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Slip flow coefficient analysis in water hydraulics gear pump for environmental friendly application

A A Yusof[a], F Wasbari, M S Zakaria and M Q Ibrahim
Faculty of Mechanical Engineering, [2]Faculty of Engineering Technology, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

E-mail: [a]anas@utem.edu.my

Abstract. Water hydraulics is the sustainable option in developing fluid power systems with environmental friendly approach. Therefore, an investigation on water-based external gear pump application is being conducted, as a low cost solution in the shifting effort of using water, instead of traditional oil hydraulics in fluid power application. As the gear pump is affected by fluid viscosity, an evaluation has been conducted on the slip flow coefficient, in order to understand to what extent the spur gear pump can be used with water-based hydraulic fluid. In this paper, the results of a simulated study of variable-speed fixed displacement gear pump are presented. The slip flow coefficient varies from rotational speed of 250 RPM to 3500 RPM, and provides volumetric efficiency ranges from 9 % to 97% accordingly.

1. Introduction

The use of water hydraulics promotes possibility in designing fluid power systems with sustainable and environmental friendly elements [1]. In this context, water hydraulics can be understood as a technology, which is using tap water or water-based fluids for transmission of energy and power [2]. The aim of using water as the hydraulic medium is to transfer the energy, power and the resource sustainably, at a rate that does not compromise the natural environment. The use of non-renewable resources, such as fossils fuel, natural gas and coal has to be decreased, in promoting green technology for a better future. This includes the use of hydraulic oil, which is acquired from petroleum-based mineral oil. The use of water is vital in developing sustainable fluid power system. Simultaneously, water characteristics involving hygiene, safety and low maintenance cost provide fascinating perspectives for design engineers due to concerns over hydraulic fluid disposal, contamination, costly maintenance and flammability. The impressive uniqueness of energy and power transmission has also brought the technology to wider scopes of applications. The challenging problems of the low lubricity and highly corrosive properties of water have been overcome with the recent development of new materials, particularly ceramics and the machining of parts to greater tolerances. All these factors have contributed to increase hardware costs when using water [3]. However, water is significantly different from oil, which at the same time, in many ways, can provide advantages in one aspect, while producing disadvantages in other aspects. Fortunately, these technical difficulties have been solved effectively by using special materials, coatings and designs [4]. Water hydraulics can offer a design for hygiene solution in various industries, as demonstrated by the development of water hydraulics driven burger machine, beef cutter and ice filled machine in the food processing industry, and the use of environment-friendly waste packer lorry [5]. Water hydraulics can also be applied in industrial

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water cleaning application, die-castings, robotics, humidification equipment's and fire protection and fighting systems [6]-[8]. Therefore, based on the above reality, this paper investigates the effect of using water on a modified external gear pump system. Previously, a test was conducted at Centre of Advanced Research on Energy, Universiti Teknikal Malaysia Melaka. The test concentrated on the operation of a hydraulic scissor lift, by replacing the hydraulic oil with reverse osmosis water. It was noted that the hydraulic pump driven scissor lift managed to lift up to 400 kg of load, with workable water temperature of 41.4°C [9]. Unfortunately, no simulation was conducted in order to understand the effectiveness of the system in a wider range of flow rates. Thus, improved experimental and simulation study is being conducted in order to determine the effect of water hydraulics system on typical spur gear pump, especially the slippage under the influence of various loading pressure and slip flow coefficient.

2. Mathematical Modeling and Analysis

In general, external gear pumps produce flow by carrying fluid in between two meshing gears. One gear is driven by the drive shaft and turns the idler gear. Pumping chambers are formed between the gear teeth, which are enclosed by the pump housing and side plates, as shown in figure 1. The clearances between gear faces, gear tooth crests and the housing create an almost constant loss or slippage in any pumped volume at a fixed pressure. Volumetric efficiencies of gear pumps run as high as 90%. At low speed, the volumetric efficiency is poor, thus for an optimum volumetric efficiencies, the gear pumps should be run close to their optimum rotational speeds.

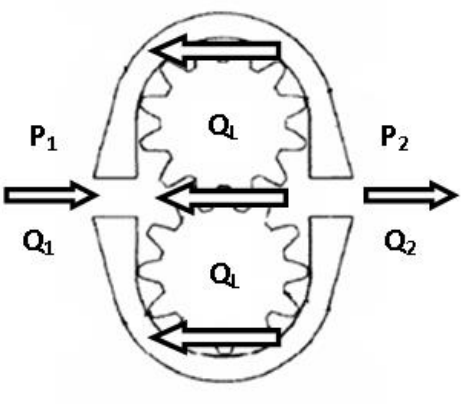


Figure 1. The flow and pressure of a gear pump.

The delivery or flow rate of an external gear pump can only be calculated by identifying the volumetric displacement of the pump. In the gear pump, one simple method of knowing the pump displacement is by multiplying the area of the chamber that displaced the hydraulic fluid, with the gear teeth width of the pump. Thus, the volumetric displacement of a gear pump, V_D can be represented by,

$$V_D = \frac{\pi}{4}\left(D_o^2 - D_i^2\right)L \tag{1}$$

where D_o, D_i, and L is referred to outside diameter, inside diameter and the width of the gear teeth. The ideal flow rate of the gear pump, Q_1, can be represented by,

$$Q_1 = V_D N \tag{2}$$

where N is the rotational speed of the prime mover. Table 1 shows the parameter for the simulated pump.

Table 1. Parameter for Simulated Pump

Parameter	Dimension
Outside Diameter	4.0 cm
Inside Diameter	3.6 cm
Gear Width	1.4 cm
Displacement	3.34 cm^3/rev
Flow Rate[a]	3340 cm^3/min

[a] Flow Rate at 1000 RPM

For any positive displacement pump, there is an inlet chamber that is increasing in volume and a discharge chamber that is decreasing. There may be leakage directly from the high pressure discharge chamber to the low pressure inlet chamber. There may also be discharge from both chambers to the drain. The volumetric efficiency of a pump can be influence by the leakage, with specific operating conditions. Any slippage or the leakage through the running clearances can increase with pressure, but at constant amount, as rotational speed and flow rate changes [11]. Because the clearances are so small, leakage flow is treated as laminar, thus,

$$Q \propto \Delta P \tag{3}$$

therefore, the outlet to inlet leakage or slip flow, Q_L, is shown as,

$$Q_L = SF\,(P_2 - P_1) \tag{4}$$

where SF is the slip flow coefficient, and P_2 and P_1 are the pump's outlet and inlet pressure. The changes of the pressure can be represented by a variable load pressure, P_L.

$$P_L = (P_2 - P_1) \tag{5}$$

By applying the principle of continuity to the inlet and outlet pipe, and taking account the slip flow, the actual flow rate, Q_2, can be represented by,

$$Q_2 = Q_1 - Q_L \tag{6}$$

where Q_1 is the ideal flow rate. Therefore,

$$Q_2 = V_D N - SF(P_L) \tag{7}$$

and the expression for volumetric efficiency, η_V, can be stated as,

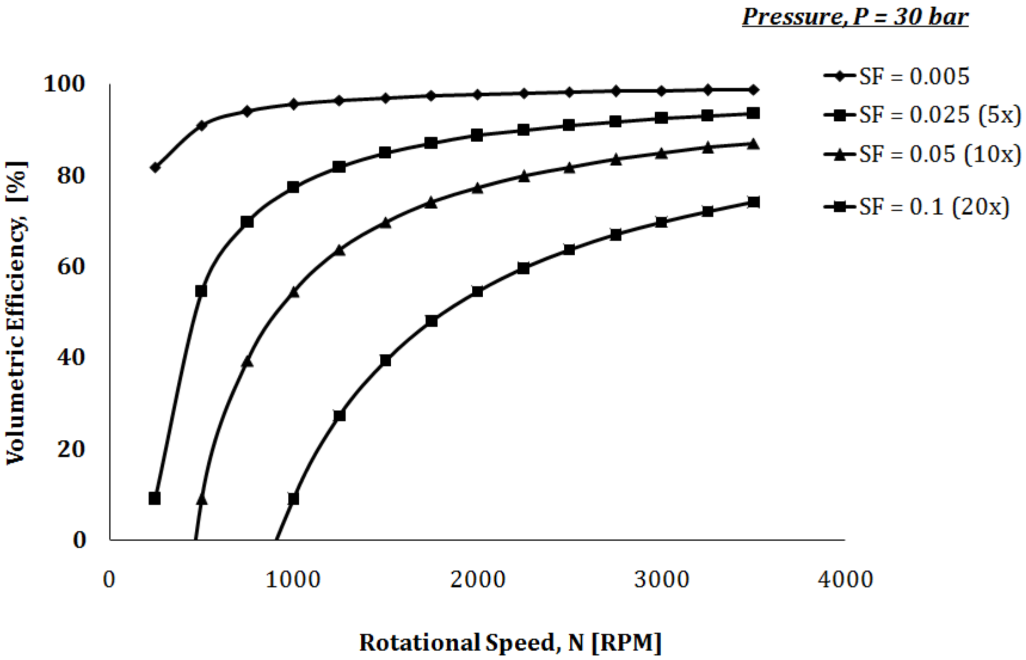
$$\eta_V = 1 - \frac{SF(P_L)}{V_D N} \tag{8}$$

3. Results and Discussion

The simulated value of volumetric efficiency, with respect to slip flow coefficient, SF, is presented in figure 2 to figure 7. The efficiency is represented with various pressures, ranging from 30 bar, 60 bar, 90 bar, 120 bar, 160 bar, and finally 260 bar. The data is also represented with various rotational speeds, ranging from 0 to 4000 RPM. All figures show the trend of the volumetric efficiency, with slip flow coefficient of —◆— 0.005, —■—0.025, —▲—0.05 and —■— 0.1. Basically, the slip flow coefficient is increased from 5, 10 and 20 times of the original SF = 0.005. The simulated data is recorded for an external, spur gear pump, having theoretical volumetric displacement of 3.34 cm^3/rev. Figure 2 shows that the value of simulated volumetric efficiency at loading pressure P_L of 30 bar, for slip flow coefficient, SF = 0.005. It is noted that the efficiency is around 80% to 98%, from 250 RPM up to 3500 RPM. The efficiency for the pump decreases when the slip flow coefficient is increased 5 times the original value, into SF = 0.025. At the same loading pressure, the efficiency is around 9% to 93%, ranging from 250 RPM up to 3500 RPM. At SF = 0.05, or 10 times the original value, the efficiency declines from 9% to 87%, which is recorded from 500 RPM to 3500 RPM. At 20 times the original value (SF = 0.1), the volumetric efficiency is around 9% to 74%, and it is only measurable from 1000 RPM to 3500 RPM.

In figure 3, the value of simulated volumetric efficiency changes significantly when the loading pressure increases to 60 bar. It is noted that for slip flow coefficient, SF=0.005, the efficiency is around 63% to 97%, from 250 RPM up to 3500 RPM. The efficiency for the pump decreases when the slip flow coefficient is increased to SF = 0.025. At the same loading pressure, the efficiency is around 9% to 87%, ranging from 500 RPM up to 3500 RPM. At SF = 0.05, the efficiency decreases from 9% to 74%, which is recorded from 1000 RPM to 3500 RPM. At SF = 0.1 (20 times the original value), the volumetric efficiency is around 9% to 48%, and it is only measurable from 2000 RPM to 3500 RPM. From this figure, it shows that at a typical rotational speed of 1750 RPM, no efficiency can be recorded with the use of pumps having slip flow coefficient of 0.1. Therefore, if the slip flow coefficient represents the use of water hydraulics in gear pumps, it would be acceptable if a higher RPM is used. And even if the highest RPM is possible, for example around 3500 RPM, it will only provide volumetric efficiency around 48%.

In figure 4, the changes can be seen more clearly when the loading pressure increases to 90 bar. For slip flow coefficient, SF = 0.005 and SF = 0.025, the efficiency is around 45% to 96%, and around 9% to 80%, from 250 RPM up to 3500 RPM and from 750 RPM to 3500 RPM respectively. The efficiency for the pump decreases when the slip flow coefficient is increased to SF = 0.05 and SF = 0.1. At the same loading pressure, the efficiency is ranging from the efficiency is around 9% to 61%, and around 9% to 22%, from 1500 RPM up to 3500 RPM and from 3000 RPM to 3500 RPM respectively. In figure 5 and figure 6, where the pressure is set at 120 bar and 160 bar, the volumetric efficiency for slip flow coefficient SF = 0.01 is out of range. This means that, if the slip flow coefficient represents the use of water hydraulics in gear pumps, the system cannot be used for loading pressure of 120 bar onwards. For slip flow coefficient of SF = 0.005 and SF = 0.025, with the same pressure of 120 bar and 160 bar, and within selected rotational speed that ranges from 2000 RPM to 3000 RPM, the volumetric efficiency are around 90% to 93%, and 54% to 69%, respectively. In figure 7, where the maximum pressure of 260 bar is set, the volumetric efficiency for slip flow coefficient SF = 0.05 and SF = 0.1 is out of range. For the same selected rotational speed of 2000 RPM to 3000 RPM, the volumetric efficiency are around 80% to 86%, and 2% to 34%, for slip flow coefficient of SF = 0.005 and SF = 0.025, respectively.



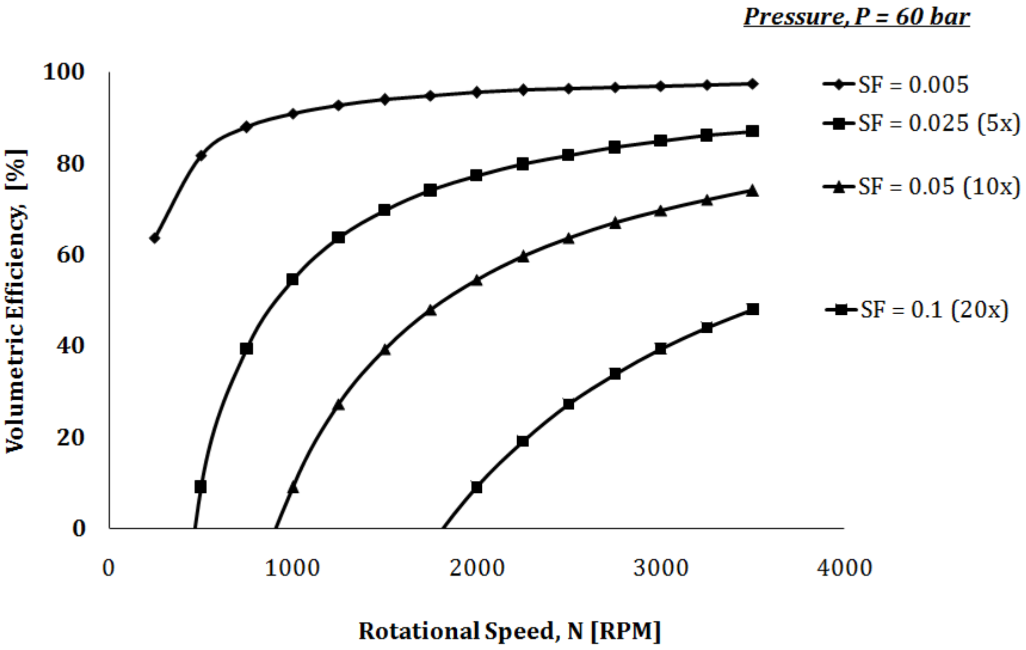


Figure 3. Volumetric efficiency at loading pressure of 60 bar.

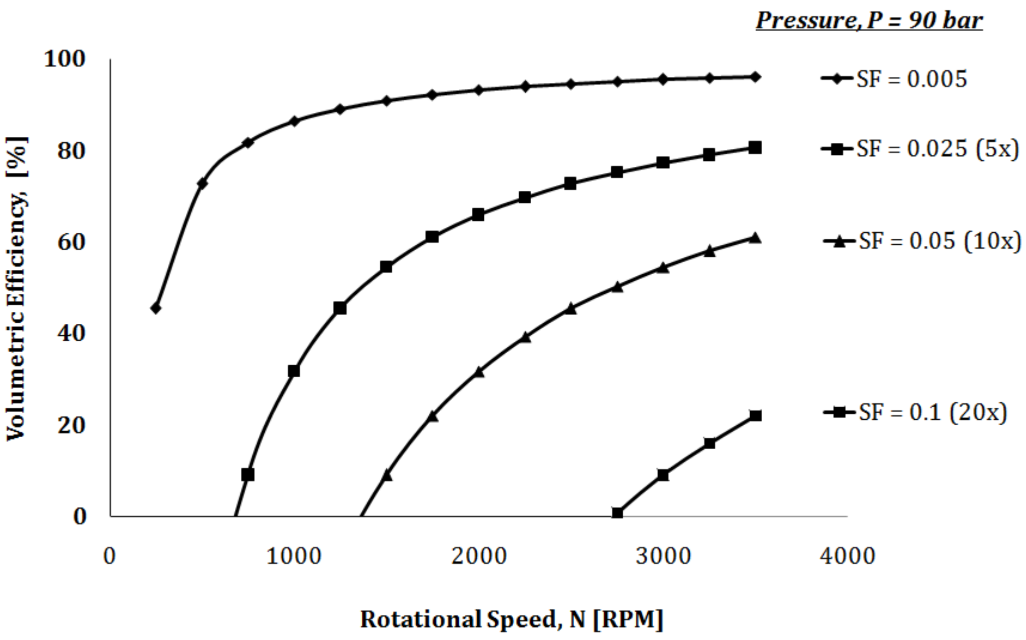


Figure 4. Volumetric efficiency at loading pressure of 90 bar.

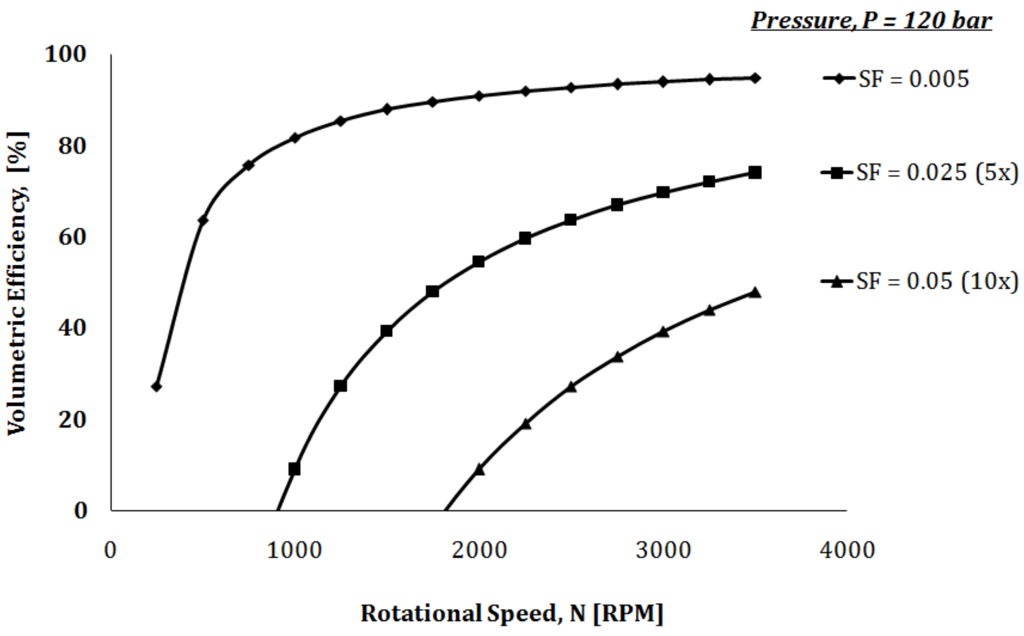


Figure 5. Volumetric efficiency at loading pressure of 120 bar.

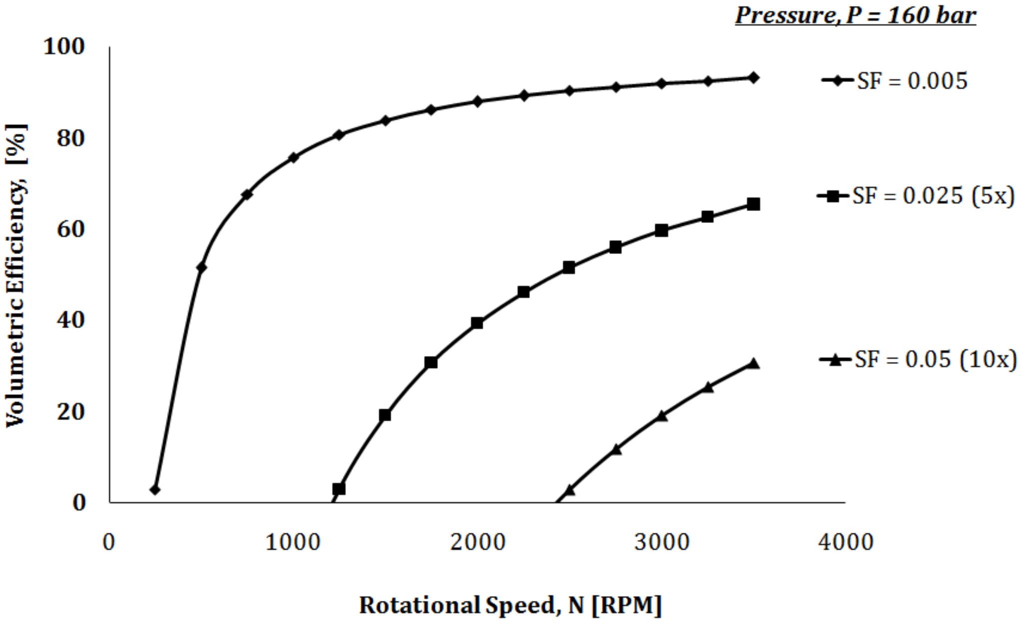


Figure 6. Volumetric efficiency at loading pressure of 160 bar.

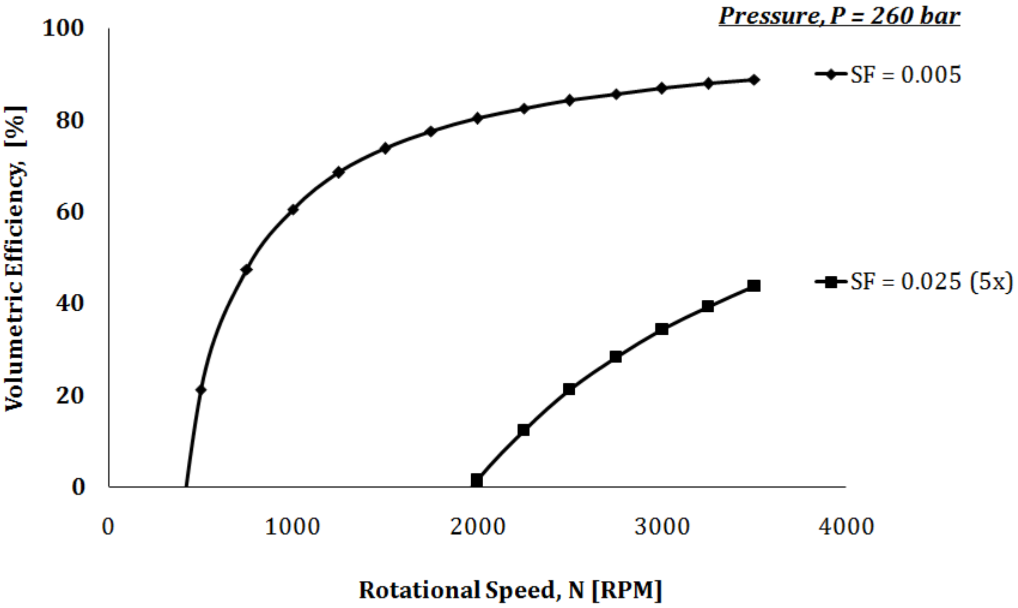


Figure 7. Volumetric efficiency at loading pressure of 260 bar.

4. Conclusion

The study on rotary gear pump for water hydraulics application is being conducted at the Centre of Advanced Research on Energy, University Teknikal Malaysia Melaka. The objective of the study is to provide variety information regarding to the use of low viscosity, sustainable water hydraulics in external, spur gear pump. In this study, the focus is limited to the slippage in between the outlet and inlet of the pump. The result suggests that the use of water is possible, if the slip flow coefficient is at constant value 0.005, with system pressure of 30 to 260 bar. The effectiveness varies from rotational speed of 250 to 3500 RPM, and provides volumetric efficiency ranges from 9 % to 97% accordingly. The result suggests that water can be applied in typical traditional oil hydraulic gear pump, and this is true if an acceptable slip flow coefficient value can be achieved.

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References

[1] Koskinen K T, Leino T Riipinen H 2008 Sustainable development with water hydraulics – Possibilities and challenges *Proc.of the 7th JFPS Int. Symp. on Fluid Power* Toyama Japan 11 – 18
[2] Trostmann E, Frolund B, Olesen B H and Hilbrecht B 2001 Tap Water as a hydraulic pressure medium (New York: Marcel Dekker)
[3] Backe W 1999 Water or oil hydraulics in the future *Proc. of the 6th Scandinavian Int. Conf. on Fluid Power* Tampere Finland 51 – 65
[4] Hilbrecht B 2000 Water as a pressure medium in water hydraulics *Proc. of the 48th National Conf. on Fluid Power* Chicago Illinois USA 555 – 559
[5] Conrad F 2005 Trends in design of water hydraulics – Motion control and open-ended solutions *Proc. of the 6th JFPS Inter. Symp. on Fluid Power* Tsukuba Japan 420 – 430
[6] Higgins M 1996 Water hydraulics – The real world *Industrial robot: An Int. J.* **23** 13 – 18
[7] Ikeo S, Nakashima H and Ito K 2008 Water hydraulics system for high speed cylinder drive *Proc. of the 7th JFPS Int. Symp. on Fluid Power* Toyama Japan 95 – 100
[8] Lim G H, Chua P S K and He Y B 2003 Modern water hydraulics – The new energy transmission technology in fluid power *Applied Energy* **76** 239 – 246
[9] Yusof A A, Mat S and Din AT 2013 Promoting sustainability through water hydraulics technology – The effect of water hydraulics in industrial scissor lift *Applied Mechanics and Materials* **315** 488 – 492
[10] Esposito A 2003 *Fluid power with application* (New York: Pearson)
[11] Merritt H 1956 *Hydraulic control systems* (New York: McGraw Hill)