Factors Influencing the Allocation Measurement Computation Procedure of Water-Cut Crude Oil

Yixin Sun[1], Zhi Cao[2]

[1]Emerson Process Control Co.LTD, No.10 Jiu Xian Qiao Road, Chao Yang District, Beijing, China
[2]Offshore Oil Engineering Co.LTD, Tianjin, China
E-mail: sunsea1027@foxmail.com

Abstract

Water-cut crude oil has a great influence on crude oil trade measurement. The accuracy of oil volume in water-cut crude oil is closely related to the interests of both buyers and sellers. In this paper, the computation procedure based on API20.1 is analyzed in order to assure one more accurate metering method for the volume of oil. This paper uses the data from one metering skid to discuss the influence effect of different factors involved in the computation procedure. The analyzed factors include the density of crude oil/water mixture at metering conditions, volume fraction of water in the crude oil/water mixture at metering conditions, shrinkage correction factor of crude oil, and temperature at metering conditions. Analysis results show that the factors did not have an equal effect on the calculated volume of oil. The density has the least influence range on the oil volume of water-cut crude oil. The temperature is the least sensitive factor. The volume fraction and shrinkage correction factor need to pay more attention to because the calculated volume of oil is highly sensitive to these two factors.

1. Introduction

One of the most important activities in the oil industry is the measurement of the volume of oil produced, processed, transported, and commercialized, which directly affects the economy. The reliability in reaching this metrological activity is very important for all companies that operate the whole value chain. But the oil quality is varied widely according to the amount and type of containment. One most common containment is water. To obtain the purpose that all parties are treated fairly, the allocation measurement used in most stages of the chain is very important.

This paper briefly describes the allocation computing procedure for crude oil containing 0~10% water. The related factors, including the density of crude oil/water mictmixturemetering conditions, the volume fraction of water in the crude oil/water mixture at metering conditions, the shrinkage correction factor of crude oil, and temperature at metering conditions, are analysed to find out the relationship with the volume of oil.

2. General Overview

This paper takes one water-cut crude oil metering skid as an example to explain how to achieve the allocation computing procedure.

2.1 Consist of Measurement System

The metering system for the water-cut crude oil is based on a Coriolis Flowmeter which also includes a flow computer, sensors/transmitters for measuring the absolute pressure and temperature of the fluid [1], and a Water-cut analyzer. An online, continuous measurement value of water content in an oil/water mixture under flowing conditions is provided by the water-cut analyzer. All these instruments are mounted on one integrated skid.

Figure1 illustrates schematically the main components of the metering system for the water-cut crude oil.

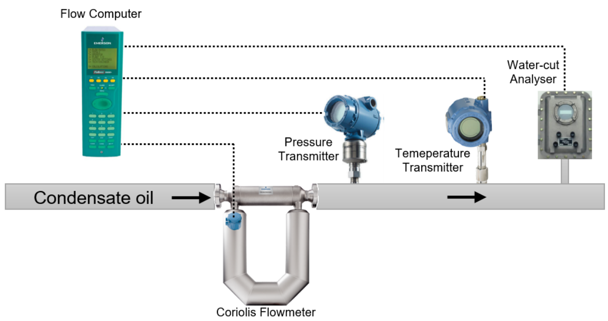

Figure 1. Water-cut Crude Oil Measurement System

The Instruments applied in this system are below：

Coriolis Flowmeter: Emerson Micro Motion, CMF300H;

Flow Computer: Emerson Floboss S600+;

Pressure Transmitter: Rosemount 3051T;

Temperature Transmitter: Rosemount 644H;

Water in cut Analyzer: Phase Dynamic,0~10% water in oil.

3. Equation in use

3.1 Equation introduce

This paper adopts the computing procedure based on API MPMS Chapter 20.1 Allocation Measurement [2]. This Standard defined the types of equipment used, the typical design of measurement facilities, and the typical operating procedures used for allocation measurement.

For the metering system configurated as Figure 1, the procedure for liquid petroleum quantity measurement by mass flow meters is applied. Since there is one on-line water-in-cut analyzer which could provide a continuous measurement of water cut in the crude oil, procedure A is determined to be adopted for this metering system.

The equation (1) is the standard equation of procedure A to compute the volume of oil in an oil/water mixture:

$$V_{o,st} = C_{uf} \times (M_e/D_{e,m}) \times MF \times (1 - X_{w,m}) \times CTL_{o,m} \times SF \quad (1)$$

Where:

$V_{o,st}$	=	volume of crude oil corrected to stock tank conditions.
C_{uf}	=	conversion units factor.
M_e	=	Mass of crude oil/water mixture indicated on the flowmeter
$D_{e,m}$	=	density of crude oil/water mixture at metering conditions.
MF	=	meter factor of the mass flow meter
$X_{w,m}$	=	volume fraction of water in the crude oil/water mixture adjusted to meter conditions
$CTL_{o,m}$	=	temperature correction factor of crude oil at meter conditions
SF	=	shrinkage correction factor of crude oil

3.2 Computation Procedure

The main steps for the computation is：

a. Determine volume correction factor of crude oil at metering temperature, $CTL_{o,m}$. Refer to API MPMS Chapter 11.1, Table 54A [3].

b. Determine density of crude oil at metering temperature, $D_{o,m}$.

$$D_{o,m} = D_{o,st} \times CTL_{o,m} \quad (2)$$

c. Determine volume correction factor of produced water at metering temperature, $CTL_{w,m}$. Refer to API MPMS Chapter 20.1, Appendix A.

d. Determine density of produced water at metering temperature, $D_{w,m}$.

$$D_{w,m} = D_{w,st} \times CTL_{w,m} \quad (3)$$

e. Compute density of oil/water emulsion at metering condition, $D_{e,m}$.

$$D_{e,m} = D_{o,m} \times (1 - X_{w,m}) + D_{w,m} \times X_{w,m} \quad (4)$$

f. Compute net volume of the crude oil.

Since the density of the oil/water emulsion at metering conditions was directly available as an output of the Micro Motion Mass Meter, steps from b to e could be skipped.

4. Factors Analysis

In this paper, only the affect degree of influence to the volume of oil from each factor is investigated. It is assumed that the factors analysed are independent of each other. All discussions shall base on the below range of the factors from the water-cut crude oil metering skid.

The measured ranges of the skid are as follows:

a. M_e, Measured mass of oil/water mixture, by Coriolis Flowmeter, 29,640~45,240 kg/h.

b. $D_{e,m}$, Measured density of oil/water mixture, by Coriolis Flowmeter, 740~780 kg/m^3.

c. $X_{w,m}$, Water cut at metering conditions，by water-cut analyser, 0~10%.

d. Metering temperature, by temperature transmitter,35~112 ℃.

e. Metering pressure, by pressure transmitter, 3,650~9,000 kPaG.

And the known Parameters are as follows:

a. Shrinkage factor (SF), provided by the lab, 0.8980.

b. Meter factor (MF) =1.0005, based on the meter.

c. Conversion unit factor (C_{uf}) = 1.0000 since SI units shall be used.

In order to facilitate the analysis, except for the factors investigated in the corresponding sections below, other parameters are based on the following constants:

C_{uf}	=	1.0000
M_e	=	44,080 kg/h
$D_{e,m}$	=	760 kg/m^3.
MF	=	1.0005
$X_{w,m}$	=	5%
$CTL_{o,m}$	=	0.9230
SF	=	0.8980

4.1 Density

It is notable that density of crude oil/water mixture $D_{e,m}$ is inversely proportional to the volume of oil $V_{o,st}$ from equation (1). Consider other parameters in the equation (1) except $D_{e,m}$ as constants, equation (1) can be simplified as equation (5).

$$V_{o,st} = K_{den}/D_{e,m} \quad (5)$$

When the above constants are substituted into the equation (1), it can be get that K_{den} is 34,726. Then the $V_{o,st}$ is calculated in the density range and the corresponding curve is drawn in figure 2.

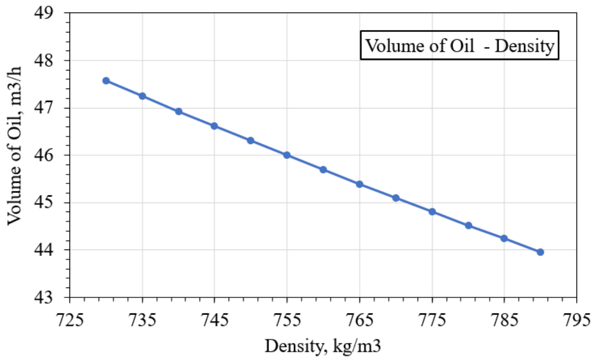

Figure 2. The Volume of Oil response to density

Figure 2 shows the variation trend of Volume of Oil $V_{o,st}$ in the measurement range of Density $D_{e,m}$. Although $D_{e,m}$ and $V_{o,st}$ are inversely proportional, figure 2 approximates a proportional function in the range of 720~790kg/m^3.

4.2 Volume Fraction of Water

It is easy to tell that the Volume Fraction of Water $X_{w,m}$ is negatively proportional to the Volume of Oil $V_{o,st}$. Considering other parameters ie equation (1) except $X_{w,m}$ as constants, equation (1) can be simplified as equation (6).

$$V_{o,st} = K_{vf,w}(1 - X_{w,m}) \quad (6)$$

When the above constants are substituted into the equation (1) except $X_{w,m}$, it can be get that $K_{vf,w}$ is 48.1. Then the $V_{o,st}$ is calculated in the $X_{w,m}$ range and the corresponding curve is drawn in figure 2.

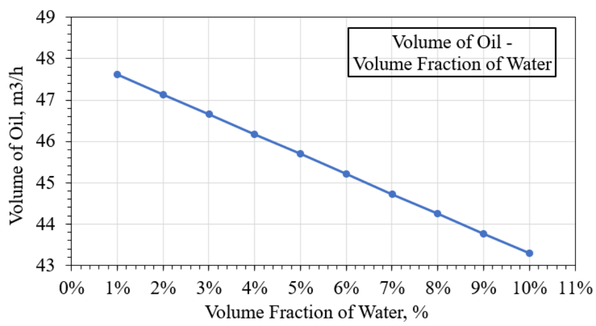

Figure 3. The Volume of Oil response to Volume Fraction of Water

Figure 3 shows that the Volume of Oil $V_{o,st}$ will decrease proportionately as the Volume Fraction of Water $X_{w,m}$ increases.

4.3 Shrinkage Factor

From equation (1) it can be seen that the Volume of Oil $V_{o,st}$ is proportional to the Shrinkage Factor SF. Equation (1) can be simplified into one linear equation (7) when consider the other paraters are constants except SF.

$$V_{o,st} = K_{sf} \times SF \quad (7)$$

When the above constants are substituted into the equation (1), it can be get that K_{sf} is 50.88. Then the $V_{o,st}$ is calculated in the SF range and the corresponding line is draw in figure 4.

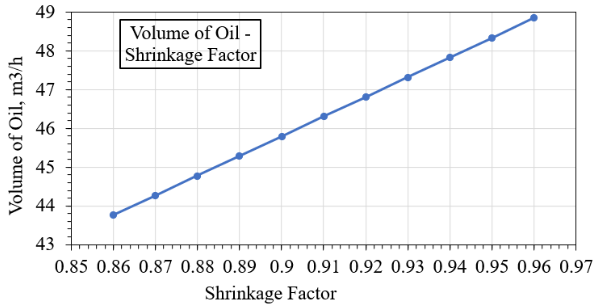

Figure 4. The Volume of Oil response to Shrinkage Factor

Figure 4 shows that the volume of oil $V_{o,st}$ will gently increase proportionally as the density increases.

4.4 Temperature

The temperature is not directly reflected in the equation (1). Temperature is involved in the computing procedure through the Temperature Correction Factor $CTL_{o,m}$, which is proportional to the Volume of Oil $V_{o,st}$. Considering other parameters in equation (1) except $CTL_{o,m}$ as constants, equation (1) can be simplified as equation (8).

$$V_{o,st} = K_{CTL} \times CTL_{o,m} \quad (8)$$

When the constants are substituted into the equation (1) except $CTL_{o,m}$, it can be get that K_{CTL} is 49.5. After the corresponding $CTL_{o,m}$ values of the temperature within the range is calculated based on API MPMS Chapter 11.1, the corresponding volume values $V_{o,st}$ can be get at the corresponding temperatures.

Table 1: $CTL_{o,m}$ and Temperature corresponding table according to API API MPMS Chapter 11.1

$CTL_{o,m}$	Temperature (°C)
0.9799	36.5
0.9706	46.5
0.9611	56.5
0.9517	66.5
0.9421	76.5
0.9326	86.5
0.9230	96.5
0.9134	106.5
0.9038	116.5

The $V_{o,st}$ is calculated by equation (8) based on the $CTL_{o,m}$ in table 1. The corresponding curve between the Volume of Oil and Temperature is drawn in figure 5.

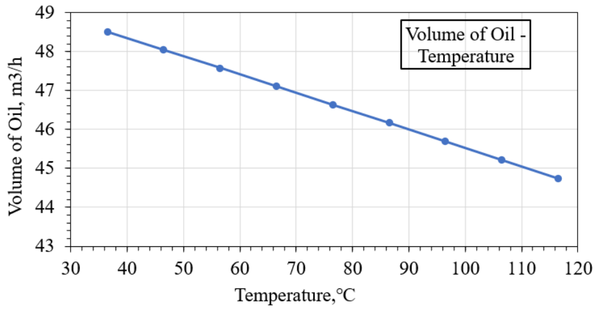

Figure 5. The Volume of Oil response to Temperature

Though the $V_{o,st}$ is positive proportional to $CTL_{o,m}$, figure 5 approximates shows a negative proportional function to temperature in the temperature range. The Volume of Oil $V_{o,st}$ will decrease as the temperature increases.

4.5 Comparison

To compare the affect degree of influence, the factors is discussed based on the same change of $V_{o,st}$. The corresbonding values of $D_{e,m}$ calculated by Equation (5), $X_{w,m}$ calculated by Equation (6) , SF calculated by Equation (7) and Temperature calculated by Equation (8) are listed on table 2.

Table 2: $D_{e,m}, X_{w,m}, SF$, and Temperature corresponding to the same $\boldsymbol{V_{o,st}}$ table

$\boldsymbol{V_{o,st}}$ (m³/h)	$D_{e,m}$ (kg/m³)	$X_{w,m}$ (%)	SF	$Temp.$ (℃)
41.00	846.9865	14.76%	0.8058	194.51
41.82	830.3789	13.05%	0.8219	177.46
42.64	814.4101	11.35%	0.838	160.4
43.46	799.0438	9.64%	0.8541	143.32
44.28	784.2467	7.94%	0.8702	126.18
45.10	769.9877	6.23%	0.8864	109
45.92	756.2379	4.53%	0.9025	91.74
46.74	742.9706	2.82%	0.9186	74.4
47.56	730.1607	1.12%	0.9347	56.94
48.38	717.7851	-0.59%	0.9508	39.36
49.20	705.8220	-2.29%	0.9669	21.63

By comparing the data from table 2, it can be noted that $D_{e,m}$, $X_{w,m}$ and Tempteraturе are decreasing by the increaseing of $V_{o,st}$, except SF. The values out of the factor range are marked in blue. By comparing the corresponding values of $V_{o,st}$ that within the range of each factor, it can be found that $D_{e,m}$ affects the minimum range while SF affects the maximum range. The change of $V_{o,st}$ is approximately to 2.4m³/h corresponding to the $D_{e,m}$ full range change from 740 kg/m³ to 780kg/m³. Meanwhile, the change of $V_{o,st}$ is approximately to 5.0m³/h corresponding to the SF full range change from 0.86 to 0.96.

In order to make the comparison more clearly, the difference ratios of each factor are calculated and listed in Table 3.

Table 3: Difference ratios of $D_{e,m}, X_{w,m}, SF$, and Temperature corresponding to the same $\boldsymbol{V_{o,st}}$ Difference table

$d\boldsymbol{V_{o,st}}$ (m³/h)	$dD_{e,m}$ (%)	$dX_{w,m}$ (%)	dSF (%)	$dTemp.$ (%)
0.82	-2.10%	-1.70%	1.68%	-15.22%
0.82	-2.02%	-1.70%	1.68%	-15.23%
0.82	-1.95%	-1.70%	1.68%	-15.25%
0.82	-1.87%	-1.70%	1.69%	-15.30%
0.82	-1.80%	-1.70%	1.68%	-15.34%
0.82	-1.74%	-1.70%	1.68%	-15.41%
0.82	-1.68%	-1.70%	1.68%	-15.48%
0.82	-1.62%	-1.70%	1.68%	-15.59%
0.82	-1.57%	-1.70%	1.68%	-15.70%
0.82	-1.51%	-1.70%	1.68%	-15.83%

It is more clearly in table 3 to show the changing trends of each factor with the same difference of $V_{o,st}$, 0.82m³/h. The difference ratio of $D_{e,m}$ is slightly decrease from -2.10% to -1.51% with the equal increments of $V_{o,st}$. The difference ratioes of $X_{w,m}$ and SF are constants, and the absolute values are approximately equal. For $X_{w,m}$, it is one negative constant -1.70%, while for SF it is one positive constant 1.68%. The difference ratio of $Temperature$ is nearly 7 times compared to other factors. It is obvious to find out the $V_{o,st}$ is not linear proportional to $Temperature$, because the difference ratio of $Temperature$ is not a constant. The difference ratio of $Temperature$ is slightly increased from -15.22% to -15.83% with the equal increments of $V_{o,st}$.

5. Conclusion

In this paper, theoretical equations based on the actual data from one metering skid are established. The Influences of several factors are analysed and compared. The following conclusions can be obtained through this research:

1. Within the range of $D_{e,m}, X_{w,m}, SF,$ and $Temperature$, it is the density $D_{e,m}$ has the least influence range on the volume of oil $V_{o,st}$.
2. When the factors are changed by the same percentage, $Temperature$ has the least effect on the volume of oil $V_{o,st}$. $Temperature$ has to change about 7 times other factors' percentage change to make the same variation.
3. The $X_{w,m}$ and SF needs to pay more attention to get more accurcte results. Because the volume of crude oil $V_{o,st}$ is very sensitive to the change of these 2 factors.

References

[1] API MPMS 5.6: Measurement of Liquid Hydrocarbons by Coriolis Meters, 2002.

[2] API MPMS 20.1: Allocation Measurement, 2011.
[3] API MPMS 11.1: Temperature and Pressure Volume Correction Factors for Generalized Crude Oils, Refined Products, and Lubricating Oils, 2004.