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NON-INVASIVE MEASUREMENT. STRIKING ACCURACY.

TEST REPORT

Applicability of the ULTIMO Technology to Density and Viscosity Measurement of Liquid Materials in Vessels - (A. Raykhman)

This report describes experiments on homogeneous liquids only
Tests conducted in December 2006
Additional analysis provided in November 2009

THEORETICAL FOUNDATION

The ULTIMO percussion method requires monitoring and evaluation of a coordinate of a mechanical dynamic system comprised of the filling material, tank wall, and external striking device (striker). In the present embodiment of the method a wall's point acceleration variable is used for the evaluation. The acceleration variable denoted a(t) is being evaluated when the wall is in the oscillating relaxation phase after a temporal mechanical load had been applied to the wall and then canceled by the striker. For qualitative analysis, a stationary dynamic model could be analyzed by its complex frequency response function. A simplified Magnitude Gain vs. Frequency Curve of the ULTIMO density/viscosity measuring device (DVM) dynamic system is denoted Gain(ω) and has the following view:

$$Gain(\omega,\rho,\xi,\eta)=\frac{\frac{1}{k(\xi)}}{\sqrt{\left(1-\frac{mass(\rho,\xi)}{k(\xi)}\omega^{2}\right)+\left(\frac{\beta(\omega,\rho,\xi,\eta)}{k(\xi)}\omega\right)}} \qquad (1)$$

$$mass(\rho,\xi)=m_{w}(\rho,\xi)+m_{fm}(\rho,\xi)$$

Wherein: m_w – effective mass of the wall, $m_{fm}(\rho,\xi)$ – effective mass of the filling material, $k(\xi)$ – wall stiffness; $\beta(\rho,\xi)$ – mechanical energy dissipation parameter; $\xi \in \Re$ – degree of the tank fullness: $\xi = 1 \Rightarrow$ *“Full”*, $\xi = 0 \Rightarrow$ *“Empty”*; ρ – filling material density, η – filling material viscosity; $\omega = 2\pi f$, f – amplitude spectrum frequency, Hz.

It follows from the (1) that the DVM dynamic system is suitable for at least the following types of non-invasive measurement operations:

- Point level measurement or level switching, $\xi \in [0,1]$
- Material presence detection, $\xi = 1$
- Density measurement; $\xi = 1$, v – *known*
- Viscosity measurement; $\xi = 1$, ρ – *known*

MODEL NUMERICAL ANALYSIS (LIQUIDS)

In the graph shown in the Fig.1 below, the Magnitude Gain vs. Frequency Curve was calculated at the following values of density (presented in the specific gravity format) and viscosity (measured in *cP*) [1,2]:

Case 1:	ρ = 0.8,	η= 1.2	Alcohol
Case 2:	ρ = 1.0,	η = 1.002	Water
Case 3:	ρ = 1.2,	η = 1.4	Brine
Case 4:	ρ = 0.9,	η = 43.2	Vegetable Oil

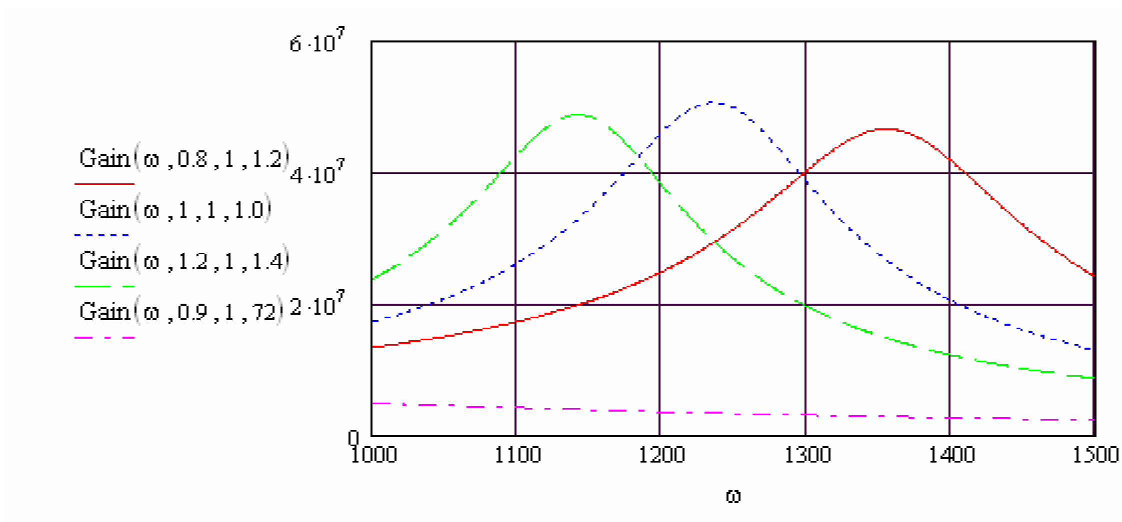

Fig.1. Magnitude Gain vs. Frequency Curve of the simulating model (1)

Sorting the calculated resonance peak values of Gain(ω,ρ,η) by descending order puts the investigated materials in the following order:

1. Water
2. Brine
3. Alcohol
4. Vegetable oil

EXPERIMENT

In order to observe the material detection and density/viscosity change effect on the DVM device, the device was mounted on the tank with the following additional requirement: the level of the filling material in the tank had been kept constant during the measurement. The tank was in the fixed position preventing its movements while being filled or emptied. The dimensions of the cylindrical tank used in the Ultimo Measurement Laboratory were: material - stainless steel, diameter = 33 mm, height = 66 mm, wall thickness = 1.2 mm. The liquid substances of the Case 1 - Case 4 were sequentially put into the tank. The device was turned on and the analog output of the DVM was recorded. This test did not require calibration.

RESULTS

The numerical results of the test are presented in the Table 1.

Table 1. Averaged readings from the DVM:
Case studies 1 through 4

ID	Filling Material	DVM Analog Output
1.	Water	37.34
2.	Brine	26.29
3.	Alcohol	19.71
4.	Vegetable Oil	6.53

DISCUSSION

The order at which the readings are presented in the Table 1 requires explanation. Adding a column of kinematic viscosities of the investigated materials to the Table 1 demonstrates measuring capabilities of the method. The complete data are presented in the Table 2.

Table 2. Averaged readings from the DVM
And kinematic viscosities if the investigated materials:
Case studies 1 through 4

ID	Filling Material	DVM Analog Output	Kinematic Viscosity, cSt
1.	Water	37.72	1.002
2.	Brine	26.29	1.167
3.	Alcohol	19.71	1.493
4.	Vegetable Oil	6.53	40 - 70

Combining experimental data from the Table 2 with tabulated kinematic viscosities of various materials outside of the investigated four materials allows modeling the DVM readings based on the modified exponential regression model:

$$DVM\_Output = ae^{\left(\frac{b}{\nu}\right)}$$
$$a = 7.0414418$$
$$b = 1.627142 \qquad (2)$$

The results of the modeling are shown in the graph of the Fig.2

Material	ν, cSt	Ultimo Device
water	1.002	35.71987162
Brine	1.167	28.39200874
Alcohol (Ethyl)	1.493	20.93997974
Alcohol (Isopropyl)	3	12.1119627
Milk	4.3	10.28018305
Syrup	10	8.285666965
Cream	20.6	7.620183312
Vedgetable Oil	48	7.284230033

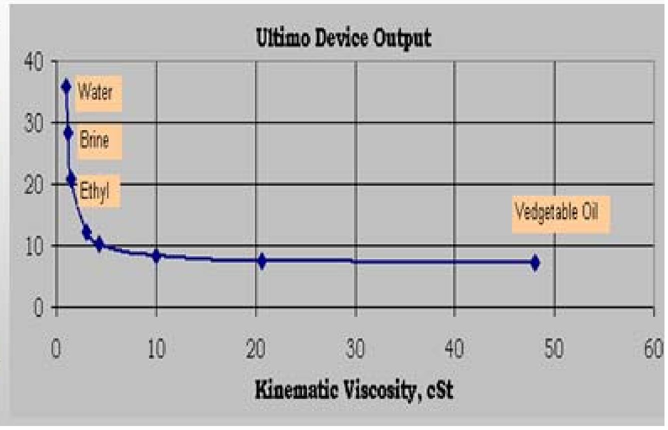

Fig.2. Modeling Ultimo DVM Output for liquid materials of various kinematic viscosity

CONCLUSION

The comparison of the trends of simulated and experimental data leads to the following conclusions:

1. ULTIMO technology is applicable to fluid material presence detection.

2. Analog output of the ULTIMO DVM is proportional to kinematic viscosity of the liquid filling material

3. An algorithm can be developed for measuring density or viscosity of liquids based on the Ultimo-developed percussion measurement technology

4. Theoretical and experimental data demonstrate similar qualitative trends. The developed mathematical model of the DVM dynamic system could be used for a preliminary analysis of the applicability of the ULTIMO technology to the detection of loose solid filling materials, thin powders in particular

REFERENCES

1. Specific gravity weights of materials from READE. www.Reade.com

2. Physics Hypertextbook. http://physics.info/viscosity/

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