Characterization of Solid Contaminants in Air Conditioning and Heat Pump Residential Split Systems and Their Effect On Compressor Reliability

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CHARACTERIZATION OF SOLID CONTAMINANTS IN AIR CONDITIONING AND HEAT PUMP RESIDENTIAL SPLIT SYSTEMS AND THEIR EFFECT ON COMPRESSOR RELIABILITY

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ABSTRACT

This paper describes the study conducted to characterize the solid contaminants that are present in residential split systems. New systems and service systems were evaluated. The study identifies the sources and the effect of these contaminants on compressor reliability.

The paper describes the device and the techniques to entrap the solid contaminants in actual field installations. The laboratory evaluation procedures to characterize the weight, size distribution, and elemental analysis of solid residue particles are described.

This paper includes comments on currently available protection devices and their use in systems to maintain system cleanliness.

INTRODUCTION

The presence of various contaminants in refrigerant systems has been a major concern to equipment manufacturers, installers, engineers, and chemists alike. The sources of contaminants are typically manufacturing and installation, and by-products during service from wear processes, and various chemical reactions. The effects of moisture, residual solvent, solid contaminants (metals, dirt, etc.), organic contaminants (sludge, wax, tars, etc.) and noncondensible gases on the refrigerants, lubricants, and motor insulation have been studied and reported. Specific corrective measures have been developed. Filter-driers and moisture indicators are incorporated in systems. Field requirements for system clean-up after a hermetic motor burnout have been established.

It is the purpose of this paper to address the solid contaminants, particularly in split systems, as they relate to compressor reliability. The first part of this paper discusses the adverse role of solid contaminants. Then details of a special study to characterize the solid contaminants from their various sources in residential heat pump split systems are presented. The results of the study are reviewed and the author has developed a standard test contaminants that will facilitate relative laboratory evaluation of compressor designs for tolerance to contaminants.

Filtration for wear control has been a known effective measure of inhibiting the machinery wear. Liquid line filter-driers are commonly used in many residential split systems. Some compressor designs require added protection from specially designed suction line filter-driers. In the final part of this paper, the effectiveness of currently available protection devices and future considerations in this field are discussed.

ROLE OF CONTAMINANTS

Solid contaminants cause difficulties in a refrigerating system by clogging, stiction, wear, and chemical breakdown. In some cases, catastrophic failures occur.

(a) Clogging: The initial blockage may be caused by lodging of one large particle or two or more smaller particles. Although not a total blockage, this invariably reduces the clearance of the orifice and, in turn, traps smaller particles. The size, shape, and the number of contaminant particles directly affect the extent of damage. In compressors, oil holes in compressor parts, if clogged, leads to improper lubrication. Expansion valve screen or capillary tubes may be plugged. If the contaminants are conductive, they are potential causes of failure when deposited on terminal block or individual motor windings with partially abraded wire insulation. Clogging of filter-driers will adversely affect pressure drops in the system leading to loss of performance and
efficiency.

(b) Stiction: When particles wedge between component surfaces, the relative motion of the surfaces are inhibited and greater forces will be required to move the component surfaces. Hard contaminant particles will result in abrasive wear and soft particles can fill in a clearance. In compressors, "gumming" of internal parts, like suction and discharge valve seats will result in partial loss of response due to stiction leading to reduced compressor efficiencies.

(c) Wear: Wear processes are affected by the contaminants and in turn are also a source of solid contaminants. Thus, the cyclic, progressive, and cumulative aspects of damage makes this a complex field of study. Three mechanisms of wear, abrasion, surface fatigue, and adhesion have been identified due to particulate contamination. There are three physical situations by which the particles come into contact and damage the surfaces, namely three body wear, two body wear and erosion. The hardness, the number, size, and shape of the particulates determine the extent of damage during these wear processes.

The design variables that directly influence the contaminants' role in wear processes are (1) embeddability characteristics of wear surfaces, (2) typical operating dynamic film thickness, and (3) typical clearance between mating surfaces. Table 1 lists some typical values for well documented cases in the high pressure fluid system components. As seen, with the lubricant film thickness in the "less than 2 micron" range, elastohydrodynamic modes of lubrication are involved requiring filtration of particles in that size range. Table 2 compares clearances for components of two refrigeration compressor designs. Tighter running clearances and requirement for a hydrodynamic oil seal are characteristics of the rotary compressor design. In addition to the clearance/oil film thickness, the directness of the path of the contaminants entering a compressor, retention characteristics of contact surfaces to embed fine particles also determine the compressor's ability to tolerate solid contaminants with or without special filter requirements. The effect of particle size has been closely studied and understood. If a particle size equals or exceeds lubricant film thickness, it results in two or three body abrasive wear. This has been confirmed in extensive study of journal bearings where to reach its optimum performance limits, contaminant particle size must be controlled to less than minimum film thickness.

(d) Chemical Breakdown: Degradation of lubricant and/or refrigerant properties will adversely affect wear modes and system performance. Contaminants' contribution to oxidation breakdown reactions have been explained by their surfaces acting as catalysts.

CONTAMINANTS STUDY APPROACH

The objective of the study was to characterize and quantify the solid contaminants that are present in U.S. residential heat pump split systems. The results of the study will be the basis to define "standard test contaminants" to be used in laboratory durability evaluation of various compressor designs for contaminants' tolerance. The net distribution of contaminants that compressors would experience in an actual system will be represented by "A+B+C-D distribution", where

- \( A = \) contaminants from compressor manufacturing process
- \( B = \) contaminants from split system components, their assembly and installation at site
- \( C = \) contaminants from wear products
- \( D = \) contaminants trapped by protection devices such as filter-driers

DATA CONSIDERATIONS

The study was designed to document (1) the amount (weight), (2) particulate size distribution, (3) shape, (4) composition, and (5) hardness. The composition will aid in pinpointing the origin/source of contaminants. The hardness and the particulate size data are crucial in defining a valid "standard test contaminants" to yield meaningful effects on wear on components.

SOURCES

New and remanufactured compressors in the condition leaving the plant were studied for contaminants' evaluation. Residential split systems in Ohio, Arizona, and Florida were chosen to include new installations and service installations (with prior history of compressor replacements). To estimate contaminant particulates from wear processes, compressors in operation for 3-5 years were studied.

SPLIT SYSTEM INSTALLATIONS

Entrapment of contaminants in actual field installations posed several problems. Several approaches were considered in technical brainstorming sessions with Battelle scientists and engineers: (1) use of a multi-stage filter with different stages, say at 100, 40, 10, and 5 microns, (2) use of a small high-efficiency cyclone that can work effectively down to 5 micron range with low pressure drop, and (3) con-
siderations to take filter samples at several intervals so the time rate of capturing the contaminants can be assessed.

The final solution consisted of designing a replaceable filter assembly core that will fit in a standard suction line filter-drier shell. A 17-18 micron size woven metal filter cloth element was chosen as the screen element. It was capable of easy assembly, disassembly, and backflushing and did not result in adverse pressure drop characteristics when tested in laboratory conditions. Figure 1 is a schematic of the entire assembly illustrating the direction of flow through the screen element. Figures 2 and 3 show the internal details and the final assembly of the filter core. This device offered the attractive reusability feature.

The special filter assembly inside a standard suction line filter-drier shell was installed in the suction line of residential split systems just ahead of the compressor. The heat pump system was subjected to a total run time of four hours with start-stop cycles every 30 minutes, thus enabling the effect of transient flows to be captured.

CHARACTERIZATION OF CONTAMINANT PARTICLES

The first step involved obtaining the entrapped contaminants from the filter assembly and compressors into solution. 1-1-1 Trichloroethane was used to backflush the filter and to rinse out the internal parts of the compressors. About a pint of the liquid was sent for particulate distribution analysis using a H1AC -320 optical particle counter calibrated per ISO-4402-1977. The particulate size distribution down to 3 micron range was thus obtained.

The total weight of solid contaminants was estimated from the weight of the residue after the entire 1-1-1 trichloroethane solution was filtered and dried.

Scanning electron microscopy (SEM) and energy dispersive x-ray fluorescence (EDX) techniques were used to analyze the filter residue samples after carefully coating the surfaces with approximately 250 angstroms of evaporated carbon.

RESULTS OF STUDY

1. The contaminants varied in sizes ranging from 1-3 microns to 200 microns. The shapes of the particles encountered varied from spherical to angular and platelets. Elements that were predominant in the x-ray fluorescence spectrums included iron, copper, silicon, zinc, aluminum, chlorine, phosphorous, and calcium. Pure metals like copper was present. Usually, many elements were present in conjunction with others as alloys or chemical compounds. Evidence of organic chlorides and other polymeric materials were found in lesser proportion.

2. Presence of pure copper, sand/clay-like minerals and copper oxides were observed in contaminants from installation sites. Construction site debris, welding, and brazing scales are constituents that contributed to silicon dioxide in the 100-200 micron ranges and copper oxide in the 30-50 micron range particles. Iron was also present in the pure form and as oxides to a lesser extent. Figure 4 (SEM 5059) displays copper in particles labelled E, G, H, K, L & M; iron is identified in particles labelled A, C & M. In Figure 5 (SEM 5060), presence of sand (silicon dioxide) was established by silicon in particles labelled A, B & G.

3. Iron and its compounds were the predominant constituents observed from compressor manufacturing sources. To a lesser extent, sand and constituents from metal removal operations were seen. Remanufactured compressor showed a significantly higher quantity of solid contaminants as compared to a newly built compressor. The particles were in the 30-80 micron range.

4. Wear products were observed in compressors from field service with 3-5 years of life. Presence of aluminum and silicon from aluminum alloys, iron and chromium from steel alloys, copper and zinc from brass-bronze type alloys, calcium, magnesium, silicon, and aluminum from sand/clay-like minerals are illustrated in two sets of SEM and EDX pictures. Figure 6 (SEM 4902) and Figure 8 (EDX 7) constitute one set for a particle labelled K. The other set consists of Figure 7 (SEM 4896) and Figure 9 (EDX 3) for a particle labelled B. Wear particles consisted of greater proportion of finer size particles (5-20 micron). The amount of contaminants from wear accounted for 70-80% of total contaminants.

5. Service installations with prior history of compressor failures were significantly inferior to new installations. Up to five fold increase in total contaminants was observed in service installations. A major proportion of this difference is due to increased amounts of wear products.
STANDARD TEST CONTAMINANTS

To understand and quantify the role of solid contaminants on compressor wear, durability and degradation, life testing of compressor designs are being conducted using a "standard test contaminants" that best represents the real world. Specific considerations were given to availability of standard constituent powders from reputable sources. The size, hardness, chemical composition, and relative proportions are maintained as close as possible in the "standard test contaminants", which is listed as follows:

<table>
<thead>
<tr>
<th>NAME</th>
<th>SIZE (MAX)</th>
<th>AMOUNT</th>
<th>SOURCE</th>
<th>GRAMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron Oxide</td>
<td>75</td>
<td>1</td>
<td>1.3</td>
<td>32.5</td>
</tr>
<tr>
<td>Arizona Coarse</td>
<td>170</td>
<td>2</td>
<td>1.0</td>
<td>25.0</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>44</td>
<td>1</td>
<td>0.5</td>
<td>12.5</td>
</tr>
<tr>
<td>Copper Oxide</td>
<td>44</td>
<td>1</td>
<td>0.5</td>
<td>12.5</td>
</tr>
<tr>
<td>Aluminum Alloy</td>
<td>100</td>
<td>1</td>
<td>0.3</td>
<td>7.5</td>
</tr>
<tr>
<td>Copper Chloride</td>
<td>150</td>
<td>1</td>
<td>0.2</td>
<td>5.0</td>
</tr>
<tr>
<td>Brass</td>
<td>44</td>
<td>1</td>
<td>0.1</td>
<td>2.5</td>
</tr>
<tr>
<td>Teflon</td>
<td>35</td>
<td>3</td>
<td>0.1</td>
<td>2.5</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>4.0</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

Source Legend

1 = Consolidated Astronautics, Saddlebrook, NJ
2 = AC Spark Plug Division of General Motors
3 = DuPont

CLOSING COMMENTS

Compressor designs that tolerate solid contaminants with self limiting wear will not require protection devices like special filter-driers. However, in cases where progressive and cumulative effects of wear continue with exposure, protection from contaminants will be specified by compressor manufacturers.

Currently available filter-driers are not efficient in the 20 micron and finer ranges. Also, they require improvement in the areas of bypass inefficiencies in assemblies. Protection from 5-20 micron and below 5 micron wear contaminants may be required and specified in some cases. This will necessitate development of newer and more efficient filtration devices that are cost effective. Careful attention must be paid to avoid plugging, yet maintaining efficiency and dirt capacity requirements. Future designs may dictate replaceable or throw-away type filters.

Precharged tubing is used by some installers to control contaminants. Precharged tubing with an estimated 3.5 milligrams per square foot of allowable foreign material compares favorably to standard tubing with 18 milligrams per square foot. However, precharged tubings cost more (about 75% more than standard tubing) and are not frequently used in U.S. residential split systems.

System cleanliness will continue to get more attention. Compressor and system manufacturers may tighten clean-out requirements prior to compressor changeout. This is especially true for service installations with prior history of compressor failures.

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### TABLE 1

**DESIGN VARIABLES IN FLUID SYSTEM COMPONENTS**

<table>
<thead>
<tr>
<th>COMPONENTS</th>
<th>DYNAMIC FILM THICKNESS (MICRO METERS) OR MICRONS</th>
<th>TYPICAL CLEARANCE (INCHES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roller Element Bearings</td>
<td>0.1-1</td>
<td>--</td>
</tr>
<tr>
<td>Journal Bearings</td>
<td>0.5-100</td>
<td>0.000,02--</td>
</tr>
<tr>
<td>Hydrostatic Bearings</td>
<td>1-25</td>
<td>0.000,04--0.001</td>
</tr>
<tr>
<td>Pump, Vane</td>
<td>Vane Sides 5-13</td>
<td>0.000,2--0.000,5</td>
</tr>
<tr>
<td></td>
<td>Vane Tip 0.5-1</td>
<td>0.000,02--0.000,04</td>
</tr>
<tr>
<td>Pump, Piston</td>
<td>Piston to Bore 5-40</td>
<td>0.000,2--0.001,6</td>
</tr>
<tr>
<td></td>
<td>Valve Plate to Cylinder 0.5-5</td>
<td>0.000,02--0.000,2</td>
</tr>
</tbody>
</table>

### TABLE 2

**DESIGN VARIABLES IN REFRIGERATION COMPRESSOR COMPONENTS**

<table>
<thead>
<tr>
<th>COMPONENTS</th>
<th>DYNAMIC FILM THICKNESS (MICRO METERS) OR MICRONS</th>
<th>TYPICAL CLEARANCE (INCHES)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RECIPIROTATING COMPRESSOR</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Journal Bearing</td>
<td>2-8</td>
<td>0.0010-0.0017</td>
</tr>
<tr>
<td>Cast Iron Piston without Rings to Cylinder</td>
<td>--</td>
<td>0.0006-0.00065</td>
</tr>
<tr>
<td>Aluminum Piston with Rings to Cylinder</td>
<td>--</td>
<td>0.0060-0.0065</td>
</tr>
<tr>
<td><strong>STATIONARY VANE ROTARY COMPRESSOR</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roller Height/Cylinder Height</td>
<td>--</td>
<td>0.0004-0.0014</td>
</tr>
<tr>
<td>Flange Bore/Shaft Journal</td>
<td>--</td>
<td>0.0004-0.0023</td>
</tr>
<tr>
<td>Roller Bore/Eccentric Bore</td>
<td>--</td>
<td>0.0005-0.0014</td>
</tr>
<tr>
<td>Vane Height/Cylinder Height</td>
<td>--</td>
<td>0.0005-0.0018</td>
</tr>
<tr>
<td>Vane Width/Vane Slot</td>
<td>--</td>
<td>0.0006-0.0014</td>
</tr>
</tbody>
</table>
FIGURE 1

STANDARD SUCTION LINE SHELL WITH REPLACEABLE CORE FILTER ASSEMBLY
FIGURE 2: Internal Details of Replaceable Filter Core

FIGURE 3: Final Assembly of Replaceable Filter Core
FIGURE 4: (SEM 5059) Copper Particles Labelled D, G, H, K, L & N & Iron Particles Labelled A, C & M.

FIGURE 5: (SEM 5060) Sand (Silicon Dioxide) Particles Labelled A, B & G

FIGURE 6: (SEM 4902) See Associated X-Ray Spectrum in Figure 8 for Particle Labelled E

FIGURE 7: (SEM 4896) See Associated X-Ray Spectrum in Figure 9 for Particle Labelled B
FIGURE 8
EDX-7. SPECTRUM FROM PARTICLE A IN SEM 04902,
SAMPLE N.R.
FULL SCALE = 1024 COUNTS
ENERGY, keV

FIGURE 9
EDX-3. SPECTRUM FROM PARTICLE B IN SEM 04896,
SAMPLE R.R.
FULL SCALE = 4096 COUNTS
ENERGY, keV