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Characteristics of Refrigerant and Oil Losses Due to a Leakage in Air Conditioning System

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ABSTRACT
Possibility of a system leakage in an air-conditioning system always exists. Once a leakage occurs refrigerant and oil escape from the system and compressor. This paper determines the characteristics of the losses. Two important factors affecting the loss characteristics are location of leakage in the system and speed of leakage or leakage rate. This paper then reasons the tested actual loss characteristics. Impact of oil loss from rotary compressor is reviewed from the standpoints of reliability and protection of compressor as a function of the two factors.

INTRODUCTION
There are two types of leakage; internal and external. In this paper, it is assumed that no internal leak in compressor has been detected beyond the acceptable level prior to system charge. It is also assumed that no external leak has been detected with a commonly accepted economic leak detection system. In a strict sense, even the acceptable products will have a finite, though acceptably small or insignificant leak rate. However, years of experiences have shown that most sealed products and closed systems intended to contain gas are not totally free from leaks, despite careful manufacturing techniques. We are concerned with leakage from several aspects. First, leakage affects critical refrigerant charge which is factory-optimized standard system charge. Secondly, it may affect reliability of compressor.

LEAKAGE POTENTIAL IN AIR CONDITIONING SYSTEM
Factory uses several processes to insure a leak-tight system. Though “leak-free” requirement is commonly used in factory but it has no precise meaning since these products can have leaks smaller than the specified leak without impairing operating life of the product. However, field installation and subsequent vibration can lead to a leakage. The number of mechanical or brazing joints dictates the probability of leakage. Leakage may occur from fitting connection, cracked tubing from vibration or resonance, impact, or mishandling of the unit. In heat pump and multi-evaporator unit, the number of mechanical connecting and brazing joints is higher than cooling-only unit or window room air-conditioner. In various air-conditioners, the number of joints that are potential leak sources falls in the range of 100~200.

Once a leak has been identified, countermeasures must be taken, especially because the leak is likely to continue undetected until noticed by consumer or serviceman. Following the leak, unit will fail to function resulting from loss of refrigerant. Compressor will continuously run for some time, but the overload protector may not function due to low amperage draw. Compressor may eventually be damaged after exposure to air and air/oil reaction. Certain kinds of oil used with HFC refrigerants are
cases in point. When a leak develops on low side, the compressor will draw in air from the ambient and contaminate the system.

THE EXPERIMENTAL SET-UP and TEST PROCEDURES

Once a leakage develops, the mixture of refrigerant and oil will continue to escape from the system as long as pressure differential exists between the system and the ambient. Two factors determine the characteristics of leakage and they are the location of leak and speed of leak or leak rate.

**Leak Locations** - Four (4) leak locations representing the following four cases are selected and indicated in Fig. 1. In each test, only one leakage was assumed as the likelihood of concurrent multiple leaks is very low.

<table>
<thead>
<tr>
<th>Location</th>
<th>Pressure</th>
<th>Running</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>Low</td>
<td>Mainly Vapor + Some Liquid</td>
</tr>
<tr>
<td>L2</td>
<td>High</td>
<td>Vapor</td>
</tr>
<tr>
<td>L3</td>
<td>High</td>
<td>Liquid</td>
</tr>
<tr>
<td>L4</td>
<td>Low</td>
<td>Mainly Liquid + Some Vapor</td>
</tr>
</tbody>
</table>

**Speed of Leakage** - There is A wide range of cases when a leakage develops. Though it has not been quantitatively flow-rated, a 1/4” hand valve was installed at each leak location and the valve was opened at different opening angles to simulate “slow,” “medium,” and “fast” leak rate. The leak duration ranged from one minute to 77 hours but majority lasted for 15 minutes.

The experiment used a window room air conditioner with unit rating of 12K Btu/h [3.5 kW] with compressor and accumulator equipped with sight glasses. The schematic diagram of the set-up is shown in Fig. 1 with locations of the four leak points, sight glasses, fourteen (14) thermocouples, and two (2) pressure taps. The unit was first operated to a stabilized condition in a room at 31~33°C ambient. Then, the valve at one location was opened to simulate a leak situation. Temperatures and pressures as well as video shots at the sight glasses were recorded. Discharge and suction pressure were at 20 and 4 kg/cm² respectively. These pressures changed to vacuum on suction side and near atmospheric pressure on discharge side during leak process. The slow leak still showed 5.5 kg/cm² for discharge pressure after 77 hours of leak. The test compressor contained 550 cc alkylbenzene oil which filled the sump to the level above the top of the cylinder. Effective volume of the accumulator was 540 cc which is sufficient volume to control the refrigerant charge of 1,000 gram.

LOSS OF REFRIGERANT

Pressure decay depends on the speed of leakage. While the decay of discharge pressure is easier to comprehend (Fig. 2), the case for suction pressure (Fig. 3) highlights the difference slow vs. fast/medium leak rates. In all tests, except the three-day leak process, most of, if not all, the initial refrigerant charged was lost during the leak durations observed.

LOSS OF OIL

A true picture of oil loss can only be estimated with many experimental data, but neglecting leak location effect, the oil loss data in Table 1 is statistically tested if the speed of leak makes a difference. The loss of oil data tends to indicate that the higher speed of leak promotes more oil loss; the very slow leak losing the least amount. In order to test the statistical significance of difference between
medium and fast leak an analysis was done. The analysis concludes that the two are statistically not different in oil loss at 0.01 level of significance. However, a possible repeatability question in testing and measurements of oil loss, the analysis requires additional test data before making a firm statistical statement.

**Leak From Non-operating Unit** - Leak is unlikely to start from a non-operating unit, nevertheless it is still a possibility. A leak will continue after stopping from the leaky operating unit. After an overnight soaking, the unit reached a balanced pressure of 10.4 kg/cm\(^2\). When a leak was created at L3 the oil sump start to bubble up releasing refrigerant and sump level continued to drop to almost half level of the sight glass. During the process a significant oil loss resulted after an overnight soaking, losing about 150 cc or 27% of the original oil charge. The fact that the amount of oil loss from the off-unit is significantly different can be easily proven at a 0.01 level of significance.

**CHARACTERISTICS OF COMPRESSOR OPERATION WITH LEAKAGE**

From the test data the following observations can be made:

**Suction Superheat** - Prior to leak initiation, suction superheat was moderate 8°C, and increased during leak process at a rate less than 2°C per minute. In the event that suction pressure decay is slow, heat transfer from the ambient makes up the heat loss due to the slow expansion process.

**Refrigerant Content in Oil Sump (Fig. 4)** - Prior to leak initiation, refrigerant content in the oil sump was close to 31% while compressor was running. This percentage coupled with 20 kg/cm\(^2\) discharge pressure gave a sufficient oil viscosity for adequate film thickness. At near the leak process the content dropped to 1~9%. The content drastically increased to 58% after overnight soak for the off-unit. This situation also decreased oil viscosity below 1.0 cSt (centi-Stokes). High side leak and/or fast leak gave faster drop in refrigerant content during leak process and this is due to faster decay of discharge pressure.

**Oil Viscosity (Fig. 5)** - During leakage oil viscosity increases to an average of 3 and up to 6 cSt. As the initial viscosity while running and just prior to leakage start was 1.8~2.0 cSt, the compressor had a decent viscosity to maintain a safe oil film thickness. The rate of increase in oil viscosity was quite different depending on the leak location. High-side leak locations, L3 and L2, give a rapid increase of the viscosity with leak duration. The low-side leak locations, L4 and L1 gives no increase in viscosity during the leak process. The leak from the off-unit showed very rapid increase in oil viscosity as discharge pressure drops rapidly and oil temperature continues to increase.

When rotary compressor loses oil, the original level established with the original oil charged into oil sump will be lowered. With the same amount of refrigerant charge, the oil/refrigerant will be lower and more refrigerant will be present for given oil amount. This, in turn, lowers oil viscosity and results in thinner oil film thickness.

**Speed of Leakage (Fig. 6)** - At the fixed leak location L3, effects of the speed of leakage are looked at for fraction of refrigerant in the oil sump. The decay patterns are alike Fig. 2 where discharge pressure decay curves at L3 are shown. From these, it can be seen that the pressure decay characterizes the refrigerant decay in the oil sump.

**Oil Sump Temperature (Fig. 7)** - Prior to leak initiation, temperature of the oil sump ranged from 73 to 100°C while compressor was running. This temperature continued to increase during the leak by 20°C,
except the off-unit which continued to drop due to discharge pressure decay.

**Slow Leak (Fig. 7)** - A slow leak at discharge line (L2) was created for over three days, but the leak rate being slow that, after the test period, discharge pressure was still at 5.5 kg/cm² though suction was in vacuum. Trend in compression ratio and refrigerant content was similar as in a fast leak; changes were just stretched over the longer period. Temperature in the oil sump, however, gradually increased to 140°C while the fast leak reached to a temperature below 90°C when refrigerant was mostly exhausted. Oil viscosity remained essentially at a constant value while the fast leak allowed to reach higher value. This is due to lower oil sump temperature and lower discharge pressure which was reached quickly. Neither sump oil superheat nor suction superheat caused any problem.

Observations from the very slow leak process at high side L2, observed for 77 hours, are as follows: Superheat at compressor suction and bottom shell temperature are high enough at 20~30°C and 38~40°C respectively and are no concern for reliability standpoint. Accordingly, viscosity of oil at 2.2 cSt is also of no concern. Fraction of refrigerant in oil sump at 18~23% range is also not excessive during the slow leak process.

**Compression Ratio** - Compression ratio starts from 1.8 but does not change by any significant amount. During the leak process compression ratio ranged from 1 to 2 while the operating envelope of the test compressor gives max 7.5 in compression ratio.

**Reliability Impacts** - Parameters that affect compressor reliability are operating temperature, liquid flooding, compression ratio, oil viscosity and load exerted on bearing. Once system matching is assured with adequate superheat, operating temperature is no issue except at slow leak where very high oil sump can be reached. Despite the high temperature, mechanical loading on bearing decreases while refrigerant content is reduced and oil viscosity remains at the safe range. Overall, leak process does not, therefore, pose a significant reliability risk.

**CONCLUSIONS**

How much oil is lost during leak process depends on leak location, speed of leak and initial percentage of refrigerant dissolved in the oil sump. From several test runs simulating leakage, no significance was observed to damage reliability of compressor. Compression ratio remains fairly constant, no flooding is evident and bottom shell superheat and viscosity of oil remains in safe range. Loss of oil from a non-operating unit can be significant, especially when refrigerant is dissolved in the oil sump to a significant extent. Thus, an over-charged system with refrigerant can be damaging to compressor given sufficient time is allowed for refrigerant migration. In the event a leakage develops, suction superheat rises and compressor operates at a higher operating temperature. Both suction and discharge pressure gradually drop and proper cooling inside the compressor lacks. Despite the built-in loss of charge protection the compressor may not trip on overload protector mainly due to low amperage draw. In a overcharged system, initial suction and oil sump superheats may be low and reduced mechanical loading and lower starting temperature should put the system out of reliability danger.

**REFERENCES**

2. Private Communication with Air-conditioner Plant Q.C. Dept., Daewoo Carrier Corp.
**Fig. 1 Location of Leak**

- **Compressor**
- **condenser**
- **Capillary Tube**
- **Evaporator**
- L1
- L2
- L3
- L4

- Sight Glass Location
- Thermocouple Location

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**Fig. 2 Discharge Pressure Decay at Location L3**

<table>
<thead>
<tr>
<th>Time (Minutes)</th>
<th>Discharge Pressure (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>24</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>12</td>
<td>0</td>
</tr>
</tbody>
</table>

- Unit On/Off: ON
- Leak Location: L1, L2, L3, L4
- Speed of Leakage: Slow, Medium, Fast

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**Table 1 Amount of Oil Loss**

<table>
<thead>
<tr>
<th>Unit On/Off</th>
<th>Leak Location</th>
<th>Slow</th>
<th>Medium</th>
<th>Fast</th>
</tr>
</thead>
<tbody>
<tr>
<td>ON</td>
<td>L1</td>
<td>-</td>
<td>58</td>
<td>43</td>
</tr>
<tr>
<td>ON</td>
<td>L2</td>
<td>6</td>
<td>31</td>
<td>30</td>
</tr>
<tr>
<td>ON</td>
<td>L3</td>
<td>-</td>
<td>18</td>
<td>40</td>
</tr>
<tr>
<td>OFF</td>
<td>L3</td>
<td>-</td>
<td></td>
<td>149</td>
</tr>
<tr>
<td>ON</td>
<td>L4</td>
<td>-</td>
<td>-</td>
<td>52</td>
</tr>
</tbody>
</table>

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**Fig. 3 Suction Pressure Decay at Location L3**

- Suction Pressure (kPa)
- Minutes after Initiation of Leak

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- Fast
- Medium
- Slow