A simple but accurate oil-filled vacuum manometer

A. T. J. HAYWARD
Basic Heat Transfer and Properties of Fluids Division, Fluids Group, National Engineering Laboratory, East Kilbride, Glasgow
MS. received 4*th December* 1962

A new oil-filled vacuum manometer is described, which has considerable advantages over conventional vacuum gauges. It is provided with a simple de-aeration chamber, in which the oil can be completely freed from dissolved gases within a few minutes, thus avoiding subsequent errors from the release of dissolved gases.

The new gauge compares favourably with a McLeod gauge of range 0–10 mmHg: it is much simpler and cheaper to construct; it is of similar accuracy (except at pressures below about 1 mmHg) and of much wider range; it gives readings continuously; and its accuracy is unimpaired by the presence of condensable vapour.

1. Introduction

Oil-filled manometers are potentially very attractive for the measurement of vacuum pressures in the range 2–50 mmHg. They possess the two great advantages of extreme simplicity and high sensitivity—a rare combination in any type of instrument.

Despite this they have never been popular because they possess one serious disadvantage. All organic liquids dissolve air and other gases, and the solubility is directly proportional to the absolute pressure. Consequently, when an oil manometer is exposed to vacuum there is always a tendency for dissolved gases to be released and to create errors.

To avoid these errors the manometer oil must be degassed *in situ* before each test. With conventional manometers it is very difficult to degas the oil completely. A new manometer of very simple design is described in which the oil may be completely degassed in a few minutes.

2. The conventional oil manometer

The most straightforward form of oil-filled vacuum manometer is a simple U-tube, with one limb connected to the system whose pressure is to be measured and the other to an independent vacuum pump. Such an arrangement, however, is expensive and the form of manometer shown in figure 1(*a*) is normally employed.

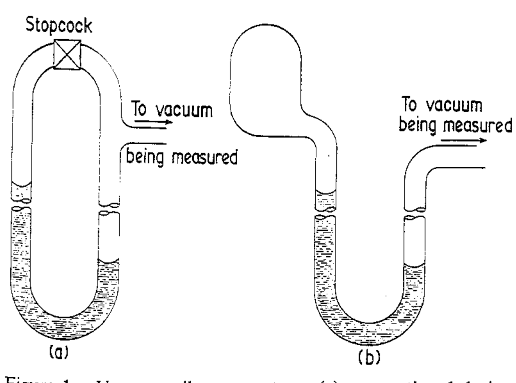

Figure 1. Vacuum oil manometer. (*a*) conventional design, (*b*) new design.

To use this manometer the stopcock at the top must first be opened, and the manometer pumped down until the oil is degassed. Then the stopcock is shut, thus sealing a vacuum into the space above the oil in the left-hand limb; the manometer is then ready for use.

This simple arrangement does away with the need for a separate vacuum pump, but it greatly increases the susceptibility to outgassing errors, since any gas liberated in the left-hand limb will accumulate and create a substantial pressure in the confined space. It is therefore most important for a manometer of this type to be completely degassed before use.

It is very difficult to degas the oil in a U-tube. The surface area of the oil is small and the depth considerable, and the rate of diffusion of a gas through oil is very slow. It would take several weeks of pumping at normal temperatures to degas a typical manometer of this class.

The usual way of speeding up the degassing operation is to provide electrical heaters in or around the manometer tubes as, for example, in the manometers of Biondi (1953) and of Phipps and Bloom (1961). This arrangement, however, is far from ideal. The time required for degassing, although reduced, is still considerable, and the heating process must be carefully controlled to avoid overheating.

The widespread employment of heating coils is possibly due to a fallacious belief that oil resembles water in having an air solubility which falls as the temperature rises. Actually, as Clark (1933), Smith (1951) and Baldwin and Daniel (1953) have pointed out, the solubility of air in hot oil is not significantly different from that in cold oil. Heating an oil accelerates the degassing process by reducing the viscosity, increasing the diffusivity and causing convection currents which help to renew the surface layer of the oil. These factors are of limited value with the low viscosity oils used in manometers.

3. The new manometer

The use of heating coils in oil-filled vacuum manometers is completely unnecessary. Experiments have shown that degassing can be carried out much more rapidly, effectively and safely by other (and much simpler) means. Only two conditions are necessary for the rapid degassing of low viscosity oil under vacuum: a large surface area and vigorous agitation of the oil.

These conditions are satisfied in the design of manometer shown in figure 1(*b*), which has a bulb at the end of the closed limb with a volume about three times that of the oil. If this manometer is tilted so that the oil runs into the bulb and is then shaken while under vacuum, very rapid degassing takes place. This degassing operation in progress is shown in figure 2. The whole process, including the time taken to

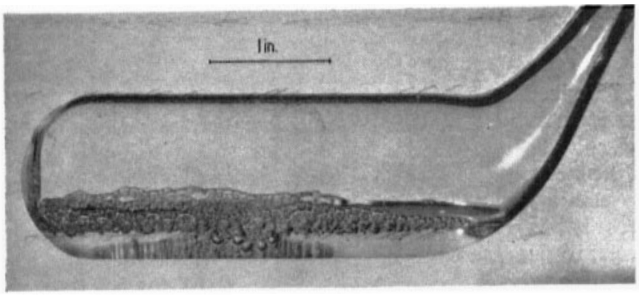

Figure 2. Oil being de-aerated in the manometer.

drain the oil into the bulb for de-aeration and to drain it back into the manometer afterwards, takes less than 10 minutes.

Another advantage of this design lies in the absence of a stopcock. This makes it appreciably cheaper than the conventional manometer and eliminates the danger of leakage at the stopcock.

4. Accuracy

Figure 3 shows the results of an accuracy test where the new manometer and a commercial manometer of conventional pattern were compared against a McLeod gauge, in measuring

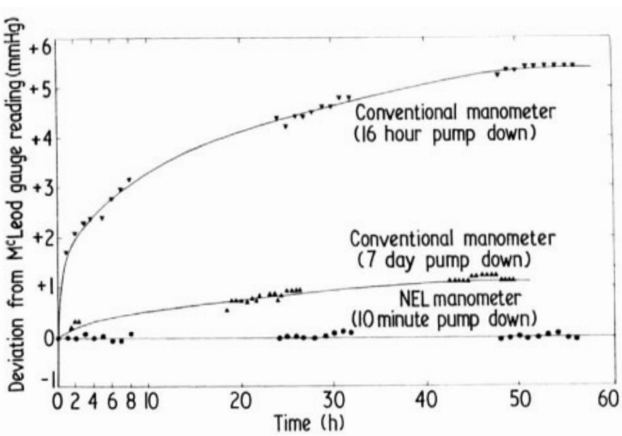

Figure 3. Comparative accuracy of manometers measuring a pressure of 9 mmHg.

a pressure of 9 mmHg. The conventional manometer, which was not provided with heating coils, was initially pumped down for 16 hours in one test and 7 days in another; if it had been heated comparable results could no doubt have been obtained after shorter periods of pumping down. The new manometer was pumped down for a total period of 10 minutes, of which about 1 minute was spent gently shaking it while the oil was in the de-aeration chamber.

The new manometer remained in complete agreement with the McLeod gauge throughout the duration of a 3 day test (apart from a random deviation of $\pm 1\%$, which corresponds to the sensitivity of the two gauges). The conventional manometer, however, rapidly developed a substantial systematic error; after 3 days this amounted to about 60% in the case of the 16 hour pump down and 10% in the case of the 7 day pump down.

In a further test for accuracy the new manometer was connected in parallel with four McLeod gauges of the miniature tilting type, and the pressure was varied in steps from 0 to 10 mmHg. The results are given in the table.

Accuracy of new manometer compared with four McLeod gauges. (All figures are in mmHg.)

A Manometer reading	B Mean of four McLeod gauge readings	Standard deviation of McLeod gauge readings	B–A
0·05	0·06	0·02	+0·01
1·13	1·19	0·09	+0·06
1·77	1·83	0·03	+0·06
2·49	2·48	0·03	−0·01
3·43	3·51	0·06	+0·08
3·96	4·00	0·07	+0·04
4·77	4·79	0·06	+0·02
6·02	5·99	0·05	−0·03
6·56	6·59	0·14	+0·03
7·23	7·24	0·07	+0·01
7·94	8·00	0·07	+0·06
8·82	8·83	0·09	+0·01
1·73	1·76	0·05	+0·03
2·51	2·58	0·10	+0·07
2·68	2·65	0·09	−0·03
3·63	3·73	0·06	+0·10
4·30	4·40	0·06	+0·10
4·70	4·78	0·10	+0·08
5·71	5·86	0·08	+0·15
6·08	6·08	0·10	0
6·32	6·31	0·13	−0·01
6·99	7·00	0·04	+0·01
8·58	8·73	0·07	+0·15
9·13	9·13	0·09	0
Mean values (ignoring signs)		0·073	0·048

Generally the values of the discrepancy between the manometer reading and the mean of the four McLeod gauge readings are rather less than the standard deviations of each set of four McLeod gauge readings. This does not provide a quantitative measure of the comparative accuracies of the two types of gauge, since the two values reported are not strictly comparable. The comparison is probably biased against the manometer, since it does not take account of systematic errors in the McLeod gauges.

It is, however, clear from these results that the accuracy of the new manometer is comparable with that of the type of McLeod gauge tested, even at these relatively low pressures. At somewhat higher pressures the manometer might be expected to be more accurate than a McLeod gauge of this type, on account of the non-linear scale of the McLeod gauge.

All these tests had to be carried out in vapour-free systems, as this is a requirement for the McLeod gauge. In other work the new manometer has given readings consistent with other data when connected to systems containing a mixture of air and water vapour, or of air and the vapour of various organic liquids.

5. Conclusions

An oil manometer has been produced which compares favourably with all other gauges for measuring pressures in the range 1–50 mmHg.

It is simpler and cheaper than any other form of gauge, and is very convenient to use.

In addition, it is more accurate than most other gauges and about as accurate as a normal commercial McLeod gauge with a range of 0–10 mmHg. It is free, however, from the well-known disadvantages of the McLeod gauge, in that it is continuous reading and that it maintains its accuracy even when condensable vapours are present.

The new manometer has been patented and it is hoped that it will soon be available commercially.

Acknowledgments

The work was carried out in the National Engineering Laboratory, Department of Scientific and Industrial Research, and this paper is published by permission of the Director.

References

BALDWIN, R. R., and DANIEL, S. G., 1953, *J. Inst. Petrol.*, **39**, 105.

BIONDI, M. A., 1953, *Rev. Sci. Instrum.*, **24**, 989.

CLARK, F. M., 1933, *J. Franklin Inst.*, **215**, 39.

PHIPPS, R. L., and BLOOM, J. H., 1961, *Vacuum*, **11**, 35.

SMITH, A. C., 1951, *Sci. Lubric.*, **3**, 20.