Bubble Elimination for Efficiency through Fluid Power

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ABSTRACT

In this paper an overview of the principles of the bubble eliminator and a brief overview of typical hydraulic circuits where the bubble eliminator has been successfully used in industrial applications are provided. Numerical analysis of the flow in the bubble eliminator is also carried out to obtain quantitative results characterizing bubble removal to provide guidance for designing the devices. It is numerically verified that the bubble eliminator can effectively remove bubbles in oil.

NOMENCLATURE

x	the horizontal axis	mm
y	the vertical axis	mm
D,D1,D2,L and L1	distance	mm

1 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. Because the earth is warming up, we have to make a paradigm shift in design concept in fluid power technology. In view point of energy saving and resources saving, one trend in hydraulic systems is to be designed in a more compact fashion. The benefits of smaller hydraulic systems are obvious — economy of materials, less energy consumption, less square-footage required /Suz05/. The presence of bubbles in working oil of hydraulic systems exhibits an enormous influence on performance. Engineers often times overlook problems caused by bubbles in oil /Suz05/. Hydraulic system troubles, which are due to the presence of bubbles in a hydraulic oil, include bulk modulus change, cavitation and aeration inception, degradation of lubrication, noise generation, oil temperature rise and deterioration of oil quality. Therefore, it is important to eliminate bubbles from oil in order to maintain the integrity of high quality products and system. Recently, one of the authors has developed a new device using swirl flow for bubble elimination capable of eliminating bubbles and of decreasing dissolved gases /Tan02/. According to experiments, the unit which requires none of the other types of power, can remove in-fluid bubbles with excellent efficiency. One of the topics to be addressed in this paper is to provide a brief description of the bubble eliminator and to describe the principle of operation when it is installed in a hydraulic circuit to physically remove bubbles from hydraulic oil /Suz04/. A brief overview of typical hydraulic circuits, where the bubble eliminator has been successfully used in industrial applications, is also provided /Suz01/. For high pressure hydraulic systems, the bubble eliminator is generally set up at a return line /Nag08/. There are two ways to install the bubble eliminator for return line of hydraulic system. One, at the outside of a reservoir and the other is in the oil of a reservoir. In order to verify a difference in oil temperature rise by locations in a hydraulic circuit the bubble eliminator is installed, oil temperature rise in a hydraulic circuit is measured in three ways; at the outside of a reservoir and in the oil of a reservoir. Flow pattern in the bubble eliminator has great influence on the performance of bubble removal/Tan99/. With a view to explaining by numerical analysis the oil flow in the bubble eliminator in this study, two-phase flow analysis is carried out to investigate the influence of separating the air to the oil by a physical parameter of the working oil, volumetric flow rate of the experimental condition, and bubble content ratio/kob06/. From the analytical result, swirl flow formed in the bubble eliminator, pressure distribution and air content ratio are numerically investigated. Thus information concerning the geometry of the bubble eliminator exhibiting the optimal performance under the given condition is obtained.

2 PRINCIPLE OF BUBBLE ELIMINATOR

The bubble eliminator, which is shown schematically in ***Figure 1***, consists of a tapered-tube that is designed such that a chamber of circular cross-section becomes smaller and then connected with a cylindrical straight tube chamber. The working oil containing bubbles flows tangentially into the tapered-tube from an inlet port and generates a swirl flow that circulates the oil through the flow passage. The swirl flow accelerates towards the downstream, and the oil pressure along the central axis decreases as the oil moves downstream. At the end of the tapered-tube, the swirl flow decelerates downstream and the pressure recovers as the oil moves to 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.

Bubbles are trapped creating air column in the vicinity of the central axis of the swirl flow, near the area where the pressure is the lowest. 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 at the downstream side of the bubble eliminator, collected bubbles are ejected through a vent port. When a throttle valve incorporated into the suction side of he pump and is adjusted to decrease the pressure between the throttle valve and pump and the pump, the capacity for dissolving gas in the oil decreased. Thus, the oil becomes over-saturated with the dissolving gas, and bubbles come out of the oil at the suction side of the pump and are then fed to the bubble eliminator and removed from the system. When dissolved gas is decreased, the rate of dispersion of gas into the oil is increased so that oil absorbs more bubbles which can then dissolved into the oil. It is experimentally confirmed that the bubble eliminator is able to eliminate the entrained bubbles and dissolved gases from the working oil efficiently. The bubble eliminator contains no moving parts and does not require any power input beyond that needed to feed the oil.

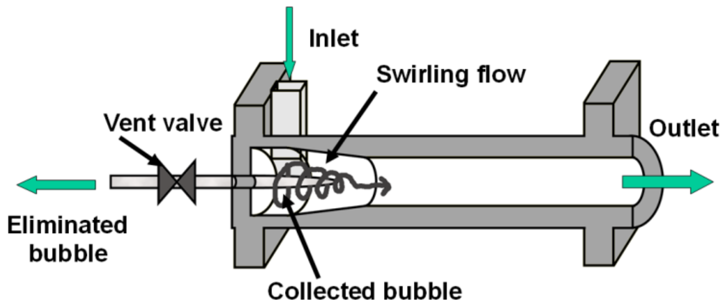

Figure 1: Principle of the bubble eliminator

3 INSTALLATION OF THE BUBBLE ELIMINATOR

The bubble eliminator is widely able to use in hydraulic systems.
The installation of the bubble eliminator is tailored to a status of hydraulic circuits and systems. Recommendable locations to install the bubble eliminator are as follows.

3.1 On a return line of hydraulic system

Figure 2 shows a circuit diagram of typical example.

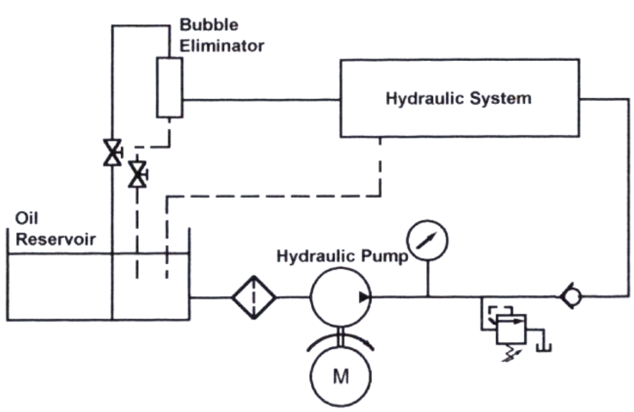

Figure 2: Hydraulic circuits

For installation of bubble eliminator, allowable pressure drop of 0.05 to 0.2MPa is required. Pressure drop differs in accordance with flow rate and viscosity of oil. The vent port of bubble eliminator goes into a reservoir where vented air and oil are separated.
Because bubbles are squeezed, and in some cases, dissolved in the oil by high pressure, installation for delivery side of high pressure pump must be avoided.
When pump is installed at downstream of the bubble eliminator, swirl flow is not generated in the device, hence entrained air is not removed.

3.2 On a delivery side of low pressure pump

Figure 3 shows a circuit diagram of typical example.

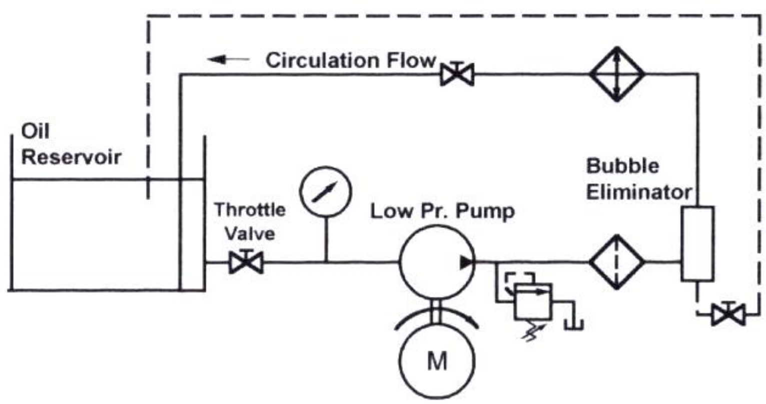

Figure 3: Low pressure system

This application has been used for many servo systems.
When a filter and cooler are incorporated into a circulation line, the filter should be located at the upper downstream side of bubble eliminator to avoid pressure build up with contaminants. When no component having pressure drop is installed, throttle valve must be installed to provide back pressure to eject collected babbles in the bubble eliminator. When a throttle valve at the pump's suction side is slightly throttled to generate negative pressure, the capacity for dissolving gas in the fluid is decreased. Then, the fluid becomes over-saturated with the dissolved gas.

Bubbles come out of the oil at the suction side of the pump and are then fed to the bubble eliminator and remove from the system. When dissolved gas is decreased, the rate of dispersion of gas into the oil is increased so that fluid absorbs more bubbles, which can then be dissolved into the oil.

3.3 On a relief return of hydro-static transmission

Figure 4 shows a typical example.

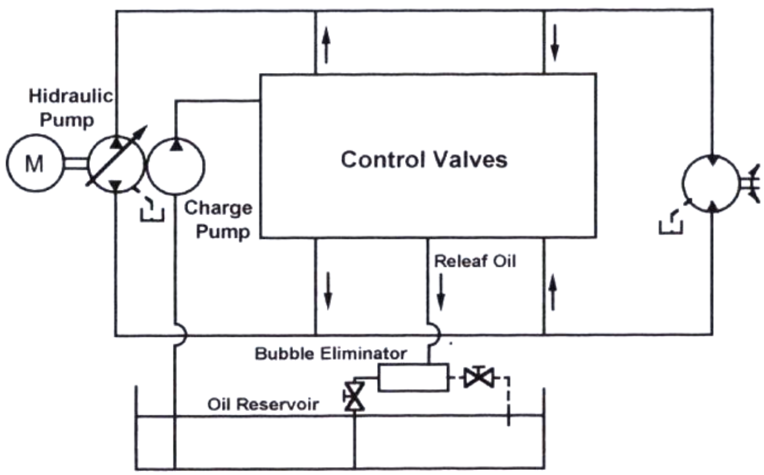

Figure 4: Hydro-static transmission circuit

In most cases of relief return, it is necessary to remind that allowable pressure loss of bubble eliminator is within 0.1 MPs, due to the pressure limit of pump case drain.

3.4 Oil temperature rise depending on location of bubble eliminator

The installation of the bubble eliminator is tailored to a status of hydraulic circuits and systems. The bubble eliminator is generally set up at a return line from hydraulic systems. There are two ways to install the bubble eliminator for return line of hydraulic system. One, at the outside of a reservoir and the other is in the oil of a reservoir. ***Figure 5*** shows a typical example for a normal type of installation for the bubble eliminator in hydraulic circuit. 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 ***Figure 6***.

In order to verify a difference in oil temperature rise by locations in a hydraulic circuit the bubble eliminator is installed, oil temperature rise in a hydraulic circuit is measured; at the outside of a reservoir and the submerged in the oil of a reservoir.

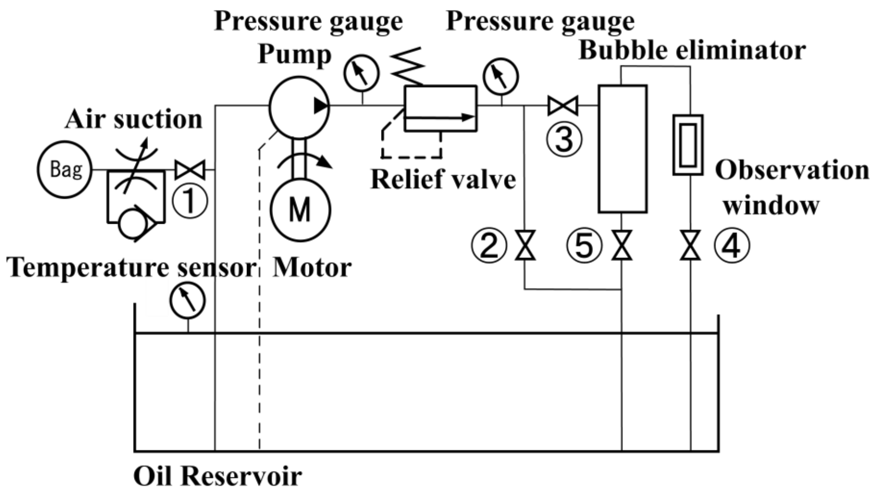

Figure 5: Circuit of normal installation

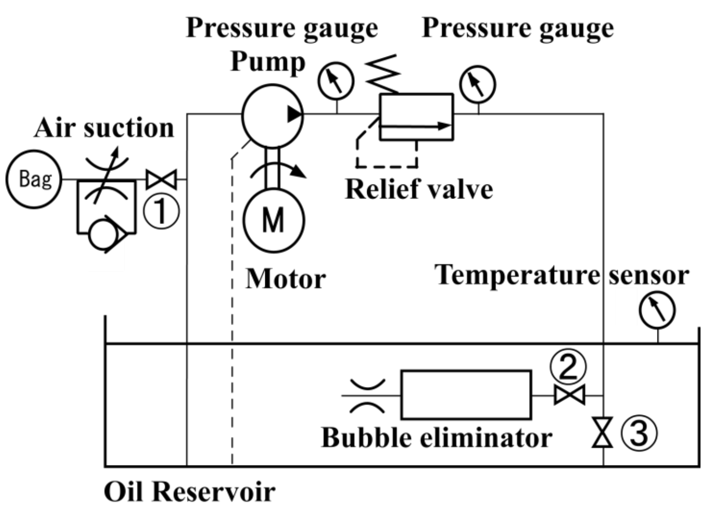

Figure 6: Circuit of submerged installation

For the submerged, different parameters such as the air supply “On” and “Off” are set for the given pump delivery conditions. In case of air supply “on”, 660ml/min air is supplied from the pump suction side.

Experimental circuits are given in *Figure 5* and *Figure 6*. Both circuits are common except location where bubble eliminator is installed. The test conditions are tabulated in ***Table 1***. The oil in a 7.5 liter reservoir pressurized by a piston pump flows through a restrictor and bubble eliminator, and returns to the reservoir. The pump delivery flow rate is adjusted at a constant value of 22 liter/min. A relief valve is set at a supply pressure of 3 MPa. A needle valve at the suction side of the pump is used to introduce external air into the hydraulic circuit.

The experiments are carried out for 120 to 150 minutes under continuous running. The initial temperature of the oil is kept within a range of 279 K to 287 K which is almost the same as atmospheric temperature. The temperature data are plotted as the values relative to the initial temperature. After more than 60 minutes of continuous running, the oil temperature increases significantly. ***Figure 7*** shows the oil temperature rise for the test cases 1 to 3 shown in *Table 1*. The highest temperature rise is measured in case 2. The oil temperature rise in case 3 becomes lower than that in cases 1 and 2 in which bubble eliminator is installed out side of reservoir. It can be explained that radiation from the bubble eliminator located outside of reservoir causes lower oil temperature rise. The comparison of the above results leads to the conclusion that the bubble eliminator should be installed outside of reservoir.

Case	Air Blowing	Working Time	Bubble Eliminator
Case1	off	150	Submerged type of Mounted
Case2	on	150	Submerged type of Mounted
Case3	on	120	Normal type of Mounted

Table 1: Experimental conditions

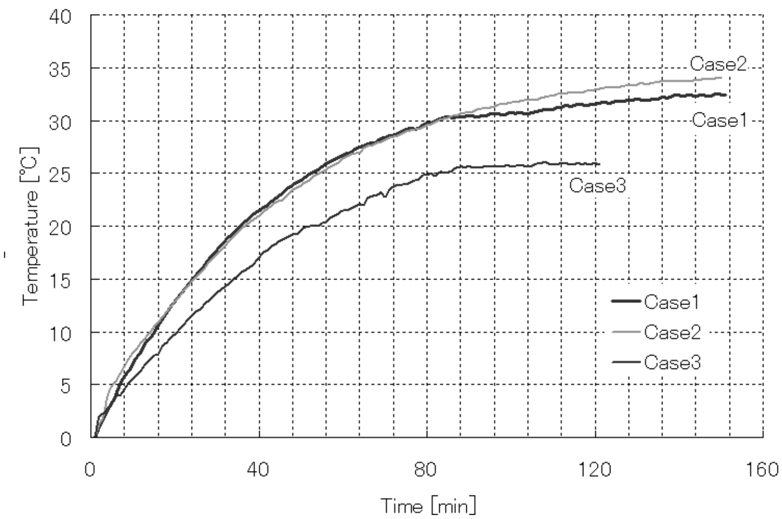

Figure 7: Experimental results for oil temperature rise

4 NUMERICAL ANALYSIS

Numerical analysis of the flow in the bubble eliminator is also carried out to obtain quantitative results characterizing bubble removal to provide guidance for designing the devices. We perform a three-dimensional flow analysis for swirl flow characteristics and volume fraction of air bubbles in the bubble eliminator, in accordance with flow rate.

The swirl flow pattern in the bubble eliminator is calculated by a three-dimensional numerical analysis for a two-phase flow. Flow simulation with two-phase analysis is carried out by utilizing Euler method by using a model applicable for a broader range suitable for the calculation of the highly-concentrated particles such as bubble flow and particle precipitation than utilization of Lagrange method applicable for spraying or thin flow of the particles. The basic equations for the numerical analysis are the equation of Navier-Stokes, the equation of continuity, the equation of motion and the energy equation. We perform a three-dimensional flow analysis of incompressibility viscous liquid using the numerical calculation software; STAR-CD. The cross section of the tube is taken up as an x-y plane. In the meantime, a three-dimensional orthogonal coordinate system taking up the central axis of the tube as the z ordinate is established.

The analytical model of the bubble eliminator is composed of a fluid inlet, tapered tube, downstream tube and air vent tube. Dimensions of the bubble eliminators are illustrated in ***Figure 8*** and ***Table 2***. Flow rate for numerical analysis is shown in ***Table 3***.

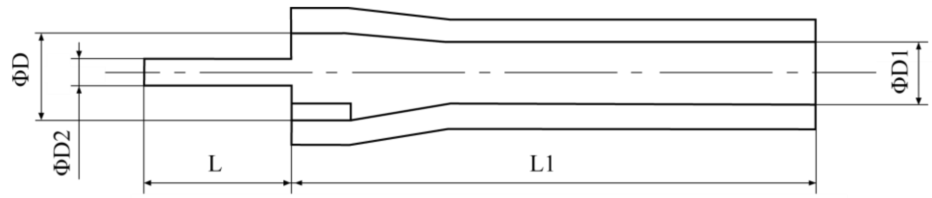

Figure 8: Geometry of analytical model

D [mm]	D1 [mm]	D2 [mm]	L [mm]	L1 [mm]
16	9	2.8	30	240

Table 2: Dimensions of analytical model

	Flow rate [l/min]
Case1	3
Case2	6
Case3	9
Case4	12

Table 3: Flow rate for numerical analysis

From the analytical result of this time, it can be estimated that the optimal ratio of the flow tube of the model allowing bubbles to be removed most efficiently to the inner diameter of the air-release tube (D1/D2) will approximately be 0.33. Thus it is expected that the geometry referred to before will exhibit the best performance.

The numerical simulation has been performed for conditions of working fluids having a kinetic viscosity of 30 mm2/s, a density of 893 kg/m3 and flow rate of 3, 6, 9and 12 liter/min. In our numerical analysis, we performed two-phase flow analysis for conditions of air having the density of 1.204 kg/m3 and the diameter of mixed air particles of 0.3 mm. Volume ratio of the air contained in the oil is set at the condition of 5 %. Examples of the analytical results are illustrated in ***Figure 9***. The results analysis revealed significantly good performance for the removal of bubbles for all given flow rate, between 3 l/in to 12 l/min. The maximum value of volume fraction of air is calculated for each case.

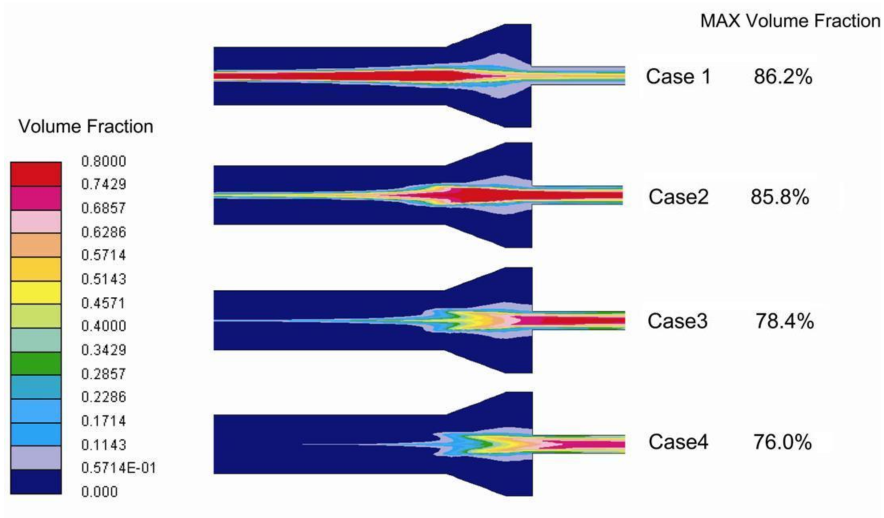

Figure 9: Analytical results

When flow rate increase, flow force to eject collect bubbles increase caused by increase of back pressure. In connection of this, the highest fraction area of bubbles moves to vent line. To make vent port variable, simulate the highest fraction area. In this way, the most preferable vent size can be decided. A methodology to establish standards of the bubble eliminator simulation is carried out in this paper. As a result of simulation, distribution of volume fraction of bubbles is shown in contour. It is able to provide quantitative insight into bubble elimination function.

CONCLUSION

In this paper, guidance to install the bubble eliminator in a hydraulic system is provided.
The bubble eliminator is generally set up at a return line from hydraulic systems. There are two ways to install the bubble eliminator for return line of hydraulic system. One, at the outside of a reservoir and the other is in the oil of a reservoir. The test results to compare temperature rise leads to the conclusion that the bubble eliminator should be install outside of reservoir. In this study, investigation has been made with the distribution of the air volumetric ratio based on the swirl flow formed in the bubble eliminator.
It is able to provide quantitative insight into bubble elimination function. The theoretical analysis provides clear guidance regarding pathways towards improving the effectiveness of removing bubbles. In fluid power systems loss of power turns to thermal energy to heat working fluids and system components.

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.

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