NET OIL METERS: A MEANS OF IMPROVED PRODUCTIVITY AND PRECISION

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A net oil meter has been developed that provides accurate measurement of the water and oil fractions and production rates of oil/water emulsions. The net oil meter incorporates integral mass flow rate, density and temperature measurements in a single package, coupled to a powerful microprocessor based transmitter. This transmitter is designed for easy installation in the oil field and on off-shore platforms. The net oil meter provides both improved productivity and precision.

The equipment simplifies net oil measurement with more results, and includes automatic well testing. Calculations are obtained for the following:

- % water cut
- emulsion flow rate
- water flow rate
- oil flow rate
- total oil production
- total water production
- test time
- total emulsion
- emulsion density
- temperature

The net oil meter operates on the basis of the Coriolis principle. The basic flowmeter and theory of operation is discussed below.

THE BASIC NET OIL METER: THEORY OF OPERATION AND PRODUCT DESCRIPTION

While mass flowmeters operating on the basis of Coriolis principles are becoming more abundant each year, a brief review of the fundamental principles may be in order since this is a relatively unfamiliar technology. The net oil meter consists of two helically formed loops joined in a flowsplitter/ flowcombiner, as shown in Figure 1. The fluid/oil flows in a hydraulically parallel fashion through the loops which are driven at their natural frequency by a coil/magnet drive assembly mounted at D1-D2.

The basic principle employed to determine mass flow is a special case of Newton's second law:

$$F = ma \qquad (1)$$

The special case concerns the forces acting on an object in a rotating co-ordinate system. An object of mass m moving with a velocity V in a frame of reference rotating with an angular velocity w experiences a Coriolis force F given by:

$$F = 2mV \times w \qquad (2)$$

where X is the cross product operator.

The Coriolis force on a moving particle is perpendicular to both V and w.

Consider the conduit shown in Figure 2, rotating at angular velocity w about a pivot point at the end of the conduit. Each mass element is subjected to a Coriolis force F according to equation (2) which acts against the wall of the conduit, perpendicular to the conduit. The mass flow rate dm/dt of a fluid of density P flowing through the conduit of cross section A with a velocity V can be expressed as:

$$dm/dt = \quad AV \qquad (3)$$

By combining equations (2) and (3), the mass flow rate can be expressed:

$$dm/dt = F / 2\, w\, L \qquad (4)$$

Now consider again the flowmeter in Figure 1, and more particularly, one of the helically formed flow tubes shown in Figure 3. As the tube is vibrated by the coil/magnet assembly, Coriolis force couples represented by AC and EB are produced when mass flows through the tube. The super-position of the motion caused by these forces couples and the drive motion of the conduits causes a phase difference to exist between the spatial motion of C1 and C2 and E1 and E2 in Figure 1. Coil/magnet assemblies mounted at these locations produce signals which are processed by an electronics package which contains a microprocessor. It can be shown from the fundamental principles that the relationship between the phase shift and the mass flow rate has the form:

$$\frac{dm}{dt} = \frac{K \quad Y \quad (t)}{fD} \tan\,(\Delta\theta - \Delta\theta_o)$$

where:

K = a coefficient that contains the meter calibration factor, scale factors and units conversion, and other proportional factors.

$\Delta\Theta$ = measured phase difference in radians

$\Delta\Theta_o$ = measured phase difference in radians under no flow conditions

fD = natural frequency of the twin loop structure in the "drive mode"

Y(T) = the elastic modulus or "spring constant" of the helical loops that depends on the absolute temperature T

The phase shift is measured by well known techniques. Note that the mass flow rate determination is independent of fluid density, temperature, viscosity or flow patterns.

DENSITY DETERMINATION

Since the natural frequency of the helical tube structure is measured to determine the phase shift used in the calculation of the mass flow rate, determination of the fluid density is a relatively straightforward task which is also performed by the manipulation of the equation

$$fn = \frac{1}{2\pi}\sqrt{\frac{K}{M}}$$

By processing the density measurement using the micro-processor based system, an emulsion density can be determined.

EMULSION MEASUREMENTS

There are a number of applications where emulsions of oil and water are transported in pipes and it is desirable to know the fraction of water and oil in the emulsion. Often, the fraction is changing dynamically in a relatively short period so that periodic laboratory analysis of the emulsion is not practical.

The microprocessor in the transmitter of the EXAC Net Oil Meter has been programmed to use the measurements of temperature, density and mass flow rate that are a standard part of the flowmeter to serve this application. The solution is essentially a three step process which, because of the computational speed of the computer, can be considered to be happening continuously.

Before being put into operation, the user must enter certain data into the data base. This is done either through the front membrane switch panel of the transmitter shown in Figure 5, or over the RS422 data link. These data includes:

- oil density
- water density
- oil expansion coefficient
- water expansion coefficient
- the temperature at which the oil and water densities were taken.

The steps the program executes are as follows:

1. Using the measured temperature, the instantaneous emulsion density is determined using the formula:

$$\ell = \beta_o[1 - \beta(T - T_o)$$

where:

ℓ = measured density
ℓ_R = reference density
β = coefficient of expansion of the constituent
T = measured temperature
T_o = reference temperature for the reference constituent density

2. Using the calculated densities, the water mass flow rate is calculated using the expression

Water mass flow rate:

$Mw = Me$ Pounds per minute

Where:

$\dot{M}e$ = emulsion mass flow rate
$\dot{M}w$ = water mass flow rate
$\dot{M}o$ = oil mass flow rate

ℓe = measured density emulsion
ℓw = calculated density of water
ℓo = calculated density of oil

3. Using the calculated water mass flow rate; the oil mass flow rate, current cut, average cut, water volumetric flow rate, oil volumetric flowrate can be calculated using the total emulsion mass flow and density measurement from the flowmeter.

Oil mass flow rate:

$\dot{M}o = \dot{M}e - \dot{M}w$ Pounds per minute

Current Cut

Current cut is instantaneous and is calculated by dividing the instantaneous water volumetric flow rate by the instantaneous emulsion volumetric flow rate X 100%.

Average cut

Average cut is calculated from the instant the reset total button is pushed. Average cut is determined by dividing the total water volume by the total emulsion volume.

Water volumetric flow rate

The water volumetric flow rate is determined by dividing the mass flow rate of water by the density of water multiplied by 4.116 barrels per day.

Oil volumetric flow rate

The oil volumetric flow rate is calculated by dividing the oil mass flow rate by the oil density and multiplied by 4.116 barrels per day.

4. All of the measured and calculated information is available at the operator display and as digital information over the RS422/485 data link.

Since oil production is usually a mixture of oil, water and gas, this net oil meter requires that the gas be removed in a gas separator prior to the measurement.

NET OIL METER USE WITH MULTIPLE WELLS

A single net oil meter has the capability to measure up to 24 separate wells. The net oil meter can store and use up to 24 separate water and oil densities, water and oil coefficients of expansion, and a reference temperature.

A user may therefore measure 24 wells each with entirely different oil and water densities.

Values may be entered either directly through the meter's front keyboard or remotely via the RS422/485 serial port.

OTHER/PREVIOUS METHODS OF MEASURING NET OIL

The net oil meter is a sound replacement of other currently used methods of measurement. The net oil meter provides cost savings in terms of lower installation costs and lower overall operating costs.

This is best illustrated in a discussion of other meter types.

For example, the turbine meter requires an extensive amount of maintenance. Problems occur due to scaling and the necessity to "mix and match" parts to ensure that the turbine meter continues to work. In contrast, the EXAC Net Oil Meter has no moving or intrusive parts thus eliminating potential to scale up and fail.

Turbine meter bearings tend to wear quickly in the harsh environment to which they are typically placed.

Turbine meters also require a freewater knock-out. This defines the turbine meter as a costly purchase and expensive operating equipment.

The EXAC Net Oil Meter requires only a two-phase separator. There is no requirement for a costly three-phase separator.

The net oil meter also represents cost savings when contrasted with capacitance type meters.

In order to function accurately, capacitance type meters work well with low (small) water cut. Any variance in oil/water dramatically affects the performance of the probe in a capacitance type meter. The EXAC Net Oil Meter produces accurate measurements for a range of cuts.

Capacitance type meters are affected by temperature changes. Temperatures will vary from well to well. The net oil meter adjusts for temperature differences from well to well by using correction through the micro processor for elasticity of the tubes, as well as correction for density measurement.

A final example in contrasting performance is the previous method of attempting to make a cut measurement by taking a sample from the pipe stream into a beaker. This method was not representative of the actual cut, as it did not account for the entire emulsion flow in the pipe at any given time. Cut measurement by this practice was therefore highly inaccurate.

NET OIL METER: USER TESTIMONIALS

TEST RESULTS

Tests were run on five wells at an oil field in the Western United States. These wells produce high water fractions because of secondary recovery efforts in this field. The oil and water densities were:

water = 1.031 gm/cc
oil = 0.813 gm/cc = 42.5 degree API
reference temperature - 101 degrees F.

The test set up was as shown in Figure 4. The emulsion mixture consisting of the oil, water and gas was first run to a gas separator where the entrained gas was separated from the emulsion. An EXAC Net Oil Sensor was installed in the discharge of the separator with a snap acting dump valve downstream of the meter. The downstream valve maintained pressure in the sensor to prevent dissolved gas from coming out of solution and effecting both the flow rate and density measurements.

Test results are shown in Table I. The test well production had water cuts (water fraction expressed as percent water by volume) of from 92.2% to 99.9%. The average error in determining the water fraction was 0.7% with a deviation of from +2.0% to -0.9%. The determination of total volume produced was within 0.9% with a deviation of from -2.2% to +0.2% for all of the test runs.

It was noted during the testing that the water/oil mixture was not homogeneous but was more of an agglomeration of oil in water. The test results demonstrate the meter's capability of integrating results from non-homogeneous emulsions.

In a second example, the results of a net oil meter test were also quite encouraging. (See Figures 5, 6, 7). Meter accuracy was +/- 0.01 gm/cc, representing a +/- 5% water cut. Note that resolution is more important than accuracy in this example. The resolution of the results of the net oil meter is +/- .003 gm/cc.

EXAC Net Oil Meters are being used to determine well efficiencies, well profiles, and lease allocations.

LIMITATIONS

The net oil meter is not conducive for all applications. The following examples indicate limitations to this procedure:

1. <u>When gas is present:</u>

   - Total oil registers increase, because the density is low, and would therefore indicate 100% oil flow or 0% cut.

   - Total water is decreased (due to same procedures as above).

   - Total emulsion registers minor volumetric effect due to changed density measurement, but shows no effect on mass measurement.

2. <u>Limitation on less than 20 degree API oil</u>:

   - Due to the lack of the density difference between oil and water
   - This affects the resolution of the differential measurement of density for net oil calculations.

3. <u>Limitations of carbon dixoide in emulsion:</u>

- In addition to those limitations stated in #1 above (regarding presence of gas), carbon dioxide applications are further limited by the tendency of CO2 to remain in the solution through the separator.

INDUSTRY TRENDS AND CUSTOMER NEEDS

EXAC Corporation believes that customer feedback is the most important element in defining future oil industry trends for oil field instrumentation. Our products are designed to meet your needs in the oil field. Customer feedback establishes the very direction of our product development.

Our net oil meter is indeed a direct reflection of your ideas.

For example, one customer was concerned with the complexity of his operators having to monitor and record 4 displays. We responded by making use of 4 function keys on the keypad - enabling all required displays to be shown at the push of a single button.

A continuous effort is devoted to exploring ways of further increasing the accuracy of net oil measurement. Density accuracy is a particular issue being addressed by our engineers.

Efforts toward product improvement continue even though the EXAC Net Oil Meter is the most accurate, and best available flow measurement device in the world today.

Our application and support group is currently working with a number of major oil companies by incorporating our net oil meter into automatic well testing along with programmable logic controllers and remote transmission units.

New applications for the net oil meter are also being addressed, i.e. offshore net oil applications as well as mass measurement for mud drilling work.

Net oil meters are clearly a means of improved productivity and precision in the oil field today, and the EXAC Net Oil Meter is also shaping the improved measuring procedures of tomorrow.

Table I
Test Results

WELL NO.	TEST NO.	EXAC TOTAL EMULSION Bbl	OIL Bbl	WATER Bbl	CUT %	Test Tank TOTAL EMULSION Bbl	OIL Bbl	WATER Bbl	CUT %	ERROR % CUT %	TOTAL EMULSION Bbl
U -12	1	151.46	0.45	148.00	99.0	148.38	0.13	148.25	99.9	0.9	-1.4
T -12	2	100.70	1.40	99.32	98.6	100.95	1.05	99.90	98.9	0.4	0.2
U-08, U-09	3	51.64	0.38	51.40	99.3	51.42	0.84	50.58	98.3	-0.9	-0.4
U-12,T-10	4	51.06	1.02	50.00	98.0	49.95	0.63	49.32	98.7	0.8	-2.2
U-12,T-10	5	61.38	3.69	57.70	93.6	60.80	3.78	57.02	93.4	-0.3	-1.0
T-10	6	49.63	4.35	45.25	90.4	49.32	3.57	45.75	92.2	2.0	-0.6
		465.87	12.30	451.67	97.1	460.82	10.00	450.82	97.8	0.7	-0.9

Densities at 121 Degrees F

Water - 1.031
Oil - 0.813

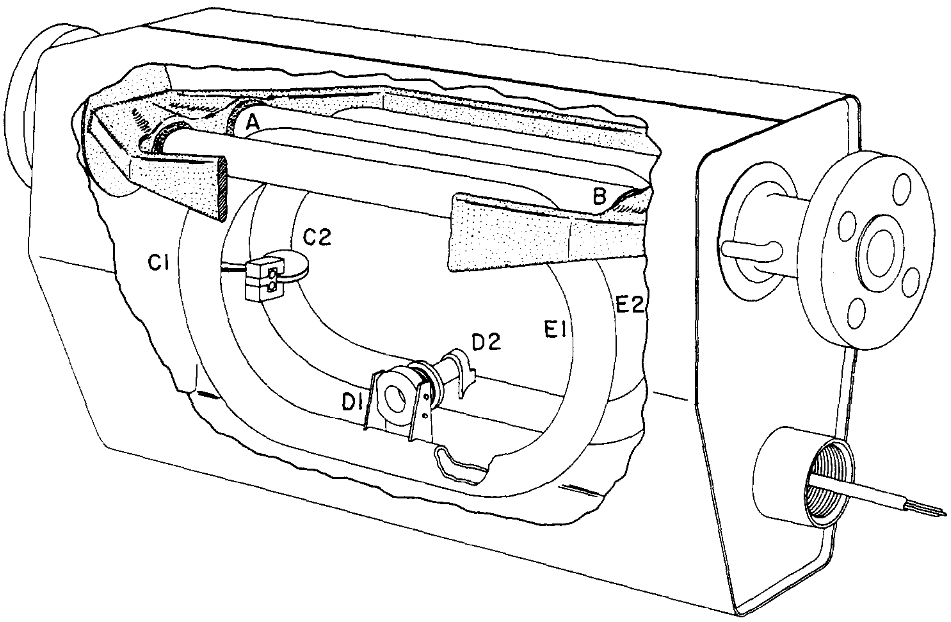

Figure 1 - Net Oil Meter —
cutaway drawing

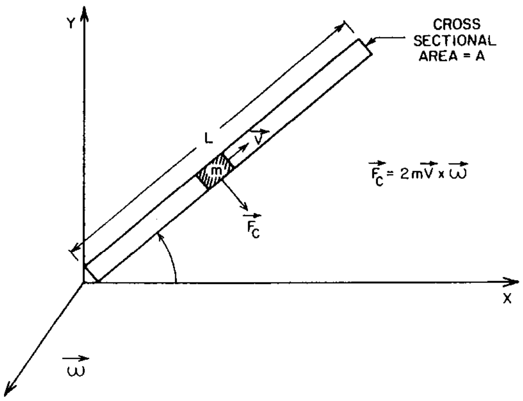

Figure 2 - Forces acting on net oil meter tube

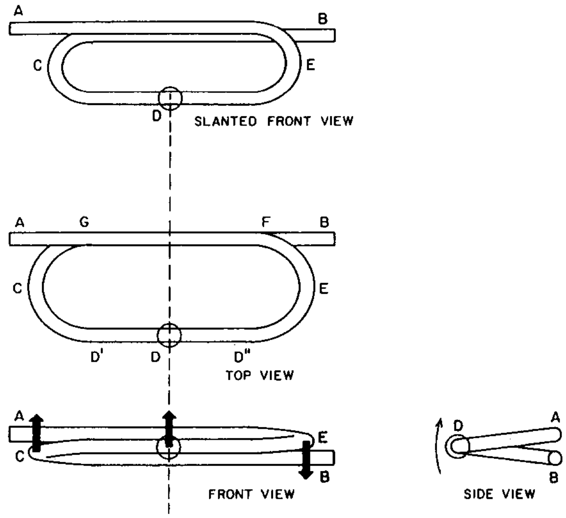

Figure 3 - Complete helical loop

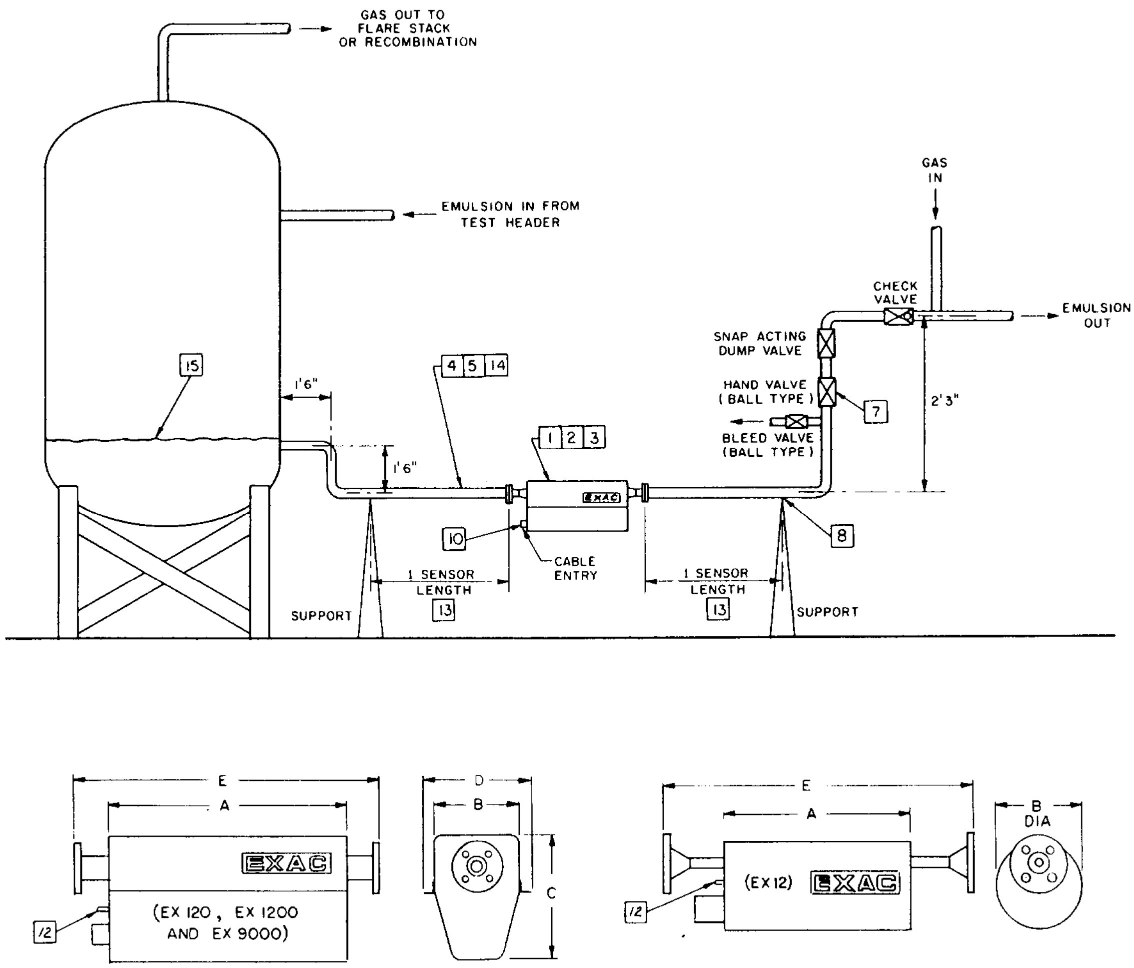

Figure 4 - Typical installation

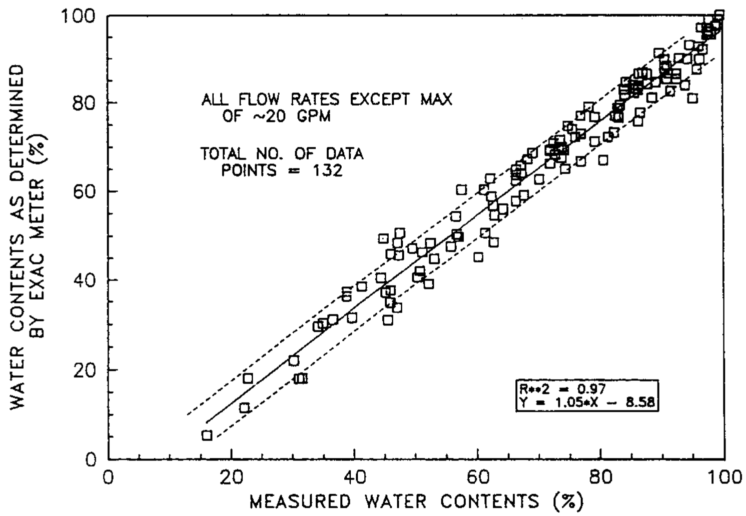

Figure 5 - Water content measurement comparison

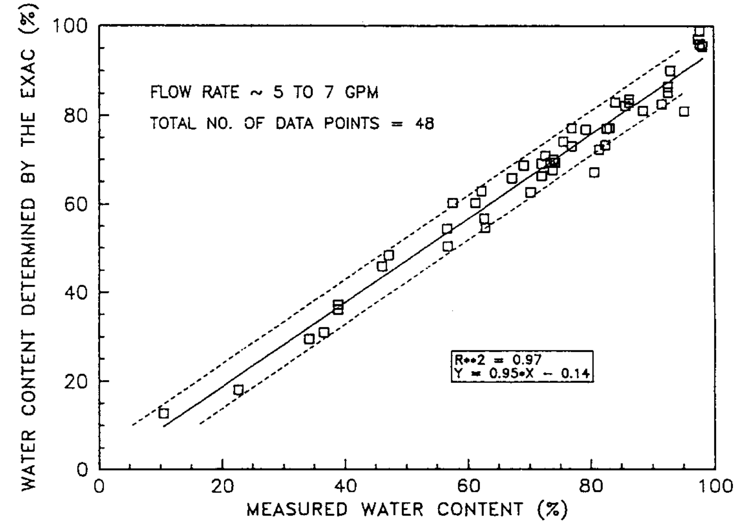

Figure 6 - Water content measurement comparison

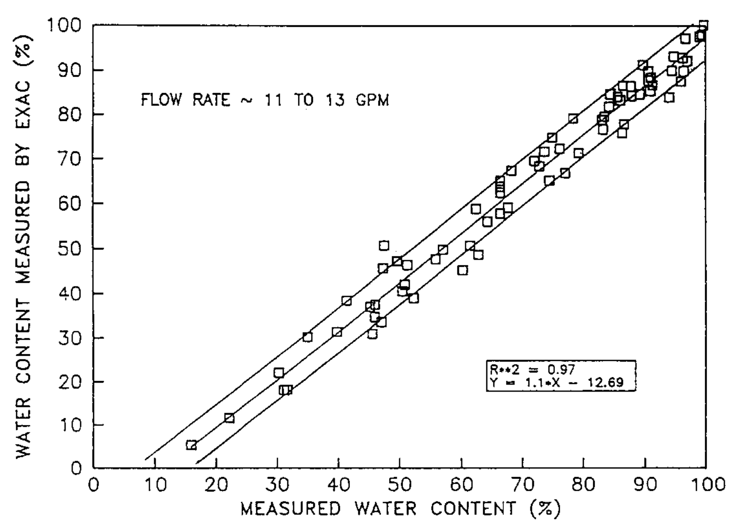

Figure 7 - Water content measurement comparison