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Simulation on the Charging Performance of Water-Based Hydraulic Hybrid System in Term of System Pressure

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ABSTRACT- Typical hydraulic hybrid system vehicles depend on oil based hydraulic fluid. Therefore, natural concerns of environment and safety promote the uses of the water-based hydraulic hybrid system. The main focus of this paper is to simulate the potential of using water hydraulic technology in hydraulic hybrid systems. The research will include an extensive study on the mathematical modeling and simulation by using Matlab/Simulink to determine the feasibility of water compared to oil HyspinAWS68 during charging modein term of the performance of energy storage of the hydraulic hybrid system. The simulation result indicates that the performance of accumulator of water and HyspinAWS68 are almost the same up until 400bar as the HyspinAWS68 has a better performance for the pressure system above 400bar.

KEYWORDS: hydraulic hybrid system; hydraulic fluid; fluid power; water hydraulic.

1. INTRODUCTION

The main function of a hydraulic fluid in a hydrostatic power system is to transmit power and movement. In addition to the power transmission, the hydraulic fluids serve to lubricate the contact surfaces, cool different elements and clean the system (Ag, 2004; Rabie, 2009). Typical hydraulic technology depends on petroleum-based hydraulic fluid. Mineral oil has come to be the most popular choice primarily because of its excellent protection against corrosion and good lubricity(Ag, 2003b). However, mineral oil used in oil hydraulic equipment poses a fire hazard in the event of a spillage or leakage. This is especially critical in vehicle accident scenarios where the oil spillage might trigger fire mishaps as explained in the previous study(A. anas Yusof et al., 2014; Ahmad Anas Yusof, Mat, & Din, 2013).

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Typical concerns of fire and safety in hydraulic systems promote the uses of the water-based hydraulic system. Through the usage of water hydraulics, problems related to safety and contamination of oil hydraulics in typical hydraulic hybrid technology can be avoided.

Water was used in the early days for the transmission of the fluid power. The main advantage of water as pressure medium is its availability (shakeel et al., 2019), fire resistance, and low cost. On the other hand, the disadvantage of water is poor lubricity, the high tendency of rust and has a narrow range of working temperature(Krutz & Chua, 2004; Rabie, 2009). Consequently, fire-resistant fluids are often used in hydraulic systems that are mainly water-based (Watton, 2009). On the other hand, the implementation of water instead of oils is offered advantages, but certain factors need to be studied in depth in order to match or surpass the current outcome of the oil hydraulics. The specific characteristics of water in term of corrosion, flow erosion, friction, internal and external leakage, lubrication, cavitation, freezing and microorganism are essential prospects that could affect the efficiency of water compared to oil as in the previous study(Conrad, 2005; Krutz & Chua, 2004; A A Yusof, Wasbari, Zakaria, & Ibrahim, 2013).In respect to the above statement, some water properties are explained in this section. The density of hydraulic fluid affects the value of hydraulic energy losses (shakeel et al., 2018) in the system because the latter is proportional to the density. In order to keep the pressure losses small and to reduce the dynamic effect on control valves, it is important to keep the density of the pressure medium as low as possible(Krutz & Chua, 2004; Trostmann, Frolund, Olesen, & Hilbrecht, 2001).

Besides that, this research of water hydraulic technology was applied to a new technology known as ahydraulic hybrid system. Generally, during a conventional vehicle slows down or decelerates the friction of brake pads and wheels produce heat that is converted from the kinetic energy (Gomathiet al., 2019). This

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heat is dissipated into the air that causes an effective energy waste up to 30% of the vehicle's generated power (Valente, Ferreira, & Automação, 2009).Hydraulic hybrid system or hydraulic regenerative braking system is a mechanism that stored a portion of the kinetic energy that was a momentum as potential energy in a form of pressure. It is stored by a short term storage system that is done by using a displacement pump to pump hydraulic fluid into an accumulator. That energy is kept until needed again by the vehicle, by which the pressure is released from the accumulator as the vehicle accelerates. This pressure will spin the drive shaft while the engine remains idle. As the vehicle achieve the desired speed or the accumulator is emptied, the engine will take over to continue the process that is beyond the capability of accumulator(Kargul, Moskalik, Newman, Barba, & Rockwell, 2015; Kumar, 2012; Lindzus & Ag, 2008; Molla, Sill, & Ayalew, 2014; Valente et al., 2009). This paper concerns on the performance of the novel water-based hydraulic hybrid system instead of the established oil-based hydraulic system, limit for the part of charging mode based on various system pressure. Therefore, a simulation was conducted to analyze these two objectives. The first objective of this paper is to analyze the fundamental knowledge in utilizing water hydraulics technology. The fundamental understanding is explained by relating the properties of water with the correlation of pressure system. The second objective of this

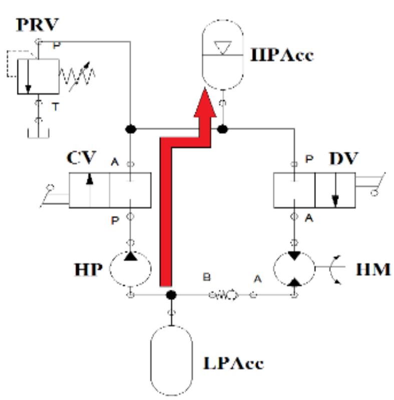

Figure 1: Hydraulic hybrids (Charge mode).

paper is to analyze the feasibility of using water as a pressure medium instead of hydraulic oil. Hence, the effect of the hydraulic fluid in term of efficiency, leakage and pressure drop was analyzed to compare both pressure medium performances. In additional, pressure, flow rate, volume, and energy storage during charging mode are studied deeply to determine the best performance for both hydraulic fluid.

Where Vg is volume displacement, is angular velocity, which is produced by the motor connected to the pump with a constant value. η is volumetric efficiency. Whereas the value of pressure is determined by the following equation:

$$p=(T_p \, n_{mech})/V_g \quad (1)$$

Where Tp is torque at the pump driving shaft, ηmech is pump mechanical efficiency.

Pressurized water is channeled by the pump to occupied HPAcc in a particular preference. The relationship of the gas volume and gas pressure between the precharge state and charge/discharge state are shown in the following equation (Mathworks, 2017a):

$$(p_G+p_A)(V_T-V_F)^k=(p_{pr}+p_A)V_T^k \quad (2)$$

In explaining equation (2), the total accumulator volume,VT is separated into the fluid chamber (left side) and the gas chamber (right side). VF is the fluid volume and (VT – VF) is the gas volume. Gas volume never becomes zero as the total accumulator volume,VT is larger than the fluid chamber capacity,VC. Subsequently, pGis the gas pressure, ppr is the precharge pressure (emptied fluid chamber) and pA is the atmospheric pressure which is 101325Pa.

2. Hydraulic Hybrid System Simulation Setup

In order to study the system dynamic characteristics of the hydraulic hybrid system, a model is implemented in Simulink using corresponded Simscape toolbox as shown in Figure 2. In this simulation, the comparison was done based on the type of hydraulic fluid which is Hyspin AWS68 and water and every each simulation was run by controlling the system pressure from 50bar till 500bar as shown inTable 2. In addition, HyspinAWS68 was selected as an example of oil to compared with water. HyspinAWS68 is based on highly refined mineral oil with a low zinc containing anti-wear system. HyspinAWS68 is classified as DIN51502 (ISO 6743/4) under the classification of HLP. HLP fluids are suitable for most fields of application(Ag, 2008; Castrol, 2009).The following Table 1 and Table 2shows the component specification and hydraulic fluid properties that used as the parameter in the simulation.

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Table 1
Hydraulic Fluid Properties (Castrol, 2009)(Mathworks, 2017b)

Fluid Properties	Hyspin AWS68	Water
System temperature [°C]	40	40
Nom kinematic viscosity [cSt]	68	0.657161
Nom fluid density [kg/m^3]	880	992.562
Bulk modulus [Pa] *	1.20E+09	2.26E+09

Table 2
Components Specification and Simulation Parameter (Ag, 2003a; Hydac, 2006; Hydraulicsco.ltd, 2005)

Component	Specification	Values	
		Bosch A4FM (oil)	Janus Motor (water)
Fixed displacement pump/motor, HP/M	Input speed, n (rpm)	1000	1000
	Volumetric displacement, V_g[cm^3/rev]	71	71
	Nompressure, p [bar]	350	350
	Nom angular velocity, ω [rpm]	3200	3200
	Nom kinematic viscosity, ν [cS]	36.14	0.6572
	Nom fluid density, ρ [kg/m^3]	865.4	992.56
High Pressure Accumulator, HPAcc (Hydac SB330 70)	Total Accumulator Volume, V_T[L]	70	
	Min gas volume, V_m[L]	17.5	
	Initial fluid volume, V_F[L]	7	
	Precharge pressure, p_o[bar]	50	
Low Pressure Accumulator, LPAcc (Hydac SB330 70)	Total Accumulator Volume, V_T[L]	70	
	Min gas volume, V_m[L]	17	
	Initial fluid volume, V_F[L]	53	
	Precharge pressure, p_o[bar]	3	
Pressure relief valve, PRV	Valve Pressure, p (bar)	50,100,200,300,400,500	

	Hydraulic Fluid	System Pressure [bar]					
		50	100	200	300	400	500
HPAccvolumetric flow rate [L/min]	HyspinAWS68	65.83	65.83	65.83	65.83	65.83	65.83
	Water	61.35	61.35	61.35	61.35	61.35	61.35
HPAcc pressure [bar]	HyspinAWS68	68.06	108.42	204.99	304.07	403.74	503.61
	Water	68.05	108.36	204.88	303.92	316.27	316.27
HPAcc volume [L]	HyspinAWS68	13.63	29.42	44.17	50.49	52.88	53.64
	Water	13.62	29.4	44.16	50.48	51.03	51.03
HPAcc time taken to fully charged [s]	HyspinAWS68	12.6	30.2	46.5	50.9	55.5	60.3
	Water	13.3	29.6	54.3	91.3	155	155
HPAcc energy stored [kJ]	HyspinAWS68	92.75	318.93	905.49	1535.21	2135.11	2701.46
	Water	92.67	318.59	904.8	1534.3	1614.1	1614.1

Specifications for every component are based on the specification sheet provided by the supplier. Specification for oil-based HP and oil-based HM were based on the axial piston fixed motor A4FM manufactured by Rexroth Bosch Group (Ag, 2012). Meanwhile, the specification for water-based HP and water-based HM are based on the axial piston fixed motor MC160-70W manufactured by The Water Hydraulics Co.Ltd. Whereas the value of nominal kinematic viscosity and nominal fluid density are assume based on the optimum range reading on viscosity index based on each spec. Besides that, the input speed of HP/M were fixed as 1000rpm as we assumed the value of momentum which the system received from flywheel while deceleration (braking) take part in the truck's motion.

3. EFFECT OF PRESSURE IN WATER AND OIL BASED HYDRAULIC HYBRID SYSTEM AT CHARGING MODE

To investigate the effect of pressure system on the hydraulic fluid, the properties value for both types of pressure medium, HyspinAWS-98 and water were applied for each simulation as shown in Table 1. On the same time, the simulation was run with system pressure as the independent variable and other parameters of the system were kept as constant as shown detail in Table 2. Figure 3(a) shows the effect of pressure at high pressure accumulator, HPAcc during charging mode. As shown in the figure that the pressure value at HPAcc was almost the same for both liquids up until 300bar. HPAcc pressure at HyspinAWS68 was continuously increasing linearly with the system pressure. Whereas at the water, HPAcc pressure was constant starting from 400bar until 500bar with 316.27 bar.

Therefore the maximum working pressure at water is 316.72bar as shown in Table 3. This is due to the internal leakage occurs at the pressure relief valve, PRV that eventually causes a pressure drop. As

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shown in Figure 3(b) that internal leakage occurs at the water were far higher compared to HyspinAWS68, especially at 400bar and 500bar. This leakage causes an increasing of pressure drop, as the internal leakage at water were more obviously increased that affected the increasing of pressure drop. The source of internal leakage is the viscosity of the liquid (Conrad, 2005; Koskinen, Leino, & Riipinen, 2008; Majdič & Pezdirnik, 2009). Water with a kinematic viscosity of 0.657161cSt has a lower kinematic viscosity compared to HyspinAWS68 which is 68cSt. For this reason, the HPAcc pressure at the water was constant starting from 400bar until 500bar as shown in Figure 3(a).

In the other hand, a 70L of total volume accumulator were used in the simulation. The effective volume which is the volume filled by the liquid can be analyzed throughout the system pressure as shown in Figure 4(a) that a very big gap of effective volume and gas volume can be compared between 50bar up till 500bar. At 50bar, only 13.6L were occupied by the liquid and another 56.4L were filled by nitrogen gas. As the system pressure increased, the effective volume of the HPAcc also increases. The effective volume was affected by the pressure applied to the liquid, as the pressure increased the force to compress the liquid also increase that eventually increased the volume filled by the liquid (F. Wasbari, Bakar, Gan, & Yusof, 2016).In relation to the effective volume, at 400bar and 500bar the effective volume of water was at constant of 51.03L while at HyspinAWS68 were still increasing up till 500bar which is 53.64L. The result of the effective volume was closely related to the pressure as mention before, and as shown in Figure 4(a) that the HPAcc pressure at 400bar and 500bar were constant that eventually affected the effective volume. Besides that, Figure 4(b) indicates that the energy stored inside the HPAcc while in charging mode. The energy stored were increased proportionally to the system pressure for HyspinAWS68 which is the maximum energy were stored at 500bar with 2701.46kJ. Whereas, the energy stored were constant for water starting from 400bar at 1614.1kJ as shown in Table 3.Potential energy in form of pressure was related to the rate of HPAcc pressure and effective volume. Therefore, based onFigure3(a) and Figure 4(a) that the HPAcc pressure and effective volume start to constant at 400 bar for water and keep increasing for HyspinAWS68.

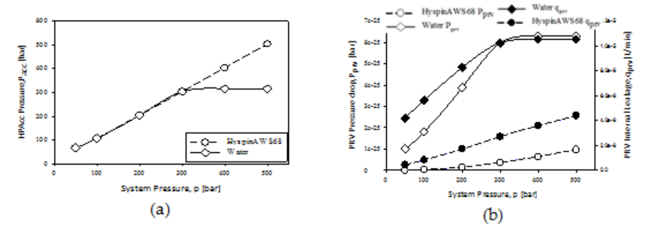

Figure 3: (a) Pressure in HPAcc at charging mode (b) Pressure drop and internal leakage at PRV.

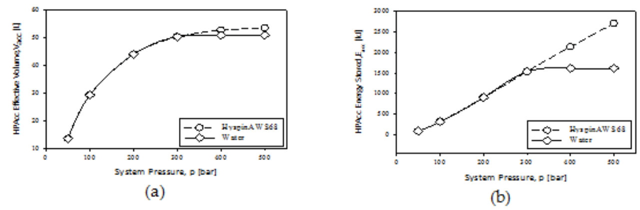

Figure 4: (a) Effective volume of HPAcc at charging mode (b) Energy stored at charging mode.

4. CONCLUSION

In conclusion, the simulation result shows that the effect of system pressure on the performance of charging process for water and HyspinAWS68. The fluid properties of both pressure medium have a very big effect on the performance of thehydraulic hybrid system in charging mode. The effect wasobviously identified starting from 400bar. Based on this simulation result it can be concluded that the most optimum output gain from the system pressure for water is 300bar. Above from 300 bar, the disadvantages of water properties with a lower viscosity and higher density compared to HyspinAWS68 influence the performance of energy storage that causes internal leakage and pressure drop. This causes the efficiency of accumulator at charging mode decrease vigorously.Based on the result, the application of water as a pressure medium instead of oil required a very depth study. In spite of this, future research should be conducted, especially on the alteration of the fluid properties such as temperature, viscosity, bulk modulus, water hammer, enthalpy and vapor pressure of water throughout the system. Thisfundamental study isimportant to ensure the optimal design and the performance of water based hydraulic hybrid system.

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