RATE OF MOVEMENT OF GAS BUBBLES IN VISCOUS LIQUIDS

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In the use of bubbled systems in chemical and petrochemical equipment it often becomes necessary to deter-
mine the rate of movement of gas bubbles in liquids with various physical properties. This problem has been ex-
amined in a number of studies [1-9] but thus far has not been solved unambiguously over a wide range of the mea-
sured parameters. Thus, formulas for determining the velocity of single spherical bubbles that have been proposed
by various investigators are frequently cited without any rigorous evaluation of their accuracy, and these formulas
will give substantial deviations in practical applications. Such deviations are explained by the fact that the experi-
mental material presented in the literature as a basis for the theoretical generalizations is far from uniform; most
of it refer to liquids having viscosities no greater than 50-100 cP, while bubbling in viscous liquids has not received
adequate experimental study.

It is noted in [1] that, in the movement of a gas bubble in a liquid, as the Reynolds number is increased, a
transition is observed from Stokes resistance force (with Re ≪ 1) to Adamar-Rybchinskii resistance force, the transi-
tion occurring at a Reynolds number from about 10^{-4} to 20, depending on the properties of the liquid.

The present work was aimed at experimental investigation of the rate of movement of single spherical gas
bubbles 1.5-6 mm in diameter (a range close to the limit of sphericity) in viscous liquids (μ = 60-3000 cP) at
Reynolds numbers Re < 2 and also at establishing the correlation giving the minimum error in determining bubble
movement rate over the entire range of parameters studied, by computer-processing the experimental data.

The investigation was carried out with a specially built unit in which bubbles of the required sizes could be obtained
by varying the gas-chamber volume with constant diameter of the outlet opening [10]. The volume of the gas chamber in-
cluded between the outlet opening (capillary) and needle valve was varied by means of a 10-cm³ medical syringe. The
bubble size and sphericity were determined on the basis of photographs taken with a synchronized flash. The negatives
were analyzed by means of a type MMI-1 calibrated-stage microscope. The relative error in determining bubble diam-
eter was at most 0.5%. A 62x62x150 mm square cuvette was used in the unit (liquid level 125 mm) with a thermo-
stated jacket made of transparent plastic. The rate of move-
ment of the bubble being photographed was measured by means
of photoelectric sensors located at a fixed distance from each
other in a vertical line along the cuvette, with an electronic
circuit for accurate measurement of the time of bubble pas-

gage through the distance between the photoelements. The
relative error in measuring the rate of bubble movement by
this method was about 0.5%. The required rate of gas dis-
charge through the outlet was set by means of the needle
valve. The frequency of bubble formation in the test liquid,
monitored by means of an electric timer, did not exceed
Fig. 2. Quantity $v\mu/\rho$ as a function of bubble diameter: 1) Curve corresponding to Adamar-Rybachinski; 2) curve obtained from computer processing of experimental data; 3) curve corresponding to Stokes formula.

### Table 1. Characteristics of Liquids

<table>
<thead>
<tr>
<th>Liquid</th>
<th>Temperature, °C</th>
<th>Viscosity, cP</th>
<th>Density, g/cm³</th>
<th>Surface tension, dyn/cm</th>
<th>$\rho/\mu$, sec/cm²</th>
<th>Reynolds number (Re)</th>
<th>Sphericity criterion, Re·$M^{0.23}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetable oil</td>
<td>20</td>
<td>61</td>
<td>0.916</td>
<td>32.3</td>
<td>1.50</td>
<td>0.35-1.84</td>
<td>0.05-0.27</td>
</tr>
<tr>
<td>Fish oil</td>
<td>19</td>
<td>61</td>
<td>0.919</td>
<td>32.1</td>
<td>1.51</td>
<td>0.44-1.88</td>
<td>0.065-0.28</td>
</tr>
<tr>
<td>Sucrose (aqueous solution)</td>
<td>14-24</td>
<td>187-383</td>
<td>1.325-1.334</td>
<td>66.2-68.8</td>
<td>0.35-0.71</td>
<td>0.64-1.68</td>
<td>0.18-0.28</td>
</tr>
<tr>
<td>Glycerol (94%)</td>
<td>20-40</td>
<td>113-450</td>
<td>1.230-1.241</td>
<td>61.7-63.4</td>
<td>0.28-1.09</td>
<td>0.2-0.94</td>
<td>0.06-0.99</td>
</tr>
<tr>
<td>Castor oil</td>
<td>10-50</td>
<td>135-2500</td>
<td>0.936-0.970</td>
<td>32.7-35.0</td>
<td>0.039-0.71</td>
<td>0.019-0.12</td>
<td>0.003-0.94</td>
</tr>
<tr>
<td>Polyesiers* (various grades)</td>
<td>25</td>
<td>142-2750</td>
<td>1.009-1.065</td>
<td>31.7-35.0</td>
<td>0.039-0.71</td>
<td>0.002-0.11</td>
<td>0.001-0.98</td>
</tr>
<tr>
<td>Glycerol (98.4%)</td>
<td>8-43</td>
<td>176-3230</td>
<td>1.243-1.262</td>
<td>56.7-60.0</td>
<td>0.039-0.71</td>
<td>0.003-0.14</td>
<td>0.0014-0.93</td>
</tr>
</tbody>
</table>

*Possibly polyesters; same word in Russian denotes both classes of compounds, and there is no indication from content as to which was used in this work - Translator.

0.05 Hz in any of the experiments; this corresponds to the regime of isolated bubbles, in which their rate of movement is independent of gas discharge rate.

The characteristics of the liquids used in the experiments are listed in Table 1. Most of the liquids were investigated at various temperatures; this was done in order to provide complete coverage and overlapping of the