SIMPLE FULL-BORE WATER-CUT MEASUREMENT TECHNIQUE

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SUMMARY

The measurement of water cut, usually done in a sample loop, will be greatly simplified when full-bore instruments become generally available. The accurate determination of density, and hence water cut, from a static pressure head measurement can now be kept reasonably compact owing to recent improvements in the accuracy of differential pressure cells. A feasibility study has been carried out of a full-bore water-cut monitor, known as the Omega tube, based on a static head measurement compensated for friction losses. The Omega tube shows promise for liquid/liquid mixtures but is intolerant to entrained gas. Accuracies within +/- 3% absolute over a range of velocities from 0.6 to 1.5 m/s have been demonstrated. Improved design should ultimately give accuracies of better than +/- 1.5% absolute over the full water-cut range, irrespective of flow velocity. By the same principle, water cut can also be derived using either a densitometer or a level measurement.

1. INTRODUCTION

The accurate measurement of water cut in crude oil lines is playing an increasingly important role in the development of new fields. These fields tend to be small and cannot support the facilities for dewatering the crude before it is transported to large terminals for export.

By far the most common technique used for measuring water cut is manual sampling followed by analysis. When automatic measurements are required, water cut is normally derived either from the density using, for example, a vibrating tube densitometer or from the dielectric constant using a capacitive sensor. These instruments are usually small-bore, hence they must be installed either in a sample line parallel to the main flow or inserted into the main line. All these existing techniques, both manual and automatic, therefore depend on obtaining a representative sample from an oil/water stream, a requirement that is both difficult to satisfy and a potential source of large measurement errors. Although the basic measurements have an intrinsic accuracy in the range 0.1 to 3% absolute, poor sampling can lead to unacceptably large errors in water cut. The reliability of the measurement would be greatly increased by removing the need to sample, and for smaller fields with minimum facilities the water-cut measurement installation would be greatly simplified. Full-bore instruments which can handle the total flow are required.

Despite the recent appearance of a number of promising commercial full-bore, in-line water-cut monitors, the need was still felt for a simpler low-cost technique. A monitor based on a measurement of hydrostatic pressure will be described.

2. OMEGA TUBE

The new monitor, under development at Shell's Exploration and Production Laboratory in The Netherlands, derives water cut from a measurement of the hydrostatic pressure head in a vertical flowline over a given height. The necessary equipment can be kept compact by incorporating the recently available highly accurate differential pressure sensors. In the present case, in which a Rosemount 1151 differential pressure (DP) cell is used, a height of only 1 m is required for the liquid column. The Omega tube principle compensates for the effects of variations in liquid velocity and viscosity. Although the technique is not new, the Omega tube is unique in that it uses a single sensor to measure the hydrostatic head regardless of the dynamic pressure losses. Previously, differential pressure measurements in a vertical section of flowline have been corrected for friction losses either by subtracting a second differential pressure measurement in a horizontal section of flowline or, more commonly, by maintaining constant velocity through the measurement section and calibrating to compensate for the effect.

The elimination of the dynamic pressure losses has been achieved by measuring the differential pressure in the upward and downward legs of an inverted U-tube, hence the name Omega tube. The principle is shown schematically in Fig. 1. Because the configuration of the Omega tube is symmetric, the dynamic or friction losses in the two legs have the same magnitude but are opposite in sign. They cancel out, while the hydrostatic head remains. From Fig. 1 the pressure at B is the result of a small static head from the liquid above points 2 and 4 plus half the friction loss between these same two points. The pressure at A is, similarly, the result of the static head above points 1 and 5 plus half the friction loss between these points. By measuring the differential pressure between A and B, all the friction loss terms disappear, leaving only the static head over height H, from which the average density of the liquid column can be deduced. Given the base densities of oil and water, the water-cut calculation is then straightforward.

A feasibility study of the technique using a prototype Omega tube has been completed and has shown that this monitor is, in principle, capable of measuring the water cut over the full range from 0 to 100% within an accuracy of +/- 1.5% absolute. In the present design, however, the Omega tube is slightly affected by an asymmetry in the pressure measurements, as is shown in Fig. 2. This asymmetry is due to undeveloped velocity and pressure profiles, particularly at pressure tappings 1 and 4. These tappings are located within 2 diameters of the bends, while from flow-metering studies it is known that around 10 diameters are required upstream for complete flow profile development. This asymmetry results in incomplete compensation for the friction losses. Despite this imperfection the prototype Omega tube measures water cut within +/- 3% absolute (Fig. 3) over a range of liquid velocities from 0.6 to 1.5 m/s, equivalent in a 3-inch pipe to 1800 to 4500 bbl/day.

The increased scatter in the measurements around 40% water cut seen in Fig. 3 is caused by the flow profile effect being aggravated by the large increase in the viscosity of the oil/water mixture in the transition region between oil and water external emulsions. This can be seen more clearly in Fig. 4, in which the differential pressure measurements for the two legs of the Omega tube are plotted separately across the full range of water cut for four different liquid velocities. This viscosity increase makes instruments based on a single differential pressure measurement unreliable in the transition region even when velocity is kept constant, as opposed to the Omega tube with its inherent compensation for friction losses. Additional tests with an improved Omega tube are planned.

3. ALTERNATIVE MEASURING METHODS

Although a DP cell is probably the most practical instrument to use, other methods can be applied to derive water cut from the Omega tube.

One possibility that has been investigated is the replacement of the DP cell by a measuring tube connected between points A and B (Fig. 5). This measuring tube fills with liquid from the flowline via the bypass lines 1-5 and 2-4. When the water cut, and hence the density, in the flowline changes, the transport of both oil and water to and from the measuring tube continues until the static head in the measuring tube is equal to the new differential pressure between points A and B. Since the measuring tube is the same height as the distance between the pressure tappings in the flowline (1-2 and 4-5), the liquid in the measuring tube then has the same average density as in the flowline. Note that although a bypass to the main flowline is used, there is in this case no requirement for representative sampling. The process continues until equilibrium is reached. When a stable situation has been achieved, the liquid mixture in the measuring tube may separate and settle out into an oil layer above a water layer.

To ensure that the proper equilibrium is reached in the measuring tube, it is important to consider the difference in velocity heads at the inlets A and B of the measuring tube caused by the flow through bypass 1-5 being greater than through bypass 2-4. When this difference in velocity heads is not compensated, the average density of the liquid in the measuring tube is lower than the average liquid density in the flowline, causing an error in the water-cut determination. This problem can be eliminated either by keeping the liquid velocity in the bypass lines low, thereby inducing a long response time, or by installing impact tubes at the inlets to the measuring tube to compensate for the velocity head (see detail in Fig. 5a).

The water cut can be derived by directly measuring the average density of the liquid in the measuring tube, by using a densitometer based on Archimedes' principle, or an oil/water interface detector (for example, the STIC multi-capacitor interface detector from Enraf Nonius) when the oil and water separate rapidly and well. The densitometer recommended for this application obtains the liquid density from the buoyancy force on a displacer submerged in the liquid. It has the advantage that it measures the average liquid density over the length of the displacer irrespective of whether the oil and water are separated or not. The other technique, using an oil/water interface detector, has the advantage that the measurement represents directly the oil/water ratio or water cut in the flowline, provided the measuring tube and the flowline are at the same temperature.

4. CONCLUSION

The basic technique, irrespective of the actual measuring method, is very promising for liquid/liquid mixtures. The presence of gas, however, affects both the differential pressure measurement and the equilibrium in the measurement tube and should be avoided. This is a disadvantage for one of the envisaged applications at the emulsion outlet of test separators, since in some cases entrained gas, caused by gas carry-under or break-out, is present in these liquid streams.

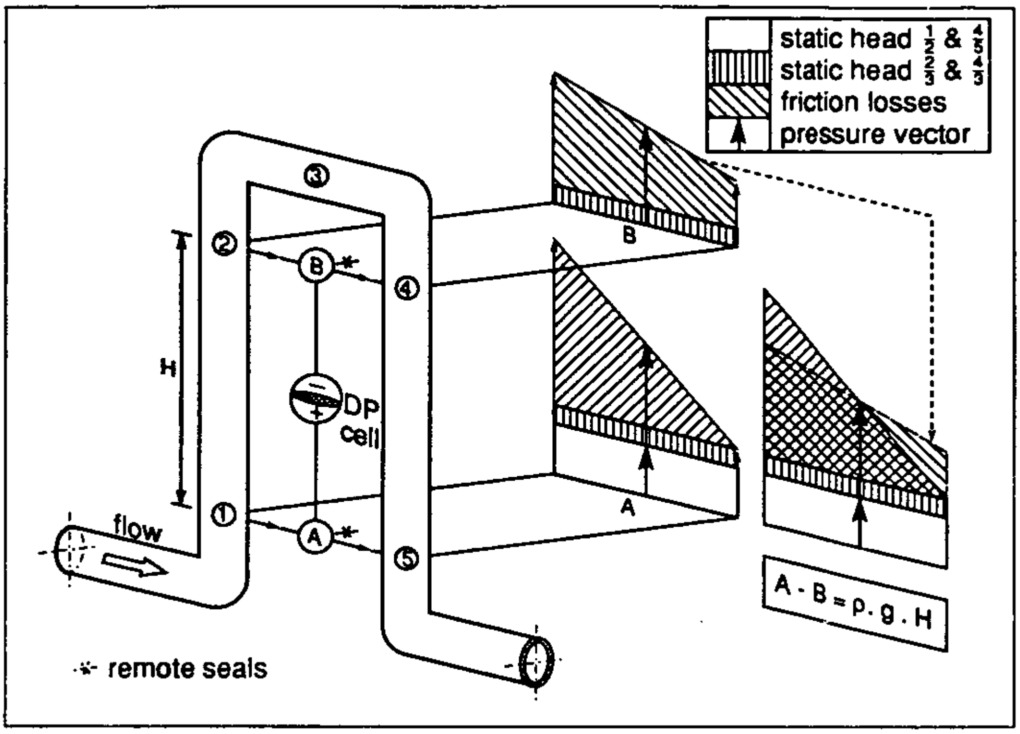


Fig. 1 Omega tube and its operating principle

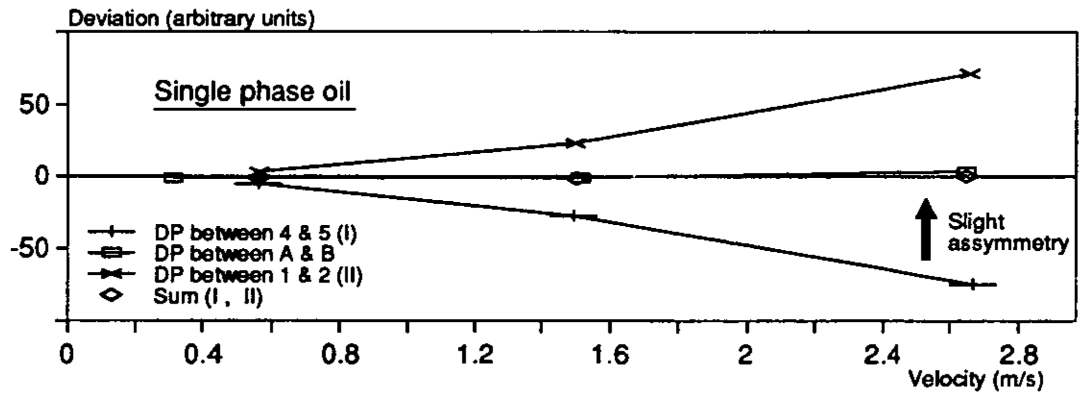


Fig. 2 Elimination of friction losses

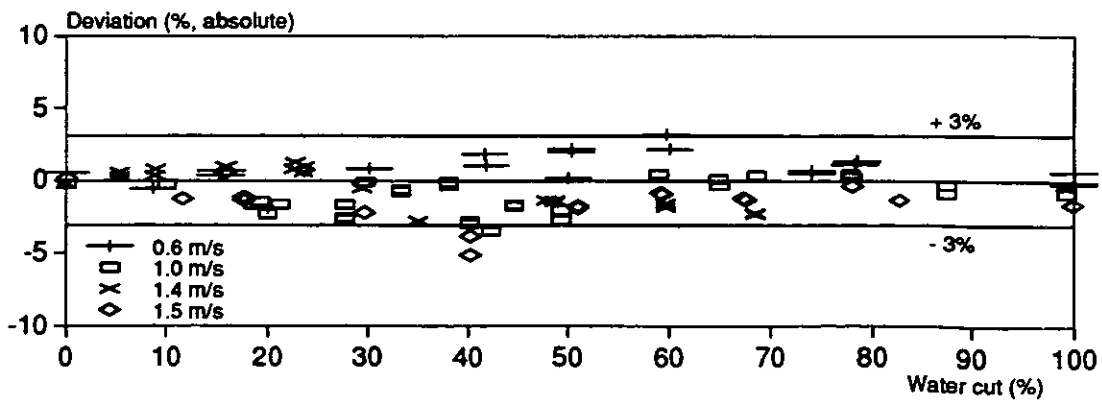
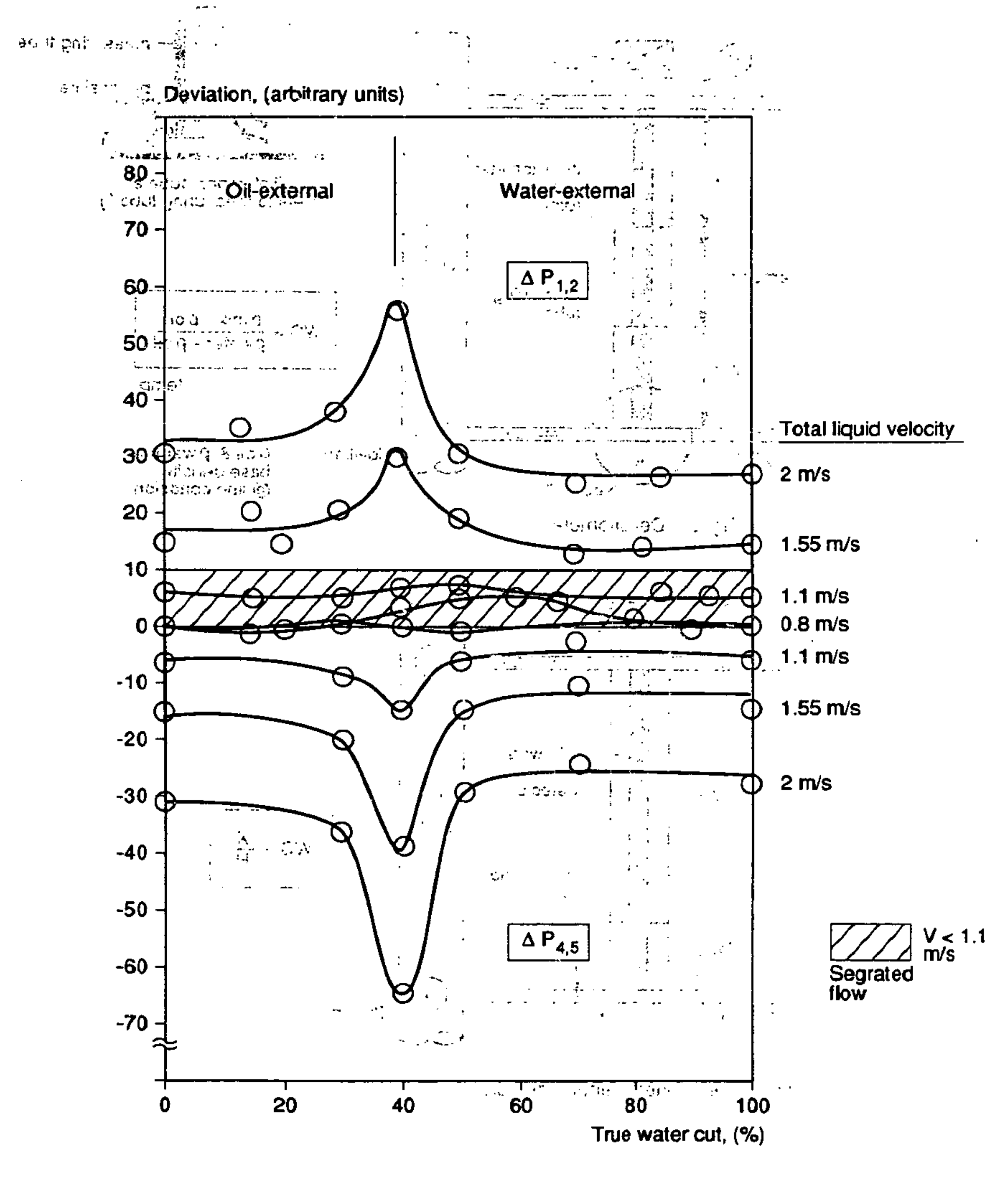


Fig. 3 Performance at different liquid velocities



Lines of constant velocity for different water cuts

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FIG. 4

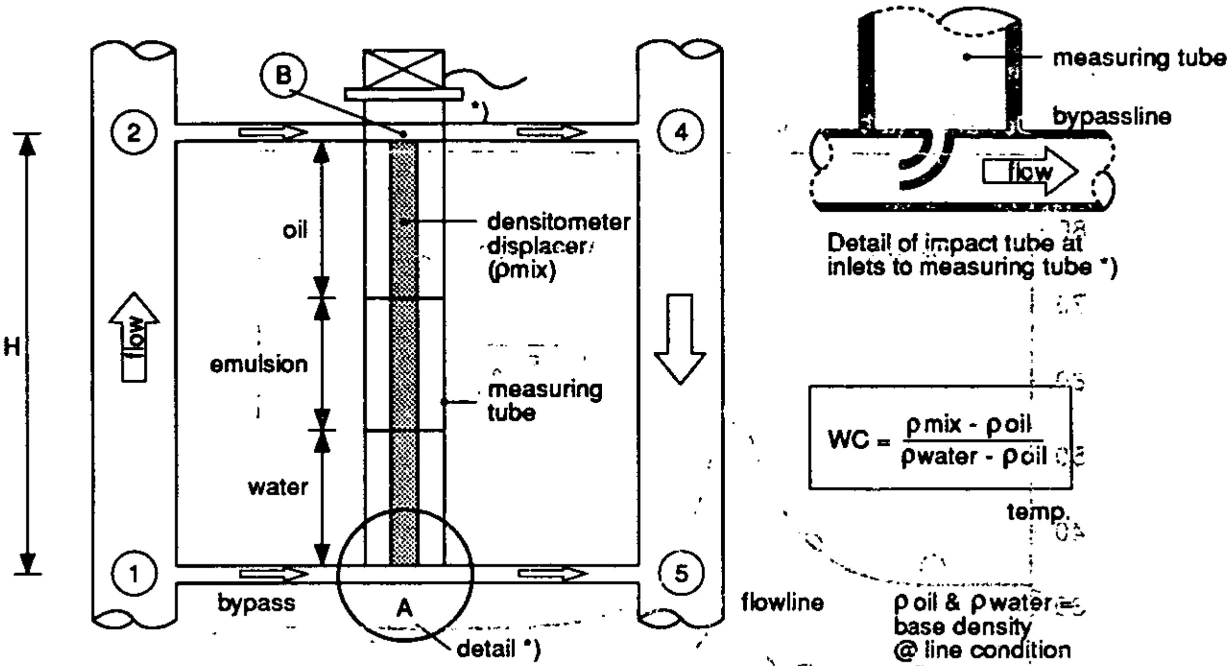

Fig. 5a Densitometer

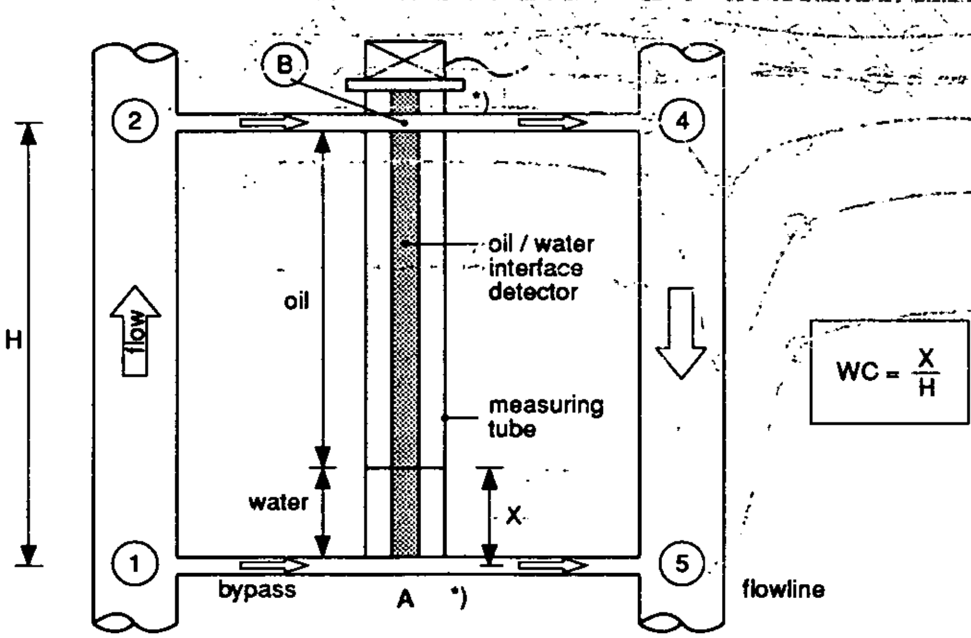

Fig. 5b Oil / water interface detector

Alternative methods for deriving the water cut (wc) from the Omega tube

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.