

Downsizing of Oil Reservoir by Bubble Eliminator

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ABSTRACT

In mobile hydraulic systems such as commercial vehicles, hydraulic fluids are splashed and agitated in the reservoirs. To overcome air entrainment in oils, the overall dimensions should enclose a sufficient volume of oil to permit air bubbles to escape passively during the resident time of the fluid in the reservoir. However, in view point of environmental compatibility, energy saving, cost saving and safety, one trend in fluid power systems is to be designed in a more compact fashion and requiring less fluid in the reservoir. One of the authors has developed a newly device using swirl flow for bubble elimination capable of eliminating bubbles and of decreasing dissolved gases. This device is called the bubble eliminator. In this paper we focus on the technical issue of oil degradation for the air bubbles and oil temperature rise in the reservoir of a test hydraulic circuit. In our experiments, surrounding air is intentionally introduced from the oil surface by vibration of the reservoir in the hydraulic circuit. The bubble eliminator solves many problems concerning the air entrainment in hydraulic systems.

KEY WORDS

Aeration, Bubble eliminator, Mobile hydraulic system, Oil degradation, Swirl flow

INTRODUCTION

In recent years we are facing technical issues pertaining to environmental protection and energy conservation in fluid power systems. Because the earth is warming up and the cost of energy rising, we have to make a paradigm shift in design concept in fluid power technology. Engineers often times overlook problems caused by bubbles in fluids. Bubbles in operating fluids greatly affect the performance of fluid power systems and sometimes cause major problems [1]. For instance, temperatures of fluid with bubbles increase

significantly when the fluid is compressed and passes through pumps [2]. Therefore, it is important to eliminate bubbles from fluids in order to maintain the integrity of high quality products and system.

One of the authors has developed a newly device using swirl flow for bubble elimination capable of eliminating bubbles and of decreasing dissolved gases [3][4]. This device is called the bubble eliminator. In our previous study, we have reported that the developed bubble eliminator is useful for preventing oil temperature rising as a result of bubbles being under low, moderate and high system pressure conditions in the stationary

hydraulic systems [2][5]. It has also been confirmed through experiments and numerical simulation that the bubble eliminator is useful for removing dispersed bubbles from the fluid in stationary fluid power systems.

In mobile hydraulic systems such as commercial vehicles, hydraulic fluids are splashed and agitated in the reservoirs and air is entrained in the hydraulic fluids. To overcome air entrainment in oils, the overall dimensions should enclose a sufficient volume of oil to permit air bubbles to escape passively during the resident time of the fluid in the reservoir. However, in view point of environmental compatibility, energy saving, cost saving and safety, one trend in fluid power systems is to be designed in a more compact fashion and requiring less fluid in the reservoir.

In this paper the performance of the developed bubble eliminator concerning the effect of preventing the oil degradation and reducing the oil temperature rise is experimentally investigated. It is experimentally verified that the bubble eliminator can solve many problems concerning the air entrainment in mobile hydraulic systems.

TROUBLES CAUSED BY BUBBLES

Bubbles in fluid power systems are generated when dissolved air is released, external air is introduced mechanically, improper bleeding is made, there is fluid contamination, a reservoir is designed improperly, and/or air vents are improperly installed.

If bubbles are present in hydraulic fluid in a reservoir, they may be sucked into a pump whereby the bubbles will increase in volume due to pressure decrease at the suction line and then be compressed when higher pressure is introduced. When bubbles in the fluid are compressed adiabatically at high pressure the temperature of the bubbles rises significantly and the surrounding fluid temperature also rises. In addition to these well known phenomena, cavitation may lead to formation of reactive chemical intermediates that will affect secondary oxidation. Cavitation occurs when hydraulic fluid pressure is less than the vapor pressure in the fluid.

Bubbles in fluids greatly influence the performance of fluid power systems and may cause various problems such as: broad and high frequency vibration, higher noise emission, cavitation erosion, material damage, thermal degradation of oil [6], acceleration of oil degradation by oxidation [7], oil temperature rise, lubricity reduction by air emulsion [8], reduction of thermal conductivity, increase in compressibility, decrease in dynamic characteristics, decrease in pump output efficiency and bulk modulus change.

Thus, it is important to eliminate bubbles from the fluid

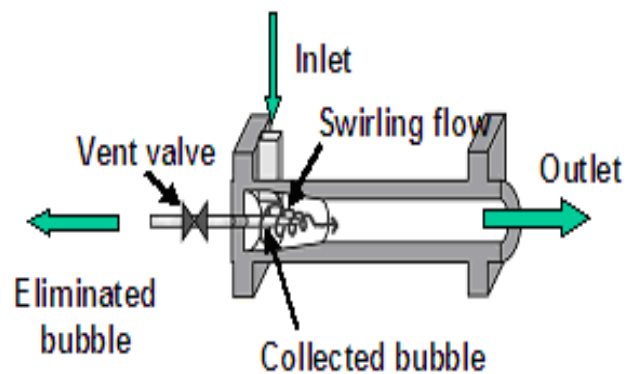


Figure 1 Principle of Bubble Eliminator

in order to preserve quality of fluid, attain sound system performance and avoid damage to components.

BUBBLE ELIMINATOR

Figure 1 illustrates the principle of the bubble eliminator. The device consists of a tapered-tube that is designed such that a chamber of circular cross-section becomes smaller and is connected with a cylindrical shaped chamber. Fluid containing bubbles flows tangentially into the tapered tube from an inlet port and generates a swirling flow that circulates the fluid through the flow passage. The swirling flow accelerates, and the fluid pressure along the central axis decreases as the fluid moves downstream. From the end of the tapered-tube, the swirl flow decelerates downstream and the pressure recovers as the fluid moves to the outlet.

There are certain position-dependent centrifugal forces created in all parts of the swirl flow, and the bubbles tend to move toward the central axis of the bubble eliminator due to the difference in centrifugal force between the fluid and the bubbles. Small bubbles are trapped in the vicinity of central axis of the swirling flow and collected near the area where the pressure is the lowest. When backpressure is applied at the downstream side of the bubble eliminator, the collected bubbles are ejected through a vent port.

The dissolved air in the fluid is also eliminated through bubbles extracted at the pump's suction side under negative pressure [9]. The bubble eliminator has the advantage of a simple structure, a low level of the pressure drop (a few hundred Pa) and of being a passive element without any power supply.

The bubble eliminator has been used in many industrial machines using fluids such as hydraulic systems, food machines and coater machines in paper products [10].

EXPERIMENTAL INVESTIGATION FOR OIL DEGRADATION

We firstly focus on technical issue to eliminate the air bubbles entrained in the oil to preserve oil quality. The oil degradation is accelerated with 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 three different conditions of bubbles for normal pump operating conditions during 96 hours of continuous running.

An experimental circuit of the hydraulic system is illustrated in Figure 2. The oil in a capacity of 5-liter reservoir pressurized by a piston pump flows through a relief valve and returns to the reservoir. 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 downstream line of the relief valve is divided into two lines. One goes through the stop valve-(3), the bubble eliminator, the stop valve-(5) and an oil cooler to the reservoir. Another goes through the bypass line, in which the stop valve-(2) is incorporated, and the relief valve to the reservoir. A needle valve-(1) at the suction side of the pump is used to introduce external air into the hydraulic circuit. A thermistor type thermometer is installed in the reservoir.

For test, the axial piston pump (Yuken type AR16) is installed. During the test, the oil temperatures are kept at 60 ± 1 centigrade. The test is performed for base stock having viscosity of $32 \text{ mm}^2/\text{s}$. The test conditions are tabulated in Table 1. Different parameters such as the bubble eliminator "With" or "Without" and the air supply "On" or "Off" are set for the given pump delivery conditions. In cases of air supply "on",

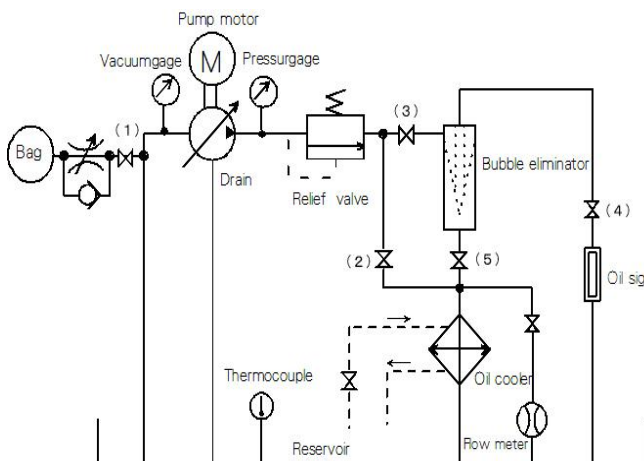


Figure 2 Experimental hydraulic circuit for oil degradation

Table 1 Test conditions

Case	Air supply	Time (Hours)	Bubble Eliminator
A	On	96	Without
B	Off	96	Without
C	On	96	With

660ml/min air is supplied from the pump suction side. To investigate processes of the oil degradation, the following analytical items and their procedure are selected:

- Color (ASTM D1500)
- TAN (ASTM D664)
- Viscosity (ASTM D445-3)
- Deposit (Millipore filter).

The changes of the oil property are investigated as a function of the operating time of 96 hours for all the data. Oil specimen is sampled once for every 24 hours. Table 2 to 4 show analytical results of the oil specimens under the test condition cases A, B and C. Figure 2 to 5 show the change of the each analytical data plotted as a function of time.

It should be mentioned that much metal debris is observed in the deposit of the oil in the cases A and B.

Table 2 Performance in Case A

Test case \ Time(hour)	0	24	48	72	96
Color	1.0	0.5	5.0	6.5	7.0
Viscosity(40°C)[mm ² /s]	31.34	31.36	31.37	31.39	31.42
TAN[mgKOH/g]	0.01	0.01	0.01	0.02	0.03
Deposit[mg/100ml]	1.3	1.1	8.5	7.2	7.1

Table 3 Performance in Case B

Test case \ Time(hour)	0	24	48	72	96
Color	0.5	0.5	1.0	1.0	1.0
Viscosity(40°C)[mm ² /s]	31.35	31.36	31.37	31.43	31.45
TAN[mgKOH/g]	0.01	0.01	0.02	0.02	0.03
Deposit[mg/100ml]	1.2	2.9	2.7	1.4	1.6

Table 4 Performance in Case C

Test case \ Time(hour)	0	24	48	72	96
Color	1.5	0.5	1.0	2.5	6.5
Viscosity(40°C)[mm ² /s]	31.36	31.37	31.39	31.41	31.45
TAN[mgKOH/g]	0.01	0.01	0.01	0.01	0.02
Deposit[mg/100ml]	2.7	0.0	1.7	2.3	4.1

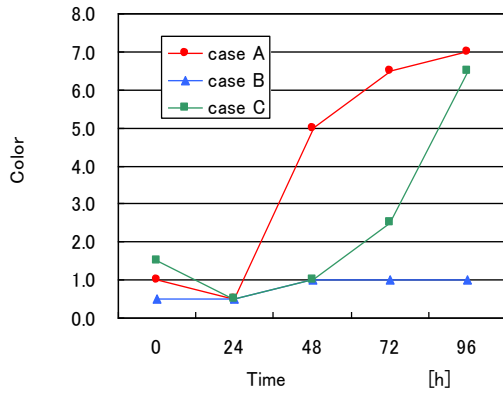


Figure 2 Color change in pump test

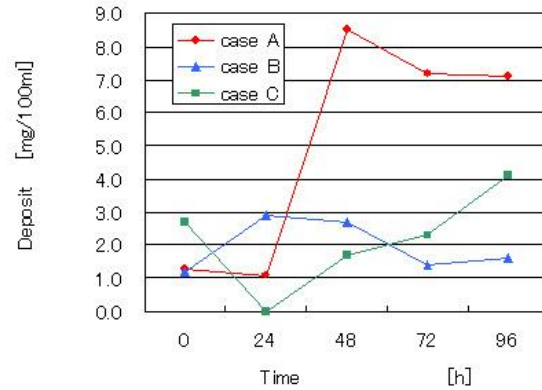


Figure 5 Deposit change in pump test

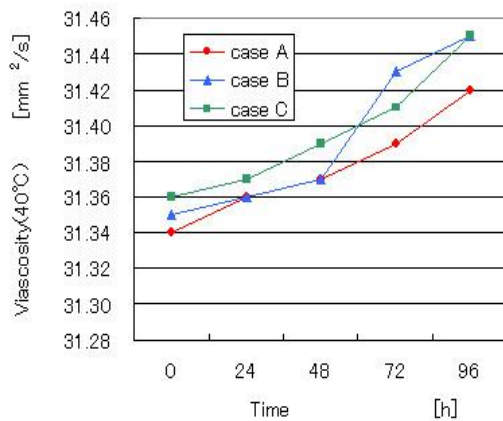


Figure 3 Viscosity change in pump test

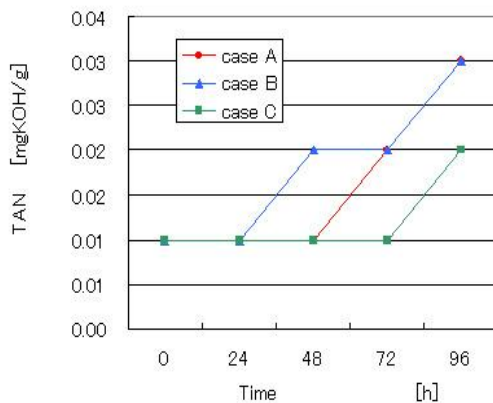


Figure 4 TAN increase in pump test

When bubbles in oil are compressed adiabatically at high pressure, the temperature of the bubbles rises sharply, resulting in generation of carbonaceous particles. Under poor lubricity caused by supplied air, wear debris is created on the boundary surface of the pump parts during pressure build-up.

In the cases A and C, much debris is produced regardless to the application of the bubble eliminator. In

these cases, the bubble eliminator located at the downstream side of the pump is unable to prevent generation of particle and wear debris on the boundary surface of the pump. The test results show clearly that the supplied air accelerate oil degradation and shorten the life of an oil.

The test oil is compressed to 7 MPa by the piston pump and then decompressed with the relief valve to a pressure close to atmospheric pressure then dissolved air is separated to cavitation air. If not removed, eventually cavitation air is compressed adiabatically and can reach high temperature in system.

In the case A, degradation of oil is caused by both supplied air and cavitation air. In the case B, cavitation air accumulated in the oil results in acceleration of oxidation. In the case C, the supplied bubbles together with cavitation air are eliminated and the TAN rise can be prevented. The comparison of the above results leads to the conclusion that the bubble eliminator is useful in making oil life longer.

No significant difference can be observed in the results of the viscosity change in our experiments. The viscosity change should not be regard as an obvious indication for an advance degradation of oil.

EXPERIMENTAL INVESTIGATION FOR MOBILE CONDITIONS

In this section we focus on technical issue for the relationship between air bubbles in the oil and oil temperature rise in the reservoir. In our experiments, surrounding air is intentionally introduced in the oil from the oil surface by vibration of the reservoir in the hydraulic circuit. An overall experimental setup and the hydraulic circuit for vibration of the reservoir are shown in Figure 6 and Figure 7, respectively. A pump-motor, a reservoir, and the bubble eliminator are located on an active linear table. A hydraulic servo cylinder forcedly vibrates the active linear table in order to infuse air to the oil of the reservoir from surrounding air.

The bubble eliminator in a main line is located in

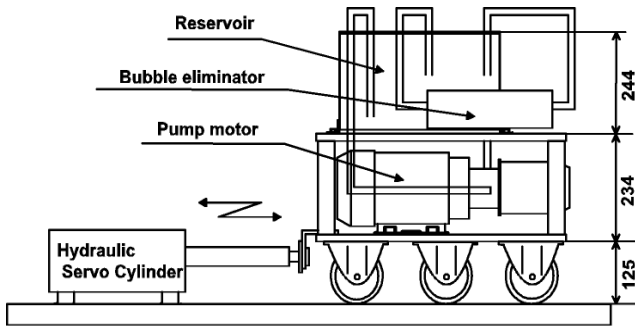


Figure 6 Overall experimental setup

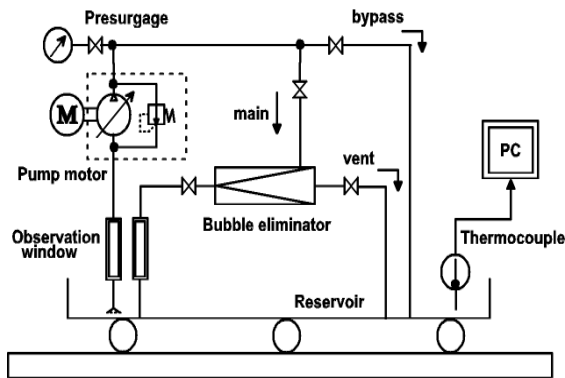


Figure 7 Experimental hydraulic circuit for mobile condition

Table 5 Test conditions for experiments

Case	Vibration Time	Bubble eliminator
A	0 min	Without
B	0 min	With
C	150 min	Without
D	150 min	With

parallel with a normal pipe of a bypath line. The reservoir and observation windows at the suction and return lines are made from transparent acrylic vessel and pipes, respectively. The air bubbles in the oil can be visually observed at the reservoir and the observation windows.

In our experimental hydraulic circuit the average flow rates delivered by the pump are kept at 12 L/min and the reservoir has a capacity of 3 Litter. It is assumed to be 1/20 model of the mobile construction machinery with the pump delivery flow rate of 240 L/min and reservoir capacity of 60 Litter.

The experimental equipment is forcedly vibrated with

the frequency of 1.2Hz and the amplitude of ± 20 mm in order to reproduce working environment of construction vehicles. Test conditions are tabulated in Table 5. There are four conditions A to D. In the case A and B, the experimental setup is not vibrated. In the case C and D, the experimental setup is vibrated during 150 minutes. Under the each condition, the oil temperature in the reservoir is measured by a thermocouple every 5 minutes during 150 minutes.

Typical experimental results of temperature rise in the reservoir are plotted in Fig.8. The temperature data are plotted as the values relative to the initial temperature. In the case A and case C, the oil flows through the bypath line. In the case B and case D, the oil flows through the bubble eliminator in the main line. Since it is considered that the bubbles are eliminated by the bubble eliminator, the oil temperature rise in the case B becomes lower than that in the case A. In the case D, the equilibrium temperature more dramatically decreases than one in the case A. This can be considered that the lower temperature rise is based on the cooling effect by the infused surrounding air and the bubble removal effect by bubble elimination. From these experimental results for measurement of oil temperature rise in the reservoir of the test hydraulic circuit, the bubble eliminator is effective in reducing the oil temperature rise under the mobile condition. The advantage obtained from the use of the bubble eliminator is a reservoir with light weight, smaller space, simpler configuration and lower cost.

CONCLUSIONS

In fluid power systems, air bubbles are the most influential factor to accelerate oil degradation. In this paper, it is experimentally verified that the bubble eliminator can effectively separate bubbles to prevent oil oxidation reactions, for extension of lifetime of oil. The authors have also examined the influence of the air

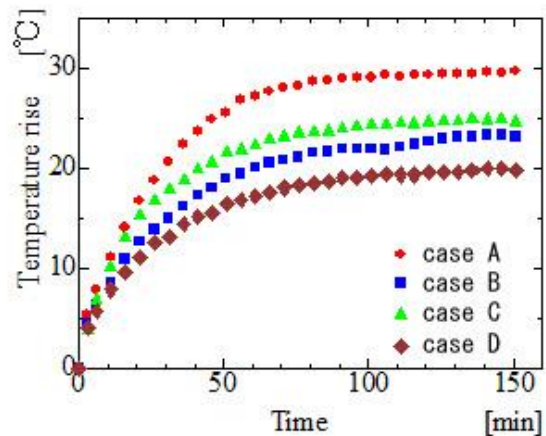


Figure 8 Typical experimental results of temperature rise (Case A, B, C, D)

bubble and the effect of the bubble eliminator to prevent temperature rise through the experimental investigations by using the oil hydraulic system. It is experimentally verified that the bubble eliminator can effectively reduce the oil temperature rise.

It must be borne in mind that the reduction of the entrained bubbles should be considered as one of the important design factors for the fluid power system. Concrete benefits obtained from the use of the bubble eliminator for the systems are:

- A reservoir with lighter weight, smaller space, simpler configuration, lower cost
- Slow fluid degradation, which extends lifetime of fluid
- Prevent pump and valve cavitations and noise
- Decrease in compressibility of oil
- Shorter heating time in cold environment
- Easier contamination control.

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