Operation and Typical Application Overview of the Use of Bubble Eliminators for De-aeration of Hydraulic and Turbine Oils

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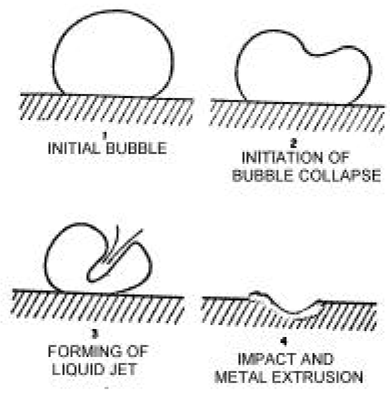
Abstract

The presence of bubbles in working fluids of hydraulic systems exhibits an enormous influence on performance. Recently, a novel device capable of successfully eliminating bubbles in hydraulic fluids using swirl flow has been developed. This device is called the "Bubble Eliminator". In this paper, an overview of the physical principles involved in bubble elimination within the Bubble Eliminator during use will be provided. A brief overview of typical hydraulic circuits where the Bubble Eliminator has been successfully used in industrial applications will be provided.

Introduction

Cavitation occurs when the pressure acting on a hydraulic fluid is less than the vapor pressure of the fluid. At this point, the liquid locally vaporizes and forms cavities. When the cavities, which are flowing within the fluid as it passes through the system, encounters a region of higher pressure, they will collapse as illustrated in Figure 1. The cavity collapsing process may be very violent causing vibrations, noise and material damage.

Another phenomenon that also leads to cavitation in hydraulic systems is the problem of dissolved gases in the hydraulic fluid. In this case, if the pressure acting on the liquid is lower than the saturation pressure, the gas will come out of solution in the form of bubbles. In the reservoir, bubbles may be concentrated at the air-liquid interface in the form of "foam" or they may be dispersed or entrained within the fluid. This is illustrated in Figure 2. If bubbles are present in the hydraulic fluid in the reservoir, they may enter the pump, where the bubbles will first increase in volume, due to the pressure decrease along the suction line and then they will be compressed when they encounter a region of higher pressure.



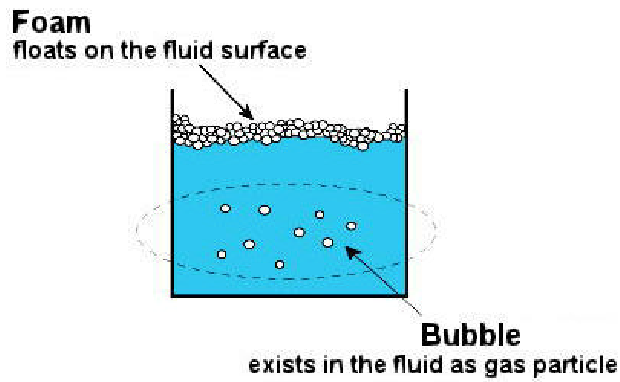


Figure 1 - Illustration of Cavitation Damage.

Figure 2 – Illustration of Foam and Entrainment.

It can be very difficult to distinguish between these two processes, therefore, both will be considered as a single cavitation process for the purposes of this discussion.

There are various sources of bubble formation within the hydraulic system which include:

1. Suction resistance.
2. Pressure drop through an orifice.
3. Pressure drops through pipes and hoses.
4. Turbulence from valves opening and closing.
5. Shock waves due to sudden closing of valves and sudden cessation of pump operation.
6. Pressure drops due to sudden opening of a valves.
7. External force on piston rod.

In gear and bearing lubrication, bubbles may be created by a churning effect of the fluid as it flows through the bearing assembly. There are undesirable physical and chemical effects resulting from these processes. For example, an increase in system noise, known as the "water hammer effect", typically accompanies cavitation.

In addition, cavitation may result in increased oil oxidation rates [1]. When an air-ignitable mixture is present within the bubble, ignition may occur from the temperature rise accompanying the compression process [2,3]. This process requires only nanoseconds and the localized temperature may be 1100ºC or higher. This process, also known as the "micro-diesel effect", may lead to oxidative degradation of the hydraulic fluid, localized hot spots, and pressure spikes and may subsequently lead to hydraulic pump or component damage by cavitation erosion [4]. In addition to these well-known processes, cavitation may lead to the formation of reactive chemical intermediates, which are capable of affecting secondary oxidation and reduction processes [5].

These and other hydraulic system problems, which are due to the presence of bubbles in a hydraulic fluid, include:

1. Oil temperature rise.
2. Deterioration of oil quality.
3. Degradation of lubrication (due to either viscosity loss or sludge and varnish formation.).
4. Reduction of thermal conductivity.
5. Cavitation and erosion.
6. Noise generation.
7. Bulk modulus change (due to fluid aeration leading to a "spongy" fluid and sluggish system control).
8. Decrease in pump efficiency.

Therefore, bubble elimination from a hydraulic system is important to prevent hydraulic oil degradation and damage of the components of a hydraulic system. However, bubble separation from a hydraulic fluid when the hydraulic circuit is in operation is a difficult technical problem. Hydraulic fluid air entrainment and air release processes have been reviewed previously [6] and their impact on hydraulic cavitation processes have also been reviewed [7,8]. The impact of the hydraulic inlet condition on air entrainment and cavitation has been described as well [9]. Recently, OPUS Systems, Inc. has developed a device to physically remove bubbles from aerated hydraulic fluids [10,12]. This device is called the *Bubble Eliminator*.

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 a hydraulic fluid [10-12]. A brief overview of typical hydraulic circuits, where the Bubble Eliminator has been successfully used in industrial applications, will also be provided.

The hydraulic circuit used for this work is illustrated in Figure 3. The hydraulic oil was contained in a 20-L reservoir, which feeds a variable displacement piston pump, where the oil flow and discharge pressure is controlled by a restrictor (needle valve). Heat exchangers were intentionally not installed in the test circuit. A relief valve was used for safety in the pump delivery line. The downstream line is divided into two lines. One goes through valve No. 3, the bubble eliminator, and the flow meter to the tank. Another goes through the by-pass line in which valve No. 2 is incorporated and the flow meter to the tank. Thermistors are installed on the pump delivery side (á), downstream side of the restrictor (â), and in the tank (ã). Valve No. 1 at the suction side is used to introduce external air into the system. Oil can be sampled at valves 4 and 6.

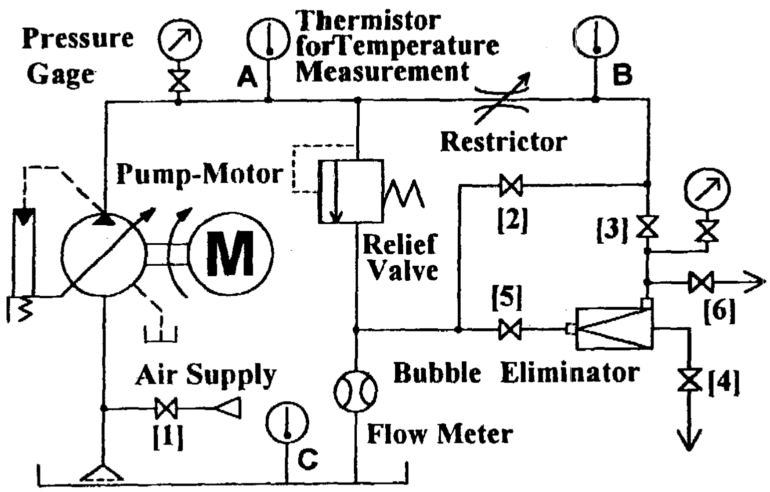


Figure 3 – Experimental hydraulic circuit.

Discussion

What is a "Bubble Eliminator" and How Does It Work?

The *Bubble Eliminator*, which is shown schematically in Figure 4, 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. 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. At the end of the tapered-tube, the swirl flow decelerates downstream and the pressure recovers as the fluid moves to the outlet. In a sense, this is a fluid-flow driven centrifuge action for bubble removal.

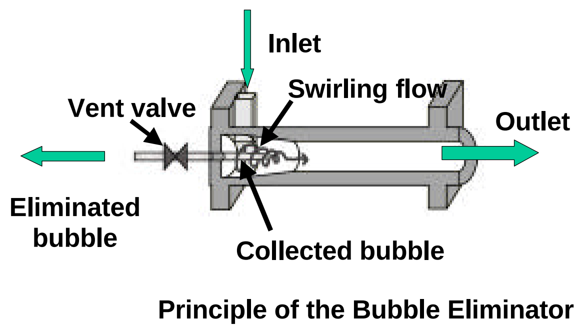


Figure 4 – Internal View of the "Bubble Eliminator"

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. Small bubbles are trapped creating an air column in the vicinity of the central axis of the swirling flow, near the area where the pressure is the lowest. When backpressure is applied at the downstream side of the *Bubble Eliminator*, the collected bubbles will be ejected through the vent port. Figure 5 illustrates the air bubble removal ability of the *Bubble Eliminator* when used with a severely aerated hydraulic fluid.

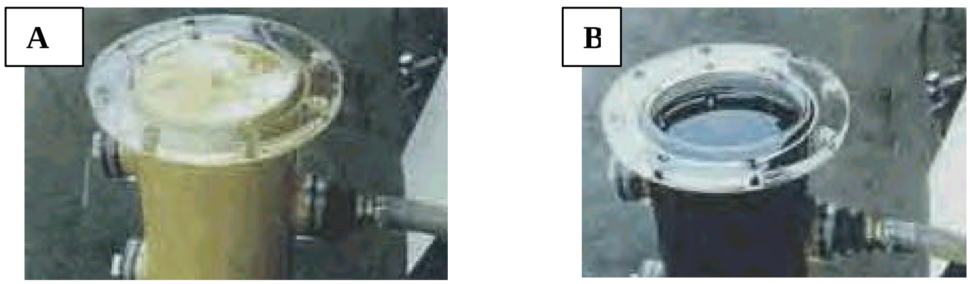


Figure 5 – Example of air bubble removal, A) aerated fluid, B) de-aerated fluid.

The *Bubble Eliminator* is manufactured in four different configurations: standard type, in-line type, coater-type and the sanitary type designs to facilitate their installation and use in a wide variety of hydraulic circuits. These are illustrated in Figure 6 along with a schematic drawing of the inside geometry of each device.

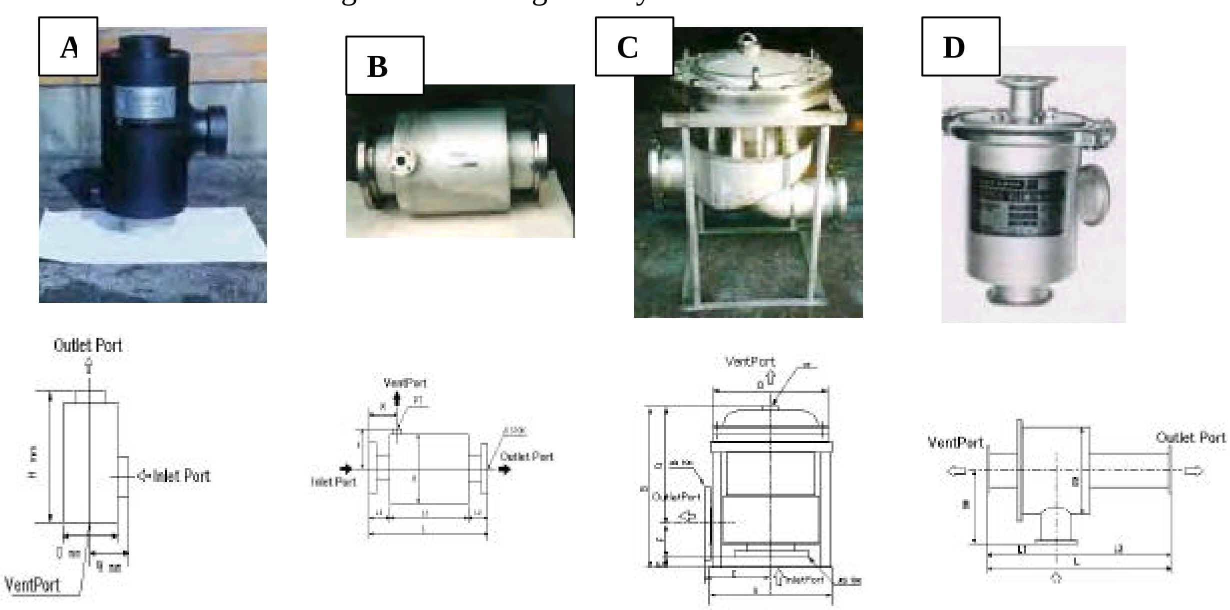


Figure 6 – The Four Configurations of the "Bubble Eliminator" are A) standard, B) in-line, C) coater, and D) sanitary.

What if the "Bubble Eliminator" is used with a Feed Pump?

If the circulation circuit to the suction side of the pump is incorporated downstream of the *Bubble Eliminator* then, theoretically, bubbles can be completely eliminated. By means of adjusting the circulation flow, the delivery flow can be controlled for the next processing stage.

If a throttle valve is incorporated into the suction side of the hydraulic pump and is adjusted to decrease the pressure between the throttle valve and pump, the capacity for dissolving gas in the fluid is decreased. Thus, the fluid becomes over-saturated with the dissolved gas, and bubbles come out of the fluid 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 fluid is increased so that fluid absorbs more bubbles, which can then be dissolved into the oil. (In some cases, such as in chemical mixing, this method is not suitable.)

Connection of the Bubble Eliminator to the Return Line or Processing Line

The *Bubble Eliminator* may also be connected to the return line of the chemical feed pump, where it may:

1. Improve surface quality.
2. Prevent uneven spreading.
3. Prevent defects in quality of products.
4. Improve flow rate measuring accuracy.
5. Decrease waste material.
6. Increase productivity.

Case Histories

Case History 1

Mitsubishi Heavy Industries recently designed and built a turbocharger which was used to carry shipping containers (66,000 ton each). During their use air became emulsified in the lubrication oil, which was caused by a churning effect due to bearing rotation. Bubbles in the oil greatly influence the performance of the lubrication system and may cause major problems such as accelerated degradation of lubrication oil, oil temperature rise, deterioration of oil quality and creation of sludge. Installation of a Bubble Eliminator into the circuit (see Figure 7) was found to eliminate these problems by effective air bubble removal from the turbo-machinery. As a result of this successful work, twenty-five (25) Bubble Eliminators, with a flow rate 660 L/min, were subsequently installed in newly built container carriers.

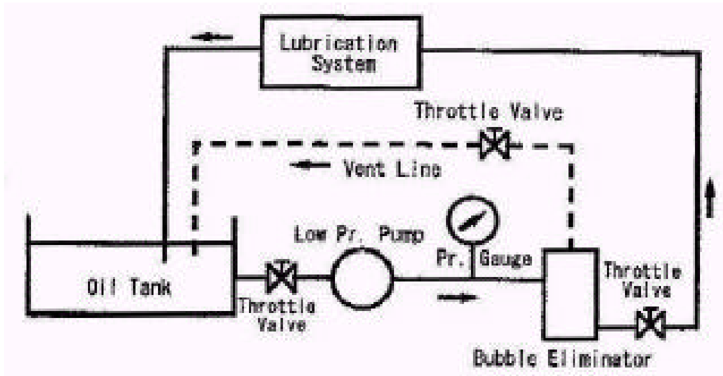


Figure 7 – Typical installation of a Bubble Eliminator into a **t**urbo-machinery circuit.

Case History 2

Regulatory changes in Japan have prompted one fire equipment manufacturer to install first-aid equipment in their hook and ladder fire engines. To create the necessary space, they initially tried to make the oil tank reservoir smaller. If the oil does not reside in this tank for a sufficient time to allow for the bubbles to reach the surface, they will re-enter the hydraulic suction line leading to many associated problems such as imprecise control, cavitation and accelerated fluid degradation. Therefore, a Bubble Eliminator was introduced into the hydraulic circuit as shown in Figure 8 to prevent entrainment of the air bubbles in the hydraulic oil system. Some of the benefits obtained were reduced oil temperature rise during use and noise reduction of the hydraulic pump. Since this initial result was obtained, seventeen (17) Bubble Eliminators with a flow rate 40-220 L/min have been installed on new equipment, which has facilitated the necessary space-savings originally sought.

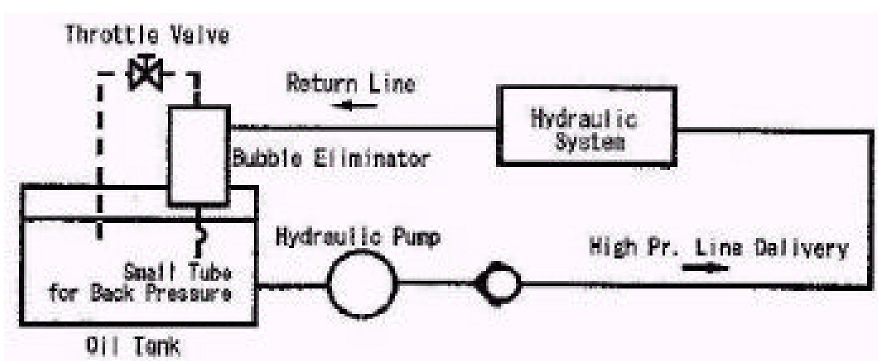


Figure 8 – Illustration of the hydraulic circuit used for the installation of a Bubble Eliminator on a fire engine.

Case History 3

A manufacturer of high precision hydraulic servo-presses for metal powder molding has used Bubble Eliminators with flow rates of 40-440 L/min to prevent excessive temperature rise of oil during use. Without the device, excessive oil temperature increases would head to elongation of the press frame and reduce the production accuracy of molded products. The hydraulic circuit used for this application is shown in Figure 9.

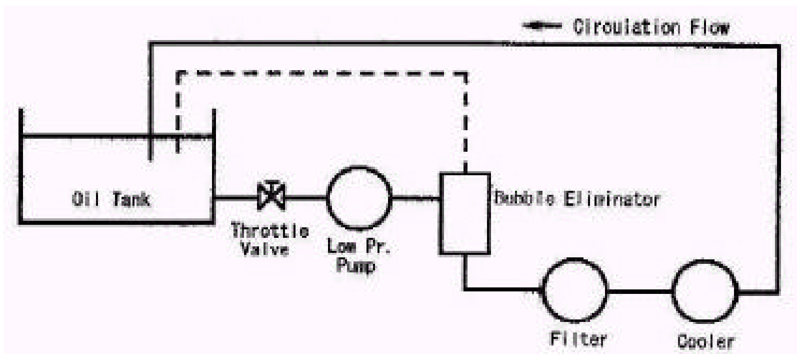


Figure 9 – Hydraulic circuit containing a Bubble Eliminator used for a hydraulic servo-press.

Toshiba Machinery Co. has used a similar circuit for hydrostatic bearings for a roll-grinding machine to maintain the hydraulic oil temperature at 20 ± 1 i n order to maintain the accuracy of the grinding rolls. Eighteen (18) Bubble Eliminators with a flow rate of 40 L/min have been successfully installed in these systems.

Case History 4

Two hydroelectric power stations (0.3 megawatt and 0.26 megawatt) have used 140 L/min Bubble Eliminators to prevent damage of thrust bearings and high-pressure pumps used in the turbo-machinery. The hydraulic circuit is illustrated in Figure 10.

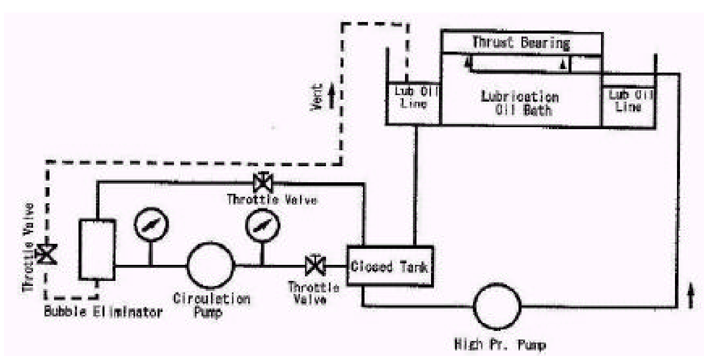


Figure 10 – Hydraulic circuit used for hydroelectric turbo-machinery containing a Bubble Eliminator to protect thrust bearings and other hydraulic equipment.

Case History 5

An equipment producer has successfully tested the Bubble Eliminator for use in eliminating air entrainment problems in agricultural equipment. The hydraulic circuit used for this work is shown in Figure 11.

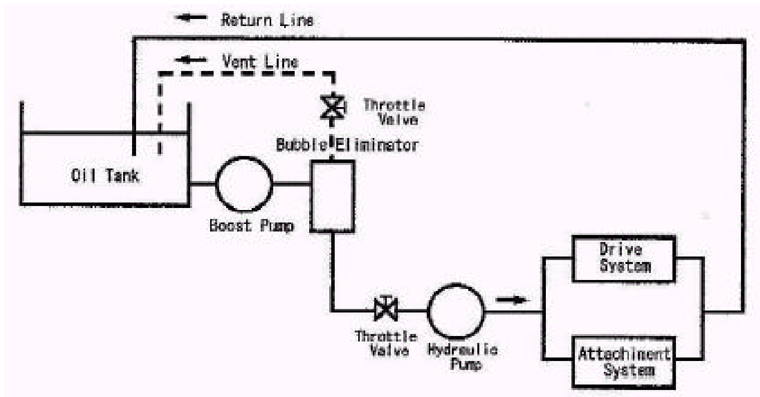


Figure 11 – Test circuit used to successfully evaluate the Bubble Eliminator to remove entrained air in agricultural equipment.

Case History 6

A hydraulic equipment manufacturer used the test circuit shown in Figure 12 to evaluate the function of the Bubble Eliminator (30 L/min) to remove entrained air from combined oil and airflows.

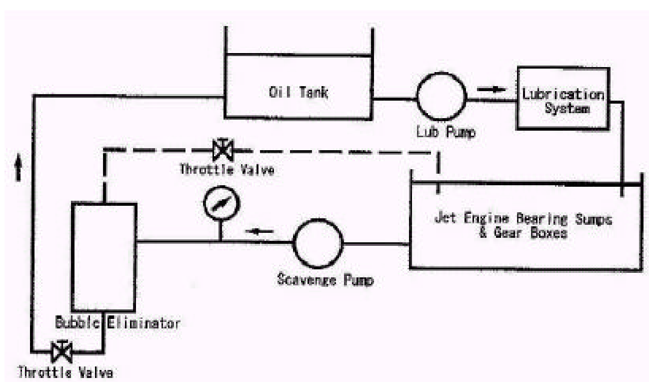


Figure 12 – Test circuit used to evaluate the successful use of a Bubble Eliminator to de-aerate combined oil/air flows.

Case History 7

Bubble Eliminators have been successfully used to remove entrained air from hydrostatic transmissions in Japan. The circuit used for these tests is provided in Figure 13.

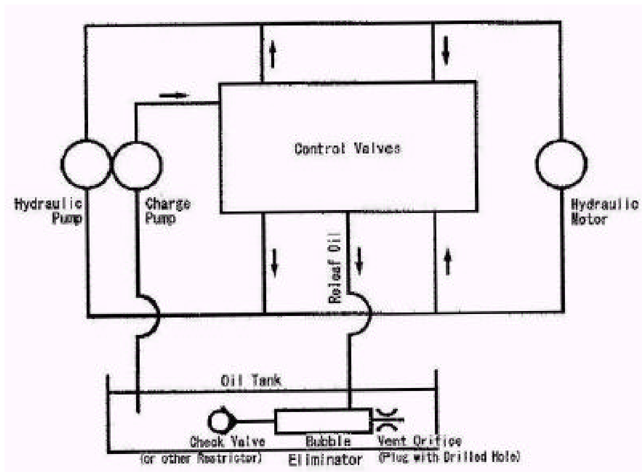


Figure 13 – Test circuit used to evaluate the use of a bubble Eliminator in a hydrostatic transmission.

Conclusions

It has been shown that the *Bubble Eliminator* is an effective design innovation for use with various hydraulic systems to remove bubbles from hydraulic fluids which may produce, cavitation damage, increased and objectionable noise, accelerated fluid degradation and other operational problems. Furthermore, in off-highway equipment design, there are ever increasing tendencies to save space and cost by using smaller reservoir designs. The use of the *Bubble Eliminator* with off-highway hydraulic systems facilitates this trend because in addition to smaller reservoir size, the following advantages are achieved:

1. Light weight, smaller space, lower cost.
2. Slows fluid degradation, thus extending fluid usable life.
3. Prevention of pump cavitation and noise.
4. Less fluid in a reservoir, less possibility of fire.
5. Less heating time in cold weather.
6. Decrease in fluid compressibility and increase in dynamic characteristics.
7. Ease of contamination control.
8. Simple configuration of reservoir with no baffle plate.

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