RECENT DEVELOPMENTS IN PERFORMANCE RATING OF GAS/LIQUID COALESCERS

Presented by:

K. Williamson, Ph.D.; P.E.
Process Equipment Development Dept.
Pall Corporation

S. Tousi, Ph.D.
Scientific and Laboratory Services Dept.
Pall Corporation

R. Hashemi, Ph.D.
Pall Corporation

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ABSTRACT

Until now it has been common practice for many filter manufacturers to equate liquid aerosol removal efficiency with DOP efficiency. A new test method has been developed that accurately measures the overall performance of a liquid-from-gas coalescer system. Called the Liquid Aerosol Separation Efficiency (LASE) test, this new technique involves:

1. Aerosol generation by a device which generates a controlled aerosol typical of the condensation aerosols found downstream of the aftercooler of a reciprocating compressor.
2. Sampling via a close-coupled, full-flow sampler capable of quantitatively capturing the total oil downstream of the test assembly.

Test data of the overall performance of several coalescer configurations have indicated that the LASE test is far superior to DOP testing, the latter being unable to characterize the performance of a coalescer system.

INTRODUCTION

During the past decade, the importance of clean environments in the manufacturing process and in product transportation has been established. A vital part of the equipment essential to providing contaminant-free systems is the filtration components.

Aerosols have always been present in the process industries including petroleum, chemical, petrochemical, and pharmaceutical. In some instances, the aerosols themselves are the desired product, for example in spray paints or perfumes. However, in most process applications aerosols are contaminants and need to be removed.

By definition, aerosols are fine solid or liquid particles suspended in the gas stream. Most aerosols are between 0.1 and 0.9 micrometres (μm) in size, which makes their removal a challenge. Conventional filtration and separation units may be ineffective in removing such fine particles. A part of the difficulty of designing an aerosol removal system is unfamiliarity with modern aerosol detection techniques. Once aerosols are accurately sized and quantified, design of separation units becomes easier.

Whenever aerosols cause a problem in a process operation, they must be removed. In this paper, their removal in the natural gas industry is studied. The same technology, with some modification, can be used in other applications. In gas treatment the following problems associated with aerosols have been identified:

a. Natural gas as a final product must have a certain quality. Liquid and solid aerosols carried from the treatment plant can render the gas unacceptable as a salable product.

b. Almost all gas treatment units, such as contact towers, dehydration units, absorption towers, and control instruments, are designed to accommodate a small amount of physical gas contamination. If the contamination builds up in the system, problems, such as excessive foaming or incomplete absorption, can occur.

c. Many of the aerosols in the gas stream enhance erosion and corrosion, leading to costly repairs.

d. When gas is injected into the oil producing formation to enhance oil recovery, solids and especially heavy hydrocarbon aerosols are known to plug the formation.

In addition to the above, undesired aerosols cause many other problems which may not be clearly associated with the aerosol contamination itself.

BACKGROUND

The traditional means of validation of performance of contamination control components are insufficient for today's needs. The most widely used of these procedures is the DOP (Dioctyl Phthalate) test. The DOP test method is well developed and has been in use for many years. However, the equipment is complex and can be used only under certain conditions. In addition, the equipment is not portable and requires precautions on exhaust of DOP vapor generated during the test (DOP is considered to be a carcinogen). Other drawbacks include test conditions that are significantly different from actual usage *(1)*.

To remove aerosols from gas streams, either gas-solid particulate filters or gas-liquid coalescers are used. Dry gas filters can be very effective when all aerosols are solid particles. When liquid droplets are present, the dry gas filters become ineffective. A coalescer is needed to merge the small liquid aerosols into larger particles and drain them downstream into a collecting sump. In some applications both components, particulate filters and liquid coalescers, are needed in order to have an effective contamination control unit.

Aerosol particle counting has rapidly become one of the most important techniques for validation and characterization of filters used in critical gaseous applications. With the availability and the relative low cost of equipment capable of monitoring particles as small as 0.01μm, such tasks have become routine *(2)*.

In this paper, the most recent developments in evaluation method for coalescer performance are discussed and comparison with other methods are made.

DOP TEST

The DOP aerosols test, adapted by ASTM in 1971, is designed for measuring fine-particle-arresting efficiency of an air or gas cleaning system or device. According to ASTM it is useful for evaluating the efficiency of depth filters, membrane filters, and other particle-collecting devices. A monodisperse aerosol of 0.3μm diameter is continuously generated by condensation of DOP vapor under controlled conditions. The aerosol generator consists of a pot containing 500 milliliters of DOP at 170°C. DOP vapor is mixed with a larger stream of quench air (at 25°C) to form the aerosol droplets. The airstream temperature must be precisely controlled, as the air temperature determines the droplet size. With aerosol generation stabilized (constant particle size and aerosol concentration), concentration is measured indirectly upstream and downstream by a light scattering photometer. The results are expressed as a percent of DOP penetration at the flow rate used, based upon the ratio of influent and effluent light intensities.

The DOP test was initially developed to test the integrity and efficiency of HEPA filters in air applications. It is of only limited usefulness for rating coalescing elements because it is run under conditions which are considerably different from those which a coalescing element experiences in compressed gas service. Some of the drawbacks of the DOP test include:

1. The test is performed on a dry or unsaturated cartridge. It does not, therefore, measure the coalescer's ability to remove liquid aerosols in a saturated condition without excessively high pressure drop (energy costs) or without liquid re-entrainment. It is critical to measure the efficiency at saturated conditions, as this is the condition which prevails during most of the coalescer's working life.

2. The test is performed below atmospheric pressure (i.e. under vacuum). It does not, therefore, reflect actual operating pressure and its effect on gas density, viscosity, and liquid shearing forces.

3. The test is performed using only one size of liquid aerosol, 0.3µm. It does not simulate actual field conditions where the coalescer will be exposed to a wide range of aerosol sizes. Originally, it was thought that 0.3µm size aerosols were the most difficult size to collect. Recent studies show, however, that the actual size of maximum penetration is not necessarily 0.3µm.

4. DOP aerosol size distribution is not monodisperse at 0.3µm. The DOP test uses an "owl," which is an optical mechanical analyzer, to determine the aerosol size distribution of the DOP. The owl, developed in the 1940s, yields inaccurate results if the aerosol is not monodisperse. These false indications of aerosol size are due to the large particles scattering significantly more light than the small particles. The small particles, therefore, contribute only a small fraction of the detected light intensities. Studies using laser automatic particle counters have shown that the DOP aerosols are not monodisperse, but have a size range of 0.1-0.4µm with a mean diameter of less than 0.2µm. The studies concluded that the mechanical analyzer cannot accurately characterize a polydisperse test aerosol and that, therefore, test personnel cannot adjust the aerosol to meet existing test specifications. The analyzer does not count individual particles, but only measures the degree of light intensity penetration around the aerosols. The result is that a coalescing element optimized for maximum DOP efficiency may very well continue to pass aerosols smaller than 0.3µm because of the inherent inaccuracies of the owl mechanical analyzer and the size distribution of the DOP aerosols.

   In addition, the above test relates to capture characteristics alone. However, coalescer performance can also be degraded by re-entrainment of the discontinuous phase caused by poor medium drainage, a property this test does not even address.

LIQUID AEROSOL SEPARATION EFFICIENCY TEST-PALL COALESCER PERFORMANCE TESTING

INTRODUCTION

The LASE test procedure is intended to measure, in aggregate, the three factors that contribute to the overall efficiency of a coalescer system, i.e. aerosol capture, medium drainage, and downstream separation. The protocol can be modified to challenge the coalescer with a wide range of conditions duplicating most of the coalescer environments found in the field today. The "Full Flow Sampling" incorporated into the procedure virtually eliminates any bias to the data caused by non-representative slip stream samples *(3)*.

GENERATION OF AEROSOL CHALLENGE

Testing was performed using the aerosol generation system utilized by Murphy *(3, 4)* which incorporates manifolded Laskin nozzles *(5, 6)* as a sparger system (Figures 1 & 2). The liquid was a representative "20 weight high detergent" compressor lubrication oil. The aerosol generated by this system ranges in size between 0.1-0.9µm in diameter and is considered to be representative of what would be typically found in the aftercooler exhaust air from a reciprocating compressor (Figure 3). By selective use of one to all five of the manifold Laskin nozzles the gravimetric aerosol challenge rate could be varied from 5-50 ppmw depending on conditions.

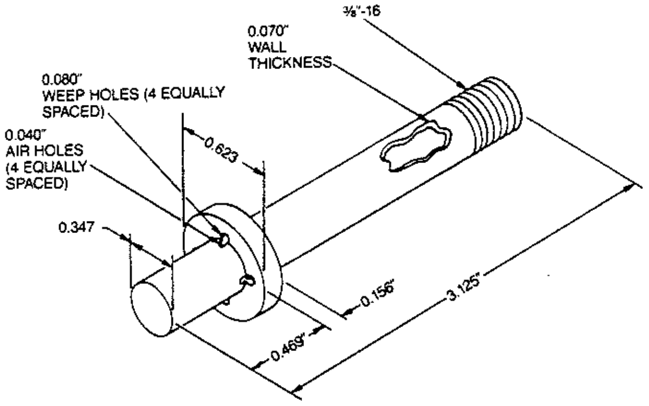
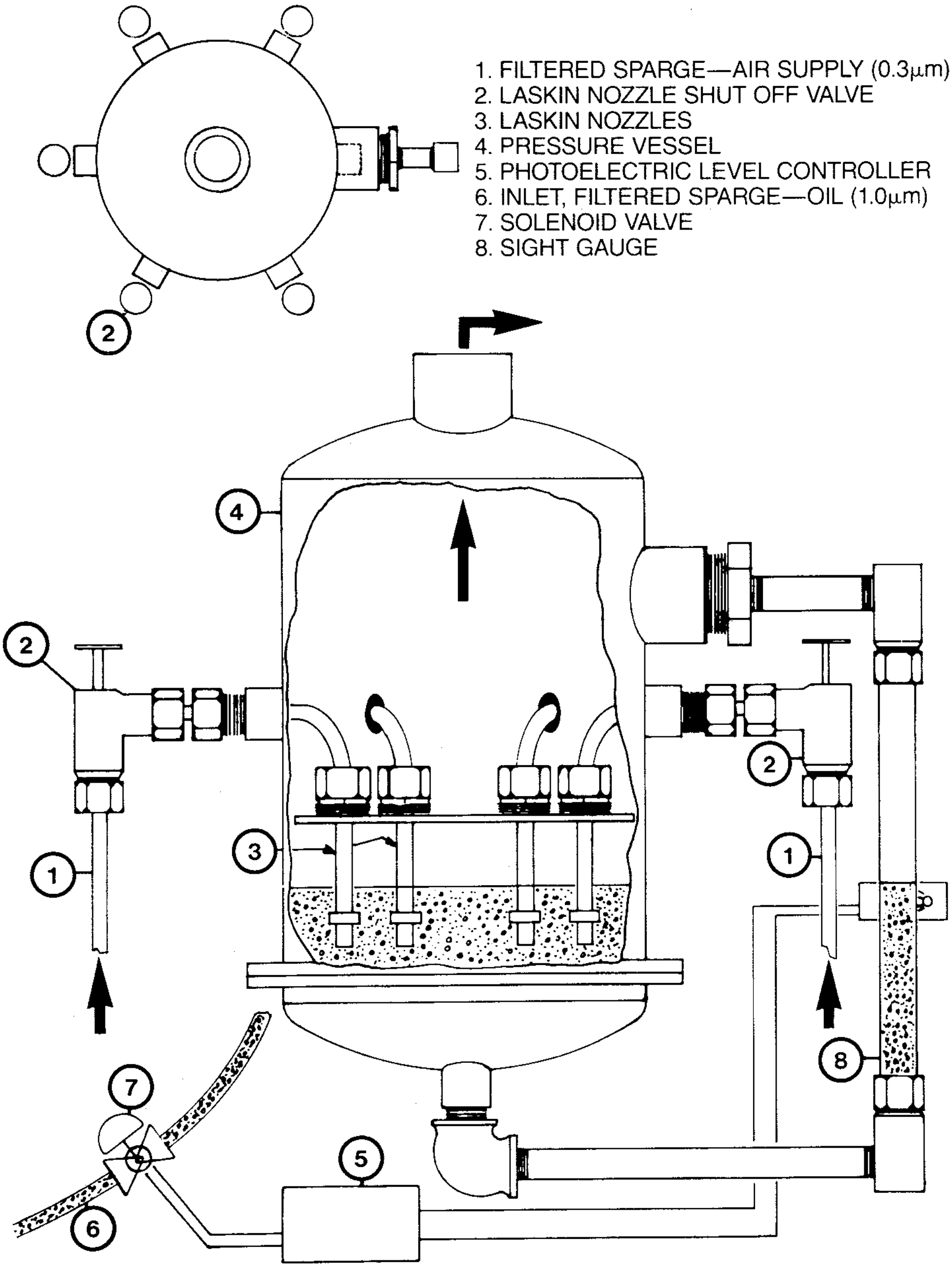


Figure 1 **Laskin Nozzle**

LASE TEST APPARATUS

A sketch of the test stand employed in these investigations is shown in Figure 4. This system incorporates a well regulated (constant pressure) oil free (< 0.003 ppmw) compressed air source. This air stream is split and an appropriate fraction is passed through the aerosol generation system. The necessary pressure drop is supplied by the first flow regulation valve, and the proportionate flow through the aerosol generator is controlled by the number of Laskin nozzle control valves which are open. The generated aerosol is then recombined with the mainstream and this mixture is swept into the coalescer assembly at the manufacturer's recommended flow rate. The coalescer effluent is measured using a close-coupled, full-flow sampler (detailed protocol below). Actual system flow rates are controlled by the second regulating valve and the flow rate is measured with a calibrated critical orifice flowmeter. System temperature and pressure are measured immediately upstream of the coalescer assembly. Differential pressure is measured across the coalescer assembly.

Figure 3 **Aerosol Size Distribution**



1. FILTERED SPARGE—AIR SUPPLY (0.3μm)
2. LASKIN NOZZLE SHUT OFF VALVE
3. LASKIN NOZZLES
4. PRESSURE VESSEL
5. PHOTOELECTRIC LEVEL CONTROLLER
6. INLET, FILTERED SPARGE—OIL (1.0μm)
7. SOLENOID VALVE
8. SIGHT GAUGE

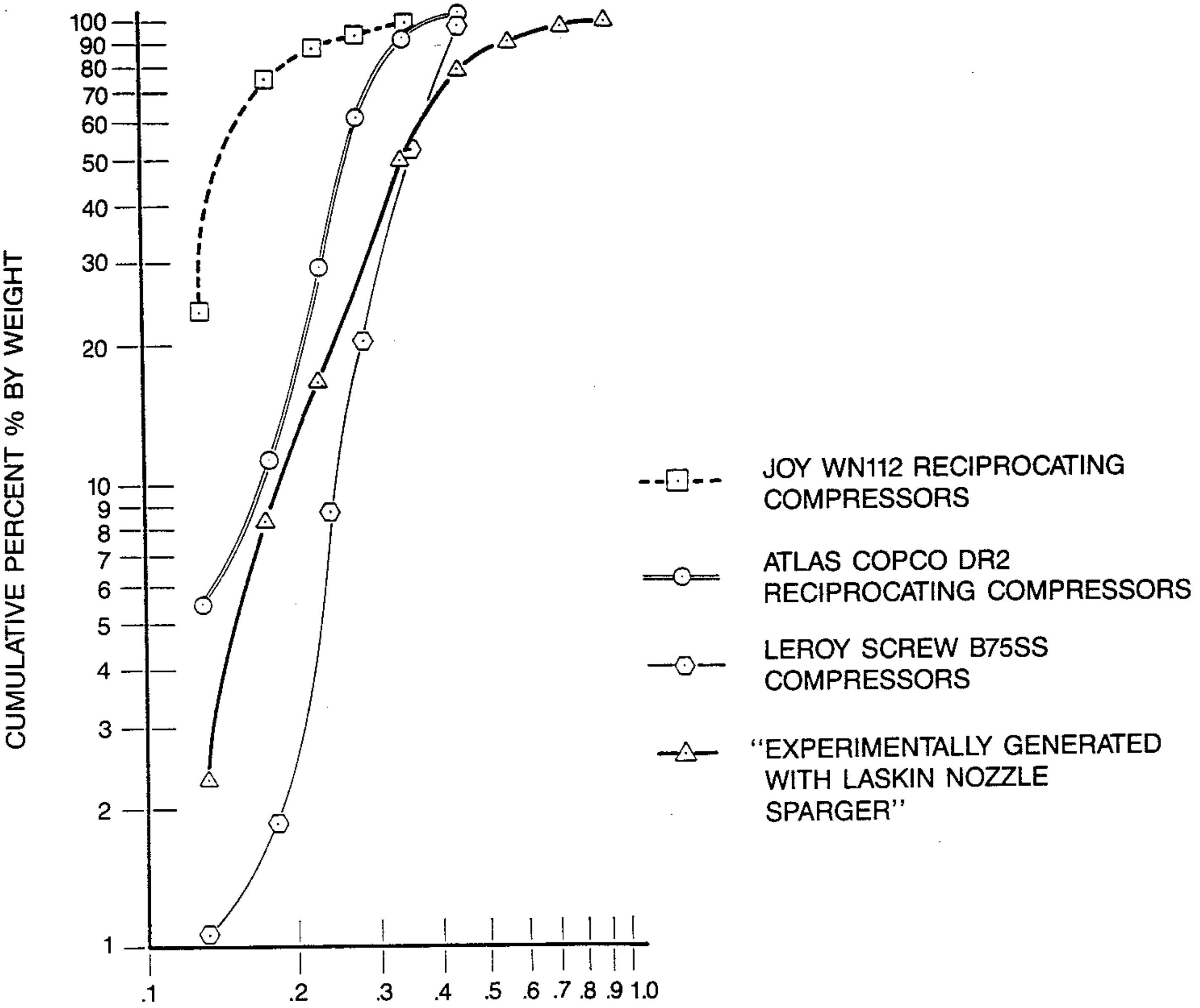


Figure 2 **Aerosol Generation System**

FULL FLOW SAMPLER

Performance measurements are taken only after the coalescer assembly differential pressure and sump drainage rate have stabilized, i.e. reached equilibrium. While the coalescer is approaching equilibrium (sometimes a period of days) a globe valve is substituted for the full-flow sampler and throttled to duplicate the clean Δp of the sampler. When equilibrium is attained, the test system is shut down briefly and the full-flow sampler (Figure 5) is installed.

The full-flow sampler utilizes an absolute-rated (99.9999% DOP efficiency) fluorocarbon membrane backed by a non-woven polyester material for strength. This membrane composite is supported by a perforated metal plate and is sealed around the edge by an o-ring when the sampler is assembled. Uniform flow across the membrane disc is facilitated by a flow distribution baffle upstream of the membrane. The inlet and outlet are equipped with two-inch Triclover™ fittings to facilitate rapid installation and demounting. Both of these fittings are capped when not installed in the test stand and during extraction procedure below. Each sampler is extracted prior to installation in the test stand to ensure that there is no oil contamination.

While samples are taken, the differential pressure across the sampler is monitored, and the sampling is terminated prior to the Δp at which the oil breaks through the membrane. This critical differential pressure is dependent on the medium and the oil and must be experimentally evaluated. Normal procedure required multiple samples for each test condition for statistical evaluation.

SAMPLER EXTRACTION

The soiled samplers are extracted by the following procedure. A weighed quantity (approximately 200 grams) of electronics grade Freon™ 113 is introduced into the sampler and the sampler refluxed for two hours. The refluxed sampler is cooled to room temperature and an aliquot of the Freon/oil solution is introduced into a one centimeter infrared grade spectrophotometric cell. The Freon solution is then scanned between 2700 and 3100 cm^{-1} in an infrared spectrophotometer.

1. REGULATOR
2. OIL RESERVOIR
3. PREFILTERED SPARGE AIR SUPPLY
4. FLOW CONTROL VALVE
5. THERMOMETER
6. FLOAT SWITCH LEVEL CONTROLLER
7. DOWNSTREAM LIQUID DRAIN POINT
8. TEST FILTER ASSEMBLY
9. DOWNSTREAM FULL FLOW SAMPLER
10. RECORDING DIFFERENTIAL PRESSURE TRANSDUCER
11. FLOW CONTROL VALVE AND CRITICAL ORIFICE

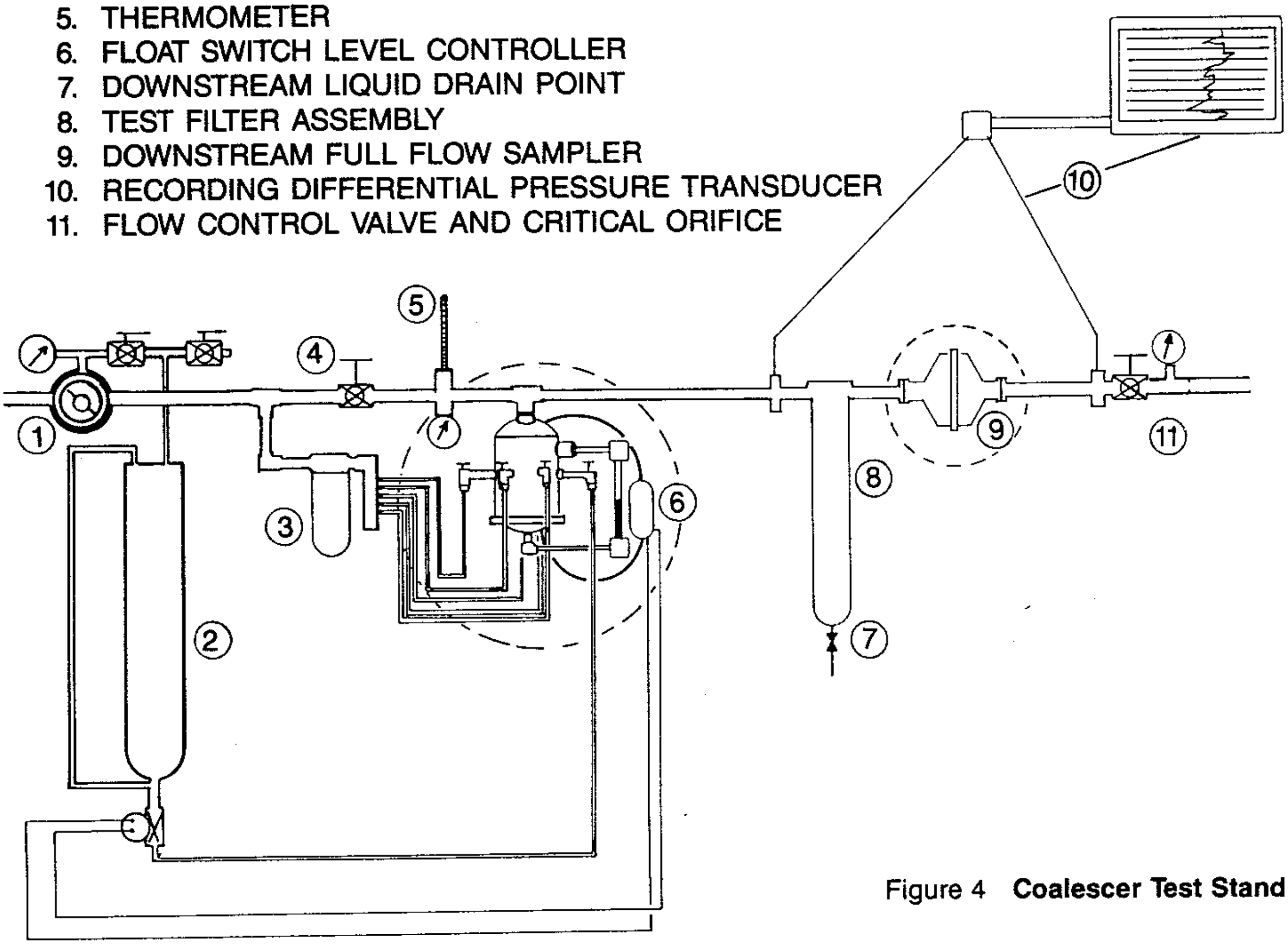


Figure 4 **Coalescer Test Stand**

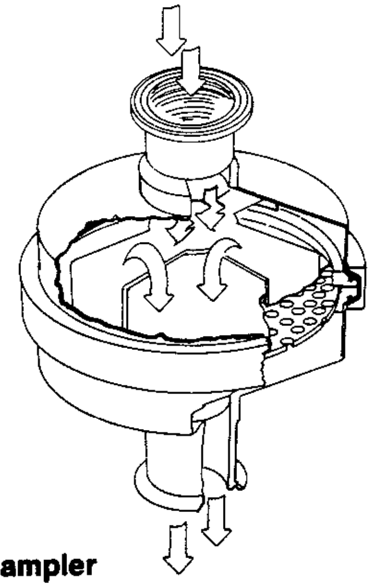


Figure 5 Full Flow Sampler

The total oil in the sampler and the downstream oil aerosol concentration are calculated by means of a Beer's Law (7) relationship between oil concentration and the absorption in the C-H stretching region of the infrared spectrum (where Freon has no infrared-active absorption bands). Minimum detectable oil level is 0.001 ppmw based on air at 100°F and 100 psig. Upstream oil concentration is determined gravimetrically by measuring the sump drainage oil from the coalescer housing during the sampling period.

RESULTS AND DISCUSSIONS

The following table represents laboratory results of coalescer cartridges which were tested at their manufacturers' recommended flow rate:

TABLE 1

GAS/LIQUID COALESCER PERFORMANCE
COMPARISON OF DOP AND LASE TEST RESULTS
AIR AT 100°F AND 100 PSIG
10 PPMW INLET OIL CONCENTRATION

CARTRIDGE	AIRFLOW (SCFM)	DOP EFFICIENCY (%)	DOWNSTREAM OIL (PPMW)	CLEAN ΔP (PSID)	SATURATED ΔP (PSID)
A	200	99.97	0.0033	0.74	1.88
B	200	99.9999	0.0076	1.51	4.31
C	60	99.9999	0.0141	0.46	1.38
D	400	99.97	0.0069	0.65	1.67
E	200	9.99999+	0.0091	0.53	1.36
F	118	99.99999+	0.0163	1.02	4.54
G	115	99.9	0.0250	0.26	1.24

As can be seen from Table 1, DOP efficiency is not a reliable measure of the performance of the coalescers. For example, element A exhibits a significantly lower DOP value than element F; however, the amount of oil measured downstream of element A is an order of magnitude lower than that of element F. In addition, the saturated pressure drop of element A is significantly lower than that of element F.

CONCLUSIONS

1. Liquid and solid aerosol contaminants are usually present in industrial plants, including gas treatment facilities.
2. Aerosols from lubricated compressors are between 0.1-0.9μm in diameter; these are the most difficult to remove. Therefore, they constitute a good test challenge.
3. High efficiency coalescing and filtration systems can remove aerosols in the 0.1-0.9μm range, with long life and low clean and saturated pressure drops.
4. An improved test method for measuring coalescing efficiency called the LASE test is described. The LASE test method can determine the overall coalescer performance with simulated process conditions.
5. Filtration and coalescing units require different qualifying tests. For filtration efficiency measurements, an actual particle count, using Automatic Particle Counters is required. For coalescing units an actual full flow performance test should be used.

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Pall Corporation
Hydrocarbon, Chemical, Polymer Group
2200 Northern Boulevard
East Hills, New York 11548-1289
516-484-5400 • 1-800-645-6532
Fax: 516-484-0364

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