Development of a Constant Flow Rate Pumping System for Oil Delivery Vehicles

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***Abstract*-In the present study, performances of a specially designed constant flow rate pumping system for different working fluids, delivery oils, with critical different density was tested experimentally. The controller is employed to maintain flow rate of a pumping system in spite of different initial condition variations such as pumping load and delivery material changes. As a result, the flow rate is rapidly recovered to a setting value when a controller system operates with the change of working fluid density and hydraulic pumping head loss.**

***Keywords*-Constant flow rate, pumping system, controller system, working fluid density, head loss.**

I. INTRODUCTION

To transport or deliver fluidic liquid and gas, a hydraulic pump is widely used from the past by inducing the pressure changes between inlet and outlet port [1-2]. Depending on their main objective, many different kinds of pumps have been developed, such as a centrifugal, gear-type and turbine pump etc. [3].

In this paper, we are trying to model the oil-tanker pump which is mounted on a side of an oil transportation truck. It is originally designed as a gear-typed hydraulic pump to deliver the contained oil-type liquid in the tanker properly.

In the real field, however, the contained liquid is not assumed to be the only one kind of specific oil material. This means that the working fluid of pump, delivery liquid, can be changed with the same pumping system mounted on a truck in spite of fluid property difference [4].

If there is no excessive equipment cost problem, we can solve it directly by employing the perfect corresponding pump selection for each different working fluid. However, a small poor company that operating this sort of oil-tanker truck cannot be free from the costly effect.

Another one important occurrence in the real field is the variation of pumping height where the delivery liquid reservoir is located. This can be a specific real situation case of fluid delivery as well.

If the reservoir location is over 10 m sea-level, however, there exist some changes in the performance of pumping system when it is operated on the normal same operating condition. There should be a great discrepancy or loss of fluidic momentum during the operation and differences increased at the higher hydraulic head location [5].

In the real field, the truck driver is the main operator of the pump and he cannot notice this kind of situation change sensitively. He can just switches on the pump system normally at the truck side where is very lower than the target oil reservoir height.

This kind of simple action will cause very severe bursting liquid out of the exit nozzle and excessive consuming of expensive petroleum or crude oil contents.

Therefore, the main objective of this study is mainly focused on the development of a narrowly optimized pumping system mounted on an oil-tanker truck side. It will have specific operator-demanding capability which is constant flow rate control despite of great hydraulic head loss and liquid density variations at the rage of real frequent circumstances.

II. EXPERIMENTAL APPARATUS AND METHOD

In the design stage of a pumping system, there could be lots of design factors to be considered such as pumping power, efficiency, outer shape, and performance etc. The power added to the fluid flow by the pump (P_o) is usually defined by the following.

$$P_o = \rho \cdot g \cdot H \cdot Q \qquad (1)$$

where P_o is the output of the pump (W), ρ is the fluid density (kg/m^3), g is gravitational constant (9.81 m/s^2), H is the energy head added to the flow (m), and Q is the flow rate (m^3/s).

In the present study, however, all these pump design parameter are not necessarily needed to be considered. Since the specific pumping system will be operating at a peculiar situation with a given one vehicle pump for different working fluids. It can be worked beyond the maximum power and efficiency condition according to situation changes.

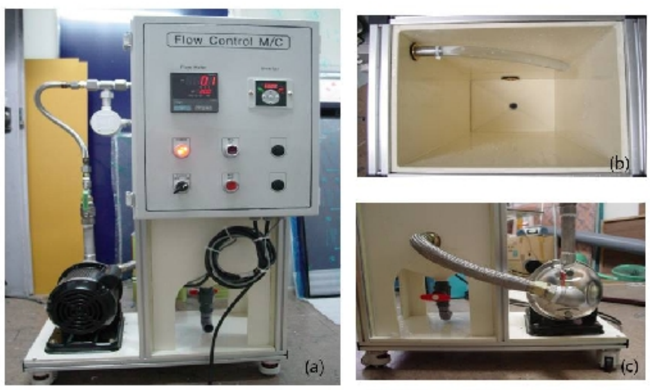

Figure (1): Photographs of constant flow rate control pumping system : (a) display panel and centrifugal pump, (b) circulation reservoir, (c) inlet and outlet piping

VOLTAGE (V/AC)	RATED OUTPUT POWER (HP)	CURRENT (A)	TOTAL DYNAMIC HEAD (m)	MAX PUMPING CAP. (L/h)
220/380	0.8	4.3/2.4	26	4200
INLET HEAD (m)	SUCTION HEAD (m)	WEIGHT (kg)	INLET DIA. (mm)	OUTLET DIA. (mm)
0	26	13.8	32	25

Table (1): Specification of centrifugal pump (PSS80066T)

WORKING FLUID	DENSITY (kg/m^3)	DYNAMIC VISCOSITY (cP)
WATER	997	0.8937
CORN OIL	930	54.44

Table (2): Properties of working fluid (at 25^oC)

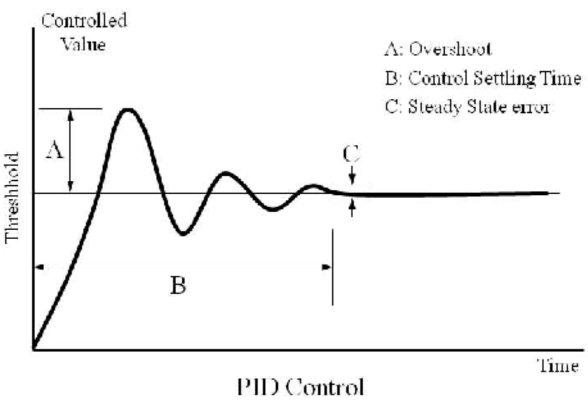

Figure (2): Flow rate response with PID controller

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To simulate the constant flow rate pumping system, a centrifugal pump, controller unit, flow meter and circulating piping system were integrated. Figure (1) shows photographs of constant flow rate pumping system used in this study. The main driving pump is centrifugal pump and its detail specification is expressed in Table (1).

For a circulation of working fluid, a big returning reservoir is located on the same stage. The flow meter sensor is installed at the end of outlet pipe.

Concerning the sensor location and position, there could be advantageous if there are several sensors through the entire piping system. However, in this study, we can assume that the outlet pipe is closed and continuity condition is satisfied.

To compare distinct working fluid density, we used two different liquids ; water and corn oil. Dynamic viscosity of corn oil is greater about 50 times that that of water. The properties are shown in Table (2).

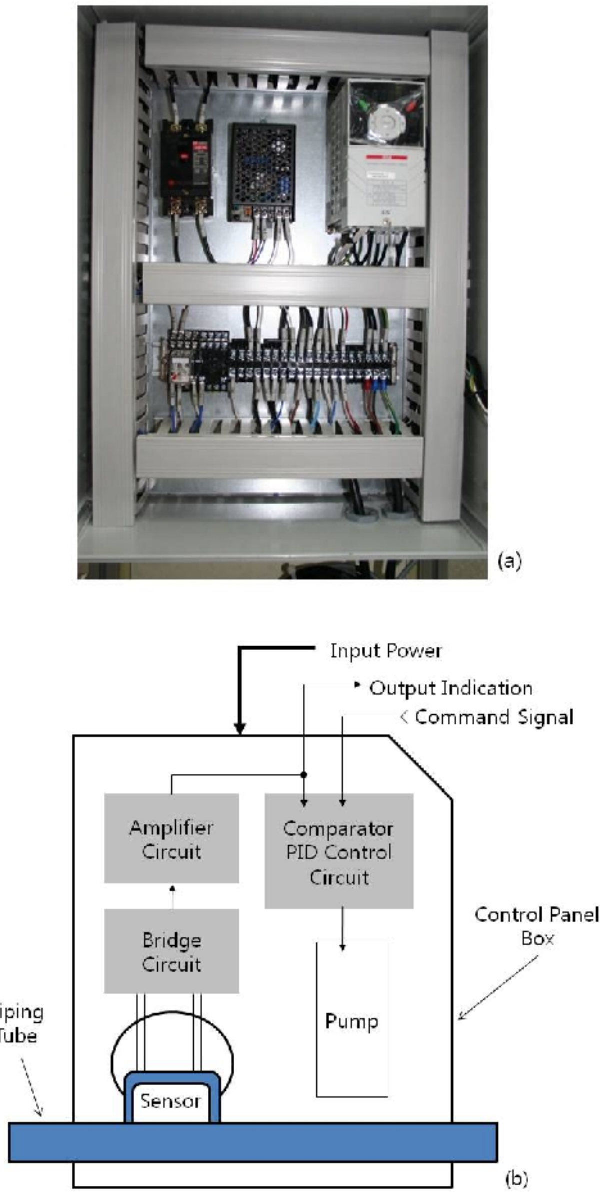

Figure (3): Flow rate controller : (a) photograph of control panel box, (b) operational diagram

In this study, there is experimental limitation in modeling the hydraulic head loss decrease by the delivery reservoir location at the higher position directly. So that, we added a flow rate control lever in front of pump outlet and simulated the reduced flow rate properly. The reduced flow rates corresponded well to those of higher reservoir locations.

Basically this kind of head loss can be calculated by employing energy conservation law and experimental head loss factors. For this calculation, we developed a program to get the exact setting pump RPM with variation of outlet height by using a graphic user interface software (HP-VEE).

The calculating procedure and more detail things are beyond the present scope so that they are not included in this paper. However, the target setting control flow rate and revolutions are referred from the result of calculation of this program.

When the target flow rate value is determined, we can input this value into the pumping system by putting in the digital value directly and it is displayed in the indicating display panel as shown in Figure (1).

In the present study, we assembled the motor speed control unit and it operates well with the PID control loop as shown in Figure (2). Total response time of the closed-loop system with PID controller is lower than 2 seconds to reach a steady state. Therefore, the output signal data of this experiment is obtained as the average of 10 seconds.

Figure (3) shows the operational diagram of constant flow rate control system used in this study. The flow rate sensor data is linearized and amplified into a 0 to 5V flow output signal by means of a bridge circuit [6].

The sensor output signal is compared with the external set point signal to the flow rate controller. The error signal that results from comparing the output signal with the set point signal directs the pump control frequency to decrease or increase motor RPM to maintain a constant flow rate.

III. RESULTS AND DISCUSSION

Figure (4) shows the basic logic diagram used for automatic constant flow rate control of the tested pumping system. When the operation mode is positioned at automatic control mode (A-mode), the feedback control system works and adjust the driving motor revolution to maintain constant flow rate.

To obtain the revolution speed of driving motor axis, a tachometer was used with the attachment of reflection plate on the moving machinery surface. For a comparison, the settling flow rate and revolution speed is correctly calibrated at manual mode (M-Mode) measurement in advance.

The target flow rate to simulate hydraulic head loss, flow rate defect ($-\Delta Q$), is controlled by hand lever valve for several valve angle variations as shown in Figure (5). Corresponding flow rate values are obtained with proper calibration procedure before the operation. The flow rate defect values are at ranges between 0 to 5 L/min.

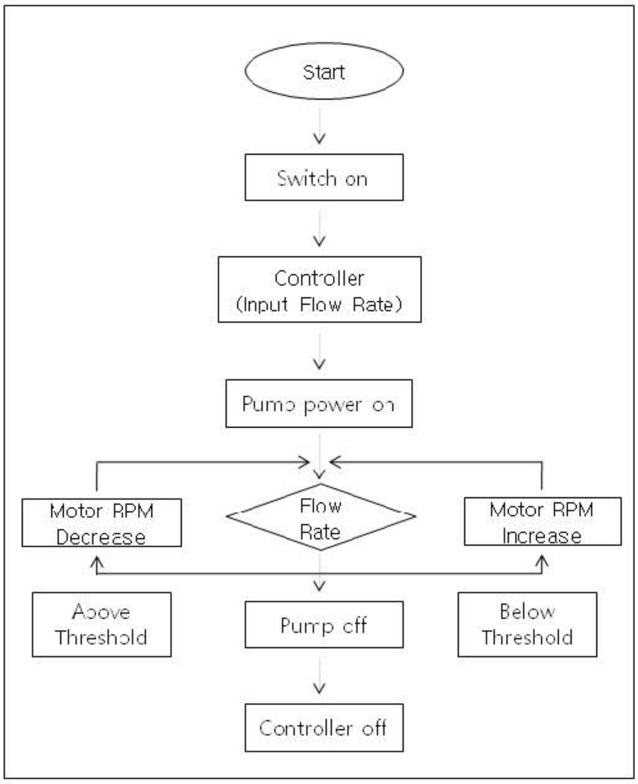

Figure (4): Basic logic diagram for constant flow rate control

Figure (5): Flow control valve for hydraulic pumping head loss

Figure (6) shows the measured inverter frequency value variation according to the flow rate decrease which corresponds to pumping head loss change with the increase of a reservoir location height. In this test, the aiming flow rate is set to 10 L/min as a reference value. Therefore, the flow rate defect value 0 corresponds to the target flow rate 10 L/min.

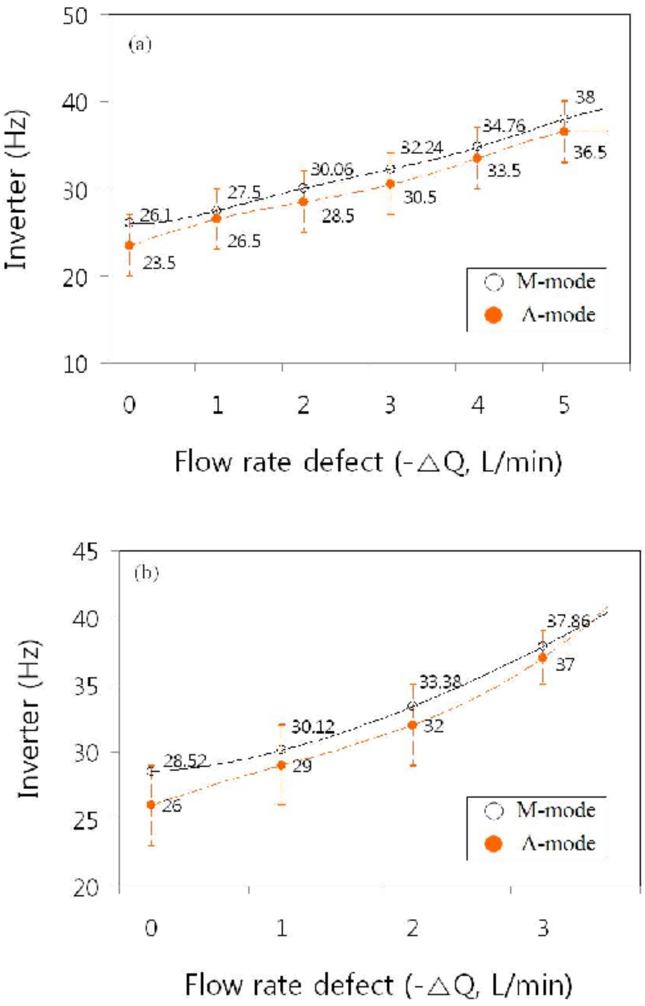

Figure (6): Variations of pump control frequency according to flow rate defect : (a) water, (b) corn oil

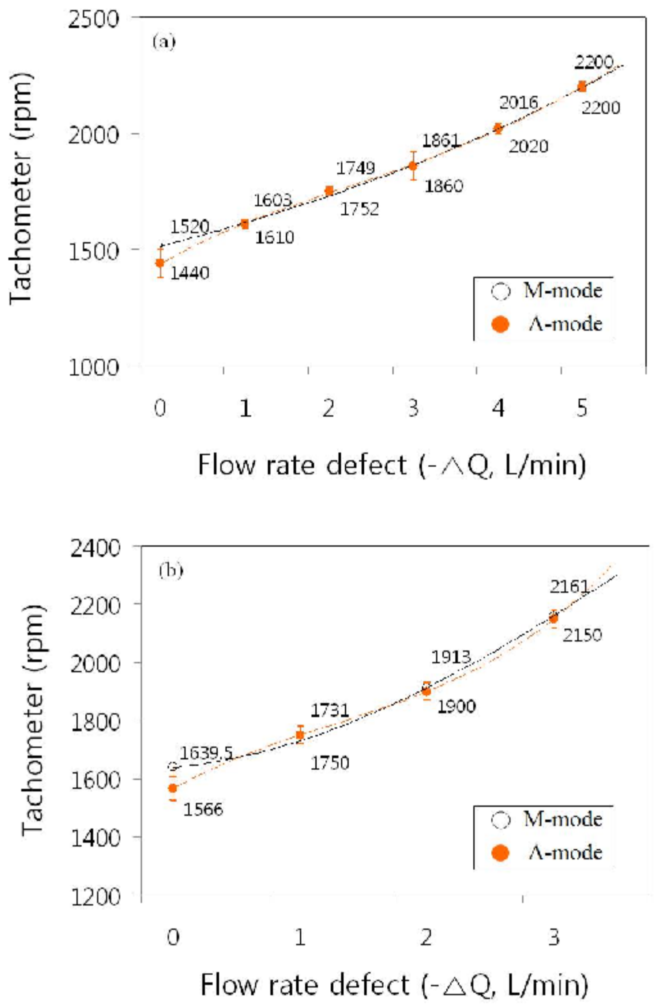

Figure (7): Revolution of driving motor with the variation of flow rate defect : (a) water, (b) corn oil

The maximum and minimum frequency values appear at the data label for references. This kind of PID control settlement recovers the driving motor revolution rapidly as mentioned before.

As the flow rate defect increases, the PID control frequency value is increased to recover the target flow rate value. By performing this kind of feedback control, the flow rate maintained as the constant value after a short settling time to steady state.

However, there still exists discrepancy between manually set flow rate value and that of automatic control mode. It is basically attributed to the other kinds of viscous and pressure loss caused from the flow blocking valve and piping system.

Figure (7) shows the corresponding driving motor revolution according to the flow rate defect. The RPM is measured from the reflecting laser signal by the handheld tachometer.

Differently the above frequency, the motor RPM value recovers more perfectly than those controls of flow rate from the flow meter sensor. It means that there exist time response lag between the electric signals following from the fluidic motion of inertia.

IV. CONCLUSION

In the present study, performance of a specially designed constant flow rate pumping system for different working fluids with critical different density was tested experimentally. The controller is employed to maintain flow rate of a pumping system despite of different initial condition variations and works well.

As a result, the flow rate is rapidly recovered to a setting value when a controller system operates with the change of working fluid density and hydraulic pumping head loss.

Based on this kind of evaluation results, we can apply this flow rate control system to an oil-tanker truck pumping system. For the future work, we should reduce the pumping system size to a proper mountable system level.

ACKNOWLEDGEMENTS

This work was supported by the NURI project, Korea Research Foundation (KRF) Grant funded by the Korea Government (MEST) (No. 20090069912) and Korea Research Foundation Grant funded by the Korean Government (KRF-2008-313-D00146).

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