Method for Calculating the Viscosity of Multicomponent Oil Blend

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Abstract. The paper shows the possibility of modeling a multicomponent mixture of oils with various rheological properties using simplex coordinates. Basing on the known priori information of the mixture formation for binary systems, the authors proposed a model for describing the multicomponent mixture formation of treated oils. The model is based on the assumption of the linear character of the level surfaces of the viscosity model of the multicomponent mixture. This model is applicable in the absence of chemical interaction between the components, especially of a minimum of viscosity, singular and irrational properties that arise quite rarely in cases of mixing oils of various origin. The article also contains analysis of the application of the existing Sheffe approximation equations for modeling the viscosity change with multicomponent mixing in a system of simplex coordinates and possibility of increasing their accuracy at the transition of modeling to logarithm of viscosity. Experiments of a three-component mixing of treated oils were made, that show good results of convergence with the model proposed by the authors and the second-order Sheffe equation with modeling of the logarithm of viscosity. A comparative analysis of all the models is performed on the basis of the criterion of the average risk functional, taking into account the correctness of correlation of complexity of the model with the amount and level of error of the available data. Plans and tasks for further studies of multicomponent mixing have been outlined.

1. Introduction

During joint pipeline transportation of different kinds of oil from numerous deposits, characterized by own rheological properties, it is a very important as well as complicated task to predict the changes in the oil blends properties for obtain correct values of oil viscosity, needed to technological calculations. It is also very important in the cases of a change in the schedule for the supply of oils from fields, during switching of technological operation regimes of pipelines, planned and forced emergency stops, especially in cold climatic conditions while pumping the high viscosity heavy oil.

Furthermore, the modeling of rheological properties for multicomponent oil blends also gives a possibility of optimization flow oil routs in complex branched trunk oil pipeline network, reduces energy consumption of pumping and as a consequence the transportation prime costs [1, 2].

In contrast to the quality of oil, linearly dependent on the blend composition, the multicomponent blend viscosity mostly does not exhibit linearly additive properties [3].

2. Modeling binary mixtures

Recent investigations in modelling of rheological properties for oil blends, in the field of pipeline transportation, mainly concern the mixing of heavy oils with diluents – in the cases of binary mixing [4-10]. To describe the change in the viscosity of binary mixtures, the Arrhenius, Kendall-Monroe, Walter and Zdanovsky equations are widely used [4, 9, 10]. According to these models viscosity curve of mixture have a concaved form to the axis of its composition and its initial steep part is not always approximated by a quadratic equation.

All the above equations have the form of curves convex to the axis of a composition. The equations differ by an initial sharp drop in the function from its maximum, so the binary mixture can not always be described by the usual quadratic equation.

However, as shown by analysis of own made rheological studies, the factual distribution of experimental points often does not coincide with the above curves. To decide this task, as discussed by authors in [11], the improving of existing equations by obtaining of empirical coefficients have been made. It should be noted, during a number of mixing experiments with different oils, no singular or irrational mixing properties, described in [12], have been matched. The appearance of minimum extremum of blend viscosity [11, 13], occurring because of dissociation associated molecules of one of the mixed components under the influence of another one, are very rare and could be meet in cases of significant differences in composition and nature of blended oils.

Thus, the modeling of multicomponent mixtures in next chapters will be performed without taking into account the possible chemical interaction of high-molecular oil components, that could be reason of anomaly of blend viscosity.

3. Modeling multicomponent mixture

In the middle of the last century, methods of investigation and modeling the properties of substances depending on the ratio of the constituent components appeared and widely applied [14, 15]. This method assumes the usage of a specially obtained equations in the so-called "simplex" coordinates. The composition of a mixture with any number of constituent components is given by a simplex - the simplest geometric figure having k vertex in the (k-1) - dimensional space.

For applying Scheffe equations of chosen order polynomial from matched by experimental data needs for a large number of experiments to find the correct values coefficients used. However, all the results gives surfaces whose level lines were of the mostly linear form character, that means the level surfaces of the (k-2) -dimensional space also could be have a linear character. This form of surfaces could be used as a priori information for the modelling of multicomponent oil blends. This condition let us reduce the required number of laboratory experiments to obtain the adequate approximation equation. Using the line equations, there two different variants of the relative location of level surfaces are possible:

1) The level surfaces are parallel to each other. Then the model can be determined by carrying out (2k-2) experiments;

2) The level surfaces have a slope with respect to each other. Then the model can be determined by carrying out (2k-1) experiments with a linear change in the slope, and (2k) - for a quadratic, etc.

4. Comparison results of modeling three-component blends in simplex coordinates with experimental data of laboratory studies

To prove the above assumptions, laboratory experiments with three-component oil blends have been made. The results of the experiments are presented in Tab. 1 and on Figures 1 and 3.

For a three-component mixture in the case of parallel lines of a level surfaces , the model can be also described in Cartesian coordinates.

Figure 5 shows the projection of the simplex coordinates for a three-component oil blend onto a Cartesian plane. Straight lines 1, 2 and 3 are level lines of surfaces. Then the point P with the simplex coordinates {x1, x2, x3} in the Cartesian system will have the coordinate y, calculating by formula:

$$y = x_3 \cos\ \alpha\ + x_2 \cos(60^\circ + \alpha) \quad (1)$$

Table 1. The results of laboratory viscosity measurements for three-component oil blends.

№	content of component x_1	content of component x_2	content of component x_3	Viscosity, ν, cst
1	1,0	0,0	0,0	5,273
2	0,0	1,0	0,0	13,287
3	0,0	0,0	1,0	121,364
4	0,5	0,5	0,0	8,612
5	0,5	0,0	0,5	19,580
6	0,0	0,5	0,5	35,188
7	0,333	0,333	0,333	17,434
8	0,2	0,2	0,6	33,804
9	0,2	0,6	0,2	15,787
10	0,6	0,2	0,2	10,624
11	0,8	0,1	0,1	6,828
12	0,1	0,8	0,1	14,568
13	0,1	0,1	0,8	61,490
14	0,5	0,3	0,2	11,650
15	0,5	0,2	0,3	13,647
16	0,3	0,5	0,2	13,449
17	0,2	0,5	0,3	18,712
18	0,3	0,2	0,5	24,787
19	0,2	0,3	0,5	27,609

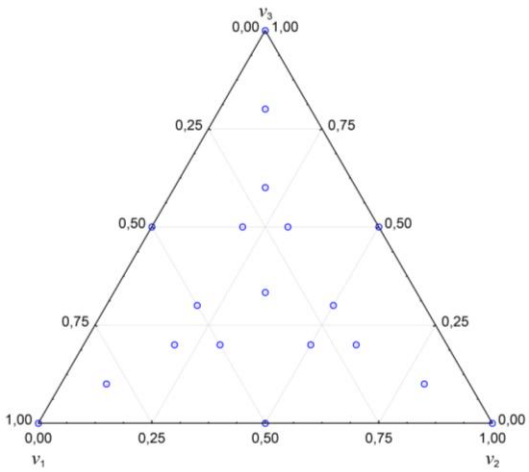

Figure 1. The planing of the experiment, presented in simplex coordinates.

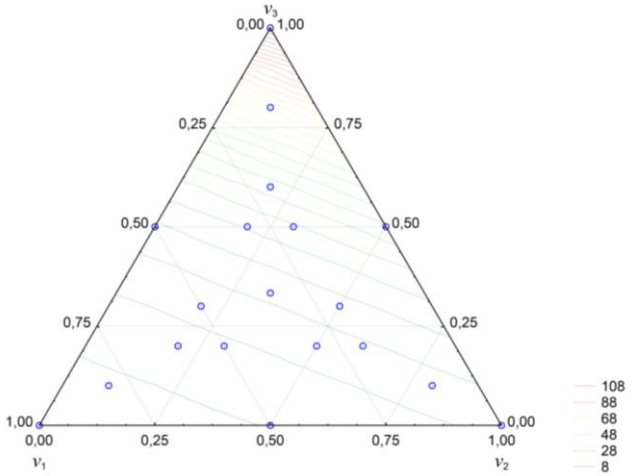

Figure 2. A map of the level lines obtained from the results of proposed modelling method of three-component blends in simplex coordinates(number of regression coefficients n=4, coefficient of determination r^2=99,990%, average risk function $I_m(a)$=0,222).

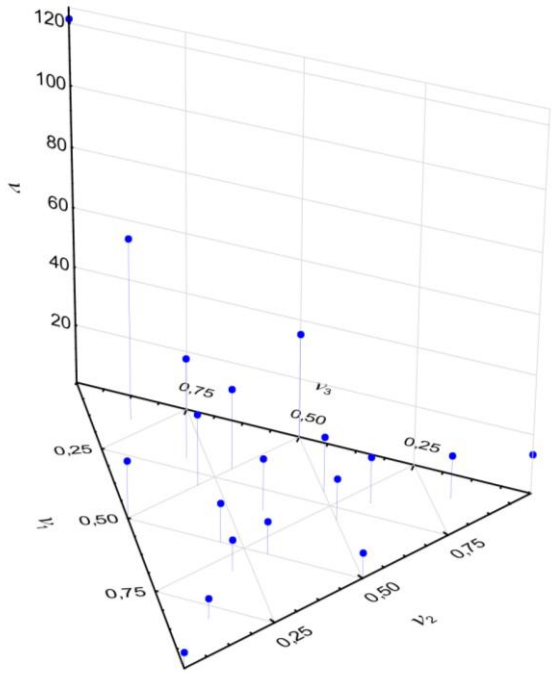

Figure 3. The results of laboratory studies in viscosity determination on the composition-property diagram.

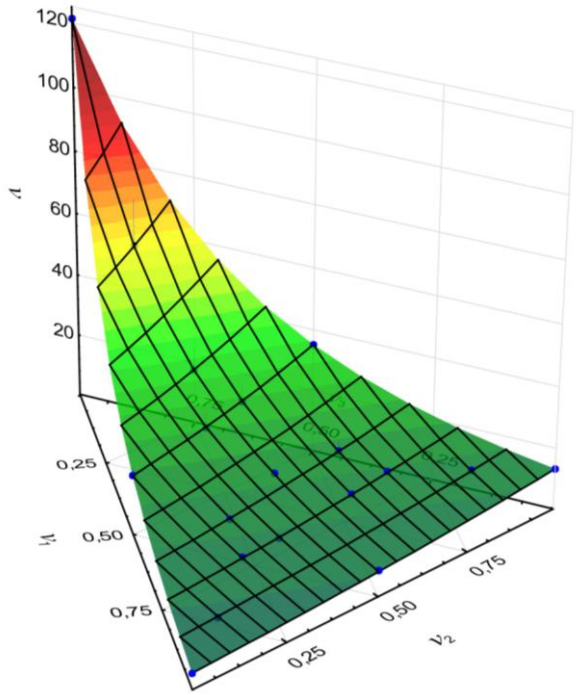

Figure 4. The results made by proposed modelling method on the composition-property diagram.

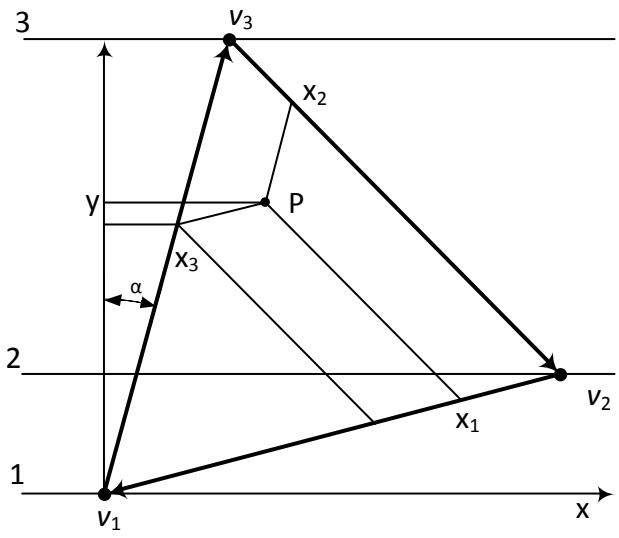

Figure 5. The way of transfer of a point with simplex coordinates to a Cartesian system in case of three-component blend.

To modelling the viscosity in the z-y coordinates, one can use any of the formulas from [11]. Using the modified Walter equation, formula to determenation of viscosity for the tested three-component oil blend takes the following form:

$$\lg\ \lg(v_{mix}+1.537)\ = y\cdot\lg\ \lg(v_1+1.537)\ + y\cdot\lg\ \lg(v_2+1.537) \tag{2}$$

$$y = x_3\cos\ 8.526^{\circ}\ + x_2\cos(60^{\circ}+8.526^{\circ}) \tag{3}$$

The results of calculation using by (6-7) are presented in Figures 2 and 4. The obtained values of viscosities have shown good convergence. The coefficient of determination of the model is 99.99%.

5. Conclusion

Figures 6-8 show the results of modeling by Sheffe equations. Because of significant deviations while used Sheffe models, also applyed Arrhenius's assumption of the additivity of the logarithm of viscosity. The results obtained (Figure 9-11) became much more accurate. The equation of the second order, determined from six experimental points, gave the best result among all the Sheffe models used.

To compare all the models obtained, a criterion for the average risk function was used, taking into account the correctness of the correlation between the complexity of the model and the amount and level of inaccuracy of the available data by the statistic method, described in [16].

The calculation of the average risk functional showed high reliability and accuracy of application of the proposed model of viscosity for three-component oil blend (Fig. 2, 6-11).

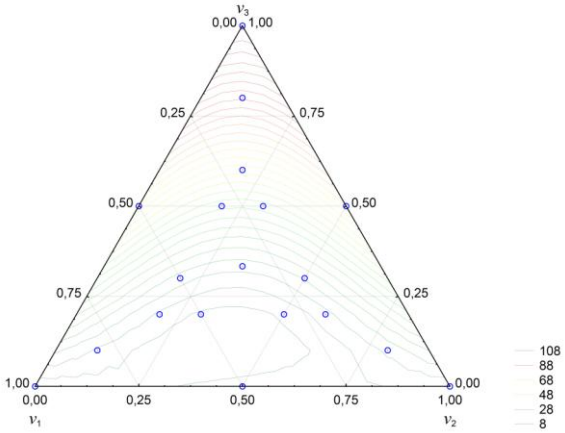

Figure 6. First-order Sheffe equation (n=4, r^2=66,037%, $I_m(a)$=722,916).

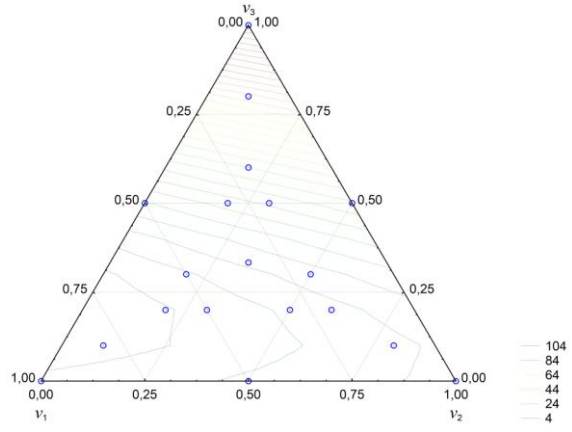

Figure 7. Second-order Sheffe equation (n=6, r^2=96,534%, $I_m(a)$=126,612).

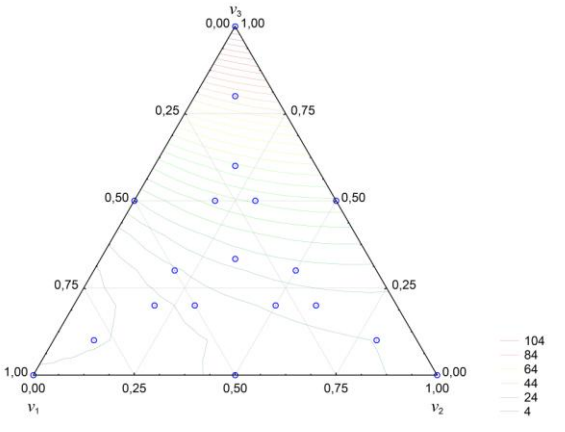

Figure 8. Incomplete third-order Sheffe equation (n=7, r^2=97,482%, $I_m(a)$=134,292).

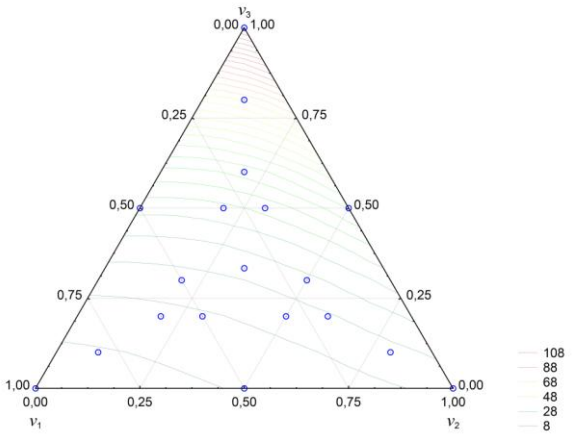

Figure 9. First-order Sheffe equation for modeling viscosity logarithm (n=4, r^2=99,069%, $I_m(a)$=19,809).

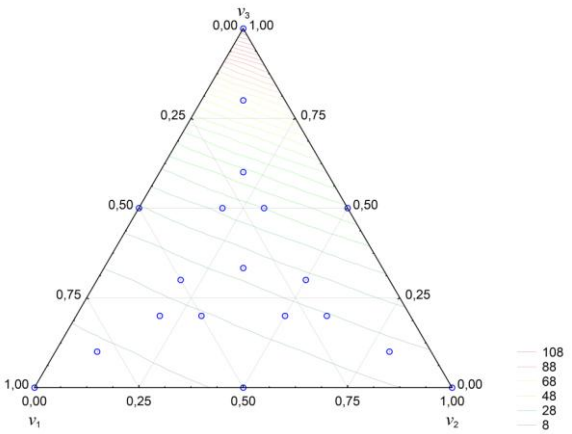

Figure 10. Second-order Sheffe equation (n=6, r^2=99,973%, I_m(a)=0,983).

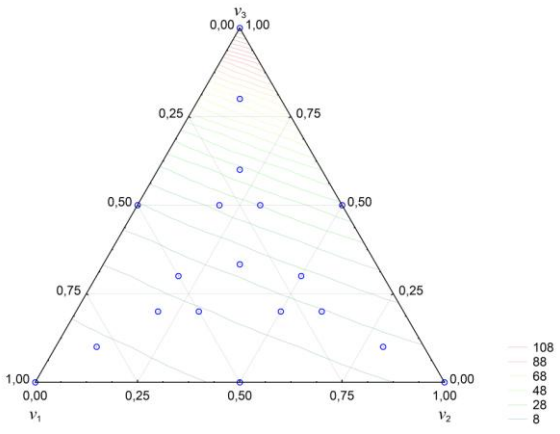

Figure 11. Incomplete third-order Sheffe equation (n=7, r^2=99,971%, I_m(a)=28,947).

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Acknowledgments
The studies were carried out with the financial support of the Russian Foundation for Basic Research for scientific project No. 18-38-00081 Mol_a.