EFFECT OF HYDRAULIC RESISTANCE ON THE ROTATION SPEED AND FLOW RATE OF GEAR PUMPS

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ABSTRACT

Gear pump performance can be degraded by hydraulic resistance (**R_h**) in the flow path connected to the pump, a condition frequently encountered in household applications. Precise flow rate control is essential for optimal pump operation. While traditional approaches assume constant pump speed, real-world scenarios show that **R_h** affects both pump speed and flow rate, impacting pressure. In this study, a combination of experiments and simulations was conducted to examine how **R_h** influences flow rate and pump speed. Experimental data was gathered from a pump module supplied with constant voltage, and simulations were used to visualize the flow field and pressure distribution. Simulation error, uncorrected for RPM variations, was found to increase with **R_h**, reaching a maximum of 48%. To enhance prediction accuracy, a feed forward neural network (FFNN) was implemented, using experimental data to predict **R_h** and pump performance across different conditions. By accounting for the impact of **R_h** on pump speed in simulations, flow rate prediction accuracy was significantly improved, with the FFNN achieving an error margin within 2% when predicting pump performance based on **R_h** in the flow path.

KEY WORDS

External gear pump, Hydraulic resistance, Feed forward neural network (FFNN), Flow rate prediction.

1. INTRODUCTION

An external gear pump is widely used in fluid systems due to its high resistance to contamination and low manufacturing costs. Accurate prediction of the pump's discharge flow rate is essential in processes like food manufacturing and chemical processing, where precise fluid supply is required. [1] Therefore, various preliminary studies have been conducted to more accurately simulate the operation of external gear pumps through computational analysis. For example, D. del Campo et al. performed an analysis that considers cavitation occurring at high rotational speeds. [2] VG de Bie et al. compared 2D model-based analysis with a 3D model to observe the relative impact of gear and casing clearance depending on the model type. [3] Despite these efforts, most studies have focused on standalone pump analysis, without considering the changes in pump performance caused by feedback resistance when the pump operates in a system with **R_h**. In academic research, the conditions of the pump, such as flow rate or inlet/outlet pressure, are controlled. [4] Therefore, existing studies do not consider the pumps for consumer products on the market cannot precisely control output due to the integrated power structure for low production costs.

In this study, the performance degradation of an external gear pump due to **R_h** was observed based on a water supply system in a refrigerator. The simulation error from the slowed pump rotation speed was observed through simulations applying different rotation speeds and compared with experimental results.

2. MATERIAL & METHOD

2.1 Experiment setup

A refrigerator equipped with a water supply system powered by a 12V gear pump (ZB-1.7, KIND) (Monarch 2, LG Electronics, South Korea) is utilized for the experiment. The pressure at the pump's downstream end was measured using a digital differential pressure gauge (665L, TPI, USA). The pump noise recorded by a microphone (Studio Pro, Titan, South Korea) was analyzed using the fast Fourier transform (FFT) tool in MATLAB R2021b (MathWorks, USA), converting the fundamental frequency component of the noise to RPM. To measure flow rate, a digital precision scale (FX-3000i, AND, South Korea) connected to a portable PC (13UD50N, LG Electronics, South Korea) was placed at the outlet to acquire mass flow by tracking the change in discharged water weight over time.

The water supply system includes two orifices of different inner diameters to prevent flow pulsation caused by the pump from affecting the flow rate. The **R_h** of these orifices was unknown, with the narrower orifice defined as W_{narrow} and the wider one as W_{wide}. To observe changes in pump performance under various **R_h**, we arranged PE pipes with inner diameters of 4.2 mm, 2.5 mm, and 1.59 mm at arbitrary lengths. The **R_h** for circular pipes was calculated using the following formula:

$$\boldsymbol{R_h} = \frac{8\mu L}{\pi r^4} \quad (1)$$

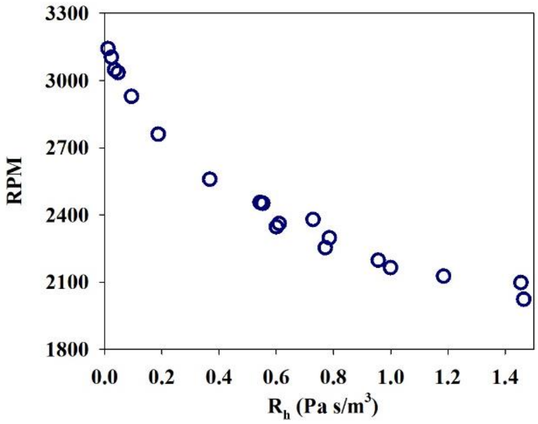

Fig. 1 Effect of $\mathbf{R_h}$ on pump rotational speed.

where μ represents the viscosity of water, L is the pipe length, and r is the inner radius of the pipe.

2.2 CFD Simulation

To simulate gear pump rotation, we used CFX (2021 R2, ANSYS Inc., USA) to observe pressure distribution and flow velocity within the pump. The working fluid was room-temperature water, with cavitation at high-speed operation considered. Both the inlet and outlet boundary conditions were set to atmospheric pressure. Through comparison with experimental results, the k-ε model is selected for turbulence model for simulation. Simulations were conducted for the ideal pump speed (3300 RPM) and the actual speeds obtained experimentally for each orifice type to compare the accuracy of flow predictions at the outlet with the experimental results.

3. RESULT & DISCUSSION

In the experiment, the pump sample operated at 3183 RPM and produced a mass flow rate of 28.24 g/s when running without any additional resistance elements. Fig. 1 shows the correlation between RPM and $\mathbf{R_h}$ when the pipe inner diameters of 4.2 mm, 3.18 mm, and 1.59 mm were varied within ranges of 16m, 10m, and 1.6m, respectively, adjusting $\mathbf{R_h}$ from a minimum of 117.1 MPa·s/m³ to a maximum of 14553.5 MPa·s/m³, while keeping the pump's voltage input constant. Based on the refrigerator's standard flow path, when using W_{wide} and W_{narrow}, the flow rates were 20.38 g/s and 7.57 g/s, respectively. Correspondingly, the pump RPMs were reduced to 2652 RPM and 2010 RPM, showing significant decreases of 18.7% and 38.34% compared to the non-resistance scenario.
Fig. 2 presents the simulation and experimental results for the water supply system with orifices of different diameters. For W_{wide}, the simulation at Fig. 2 Effect of rotational speed compensation on the flow rate error between simulations and experiments using two types of orifices. 3300 RPM showed an 11.5% flow rate discrepancy from the experimental result, while for W_{narrow} with higher resistance, a larger 48.0% discrepancy was observed. This indicates that as the system's $\mathbf{R_h}$ increases, the deviation between simulation and

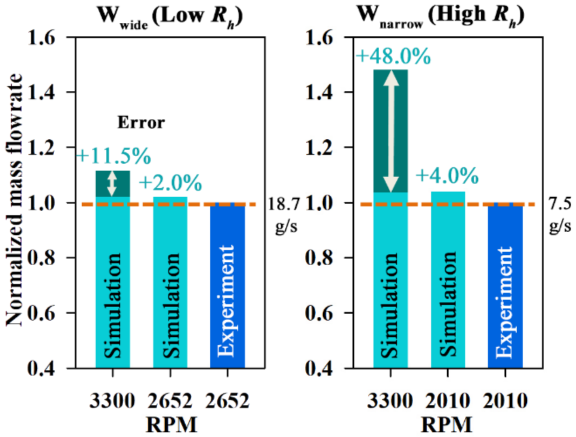

Fig. 2 The effect of rotational speed compensation on the flow rate error between simulations and experiments using two types of orifices.

experiment grows if RPM reduction is not accounted for. When experimental RPM reduction was used in the simulation, the discrepancies improved to 2.0% and 4.0%, respectively. Thus, to accurately predict flow rates in systems with gear pumps, the RPM reduction due to $\mathbf{R_h}$ should be incorporated as a boundary condition in the simulation. normalized relationships among $\mathbf{R_h}$, RPM, pressure, and flow rate obtained from the experiments. This model will then be used to estimate unknown $\mathbf{R_h}$ values through regression analysis. Furthermore, by predicting pump performance based on the $\mathbf{R_h}$ of each component, we intend to provide a practical tool for estimating discharge flow rates. This tool could be used to design derivative products by modifying the flow path based on the same components.

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