EVALUATION OF FILTERS FOR THE ROYAL NAVY

BY

COMMANDER M. RICHARDS, R.N., C.ENG., M.I.MECH.E.

This article first appeared in the November/December issue of Filtration and Separation *and is reproduced by permission of the Editor.* *It describes the technique now used at the Admiralty Engineering Laboratory for the evaluation of filters for lubricating oil and hydraulic systems in the Royal Navy.*

For some years the Admiralty Engineering Laboratory has been charged with the task of evaluating filters for naval hydraulic systems and for the lubrication systems of main and auxiliary machinery of warships. Until fairly

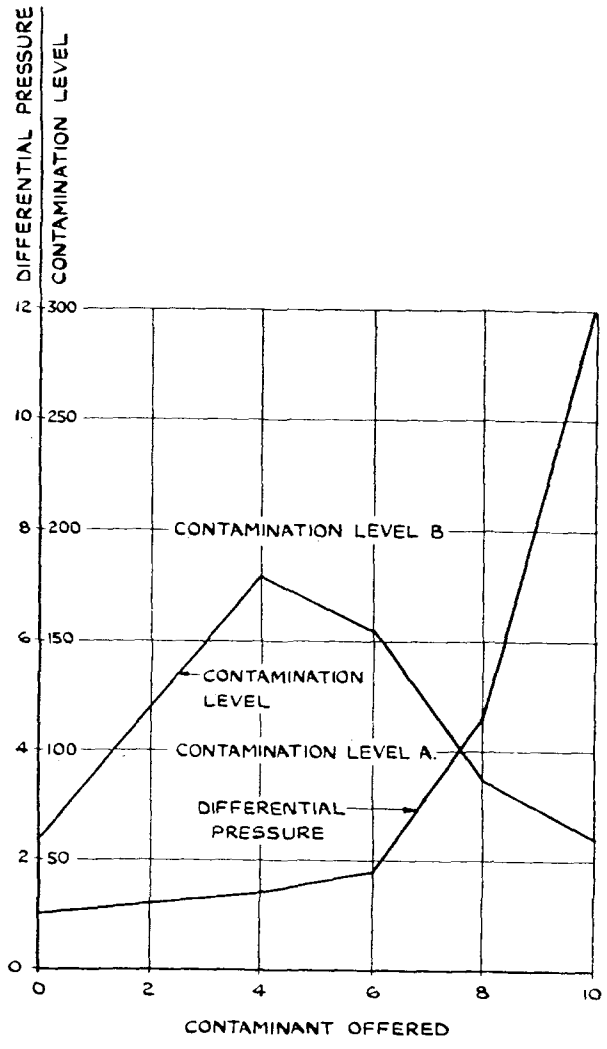

FIG. 1—FILTER PERFORMANCE PRESENTATION

recently the Transmission Curve was used as the criterion of filter performance. Consequently the evaluation procedure had as its object the production of the transmission curve for the nominally clean filter.

Later on dirt capacity assessments were called for. This requirement led to some rethinking and a consequent revolution in the experimentation work. Now there has been a complete revision of views on filter performance criteria.

Aims, Principles and Presentation

This filter evaluation technique has two aims:

(*a*) To assess the system clean-up capability of the filter throughout its service life.

(*b*) To make a comparative assessment of life in service between element replacements or cleanings.

Three principles are basic:

(*a*) The flow rate and viscosity of the liquid during the test are the same as specified for the intended service.

(*b*) A standardized formulation of test contaminant is used which in size distribution and in concentration offered to the filter is not unrealistic by comparison with contaminant that may occasionally be encountered in service.

(*c*) A standard means of assessing the contamination level of the filter test system is used, that is also applicable to lubricating oil and hydraulic systems in practice.

The end product of the evaluation is a presentation like FIG. 1. Here are two curves plotted on a common base of mass of the standard contaminant offered to the filter. One curve shows how the differential pressure is affected; it can be used to assess service life vis-a-vis other filters for the same duty. The other curve indicates the corresponding contamination level. A filter that performs as shown should not be used in a system for which the maximum acceptable contamination level is A in FIG. 1. It would be suitable, however, for service in a system for which the maximum acceptable level is B.

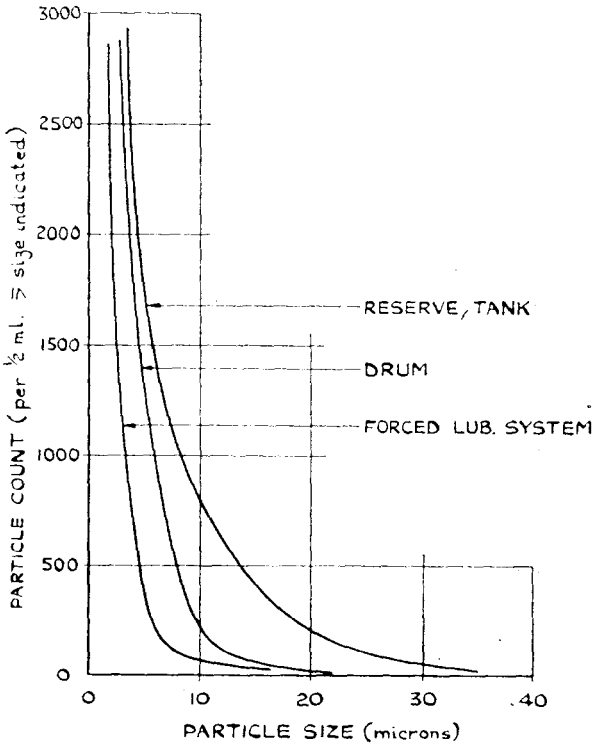

FIG. 2—TYPICAL CONTAMINATION COUNTS

Contamination Level Assessment

FIG. 2 is a graphical presentation of contamination counts made on lub. oil from three sources:

(*a*) The reserve tank of a warship

(*b*) A drum of oil supplied for warship use

(*c*) The forced lubrication system of a warship.

The ordinate of a typical point on these curves represents the number of particles of contaminent contained in a sample volume of 0·5 ml that equal or exceed the size represented by the abscissa of that point. The means of establishing these data is discussed later in this article.

A criterion of contamination level is the number represented by the ordinate corresponding to a specified size. For example, from FIG. 2 the ordinates corresponding to 10 microns are, in ascending order of contamination, 60, 230, 790. This criterion is known as the 10+ count. In the present state of our knowledge the 10+ count appears to be a practical way of tagging the contamination level of lub. oil and hydraulic systems. It may turn out that a finer assessment will be needed for the most sensitive hydraulic systems. Should this prove to be the case the 5+ count would probably be used.

To give meaning to filter performance as presented in FIG. 1 it is necessary to establish standards of maximum acceptable contamination level for lub. oil and hydraulic systems. A programme of work is in hand to this end. Numerous samples are being taken from warship systems known to be free of any shortcomings for which the presence of dirt is suspected. In due course the Royal Navy should have systems hygiene standards against which filters can be specified. There appears no reason why the same standards should not also be valid in non-naval applications.

Test Rig

FIG. 3 is a diagrammatic sketch of the rig. It is essentially a lubricating oil system designed to be as free as practicable of pockets in which dirt can collect. The objects of filter evaluation are:

(*a*) To determine the effectiveness of the filter on test in cleaning up this system

(*b*) To determine the effect of the arrested contaminant on the flow characteristic of the filter.

A variable speed rotary positive-displacement pump VSP takes suction from the bottom of a conical tank CT1. It discharges oil via a diaphragm-type regulating valve RV1 and a combined heater and cooler H/C back to the top

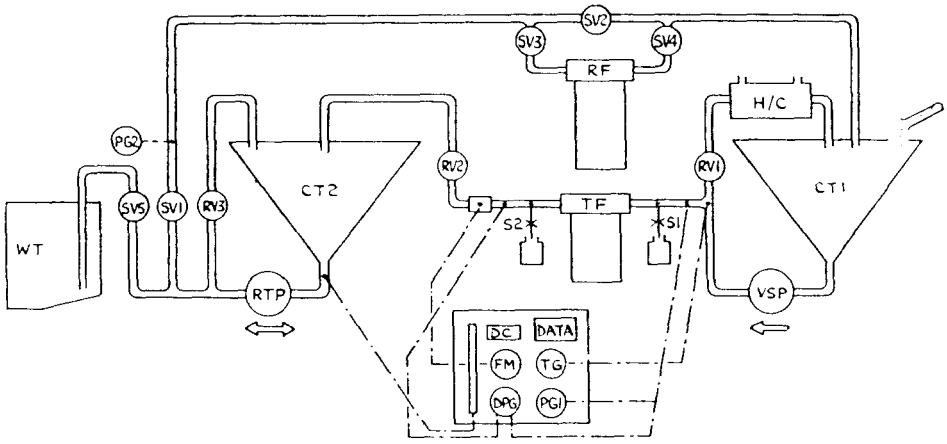

FIG. 3—FILTER EVALUATION RIG

of CT1. The discharge pressure is controlled by the speed of VSP and the setting of RV1. The heater/cooler is a water jacket surrounding a length of the return pipe. Cooling is effected by water flow through the jacket. Heating is by an electrical heating element wound round the outside of the jacket. Temperature control is manual.

A branch from the rising discharge main of VSP is connected to the inlet of the test filter TF. The outlet of TF is connected to a pipe leading to the top of a second conical tank CT2. The pressure at inlet and the flow rate through the filter can be regulated by manipulating the speed of VSP and the settings of RV1 and a down-stream diaphragm valve RV2. Pitot-tube sampling connections S1 and S2 are provided at the inlet and outlet branches adjacent to the filter. They have short tail pipes of plastic tubing, closed by laboratory-type screw clamps known as Hoffman clips.

A fixed-speed reversible rotary positive-displacement transfer pump RTP takes suction from the bottom of CT2. It can transfer oil back to CT1 via the ball stop valve SV1. The return pipe has in parallel with it a permanent rig filter RF. Ball stop valves SV2, SV3, SV4 enable RF either to be by-passed or to be placed on stream, as desired. When RF is in use the upstream oil pressure may be read at pressure gauge PG2. It can be controlled by the setting of diaphragm regulating valve RV3, which allows oil to recirculate to the top of CT2. A third branch connects RTP with the bottom of a waiting tank WT. The reversible action of RTP enables oil either to be pumped from WT to CT2 or vice versa.

The instrumentation is grouped on a gauge panel specifically designed and arranged for readings to be recorded by camera. Photo-recording is either manual, by remote push-button control, or automatic, by a timing device that gives a wide choice of interval between successive exposures. Shutter operation triggers a bank of electronic flash lights. Film wind-on is automatic after each exposure. The gauge panel array comprises:

(*a*) Calibrated gauge glass showing the level of oil in CT2

(*b*) Digital clock DC

(*c*) Flowmeter FM; the inferential sensing element is in the pipeline down-stream of TF and S2

(*d*) Differential pressure gauge DPG measuring the pressure drop across TF

(*e*) A display of data relevant to the test record

(*f*) Temperature gauge TG

(*g*) Pressure gauge PG1 reading pressure at inlet to TF.

Test Procedure

Before evaluation proper, the test rig system is cleaned up by a standardized technique. A quantity of oil sufficient for about 2 minutes at the specified filter flow rate is dispensed to CT1. This is ordinarily OM33, a mineral oil suitable for normal hydraulic service, having a kinematic viscosity of 28 centistokes at 100 degrees F. The test filter *minus* its element assembly is fitted in place in the rig. Oil is pumped at a high rate from CT1 through TF to CT2. Vigorous recirculation is maintained in sub-systems CT1-VSP-RV1-H/C and CT2-RTP-RV3 to ensure the best possible flushing conditions. When CT1 is almost empty, RV2 is shut and the oil from CT2 is pumped back to CT1 via the rig filter. This procedure is carried out repeatedly while the system is brought to the appropriate test temperature. Typically, a dozen passes would be made. Finally a sample is taken from S2.

The element assembly is then fitted to TF. Oil is passed through it at the specified rate and viscosity; gauge readings are recorded by photographing the panel. When CT1 is nearly empty, oil is transferred back to it directly from CT2, the rig filter being by-passed from this time on. A number of passes are made until the differential pressure is seen to be steady. In this and all subsequent parts of the test at least five passes through the test filter are made in each sequence. A photo-record is made if the differential pressure has altered.

Now come the clean-up sequences. RV2 is closed and oil is recirculated vigorously round the CT1-VSP-RV1-H/C sub-system. The first dirt load, equal to 1 gram. per 10 gal. of oil in the system, is dumped into CT1. After a period of between 5 and 10 minutes mixing is complete. The first clean-up sequence is begun by opening RV2 and adjusting the flow to the specified rate. The technique is similar to the preliminary sequence. At least five passes are made; photo-records and effluent samples are taken on the last run. During this sequence and from here on to the end of the test a constant flow is maintained through the filter.

Further clean-up sequences are made in similar fashion except for the premixing of the contaminant additions. Standard dirt loadings are added to CT1 at the start of each clean-up sequence. The test is terminated when a prescribed limit of differential pressure is reached.

The formulation of the test contaminant used at the A.E.L. gives a size distribution similar to dirt measured in a sample from a warship reserve lubricating oil tank. At the usual concentration of 1 gram. in 10 gal. of oil the contamination level is not much greater than that of the reserve-tank sample. The test contaminant is made up of a mixture of three grades of carborundum (silicon carbide), by weight:

(*a*)	Grade 280	0·135
(*b*)	Grade 400	0·675
(*c*)	Grade 700	0·190

Sample Preparation and Processing

Wide-mouthed glass bottles of 120 ml capacity, with ground glass stoppers, are used for taking effluent samples. They are prepared by a standardized cleaning technique. The cleaning equipment comprises two 40 kHz ultrasonic cleaning baths, each of 4 gal. capacity, housed in an open-fronted clean-air cabinet. Up to 18 bottles can be prepared in one batch. One tank is used for washing, the other for rinsing. Filtered tap water and a liquid detergent are used for washing; filtered tap water is used for rinsing. Drying is accomplished by shaking with filtered acetone placed in each bottle, draining, and leaving to dry in the heated clean-air cabinet. When the smell of acetone is no longer discernible the stoppers are fitted. The bottles are then labelled for their places in the evaluation routine.

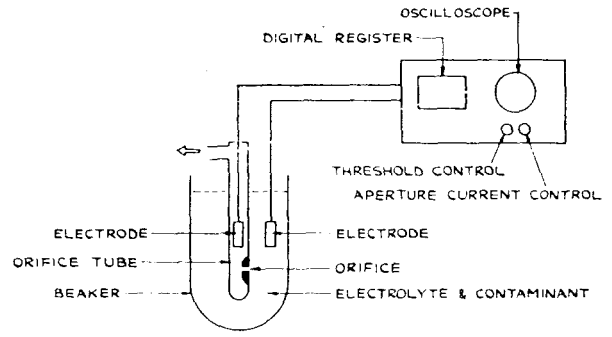

FIG. 4—PRINCIPLE OF COULTER COUNTER

Two samples are taken at each occasion of sampling. Ordinarily only one sample of each pair is processed and counted; the second is kept in reserve in case of mishap or for confirmation of the first, if required. When sampling, the plastic sampling tube is allowed to run full-bore. The bottle is placed to collect the sample after a brief period for flushing the sampling tube clear of liquid from the previous sampling.

To assess the contamination level of an effluent sample it is necessary to substitute an electrolyte for the oil, for reasons that will appear presently. The first step is to trap the contaminant on a porous cellulose plastic membrane. Plain membranes of pore size 1.2 microns are customarily used. A conventional laboratory filter funnel, conical flask, liquid trap and vacuum-pump set-up is assembled. The filter funnel serves to guide the oil into the membrane, which is contained in a plastic supporting enclosure within a metal housing. All glassware used in the processing is cleaned in broadly similar fashion to the sample bottles; all handling operations are carried out within an open-fronted clean-air cabinet. The contaminant filtration procedure is standardized. Each sample bottle filtered requires 500 ml of filtered petroleum ether, to reduce the viscosity of the sample and to enable all contaminant to be flushed from the bottle, stopper and funnel, into the membrane. Finally the membrane is dried by further operating the vacuum pump.

Before the final step of the processing, the membrane is examined under the microscope to locate the largest particle present. The site of this particle is photographed. Now the membrane is placed in a round-bottomed beaker containing 60 ml of a filtered mixture made up of 70 per cent by volume of acetone and 30 per cent of dimethylformamide. This mixture is a solvent of the membrane material. The beaker is held in a small ultrasonic bath until the membrane is dissolved and the transferred contaminant dispersed completely. 60 ml of a solution of ammonium thiocyanate in filtered isopropyl alcohol, at a concentration of 50 gram. per litre, are then added. This being an electrolyte, the contaminant is now thoroughly dispersed in an electrically conductive liquid equal in volume to the original effluent sample.

Counting

Effluent contamination level is assessed by means of the Coulter Counter. Originally developed for hospital use in making blood counts, this instrument is increasingly employed in technology. The principle of its operation is described with the help of FIG. 4. A current passes between two electrodes, one of which is in a closed-ended orifice tube and the other is in the beaker containing the electrolyte plus dispersed contaminant. The continuity of the conductive path between the electrodes is assured by a small orifice in the aptly-named orifice tube. Electrolyte is drawn from the beaker via the orifice and orifice tube. So long as pure electrolyte passes through the orifice, the current remains unchanged; there will be no blips on the oscilloscope and no change in the digital register. When a particle of contaminant passes through the orifice there is a momentary change of current. This is a consequence of the change in electrical resistance between the electrodes caused by the partial blocking of the conductive area of the orifice by the virtually non-conducting particle.

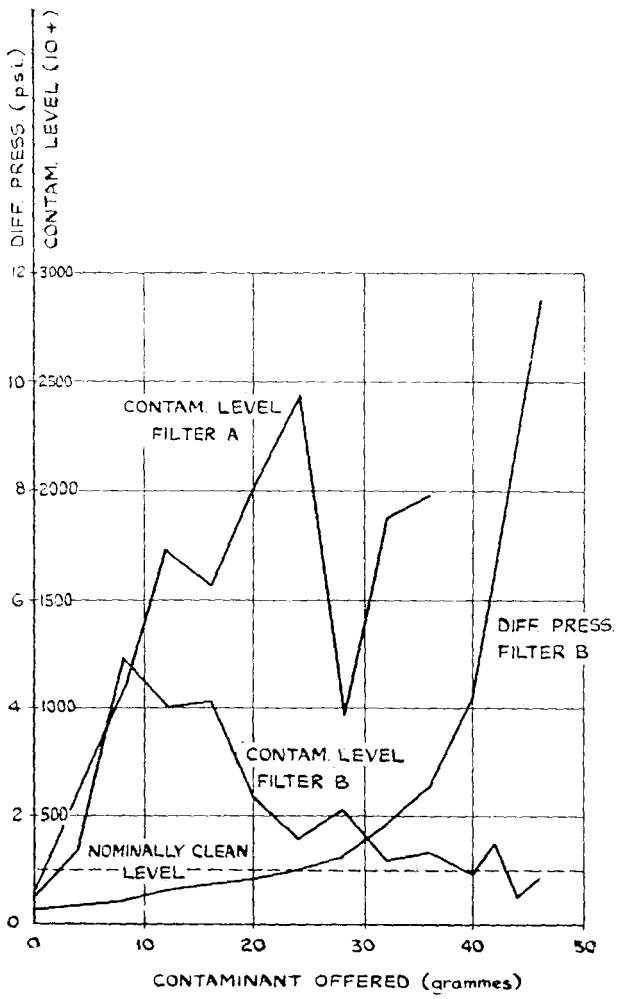

FIG. 5—TWO FELT ELEMENTS COMPARED

The current change is small for the smaller particles, larger for the bigger ones. Two controls are provided, one for aperture current, the other for threshold. The joint setting of these determines the limiting size of the particle below which the resultant changes will not show up on the oscilloscope and will not add to the count shown on the digital register. The instrument is provided with automatic switching to ensure that a known selected constant volume of liquid is counted each time.

Irrespective of its shape, a particle is sized by the Coulter Counter by its volume. In practice, therefore, particle size is quoted as the diameter of the sphere having the same volume. This definition is not the same as may be used in some other methods of sizing and counting.

Certain corrections have to be made to the counts read from the digital register. The most important of these corrections is for the background count. This is the count contributed by the sample bottle, the membrane, the membrane solvent, and the electrolyte. To assess background two bottles in every batch prepared are kept for this purpose only. They are treated in precisely the same way as the samples. The resulting count is used as the background count, to be deducted from the raw counts indicated on the counter register.

Results to Date

FIG. 5 shows how two felt filter elements performed. The elements were from different manufacturers though supplied for the same duty. Element A showed no increase in differential pressure during the evaluation. This resistance to choking is a doubtful virtue, since the effluent contamination levels soared. Element B choked as shown by the differential pressure curve. Correspondingly its effluent contamination levels were much better than those of A. Even so, counts of 250 or less were not achieved until near the end of the evaluation, at a stage of choking when in practice the element would need to be changed. The 10+ count of 250 has been marked as a nominally clean count, since that value has been observed in clean oil as supplied for ship use. There is more recent evidence that much cleaner oil may also be supplied. As felt filter elements are much used in the Royal Navy the results of FIG. 5 are disquieting. It is intended to evaluate a paper element specified for the same duty as these felt elements to see whether an improvement in performance might result by changing from felt to paper.

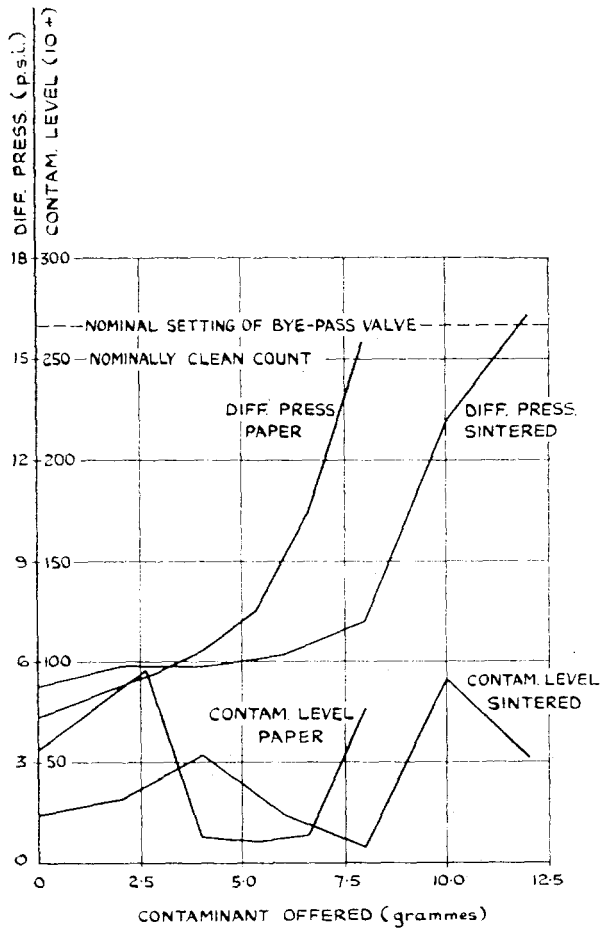

FIG. 6—SINTERED AND PAPER ELEMENTS COMPARED

FIG. 6 compares two different elements specified for the same auxiliary machinery lubrication system duty. One element is made of a sintered material, the other of paper. Both elements performed comparably well in keeping the system contamination level commendably low. The paper element had about two thirds the life, to an arbitrary choked condition, of the sintered element. In this case, economic and logistic considerations would probably become deciding factors in the adoption of one element type rather than the other.

Some results of the current work of assessing the contamination levels in satisfactory working hydraulic and lubrication systems are now available. No clear pattern has so far emerged. While the aforementioned nominally clean count of 250 still appears to be a reasonable standard to aim for, very much larger 10+ values have been observed. The extreme of these was over 10,000, but it may well have been a pocket of contamination not representative of the system elsewhere. The lowest 10+ count found in a working system sample to date is 80.

Acknowledgements

The author would like to place on record his appreciation of the services and co-operation of the following members of the Admiralty Engineering Laboratory in the work of filter evaluation and systems sampling:

Mr. R. Wickham, a Senior Experimental Officer of the Royal Naval Scientific Service, who pioneered the method of processing and counting samples;
Mr. M. L. Galpin, an Experimental Officer of the Royal Naval Scientific Service, who developed the present test rig and many of the techniques now used, and who is responsible for the actual evaluation work; and
Mrs. A. Stone, who prepares the samples and operates the Coulter Counter.

Finally, he is obliged to the Superintendent, A.E.L. and to the Ministry of Defence, with whose permission this article is published, but whose opinions are not necessarily reflected by the information therein.