METHODS AND APPARATUS FOR REDUCING THE NOISE LEVEL OUTPUTTED BY OIL SEPARATOR

A muffling apparatus (100) having a first, muffling segment (1010) and a second (1020), non-muffling segment is provided for placement within an oil separator of refrigeration or cooling system, wherein the apparatus has a non-straight shape and a lumen defined therein to allow for noise-creating pressure pulsations/waves to come into contact with absorbing material (120) of the muffling segment (1010) in order to attenuate the energy of the pressure waves/pulsations into heat and thus reduce oil separator vibrations caused thereby.
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FIELD OF THE INVENTION

This invention relates to oil separators for use in refrigeration and cooling systems, and, in particular, to methods and apparatus for reducing the noise levels outputted by an oil separator that is located within a refrigeration or cooling system.

BACKGROUND OF THE INVENTION

As illustrated by FIG. 1, a water cooled chiller type refrigeration system 10 using a screw compressor 20 typically includes a condenser 30, a cooler 40, an oil separator 50, a condenser fan 60 and one or more expansion devices 70. The compressor 20 requires oil for lubrication, wherein the oil is typically entrained in a refrigerant. The combined oil and refrigerant mixture is carried through a compression cycle and discharged into the oil separator 50, where the oil must be removed from the refrigerant to allow for proper operation of the cooler 40. From the oil separator 50, the clean refrigerant flows to the condenser 30 and the separated oil is returned to the compressor 10.

Most known oil separators, such as those described in U.S. Pat. No. 5,704,215 to Lord et al. (the entirety of which is incorporated by reference herein), perform this separation function well. However, it has been observed that high noise levels are often generated in the vicinity of an oil separator 50 within a refrigeration system, such as the system 100 illustrated in FIG. 1. Without wishing to be bound by theory, it is believed that this is caused by high pressure waves or pulsations (i.e., 250 Hz or above) emanating from the compressor 20 that are transferred to the oil separator 50, which acts as a resonant cavity and thus is excited by the compressor pulsations. This excitement causes high vibration levels at the surface of the oil separator 50, and that, in turn, translates into high noise levels outputted by the oil separator. These excess noise levels can be distracting and bothersome, or, even worse, can be damaging to the hearing of those working around the oil separator 50 and/or can be in violation of applicable noise ordinances.

Previous efforts by those in the art to reduce the high noise levels produced by an oil separator 50 have focused on placing noise reduction equipment or devices between the oil separator and the compressor 20. Often, however, such equipment is subjected to high pressure differentials between the compressor discharge within the equipment and the atmosphere outside of the equipment. In such instances, the noise reduction equipment functions, in essence, as a pressure vessel, thus implicating strict design rules, certifications, and, consequently, added costs. Moreover, the added noise reduction equipment causes the refrigeration/cooling system to occupy a larger overall footprint, which is suboptimal and can even outweigh any beneficial noise reduction that actually is achieved through use of the equipment.

Therefore, a need exists for methods and apparatus to reduce the noise output of an oil separator without interfering with the functioning of the oil separator or any other equipment utilized in connection with the refrigeration system, and wherein such methods and apparatus would not be plagued by any of the various drawbacks associated with muffling apparatus known in the art.

SUMMARY OF THE INVENTION

These and other needs are met by the present invention, which provides a muffling apparatus and methods for using the muffling apparatus to reduce the noise level output of an oil separator within a refrigeration or cooling system. The muffling apparatus of the present invention has a first, muffling segment and a second, non-muffling segment and is placed within an internal area of an oil separator.

The muffling segment of the muffling apparatus is at least partially formed of an absorbent material. The absorbing material is effective to attenuate the energy of pressure waves/pulsations from the compressor into heat, thus reducing the resultant vibrations of (and, in turn, noise levels outputted from) the oil separator caused by energy from the waves/pulsations. The muffling segment is comprised of a tubular body that includes an external shell, wherein the external shell surrounds an internal layer and wherein the internal layer surrounds an internal shell. The muffling segment also has a first end, a second end and a lumen therebetween, wherein the lumen is surrounded by the internal shell of the muffling segment.

In an exemplary aspect of the present invention, the internal layer of the muffling segment of the muffling apparatus is made of the absorbing material, and the internal shell has a plurality of perforations/openings defined therein. Each opening provides a direct fluid/air pathway from the lumen to the internal layer of absorbing material. The purpose of the openings is to enable the pressure waves/pulsations that propagate through the lumen of the muffling segment to come into contact with the internal layer of absorbing material, thus enabling the absorbing material to attenuate the pressure waves/pulsations.

In another exemplary aspect of the present invention, the non-muffling segment of the muffling apparatus has a tubular body, wherein the first end of the non-muffling segment is connected to the second end of the muffling segment and the second end of the non-muffling segment is connected to an internal area of an oil separator.

In yet another exemplary aspect of the present invention, the muffling apparatus has a non-straight shape, such as a bent shape or a curved shape, wherein the bent or curved portion(s) of the non-straight muffling apparatus are part of the non-muffling segment.

Still other aspects, embodiments and advantages of the present invention are discussed in detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

For a fuller understanding of the nature and desired objects of the present invention, reference is made to the following detailed description taken in conjunction with the accompanying figures, wherein like reference characters denote corresponding parts throughout the views, and in which:

FIG. 1 is a schematic view of a known exemplary arrangement of a refrigeration/cooling system utilizing an oil separator.

FIG. 2 is a perspective view of an exemplary embodiment of an oil separator muffling apparatus in accordance with the present invention.

FIG. 3 is a side, cross-sectional view of the muffling apparatus of FIG. 2 taken along line 3-3 of FIG. 2; and
FIG. 4 is a perspective view, with partial cutaway, of an exemplary oil separator wherein the muffling apparatus of FIGS. 2 and 3 has been placed within an internal area thereof.

DETAILED DESCRIPTION

The present invention provides a muffling apparatus and methods of using the apparatus to reduce the noise level output produced by an oil separator of a refrigeration or cooling system, such as a water-cooled chiller type refrigeration system. In use, the muffling apparatus of the present invention is placed within an oil separator in order to attenuate pressure waves/pulsations that emanate from the compressor of the refrigeration system. As discussed above, such pressure waves/pulsations are believed to be responsible for creating vibrational forces that cause the oil separator surface to vibrate and, in turn, to disadvantageously generate high noise levels in its vicinity.

Attenuation occurs during use of the muffling apparatus of the present invention because the pressure waves/pulsations come into contact with an absorbing material located within a muffling segment of the muffling apparatus. The absorbing material attenuates the energy of the pressure waves/pulsations into heat and thus reduces the resultant vibrations of (and, in turn, noise levels outputted from) the oil separator that are caused by energy from the pressure waves/pulsations.

The muffling apparatus of the present invention has many benefits. In particular, not only does the muffling apparatus successfully reduce oil separator noise levels, but it does so while being sited within an oil separator, thus not requiring the refrigeration/cooling system to occupy added space and not exposing the muffling apparatus to high pressure differentials. The design of the muffling apparatus also provides cost savings, as will be discussed in detail below.

FIGS. 2 and 3 depict an exemplary oil separator muffling apparatus 100 in accordance with the present invention. The muffling apparatus 100 has at least two segments, wherein each segment serves a different purpose in accordance with the present invention and is made of different materials or material combinations than the other segment(s). The segments are connected to each other as is known in the art, e.g., by welding, brazing and/or through the use of rivets.

As is currently preferred, and as is best shown in FIG. 3, a muffling apparatus 100 of the present invention has a first, muffling segment 1010 and a second, non-muffling segment 1020. The muffling segment 1010 has a tubular body comprised of an external shell 110 that surrounds an internal layer 120, wherein the internal layer has an internal shell 130—that is, the external shell and the internal shell "sandwich" the internal layer. Although it is currently preferred for the number and arrangement of the shells 110, 130 and the internal layer 120 of the muffling segment 1010 to be as shown in FIGS. 2 and 3, it is also within the scope of the present invention for the muffling segment to be comprised of more or fewer layers and/or more or fewer shells than are depicted in the Figures, and/or for the layer(s) and/or the shell(s) to have a different arrangement than that which is shown.

The muffling segment 1010 has a first end 1100, a second end 1500 and a lumen 1600 therebetween, wherein the lumen is surrounded by the internal shell 130. The second end 1500 of the muffling segment 1010 is adapted for connection to a first end 1100 of the non-muffling segment 1020 by techniques known in the art, e.g., welding, brazing and/or through the use of rivets.

As noted above, the purpose of the muffling segment 1010 is to reduce the noise level output of an oil separator in which the muffling apparatus 100 is placed. To enable that to occur, at least one of the external shell 110, the internal layer 120 and the internal shell 130 of the muffling segment 1010 should be made, at least partially, of a material that will absorb the energy from pressure waves (that emanate from the compressor and are transferred to the oil separator) and dissipate/attenuate that energy into absorbable heat. According to a currently preferred embodiment of the present invention, the internal layer 120 of the muffling segment 1010 is made of such an absorbing material. The specific choice of the absorbing material can vary according to several factors, including but not limited to cost, damping characteristics, availability and designer preference. According to an exemplary embodiment of the present invention, the absorbing material is a fiberglass material. A currently preferred fiberglass material is comprised of glass fibers with a phenolic resin, wherein the material has a density in the range of about 86 kg/m³ to about 105 kg/m³ and a maximum temperature of about 177°C.

The material(s) from which the external shell 110 and the internal shell 130 of the muffling segment 1010 are constructed should be strong and durable, yet inexpensive. The external shell 110 and the internal shell 130 can be constructed of different or identical materials; however, according to an exemplary embodiment of the present invention, both the external shell 110 and the internal shell 130 are constructed of a sheet metal material. A currently preferred sheet metal material is steel, but other metal-based materials can be utilized as well.

As shown in FIGS. 2 and 3, the internal shell 130 of the muffling segment 1010 has a plurality of perforations or openings 170 defined therein. Each opening 170 provides direct fluid communication between the lumen 160 and the internal layer 120 of absorbing material. The purpose of the openings 170 is to enable the pressure waves/pulsations that are propagating/intersecting through the lumen 160 of the muffling segment 1010 to come into contact with the internal layer 120 of absorbing material, thus enabling the absorbing material to attenuate the pressure waves/pulsations.

The size, shape, number and spacing interval of the openings 170 can vary depending on several factors, including, but not limited to, the frequency of the pressure waves/pulsations that are expected to be encountered. According to a currently preferred embodiment of the present invention, openings 170 are defined in a range of about 10% to about 50% of the overall surface area of the internal shell 130. Moreover, although the openings 170 can have any shape and any spacing interval, it is currently preferred for the openings to be substantially round and spaced apart from each other at substantially identical distances, as best shown in FIG. 3.

The non-muffling segment 1020 of the muffling apparatus 100 also has a tubular body, and has first and second ends 1100, 1200. The first end 1100 of the non-muffling segment is connected to the second end 150 of the muffling segment 1010, and the second end 1200 of the muffling segment is connected to an internal area 510 of an oil separator 500, as shown in FIG. 4. Such connections are made as is generally known in the art, e.g., via welding, brazing and/or through the use of rivets.
Although the non-muffling segment 1020 of the muffling apparatus 100 can have more than one layer and can be made of more than one material, it is currently preferred to form the non-muffling segment of one layer and one material, wherein suitable materials include sheet metal materials such as steel. There are several advantages of forming the non-muffling segment 1020 of the muffling apparatus entirely from a metal-based material, including, but not limited to, cost savings and design flexibility. The cost savings occurs because sheet metal material is less expensive to purchase as compared to the absorbing material used in the muffling segment 1010. Also, there is design flexibility because one can purchase many different pre-formed shapes and sizes of the sheet metal material from which the non-muffling segment 1020 is formed.

The size and shape of muffling apparatus 100 also can vary; however, it is currently preferred for muffling apparatus 100 to have a non-straight overall shape. For example, FIGS. 2 and 3 depict a muffling apparatus that has a curved shape. The non-straight shape of muffling apparatus 100 is preferred because it enables the apparatus to have a larger size (as compared to an apparatus with a straight shape) while still fitting within the space confines of an oil separator. That allows for a longer length 160 to be defined between the first and second ends 140, 150 of the muffling segment 1010, thus providing added opportunities for pressure waves/pulsations to come into contact with the internal layer 120 via openings 170.

As shown in FIGS. 2 and 3, and as is currently preferred, muffling segment 1010 of muffling apparatus 100 has a substantially straight shape and non-muffling segment 1020 has a curved shape. Such an arrangement is advantageous because a cost savings is achieved by not forming the muffling apparatus entirely of the muffling segment materials, yet the muffling apparatus is still capable of providing significant noise reduction, as will be discussed in more detail below.

Optionally, and as shown in the Figures, support element 600 is attached (e.g., by welding) to the first end 150 of the muffling segment 1010 and to the internal area 510 of the oil separator 500. The presence of the support element 600 provides additional support to muffling apparatus 100 by bearing the weight of muffling segment 1010. Support element 600 can be made of a variety of materials, including, but not limited to, one or more metal-based materials (e.g., steel).

The size of the muffling apparatus 100 can vary depending on several factors, most notably the size of the oil separator in which the muffling apparatus is installed. It is currently preferred for the size of the muffling apparatus 100 to vary proportionally with the size of the oil separator. For example, the muffling apparatus 100 will have a different predetermined size in order to fit within a 14 inch oil separator than it would to fit within a 16 inch oil separator or an 18 inch oil separator, wherein the size of the muffling apparatus for a 16 inch oil separator generally will be approximately 16/14 times the size of the muffling apparatus for a 14 inch oil separator and approximately 16/18 times the size of the muffling apparatus for an 18 inch oil separator.

According to an exemplary embodiment of the present invention in which the muffling apparatus 100 is placed in a 14 inch oil separator, the effective height, H (see FIG. 3), occupied by the muffling apparatus is in the range of about 7.5 inches to about 9.5 inches, with an effective height of about 8.5 inches being currently preferred, and the effective length, L (see FIG. 3) occupied by the muffling apparatus is in the range of about 11 inches to about 13.5 inches, with an effective height of about 13.2 inches being currently preferred. For placement within a 16 inch oil separator, these measurements would be approximately 16/14 times those for the 14 inch oil separator; and for placement within an 18 inch oil separator, they would be approximately 18/14 times those for the 14 inch oil separator.

The length of muffling segment 1010 also can vary according to several factors, including the frequency of the pressure waves expected to the encountered within the oil separator. For example, the length of muffling segment 1010 can be comparatively greater when the frequency of the pressure waves is expected to be about 2000 Hz versus 125 Hz. According to an exemplary embodiment of the present invention in which muffling apparatus 100 is placed within a 14 inch oil separator, the length of the muffling segment 1010 is about 4.5 inches to about 6.5 inches, wherein a length of about 6 inches is currently preferred. Stated differently, the length of muffling segment 1010 generally comprises about 30% to about 60% of the overall length, L, of the muffling apparatus 100. Therefore, within a 16 inch and 18 inch oil separators, the length measurements would be approximately 16/14 times greater and 18/14 times greater, respectively.

Experiments were conducted to assess the noise reduction efficacy of a muffling apparatus 100 of the present invention. The experiments were performed in accordance with the guidelines of International Organization for Standardization (ISO 9614). The results of the experiments are shown in Table I below:

<table>
<thead>
<tr>
<th>Pressure Wave (octave In Hz)</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustic change (dBA) due to presence of muffling apparatus</td>
<td>-1</td>
<td>-12</td>
<td>-6</td>
<td>-1</td>
<td>-7</td>
<td>-12</td>
</tr>
</tbody>
</table>

Global dBA = -4

To accumulate the test results in Table I, a refrigeration system was first operated such that its oil separator encountered six different pressure wave frequencies (125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz) emanating from its compressor, wherein the noise level outputted by the oil separator in response to each of these pressure wave levels was measured and recorded. A muffling apparatus 100 of the type shown in FIGS. 2 and 3 was then installed within the oil separator and the testing conditions were repeated to gather comparable data.

The experimental results in Table I demonstrate that there was an acoustic reduction at each pressure wave frequency level due to the presence of muffling apparatus 100, wherein the acoustic reduction was calculated as the difference between the acoustic level at the oil separator without a muffling apparatus versus the acoustic level at the same oil separator with a muffling apparatus of the present invention installed within an internal area thereof. Therefore, the -12 dBA measurement at 250 Hz indicates that the noise level measurement taken after the muffling apparatus 100 was installed within the oil separator was 12 dB less than the measurement taken when the same oil separator was not equipped with the muffling apparatus. The Global dBA of -4 dBA also supports that there was an acoustic reduction.
that the dominant frequency band of the pressure waves/pulsations was in the range of about 500-1000 Hz.

[0038] The results in Table 1 are very favorable. In particular, noise reduction levels were observed for each of the six selected pressure wave frequency bands. This is important because different compressors operate at different dominant pressure output levels, and thus would produce different Global dBA measurements. Moreover, noise reduction occurred despite the fact that the muffling apparatus was only partially formed of a muffling segment 1010. This signifies that by forming the muffling apparatus from a muffling segment 1010 and a non-muffling segment 1020, one can achieve noise reduction while enjoying cost savings and design flexibility.

[0039] Thus, a muffling apparatus 100 of the type shown in FIGS. 2 and 3 can be installed in an oil separator with confidence that the noise level reduction will be at least 1 dB, with a noise reduction level of up to 12 dB being possible as well depending on the dominant frequency band of the pressure/wave pulsations emanating from the compressor. These are significant noise reduction levels, especially when considering the effects of exposure to the reduced noise level over the lifetime of the refrigeration system in which the oil separator is located. Moreover, a noise reduction level of between 1 dB and 12 dB will be even more significant if, as is commonly the case, multiple refrigeration systems that include oil separators are installed in close proximity.

[0040] Although the present invention has been described herein with reference to details of currently preferred embodiments, it is not intended that such details be regarded as limiting the scope of the invention, except as and to the extent that they are included in the following claims—that is, the foregoing description of the present invention is merely illustrative, and it should be understood that variations and modifications can be effected without departing from the scope or spirit of the invention as set forth in the following claims. Moreover, any document(s) mentioned herein are incorporated by reference in their entirety, as are any other documents that are referenced within the document(s) mentioned herein.

We claim:

1. A method for reducing the noise level outputted by an oil separator within a refrigeration or cooling system, comprising the steps of:
   - providing a muffling apparatus having a first segment and a second segment, wherein the first segment includes an absorbing material; and
   - placing the muffling apparatus within an internal area of an oil separator.

2. The method of claim 1, wherein the muffling apparatus has a non-straight overall shape.

3. The method of claim 2, wherein the non-straight overall shape is selected from the group consisting of a bent shape and a curved shape.

4. The method of claim 2, wherein the first segment has a substantially straight shape and the second segment has a substantially curved shape.

5. The method of claim 1, wherein the first segment has a first end, a second end and a lumen defined therebetween, and wherein at least a portion of the absorbing material is in direct fluid communication with the lumen.

6. The method of claim 5, wherein at least a portion of the absorbing material is in direct fluid communication with the lumen via a plurality of openings.

7. The method of claim 1, wherein the step of placing the muffling apparatus within the internal area of the oil separator is accomplished by attaching the muffling apparatus to the internal area of the oil separator.

8. The method of claim 1, wherein the muffling apparatus is attached to a first end of a support element, and wherein a second end of the support element is attached to the internal area of the oil separator.

9. The method of claim 1, wherein the absorbing material is a fiberglass material.

10. A muffling apparatus for placement within an internal area of an oil separator, the muffling apparatus comprising:
    - a first segment having a first end, a second end and a lumen therebetween, wherein the first segment is at least partially constructed of an absorbing material; and
    - a second segment connected to the first segment.

11. The muffling apparatus of claim 10, wherein at least a portion of the absorbing material is in direct fluid communication with the lumen.

12. The muffling apparatus of claim 10, wherein the first segment is comprised of:
    - an external shell;
    - an internal layer formed at least partially of the absorbing material, wherein the internal layer is surrounded by the external shell; and
    - an internal shell, wherein the internal shell surrounds the lumen.

13. The muffling apparatus of claim 12, wherein the internal layer has a plurality of openings defined therein to enable direct fluid communication between the absorbing material and the lumen.

14. The muffling apparatus of claim 10, wherein the absorbing material is a fiberglass material.

15. The muffling apparatus of claim 12, wherein each of the external shell and the internal shell is made of a sheet metal material.

16. The muffling apparatus of claim 11, wherein the muffling apparatus has a non-straight overall shape.

17. The muffling apparatus of claim 16, wherein the non-straight overall shape is selected from the group consisting of a bent shape and a curved shape.

18. The muffling apparatus of claim 16, wherein the first segment has a substantially straight shape and the second segment has a substantially curved shape.

19. The muffling apparatus of claim 11, wherein the muffling apparatus is attached to a first end of a support element, and wherein a second end of the support element is attached to the internal area of the oil separator.

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