APPLYING VORTEX METERS TO WATERFLOOD MEASUREMENT

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INTRODUCTION

Accurate and timely information is necessary if oil-producing facilities are to be operated properly. The operation of oil-producing properties at the optimum degree of efficiency is rapidly becoming an absolute necessity in the present social, economic, and political climate. The rates and volumes of the oil production, produced water, well test, and injection water are all important parts of the required information. It is not reasonable to expect a high degree of efficiency without this information being available. This paper discusses one phase of the continuing effort to provide this information to the operating personnel in the best possible manner. This effort is in fluid measurement.

Several production units were formed in the Slaughter Field in Hockley and Cochran Counties in West Texas in the mid 1960's; they were placed under waterflood soon after the units were formed. Meters were installed as a part of the initial water-injection system. The injection lines were laid in a trunk and lateral system and, therefore, the individual injection-well meters are scattered throughout the field with a central remote readout capability. In the nearly 15 years since this metering system was installed, there have been technical advances in the art of metering, and economic conditions have also changed. A significant improvement in metering technology has been the development of sensing devices which make possible more positive detection of primary signals of low intensity. The economic changes have, of course, been the increased cost of equipment and labor. The cost that we are primarily concerned with is the one which we have the most control over: the cost of repair or maintenance. These two changing factors, coupled with the increasing importance of operational data, brought about the study of the application of the vortex meter as a possible improvement in metering systems.

PRINCIPLE OF OPERATION

The operation of the vortex meter is based on a natural phenomenon. As the name of the meter suggests, this natural occurrence is referred to as vortex shedding. The example nearly always given of vortex shedding is that of a flag waving. In this widely observed occurrence, the interaction of the air moving past the flag pole causes the flag to wave. (Figure 1). However, the vortex shedding principle can probably be better defined for our purposes in the study of the movement of water flowing past a stationary obstruction in a pipe. At low flow rates, the flow past a cylindrical obstruction is completely viscous and the water will move around the obstruction and return to its normal flow pattern as it moves downstream (Figure 2). Increasing the flow rate will cause the boundary layer of the water to separate symmetrically from the two sides of the cylinder and form two weak standing eddies. The boundary layer is described as the thin layer of fluid flowing next to the surface in which viscosity influences the flow. The layer outside of this boundary layer is considered to be frictionless and thus ideal in its flow characteristics. Further increase in the flow rate causes the eddies to break off and wash downstream. These eddy currents will break off first from one side and then the other in an alternating pattern (Figure 3). We know that this phenomenon was observed as early as the 15th century because of sketches made by Leonardo de

Vinci which depict the movement of vortices downstream from a barrier.

FIGURE 1

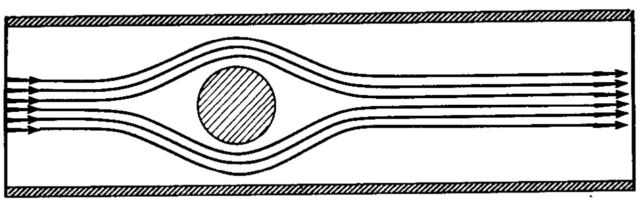

FIGURE 2

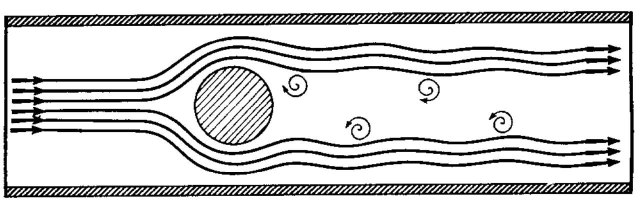

FIGURE 3

Near the end of the 19th century, the relation between the shedding of the eddies, or vortices as they are more commonly referred to, and the flow rate was identified. From experiments done by V Strouhal, the following quantitative equation was developed.

$$f = S_T \left(\frac{V}{L}\right) \qquad (1)$$

where:

f = frequency of shedding

V = velocity of the fluid

L = width of the shedder

S_T = Strouhal number (a constant)

Equation 1 shows the direct relationship of the frequency of the vortex shedding to the velocity of the fluid. For any given meter, the physical dimensions of the cross sectional area of the pipe or meter body and width of the shedder are constant. The volumetric flow rate equation, as follows, can be used.

$$Q = VA \qquad (2)$$

where:

Q = Volumetric flow rate

V = velocity

A = cross sectional area of the pipe

Equations 1 and 2 are combined to form an equation showing that the frequency of vortex shedding is proportional to the volumetric flow rate.

$$f = \frac{S_T\,(Q)}{LA} = K(Q) \qquad (3)$$

In equation 3, K is a constant and is the meter factor for each meter. This constant is dependent upon physical dimensions and is, therefore, subject to manufacturing tolerances. Next, both sides of equation 3 are divided by "time".

$$f/t = K(Q/t) \qquad (4)$$

The result is as follows.

$$H_z = K(Q/t)$$

where:

H_z = cycles per second

K = meter constant

Q/t = barrels per day

Equation 4 shows that the frequency of vortex shedding is directly proportional to the volume passing the shedder. This is the basis of vortex metering.

There is another characteristic of vortex shedding which is important. Von Karman analyzed the vortices as they broke off from the shedder and washed downstream. His extensive studies resulted in the documenting of the well known pattern refered to as the "Karman vortex trail" (Figure 3).

In this pattern, which the experimentation showed was formed downstream of the shedder, the vortices are shed first from one side and then the other. His analyses showed that there is only one spacing of these vortices which is stable for any particular flow rate. This fact enables us to have a device which not only sheds the vortices at a given frequency for a particular flow rate, but is linear over a range of different flow rates. Therefore, a meter body consists of a pipe of a specific cross-sectional area; a shedder consisting of a stationary obstruction of a given shape and width; and a sensor consisting of a device for detecting the frequency of the vortices being shed (Figure 4).

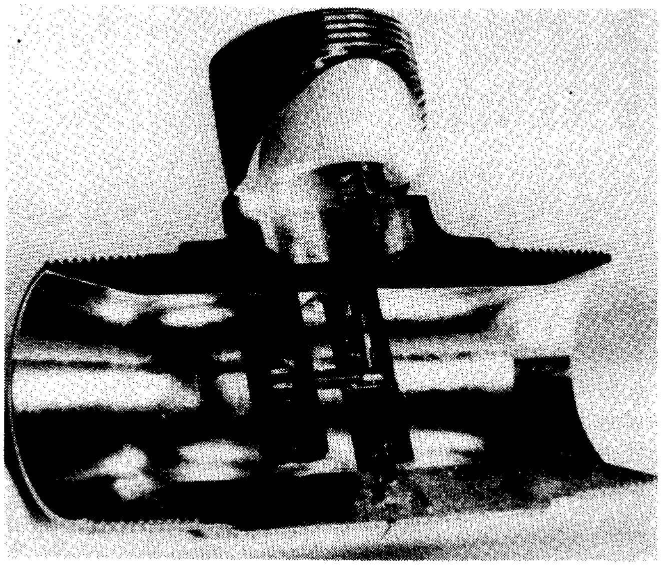

FIGURE 4

Several other considerations are required for practical application of this theory.

First, the intensity of the vortices is affected by the shape of the shedder. If the shedder were a streamlined barrier, very small eddies are formed. If the shedder were a flat plate, an unstable turbulent flow pattern is created. Thus the design of the shedder requires a shape that will cause formation of a vortex trail of as high an intensity as practical without causing instability. The method used to detect the vortices will also influence the shape of the shedder (Figure 5).

Second, the shedding occurs in a linear manner only when the Reynolds number is above a certain minimum. Below this Reynolds number, the frequency is not directly proportional to flow and cannot be measured accurately. The critical flow rate for water has been found to be about 7 gpm in a 2-inch pipe (or, having a Reynolds number of approximately 10,000). This requirement of the flow rate being of a sufficient velocity to cause the meter to be above a minimum Reynolds number is the reason that viscosity is said not to affect the measurement. Actually, viscosity affects the minimum flow rate for any given meter. Since the Reynolds number is inversely proportional to the kinematic viscosity, an increase in viscosity causes the Reynolds number to decrease, and thus an increase in flow rate is necessary to keep the Reynolds number above the minimum required for obtaining accurate measurement. For most liquids, the kinematic viscosity is inversely proportional to temperature. This is usually not an exact linear relationship, but needs to be considered particularly if oil and water are being measured through the same meter. This might be the case on a well test meter where total well production was being determined.

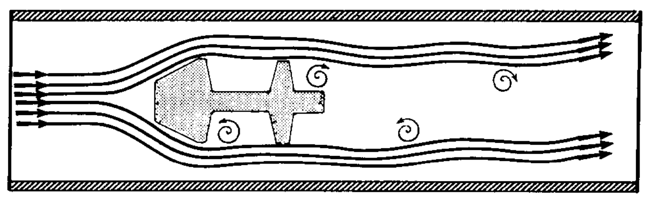

FIGURE 5

Third, after good vortex shedding is obtained, a reliable sensor is necessary to detect the frequency of shedding. There are a number of different methods in common use to detect the vortices. The vortices, as they are shed, form an alternate pattern of high and low pressure cells as they pass downstream. This pressure differential is detected by most sensors. The energy level is normally quite low even with good shedders. Thus the measurement requires a method of detecting a very small pressure change. A piezoelectric crystal responds to changes in pressure with a change in emf. The pickup on a record player is an example of this device. A strain gauge responds to changes in pressure with a change in resistance. A thermistor is a device for detecting the temperature changes which occur concurrent with the vortices. There are also methods which measure mechanical movement with proximity switches. These different devices are all based on sound principles; thus, the merits of each is strongly dependent on methods of physical mounting and methods of quality control in manufacturing.

After the vortex frequency has been detected, a certain amount of signal conditioning is necessary. The signal conditioning is done electronically. The electronic circuits usually provide for amplification of the basic signal, then shaping, and finally counting the frequency of vortices. The readout is for the purpose of giving a useable engineering value to the meter reading. The readout can be obtained as digital, which would usually be counts per barrel, or it can be analog. The analog signal is a current or voltage output which is proportional to volume. The analog signal can be read with a voltmeter or ammeter which has been properly scaled to represent gallons-per-minute or barrels-per-day. In a growing number of installations, analog to digital converters are being used. These are especially common in installations which utilize computer-oriented data-acquisition systems. Of primary importance in the signal conditioning is the filtering and amplification which is necessary to provide a signal-to-noise ratio which eliminates extraneous noise and faithfully reproduces the correct frequency. Additionally, the electronics should be stable over the normal range of temperatures. The components should be protected against moisture and hydrogen sulfide. The normal precautions of lightning protection are required.

FIELD TESTING

These foregoing principles of operation have been laboratory tested and proven to be true by many scholars. The work is well documented in textbooks and technical publications. However, the application of the vortex meter to the uncontrolled and often hostile environment found in oilfield measurements has not been so widespread. The vortex meter has been tested by several operators for use in gas measurement, and it has proven to be satisfactory.

In the measurement of water volumes, however, my organization's first field installation was made in May of 1974 (Figure 6). This meter was placed in service in a San Andres battery in the Slaughter Field. The fluid to be measured was the produced water. Sufficient information was to be collected to determine the practicality of vortex metering. The specific purpose of the initial test was to determine what effect the field environment would have on the physical characteristics of the meter and what effect the fluid would have on the accuracy of measurement.

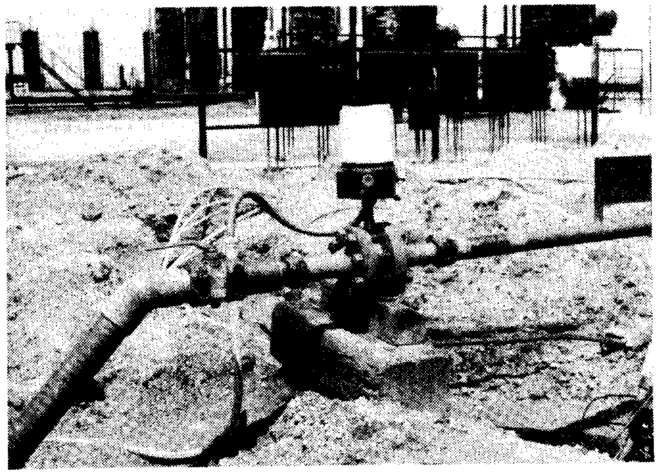

FIGURE 6

The fluid measured was brine water with some entrained hydrogen sulfide. The meter was located about 12 feet from a centrifugal pump on the discharge line. This meter was left in service for 6 months and then removed for inspection. The meter was thoroughly checked for any evidence of corrosion and erosion. There was no mineral buildup of any sort, nor was there any pitting of the surfaces inside of the meter. We also checked the shedder for any change in dimension or shape which would affect the frequency of vortex shedding and we found no change. Thus the meter passed the first test of its physical suitability for operation in an oil field environment. In this first test the instantaneous and daily rates were recorded, but no method was provided for checking the measurement against a known volume.

The second phase of the testing was to install a meter in injection-water service. This was done to determine the accuracy of the vortex meters in comparison to the turbine meters which were installed in the initial system. The turbine meters have undergone exhaustive testing in the past and their accuracy has long been considered to be acceptable for waterflood applications. The test vortex meter was installed on the East Mallet Unit WIW 48 in February, 1975. The East Mallet Unit had used a computer-controlled data-acquisition system for several years. This system provided an excellent tool for monitoring the rates measured by the vortex meter and the turbine meter which were in the same line. Examination of the daily and instantaneous rates for 90 days indicated that the accuracy of the two meters was comparable. Also, it was recorded that changes in water rates and pressures had no adverse effect on the vortex meters ability to accurately read rates. Noise generated by hydraulics, mechanical devices, or electrical sources under normal operating circumstances did not adversely affect the measurement. It was later determined at other locations that hydraulic and mechanical noises can be a problem and the vortex meters should not be located in sites which have high levels of vibration such as the discharge of positive displacement pumps. This comparison test was continued for six months.

After approximately sixty days of monitoring the test meter installation on WIW 48, it was decided that a more extensive test was warranted. One of the features that was undesirable in the first two installations was the physical installation of the meter in the meter run. The meters were built for flange mounting which did not lend itself very well to water injection service. The injection service is usually high pressure; however, the more conventional threaded body style of the turbine meter lends itself to a much more convenient installation. A meter utilizing unions is much easier and less costly to install and maintain. Therefore, when the test were expanded, a different body style was proposed. A prototype was built and installed in September, 1975. One prototype meter was installed on the original WIW 48 to continue monitoring at the same site (Figure 7). One meter was installed on WIW 25 which was an injection well that had a history of stoppage of the turbine meter because of foreign objects in the water. And the third meter was installed at a well test site No. 1 on the F.L. Woodley Lease.

Lightning damaged one of the electronic readouts in the first month and both meters were taken out of service for a few days to permit installation of a newer version of the electronic signal-conditioning board. These two meters have been in satisfactory service now for 18 months. Twice in the first 12 months of operation, the turbine meter on WIW 25 ceased to function because of foreign objects in the meter, but in both instances the vortex meter

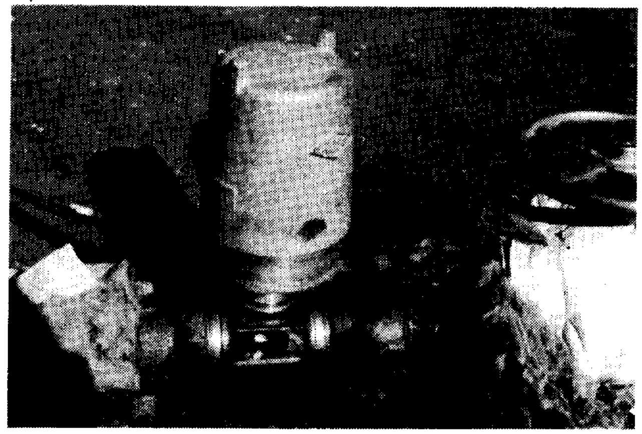

FIGURE 7

continued to measure accurately. Delivery of an additional 23 meters for installation on water injection wells in the Slaughter Field was begun in January, 1976.

DISCUSSION

The accuracy of measurement of the turbine-meter system that has been in use for many years was not an issue in the study. Many people have spent a lot of time and effort to establish the acceptability of turbine meter measurement. Therefore, one of the guidelines in this test was to ascertain that the accuracy of the vortex meter was at least equal to that of the turbine meter. When properly applied, the accuracy was found to be equal. The primary object of the test was to determine if the maintenance of the vortex meter could be expected to be less than that of the turbine meter. It was anticipated that it would be since it has no moving parts. As of this date, no mechanical maintenance has been required on any vortex meter. A few meters have been cleaned, including one which was accidently plugged with grease during installation. Principal problems have been related to the electronic signal conditioning and readout. These problems were not directly related to the vortex meter itself. In most installations the operating expense has been found to be considerably lower. The use of the vortex meter is not expected to be the solution to all metering problems. Like all meters, the vortex meter has its good features and its limitations. Applications which have flow rates which cause a drop below the minimum Reynolds number definitely do not permit satisfactory performance. Installations which have large amounts of vibration or other noise interference will have difficulty in obtaining good results. Our tests will be continued and expanded into other areas. The best features of the meters are accurate measurement with a reduced operating cost. These meters are now being installed in several new locations. The conclusions from the field test are that when prudent attention is given to the application, the vortex meter will provide the accurate water measurement required by the operating personnel and thus contribute to the overall improvement in operating efficiency.

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