Experimental Studies on Flow Characteristics of Peristaltic Pump

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Abstract

There is significance to understanding flow characteristics of a peristaltic pump for optimum design and usage. In this work, several studies of flow characteristics have been investigated by implementing an adjustable experimental rig for a peristaltic pumping purpose. For pulsating fluid transport in a tube, the inner diameter of a flexible tube d = 1.2 cm was held constant through all the experiments. Each experiment was set by different parameters of the peristaltic pump, which are composed of radius of rotation r = 4, 5.5, 7, 8.5 cm, number of rollers N = 3, 4, 6 and sweeping angle λ = 120, 180, 240, 300 degree. The corresponding flow characteristics in the volume flow rate and the pressure rise across the peristaltic pump were measured for such conditions in real applications. It is concluded that the radius of rotation has the most influence on the flow characteristics of a peristaltic pump, whereas the number of rollers and the sweeping angle are not impact factors on flow characteristics.

Keywords: peristaltic pump, flow characteristics, pump design

1. Introduction

In fluid mechanics, a pump is an essential device used to transport liquids from lower pressure to higher pressure, and overcomes this difference in pressure by adding energy to the system. A peristaltic pump is one of the most conventionally used pumps. Functionally, the fluid is contained within a flexible tube fitted inside a circular pump casing. The flexible tube is compressed at a number of points in contact with the rollers, which are driven by a rotor with different speeds. The fluid is forced to move through the flexible tube with each rotation of the rotor.

Nowadays, a peristaltic pump is designed for various applications requiring dependability and volume pumping such as pharmaceutical, food, chemical and wastewater applications. For example, in advanced MicroElectroMechanical Systems MEMS technology, an embedded PZT actuated peristaltic micro-pump is a part of an implantable medical drug delivery system [1]. For a large size peristaltic pump, the diameter of rotation can be greater than the height of an operator [2].

For reliability of optimum engineering design, understanding flow characteristics of the pumps is significant. The design directions can be based on available knowledge and experience gained from experiments. The flow characteristics of pumps have been known in literature but are focused on some of the most widely used commercial and industrial pumps such as centrifugal pumps [3]. Unfortunately, there is rare published information on flow characteristics of a peristaltic pump since it is probably limited to low pressure-rise applications.

In this work, structural factors of the peristaltic pump such as pump size (diameter), number of rollers and sweeping angle of rotation are to be investigated experimentally on how these effect the flow characteristics.

2. Experimental setup

The experimental rig as shown in Fig. 1 was constructed in such a way that the parameterization of the peristaltic pump can be adjusted. That is, the radius of the rotor can be varied from 4 cm to 8.5 cm, the number of rollers can be changed to 3, 4, and 6. The sweeping angle of the peristaltic pump can be changed from 60 degrees to 300 degrees. The diameter of the flexible tube made of silicone is 1.2 cm. The rotor of the peristaltic pump was driven by a servo DC motor through a gear transmission at various speeds. The assembly in details is illustrated in Fig. 2. The upper part and lower part are the peristaltic pump and the DC servo motor, respectively. A volumetric method of flow measurement was implemented for this study since the flow rate was quite stable. It simply consists of measuring how long a pump, operating at steady state, takes to fill a known volume in a vessel. The measured volume, divided by the time, equals the average pump flow rate. In this experiment, the differential pressure across the peristaltic pump was measured by a U-tube manometer, which used water.

3. Theoretical approach on flow characteristic flow of peristaltic pump

In this section, a mathematical model for a steady uniform flow in and out of a control volume through the flexible tube of the peristaltic pump is to be derived as follows. Let's consider the flow of fluid through the flexible tube as one-dimensional frictionless flow. The properties are assumed to have bulk average values over the cross section. Without leakage between two adjacent rollers, average velocity of fluid is assumed to be equal to the speed of the rollers. The volume flow rate is given by:

$$Q = Av \tag{1}$$

where Q is the flow rate of fluid, A is cross-sectional area normal to flow direction and v is average fluid velocity normal to A.
The cross-sectional area and the diameter of the flexible tube are related by:

$$A = \frac{\pi d^2}{4} \tag{2}$$

where d is the diameter of the flexible tube.
Furthermore, the average fluid velocity and the speed of rotation are related by:

$$v = 120\pi fr \tag{3}$$

where f is the speed of the rotation (rpm) and r is the radius of the rotation which is measured from the rotor axis to the center of the roller. The volume flow rate of the peristaltic pump can be expressed in terms of the parametric factors of the peristaltic pump.

$$Q = 30\pi^2 d^2 fr \tag{4}$$

From Eq. (4), it can be remarked that for a given size of the flexible tube in the peristaltic pump, the volume flow rate is dependent upon not only the speed of the rotation, but also the radius of the rotation. On the other hand, the number of the rollers and the sweeping angle are not impact factors on the flow characteristics in the volume flow rate. In the next section, the experimental results are presented to reveal the theoretical remarks above.

4. Results and Discussion

To observe and study flow characteristic of the peristaltic pump, the experimental rig explained in the section of experimental setup was used. The parametric factors of the peristaltic pump are specified as the radius of rotation r = 4, 5.5, 7, 8.5 cm, the number of rollers N = 3, 4, 6 and the sweeping angle λ = 120, 180, 240, 300 degrees. For each condition in experiments, the radius of rotation, the number of rollers and the sweeping angle was set up first and then the peristaltic pump was operated at various speeds of rotation, by varying low motor speed from around 60 rpm to a high speed of around 300 rpm. The volume flow rate and the pressure rise of the water flow were observed and recorded for various speeds of the pump rotor.

Figs. 3-6 illustrate of the relationships the volume flow rate of the peristaltic pump and the rotor speed of the peristaltic pump with different conditions of the parametric factors. In overall performance, the volume flow rate of the peristaltic pump increases as the speed of the rotor increases. Likewise, the pressure rise across the peristaltic pump gets higher as the rotor speeds up as shown in Figs. 7-10. As expected from Eq. (4), the volume flow rate is proportional to the rotor speed of the peristaltic pump. The corresponding results of the linear regression analysis are revealed by the linear function (y-x) and Pearson's coefficient of regression R^2 in the right upper part of each figure.

The experimental results are very interesting in view of one figure at a time from Fig. 3 to Fig. 10. It should be remarked that Fig. 3, Fig 4, Fig. 5, and Fig. 6 depict the experiment data of the volume flow rate in the case that the radii of the rotation are 4 cm, 5.5 cm, 7 cm, and 8.5 cm, respectively. As defined in Figs. 3-6, the different symbols of plots indicate the volume flow rate at specified values of the number of rollers and sweeping angles. It was observed that the different symbols were grouped at the same volume flow rate when the peristaltic pump was operated at the same rotor speed. This fact reveals that the volume flow rate is not affected by the number of the rollers and the sweeping angle. The volume flow rate of the peristaltic pump can be increased or decreased by adjusting the rotor speed but not by modifying the number of the rollers or the sweeping angle. Furthermore, the volume flow rate can be magnified proportionally as the radius of rotation of the peristaltic pump increases. This can be noticed from the slopes of the linear function from Fig. 3 to Fig. 6. The same consideration can be repeated in Figs. 7-10 for case studies of the pressure rise. Accordingly, the pressure rise increases as the rotor speed increases. The magnification of the pressure rise can take place when the radius of the rotation increases. The radius of rotation is a significant impact factor on the pressure rise in the peristaltic pump.

5. Conclusion

The flow characteristics are independent upon both the number of the rollers and the sweeping angle. In addition to the rotor speed, the radius of rotation has the most influence on the flow characteristics in both the volume flow rate and the pressure rise of a peristaltic pump. When the size of the flexible tube is constrained for a purpose, the radius of rotation into the peristaltic pump can be taken into account for an effective design variable to fulfill the desired capacity.

6. References

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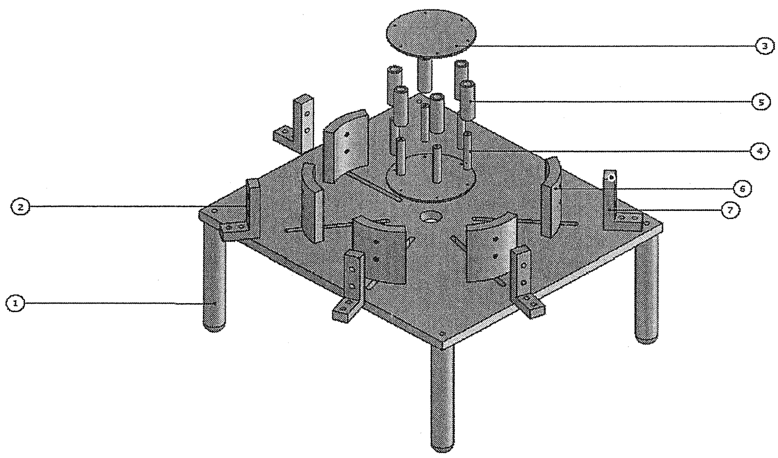

Fig. 1 Experimental rig with structural components: supporting column with slotted plate (1), sliding L-shaped support (2,7), conjoining disk (3), shaft bush (4), roller (5), curved guide for flexible tube (6).

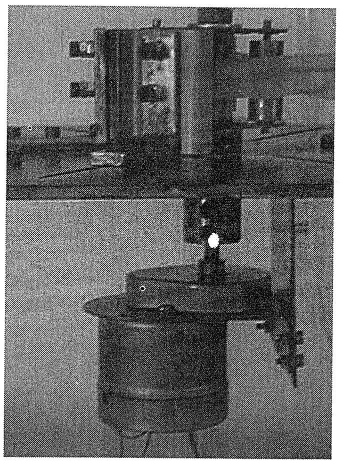

Fig. 2 Experimental rig of peristaltic pump (upper) driven by DC servo motor (lower).

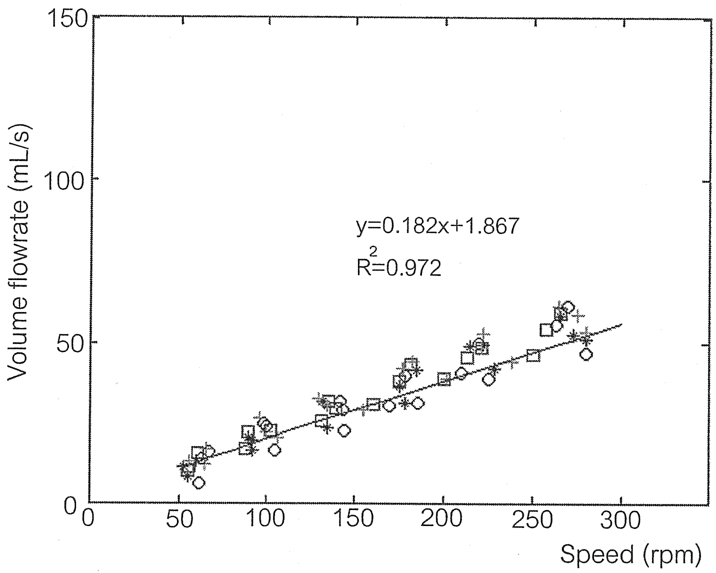

Fig. 3 Plot of volume flow rate against rotor speed with r = 4 cm; symbols □ (λ=300,N=3, 4, 6), * (λ=240,N=3, 4, 6), + (λ=180,N=3, 4, 6), o (λ=120,N=3, 4, 6).

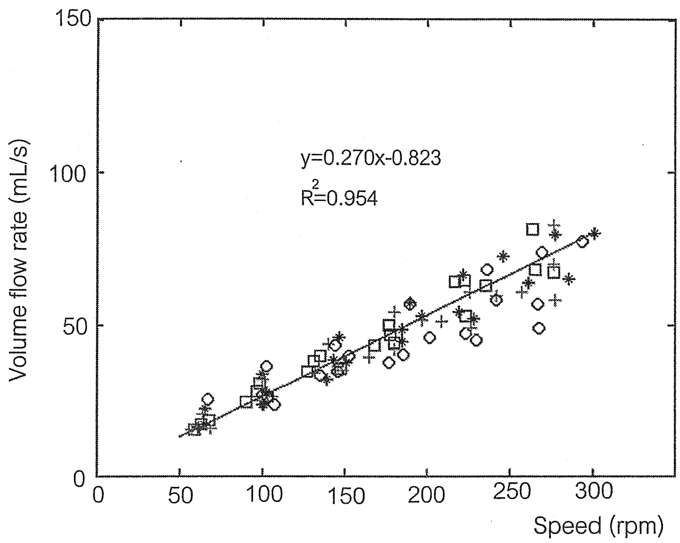

Fig. 4 Plot of volume flow rate against rotor speed with r = 5.5 cm; symbols □ (λ=300,N=3, 4, 6), * (λ=240,N=3, 4, 6), + (λ=180,N=3, 4, 6), o (λ=120,N=3, 4, 6).

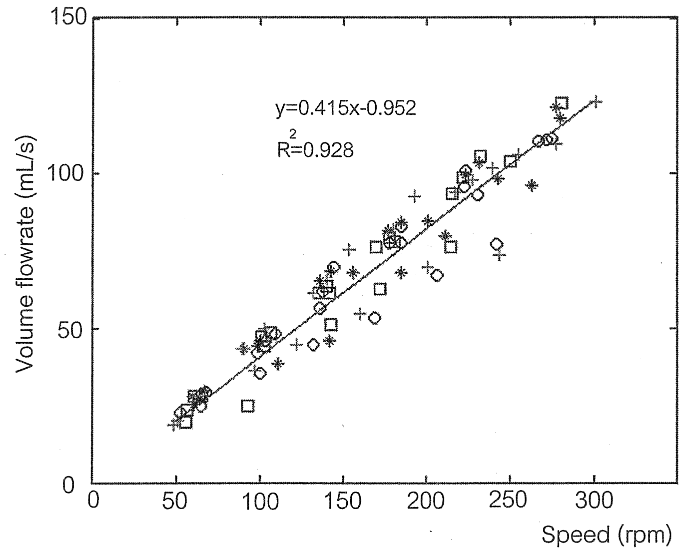

Fig. 5 Plot of volume flow rate against rotor speed with r = 7 cm; symbols □ (λ=300,N=3, 4, 6), * (λ=240,N=3, 4, 6), + (λ=180,N=3, 4, 6), o (λ=120,N=3, 4, 6).

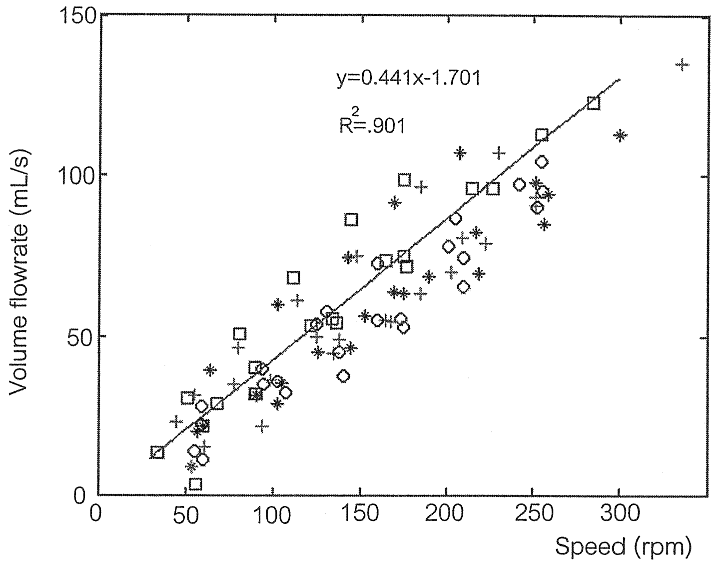

Fig. 6 Plot of volume flow rate against rotor speed with r = 8.5 cm; symbols □ (λ=300,N=3, 4, 6), * (λ=240,N=3, 4, 6), + (λ=180,N=3, 4, 6), o (λ=120,N=3, 4, 6).

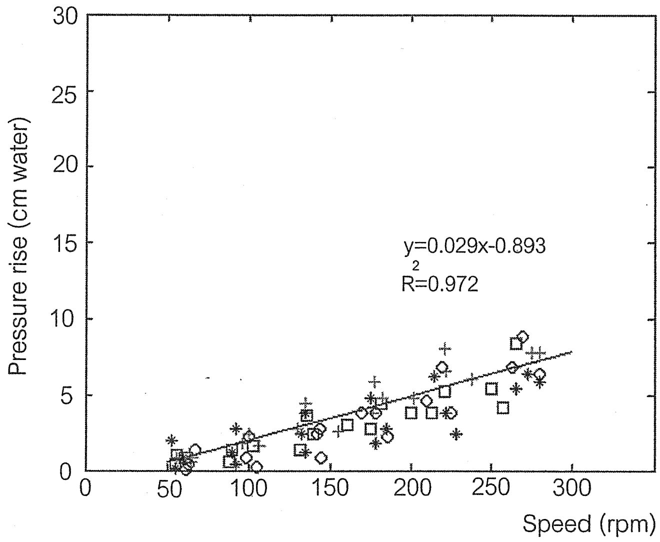

Fig. 7 Plot of pressure rise against rotor speed with r = 4 cm; symbols □ (λ=300,N=3, 4, 6), * (λ=240,N=3, 4, 6), + (λ=180,N=3, 4, 6), o (λ=120,N=3, 4, 6).

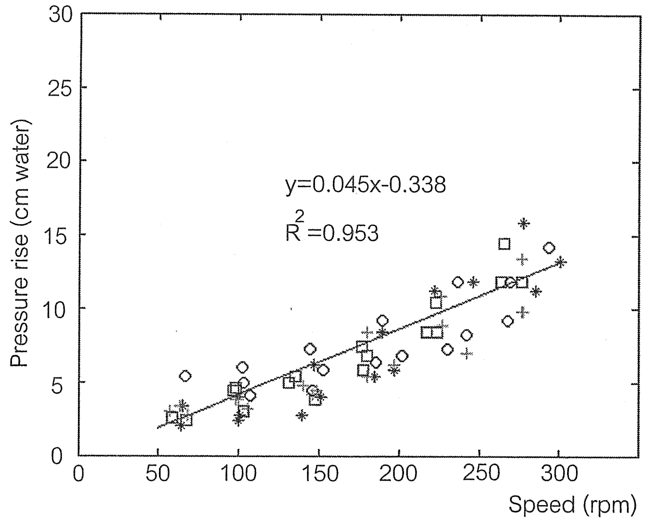

Fig. 8 Plot of pressure rise against rotor speed with r = 5.5 cm; symbols □ (λ =300,N=3, 4, 6), * (λ =240,N=3, 4, 6), + (λ =180,N=3, 4, 6), o (λ =120,N=3, 4, 6).

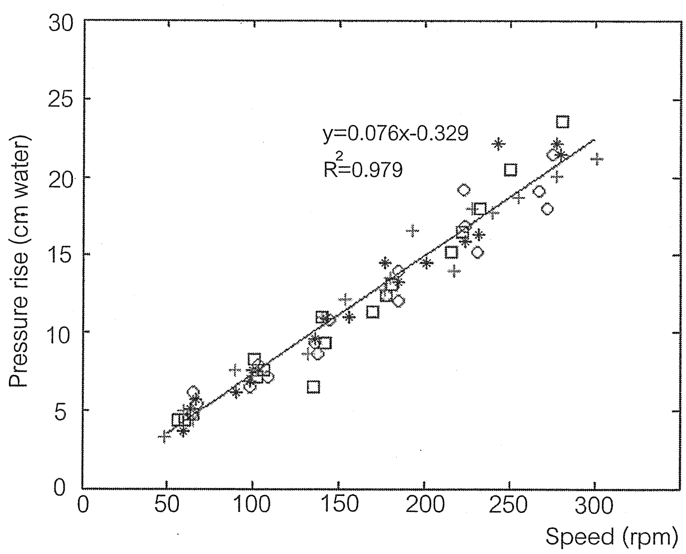

Fig. 9 Plot of pressure rise against rotor speed with r = 7 cm; symbols □ (λ =300,N=3, 4, 6), * (λ =240,N=3, 4, 6), + (λ =180,N=3, 4, 6), o (λ =120,N=3, 4, 6).

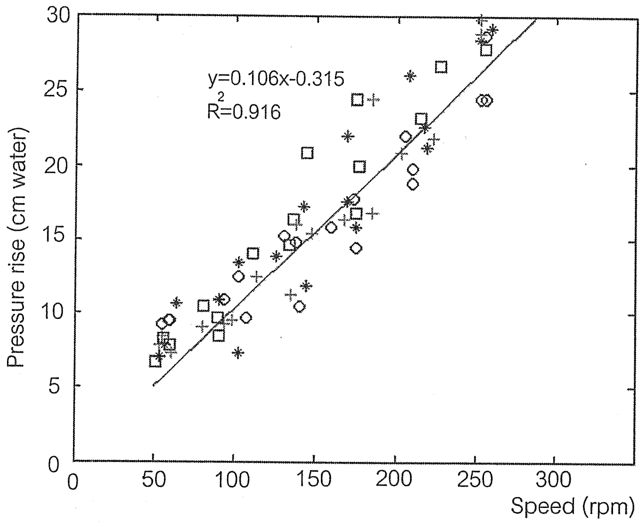

Fig. 10 Plot of pressure rise against rotor speed with r = 8.5 cm; symbols □ (λ=300,N=3, 4, 6), * (λ=240,N=3, 4, 6), + (λ=180,N=3, 4, 6), o (λ=120,N=3, 4, 6).