Wave estimation of volume of the liquid, granular and mixed compositions in cylindrical tanks

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Abstract

The acoustic measurement of volume of the liquid, granular and mixed compositions in cylindrical tanks are considered. The knock acoustic source of sound vibrations is installed on the outside surface of the vertical cylindrical tank with the impedance bottom, the rigid walls and the rigid roof. The results of the mathematical and physical simulations of sound transmission are shown. The sound intensity measurements of free air volumes into tank are controlled with a pair of microphones and corresponded to the different substance volumes. The intensity diagrams considerably differed from each other in low frequency band are analyzed.

1 Introduction

There is the necessity to increase the accuracy of weight registration of the liquid, loose and mixed compositions into tanks because of transportation widening of freight ton-miles by air, ground and a sailing charter.

The complexity and the high cost of contactless elements of radio systems interfere of the wide practice substance volume measurement into tanks because of data control during measurements must be all time. At the same time the acoustic measurement technology for determination of substance volume by measurement of reverberation time with smaller accuracy than radar but with less influence of variable external and internal technological conditions are actual and find the application [1]. So for estimation of volume (mass) of any liquid, loose and mixed modular compositions in vertical cylindrical tanks the standard time reverberation measuring process is used. The substance configuration with greater absorption then steel walls is precisely fixed by time of reverberation.

In the big air tank the perfect conditions of diffuse sound field are created. It allows to determine the total equivalent sound absorption consisting of a sound absorption of internal (steel) surface S_{st} and sound absorption of the sludge surface S_s without dependence from height H (Fig. 1). The air volume V_0 (and also volume of sludge rest V_s) can be easily found from established Sebin dependence for measured of standard time reverberation T_{60}

$$T_{60} = 0.16V_0/(A_{st} + A_s) \tag{1}$$

were V_0 is the air volume of the big tank, A_{st} is the still surface absorption, A_s is the substance surface absorption.

However the finding substance surface absorption A_s represents as difficult task because of the variable technological conditions (temperature of the sludge rest, density, water vapor, etc.) essentially influence on the sound substance absorption. So the results of measurements of normal sound absorption coefficient for sludge by the standing waves

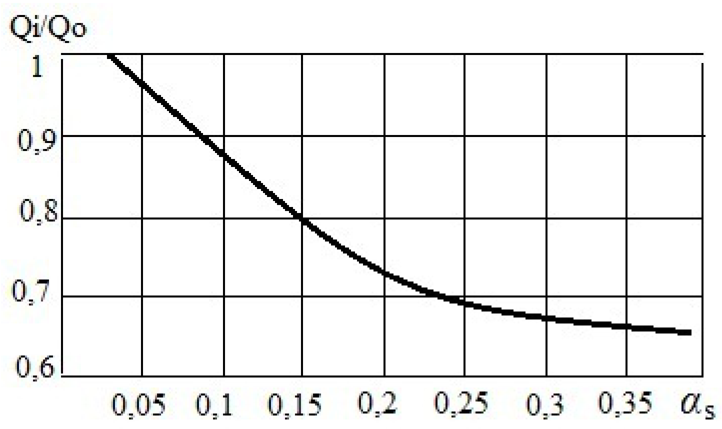

Figure 1: The measurement scheme of sludge volume: M1 and M2 are the identical microphones; the AC is the two-channel spectrum analyzer; PC is the computer; S is the shock source of sound fluctuations; P is the flow out water pipeline; H = 10 m; D = 6 m.

method ("SWA TYPE-4002") show that the normal sound absorption coefficient for sludge for frequency 250 Hz accepts value from $\alpha_1 = 7 \times 10^{-3}$ up to $\alpha_2 = 4,2 \times 10^{-3}$, i.e. increases in 6 time.

For this reason the factor the sludge absorption in the formula (1) has been received experimentally in real technological conditions by a method of two microphones-receivers of pressure.

2 Creation of the cross-spectrum by the method of two microphones-receivers of pressure

In a near acoustic sound field the pressure and the speed of particles are not in a phase with each other especially in low frequencies. To avoid the errors that caused by these factors the measurement of the sound intensity instead of measurements of sound pressure was made. The sound intensity is determined as average value of sound energy passing in the unit of time through the unit area can be expressed by the dependence

$$I_r = \frac{1}{T} \int_0^T p(t)v(t)dt \tag{2}$$

where I_r is the sound intensity in a direction r in some point between receivers, $p(t)$ is the instant sound pressure in this point, a component of instant value of speed of particles in a direction r, T is time of measurement.

The projection of oscillatory speed of particles to the direction r is expressed by the dependence:

$$V_r(t) = \frac{1}{\rho} \int \frac{\partial p}{\partial r} dt \approx \frac{1}{\rho} \int \frac{p_2(t) - p_1(t)}{\triangle r} dt \tag{3}$$

where ρ is the air density, $p1(t)$ and $p2(t)$ are the instant values measured by two not directed microphones-receivers of sound pressure in two points and the distance between which is equal $\triangle r$.

Pressure between two points of measurement is approximately equal this average point:

$$p(t) \cong \frac{p_1(t) + p_2(t)}{2} \tag{4}$$

The sound intensity in the direction r in the average point between two microphones can be found by integration of product $p(t)$ and $V_r(t)$ (t), proceeding from the equations (2), (3) and (4). This integration has been executed by the two-channel spectrum analyzer.

Using the two-channel spectrum analyzer for definition of sound intensity is based on expression for intensity with application of the Cross-spectrum density (5). The intensity of the sound is connected with the Cross-spectrum density $p_1(t)$ and $p_2(t)$ by expression [3]:

$$I \approx \frac{1}{2\pi\rho\triangle r}\int_0^\infty \left(\frac{Q(p_1,p_2)}{f}\right) df \tag{5}$$

where $Q(p_1,p_2)$ is the imaginary part Cross-spectrum $p_1(t)$ and p_2 in two positions of microphones.

3 Creation of the test cross-spectrum in model for calculation of the sound absorption

Firstly, the test relative Cross-spectrum (relative according to the empty tank) were the normalized Cross-spectrum density from the well known sound absorption test materials that were located on the bottom of the tank in the model 1:10 is received (Fig. 2).

The measuring installation (Fig. 1) consisted of two measuring microphones (BK), the shock source of the fluctuations, the filter and the two-channel spectrum analyzer. The microphones were connected with the spectrum analyzer through the filter passing fluctuations only the second axial mode and. Otherwise the influence of standing waves of the higher harmonic axial modes and the first radial mode on the result can deform measurements.

In a method of two microphones two receivers of sound pressure located on small distance from each other [3] are used. To get rid of the error of measurements (that is limited not more 1,5 dB) the following limits of parameters were used:

$$0.1 \le k\triangle r \le 1.3 \qquad 0 \le \frac{\triangle r}{r} \le 0.5 \tag{6}$$

For a case of measurement the Cross-spectrum in model of the tank the low boundary frequency is determined by the first axial mode $f_1 = 170Hz$ according expression (6) as $\triangle r = 0.03m$ then the top boundary frequency for this $\triangle r$ accepts as $f_2 = 2500Hz$.

The test diagram of dependence the second axial mode of relative Cross-spectrum Q_i/Q_0 from sound absorption α_s (Fig. 2) is constructed by results of measurements for seven different test materials.

4 Normalized technological tank for calculation sludge volume using the sludge absorption and time reverberation

Secondly, the technological tank was normalized with the same measuring scheme as on Fig.1. The low boundary frequency is determined for excitation of the first axial fashion $f_1 = 17Hz$ then the top boundary frequency accepts $f_2 = 250Hz$, and the distance between microphones is determined from expression (6).

So when the thin flat sludge layer was arranged on the bottom of the technological tank then the relative Cross-spectrum amplitude of the second axial mode was measured. Then this sludge sample was located into model 1:10 where the amplitude of the relative

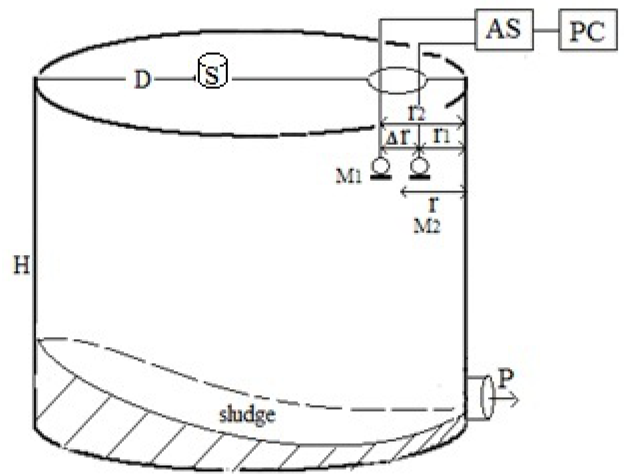

Figure 2: The test dependence the second axial mode relative Cross-spectrum Q_i/Q_0 from sludge absorption α_s

test Cross-spectrum for second axial mode was measured as into technological tank. So according this amplitude of the relative test Cross-spectrum for second axial mode the sludge absorption was find out by test diagram.

Such measurements was repeated with several various sludge compositions in the technological tank and with model and using this sludge absorption data the normalized technological tank diagram was constructed. Then to find the sludge absorption of any sludge rest it is enough to measure only relative Cross-spectrum in technological tank and using the dependence (1) to calculate sludge volume.

5 Conclusion

The invented method for determining sludge absorption by the second axial mode relative Cross-spectrum amplitude allows to find out sludge volume in tank by reverberation time and to estimate the critical sludge volume in tank when the further tank operation will go to emergency conditions.

The investigated system of the acoustic control can find application for registration of volume of the liquid, loose and mixed modular compositions in the vertical cylindrical tanks which are carried out in air, sailing charter and not excepting nuclear industry.

References

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