BUBBLE ELIMINATION FOR HYDRAULIC SYSTEMS

- New Design of Hydraulic System for Environmental Compatibility -

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In view point of environmental compatibility, energy saving, cost saving, high performance and high efficiency, one trend in fluid power systems is to be designed in a more compact fashion and requiring less fluid in the reservoir. Air entrainment in working fluids have great detrimental effects on function and lifetime of the fluid power components and systems. Our project research supporter, Suzuki, R. has developed a new device using swirl flow for bubble elimination capable of eliminating bubbles and of decreasing dissolved gases. In this research project, we focus on the technical issue for the air bubbles and aging behaviour of hydraulic oils with various conditions by using of the air bubble removal device. To investigate processes of the oil degradation, a colour and a total acid number are selected as analytical items and their two procedures. The test results show clearly that the air bubbles accelerate oil degradation and shorten the life of the oil. The new design of hydraulic system including the bubble eliminator is necessary for environmental compatibility of fluid power systems.

Keywords: Air bubble, Bubble eliminator, Oil degradation, Long lifetime of oil, Construction machinery

1 INTRODUCTION

An environmental protection movement has gained momentum under the global issue. In view point of environmental compatibility, energy saving, cost saving, high performance and high efficiency, one trend in fluid power systems is to be designed in a more compact fashion, long life time of working fluids and requiring less fluid in the reservoir. Construction and heavy industrial machineries are operated by fluid power. In mobile hydraulic systems such as construction machineries, hydraulic fluids are accumulated, splashed and agitated in the reservoirs. Air entrainment in working fluids has great detrimental effects on function and lifetime of the fluid power components and systems. Entrained air may cause major problems, such as bulk modulus change, cavitation and aeration, noise generation, oil temperature rise, deterioration of oil quality. Especially, when bubbles in oil are adiabatically compressed at high pressure in a pump chamber, the temperature of the bubble rises sharply, the surrounding fluid temperature also rises, and the oil degradation is accelerated, which is reported by

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Backe,W. and Lipphardt,P. (1976). 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 research project supporter, **Suzuki,R.** (1994) has developed a new device using swirl flow for bubble elimination capable of eliminating bubbles and of decreasing dissolved gases (US Patent No. 5,240,477). This device is called the bubble eliminator. Using the bubble eliminator will enable the fluid power system to perform better.

In our research project, we focus on the technical issue for the air bubbles and aging behaviour of hydraulic oils with various conditions. 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 in our laboratory's test bench, changes of oil degradation are observed under two different conditions of bubbles for pump operating conditions.

To investigate processes of the oil degradation, a colour (ASTM D1500) and a total acid number (TAN; ASTM D974) analytical items and their two procedures are selected. The changes of the oil properties are investigated as a function of the operating time. We propose the new design of hydraulic system including the bubble eliminator for environmental compatibility of mobile hydraulic systems.

2 OIL DEGRADATION BY ENTRAINED AIR

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 occurs 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. The following is a list of factors involved in the formation of air bubbles and the areas in equipment where air bubbles are likely to form.

- Suction resistance
- Throttle and orifice
- Branch and pipe joint
- Valves that are opening and closing frequently
- Shock waves due to suddenly closing
- Pressure drop at pipe end due to the sudden opening of valves
- External force on piston rod or on gears or bearings
- Splash and agitation in oil reservoirs

Under these conditions the air bubble is sucked in 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.

Air entrainment in working fluids has great detrimental effects on function and lifetime of the hydraulic fluids or the fluid power components and systems. **Totten, G. and Bishop, S.** (1997) have pointed out that the entrained air may cause major problems, such as bulk modulus change, cavitation and aeration, noise generation, oil temperature rise, deterioration of oil quality.

Especially, when air bubbles in oil are compressed quickly at high pressure in cylinders of a pump, the temperature of the bubble rises sharply, and the surrounding oil temperature also rises. Figure 1 shows a heat generation model of air bubble during compressed process. If the compressed process is accomplished quickly by the pump at high pressures, the change of process is able to be adiabatic. 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 equation.

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

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 (=0.1 MPa) is initial or atmospheric pressure, P_2 is compressed pressure by the pump and κ (=1.4) is a specific heat ratio of the air.

Under the compressed pressure P_2 of 28 MPa, the temperature of the compressed air bubble T_2 rises by a factor of five to the ambient temperature T_1. Under high pressure conditions, the temperature of the air bubble dramatically rises and the surrounding oil will be locally situated under the elevated temperature at the moment. **Backe,W. and Lipphardt,P.** (1976) have pointed out that during the compression of air bubbles in the oil volume ignition has been occurred due to the rising temperature on the boundary surface between the bubbles and the oil. These physical interrelations are so called Diesel effect. The high temperatures, locally caused by compression, affect an accelerated aging of the oils.

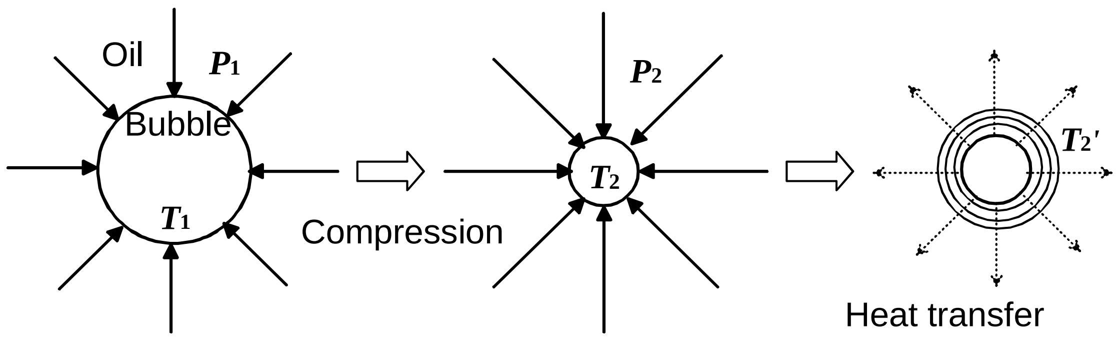


Fig. 1: Heat generation model of air bubble

3 DESIGN CONCEPT FOR HYDRAULIC SYSTEM

3.1 Bubble Elimination Device

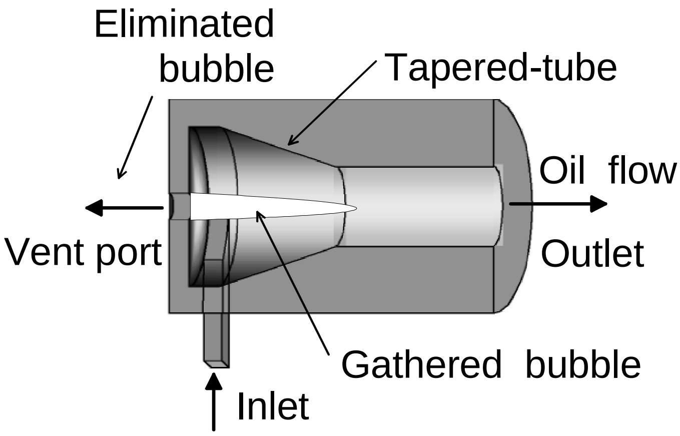


Figure 2 illustrates the principle of the bubble eliminator (**Suzuki, R. and Yokota, S.** (1994)). The tapered-tube type device is designed such that a chamber of cross sectional round shape becomes gradually smaller and is connected to a cylindrical shaped chamber. The working fluid with bubbles flows tangentially into the tapered-tube from an inlet port and forms a swirl flow that circulates fluid through the flow passage. The swirl flow accelerates towards the downstream. Bubbles are trapped to near the central axis because of a difference in the specific gravity of the oil and the bubble, and collected near the area where the pressure is lowest. When some back pressure is applied by a check valve or an orifice located at the downstream side of the bubble eliminator, bubbles are ejected oneself through a vent port. The dissolved gas in the fluid is also eliminated through the bubbles extracted at the supplied pump suction side under the negative pressure. In the authors' previous study (**Tanaka, Y. and Suzuki, R,** (2002)), it was experimentally confirmed that the bubble eliminator is able to eliminate the entrained bubbles and dissolved gases from the working fluid efficiently.

The photo of Fig.3 reported by **Tanaka,Y. and Suzuki,R.** et al. (2001) shows the flow visualization in the tapered-tube of a transparent bubble eliminator made from an acrylic pipe. The swirl flow at the tapered-tube is observed by means of fine bubbles suspended in the oil. Small bubbles gather to make a large air column around the central axis of the swirl near the vent port.

The swirl flow pattern and the pressure distribution in the tapered tube chamber of the bubble eliminator greatly influence the effectiveness of bubble removal. Geometry of the tapered tube chamber is important factor in design of the bubble eliminator. Numerical analysis and investigation of the flow pattern in the bubble eliminator has been carried out by **Tanaka,Y. and Suzuki,R.** et al. (1999).

Fig. 2: Bubble eliminator

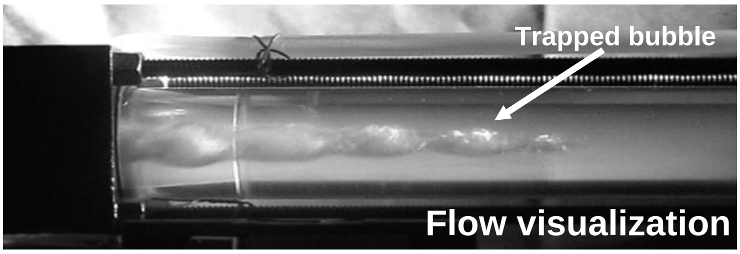
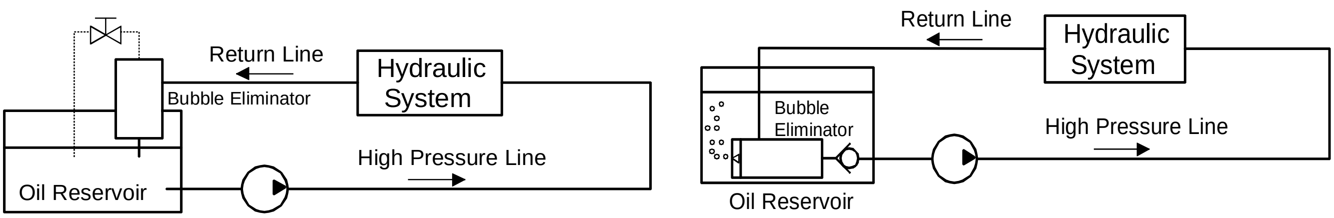


Fig.3: Flow visualization in transparent bubble eliminator

3.2 Installation of Bubble Eliminator in Hydraulic Circuit

The bubble eliminator is widely able to use in hydraulic systems. Figure 4 (a) shows a typical example for a normal type of installation for the bubble eliminator in hydraulic circuit. The bubble eliminator is generally set up at a return line from hydraulic systems. From view points of a more compact fashion of fluid power system, the bubble eliminator is able to be directly installed in the oil reservoir as shown in Fig.4 (b). The overall bubble eliminator is submerged in the working oil in the reservoir and the eliminated air bubbles are coming up to the oil surface. The installation of the bubble eliminator is tailored to a status of hydraulic circuits and systems.



(a) Normal type of installation (b) Submerged type of installation

Fig.4: Installation types of bubble eliminator

4 EXPERIMENTAL INVESTIGATION

4.1 Laboratory Test

An experimental hydraulic circuit of the laboratory's test bench for oil degradation is illustrated in Fig.5. The oil in a capacity of 6.85-liter reservoir and pipes pressurized by an axial piston pump flows through a relief valve and returns to the reservoir. The pump delivery flow rate is adjusted at a constant value of 23±0.5 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 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.

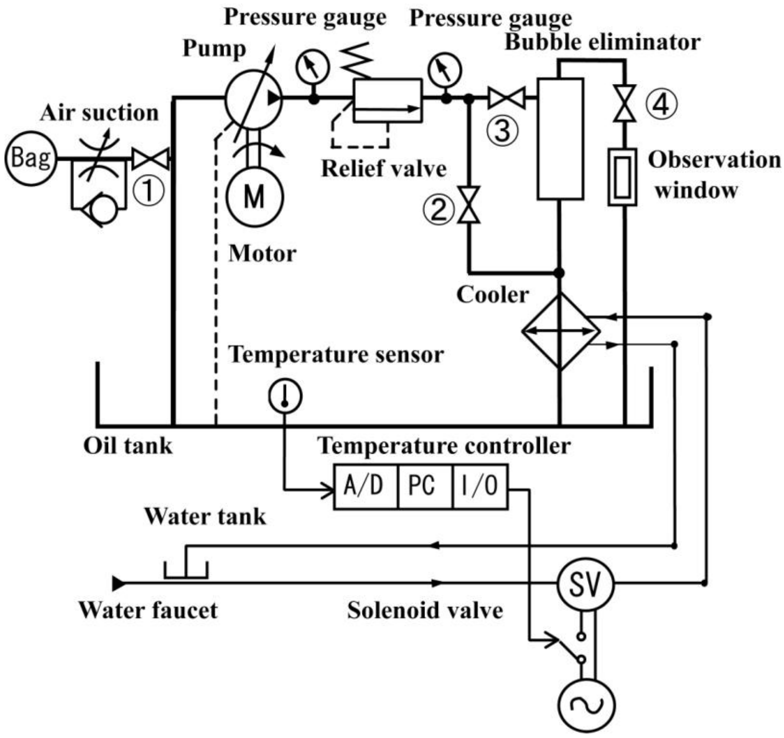


Fig.5: Experimental hydraulic circuit for oil degradation

Table 1: Test conditions

Case	Air blowing	Working time [h]	Bubble eliminator
A	On	456	Unmouted
B	On	456	Mounted

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 bases oil with the only anti-wear additive having viscosity of 32 mm^2/s. An 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 both data.
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. 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.
To investigate the change of the oil properties, total acid number (TAN) and visual determination of colour regulated by ASTM D974 and D1500 respectively, are selected. The TAN and colour change can be regarded as a measure of evaluation for the degradation of oils. The TAN determines the level of acidity by mixing in an indicator solution and then adding potassium hydroxide (KOH) until the solution changes colour. The acidity is expressed in the milligrams of KOH required to neutralize a gram of oil (mg KOH/g) and indicated the change in acidity from the new oil.
Figure 6 shows the changes of the total acid number as a function of working time. In both cases A and B, blowing air from the suction side is compressed to 7 MPa, and the

temperature of the bubbles rises sharply, resulting in acceleration of oil degradation. Blowing air is more influential for oil oxidation than the cavitation air. The bubble eliminator located at the downstream side of the pump is unable to prevent oil degradation. Blowing air is decompressed with the relief valve to a low pressure close to atmospheric pressure. Dissolved air is separated to cavitation air and dispersed in the oil.

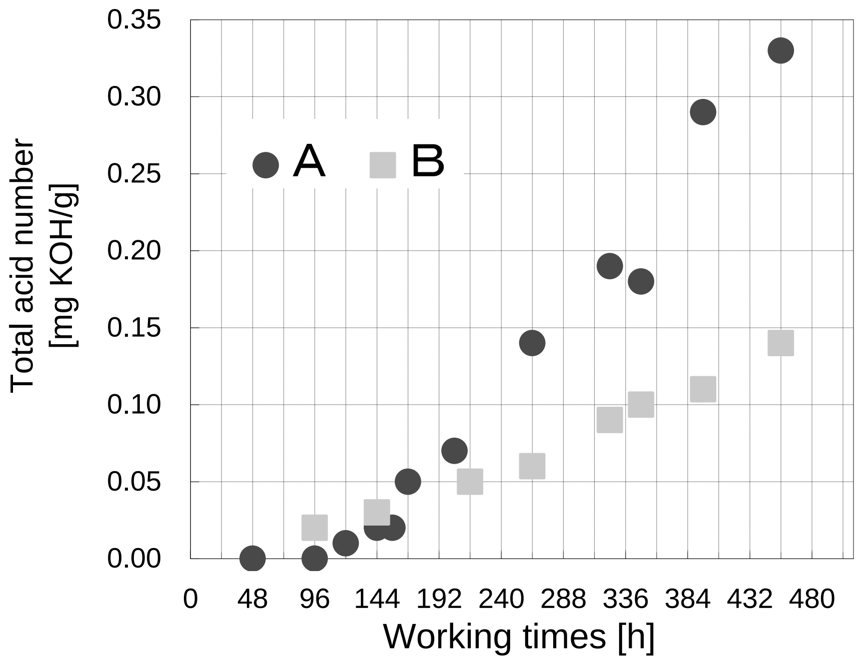


Fig.6: Change of total acid number in pump test

If the air bubbles in the oil are not removed in case A, 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 A, 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 A and B, the TAN change becomes steeper when no bubble elimination is use. In case B, 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.

Measurable effect of the bubble eliminator is donated as the value, TAN in case A minus TAN in case B. Comparison between the case A and B leads to the conclusion that the bubble eliminator is useful in making oil life time longer. In fluid power systems loss of power turns to thermal energy to heat working fluids to shorten the service life.

No significant difference can be observed in the results of the colour change in both of our experimental conditions. The colour change should not be regarded as an obvious indication for an advance degradation of oil.

4.2 Field Test of Construction Machinery

In our previous study in the laboratory test bench, **Suzuki, R., Tanaka, Y. and Yokota, S.** (1998) have reported that the bubble eliminator is able to prevent the oil temperature rise in the hydraulic system.

A field test of the medium excavator has been carried out to investigate the oil degradation and oil temperature rise in the reservoir during loading. Figure 7 shows the installed bubble eliminator in the excavator. In our field test the bubble eliminator in a main line of the hydraulic circuit is located in parallel with a normal pipe of a bypath line. The average flow rate delivered by the pump is 268 liter/min and the reservoir has a capacity of 130 liters and a baseline level of 69 liters of the working fluid.

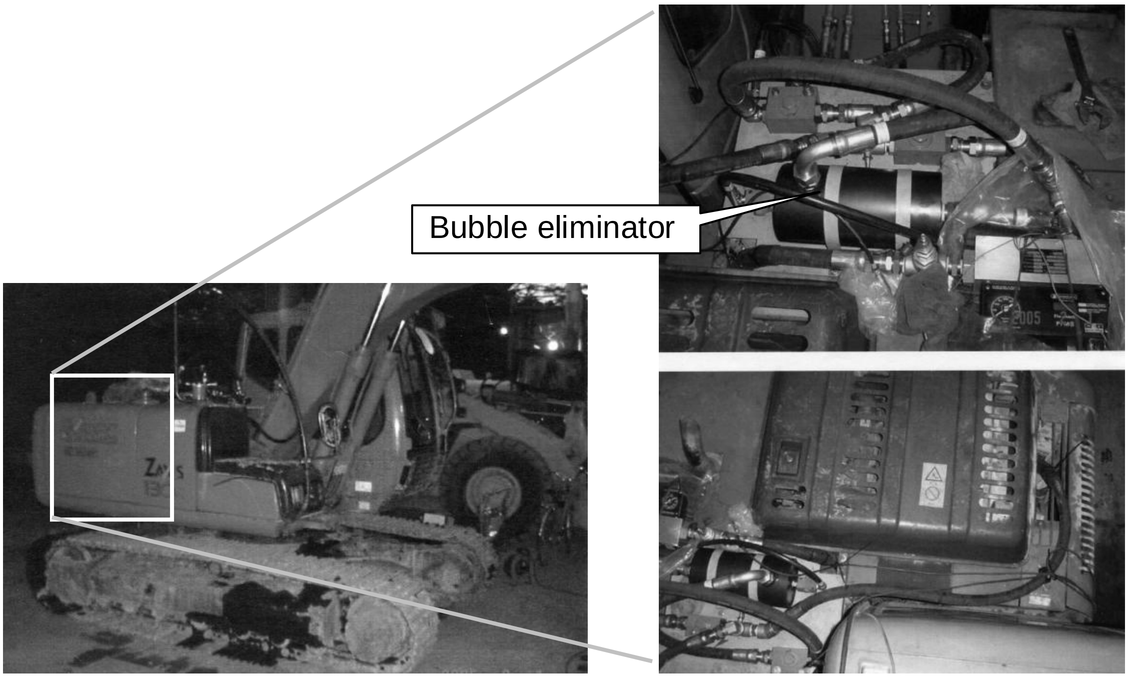


Fig.7: Bubble eliminator installed in excavator

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. The initial temperature of the oil is kept within a range of atmospheric temperature. Since it is considered that the air bubbles are eliminated by the bubble eliminator, the oil temperature rise becomes lower than that in the case without the bubble eliminator. When the bubble eliminator is used, the infused bubble from sloshing in the reservoirs is eliminated and temperature rise can be prevented. The air bubbles are also considered as a heat insulator, so the existence of the air bubbles reduces thermal conductivity of the oil.

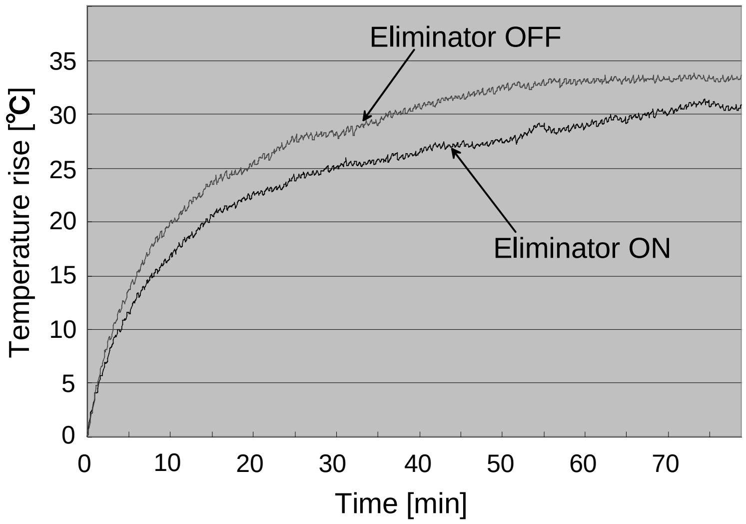


Fig.8: Oil temperature rise in the reservoir of the excavator

5 CONCLUSION

To remove air bubbles from the working fluid of the fluid power system, the bubble eliminator is the essential device to reduce energy loss and to prevent aging of the oil. Use of the bubble eliminator may allow the hydraulic designer to reduce the system's reservoir size, as well as gain the following benefits:

- a reservoir with lighter weight, smaller space, lower cost
- slow fluid degradation, which extends lifetime of oil
- prevent pump and valve cavitation and noise
- less fluid in reservoir, which reduces cost and increases safety
- shorter heating time in cold environment
- decrease in compressibility of oil
- easier contamination control, and
- simpler and more compact configuration of reservoir without baffle plate needed.

The bubble eliminator can solve the problems concerning the air entrainment in the fluid power systems. Design of the fluid power systems, e.g. calculation of the pump driving power in accordance with the pressure and the flow rate, has been conventionally carried out on the assumption that the oil in the system contains no bubbles. Bubbles or foam, however, have much influence the power loss and the damage of the fluid power system and the components. It must be borne in mind that the reduction of the entrained bubbles should be considered as one of the important designing factor for the environmentally friendly fluid power system.

6 ACKNOWLEDGEMENTS

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7 LIST OF NOTATIONS

P_1, P_2	Pressure	Pa
T_1, T_2	Oil or bubble temperature	K
κ	Specific heat ratio	-

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