Penerbit Akademia Baru

CFD Letters

Journal homepage: www.akademiabaru.com/cfdl.html
ISSN: 2180-1363

Simulation of System Pressure Impact on the Water Hydraulic Hybrid Driveline Performance

Open Access

Ahmad Anas Yusof[1,*], Saiful Akmal Sabaruddin[1], Syarizal Bakri[1], Suhaimi Misha[1]

[1] Fakulty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

ARTICLE INFO

Article history:
Received 29 September 2018
Received in revised form 16 December 2018
Accepted 24 December 2018
Available online 28 December 2018

ABSTRACT

Typical hydraulic hybrid system vehicles depend on oil-based hydraulic fluid. Due to the natural concerns of environment and safety, promote the uses of the water-based hydraulic hybrid system. The aim of this research to investigate the potential of using water-based hydraulic technology instead of the current oil-based hydraulic technology. The main subject of this technology is in heavy commercial vehicles that frequently in a stop and go modes such as garbage trucks or delivery trucks that produce an immense amount of energy in a moment. The hydraulic hybrid driveline presented in this research is a series type, and the output of the driveline is connected to a Mitsubishi Fuso 6D34-0AT2 as a load to the system. In addition, the driveline is contained of hydraulic component (accumulator, hydraulic pump/motor) which serves to store and distribute power. HyspinAWS68 (mineral oil) was used as a pressure medium to create a comparison with water. Extensive study on the component modelling and simulation by using Matlab/Simulink has been conducted. Based on the simulation, several data were collected such as time taken to fully charged, pressure, volumetric flow rate, torque, power, vehicle speed and also efficiency. The simulation result indicates that as one might expect that HyspinAWS68 has a higher performance of hydraulic hybrid driveline compared to water. This is due to the weakness of water properties as a pressure medium in terms of the density, viscosity, bulk modulus that causes a significant effect on the efficiency and performance of the hydraulic hybrid driveline. Several serious issues faced by water are internal leakage, pressure drop and also the capability to be compressed. Despite this, the implementation of water hydraulic a potential response that required depth studies in terms of the properties and the component parameter to achieve the optimum performance of water-based hydraulic hybrid driveline.

Keywords:
Water Hydraulics, Hydraulic Hybrid System, Fluid Power

1. Introduction

Heavy commercial vehicles that frequently in a stop and go modes such as garbage trucks or delivery trucks produce an immense amount of energy in a moment [1]. This energy which is generated from a high load of the engine is converted to waste heat energy that released to the airstream. Precisely, when a conventional vehicle slows down or decelerates, the friction of brake

* *Corresponding author.*
E-mail address: anas@utem.edu.my (Ahmad Anas Yusof)

pads and wheels produce heat that is converted from the kinetic energy. This heat is dissipated into the air that causes an effective wasted energy up to 30% of the vehicle's generated power [2].

Hydraulic hybrid system or hydraulic regenerative braking system is a mechanism that stored a portion of the kinetic energy from the braking momentum as potential energy in the form of pressurized liquid. Figure 1 shows the hydraulic hybrid system develop by the United States Environmental Protection Agency's (EPA). The pressurized liquid is compressed by a hydraulic pump to occupy the high-pressure accumulator as an energy storage. The energy is kept up until it is required by the vehicle, by which the pressurized liquid is released from the accumulator as the vehicle accelerates. The pressurized liquid generates the drive shaft while the engine remains idle. As the vehicle achieves the desired speed or the accumulator is emptied, the engine is taking over to continue the process that is beyond the capability of the accumulator [1-4].

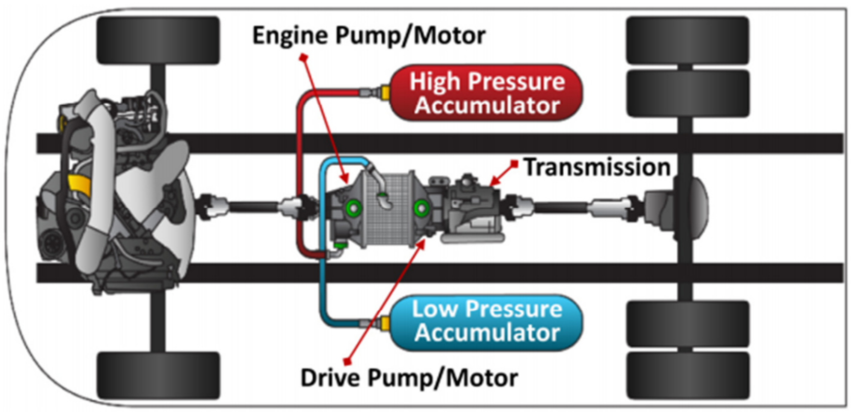

Fig. 1. The basic mechanism of a hydraulic hybrid system configured by the United States Environmental Protection Agency's (EPA) [5]

Typical hydraulic hybrid vehicles depend on petroleum-based hydraulic fluid. Essential concerns of fire and safety in hydraulic systems promote the use of the water-based hydraulic system. Mineral oil used in hydraulic oil 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 Through the usage of water hydraulics, problems related to safety and contamination of oil hydraulics in conventional hydraulic hybrid technology can be avoided. [6]-[11].

Water hydraulics can be simplified as a fluid power system which is using water as a medium transmission of energy and power [12]. The use of water as the transmission medium is a new concept, since the industry are more familiar with hydraulic oil. However, since during the 90s, the concern on safety issues and environmental crisis led to many new companies implementing the use of water hydraulics technology. The replacement of oil hydraulic to water medium bring the world one step forward towards a better future technology since water hydraulics offers an environmentally friendly, non-flammable, non-toxic, and low costs solutions. Moreover, water also has a higher rate of density, torque and power efficiency compared to electric and pneumatic technology [13]-[14].

2. Methodology

In this simulation, the main comparison was made based on the comparison of oil-based hydraulic hybrid driveline and water-based, which is between Hyspin AWS-68 and water. Table 1 shows the fluid properties applied in this simulation. The hydraulic hybrid driveline was considered operating at 40℃ at the isothermal process. In respect to that, the values of kinematic viscosity and fluid density were implemented at 40℃.

Table 1
Hydraulic Fluid Properties

Fluid Properties	Hyspin AWS68	Water
Relative amount of trapped air	0.005	0.005
System temperature [℃]	40	40
Viscosity operating factor	1	1
Nom kinematic viscosity [cSt]	68	0.657161
Nom fluid density [kg/m^3]	880	992.562
Bulk modulus [Pa] *	1.20E+9	2.26E+9

* Bulk modulus at atm. pressure

Table 2 shows the component specification that required in the Matlab/Simulink block diagram of hydraulic hybrid driveline circuit. Specification for the oil-based hydraulic pump, HP and oil-based hydraulic motor, HM is based on the axial piston fixed motor A4FM manufactured by Rexroth Bosch Group. The value of nominal kinematic viscosity and nominal fluid density are assume based on the optimum range reading of viscosity index as shown in Figure 2. HyspinAWS68 is under the group VG68 with the label of orange colour. The specification for the water-based hydraulic pump, HP and water-based motor, HM is based on the axial piston fixed motor manufactured by Janus motor [15].

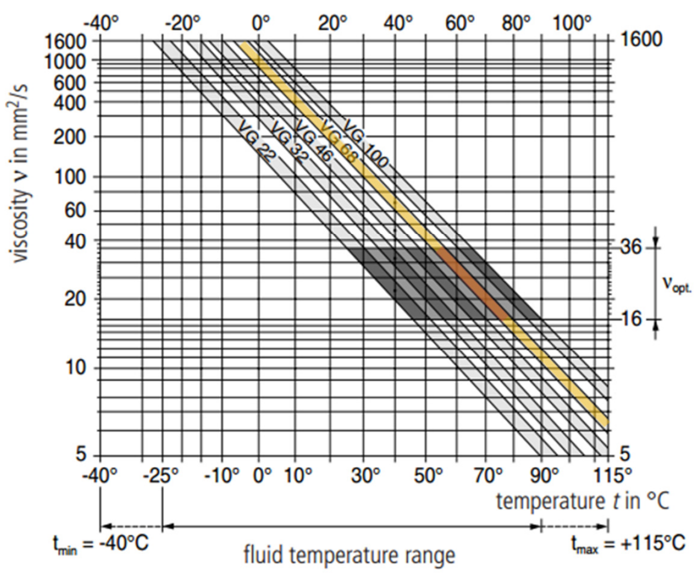

Fig. 2. Optimum viscosity ranges for particular volumetric displacement

Besides that, low and high-pressure accumulator's values were determined based on the Hydac SB330 70 specification sheet of standard bladder accumulator manufactured by Hydac Corporation [16]. The value of min gas volume, V_{dead} and initial fluid volume, V_{init} were determined so that the Simulink's component of accumulator will operate as a bladder accumulator. As a result, the mechanical output of HM was connected with the truck's body of Mitsubishi Fuso 6D34-0AT2 manufactured by Mitsubishi Fuso Truck and Bus Corporation. This model of truck was selected, as this model is often used by certain waste management company as a garbage truck which is our main target vehicle to apply water-based hydraulic hybrid system. Every blocks are link to the Matlab circuit with the mathematical modeling for hydraulic fluid, pressure relief valve, fixed-displacement pump, fixed displacement motor, high pressure accumulator and Mitsubishi Fuso 6D34-0AT2.

Table 2
Components Specification

Component	Specification	Values: Bosch A4FM (oil)	Values: Janus Motor (water)
Fixed displacement pump/motor, HP/HM	Input speed, n_{in} [rpm]	1000	
	Volumetric displacement, D [cm^3/rev]	(2) *71*	(2) *71*
	Volumetric efficiency, η_v	0.65	0.65
	Nom pressure, p_{nom} [bar]	350	350
	Nom angular velocity, n_{nom} [rpm]	3200	4000
	Nom kinematic viscosity, v_{nom} [cSt]	36.14	0.6572
	Nom fluid density, ρ_{nom} [kg/m^3]	865.4	992.56
High-Pressure Accumulator, HPAcc	Total accumulator volume, V_T [L]	(3) *70*	
	Min gas volume, V_{dead} [L]	(a) 5, 10, 12.5, **17.5**, 20, 25	
	Initial fluid volume, V_{init} [L]	(a) 2, 4, 5, **7**, 8, 10	
	Pre-charge pressure, p_o [bar]	(4) *50*	
Low-Pressure Accumulator, LPAcc	Total accumulator volume, V_T [L]	(3) *70*	
	Min gas volume, V_{dead} [L]	(a) 4.5, 9.5, 12, **17**, 19.5, 24.5	
	Initial fluid volume, V_{init} [L]	(a) 15.5, 30.5, 38, **53**, 60.5, 75.5	
	Pre-charge pressure, p_o [bar]	3	
Pressure relief valve, PRV	Valve pressure, p [bar]	(1) *200*	
Gear Ratio	Simple gear ratio, SG1	1.2	
	Simple gear ratio, SG2	2	
Mitsubishi Fuso 6D34-0AT2	Gross Vehicle Mass, GVM [kg]	11000	
	Wheel radius, [m]	0.4	
	1st Gear ratio	5.494	
	2nd Gear ratio	3.196	
	3rd Gear ratio	1.689	
	4th Gear ratio	1	
	5th Gear ratio	0.723	
	Differential gear ratio	5.285	

Table 3
Simulation Variables Parameter

	Variables	Component	Value
1.	System Pressure, p [bar]	PRV	50, 100, 200, 300, 400, 500

Table 3 shows the selection range for every parameter. The range value of system pressure, p is selected within the range of 50 bar to 500 bar. This due to the effect on the water properties and the relation on the specification of the hydraulic motor and the load. The kinematic viscosity of the fluid is related to the changes of temperature and pressure. As the pressure increase, the kinematic viscosity decreases linearly. Therefore, the limitation for the maximum pressure which suitable for water and mineral oil is determined. The maximum range of pressure in a compatible form is at 500 bar, whereas mineral oils are up to 1500 bar [17]-[18]. The minimum value to be set in this parameter was determined based on the minimum pressure required to run the hydraulic motor. The minimum pressure required to run the A4FM of Bosch is 50 bar, whereas 25 bar is required to run the Janus motor [19].

Secondly, the range for volumetric displacement was selected based on the specification provided by the manufacturer. The selection was based on the specification to ensure that the recommended experimental method is correlated to the current simulation [19]. The range for total accumulator volume was selected based on the specification provided by the manufacturer. The range of 20 to 100 L was select based on the output volumetric flow rate with the time taken to fully discharge the fluid. The minimum requirement to drive a 11000 kg of heavy vehicle is at a constant 40 L/min for at least in a period of 20 s. Hydac's manual shows that the optimum range to fully satisfied the requirement is between 20 to 100 L [20]. The selections for pre-charge pressure were based on the curve of the bladder accumulator. The curve shows the selection of pre-charge pressure based on the range of system pressure. Therefore, the value of pre-charge pressure is acquired with the value of system pressure. The hydraulic hybrid system is separated into two main processes: charge and discharge mode. Charge mode (as shown in Figure 3) is a process of regenerate the kinetic energy from braking friction and stored the energy in form of pressure in accumulator. Meanwhile, discharge mode (as shown in Figure 5) occurs as the throttle is applied, the energy stored in the accumulator is released to run the motor that eventually will drive the vehicle forward. Figure 4 and Figure 6 show the full Simulink schematic diagrams of Figure 3 and Figure 5, respectively.

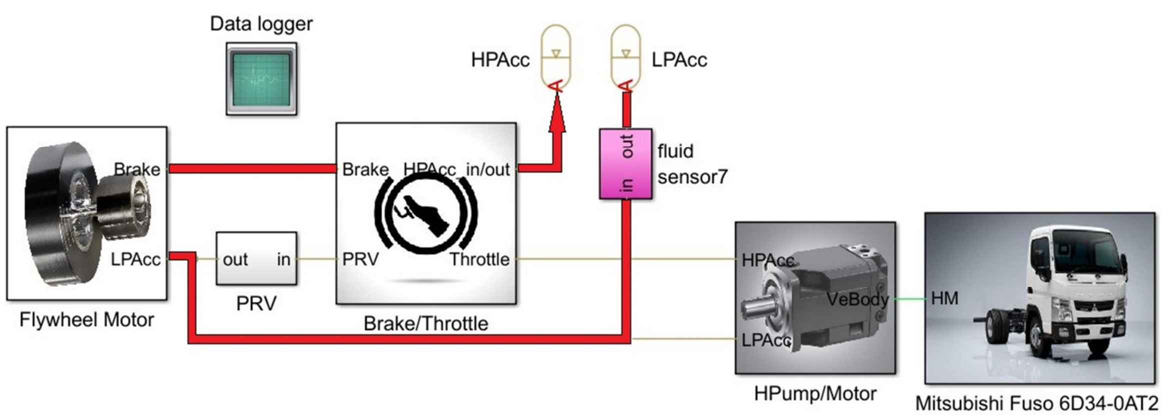

Fig. 3. Hydraulic hybrids driveline (Charge mode) by using Matlab/Simulink

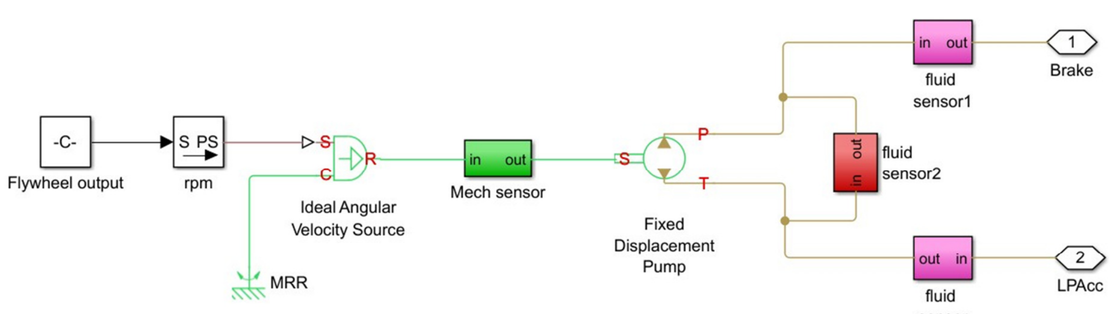

Fig. 4. Input speed at flywheel motor mask

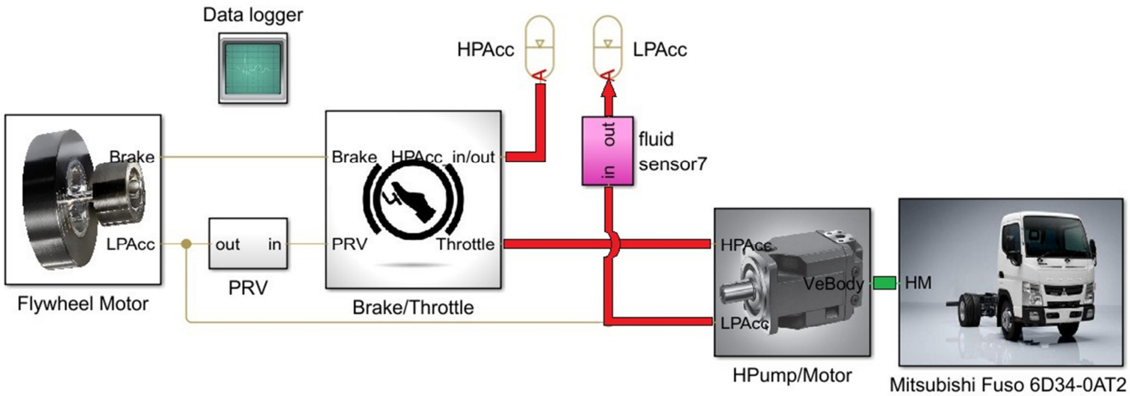

Fig. 5. Hydraulic hybrids driveline (Discharge mode) by using Matlab/Simulink

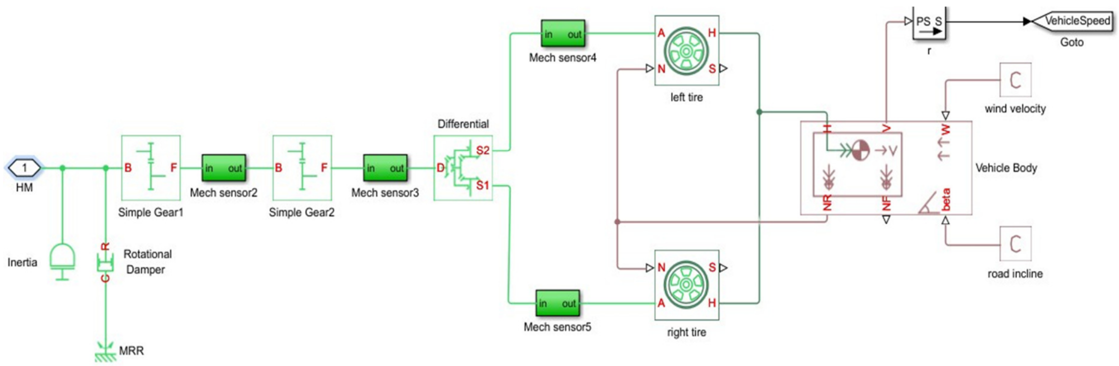

Fig. 6. Mitsubishi Fuso 6D34-0AT2 simple transmission, wheels, and truck body structure

3. Results and Discussion

3.1 Effect of System Pressure during Charge Mode

The analysis on the effect of pressure system on the performance of HPAcc as an energy storage is discussed in this subsection. Simulation results for the effect of the pressure medium in the hydraulic hybrid system while charging is shown from Figure 7 to Figure 13. Table 4 indicates the maximum value gain for time taken to fully charge the HPAcc and energy density of HPAcc, based on the system pressure that was controlled.

Table 4
Effect of pressure system during charge mode at HPAcc

	Hydraulic Fluid	System Pressure, p [bar]					
		50	100	200	300	400	500
HPAcc time taken to fully charged, t_c [s]	Hyspin AWS68	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 Density, $E_{d\,HPAcc}$ [kJ/L]	Hyspin AWS68	6.8062	10.842	20.5	30.407	40.374	50.361
	Water	6.8047	10.836	20.489	30.393	31.631	31.631

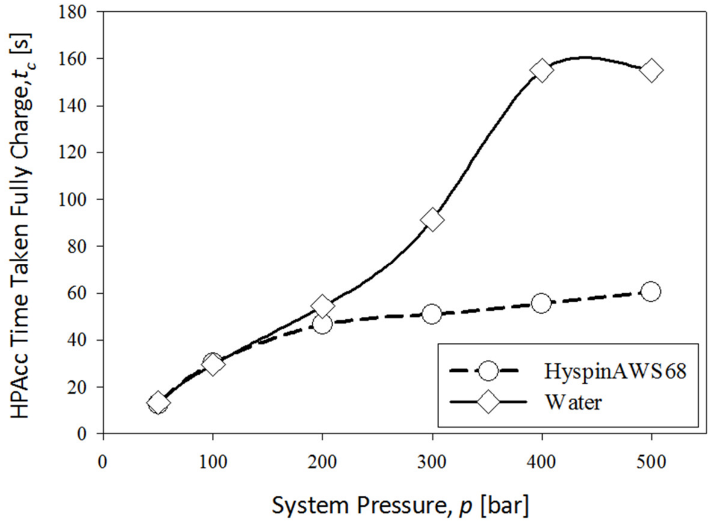

Fig. 7. Time taken to fully charged HPAcc during charging mode

Figure 7 indicates that water consumes longer time to fully charge the HPAcc and the difference is getting wider as the system pressure increased. The most striking gap to emerge from the data is at 400 bar and 500 bar. There are two interesting issues to be discussed. The first point is the gap of time taken between water and HyspinAWS68. The second point is the wide difference of time taken at 400 bar and 500 bar compare to the lower system pressure.

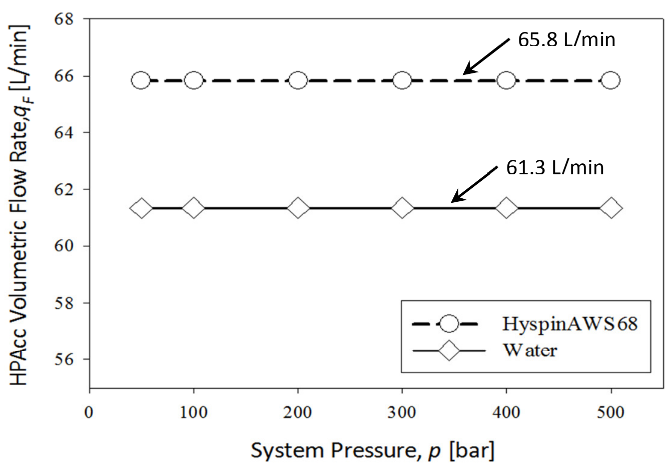

Fig. 8. Volumetric flow rate of HyspinAWS68 and water

As shown in Figure 8, the volumetric flow rate of HyspinAWS68 is higher than water. The theoretical concept that volumetric flow rate is the flow of a volume of liquid through a surface per unit time, or in other words, it is written as $q = V/t$ [15]. Therefore, at a constant volume, the increase in volumetric flow rate causes the declination of the time taken to fully charge the HPAcc. In the other hand, the higher volumetric flow rate of HyspinAWS68 causes the time taken to be shorter as compared to water.

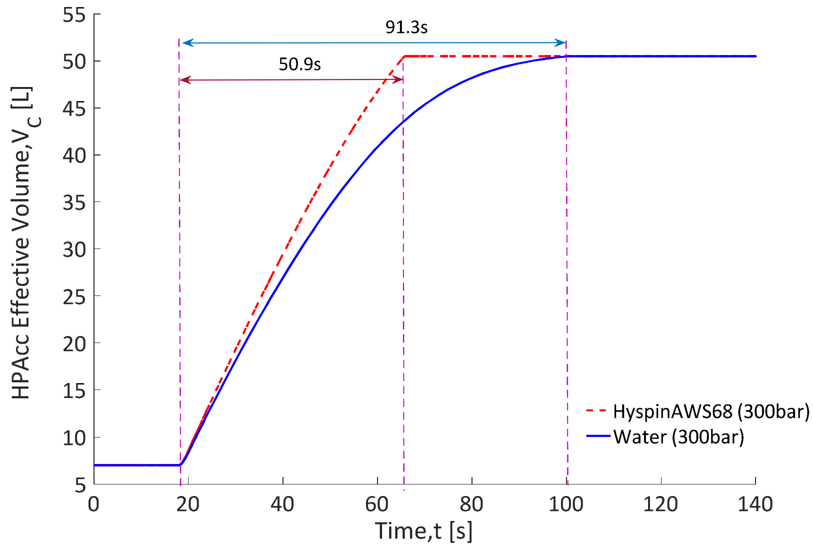

Fig. 9. Effective volume of HPAcc based on the time changes at 300 bar

Figure 9 shows the result of the time taken required to occupy HPAcc at 300 bar as an example for the flow rate comparison between HyspinAWS68 and water. The figure indicates that to occupied 50.5 L of the effective volume of HPAcc, HyspinAWS68 required 50.9 s which is faster compared to water that required 91.3 s. This difference may be explained by the fact that the density of water is higher compared to HyspinAWS68 (Table 2). The density of substances is its mass, *M* per unit volume, *V* as shown in $\rho = M/V$. This equation proves that the decreasing of density causes the increasing of volume that eventually increases the volumetric flow rate. For that reason, HyspinAWS68 has a higher volumetric flow rate compared to water in answering the issue at Figure 7. In the other hand, optimal properties of hydraulic fluid, density should be low as possible to minimize losses. [21]-[22].

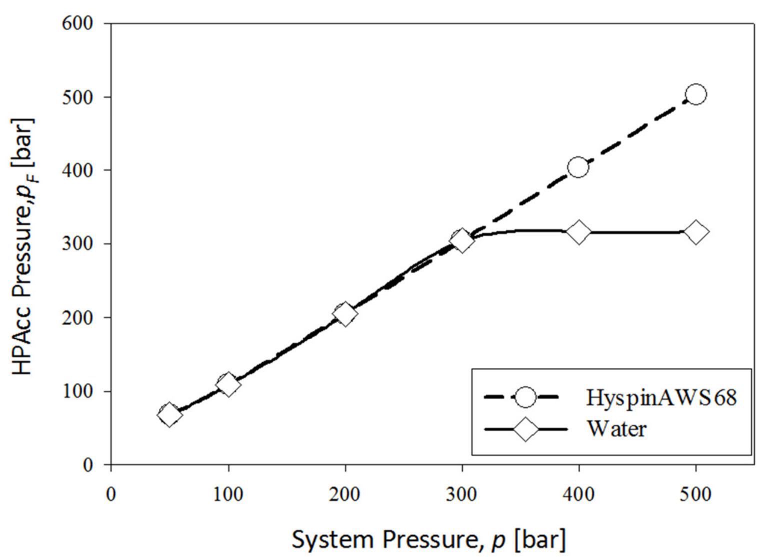

Fig. 10. Effect of pressure at HPAcc based on the changes of system pressure

Back to the second issue of 400 bar and 500 bar as shown in Figure 7. Surprisingly, the difference between water and HyspinAWS68 at 400 bar and 500 bar are obviously wider as compared to the others. At 400 bar and 500 bar, water required 155 s to fully charge the HPAcc compared to HyspinAWS68 which required average 57 s as stated in Table 4. This is due to the low pressure of water at HPAcc at 400 bar and 500 bar as shown in Figure 10. Starting from 300 bar, the value of water pressure starts to constant compared to HyspinAWS68 which is still in the mode of increasing proportionally to the changes in system pressure. The low pressure of water at 400 bar and 500 bar causes the system could not compress the water that eventually the time to occupy the HPAcc increases. Moreover, the high gradient of HyspinAWS68 starting from 300 bar representing an over-pressure condition which not good for the lifespan of the accumulator [23]-[24].

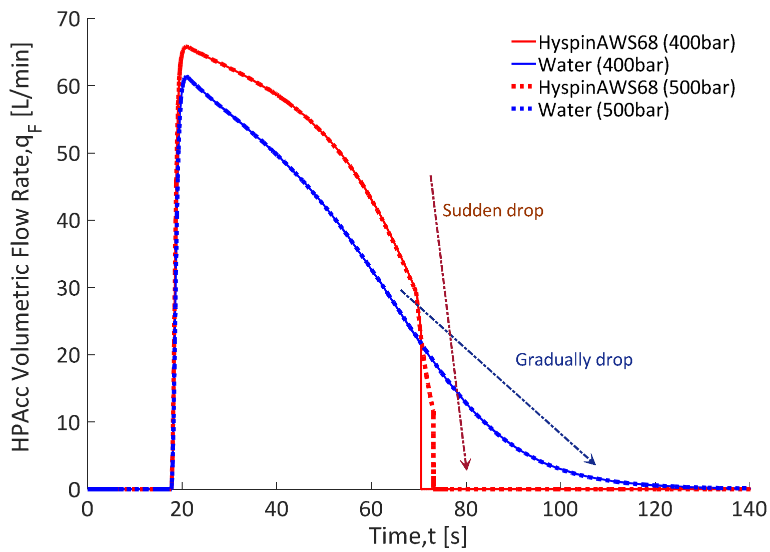

Fig. 11. Volumetric flow rate of HyspinAWS68 and water at 400 bar and 500bar

Meanwhile, the gap of HPAcc pressure at 400 bar and 500 bar is due to the sudden drop in flow rate as shown in Figure 11. Theoretically, as flow rate is inversely related to the pressure, this strengthens the idea of the sudden drop causes the pressure increases. Contrarily to the water, the volumetric flow rate decreasing gradually causes no significant effect on the pressure that eventually the value starts to constant.

Further analysis on the effect of HPAcc effective volume shows the significant result on the compatibility of water as a pressure medium. Figure 12 indicates that the HPAcc effective volume of water at 400 bar and 500 bar start to constant at 51.03 L. Meanwhile, HyspinAWS68 is still increasing linearly to the changes of system pressure. It is noted that bulk modulus is reciprocal to the compressibility, $\beta = 1/\kappa$. Thus, this indicates that the lower bulk modulus of HyspinAWS68 causes the oil is easily compressible compared to water. As shown in Figure 10, the HPAcc pressure of HyspinAWS68 is increasing starting from 300 bar, causes more force to compress the fluid. Therefore, less amount of force was channeled to compress the water.

These findings enhance our understanding that the incompatible of 400 bar and 500 bar as the system pressure for water. Some of the issues emerging from these findings which are the benefit of the charging system at 400 bar and 500 bar are not worthy compared to the result achieved. As it can be observed that the result of HyspinAWS68 with the increases in terms of pressure, volumetric flow rate and effective volume is just a slight increment. Worse than that, no obvious advantages gain in the case of water. Obviously, the more time required to occupy the HPAcc at 400 bar and 500 bar is an obvious incompatible parameter of water.

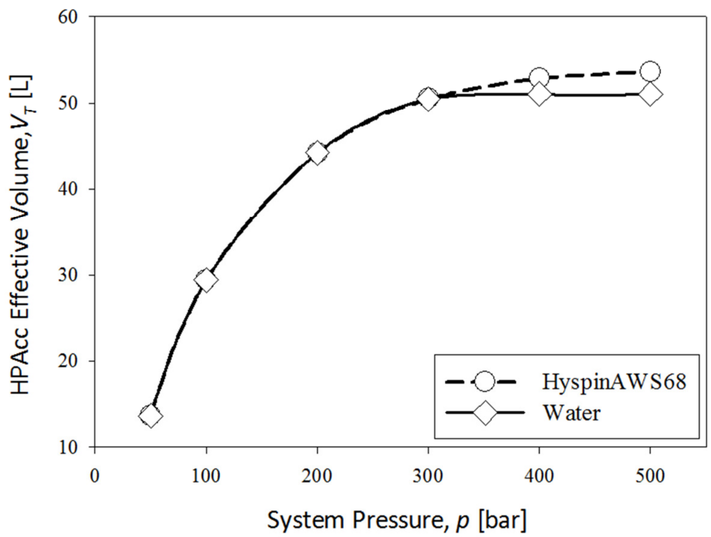

Fig. 12. The effect of HPAcc effective volume on the changes of system pressure

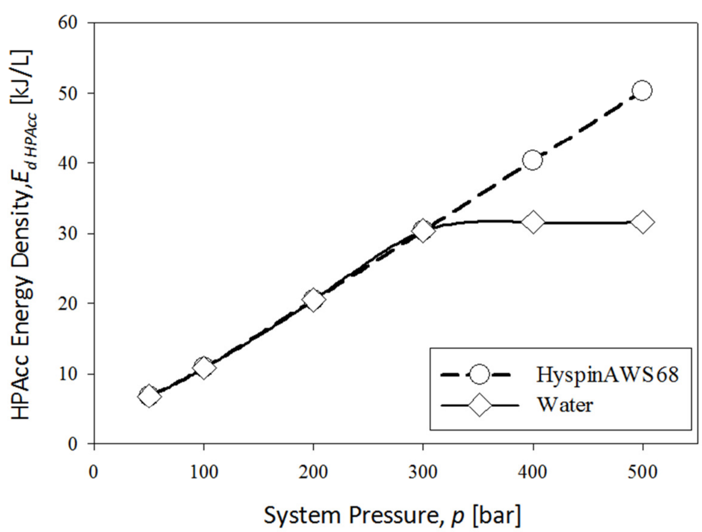

Fig. 13. Energy density of HPAcc during charging mode

Figure 13 shows that the energy density of HPAcc as an energy storage. In case of HyspinAWS68, the energy stored were increased proportional to the system pressure, with the maximum energy density at 500 bar is 50.36 kJ/L (refer Table 4). However, the energy density was constant for water starting from 400 bar at 31.63 kJ/L. Potential energy in the form of pressure was related to the rate of HPAcc pressure and effective volume. Therefore, based on Figure 10 and Figure 12, the HPAcc pressure and effective volume started to constant at 400 bar for the case of water.

In brief, an explanation based on the multiple regression analysis on water application revealed that the most optimum performance system pressure for HPAcc as an energy storage is in the range of 200 bar to 300 bar. One of the most significant findings to emerge from this study is incompatible of system pressure value, starting from 300 bar upwards. The study has gone some way towards enhancing our understanding of the limitation of system pressure in the application of water as the pressure medium in the hydraulic hybrid driveline.

3.2 Effect of System Pressure during Discharge Mode

The analysis on the effect of pressure system on the performance of HM and Mitsubishi Fuso 6D34-0AT2 during discharge mode is discussed in this subsection. Simulation results for the effect of the pressure medium in the hydraulic hybrid system while discharging are shown from Figure 14 to Figure 22. Meanwhile, Table 4 indicates that the maximum value gain for every variable based on the system pressure that was controlled.

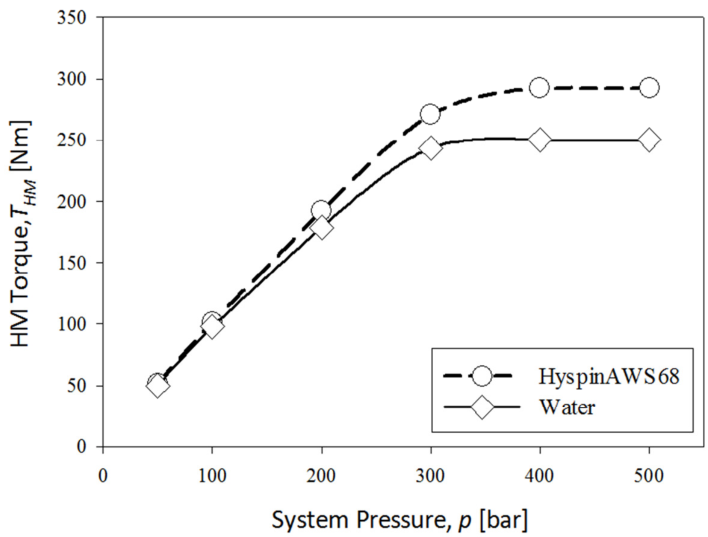

Fig. 14. The effect of HM torque during discharge mode

The result of the simulation of hydraulic hybrid driveline during discharge mode (as shown in Figure 14) indicates that the torque of HM is increasing proportionally to the system pressure. However, at 300 bar, HM torque start to constant. Torque is related to the pressure difference. A possible explanation for this issue is the specification limit of HM in terms of the nominal pressure for both Bosch A4FM and Janus Motor which is 350 bar as shown in Table 2. Therefore, the pressure difference at HM could not surpass the specification limit of HM as shown the result of HM pressure difference in Table 5.

Table 5
Effect of pressure system during discharge mode at HM and Mitsubishi Fuso 6D34-0AT2

	Hydraulic Fluid	System Pressure, p [bar]					
		50	100	200	300	400	500
HM Pressure Difference, Δp_{HM} [bar]	Hyspin AWS68	47.92	94.73	179.61	253.26	273.34	273.40
	Water	46.65	91.31	167.13	227.47	234.11	234.11
Mitsubishi Fuso Speed, v [km/h]	Hyspin AWS68	6.19	14.59	21.78	25.12	22.44	22.39
	Water	5.46	12.88	19.17	21.94	22.19	22.19

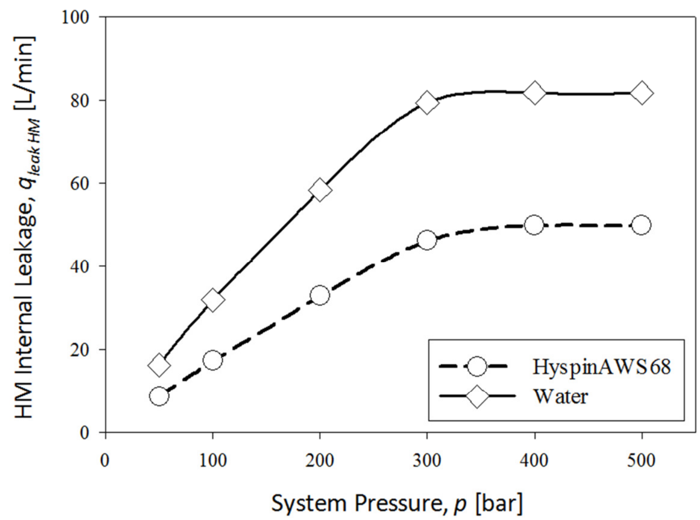

Fig. 15. Internal leakage at HM during discharge mode

One anticipated finding was that the HyspinAWS68 has a higher torque compared to water. As shown in Figure 15 the internal leakage at water is obviously larger compared to HyspinAWS68. Due to this reason, pressure drop occurs more at water that causes the torque of water is smaller than HyspinAWS68. In addition, the maximum internal leakage takes place in the system is at 400 bar and 500 bar. The internal leakage occurs because of the hydraulic fluid properties, which is the viscosity of the liquid. Water with a kinematic viscosity of 0.657 cSt has a lower kinematic viscosity compared to HyspinAWS68 which is 68 cSt. The flow rate is inversely proportional to the viscosity of the fluid. In consequence, flow rate is proportional to the shaft speed and reciprocal to the torque. To be more precise, the lower viscosity of water causes frequent internal leakage that eventually decreases the performance of torque.

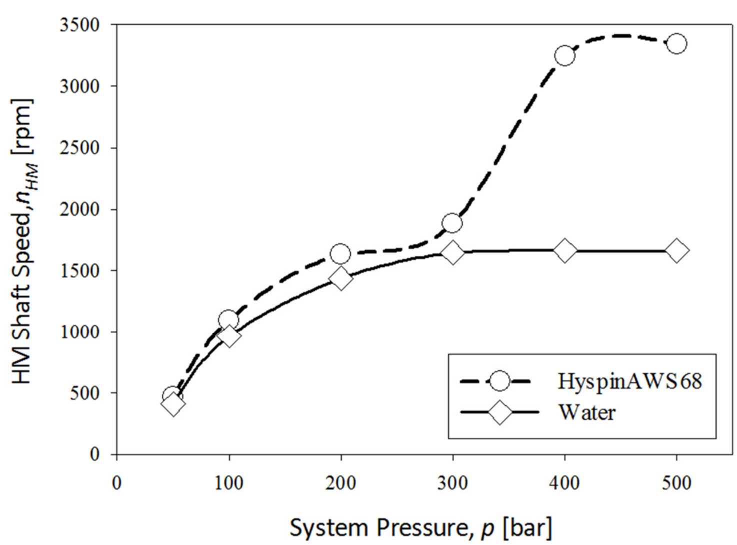

Fig. 16. The effect of HM shaft speed during discharge mode

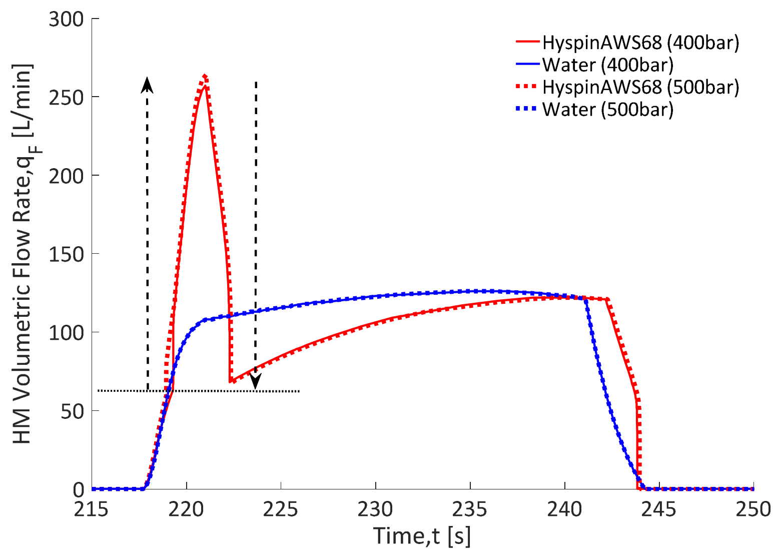

Fig. 17. HM volumetric flow rate at 400 bar, and 500 bar

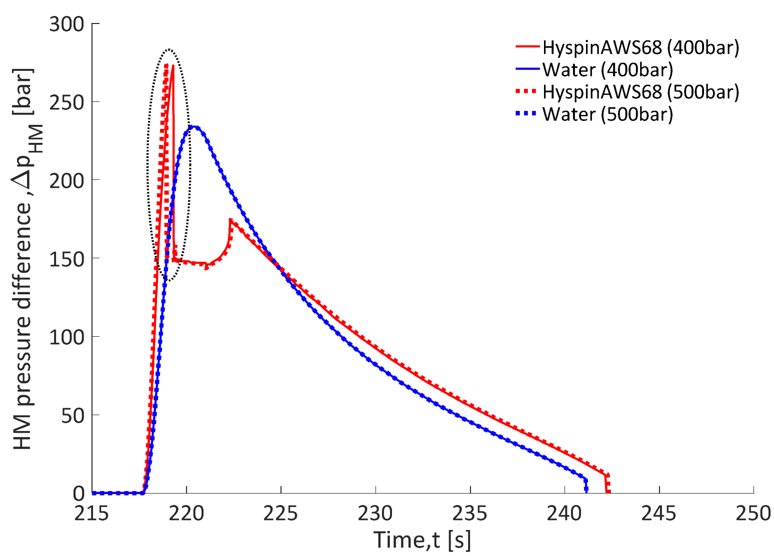

Fig. 18. Pressure spike at HyspinAWS68 at 400 bar and 500 bar

Figure 16 shows the effect of HM shaft speed during discharge mode. At 400 bar and 500 bar, shaft speed at HyspinAWS68 increase instantly causes a wide gap between HyspinAWS68 and water. Surprisingly, Figure 17 shows that an instant increment of HM volumetric flow rate at 400 bar and 500 bar of HyspinAWS68 which is the explanation for the immediate increase of HM shaft speed. In general, shaft speed is related to the volumetric flow rate. In response to the assertion above, Figure 18 indicates that a pressure spike has been detected at HyspinAWS68 at 400 bar and 500 bar. This factor causes the sudden increment at shaft speed and volumetric flow rate. A reasonable approach to tackle this issue by analyzing on the HM volumetric efficiency. As seen in Figure 19, the optimum volumetric efficiency for hyspinAWS68 and water is in the range of 100 bar to 300 bar. At 400 bar and 500 bar, the volumetric efficiency of HyspinAWS68 drops due the issue of shaft speed that increase instantly as shown in Figure 16.

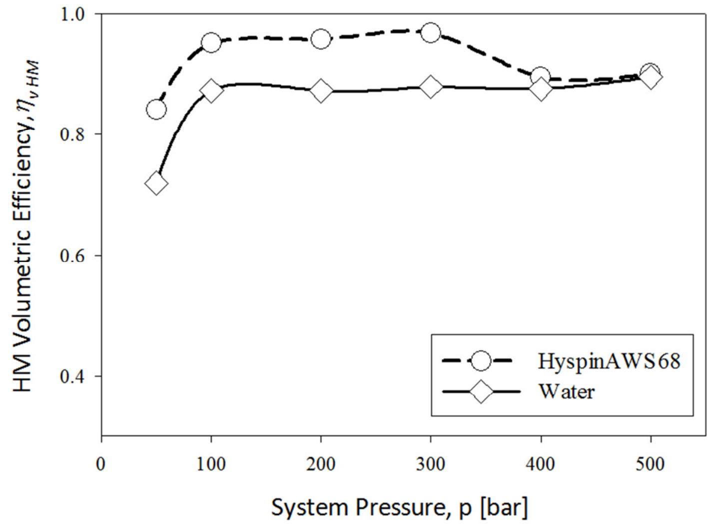

Fig. 19. HM volumetric efficiency during discharge mode

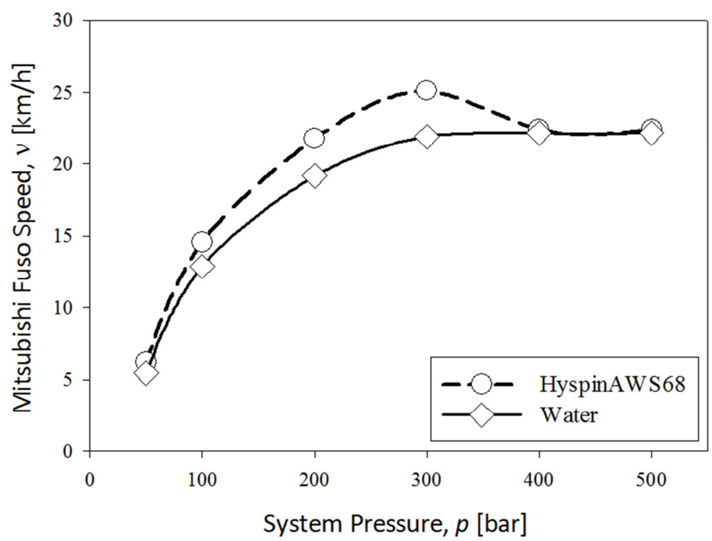

Fig. 20. Mitsubishi Fuso 6D34-0AT2 optimum speed during discharge mode

From the curve in Figure 20, it is apparent that the application of HyspinAWS68 leads the Mitsubishi Fuso 6D34-0AT2 to move faster compared to water. This due to the low power losses of HyspinAWS68 as shown in Figure 21, and higher total efficiency as shown in Figure 22. The most striking result emerges from the curve is that the fastest speed of both liquids is at 300 bar with the rate of 25.12 km/h for hyspinAWS68 and 21.94 km/h for water as shown in Table 5. A faster speed at the 1st gear of vehicle contributes advantages compared to other system pressure as it will cut down the use of diesel oil that is ingested by the truck. However, the most significant factor should be considered at the 1^{st} gear is the capability of torque to drive the Mitsubishi Fuso 6D34-0AT2 to move forward from a static position. Moreover, as shown in Figure 22, the best efficiency of water is in the range of 50 bar to 200 bar. Furthermore, power loss less occurred in the system at the same range of 50 bar to 200 bar. So that, multiple regression analysis revealed that the best performance of Mitsubishi Fuso 6D34-0AT2 during discharge mode is in the range of 100 bar to 200 bar.

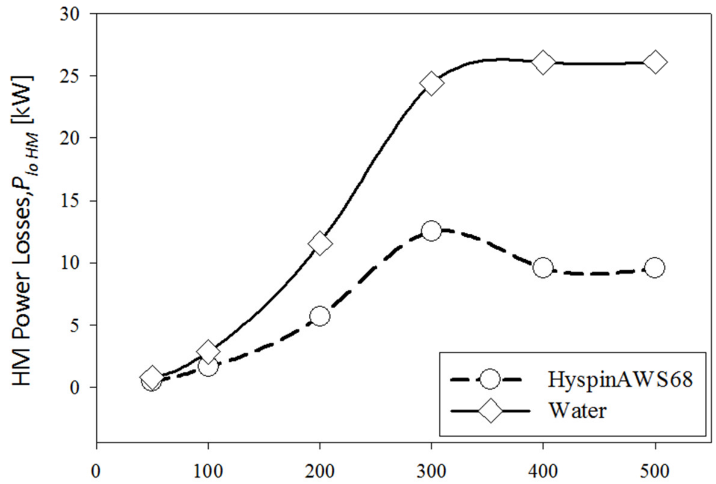

Fig. 21. Power losses at HM during discharge mode

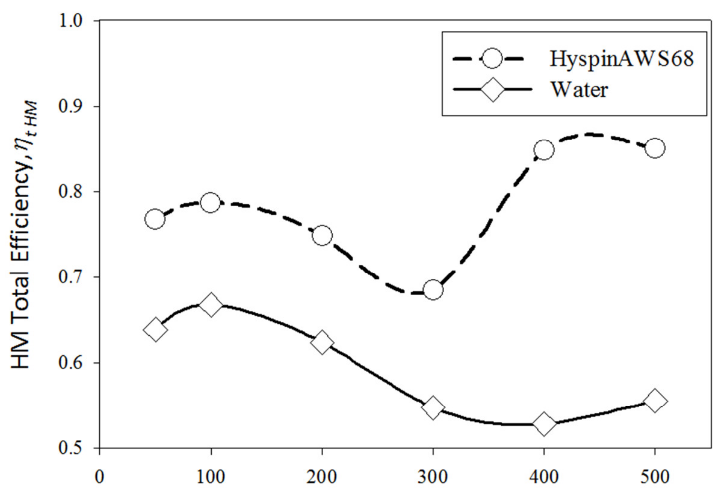

Fig. 22. Total efficiency of HM during discharge mode

4. Conclusions

Water has a bright future to replace mineral oil as a hydraulic fluid for power-control hydraulic. Although, mineral oil has a better efficiency compared to water, the value of efficiency proves that the difference of efficiency between both liquids is at average of 0.15, so that water still has a huge opportunity to surpass the feasibility of mineral oil. The lack in efficiency is due to the new technology of water causes less hydraulic component that compatible with the properties of water was introduced to the industry. Undoubtedly, the awareness of the industrial to the benefit of water hydraulic technology influences the advancement of water hydraulic technology. The study on the effect of system pressure, specification of hydraulic motor and accumulator sizing on the hydraulic hybrid driveline shows significant indication regarding the fluid properties. There are several challenges faced by the hydraulic technology such as internal leakage, pressure drop, bulk modulus, density of the fluid. These findings provide a clear guide for future research.

Acknowledgement
This research was funded by a grant from Ministry of Higher Education of Malaysia (FRGS/1/2016/TK03/FKM-CARE-F00317).

References

[1] Lindzus, Eric, and Bosch Rexroth AG. "HRB–Hydrostatic Regenerative Braking System: The Hydraulic Hybrid Drive from Bosch Rexroth." *Bosch Rexroth AG* (2008).
[2] Valente, Sérgio, and Hélder Ferreira. "Braking energy regeneration using hydraulic systems." *Portugal: Polytechnic Institute of Porto (IPP)* (2008): 8.
[3] Kumar, E.R.A., Hydraulic Regenerative Braking System. *International Journal of Scientific & Engineering Research* 3(4) (2012) 1–12.
[4] Clegg, S. J. "A review of regenerative braking systems." (1996).
[5] Kargul, John, Andrew Moskalik, Kevin Newman, Daniel Barba, and Jeffra Rockwell. "Design and Demonstration of EPA's Integrated Drive Module for Commercial Series Hydraulic Hybrid Trucks and Buses." *SAE International Journal of Commercial Vehicles* 8, no. 2015-01-2850 (2015): 549-567.
[6] Chen, H., P. Chua, and G. Lim. "Fault diagnosis of water hydraulic motor by adaptive wavelet analysis optimized by genetic algorithm." *International Journal of Applied Mathematics and Mechanics* 2 (2005): 57-78.
[7] Yusof, Ahmad Anas, Shafizal Mat, and Abdul Talib Din. "Promoting sustainability through water hydraulic technology–The effect of water hydraulic in industrial scissor lift." In *Applied Mechanics and Materials*, vol. 315, pp. 488-492. Trans Tech Publications, 2013.
[8] Yusof, Ahmad Anas, Faizil Wasbari, and Mohd Qadafie Ibrahim. "Research development of energy efficient water hydraulics manipulator for underwater application." In *Applied Mechanics and Materials*, vol. 393, pp. 723-728. Trans Tech Publications, 2013.
[9] Yusof, Ahmad Anas, F. Wasbari, Mohd Shukri Zakaria, and Mohd Qadafie Ibrahim. "Slip flow coefficient analysis in water hydraulics gear pump for environmental friendly application." In *IOP Conference Series: Materials Science and Engineering*, vol. 50, no. 1, p. 012016. IOP Publishing, 2013.
[10] Zaili, Zarin Syukri, Ahmad Anas Yusof, Mohd Nor, Nur Fathiah, Mohd Hanafi, Mohd Hafidzal, and Mohd Qadafie Ibrahim. "Characteristics of a Reciprocating Pump for Low-Cost Sustainable Water Hydraulic Technology Demonstrator." In *Applied Mechanics and Materials*, vol. 699, pp. 736-741. Trans Tech Publications, 2015.
[11] Yusof, Ahmad Anas, Zarin Syukri Zaili, Siti Nor Habibah Hassan, Tee Boon Tuan, Mohd Noor Asril Saadun, and Mohd Qadafie Ibrahim. "Promoting water hydraulics in Malaysia: A green educational approach." In *AIP Conference Proceedings*, vol. 1621, no. 1, pp. 297-302. AIP, 2014.
[12] New Hampshire Department of Environmental Services. Environmental Fact Sheet 2014. “Diesel Vehicles and Equipment: Environmental and Public Health Impacts,” no. 1–2.
[13] Lim, G. H., P. S. K. Chua, and Y. B. He. "Modern water hydraulics—the new energy-transmission technology in fluid power." *Applied Energy* 76, no. 1-3 (2003): 239-246.
[14] KOBAYASHI, Wataru, Kazuhisa ITO, Shigeru IKEO, Tsuyoshi YAMADA, and Koji TAKAHASHI. "Study on Energy Efficiency of Water Hydraulic Fluid Switching Transmission." In *Symposium on Fluid Power*, vol. 2011. 2011.
[15] Hydraulics co.ltd. The water, 2005. *Janus Motors - Axial Piston*. FM87247. Retrieved from Water Hydraulics Company Website: https://www.waterhydraulics.co.uk/motors.html (accessed 5 December 2016).
[16] Hydac, 2012. Bladder Accumulators Standard. Retrieved from Hydac Website: https://www.hydac.com/de-en/products/hydraulic-accumulators/bladder-accumulators/standard high-pressure-bladder-acc/show/Download/index.html (accessed 6 December 2016).
[17] Wu, Bin, Chan-Chiao Lin, Zoran Filipi, Huei Peng, and Dennis Assanis. "Optimal power management for a hydraulic hybrid delivery truck." *Vehicle System Dynamics* 42, no. 1-2 (2004): 23-40.
[18] KOSKINEN, Kari T., Timo LEINO, and Hannu RIIPINEN. "Sustainable Development with Water Hydraulics-Possibilities and Challenges." In *Proceedings of the JFPS International Symposium on Fluid Power*, vol. 2008, no. 7-1, pp. 11-18. The Japan Fluid Power System Society, 2008.
[19] P. Drexler. “A Training Manual for the Planning and Design of Hydraulic Power Systems” *Hydraulic Trainer*. Vol. 3. Bosch Rexroth. 2003.
[20] Hydac. Catalogue. Bladder Accumulators Standard, E 3.201.29/01.17.2012.

[21] Krutz, Gary W., and Patrick SK Chua. "Water hydraulics–theory and applications 2004." In *Workshop on Water Hydraulics, Agricultural Equipment Technology Conference (AETC'04)*, pp. 8-10. 2004.
[22] Trostmann, Erik. *Tap water as a hydraulic pressure medium*. CRC Press, 2000.
[23] Wasbari, F., R. A. Bakar, L. M. Gan, M. M. Tahir, and A. A. Yusof. "A review of compressed-air hybrid technology in vehicle system." *Renewable and Sustainable Energy Reviews*67 (2017): 935-953.
[24] Saadun, Mohd Noor Asril, Ahmad Anas Yusof, and Muhammad Ismail Zakaria. "Development and Analysis of Small Scale Water Accumulator by Using Piston Type." *Applied Mechanics & Materials* 761 (2015).