycerin, and even air in their tests for convenience [6–8]. It is questionable whether the pump performance of Newtonian fluid is consistent with the performance of human blood, which is a non-Newtonian shear-thinning fluid.

Even though available data of non-Newtonian fluid test in blood pumps are rare, they do show that the effects of non-Newtonian fluid on the pump performance are remarkable. Mann et al. [9] measured the fluid dynamics behavior of a Newtonian water/glycerol solution, a non-Newtonian polymer (Separan) solution and bovine blood in an Electrical Ventricular Assist Device (EVAD) using a pulsed Doppler ultrasound velocimetry, and the results showed that water/glycerol solution does not accurately model the flow characteristics of bovine blood, and the non-Newtonian Separan solution produced results closer to those of bovine blood than did the water/glycerol solution. Akamatsu et al. [10,11] tested the Kyoto-NTN magnetically suspended impeller centrifugal blood pump (MSCBP), and found that the pump generates a slightly higher pressure head with bovine blood and sheep blood than that with a mixture of water and glycerin. Miklosovic [5] tested an enlarged centrifugal blood pump model but with aqueous Xanthan gum solutions, and found that the non-Newtonian fluid yielded pump performance deficits of first-order importance, or up to 11% of the Newtonian performance. The result of Miklosovic seems to be contradictory to that of Akamatsu et al. Whether non-Newtonian fluids improve or deteriorate the pump performance needs to be further investigated.

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Nomenclature

b	impeller vane width (m)
D	outside diameter of the impeller (m)
H	head pressure (Pa)
N	impeller rotary speed (rpm)
Q	flow rate (m^3/s)
r	radius of impeller (m)
ρ	density (kg/m^3)
η	apparent viscosity (Pa.s)
ω	angular velocity of impeller (rad/s)
τ	shear stress (Pa)
$\dot{\gamma}$	shear rate (s^{-1})
Re	Reynolds Numbers ($=\rho\omega \cdot D^2/\eta$)
ψ	dimensionless head ($=H/(\rho r^2\omega^2)$)
Φ	dimensionless flow rate ($=Q/(2\pi r^2 b\omega)$)

Other choices of blood substitutes for pump tests are possible, such as aqueous Carboxymethylcellulose solution [12] and aqueous Polyacrylamide solution [9], etc., but the ideal one seems to be aqueous Xanthan gums solutions [3,4], since Xanthan gum is resistant to degradation, non-toxic and inexpensive, and produces nearly transparent solution.

In the present study a 2:1 scaled-up model of the Kyoto-NTN MSCBP [10,11] developed by Kyoto University, Japan, is built, and the hydrodynamic characteristics and scaling law of the model pump are investigated using aqueous Xanthan gum solution as working fluid with a wide range of pump rotary speeds and solution concentration. A special attention is focused on the effect on the pump performance of non-Newtonian fluid property and pump operating conditions.

2. Pump configurations and test rig

A schematic diagram of the model pump is given in Fig. 1. The pump has a double volute casing comprised of two circular arc-shaped enclosures surrounding an impeller with an inlet and discharge pipe diameters of 24 mm and 32 mm, respectively. The impeller is sandwiched between the volutes and allowed to rotate freely without rubbing the inner surfaces of the volutes. The impeller has an inner and outer diameter of 26 mm and 50 mm, respectively, and is formed by sandwiching the seven vanes with a uniform height of 7 mm between the upper and lower shrouds. The blade profiles and the lower shroud of the impeller are machined from a solid brass block, and a Perspex upper shroud is mounted onto the lower shroud using screws. The impeller is then mounted onto a shaft, which is driven by a servo-motor unit and the rotary speed of the model pump ranges from 100 rpm to 800 rpm with an accuracy of ±0.5%.

The model pump is tested in a closed loop circuit which consists of a fluid reservoir, two throttle clamps, and an electromagnetic flow meter. The head developed by the pump is derived from the difference between the inlet and outlet pressures of the pump measured using a capacity type differential pressure transducer, DP 1151, with a measuring range of 0 to 250 mm Hg and an accuracy of 0.04% of full scale.

The fluid mediums used at the present investigation are water and aqueous Xanthan gum solutions. The Xanthan gum solutions are made by mixing powder of a food-grade Xanthan gum (Zibo Zhongxuan Biologic Joint-Stock Company, Shandong, China) and tap water, and the concentration of the solutions are 400 ppm,

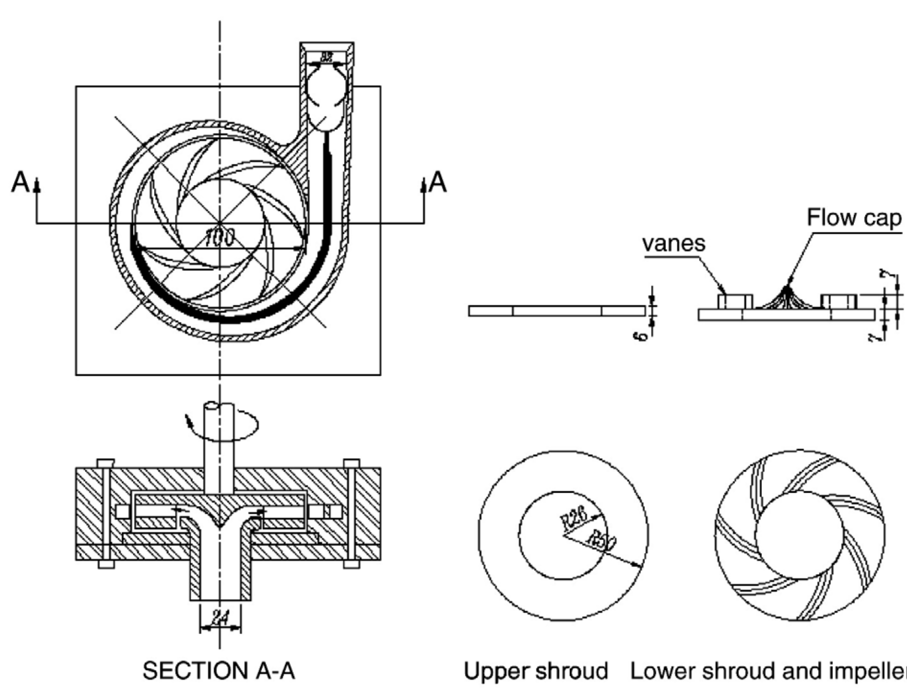

Fig. 1. A schematic diagram of the model pump and impeller.