APPARATUS AND METHOD FOR REMOVAL OF OIL ENTRAINED IN AIR

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19 Claims. (Cl. 55—74)

This invention relates to apparatus and to a method for removing oil entrained in air, and particularly, oil entrained in compressed air.

Compressed air is utilized in a great many industrial applications, and many types of equipment for compressing air are in use, such as compressors of the reciprocating piston type, rotary compressors, turbines, and the like. Such compressors are lubricated with petroleum hydrocarbon lubricants. During compression, air temperature is raised, generally in the range of 400° to 700° F. or higher for air compressed by a factor of more than four in air used in pneumatic control systems. High temperatures during lubricating oil vaporizes, and many of the components of the vapor react with each other and with air to form a wide range of organic products including oxygenated and partially oxygenated compounds, nitrogen compounds, and hydrocarbons in the low to intermediate molecular weight classes. Such vapor phase contaminants are in addition to liquid phase lubricants that are mechanically entrained in the air.

As a result, air compressed in conventional fashion generally contains from about 5 to 25 parts per million of air by weight of lubricating oil-derived contaminants, varying from non-condensible hydrocarbon gases to droplets of lubricant 25 microns or more in diameter. In many industrial applications, the presence of even trace quantities of such contaminants is extremely objectionable. For example, the presence of such contaminants in air used in pneumatic control systems causes orifices and moving parts to become covered with oil, thereby leading to dust collection and consequent instrument malfunction. Flow meters of some types will offer false data if coated with oil. As little as 3 parts per million of hydrocarbons entrained in air at high pressures, for example 3000 p.s.i.g., can form an explosive mixture. It is particularly essential that air or other inert gases used for compressing oxidizing agents such as liquid oxygen, nitric acid, or hydrocarbon peroxide, be free of hydrocarbons to avoid possibility of explosion. Compressed air intended for human breathing, as, for example, in underwater diving equipment, should be free of all potentially harmful contaminants. In chemical processes, oil in compressed air added to a reactor can introduce impurities or change the course of the reaction. Sewage disposal units require compressed air free from entrained oil in order to prevent buildup of sludge.

Different approaches are in use to obtain substantially oil-free compressed air. A compressor which does not need oil lubrication can be used, such as a liquid-packed ring type rotary compressor. This type of compressor, however, gives a much lower maximum pressure than a piston type compressor. Diaphragm type and carbon ring compressors are generally considered to involve overly great expenditures, both in initial cost and for maintenance. It has been proposed to filter oil from compressed air. However, oil entrained in air is composed of a plurality of droplets having varying sizes, ranging from a diameter of more than 25 microns down to molecular dimensions. While filtration is adequate to remove large droplets, droplets of the order of magnitude of about 0.3 micron and higher, no filter has been available which has been capable of removing smaller sized droplets without at the same time causing an unduly large pressure drop in the air being treated. The pressure drop problem is particularly noticeable when air at a pressure greater than about 25 p.s.i.g. is being treated since conventional low pore size-high voids content filter media are generally incapable of resisting such high pressures, necessitating resort to more rigid, much less porous filter media such as ceramic filters. Ceramic filters, while capable of withstanding high pressures, cause extremely high pressure drops in the air being treated. Despite this, such filters have not been capable of removing vaporized impurities in the air or even liquid droplets in the size range of 0.05 micron and smaller.

Activated carbon beds or beds of other sorbents remove entrained vapors and droplets smaller than about 10 to 20 Angstrom units (.001 to .002 micron), but have no effect on larger droplet sizes. Conventional filters having a sufficiently high degree of porosity to minimize pressure drop and suitable for use in treating compressed air can remove only droplets larger than about .3 to 25 microns in diameter, depending upon the pore size of the filter. Hence, a combination of an active carbon bed and a conventional filter removes droplets of 0.3 to 3 microns in diameter and larger, and droplets of less than .001 to .002 micron in diameter but has substantially no effect on droplets which are larger than .001 to .002 micron but smaller than about .3 to 3 microns.

The proportion of oil droplets entrained in compressed air having diameters within the range of .0015 to 1.5 microns has been found generally to range from 5 to 30% by weight of the total oil content entrained in the air. Accordingly, if the original oil content of the compressed air were 20 parts per million by weight, the use of a conventional filter plus an activated carbon bed would fail to remove from 1 to 6 parts per million of entrained oil, a residual oil content much too large for many applications. By means of the apparatus and method of this invention, substantially all of the oil and hydrocarbons higher than methane in molecular weight entrained in compressed air can be removed. This invention is particularly applicable to compressed air having a pressure greater than 25 p.s.i.g.

The method of this invention comprises two essential treatment steps: passing the compressed air through a pleated high area microporous filter element of the fibrous depth type having an average pore size of less than 1 micron and a voids volume of at least 75 percent and contacting the compressed air with a sorbent containing hydrocarbon vapors. The two steps can be carried out in either sequence. The air can be first contacted with the sorbent and then passed through the microporous filter element or vice versa. Each sequence has certain advantages as will be seen from the following description. Optionally, the two essential steps can be preceded by an additional filtration step in which a conventional filter is employed.

The microporous filter should have an average pore size of less than about 1 micron and preferably an average pore size of less than about 0.5 micron. Microporous filters having average pore sizes greater than about 1 micron are not satisfactory for removing oil entrained in compressed air, since they permit the passage of oil droplets which are not ordinarily removed either by the conventional filter, if one is employed, or by the sorbent. There is no effective lower limit on the pore size of the
Fibrous material is preferred as the particulate material to be deposited because of its versatility, and because of the greater ease of deposition as a film. A great variety of diameters of fibers are available, thus making it possible to achieve a very large assortment of mixtures of different diameter fibers for making fibrous material of any porosity, and such fibers can be made of any length, so as to take advantage of the greater cohesiveness of a layer of long fibers, as compared to granular material layers. Generally, fibers having diameters of 2 microns or less are preferred. Typical fibrous materials include glass, asbestos, potassium titanate, alumina, silicon, mineral wool, regenerato cellulose, polystyrene, polystyrene chloride, polyvinyl chloride, polyvinylidene chloride, polyacrylonitrile, polyethylene, polypropylene, rubber, polymers of terephthalic acid and ethylene glycol, polyamides, casein fibers, zein fibers, cellulose acetate, viscose rayon, hemp, jute, linen, cotton, silk, wool, mohair, paper, and metallic fibers such as iron, copper, aluminum, stainless steel, brass, Monel, silver, and titanium.

Nonfibrous particulate materials can be used in admixture with fibrous materials. However, in order to achieve the requisite microporosity and voids volume, it is essential to employ at least one part by weight of fibrous material for every three parts of nonfibrous materials. When nonfibrous particles are employed, they should have an average size which is essentially not greater than the porous base material. Those nonfibrous materials containing a fine internal structure or porosity are preferred.

Typical nonfibrous particulate materials are diatomaceous earth, magnesia, silica, talc, silica gel, alumina, quartz, carbon, activated carbon, clays, synthetic resins and cellulose derivatives, such as polyethylene, vinyl chloride, polystyrene, polypropylene, ureaformaldehyde, phenol-formaldehyde, polytetrafluoroethylene, polytrifluoro-chloroethyline, polymers of terephthalic acid and ethylene glycol, polycrylonitrile, ethyl cellulose, poliamides, and cellulose acetate-propionate, and metal particles such as aluminum, silver, platinum, iron, copper, nickel, chromium and titanium and metal alloys of all kinds, such as Monel, brass, stainless steel, bronze, Inconel, cupronickel, Hastelloy, beryllium, and copper. Combinations of diatomaceous earth and glass fibers give excellent results.

Any porous material whose pores extend from surface to surface is employed, provided that the thickness of the microporous layer is deposited. One or several layers of the same or varying porosity can be employed and can be composed of cellulose or other fibers. Paper, which can, if desired, be resin impregnated, is a preferred base material since it yields an effective, versatile and inexpensive microporous fluid-permeable medium. Where desired, other base materials can be used, such as porous sintered powders or forms of metals and of natural or synthetic plastic materials, such as aluminum, and synthetic resins and cellulose derivatives, in the form of spongy layers of any desired thickness, such as polyurethane (see Patent No. 2,961,710), polyvinyl chloride, polystyrene and polypropylene sponges and foams, woven wire products, sintered or unsintered, textile fabrics and woven and nonwoven fibrous layers of all kinds, such as felts, mats and bats, made of fibrous materials of any of the types listed below in connection with the particulate material. The porous base material will have an average pore diameter of not less than about 25 microns. Such materials will of course have pores as large as 20 to 25 microns, or more.

The fluid medium used for the dispersion is preferably inert to the particulate material and the base material. It should not dissolve a substantial amount thereof, although if the fluid is reused, the fact that some material is in solution is not a disadvantage, since a saturated solution is quickly formed ab initio. The fluid should be volatile at a reasonably elevated temperature below the melting point of the material to facilitate removal after the dispersion is deposited. However, nonvolatile fluids
may be desirable under certain conditions, and those can be removed, by washing out with a volatile solvent that is a solvent for the fluid but not for the particulate material.

Typical fluids are water, alcohols, polyalkylene glycols, such as polyethylene glycols, poly 1,2-propanediol glycols, and mono and di alkyl ethers thereof, such as the methyl, ethyl, butyl and propyl mono and di ethers, dialkyl ethers of aliphatic diols and similar solvents, such as, diethylene glycol, adipate and glutarate, mineral lubricating oils, hydraulic fluids, vegetable oils, and hydrocarbon solvents such as xylene and petroleum ether, silicone fluids, chloro, bromo and fluoro hydrocarbons, such as the Freons. Since the final product is permeable to any liquid, depending upon the choice of particulate material, obviously a wide selection of fluids is available, and such would be known to one skilled in this art.

The sorbent with which the compressed air is to be contacted can be of any type known to the art for use in sorbing hydrocarbon contaminants from air. The term "sorption" is inclusive of the processes known as "adsorption" and "absorption," the distinction being that molecules are said to be "adsorbed" when they enter the inside of a solid material, i.e., the sorbent, and are said to be adsorbed when the molecules remain attached to the surface of the solid sorbent.

Activated carbon is the preferred sorbent for use in this invention, since it is capable of efficiently sorbing hydrocarbon contaminants such as oil from air without being affected by an moisture contained in the air. Activated carbon can be employed alone, or it can be catalyzed with from about 0.2 to 5% of palladium, platinum, rhodium, cesium, rubidium or cuprous oxide. Activated carbon is also increased in activity by the addition of from about 5 to 20% by weight of the mixture of the oxides of copper, cobalt, manganese and silver, commercially known as "Hopcalite."

A number of other materials also have activity as sorbents, such as, for example, various crystalline substances and such other materials as chabicite, pumice, either alone or catalyzed with up to 10% nickel, silica gel, chromic oxide gel, lithopone, powdered porous glass, glass wool, activated alumina, quarts crystals, fuller's earth, Cecil soil, Barnes soil and glass wool, which is useful particularly in removing oil from air of low water vapor content.

It is preferable that the sorbent employed have a large surface area exposed to the passage of compressed air. Accordingly, it is preferred that the solid sorbents be in particulate form, and not be compressed.

The sorbent should be located within a confined area which is permeable to the free passage of the compressed air, so that the air is passed through or over the sorbent. For example, the sorbent can be located within a chamber in the path of the compressed air. At least two walls of the chamber are comprised of a porous material which has pores large enough so as not to restrict the passage of compressed air, but small enough to prevent the loss and consequent contamination of the air by particles of the sorbent.

The quantity of sorbent required is proportional to the volume of air to be treated per unit time, and the amount of oil entrained. The greater the volume of air containing a given oil content, per unit time, the greater will be the amount of sorbent necessary to operate effectively. For most applications, the quantity of sorbent employed should be at least 25 grams per cubic foot of air passed through the apparatus per minute, calculated on the basis of standard temperature and pressure.

A preliminary filtration using a conventional filter is frequently, albeit not necessarily, desirable. Such preliminary filtration, which can be accomplished with any conventional filter media, preferably having a pore size of between 25 and 100 microns to avoid any undue pressure drops, serves to remove any very large oil droplets which might tend to clog the pores of the sorbent or the microporous filter. Exemplary of such conventional filters are filter paper and perforated metal sheets.

The microporous filter used in this invention is preferably in pleated or corrugated form to expose maximum surface area to the passage of compressed air within the limits of a confined unit. Where the filter employed is not in corrugated form but instead is of the smooth cylindrical type, even if one of the preferred fibrinous depth variety of filter, a greater resistance to the passage of air will be developed unless a much larger size filter is employed, thus making the unit very large and inconvenient for use. Where, of course, size or space limitations are not a problem or where only negligible quantities of entrained oil are to be removed, smooth filters can be resorted to if the pleated or corrugated variety is not available. The length of the corrugated filter element as well as the depth and number of the corrugations will depend upon actual service requirements. Generally, elements having a length of from 2 to 30 inches, internal diameters (measured at the base of the corrugations) of from 0.5 to 10 inches, external diameters of from 0.8 to 2.5 inches and from about 10 to 100 pleats give good results. However, elements having different dimensions are useful under particular operating conditions.

In operation, the method of this invention can be carried out by employing a separate filter unit in which the filter element is made of a microporous flexible material as above described and a porous canister containing a quantity of the sorbent material such as activated charcoal. These two separate units can be placed at any point downstream of the air compressor and upstream of the ultimate end use for the air, and the results of this invention may thereby be achieved. Optionally, the initial conventional filtration step can also be employed at any point prior to either of the other operations.

A preferred oil removal unit of this invention is shown in FIGURE 1, and is composed of three concentric layers, the outer layer being a perforated metal cylinder, the intermediate layer being a sorbent, such as activated carbon, and the inner layer being a microporous flexible filter. This treating unit can be placed downstream of a compressor and the air forced to pass through, in sequence, firstly the perforated metal cylinder, secondly the sorbent and thirdly the microporous filter, the air exiting from the composite unit in a condition substantially free from entrained oil, and suitable for applications in which the presence of even trace amounts of oil would be undesirable.

An alternative type of oil removal unit of this invention is shown in FIGURE 3, and can be connected to a compressed air line between any two points thereof, so that the compressed air passes in sequence through the microporous flexible filter and the sorbent, but in either order, as desired.

Further details of the apparatus of this invention can be had by reference to the drawings, in which—

FIGURE 1 illustrates a cartridge for an oil removal unit comprising two concentric filter layers and one sorbent layer.

FIGURE 2 is a cross section of the cartridge of FIGURE 1, taken through the line 2—2 of FIGURE 1; and

FIGURE 3 illustrates an oil removal unit for connection to a compressed air line so that air passes, in sequence, through a microporous flexible filter and then through a sorbent.

The oil removal cartridge of FIGURE 1 is in the form of a hollow cylindrical shell 1 of a perforated metal, having relatively large holes of an average diameter of 0.025 inch. The open ends are closed off by nonporous outer end caps 2 and 3 having central apertures 4 and 5 opening into the interior 6 of a perforated steel core 7 held by inturned portions 8 and 9 of the inner end caps 10 and 11. The inner end caps 10 and 11 in turn hold
the ends of a concentrically corrugated cylinder 12 of a microporous flexible fibrous depth type filter made in accordance with the procedure of application Serial No. 215,518 filed August 6, 1962, and having an average pore size of less than 1 micron, a voids volume of about 90%, an internal diameter of about 1 inch, and external diameter of about 1 1/2 inches and about 30 corrugations. Disposed in the space intermediate the inner cylinder 12 and the outer cylinder 13 is a sort of layer 13, made up of approximately 350 grams of particulate activated carbon having an average particle size of 4 to 6 mesh, held in place by the cylinders and outer end caps 2 and 3. Flat gaskets 14 and 15 are fitted in grooves in the end caps 2 and 3, so as to seal the oil removal cartridge in an oil removal unit, and prevent intermingling of treated air with untreated air.

In operation, the cartridge and oil removal unit are put, for example, downstream of the compressor in a compressed air system, and air containing entrained oil and other hydrocarbon impurities is caused to enter the cartridge through perforated cylinder 1 which serves as a prefilter. The air then passes through sorbent 13 and the microporous filter 12, during which passage entrained oil is removed, so that oil-free air enters interior passage 6. Interior passage 6 is connected to the feed of oil-free compressed air. The apparatus illustrated in FIGURES 1 and 2 was found to be capable of removing oil from compressed air at air flow rates of up to 15 cubic feet per minute and pressures of up to 75 p.s.i.g.

The oil removal unit shown in FIGURE 3 is connected at each end to a compressed air line 20. Oil-entrained air enters the unit at inlet 21, and emerges oil-free at outlet 22.

The unit is composed of two parts, designated A and B, each comprising a bowl-supporting head, 24 and 25, respectively.

The head 24 comprises an inlet 26 and a concentric outlet 27 opening into the bowl 28 and communicating, respectively, with the outside and inside of a plurality, in this case, three, of oil-removal cartridges 29. However, one cartridge may be used, or more than three, depending on the system requirements. Each cartridge is composed of an outer shell 30 of a corrugated microporous depth type filter of the type used in the FIGURE 1 apparatus, having an average pore size of less than 1 micron. The open ends of these shells are closed off by end caps 31 having central apertures opening into the central passage 32 of a perforated metal core 33, of plated or stainless steel. Beneath each end cap adjacent the aperture and webbed thereto for support is a V-shaped inner cap 34 which engages a matching connector 35 to communicate the central passage 32 of one cartridge with the next adjacent cartridge. The O-ring gaskets 36 prevent leakage between the cartridges 29.

The bottommost cartridge 29 receives in its adjuster 34 a cap 38 which is biased by spring 39 upwardly, to hold the cartridge assembly firmly against the projecting end of outlet 27. Leakage is prevented at both points by gaskets 36. Oil separated by the cartridge collects at the bottom of the bowl 28, and is removed via outlet 40.

The bowl 28 is movably attached to the head 24 by clamps 41, which engage the upper lip 42 of the bowl and hold it firmly against the corresponding lip 43 of the head. Leakage at the point therebetween is prevented by gasket 44.

The second unit is attached to head 25, which has an inlet 50 and an outlet 51 opening into bowl 52 on the outside and inside, respectively, of cartridge 53. The cartridge is composed of a perforated metal cylinder 54 of plated steel or stainless steel, the open ends of which are closed off by end caps 55, each of which has a central aperture. Beneath each cap, adjacent the aperture and welded thereto for support, is a V-shaped inner cap 56, which holds the ends of a corrugated paper filter 57, the interior of which is provided with a support spring 58. The space intermediate the shell 57 and cylinder 54 is filled with a sorbent 59 such as activated carbon. The interior of shell 57 is open, the central passage 60 thereby defined communicating directly with outlet 51.

The bottom of cartridge 53 receives in the aperture of the end cap a cap 61 which is biased by spring 62 upwardly to hold the cartridge firmly against the projecting end of outlet 51. Leakage is prevented at both points by gaskets 63.

The bowl 52 is movably attached to head 25 in exactly the same manner as bowl 28.

In operation, the oil removal unit of FIGURE 3 is connected to a compressor 65 from which oil-entrained air enters inlet 26, filter bowl 28, one of cartridges 29, through filter shell 30 into passage 32. Oil separated by the filter at the surface of the cartridge drops into the sump of the bowl, and is removed at 40 from time to time.

Air still containing oil droplets too fine to be removed by filter 30 leaves the bowl 28 via outlet 27, and enters the second unit at inlet 50, passing into bowl 52, and then through the sorbent 59 and paper filter 57 into passage 60. Now, the air is oil-free, and returns to the line 20 through outlet 51.

It will be readily understood that if desired, the apparatus can be constructed so as to have the air contact the sorbent prior to contacting the microporous filter or vice versa.

We claim:

1. A process for separating hydrocarbon vapors and droplets from compressed air which comprises the steps, taken in any order, of (1) passing the air over a sorbent for hydrocarbons and (2) passing the air through a microporous fibrous depth filter having an average pore size of less than one micron and a voids volume of at least 75%.

2. A process in accordance with claim 1 in which the order of steps is such that the air is first passed over the sorbent and then passed through the microporous filter.

3. A process in accordance with claim 1 wherein the order of steps is such that the air is first passed through the microporous filter and then is passed over the sorbent.

4. A process in accordance with claim 1 wherein the compressed air is subjected to a preliminary filtration by passing the air through a filter having a pore size of between about 25 and about 100 microns.

5. Apparatus for separating hydrocarbon vapors and droplets from compressed air comprising, in combination, a housing having an inlet and an outlet for flow of compressed air therethrough, and disposed across the line of air flow between the inlet and outlet so that all air flows therethrough, a microporous fibrous depth type filter having an average pore size of less than one micron and a voids volume of at least 75%, and a bed of particulate sorbent capable of sorbing hydrocarbons.

6. Apparatus in accordance with claim 5 wherein the microporous filter and sorbent are so arranged in the line of air flow that the sorbent is contacted first by the compressed air.

7. Apparatus in accordance with claim 5 wherein the microporous filter and sorbent are so arranged in the line of air flow that the sorbent is contacted first by the compressed air.

8. Apparatus in accordance with claim 5 including, first in the line of fluid flow, a filter having an average pore size of between about 25 and about 100 microns.

9. Apparatus in accordance with claim 5 wherein the microporous filter comprises a porous base having superimposed thereon and adherent thereto a microporous layer comprising a fibrous material.

10. Apparatus in accordance with claim 5 wherein the microporous filter is in corrugated form.

11. Apparatus in accordance with claim 5 wherein the
microporous filter and the sorbent bed are disposed concentrically within the housing.

12. Apparatus in accordance with claim 5 wherein the sorbent is activated carbon.

13. Apparatus for removing hydrocarbon vapors and droplets from compressed air comprising, in combination, a cylindrical canister having a side wall provided with openings for passage therethrough of compressed air and having at least one open end closed by an end cap having a passage therethrough for flow of compressed air, a microporous tubular fibrous depth filter having an average pore size less than one micron and a voids volume of at least 75% disposed within the cylindrical canister, a tubular core support disposed concentrically and internally of the microporous filter, and a layer of particulate sorbent disposed between the core and the container side wall on one side of the microporous tubular filter in a manner such that compressed air entering the container must pass through the sorbent layer and the microporous filter before emerging from the container.

14. Apparatus in accordance with claim 13 in which the microporous filter is in corrugated tubular form.

15. Apparatus in accordance with claim 13 wherein the sorbent layer is disposed internally of the filter.

16. Apparatus in accordance with claim 13 wherein the sorbent layer is disposed externally of the filter.

17. Apparatus in accordance with claim 13 wherein the microporous filter comprises a porous base having superimposed thereon and adherent thereto a microporous layer comprising a fibrous material.

18. Apparatus for removing hydrocarbon vapors and droplets from compressed air comprising, in combination, a head having air inlet and air outlet passages therethrough, a bowl attached to the head in a manner to receive air from the air inlet and to deliver air to the air outlet, and disposed in the bowl across the line of air flow from the inlet to the outlet a tubular microporous depth type filter having an average pore size of less than one micron and a voids volume of at least 75%, and a layer of sorbent for hydrocarbon vapors and droplets.

19. Apparatus in accordance with claim 18 wherein the microporous filter comprises a paper layer having relatively large pores and having deposited thereon a layer of fibrous material in an amount to reduce the average pore diameter thereof to less than one micron.

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