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Effects of Flow and Oil Properties on Filter Service Life¹

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1. Introduction

In fluid power systems, one of the most common causes of failure is contamination of the hydraulic fluid. In addition to its main function, i.e., to transfer energy, the fluid acts as a lubricant between moving parts in the components, enabling control of friction, wear and operating temperature.

In order to avoid machine downtime and loss of production, it is important to maintain adequate technical performance level of the fluid at all times. This is done by filtering, without which the fluid gets contaminated with harmful particles over time. Excessive concentration of particles in the fluid will cause excessive wear of components or block motion of parts in flow control valves. Wear can cause, e.g., insufficient efficiency or even failure of pumps, and jammed parts in control valves can cause unreliable and erratic motion in actuators. These potential detrimental effects stress the importance of maintenance of fluid filter units.

Filter elements are usually replaced according to pre-defined time-schedules, but this is inefficient as the maintenance actions are not based on the actual time-history of the filter unit and the fluid system. Time-based maintenance can either lead to premature replacement of filters, or lead to excessive contamination levels in the fluid due to unforeseen sudden increase of particle load during the presumed service period. Condition-based maintenance of filter elements can be made possible by continuously measuring the pressure drop over the filter element and using the measured value in a filter model to predict the remaining lifetime of the element.

Comprehensive laboratory tests have been made in order to produce filtration performance data relating the effect of flow rate, contaminant particle concentration, and fluid temperature to the pressure drop measured over the filter element. This work demonstrates the mathematical correlation models derived from the experimental data.

¹ This extended abstract is a synopsis of the work submitted for publication in [1] and [2].

2. Methodology

The study to create correlation models for the pressure drop across a filter element was twofold: perform laboratory tests at different fluid conditions, and then develop mathematical correlations describing the effects of different conditions on the pressure drop development.

2.1 Experimental

The experimental part consisted of measuring the filter pressure drop at different oil conditions. For this purpose, a test bench with multiple sensors monitoring the different conditions was constructed. The filter type used in the experiments was a 5 μm rated commercial filter with glass fiber media that has an effective surface area of 0.154 m^2 through 57 pleats. The oil that was used was the standard ISO VG 32 hydraulic oil. [3]

The different oil conditions considered for this study were the oil flow rate, temperature, and gravimetric contamination level. For adjusting the gravimetric contamination level, the fluid was subjected to ISO medium test dust (ISO12103-1-A3) at different rates resulting in four different contamination levels at 2 mg/l, 5 mg/l, 8 mg/l and 10 mg/l. The flow rates at different experiments were set to be either 40 l/min, 80 l/min or 120 l/min, and the fluid temperatures were adjusted between 30 °C, 40 °C, 50 °C, and 60 °C. With four different contamination levels, three different flow rates, and four different fluid temperatures, 48 experiments in total were conducted. Figure 1 showcases examples of different experiments, and illustrates the types of effect that the different oil conditions have on the pressure drop development over time.

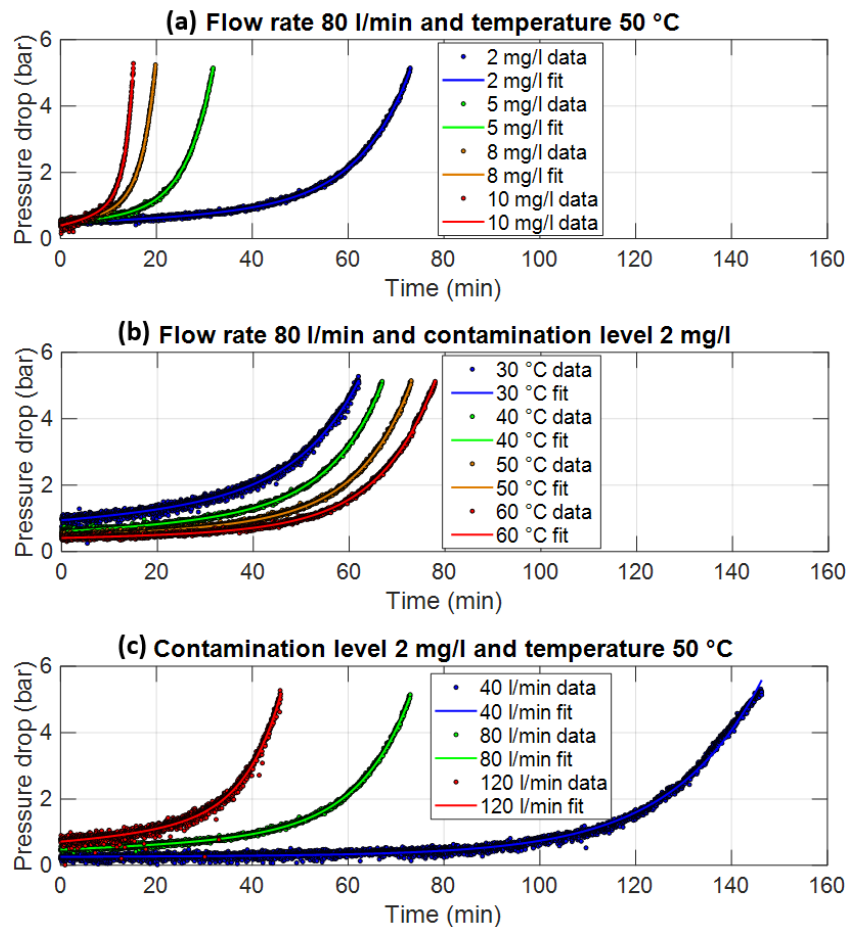


Figure 1. Example of effects of operating conditions on the pressure drop development during experiments.

2.2 Modelling

The main goal of this study was to establish models that will describe the development of the pressure drop across the filter element and the length of its service life. Based on the experimental data, the model will consist of an equation of physical variables:

$$\Delta p = f(t, q_v, T, \rho_c) \quad (1)$$

where t is time, q_v is volumetric flow rate, T is temperature, and ρ_c is mass concentration i.e. the gravimetric contamination level. The approach used for constructing the model was regression analysis. Different models were experimented with, but the best fitting was discovered to be with an exponential function that has two exponential terms, resulting in a function:

$$\Delta p = \left(\Delta p_0 - \left((x_1 q_v \rho_c + x_2 q_v^{x_3}) \nu + x_4 q_v^{x_5} \rho_c + x_6 q_v \right) e^{x_7 q_v \rho_c t} + \left((x_1 q_v \rho_c + x_2 q_v^{x_3}) \nu + x_4 q_v^{x_5} \rho_c + x_6 q_v \right) e^{x_8 q_v \rho_c t} \right) \quad (2)$$

where Δp_0 is the initial pressure drop, ν is kinematic viscosity, which is calculated from temperature, and x_1 — x_8 are constants.

In addition to deriving an equation for the entire pressure drop development, a simpler equation was derived that would only give the service life duration of a filter element. This was possible as the slopes of the different Δp curves were found to be extremely similar. Figure 2 demonstrates how the different oil parameters affect the total lifetime of a filter unit.

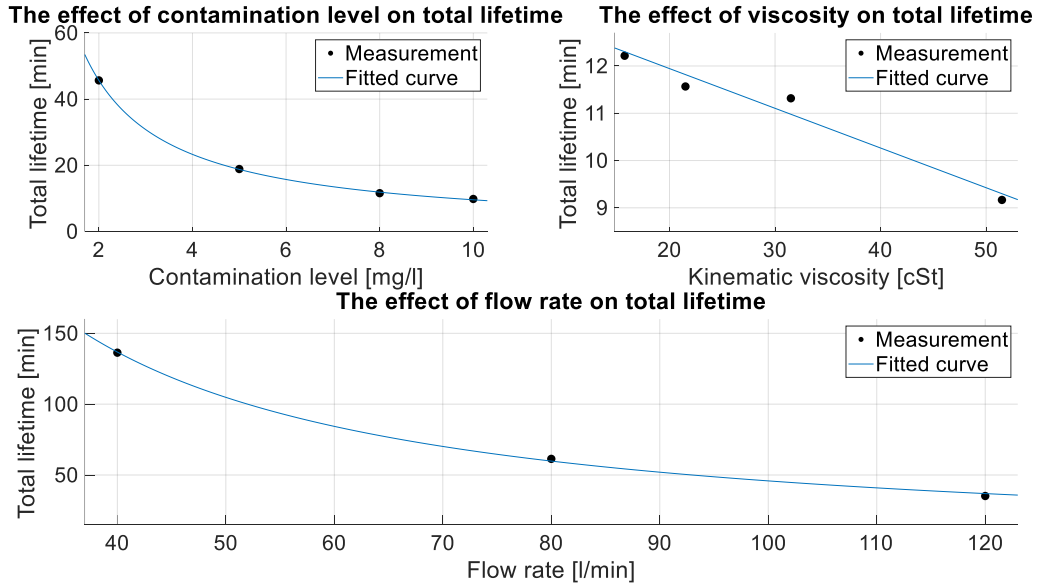


Figure 2. Examples of effects of operating conditions on the total lifetime. Cases 120 l/min and 50 °C (upper left), 120 l/min and 8 mg/l (upper right), 2 mg/l and 30 °C (bottom).

With regression analysis, the following equation was derived for the total lifetime of the filter element:

$$t = (x_2 \cdot \nu + x_3 \cdot q_v^{x_4}) \cdot \rho_c^{x_1} \quad (3)$$

where q_v is volumetric flow rate, ρ_c is contamination level, ν is kinematic viscosity, and x_1 — x_4 are constants.

3. Results

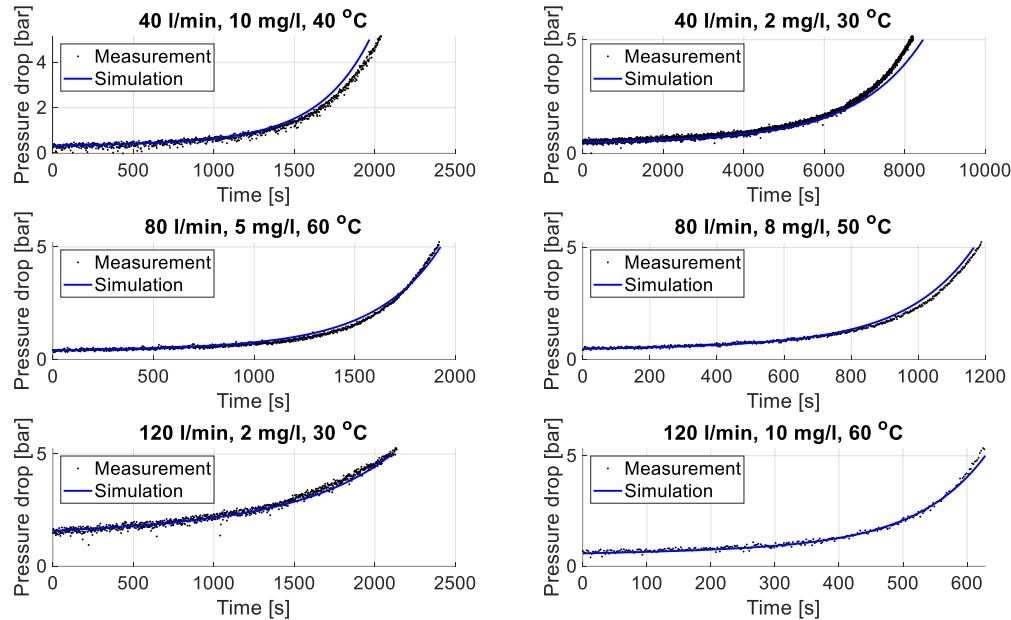


Figure 3. Comparisons of measured pressure drop curves and simulated with Equation (2).

Table 1. Comparing the lifetimes of experimental results and estimated that were calculated with Equation (3).

Flow configuration (q_v - T - ρ_c)	Actual lifetime (min)	Predicted lifetime (min)	Error (%)
40-30-2	136.3	138.3	1.5
40-40-10	31.7	33.8	6.1
80-50-5	30.5	31.7	3.5
80-60-10	16.3	16.5	1.3
120-50-5	19.4	18.9	3.0
120-30-8	9.0	9.2	2.1

4. Discussion

The model developed in this study can predict the development of Δp up to 5 bar with a high degree of accuracy (Figure 3). When comparing the simulation results with corresponding measurements, the coefficient of determination R^2 typically had a value of over 0.98. The greatest variance between the simulated and measured results can typically be observed at the end of the simulation, though the greatest inconsistencies in the experimental results also occurred at the end, making the end of the Δp curve the greatest area of uncertainty. The simpler equation for the total filter lifetime can predict the service life accurately as well, with only a small percentage of error (Table 1).

The models can accurately describe the pressure drop evolution over the whole filter lifetime as well as give the total lifetime estimation, when the operating conditions remain stable. This situation is likely in many industrial applications with fluid power systems, or lubrication systems running continuously until the next service break. However, there is no guarantee that the models would work for applications with varying flow conditions. Another aspect is that the models are most likely media specific, and cannot therefore be directly applied for other filter types. The coefficients that were considered constants in this study would most likely vary based on the filter media. Though the effects of different oil conditions on filter service life as demonstrated in Figure 2 are likely similar across different types of hydraulic oil depth filters. As laboratory tests that were performed at careful conditions were the basis of this research, further confirmation of the accuracy of the developed models would require additional field-testing.

5. Conclusions

The objective of this study was to develop correlation models for the pressure drop across a filter element that is subjected to a stream of contaminated oil at different oil contamination levels, flow rates and temperatures. The resulted models were validated against experimental data and were found to match the data with high degree of accuracy.

This study has been done as part of an initial research in order to investigate correlations between oil conditions and filter service time. The ultimate goal of the research is to develop an intelligent oil filter that can predict its remaining lifetime. This information will be used in predictive maintenance to eliminate unnecessary filter replacements, and to prevent downtime due to a filter failure.

References

- [1] Jokinen, A., Caloniuss, O., Gorle, J., and Pietola, M. Data correlation models for hydraulic fluid filter condition monitoring. The Sixteenth Scandinavian International Conference on Fluid Power (SICFP), May 22-24, 2019, Tampere, Finland. In review.
- [2] Gorle, J.M.R., et al. Correlation between flow and fluid parameters for hydraulic filter element's lifetime. 29th CIMAC World Congress on Internal Combustion Engines, 10–14 June 2019, Vancouver, Canada. In review.
- [3] Gorle, J., Heiskanen, V-M., Nissi, S. & Majas, M. 2018. Effect of temperature, contamination and flow rate on hydraulic filtration. *MM Science Journal* 2018, pp. 2490-2493.
https://doi.org/10.17973/MMSJ.2018_10_201852.