AIR RELEASE OF USED HYDRAULIC MINERAL-BASED OILS

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Among the properties of oil, air release and foaming tendency are very important. This is mainly because oil fills are getting smaller and the associated circulation times are getting shorter. The oil has less and less time to release air in the tank before it is recirculated. When we use additives to reduce the tendency of the oil to foam, we usually also decrease the rate at which the air is released from the oil. It is therefore a challenge for lubricant manufacturers to harmonise these two properties. This paper will present measurements of both foaming and air release from the oil. Requirements for fresh hydraulic oils will be given as a point of reference. The influence of different viscosity grades of fresh mineral hydraulic oils will be shown. The results of the measurements on different types of base oils will be presented.

Keywords:
hydraulic oil,
air release,
foaming,
base oil,
viscosity

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1 Intruduction

Hydraulic fluid is an essential component of hydraulic system that is often overlooked. Besides the main purpose of power transmission, it also performs various other functions, including reducing friction and wear, preventing leakage, removing heat, flushing away wear particles and contaminants, and protecting surfaces from rust and corrosion. The oil quality required for hydraulic systems depends on the specific application and components used [1]. Viscosity, viscosity index, wear protection, oxidation stability, antifoam and air separation characteristics, demulsibility, rust protection, and compatibility are important characteristics of hydraulic fluids.

Air release and foaming tendency are critical properties of hydraulic oils, especially as oil fills are getting smaller and circulation times are getting shorter. Lubricant manufacturers face the challenge of balancing these two properties.

This paper presents measurements of both foaming and air release from the oil, along with requirements for fresh hydraulic oils as a reference point. The influence of different viscosity grades of fresh mineral hydraulic oils will be shown, as well as the results of measurements on various types of base oils, including used hydraulic oils.

2 Air content in oil and its consequences

Hydraulic devices typically have proportions of undissolved air around 5 vol. % up to 10 vol. % in size. This applies particularly to mobile hydraulics. Often, the fluid cannot remove air bubbles, impurities and cool down, which can cause oil to foam excessively. Air can get trapped inside the device for various reasons and in different forms. The trapped air can be seen by the naked eye, forming a foam or tiny air bubbles. Alternatively, it can be dissolved in a liquid and remain "invisible". The “invisible” (dissolved) air could be also detected in the form of bubbles when the operating conditions change (e.g., pressure), which is also closely related to the design of the individual hydraulic components [2], [3].

The most common causes of the air presence in the oil are certainly the intrusion of air through leaky places (so-called aeration), unsuitable design of the components of the hydraulic system (e.g., tank, pipe network, valves and valve blocks...) or significant inappropriate changes in the operating point related to the design of the hydraulic devices.

Foams that appear on the surface of the liquid in the tank are not directly dangerous and do not affect the compressibility of the hydraulic fluid. Air bubbles that are in the fluid itself are threatening, which leads to various consequences. Thus, the presence of air bubbles in the device primarily affects the compressibility or fluid stiffness, which in turn has a greater or lesser impact on the operation of the hydraulic device itself, such as the accuracy of actuator movement, the occurrence of oscillations, the transmission of signals, the need to change the settings of the regulator parameters, etc.

Air-containing hydraulic oil impairs the lubricating abilities of the oil itself and has an adverse effect on the ageing of the oil. That often leads to premature oxidation of the oil or even to its burning, destruction of seals and consequent leakage, besides this cavitation could occur on the pump and other elements [3], [4].

3 The influence of base oil and additives on foaming

Base oils typically have a low foaming tendency and good stability, though this can vary based on the source of the crude oil and its processing. Studies indicate that there is a direct correlation between foaming tendency and surface tension. If the foam is generated mechanically, using synthetic oil may help decrease the impact of foaming.

- Polyalphaolefin (PAO) and hydrocracked oils have a lower tendency to foam due to their high surface tension compared to petroleum hydrocarbons.
- Organic esters without additives do not foam, but they are easily contaminated or affected by additives.
- Polyglycols (PG) can be challenging to classify due to their ability to absorb water, which may affect their foaming behaviour.

Foam production is highest in base oils with a viscosity of 280 mm²/s, as noted in reference [5]. Lower or higher viscosity can decrease foam amount and stability.

A commonly used additive in detergent oils to prevent foam is based on silicone, specifically polydimethylpolysiloxane (PDMS). Silicones have a low surface tension and tend to gather at the interface of air and oil. To be effective in preventing foam, the silicone must be insoluble in oil and the particles should be less than 5 to 7 microns for long-term performance. The way antifoam additives work is by contacting a bubble's film and spreading around it, thinning the bubble wall until it ruptures. One property of silicones is their higher density compared to surrounding fluids, which slows the ascent of bubbles to the surface. Figure 1 illustrates the effects of silicone on air release, showing that silicone reduces the number of bubbles formed but may also retain them longer during a settling phase.

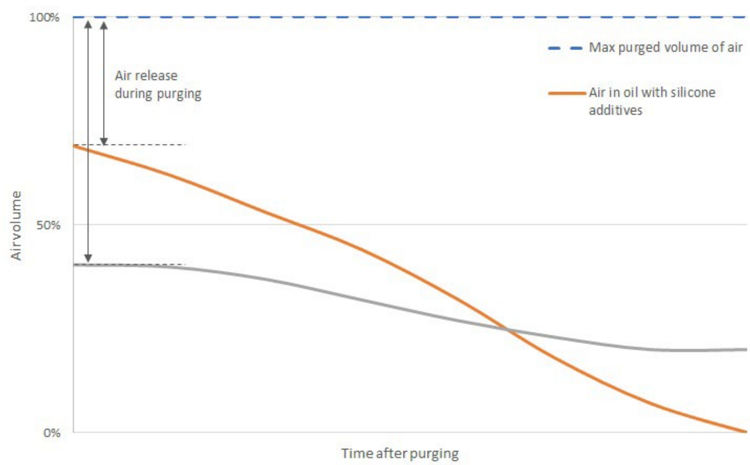

Figure 1: Device for determining air release.
Source: own.

4 Measurements of air release and foaming

In order to prevent or reduce the negative effects of air in oil, it is important for the oil to quickly separate any excess air. This behaviour is known as air release property and is determined in the laboratory. Factors such as the type of base oil, additives, viscosity, and temperature can influence the air release value (ARV; also, using the abbreviation from German, LAV). Additionally, impurities and mixtures can affect the size of air bubbles. Comparing the ARV of used oil to that of fresh oil or a previous analysis can help determine the cause of operational failures or damage, as well as provide insight into continued usage. By examining other analysis values, conclusions can often be drawn regarding why the ARV value has deteriorated.

To determine the ARV using ISO 9120 and ASTM D3427 standards, the air is discharged into a 200 ml sample of the oil being analysed. The time it takes for the air to separate from the oil until only 0.2 vol. % remains is measured in minutes. Preheated air is discharged through a nozzle at a fixed pressure for a specific period of time, and the dispersed air bubbles gradually escape the oil due to its density. This process is recorded graphically until the volume no longer changes. The time from when the air intake is switched off until the density no longer changes is known as the air release time [6]. The device used for determining air release is depicted in Figure 2.

Figure 2: Device for determining air release.
Source: own.

The measurements were carried out in accordance with ASTM D3427. To ensure a proper comparison, all samples were measured at 50 °C regardless of their viscosity.

To assess the foaming properties of hydraulic oils, a few standards can be used, such as ASTM D892, DIN 51566, and IP 146. The ASTM D892 method was utilized to measure the foaming of the samples. This method involves determining the foaming characteristics of lubricating oils at 24 °C and 93.5 °C. The measurements were performed using Linetronic Technologies device LT/FB - 192000 [7], shown in Figure 3.

Figure 3: Device for determining foaming properties of lubricating oils.
Source: [7]

The measurement process begins with 190 ml of the sample being heated to a particular temperature in two parallel measurements, based on the sequence. Preheated air is discharged via a spherical, porous stone into the sample of oil. This leads to an air in oil dispersion in the form of fine bubbles which rise to the surface and create a layer of foam. The foam volume is measured immediately after the air is switched off and again after 10 minutes. Table 1 outlines the specific parameters for temperature, airflow, and aeration time for each sequence.

Table 1: Parameters of temperature and aeration time for each sequence for determination foaming characteristics of lubricating oils

<table>
<tr><th>Sequence number</th><th>Temperature / °C</th><th>Air flow / ml/min</th><th>Aeration time / min</th><th>Waiting time/ min</th></tr>
<tr><td>I.</td><td>24</td><td rowspan="3">94</td><td rowspan="3">5</td><td rowspan="3">10</td></tr>
<tr><td>II.</td><td>93.5</td></tr>
<tr><td>III. (sample from II.)</td><td>24</td></tr>
</table>

To ensure that the oil can be used for an extended period, it is essential to have good output values. Therefore, it is important that the air release and foaming properties of newly bought hydraulic oils do not exceed the limit values mentioned in Table 2.

Table 2: Requirements for foaming and air release properties of fresh hydraulic oils

Hydraulic oil type	Requirements				
Designation according to DIN	HLP 22	HLP 32	HLP 46	HLP 68	HLP 100
Designation according to ISO	ISO VG 22	ISO VG 32	ISO VG 46	ISO VG 68	ISO VG 100
ARV_{max} at 50 °C / min	5	5	10	13	21
$Foaming_{max}$ /ml 24 °C (sequence I.) 93.5 °C (sequence II.) 24 °C (sequence III.)	150/0 75/0 150/0				

Source: DIN 51524-2

5 Foaming and air release of fresh hydraulic and base oils – results

The fresh hydraulic oils have been prepared according to a formulation that meets the requirements of ISO VG.

For purpose of comparison, hydraulic oils were prepared using common base oils SN 150 and SN 600 from two different producers (Base oil A and Base oil B). The requirements of ISO VG were achieved using the same amount of additives, widely familiar to experts in the field.

Table 3 compiles the findings for foaming and air release, alongside viscosity measurements at 40 °C and 100 °C, along with the viscosity index.

Figure 4 depicts the relationship between air release time at 50 °C and viscosity grade in the form of a graph.

Figure 5 represents the foaming characteristics of hydraulic oils as a function of viscosity grade.

In Table 4 viscosity, foaming and air release properties of base oils A and B are shown.

Table 3: Comparison of viscosity, foaming, and air release properties between hydraulic oils based on two different base oil sources

Hydraulic oil type according to ISO		Base oil A				
		VG 22	VG 32	VG 46	VG 68	VG 100
Viscosity / mm²/s	40 °C	22.22	32.65	47.23	69.37	100.7
	100 °C	4.418	5.565	7.050	9.007	11.37
Viscosity index		108.5	107.7	106.5	103.8	98.96
ARV at 50 °C / min		1.2	2.2	5.5	10.0	16.7
Foaming[1] / ml	I.	150/0	50/0	20/0	10/0	10/0
	II.	10/0	20/0	20/0	10/0	40/0
	III.	140/0	30/0	20/0	10/0	10/0
Hydraulic oil type according to ISO		Base oil B				
		VG 22	VG 32	VG 46	VG 68	VG 100
Viscosity / mm²/s	40 °C	22.07	32.36	49.78	69.06	100.5
	100 °C	4.407	5.526	7.273	8.941	11.30
Viscosity index		109.1	107.2	105.6	102.9	98.18
ARV at 50 °C / min		1.2	1.6	5.1	9.4	15.3
Foaming[2] / ml	I.	150/0	20/0	20/0	30/0	30/0
	II.	20/0	20/0	20/0	20/0	70/0
	III.	150/0	30/0	50/0	30/0	30/0

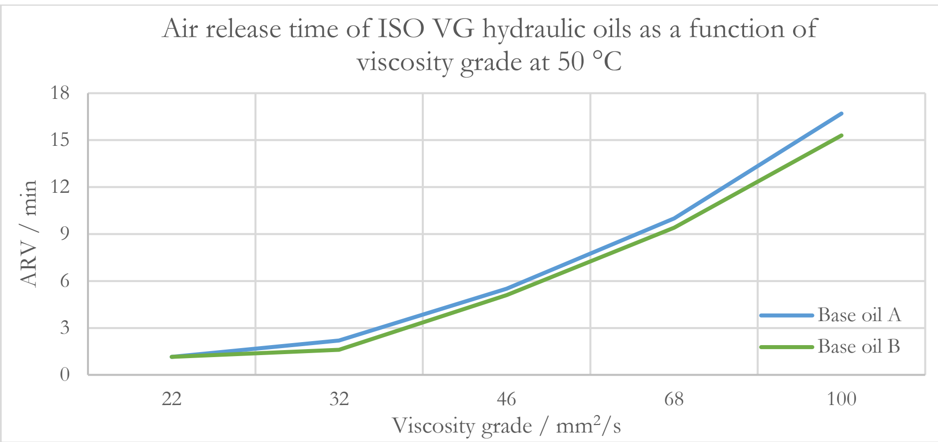

Figure 4: The relationship between air release time and viscosity grade of hydraulic oils.
Source: own.

[1] The results of foaming are given in format [at the end of aeration / after 10 minutes].
[2] The results of foaming are given in format [at the end of aeration / after 10 minutes].

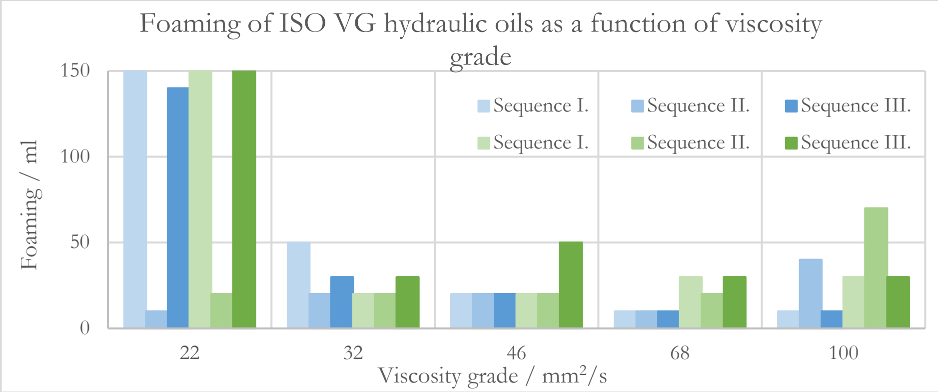

Figure 5: Foaming characteristics of ISO VG hydraulic oils as a function of viscosity grade. Results of hydraulic oils based on base oils A and B are presented with blue and green columns, respectively.

Source: own.

Table 4: Viscosity, foaming and air release properties of base oils A and B

		Base oil A	
		SN 150	SN 600
Viscosity / mm²/s	**40 °C**	30.00	111.6
	100 °C	5.243	12.07
Viscosity index		105.5	97.30
ARV at 50 °C / min		1.1	17.8
Foaming[3] / ml	**I.**	370/0	160/0
	II.	30/0	80/0
	III.	370/0	220/0
		Base oil B	
		SN 150	SN 600
Viscosity / mm²/s	**40 °C**	31.94	111.0
	100 °C	5.441	11.94
Viscosity index		105.0	96.05
ARV at 50 °C / min		1.5	11.5
Foaming[4] / ml	**I.**	390/0	580/20
	II.	30/0	60/0
	III.	390/0	530/20

In Figure 6 the results of air release time and foaming for base oils A and B are presented as a function of initial viscosity grade (SN 150 and SN 600).

[3] The results of foaming are given in format [at the end of aeration / after 10 minutes].
[4] The results of foaming are given in format [at the end of aeration / after 10 minutes].

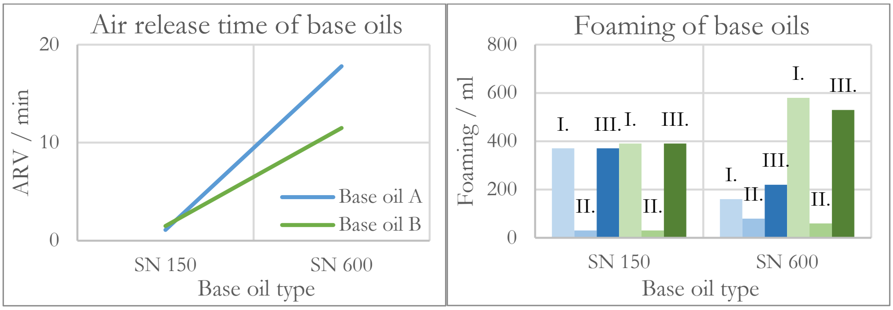

Figure 6: The relationship between air release time and viscosity grade of base oils (left) and foaming characteristics by sequences of base oils (right). Results of base oil A and B are presented with blue and green curve/columns, respectively.

Source: own.

From the results collected in Tables 3 and 4, presented in Figures 4, 5, and 6, it can be concluded that the air release time is a function of viscosity grade – the higher the viscosity, the more difficult it is for the oil to release the air trapped in a sample. The results are comparable with air release values for base oils, which were used to prepare ISO VG hydraulic oils. If we compare hydraulic oils in general based on the base oil, from which they were prepared, we can observe that the higher the air release value for base oil, the higher the air release of hydraulic oils based on the same base oil.

Foaming as a function of viscosity grade does not show the same trend as an air release. Based on the results of foaming of base oils, we cannot observe the same trend for hydraulic oils. Hydraulic oils tend to foam extensively at low viscosity grades, while the effect is barely noticeable at viscosity grades from 32 mm^2/s to 68 mm^2/s and slightly higher at viscosity grade 100 mm^2/s.

It can be concluded that the air release of hydraulic oils is strongly correlated with the air release of base oils and initial viscosity while the same cannot be confirmed in the case of foaming tendency.

6 Summary

Air release time and foaming tendency were checked on fresh hydraulic oils of several viscosity grades prepared from two different base oils. Air release value (ARV) was measured at 50 °C for comparative purposes, regardless of the initial viscosity of hydraulic oils. The results of ARV confirmed the relationship between base oils and hydraulic oils made from those base oils. The ARV strongly depends on the viscosity grade of hydraulic oils – the higher the viscosity, the more difficult it is for oil to release trapped air. The same trend was not observed at foaming – higher values were determined at samples of hydraulic oils with low viscosity, while the foaming tendency decreased at viscosity grades from 32 mm^2/s to 68 mm^2/s and slightly increased at viscosity grade 100 mm^2/s.

It can be concluded that the air release of hydraulic oils is strongly correlated with the air release of base oils and initial viscosity value, while the same cannot be confirmed for foaming.

Examining the hydraulic oils in use reveals that the propensity for alterations in foaming characteristics becomes more apparent after a specific period of utilization. Nevertheless, the air release value (ARV) does not exhibit such heightened sensitivity in this particular case.

Further investigation will be performed, starting with more base oils from different producers and with other types of hydraulic oils.

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