

Van Der Waals Interaction of Nanonized Oil Particles in a Porous Medium

E.K. Shahbazov¹, Sh.A. Farzalizade², T.E. Zeynalzade²

SOCAR Azerbaijan Oil Industry Journal¹, Baku Higher Oil School²

eldar@socar.az, shamilfarzalizade@gmail.com, turkan.zeyn@gmail.com

Abstract

The article proposes an analytical calculation of van der Waals forces acting on oil by nanoparticles, which suggests their role in changing the rheological properties of oil and the subsequent transition to a new regime. In the intricate geometrical configurations of the oil and gas industry, understanding Van der Waals interactions governing nanofluid particles within porous media becomes crucial. Results demonstrate a flat-sphere model for nanofluid behavior in porous media, specifically between oil, rock, and nanoparticles. The free energy associated with non-retarded Van der Waals interactions is expressed through equations, revealing the proportional relationship with the Hamaker constant. Utilizing addition rules for multicomponent systems, the study calculates the Hamaker constants for aluminum, sand, and oil, showcasing the superiority of nano-induced Van der Waals forces compared to porous media without nanoparticle exposure. Furthermore, according to laboratory data of nanoparticle injection study, 5 models for the dependence of surface tension, force, and nanoparticle concentration have been constructed.

Key words: van der Waals forces, nanofluid, nanotechnology, small concentrations and perturbation effect, Hamaker constant, oil rheology.

Introduction

Modern advances in nanotechnology in the petroleum industry demonstrate that in various applications such as oil and gas production, offshore and onshore drilling, residual oil recovery, petrochemical industry, efficient use of underground and surface oil and gas equipment, surfactant processing, as well as in investigations and applied work at the atomic and molecular level, significant progress has been made. These results are presented in the Israeli journal "Scientific Israel Technological Advantages" in various issues such as Vol. 17, No. 4, 2015; Volume 17, No. 2, 2015; Volume 18, No. 2, 2016; Volume 18, No. 4, 2016; Volume 18, No. 3, 2016; Volume 19, No. 2, 2017; Volume 20, No. 3, 2018, and are also reflected in the articles published in the issue Volume 20, No. 6, 2018 [1]. The mentioned collection presents research and practical applications of nanostructured lattices, initiated by the theory of “small concentrations and perturbation effect,” which allows them to be manipulated in solid and liquid states at the atomic and molecular levels.

In this collection, authored by one of the co-authors, Prof. E. Shahbazov puts forward that during the study of aluminum nanofluid, developed on the basis of the “effect of small concentrations and perturbation”, separation of oil from formation water occurs due to the hydrophilic-hydrophobic phenomenon, crushing of gas bubbles formed in the formation, and resistance decreases [1]. Thus, the viscosity of the oil decreases and the flow intensifies. As a result, nanoparticles open channels in the porous medium and direct difficult-to-recover oil into the reservoir. In addition, studies have proven the occurrence of an enhanced paramagnetic resonance effect (EPR) in oil. These effects that occur during the injection of nanofluids are a manifestation of the change in the rheological properties of oil, and thus the result of the change in the flow regime of oil has emerged. This article proposes to analytically evaluate the intermolecular van der Waals forces acting on oil by nanoparticles and show that, against the background of van der Waals forces, it is possible to explain the mechanism of oil transition to a new oil flow regime.

To understand the stabilizing effect of nanosystems in shale rocks, it is necessary to consider their intermolecular (or interparticle) interactions with each other, as well as their effect on charged shale surfaces. In particular, electrostatic and electrodynamic interactions between nanoparticles and the shale surface, driven by van der Waals forces and electrostatic repulsion forces based on van der Waals interactions, are the main mechanisms explaining the effects occurring in pore throats. This leads to a decrease in pressure transfer, which, in turn, slows down the growth of pore pressure in the near-wellbore zone and effectively reduces stress, improving the stability of wells due to reduction [2].

In the realm of the oil and gas industry, the diverse and intricate geometrical configurations inherent in exploration and extraction processes underscore the critical significance of comprehending the van der Waals interactions governing nanofluid particles within porous media. In literature, conceptualized representations exist for computing the Van der Waals interaction energy (W) among macroscopic bodies with varying geometries, given in relation to their Hamaker constant, denoted as A . The Hamaker constant (A) is a coefficient that relates the interactive Van der Waals energy (E_{vdw}) to the distance of separation between two molecules, where the interactive force is pair-wise additive and independent of the intervening media [3].

Results

In a study conducted by Rostami, P., Sharifi, M., Aminshahidy, B., et al., it was demonstrated that the detachment of oil droplets from pore walls occurred with an increase in contact time between the nanofluid and the glass micromodel. This phenomenon was attributed to the development of a thin nano-layered film on the glass surface, identified as the wedge layer (refer to Figure 1) [4]. The insights derived from Figure 1 can serve as a foundational basis for selecting an appropriate

interaction model to characterize Van der Waals forces in the system.

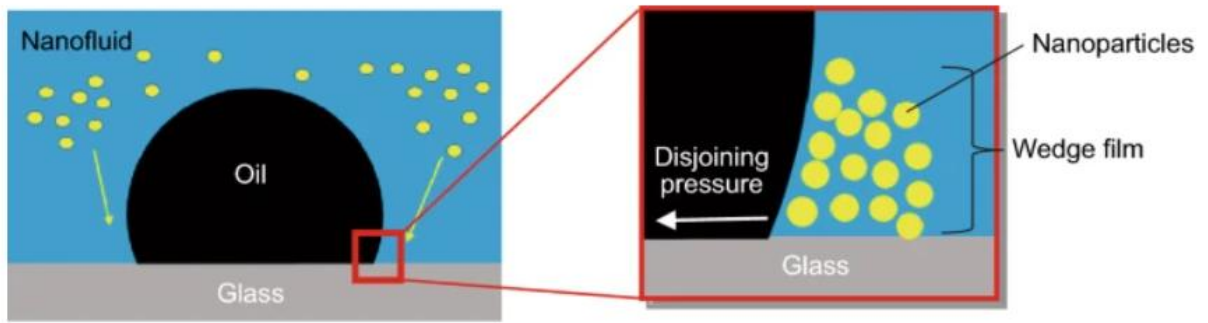
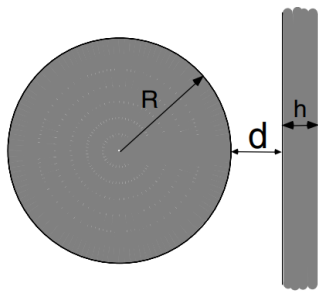


Figure 1. Depiction of the detachment of an oil droplet from a glass surface through the adsorption of silica particles [4]

Predicated upon the Figure 1, the geometric configuration that accounts for the nanofluid behaviour in porous media between oil, rock and nanoparticles can be modelled on the basis of a spherical molecule near a flat wall surface.

The free energy (W) associated with non-retarded van der Waals interactions between a sphere of radius (R), a flat surface, and the distance (D) separating the two objects is expressed by the following equation [5]:



$$W_{sphere-flat} = -\frac{A_{AB}R}{6D} \quad (1)$$

$$F_{sphere-flat} = -\frac{A_{AB}R}{6D^2} \quad (2)$$

Figure 2. Sphere-surface configuration for the interaction of nanonized oil particles

It is obvious that both parameters are proportional to the Hamaker number. The so-called addition rules are widely used in calculating the approximate values of the Hamaker constants of multicomponent systems, if the Hamaker constants for systems with fewer components are known [6]:

$$A_{12} = \pm\sqrt{A_{11}A_{22}} \quad (3)$$

Since the model we are considering is also multicomponent, consisting of rock particles, oil and nanoparticles, the following relation can be derived to derive the ratio of forces acting in the system before and after the injection of aluminium nanofluid into a porous medium:

$$\frac{F_{final}}{F_{initial}} = \frac{F_{oil-Al}}{F_{oil-sand}} \approx \frac{A_{oil-Al}}{A_{oil-sand}} = \sqrt{\frac{A_{oil} \times A_{Al}}{A_{oil} \times A_{sand}}} = \sqrt{\frac{A_{Al}}{A_{sand}}} \quad (4)$$

The Hamaker constants for aluminium (Al), and sand are $A_{Al}=1.5 \cdot 10^{-19}$ J, $A_{sand}=8 \cdot 10^{-20}$ J [6, 7].

$$\frac{F_{oil-Al}}{F_{oil-sand}} = \sqrt{\frac{1.5 \cdot 10^{-19} \text{ J}}{8 \cdot 10^{-20} \text{ J}}} = 1.37$$

The force ratio of 1.37 for the main forces present in the system indicates that the forces induced by the injected nanoparticles are greater by 37%, highlighting the enhanced nano-induced Van der Waals force compared to porous media without prior exposure to the Al-nanoparticles.

When the nanosystem is injected into pipelines and collectors, it lowers the surface tension between the liquid and the pipe walls by creating a nanocoating on the inner walls of the pipelines, reduces the hydraulic resistance of the liquid on the contact surface, and increases the flow rate of the liquid.

The nanosystem prevents the formation of asfaltene-resin-paraffin and heavy hydrocarbon deposits in pipelines, creates a nanocoating on the walls of pipes and pipelines in the transportation of oil and gas. This prevents complications during oil and gas transportation.

The nanocoating formed on the equipment and pipes prevents the corrosion that occurs in the pipes and equipment during the transportation of oil and gas production, and increases the service life of the pipes and equipment.

Mathematical and 3D model of the results obtained by the application of nanotechnologies

Models for the relation between calculated values for van der Waals force and experimental figures for the size of nanoparticle and surface tension of oil have been obtained. According to the laboratory data of nanoparticle injection study, 5 models for the dependence of surface tension, force, and nanoparticle concentration have been constructed to see the dynamics of tension minimization process.

Table 1. Model 1 figures.

		Concentration, M									
		0.0006	0.0007	0.0008	0.0009	0.001	0.0011	0.0012	0.0013	0.0014	0.0015
Force nano- oil	5.29839E-14	10.6	9.2	8.5	8.6	8.8	8.9	9	9.1	9.2	9.3
	4.54148E-14	10.6	9.2	8.5	8.6	8.8	8.9	9	9.1	9.2	9.3
	3.78456E-14	10.6	9.2	8.5	8.6	8.8	8.9	9	9.1	9.2	9.3
	3.02765E-14	10.6	9.2	8.5	8.6	8.8	8.9	9	9.1	9.2	9.3
	2.64919E-14	7.4	7.2	7.2	7.3	7.4	7.6	7.7	7.8	8	8.3
	2.27074E-14	7.4	7.2	7.2	7.3	7.4	7.6	7.7	7.8	8	8.3
	1.89228E-14	7.4	7.2	7.2	7.3	7.4	7.6	7.7	7.8	8	8.3
	1.51383E-14	7.4	7.2	7.2	7.3	7.4	7.6	7.7	7.8	8	8.3

Dependence of surface tension on F nano-oil and concentration (1)

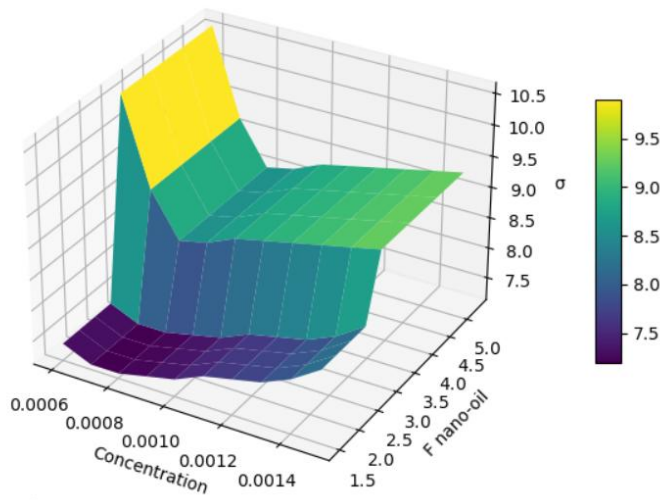


Figure 3. 3D dependence of nanoparticle concentration over van der Waals force and surface tension in the porous medium for the first model

The first model (Fig. 3) was constructed in 3D format according to the values determined in the previous studies of van der Waals forces from 1.514×10^{-14} to 5.298×10^{-14} and the concentration range from 0.0006 to 0.0015. It was implemented with the help of other software. The colouring of the image of the expected return for the adjustment of the appreciation of the obtained ternary model and the nanomaterials studied for this purpose are described in six intervals: up to 7.5, from 7.5 to 8.0, from 8.0 to 8.5, from 8.5 to 9.0, 9.0 up to - to 9.5, greater than 9.5. the intervals are matched with the colours reflected in the model (from the bottom to the top in colour) and this way the colouring is applied to all five models.

Table 2. Model 2 figures

		Concentration, M									
		0.00066	0.0007	0.00077	0.00085	0.001	0.001	0.0011	0.0011	0.0012	0.0013
Force nano- oil	2.01516E-14	7.28	7.2	7.2	7.25	7.37	7.47	7.6	7.61	7.7	7.84
	2.02711E-14	7.28	7.1	7.2	7.25	7.37	7.47	7.6	7.61	7.7	7.84
	2.33859E-14	7.28	7.2	7.2	7.25	7.39	7.47	7.6	7.61	7.7	7.84
	2.83977E-14	8.54	8.135	7.961	7.9	8.06	8.16	8.26	8.26	8.35	8.48
	2.90666E-14	8.98	8.46	8.23	8.13	8.3	8.4	8.48	8.49	8.58	8.71
	2.92569E-14	9.11	8.56	8.3	8.196	8.37	8.47	8.55	8.56	8.65	8.77
	4.5846E-14	9.78	9.06	8.71	8.55	8.74	8.83	8.9	8.91	8.997	9.12
	4.84856E-14	9.78	9.06	8.71	8.55	8.74	8.83	8.9	8.91	8.997	9.12

Dependence of surface tension on F nano-oil and concentration (2)

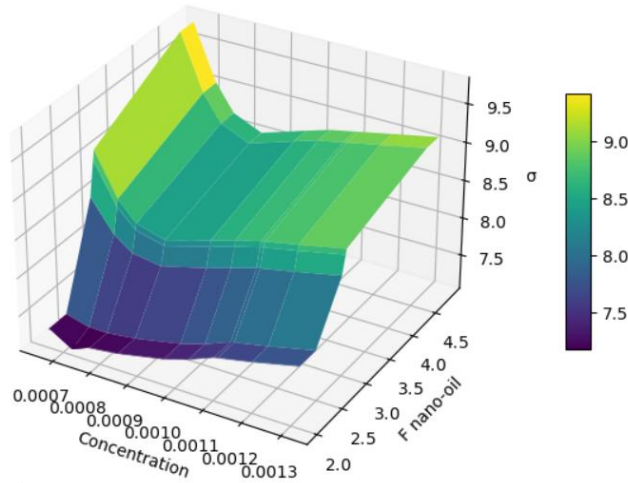


Figure 4. 3D dependence of nanoparticle concentration over van der Waals force and surface tension in the porous medium for the second model

The second model (Fig. 4) was created on the basis of new calculated values of nanoparticle size, concentration, and surface yield, based on a new algorithm designed to determine the studied dependence. As can be seen from the three-dimensional model, the first two characteristics reflect the existing intervals, while the distribution of colours retains the colour sequence shown above.

Table 3. Model 3 figures

		Concentration, M									
		0.0006	0.0007	0.0008	0.0009	0.0010	0.0011	0.0012	0.0013	0.0014	0.0015
Force nano-oil	5.29839 E-14	7.1	9.2	8.5	8.6	8.8	8.9	9	9.1	9.2	9.3
	4.54148 E-14	10.6	9.2	8.5	8.6	8.8	8.9	9	9.1	9.2	9.3
	3.78456 E-14	10.6	9.2	8.5	8.6	8.8	8.9	9	9.1	9.2	9.3
	3.02765 E-14	10.6	9.2	8.5	8.6	8.8	8.9	9	9.1	9.2	9.3
	2.64919 E-14	7.4	7.2	7.2	7.3	7.4	7.6	7.7	7.8	8	8.3
	2.27074 E-14	7.4	7.2	7.2	7.3	7.4	7.6	7.7	7.8	8	8.3
	1.89228 E-14	7.4	7.2	7.2	7.3	7.4	7.6	7.7	7.8	8	8.3
	1.51383 E-14	7.4	7.2	7.2	7.3	7.4	7.6	7.7	7.8	8	8.3

Dependence of surface tension on F nano-oil and concentration (3)

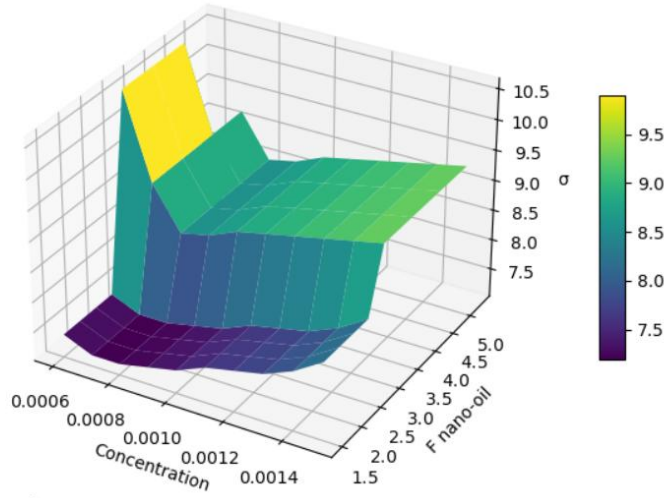


Figure 5. 3D dependence of nanoparticle concentration over van der Waals force and surface tension in the porous medium for the third model

Model 3 (Fig. 5): This is the configuration of the new three-dimensional model obtained by replacing the first Surface yield value of the first model with the minimum Surface yield value of the predetermined model.

Table 4. Model 4 figures

		Concentration, M									
		0.0006	0.0007	0.0008	0.0009	0.001	0.0011	0.0012	0.0013	0.0014	0.0015
Force nano-oil	1.32E-14	3.4	3.1	3	3.1	3.15	3.2	3.3	3.4	3.35	3.5
	1.14E-14	3.4	3.1	3	3.1	3.15	3.2	3.3	3.4	3.35	3.5
	9.46E-15	3.4	3.1	3	3.1	3.15	3.2	3.3	3.4	3.35	3.5
	7.57E-15	3.4	3.1	3	3.1	3.15	3.2	3.3	3.4	3.35	3.5
	6.06E-15	0.8	0.9	1	1.1	1.2	1.4	1.5	1.6	1.7	1.8
	4.54E-15	0.8	0.9	1	1.1	1.2	1.4	1.5	1.6	1.7	1.8
	3.03E-15	0.8	0.9	1	1.1	1.2	1.4	1.5	1.6	1.7	1.8
	1.51E-15	0.8	0.9	1	1.1	1.2	1.4	1.5	1.6	1.7	1.8

Dependence of surface tension on F nano-oil and concentration (4)

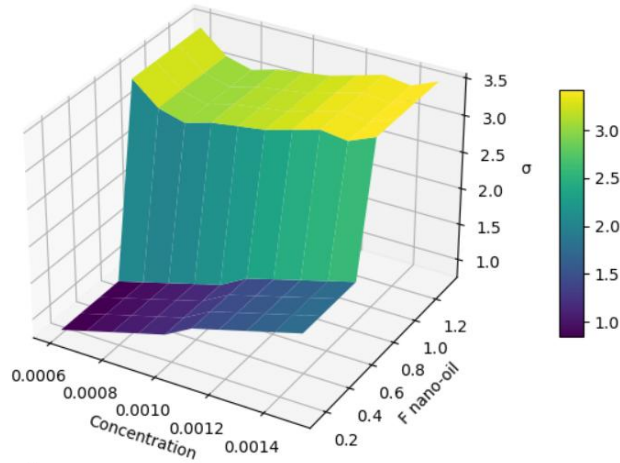


Figure 6. 3D dependence of nanoparticle concentration over van der Waals force and surface tension in the porous medium for the fourth model

The software designed for the purpose of determining the optimal solution allowed the analysis of the values of the surface yield due to the figures for forces of smaller nanoparticles at the specified concentration values (Fig. 6). Thus, the fourth model reflects the range of dimensions from $1.51 \cdot 10^{-15}$ to $1.32 \cdot 10^{-14}$, reflects the sharp distribution of either the values of the surface income or the essence of the form. The minimal characteristics set in the considered model are included in the next model and provide the pragmatic essence of the minimization process.

Table 5. Model 5 figures

		Concentration, M									
		0.0006	0.0007	0.0008	0.0009	0.001	0.0011	0.0012	0.0013	0.0014	0.0015
Force nano-oil	1.32 E-14	0.8	3.1	3	3.1	3.15	3.2	3.3	3.4	3.35	3.5
	1.14 E-14	3.4	3.1	3	3.1	3.15	3.2	3.3	3.4	3.35	3.5
	9.46 E-15	3.4	3.1	3	3.1	3.15	3.2	3.3	3.4	3.35	3.5
	7.57 E-15	3.4	3.1	3	3.1	3.15	3.2	3.3	3.4	3.35	3.5
	6.06 E-15	0.8	0.9	1	1.1	1.2	1.4	1.5	1.6	1.7	1.8
	4.54 E-15	0.8	0.9	1	1.1	1.2	1.4	1.5	1.6	1.7	1.8
	3.03 E-15	0.8	0.9	1	1.1	1.2	1.4	1.5	1.6	1.7	1.8

	1.51 E-15	0.8	0.9	1	1.1	1.2	1.4	1.5	1.6	1.7	1.8
--	--------------	-----	-----	---	-----	-----	-----	-----	-----	-----	-----

Dependence of surface tension on F nano-oil and concentration (5)

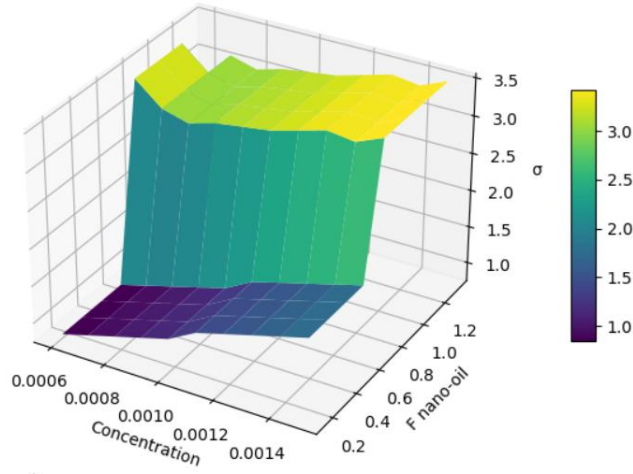


Figure 7. 3D dependence of nanoparticle concentration over van der Waals force and surface tension in the porous medium for the fifth model

The fifth model (Fig. 7) reflects the three-dimensional space determined form of the surface yield, which the nanoparticles acting with the force in the range from $1.51 \cdot 10^{-15}$ to $1.32 \cdot 10^{-14}$ reveal due to the appropriate concentration values and keep the minimum value.

Model 5: The configuration of the new three-dimensional model obtained by replacing the first Surface yield value of the fourth model with the minimum Surface yield value of the predetermined model.

Conclusions

The approximated force ratio, calculated based on these constants, emphasizes the enhanced effect of nano-induced forces. The conceptualized representations for computing Van der Waals interaction energy, as presented in the article, provide insights into the complex interplay of forces within porous media. The force ratio calculated from the van der Waals equation for the selected geometric configuration to be 1.37 highlights the great potential of nanoinduced forces to overcome

resistance within porous structures, facilitating the transition to a new oil flow regime and, therefore, more efficient oil flow.

For the first time, we have established that the additional intermolecular forces of 37% induced by the introduction of nanoparticles into a porous medium are equivalent to an increase in the production of nanonized oil. According to laboratory data of nanoparticle concentration and surface tension as well as calculated van der Waals force, 5 3D surface models have been constructed.

The findings contribute to the understanding of nanotechnology's impact on flow behaviour in porous mediums, opening avenues for further research and application in enhancing the efficiency of petroleum industry practices.

References

1. E.Q. Şahbazov, (2019) "Neft Sənayesində Nanotexnologiyalar", Scientific Israel Technological Advantages.
2. Hoxha, B. B., Oort, E. van, & Daigle, H. (2017). How Do Nanoparticles Stabilize Shale? SPE International Conference on Oilfield Chemistry.
3. Erle C. Donaldson and Waqi Alam. 2008. Wettability. Gulf Publishing Company, pp 82-83.
4. Rostami, P., Sharifi, M., Aminshahidy, B. et al. The effect of nanoparticles on wettability alteration for enhanced oil recovery: micromodel experimental studies and CFD simulation. *Pet. Sci.* 16, 859–873 (2019)
5. Tadmor, R. (2001). The London-van der Waals interaction energy between objects of various geometries. *Journal of Physics: Condensed Matter*, 13(9), L195–L202.
6. Israelachvili, J. N. 2011. Intermolecular and surface forces, Third Edition. Academic Press, Oxford.
7. Rabinovich, Y. I. & Churaev, N.V. 1990. Results of numerical calculation of dispersion forces for solids, liquid interlayers, and films. *Colloid Journal of the USSR* 52, pp 256- 262.