# OIL MIST REMOVAL IN A SYNTHETIC AMMONIA PLANT

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It is certainly well established that a compressor introduces lubricating oil into the compressed gas (1). In the chemical processing industry the introduction of lubricating oil into compressed gases is undesirable because it is a contaminant; it is possibly explosive in compressed oxygen. However, most important in subsequent liquefaction, entrained oil will impinge or condense on heat exchanger surfaces reducing the heat transfer coefficient, and clogging gas passageways.

## Heat exchanger fouling

For the purpose of discussion one shall concentrate on heat exchanger fouling. In considering the effect of entrained lubricating oil on a heat exchanger one is basically interested in the physical state of the oil. That is, from the time the lubricating oil is metered to a compressor it passes from essentially standard conditions, i.e., one atmosphere at 68°F, through a state of mechanical agitation and aspiration, to a condition of several atmospheres in a gas other than air.

This general subject has been studied and reported by two Russian scientists—D. Iu. Gamburg (2) and D. S. Tsiklis (3). A thorough and authoritative study of typical oils and the extreme conditions of physical state have been reported by an American team, A. Beerbower and D. F. Greene (4). An associated paper on the test methods to determine vapor pressure of complex mixtures is by A. Beerbower (5). Vapor pressure charts of petroleum hydrocarbons (6) also apply to the subject under consideration. A report on a highly efficient heat exchanger and how it was affected by entrained oil is by Hamberg (7).

## Physical state of compressed oil

A brief review and discussion of these references will suggest several conditions of the physical state of entrained and compressed lubricating oil. The reason for looking closely at the physical state of the compressed oil is to establish, theoretically, whether the oil would be removed by filtering (if particulate) or adsorbed (if vaporous). If one finds that the vapor pressure is extremely low, or that the lubricating oil solubility in a given compressed gas is low, it would be reasonable to expect that physical filtration would completely remove the oil. Subsequent heat exchanger refrigeration would not cause condensation to foul heat exchanger surface.

Conversely, if one finds that the oil has a high vapor pressure in compressed gas or that it is relatively soluble in the gas then the entrained oil should be removed by adsorbents to prevent subsequent condensation.

## Oil solubility in gas

The Russian Gamburg (2) in 1947 concluded that,

> "... contrary to the opinion that oil is suspended in the compressed gas after compression in the form of a spray or fog and, thus, mechanically carried out of the compressor, it was shown that a large amount of oil is soluble in the compressed gas."

Figure 1, solubility of compressor oil M in nitrogen gas, is a plot of Gamburg's data obtained between 100 and 1,000 atm. He further concludes that,

> "... since oil is a mixture of hydrocarbons of different molar volumes, the solubilities of the individual oil fractions in the compressed gas are different."

He finally proposed that compressor lubricating oil be manufactured by pressure distillation in the gas stream under consideration to obtain an oil possessing lowest solubility in the compressed gas.

Examination of Figure 1 shows that Gamburg was justified in dwelling on the various aspects of oil-gas solubility, especially at 900 atm. and 150°C. However, the dashed line on Figure 1 gives one a measure of compressor oil M solubility in nitrogen at 31.6 atm. (450 lb./sq. in. gauge) which is a suitable pressure for nitrogen liquefaction, and a condition more commonly encountered.

In this case compressed nitrogen would dissolve 2 mg./cu. m. of compressor oil M (see Table 1 for properties). This amount is five magnitudes smaller than Gamburg's highest values and suggests a low degree of oil-gas solubility at 31.6 atm., i.e., entrained oil could be expected to be particulate aerosol mist.

## Solubility in ethylene

The Russian Tsiklis (3) has shown that ethylene can readily hold large amounts of oil in solution; Tsiklis data are given in Figure 2.

In Figure 2 the dashed line is extended to 18.7 kg./sq. cm. (250 lb./sq. in. gauge) at which pressure

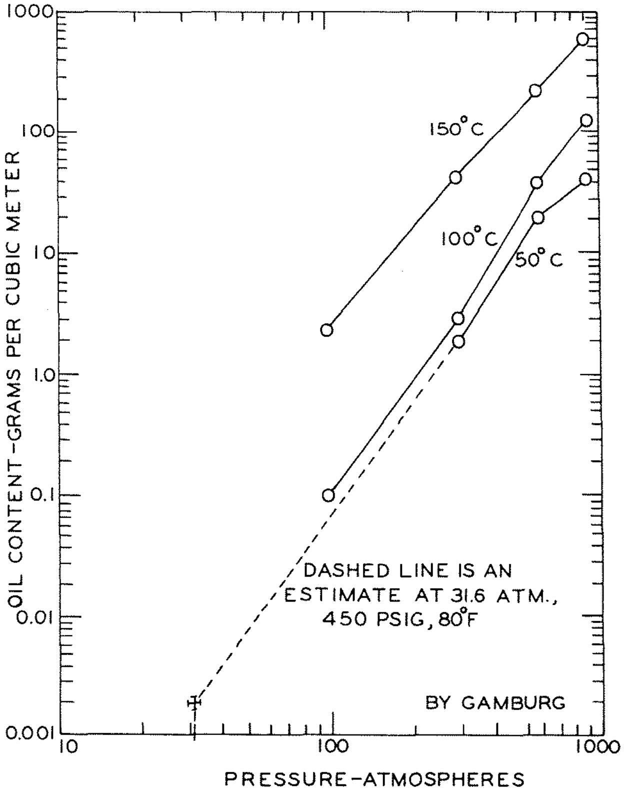


Figure 1. Solubility of compressor oil M in Nitrogen.

ethylene can be liquefied. By coincidence the same oil-gas solubility value is obtained as before, i.e., 2 mg./cu. m. This information also suggests a low degree of oil-gas solubility and that the entrained oil could be expected to be a particulate aerosol mist. Table 2 gives the properties of machine oil C. Note that this oil is a lighter fraction than usual. This work suggests that gases close to critical conditions can hold large amounts of oil in solutions.

## Silicone antifoam additives

Beerbower and Greene (4) have reported on eight forms of oil-gas interaction with regard to gas turbines and gas-cooled nuclear reactors. It is interesting to note that they state silicone antifoam additives, in general, tend to increase gas in oil foaming and to make oil in gas "fogging" persist. This suggests that compressor lubricating oil with such additives may tend to dissolve in a compressed gas more readily than with a straight mineral oil.

Beerbower (5) has reported on test procedures to accurately determine the vapor pressure of complex mixtures such as lubricating oil. He shows that a curve is required to express the pattern of vapor pressure versus fraction evaporated.

TABLE 1. PROPERTIES OF COMPRESSOR OIL M (2).

| | |
|---|---|
| Specific gravity | 0.9 |
| Flash, Brenken, °C | >218 |
| °F | >425 |
| Viscosity, 50°C, Engler | 8.0 |
| Molecular weight | 343 |
| Boiling point calculated by | |
| Nelson's equation, °C | 415 |
| °F | 780 |

TABLE 2. PROPERTIES OF MACHINE OIL C BY TSIKLIS (3).

| | |
|---|---|
| Specific gravity | 0.917 |
| Flash, Brenken, °C | 190 |
| °F | 375 |
| Viscosity, 0°C, Kinematic, cp. | 41-53 |
| Engler | 5.5-7.0 |
| Acid number, mg. KOH/g. oil | 0.35 |
| Ash, % | 0.007 |
| Pour point, °C | -10 |
| Molecular weight | 352 |

## Conclusion from literature

The foregoing data gives an implied answer to the question regarding the physical state of the lubricating oil in a compressed gas. Estimation of Gamburg and Tsiklis' quantitative data in the critical pressure area for nitrogen and ethylene give oil-gas solubility values. In both cases only 2 mg. of oil/cu. m. are estimated to be in solution. The amount of condensation to be expected by heat exchanger chilling is small.

Therefore, in the case of ethylene at 250 lb./sq. in. gauge, and 80°F and nitrogen at 450 lb./sq. in. gauge, and 80°F there is a good basis for expecting most of the entrained oil to be particulate which presumably can be physically separated.

One will now consider the details necessary for the continuous removal of particulate oil from a compressed gas.

## Proposed uses

There are two situations to be considered in the continuous removal of particulate oil as follows:

1. Relatively large droplets ranging from 50 microns in diameter up.

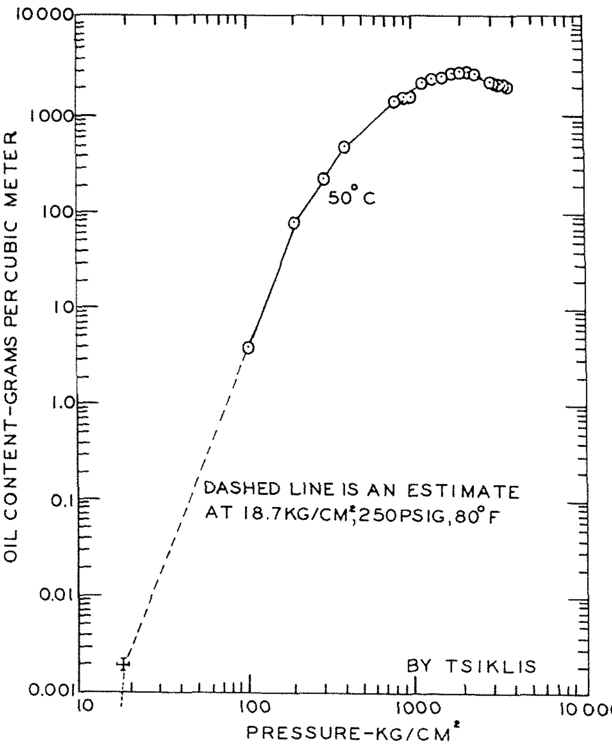


Figure 2. Solubility of machine oil C in ethylene.

2. Small particles which are familiarly known as an aerosol. By definition an aerosol includes particles which range in size from submicronic up to 50 microns (8).

The large sized droplets of oil can be removed quite efficiently using standard liquid in gas phase separation systems (9). Useful equipment, in the area of continuous operation, is the cyclone or intricately baffled vessels. Continuous removal is obtained by collection of oil in a sump which can be periodically emptied by pressure blow down.

For the purpose of generality, one will refer to this equipment as a mechanical-type separator (MTS). Further, it will be convenient to think of this step as the pick and shovel part of the job.

One will now consider the removal of the compressor lubricating oil aerosol.

## Particle size data

Quantitative aerosol data on the nature and particle size analysis of the entrained lubricating oil would permit efficient filter medium design. However, particle size data are not currently available. Previous field experience has shown that high pressure compression (1,000 to 2,000 lb./sq. in.) aspirates small size particles, a high percentage one micron in size. Lacking actual particle size data it has been assumed that gases compressed to 500 lb./sq. in. or less entrain particles 5 to 10 micron in diameter.

However, it is physically practical to obtain a relatively low pressure drop wool felt with a one micron rating. This presumably would clean out all of the dispersed oil and give a workable process.

At this point it will be helpful to pause and reflect on the definition of the exact problem in hand.

## Continuous basis

In order to solve this specific problem one must remove the entrained oil effectively on a continuous basis. Mechanical-type separators, as proposed for use on the larger sized quantities of oil, fortunately, are inherently continuous.

However, in the general case of aerosol filtration cyclic operation is normal because a filter cake is collected which, subsequently, clogs the filter medium. Further, aerosol filtration usually requires that the filter medium be discarded because it is irrelievably clogged by solid particles.

Figure 3, a flow sheet for the proposed process, shows the starting point as filtered gas. The significance of this point is that solid particles, whatever their origin, are removed from the gas stream. Presumably the compressor will not add particles to the compressed gas, therefore, the only contaminant in the gas stream will be the gross content of compressor lubricating oil. Passage of the gas through the mechanical-type separator removes the macro-particles, leaving only pure compressed lubricating oil finely dispersed as an aerosol.

## Chronological steps

Now that one has established the exact nature of the contaminant, i.e., a finely dispersed aerosol of lubricating oil, one should consider the mechanisms involved in physical filtration (8). It is assumed that the following steps will apply chronologically as listed:

1. Liquid particles of compressor oil will essentially follow the same filtration mechanisms as for dust or solid particles.
2. Once a liquid particle is intercepted in the filter medium it will be held to the fiber by Van der Waal forces.
3. After a number of liquid particles are collected in the fibrous mass individual liquid particles coalesce due to the force of surface tension.
4. Coalesced particles join together until the weight of the particle is heavy enough to flow downward and further overcome capillarity to drop from the felt.

Based on the foregoing items, it appears that the basic requirements are satisfied for continuous removal of particulate compressor oil from a compressed gas.

## Filtration-coalescence mechanisms

To recapitulate, a pure lubricating oil aerosol dispersed in a compressed gas (free of solids) is filtered through a wool felt having a one micron rating. Extensive industrial filtration has shown that felt can remove 100% of one micron particles and some fraction of submicronic particles.

As the oil is collected on the wool felt the oil particles coalesce to larger particles which, by gravity, settle down and out of the felt permitting continuous filtration and coalescence.

Figure 3 shows the proposed scheme.

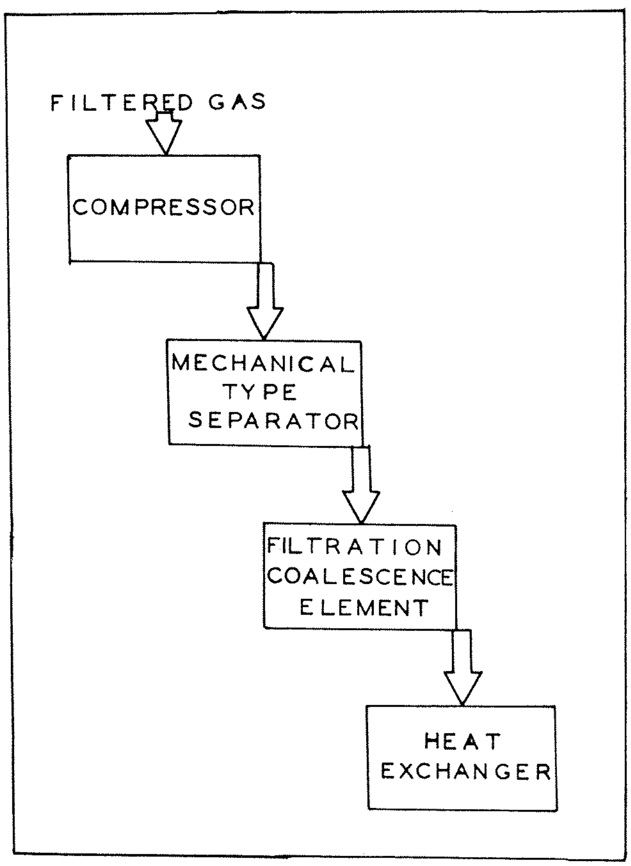


Figure 3. Proposed process for oil removal.

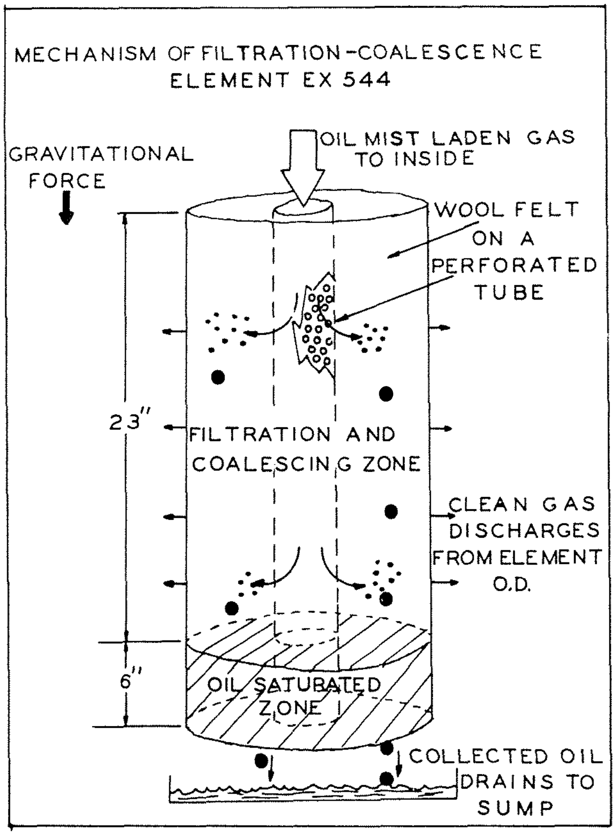


Figure 4. Mechanism of filtration-coalescence in element, EX-544.

## Design of actual unit

For the purpose of illustration one can look at the design of an actual unit, pictured in Figure 4 and 5.

The filtration-coalescence element, EX-544 is an "inside-out" unit. The designed flow rate is 75 actual cu. ft./min. at a pressure drop of 1/2 in. of water and the flow is from inside to the outside for the following reasons:

1. High ingress velocity, 436 ft./min. at tube perforated hole. This high velocity develops high retention efficiency of the larger particles.
2. Low discharge velocity, 12.5 ft./min. at the extended surface, see Figure 5. This relatively low velocity eliminates entrainment and increases the efficiency of small particle removal.
3. Variable velocity spectrum, the incoming and outgoing velocities have a ratio of 1 to 37. This range of velocities develops optimum retention values for the aerosol size particles.

An example of optimum particle size-velocity is as follows: polystyrene particles 1.17 microns in diameter when filtered through the Institute of Paper Chemistry Institute filter mat has a 30% efficiency at 10 ft./min. but a 92% efficiency at 500 ft./min.)

## Optimum oil retention

For a given filter medium there is a velocity at which a given particulate of a definite size will show an optimum retention (8). Further, lower velocities, approximately 5 ft./min., are more efficient on small particles. This is attributed to more effective diffusion also called Brownian movement. The higher velocities, approximately 500 ft./min., are more effective on larger particles due to the impaction phenomenon.

The operation of EX-544 is completely automatic because as oil particles are intercepted and coalesced they drain downwards away from the filtration and coalescing zone.

Fibrous and fine porosity materials have a capillarity action familiarly known as wicking, Figure 4 (lower portion labelled as "oil saturated zone"). In actual practice the height of the oil saturated zone varies from 3 to 6 in. This height is a dynamic action dependent on the balance of surface tension force and mass of the suspended liquid. In practice, when one drop enters the oil saturated zone an equivalent drop leaves the bottom which proceeds onward to the collecting sump.

## Wool felt characteristics

Wool felt was chosen for this application for the following points:

1. Manufactured to strict specifications by the felting process (10).
2. Completely free of outside binders, surface treatments, or the like.
3. Springy, resilient, three dimensionally uniform product.
4. Homogeneous fiber distribution which incidentally has high solids capacity for a given flow rate.
5. Is not brittle, abrasive, or dust forming.
6. Wool fiber is completely stable and inert in petroleum products and the common gases.

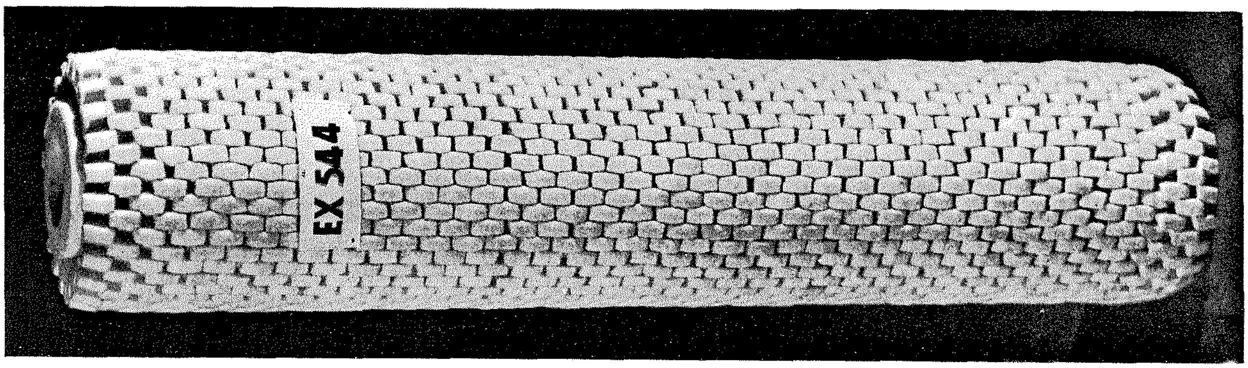


Figure 5. Filtration-coalescence element, EX-544.

7. Wool fiber is oleophilic; this property is considered an advantage during the coalescing phase, i.e., when a particle of oil is intercepted it immediately and thoroughly wets the wool fiber. When enough oil has been intercepted coalescence proceeds as described before.

Based on a compressor oil which has a viscosity of 1,775 SSU at 100°F, as shown in Table 3, EX-544 has a maximum drainage flow rate of 0.1 gal./min. However, in use it is not expected to collect over 2 gal./day (0.001 gal./min.).

TABLE 3. PROPERTIES OF COMPRESSOR OIL EUREKA Q*.

| | |
|---|---|
| Description | Mineral oil, solvent, refined, no additives |
| Flash, atmospheric, °F | 530 |
| Viscosity, SSU, 100°F | 1775 |
| 210°F | 115 |
| Distillation curve | |
| Vacuum, 10 mm. Hg | |
| 0% | 450°F |
| 58% | 700°F |
| Atmospheric equivalent | |
| 0% | 650°F |
| 58% | 958°F |

*Manufactured by the Atlantic Refining Co.

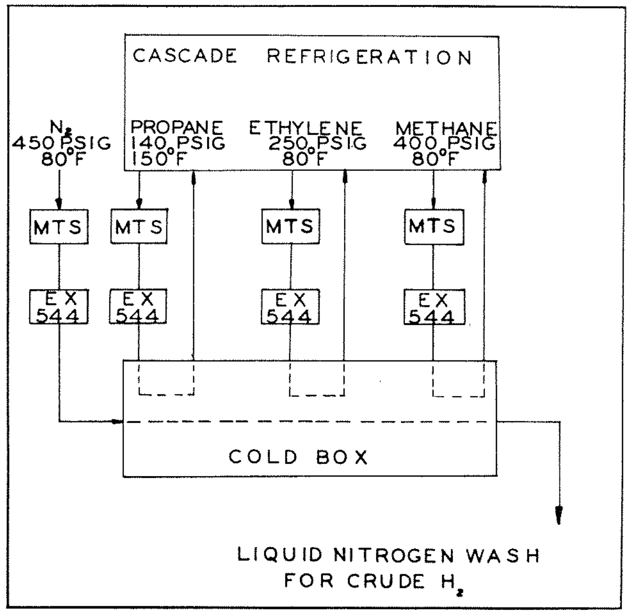


Figure 6. Schematic showing location of mechanical-type separators and filtration-coalescence elements in a low temperature hydrogen purification plant.

## Case history

One plant test using EX-544 is now approaching the fourth year of continual and successful operation. The location of test is the synthetic ammonia plant of the Atlantic Refining Co. at Philadelphia, Penn. A detailed report on this plant has already been published (7); however, this report specially emphasizes the construction and development problems of the very efficient Trane heat exchangers.

Prior to 1960, Atlantic Refining closed down its plant at 6-month periods to clean out the heat exchangers which were fouled with compressor lubricating oil. This involved several units, time, labor and lost production. During 1960 a single EX-544 was installed as shown in Figure 3. After 6 months of operation a routine inspection showed the subject heat exchanger to be clean. Subsequently, four installations were made as shown in Figure 6. Since 1961 the equipment has been in full production continuously. At this writing the heat exchangers have not been cleaned and it is not anticipated they will need cleaning.

## Fifteen gallons per week

Incidentally, each of the mechanical-type separators indicated in Figure 6, remove approximately 15 gal. of oil/week. The gas flow rates in the cascade refrigeration are about a million std. cu. ft./day for each type of gas.

The oil involved in the tests, Atlantic's Eureka Q oil, Table 3, is especially suited to such treatment because it is a high temperature cut, straight mineral oil. Even though some atomization may occur, there has been no perceptible condensation after 3 1/2 years of continuous use.

## Complete elimination of fouling

The advantages of using EX-544 is quite obvious because of the complete elimination of heat exchanger fouling along with complimentary advantages. An itemization is given here to emphasize what has been accomplished.

1. Ideally suited, operation is continuous, trouble-free and effective.
2. Safer, removal of explosive hazard.
3. Removal of unwanted contaminates.
4. No lost production profits or extra labor charge for cleaning.
5. Emergency personnel released due to elimination of problem.

## Proposed process

The progress here is a step toward the need for superclean compressed gases. The principles discussed are broad enough in scope so that many compressed gas applications can consider the use of a filtration-coalescence element and what the operating advantages can be.

## Acknowledgment

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