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BUBBLE ELIMINATION FOR ENVIRONMENTALLY FRIENDLY DESIGN OF HYDRAULIC SYSTEMS

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ABSTRACT

Air entrainment in working fluids has great detrimental effects on function and lifetime of the fluid power components and systems. It is important to eliminate the air bubbles from the working oil to preserve oil quality, system performance, and to avoid possible damage of the components. In view point of environmental compatibility, energy saving, cost saving, and high efficiency, one trend in fluid power systems is for them to be designed in a more compact fashion, requiring less fluid in the reservoir and long lifetime of the working oil. A new device using swirl flow for bubble elimination capable of eliminating bubbles and of decreasing dissolved gases has been developed. In this paper we focus on the technical issue for the air bubbles and aging behavior of the hydraulic oil. In order to investigate the effectiveness of the developed bubble elimination device, changes of oil degradation were experimentally measured on our laboratory test bench under the pump operating conditions during 456 hours of continuous running. Oil specimens are sampled and change of a total acid number and a color is investigated as a function of the working time.

KEY WORDS

Bubble elimination, Environmental compatibility, Long lifetime of oil, Total acid number

NOMENCLATURE

P_1 : atmospheric pressure
P_2 : supplied pressure
T_1 : ambient temperature
T_2 : temperature of compressed bubble
κ : specific heat ratio of air

INTRODUCTION

In the 21st century, prevention of global warming and consideration for environmental compatibility are the most important problems for sustainable development of human beings. Recent energy prices and raw material costs are soaring into the stratosphere. Status of fluid power components and systems is becoming an increasingly severe situation. Improvement in efficiency of current uses of fluid power in industries saves energy costs. Meanwhile the advantage of fluid power is to be a compact, portable and powerful actuation.

In view point of environmental compatibility, energy saving, cost saving, and high efficiency, one trend in fluid power systems is to design in a more compact fashion, requiring less oil in the reservoir and long

lifetime of the working oil.
All hydraulic fluids contain an amount of dissolved air, which can be released when the pressure is decreased rapidly from the high pressure to the atmospheric pressure conditions. A cavitation occurrs and bubbles can be created under these conditions. This can occur at valves and orifices, as well as where the fluid returns to the reservoir. Moreover, in mobile hydraulic systems, hydraulic fluids are accumulated, splashed and agitated in the reservoirs. Under these conditions air is sucked into the hydraulic fluid. To overcome air entrainment in hydraulic fluids, the overall dimensions should enclose a sufficient volume of oil to permit air bubbles to escape passively during the stationary time of the fluid in the reservoir. These design policies turn the clock back to more compact design of fluid power systems.
Air entrainment in working fluids has great detrimental effects on function and lifetime of the hydraulic fluids or the fluid power components and systems. The entrained air may cause major problems [4], such as bulk modulus change, cavitation and aeration, noise generation, oil temperature rise [2], and deterioration of oil quality [1]. Especially, when bubbles in oil are adiabatically compressed at high pressure in piston chambers of pump, the temperature of the bubble rises sharply, the surrounding fluid temperature also rises, and the oil degradation is accelerated. Thus, it is important to eliminate the air bubbles from the oil to preserve oil quality, system performance, and to avoid possible damage of the components.
One of the authors has developed a new device that could effectively eliminate air bubbles from working oils [5]. This device is called a bubble eliminator.
In this paper we focus on the technical issue for the air bubbles and aging behavior of the hydraulic oil. In order to investigate the effectiveness of the developed bubble elimination device, changes of oil degradation are experimentally measured on our laboratory test bench under the pump operating conditions during 456 hours of continuous running. Oil specimens are sampled and change of a total acid number is investigated as a function of the working time. It is experimentally confirmed that the bubble elimination prevents the degradation of hydraulic oils.

BUBBLE ELIMINATOR

Figure 1 illustrates the structure and principle of the bubble eliminator. It consists of an inlet tube having two inlet ports, a tapered tube chamber and a straight tube. When the oil with bubbles flows tangentially into the inlet tube, a spiral flow generates in the inlet tube and the tapered tube chamber. The air bubble is separated from the working oil and trapped near the central axis by a swirling flow, because the weight of the air bubble is lighter than the oil. The pressure along the central axis diminish toward the end of the tapered tube chamber and recovers gradually along the straight tube. The trapped bubbles gather together and form an air column. Figure 2 shows an experimental result of flow visualization using a transparent bubble eliminator. When backpressure is applied and a vent port is opened, all collected bubbles are pushed out and ejected from a vent port. The vent port is normally leaved open and the collected bubbles are continuously ejected and returned to a reservoir with a small amount of oil.
The bubble eliminator has a simple structure and direct connection of in-line installation of hydraulic circuits. In addition, it is an energy saving device, because it can remove air bubbles efficiently with only flow energy through the hydraulic circuit without a supplementary power source. The bubble eliminator has a good performance of eliminating bubbles from the working oil [3].

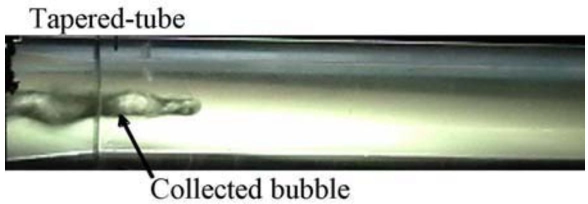

Figure 2 Flow visualization of trapped bubble

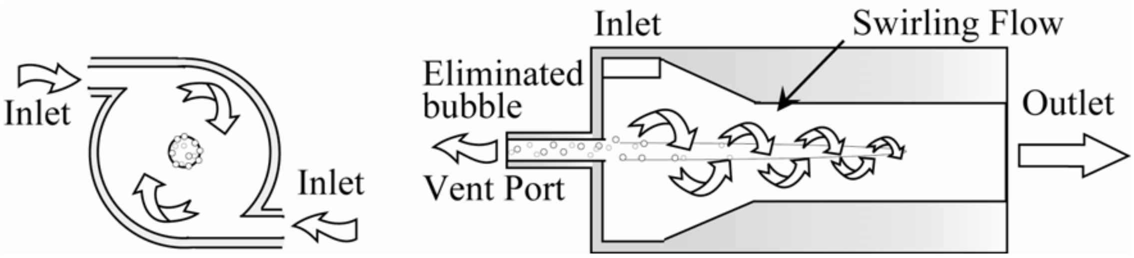

Figure 1 Principle of bubble eliminator

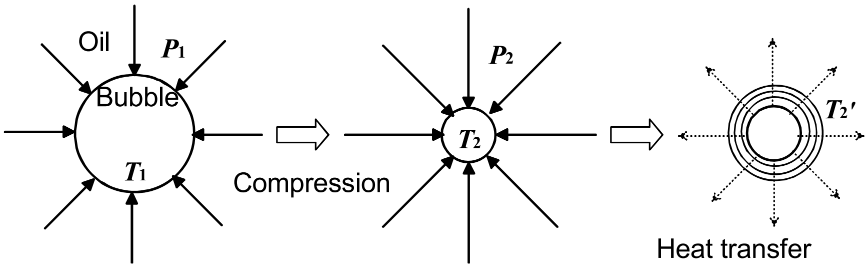

Figure 3 Heat generation model of air bubble

DETERIORATION OF OIL

The main cause of the deterioration of hydraulic fluids is oxidation with oxygen under high pressure and high temperature conditions. A typical solution to improve the oxidation stability of the hydraulic oil is to use additives to the oil. In more compact, high pressure and high performance of fluid power systems, the oxidation stability of commercial hydraulic oils is becoming insufficient for hydraulic designers.

Figure 3 illustrates a heat generation process of a compressed air bubble in oil. When air bubbles in oil are compressed quickly at high pressure in chambers of a pump, the temperature of the bubble rises sharply, and the surrounding oil temperature also rises. If the compressed process is accomplished quickly by the pump at high pressures, the change of process is assumed to be adiabatically. The assumption of the adiabatic compressed process of the air leads to a relationship between a temperature ratio T_2/T_1 and a pressure ratio P_2/P_1 as following Eq. (1).

$$\left(\frac{T_2}{T_1}\right) = \left(\frac{P_2}{P_1}\right)^{\frac{\kappa-1}{\kappa}} \quad (1)$$

where T_1 is an initial temperature or ambient temperature of the air bubble, T_2 is the temperature of the compressed air bubble, P_1 is initial or atmospheric pressure, P_2 is a supplied pressure by the pump and κ (=1.4) is a specific heat ratio of air.

Relationship between the supplied pressure P_2 and the temperature ratio T_2/T_1 is plotted in Fig.4. The initial pressure P_1 is fixed at atmospheric pressure of 100 kPa. When the oil with bubbles is compressed at 28 MPa in the pump, the temperature of the compressed air bubble T_2 rises by a factor of five to the ambient temperature T_1. If the ambient temperature, T_1 stands at 300 K (=27 °C), the temperature of the compressed air bubble, T_2 adiabatically rises to 1500 K (=1227 °C).

Under highly pressure conditions, the temperature of the air bubble dramatically rises and the surrounding oil is locally situated under the elevated temperature at the moment. During the compression of air bubbles in the

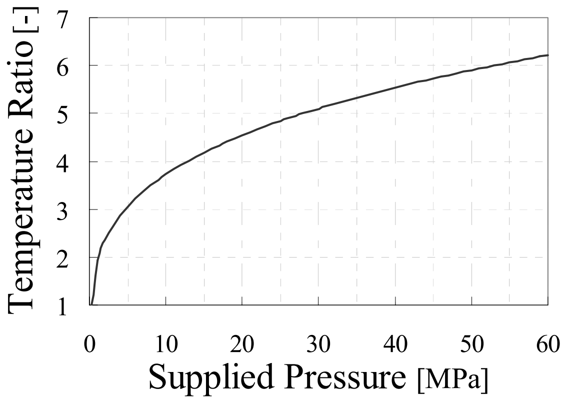

Figure 4 Temperature rise under adiabatic process

oil volume ignition and combustion occur due to the rising temperature on the boundary surface between the bubbles and the oil. The high temperatures, locally caused by compression, affect an accelerated aging of the oils.

EXPERIMENTAL INVESTIGATION FOR INFLUENCE OF BUBBLES

We focus on the technical issue to eliminate the air bubbles entrained in the oil to prevent troubles caused by bubbles. The oil degradation is accelerated with an effective oxygen supply of air, the most influential factor in shortening the life of the oils.

In order to investigate the effectiveness of the developed bubble eliminator experimentally, changes of oil degradation are observed under two different conditions of bubbles for normal pump operating conditions.

Test Bench

An experimental hydraulic circuit of the laboratory's test bench for oil degradation is illustrated in Fig.5. The oil pressurized by an axial piston pump flows through a relief valve and returns to the reservoir. A relief valve is set at a supply pressure of 7 MPa. The downstream line of the relief valve is divided into two lines. One goes through the bubble eliminator and oil cooler to the reservoir. Another goes though the bypass line, in which a stop valve is incorporated and the relief valve to the reservoir.

During the test, the oil temperatures are kept at 60±1.5 °C with the oil cooling system by tap water. The test is performed for base stock of mineral based oil. An oil specimen of 60 cm^3 is sampled once for every 24 hours during continuous running. The changes of the oil properties are investigated as a function of the working times.

Three analytical items and procedures, a visual determination of color regulated by ASTM D1500, a deposit measured by millipore filter methods and a total acid number (TAN) regulated by ASTM D974, are selected to investigate the change of the oil property as an analysis of evaluation for the degradation of oils.

Test-1: Pure Base Stock Oil

In the first experiment, a test is performed for the pure base stock oil having viscosity of 32mm^2/s, having no influence by oxidation inhibitor and anti-wear additive. The pump delivery flow rate is adjusted at a constant value of 9 liter/min. A relief valve is set at a supply pressure of 7 MPa.

The test conditions are tabulated in Table 1. Different parameters such as the bubble eliminator “Unmounted” or “Mounted” are set for the given pump delivery conditions by opening the throttle valves of No.2 or No.3. In cases of air blowing “on”, 660cm^3/min air is blowing from the pump suction side.

The changes of the color and the deposit are investigated as a function of the operating time of 96 hours in both cases. Figure 6 and Fig.7 show the change of the analytical data on the deposit and the color plotted as a function of working time, respectively.

Using the bubble eliminator slightly prevents the change of the deposit and the color of the oil. After test running for both cases, much wear debris of the metal in the oil specimen was measured at the end of the test. It should be mentioned that much metal debris is observed in the deposit of the oil in cases A and B. Under poor lubricity caused by supplied air, the wear debris is created on the boundary surface of the pumping elements during pressure build-up.

During 96 hours continuous running, however, no significant difference can be measured in the results of the TAN change in both conditions. In both test conditions, we were not able to keep on carrying out pump running tests, because there was much wear debris in the oil, friction greatly increased and the pumping elements seized.

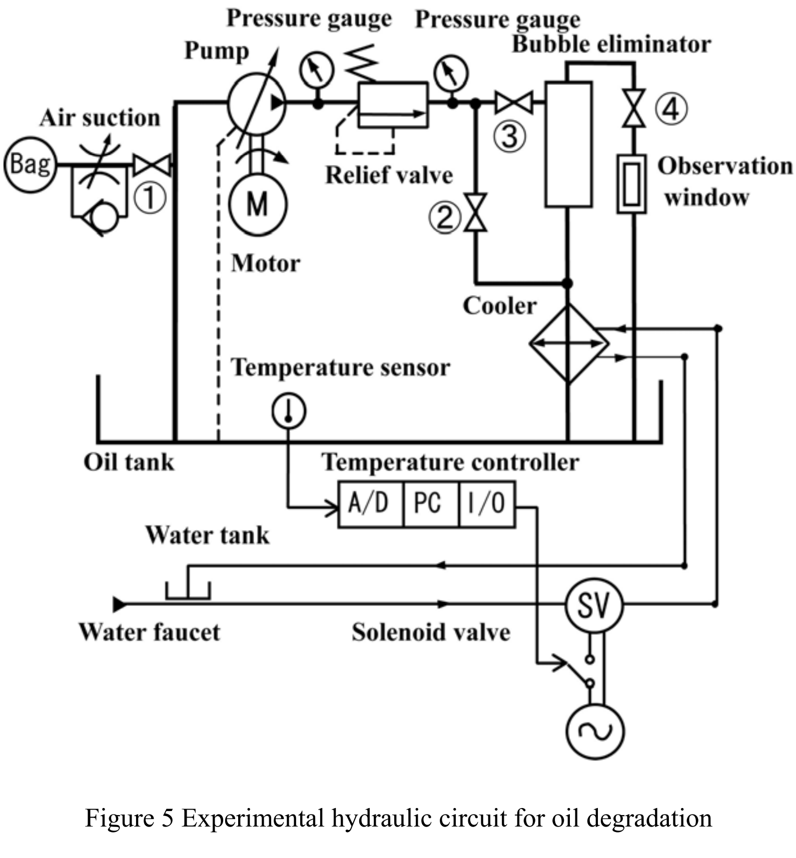

Figure 5 Experimental hydraulic circuit for oil degradation

Test-2: Base Stock Oil with Anti-Wear Additive

The next test is performed for the base stock of mineral based oil with the only anti-wear additive having viscosity of 32 mm^2/s. The newly pump delivery flow rate is adjusted at a constant value of 23 liter/min. The relief valve is set at a supply pressure of 7 MPa. Oil specimen of 60 cm^3 is sampled once for every 24 or 48 hours during continuous running. The changes of the oil property are investigated as a function of the working times of 456 hours for the both data.

The test conditions are tabulated in Table 2. Air is forced to be blowing of 690 cm^3/min, 3% versus the pump delivery flow rate at the suction side of the pump. Figure 8 shows the changes of the total acid number as a function of working times. If the air bubbles in the oil

Table 1 Test-1 conditions

Case	Air blowing	Working time [h]	Bubble eliminator
A	On	96	Unmouted
B	On	96	Mounted

Oil: Base stock without additive

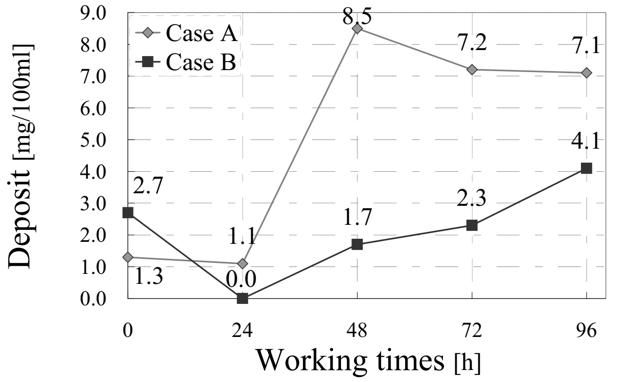

Figure 6 Deposit change in pump test-1

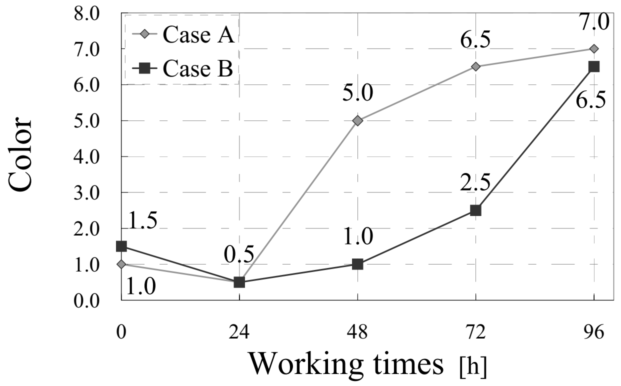

Figure 7 Color change in pump test-1

Table 2 Test-2 conditions

Case	Air blowing	Working time [h]	Bubble eliminator
C	On	456	Unmouted
D	On	456	Mounted

Oil: Base stock with anti-wear additive

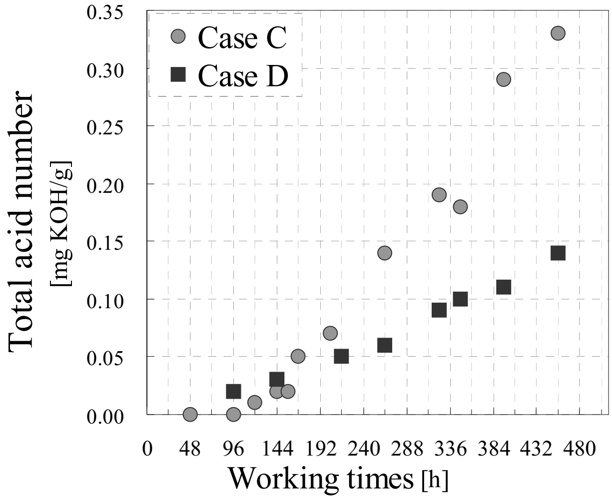

Figure 8 Change of total acid number in pump test-2

are not removed in case C, the oil with the air bubbles compressed adiabatically and the temperature of the air bubbles rose higher. The application limits of the total acid number for hydraulic systems are less than 0.2 mg KOH/g. In case C, the blowing air and cavitation air cause degradation of oil, and the change of TAN increases and exceeds applicable limits on the working times of 350 hours. Judging from the comparison of the plots of C and D, the TAN change becomes steeper when no bubble elimination is use. In case D, the blowing air together with cavitation air are eliminated at the downstream side of the relief valve by the bubble eliminator and the TAN rise can be prevented.

No significant difference can be observed in the results of the color change in both of our experimental conditions. The color change should not be regarded as an obvious indication for an advance degradation of oil. Comparison between the case C and D leads to the conclusion that the bubble eliminator is useful in making oil lifetime longer.

CONCLUSIONS

In this paper we focus on the technical issue for the air bubbles and aging behavior of the hydraulic oil. When

the oil with air bubbles is pressurized, the oil degradation is accelerated. It is experimentally verified that bubble elimination prevents oil degradation. Active removal of air bubbles from the working oil is to realize long lifetime of working oils.
Use of the bubble eliminator may allow the hydraulic designer to reduce the system's reservoir size, extend fluid's useable life and realize environmentally friendly design of fluid power systems.

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