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VISCOSITY AND STABILITY OF DISTILLATE PETROLEUM OIL – RESIDUAL PETROLEUM OIL AND DISTILLATE PETROLEUM OIL – SHALE OIL BINARY BLENDS

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The evaluation of the kinematic viscosity and stability of distillate petroleum oil – residual petroleum oil, distillate petroleum oil – distillate shale oil and distillate petroleum oil – residual shale oil binary blends is discussed. It is shown that when the low viscosity component is the petroleum originated light gas oil, the blend experimental kinematic viscosity is always higher than the calculated one, which is obtained using the standard blending calculation technique accepted for hydrocarbon oil blends. When shale oils, both distillate and residual, are blended with the so-called PTU-oil, an aromatic rich gas oil fraction, the blend kinematic viscosity can be evaluated by the standard blending calculation technique. Contrary to this, the PTU-oil – residual petroleum oil blend kinematic viscosity is always lower than the calculated one. For evaluation the difference between the experimental and calculated values of kinematic viscosity, a simple equation can be used. The dependence of the blend's stability on the volume fraction of components is studied.

In our previous paper [1] it was shown that the kinematic viscosity of shale oil originated distillate oil – residual petroleum oil binary blends is lower than the calculated value, which is obtained using the standard blending calculation technique accepted for hydrocarbon oils. This phenomenon leads to a conclusion of applied relevancy: Estonian kukersite shale oil distillates are more effective diluents for heavy petroleum residues than petroleum originated distillates having the same nominal viscosity.

There is only one exception: when the shale oil originated low viscosity component is the light "diesel oil" fraction with a boiling range as low as 180–230 °C, the blend kinematic viscosity can be evaluated, using the standard blending calculation technique. This fraction consists only of a low amount of hydroxybenzene series phenols and is more similar to hydrocarbon oils than to a typical shale oil distillate.

In this paper, the evaluation of the kinematic viscosity and stability of distillate petroleum oil – residual petroleum oil and distillate petroleum oil – distillate and residual shale oil binary blends are discussed.

Experimental and Results

Component Oils. Oil blends were prepared by blending of conventional petroleum originated hydrotreated light gas oil or so-called PTU-oil with a long residue from crude petroleum distillation (conventional heavy fuel oil 40) or with shale oil originated oils, both distillate and residual.

The PTU-oil is an aromatic-rich middle fraction of petroleum-originated kerosene or light gas oil thermal pyrolysate. This fraction is produced by *Kiviter* Ltd. (now *Viru Keemia Grupp* AS) as a commercial product.

All shale oils for blending are also produced by *Kiviter* Ltd. and were sampled at their shale oil distillation unit.

Density and viscosity characterization constants, *A* and *B* (Equation (1) in [2]), of component oil samples are presented in Table 1.

Methods. Kinematic viscosity for the component oils and their binary blends was determined as established by generally accepted standard specifications [3, 4]. For each blend, the viscosity was determined, as a minimum, at 6–8 various temperatures. Compatibility of component oils and stability of blends were determined, using standard spot test procedure [5].

For calculation of a blend's "theoretical" viscosity the Wright standard method [6–8] was used. Viscosities found using a computer technique [9],

Table 1. **Component Oils Used for Blending**

Component oils	Density at 20 °C, kg/m^3 *1	Nominal viscosity at 50 °C, mm^2/s *1	Viscosity characterization constants	
			A	*B*
Low viscosity components				
Hydrotreated light gas oil *2	849.1	3.133	9.54791	3.91938
PTU-oil *3:				
Sample 1	1030.4	3.140	11.12299	4.54861
Sample 2	992.6	2.997	11.27687	4.61690
High viscosity components				
Shale oil originated oils:				
Light gas oil fraction:				
Sample 1	956.8	8.506	12.54870	5.00700
Sample 2	973.0	12.08	12.34257	4.90101
Heavy gas oil fraction:				
Sample 1	1029.1	212.5	12.25911	4.73897
Sample 2	1027.4	178.6	12.69887	4.47247
Reduced shale oil	995.0	51.06	11.26705	4.39668
Residual shale oil (long residue)	1055	3131.8	11.76679	4.47247

*1 For low viscosity components the density is given at 15 °C and the nominal viscosity at 40 °C.
*2 Aromatic content 29.4 %.
*3 Aromatic content: sample 1 – 98 %, sample 2 – 92 %.

similar to that described by Huggins [10], are further interpreted as "calculated" values (ν_{calc}), contrary to the experimental ones (ν_{exp}) measured in the laboratory.

Kinematic Viscosity of Blends. From the results obtained, it follows that when the petroleum originated light diesel oil is blended with shale oil fractions, both distillate and residual, as well as with residual petroleum oil (heavy fuel oil), the values of experimental viscosity systematically differ from calculated ones. As a rule, for these blends values of ν_{exp} are always higher than ν_{calc} (Figures 1 and 2).

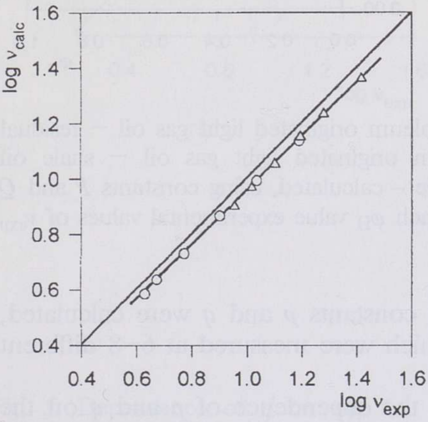


Fig. 1. Experimental and calculated values of kinematic viscosity for petroleum originated light gas oil – residual petroleum oil blends. Volume fraction high viscosity oil (φ_H): ○ – 0.40, Δ – 0.60

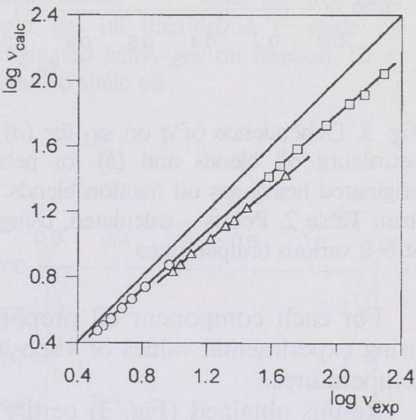


Fig. 2. Experimental and calculated values of kinematic viscosity for petroleum originated light gas oil – shale oil long residue blends. Volume fraction high viscosity oil (φ_H): ○ – 0.25, Δ – 0.50, □ – 0.75

In our previous papers [1, 9] it was found that in these events the difference Δ between the logarithms of ν_{exp} and ν_{calc} depends on ν_{exp}, as well as on the volume fraction of component oils H (high viscosity component) and L (low viscosity component). This dependence was expressed by the following equation:

$$\Delta = p + q \log \nu_{exp} \quad (1)$$

where p and q are empirical coefficients.

Values of p and q depend on the volume fraction of component oils φ_H and φ_L as follows:

$$p = P\varphi_H\varphi_L \quad (2)$$

$$q = Q\varphi_H\varphi_L. \quad (3)$$

where constants P and Q depend on the chemical nature of blend components, but do not depend on component oil proportion.

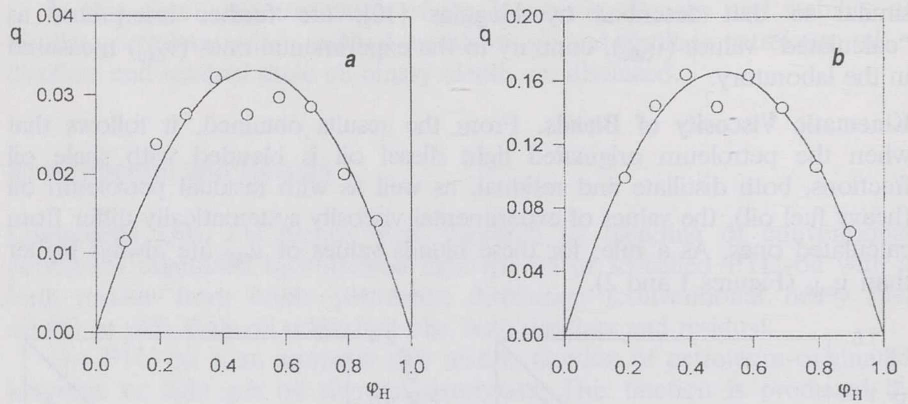


Fig. 3. Dependence of q on φ_H for (*a*) petroleum originated light gas oil – residual petroleum oil blends and (*b*) for petroleum originated light gas oil – shale oil originated heavy gas oil fraction blends. Curve – calculated, using constants P and Q from Table 2. Points – calculated, using at each φ_H value experimental values of ν_{exp} at 6–8 various temperatures

For each component oil proportion, constants p and q were calculated, using experimental values of viscosity which were measured at 6–8 different temperatures.

Results obtained (Fig. 3) certify that the dependence of p and q on the volume fraction of components actually can be described by Equations (2) and (3).

Using the equation

$$\frac{\Delta}{\varphi_H \varphi_L} = P + Q \log \nu_{exp}, \tag{4}$$

constants P and Q were estimated for each blend oil by the least square method (Table 2).

Table 2. **Constants *P* and *Q* for Oil Blends**

Low viscosity component	High viscosity component	P	Q	s_y*	Number of experimental values of blend viscosity
Petroleum originated light gas oil	Residual petroleum oil	0.060±0.017	0.133±0.015	0.050	59
	Shale oil originated oils:				
	Light gas oil fraction	−0.041±0.059	0.464±0.087	0.044	12
	Heavy gas oil fraction	−0.261±0.019	0.665±0.016	0.054	55
	Reduced shale oil	−0.053±0.035	0.556±0.039	0.016	5
	Long residue	0.058±0.042	0.535±0.030	0.075	22
PTU-oil	Residual petroleum oil	0.147±0.018	−0.447±0.018	0.056	73

* $y = \Delta / \varphi_H \varphi_L$.

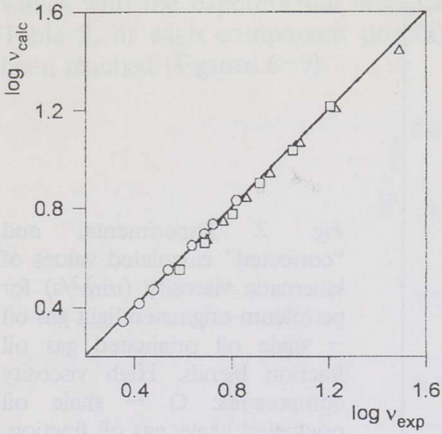


Fig. 4. Experimental and calculated values of kinematic viscosity for PTU-oil – shale oil blends. High viscosity components: O – shale oil originated light gas oil fraction, Δ – shale oil originated heavy gas oil fraction, □ – reduced shale oil

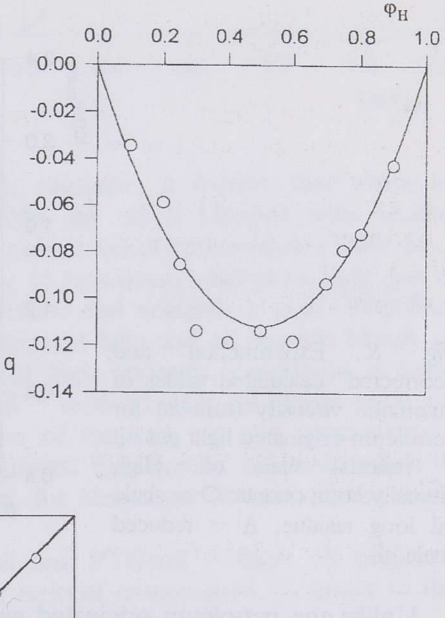


Fig. 5. Dependence of q on φ_H for PTU-oil – residual petroleum oil blends. Curve – calculated, using constants P and Q from Table 2. Points – calculated, using at each φ_H value experimental values of ν_{exp} at 6–8 various temperatures

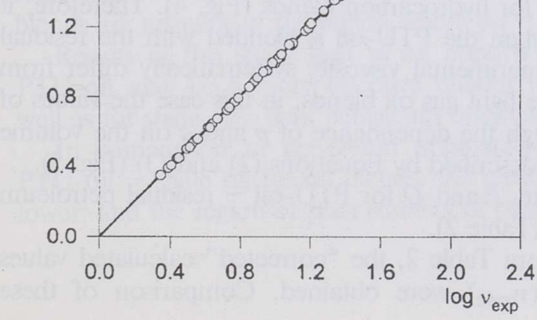


Fig. 6. Experimental and "corrected" calculated values of kinematic viscosity (mm²/s) for petroleum originated light gas oil – residual petroleum oil blends. Volume fraction high viscosity oil (φ_H) varies from 0.10 to 0.90

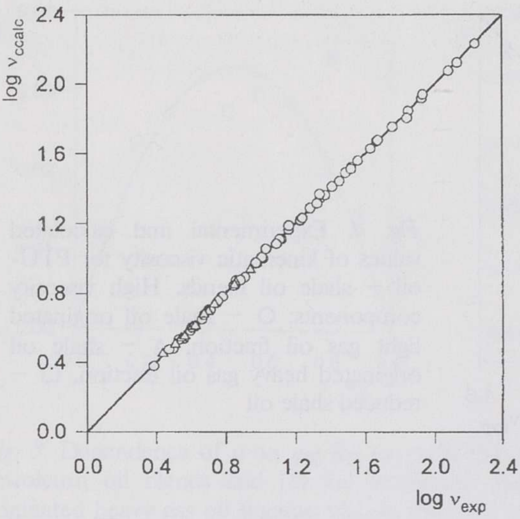


Fig. 7. Experimental and "corrected" calculated values of kinematic viscosity (mm^2/s) for petroleum originated light gas oil – shale oil originated gas oil fraction blends. High viscosity components: O – shale oil originated heavy gas oil fraction, Δ – shale oil originated light gas oil fraction

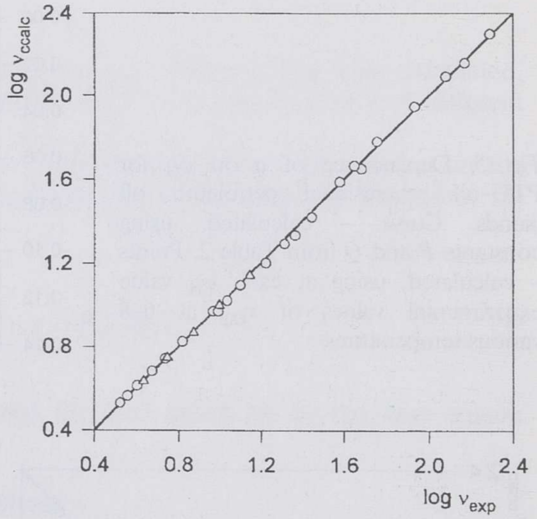


Fig. 8. Experimental and "corrected" calculated values of kinematic viscosity (mm^2/s) for petroleum originated light gas oil – residual shale oil. High viscosity components: O – shale oil long residue, Δ – reduced shale oil

Unlike the petroleum originated gas oil blends, the viscosity of PTU-oil blends with the reduced shale oil or with the shale oil originated gas oil fractions, both light and heavy, can be evaluated by the standard blending calculation technique accepted for hydrocarbon blends (Fig. 4). Therefore, it is somewhat unexpected that when the PTU-oil is blended with the residual petroleum oil, the values of experimental viscosity systematically differ from calculated ones. Contrary to the light gas oil blends, in this case the values of ν_{exp} are lower than ν_{calc}, although the dependence of p and q on the volume fraction of components can be described by Equations (2) and (3) (Fig. 5).

Using Equation (4), constants P and Q for PTU-oil – residual petroleum oil blends were also calculated (Table 2).

Using values of P and Q from Table 2, the "corrected" calculated values of blend kinematic viscosity (ν_{ccalc}) were obtained. Comparison of these values with the experimental ones confirms that for all blends presented in Table 2, at each component proportion a good accordance of results has been reached (Figures 6–9).

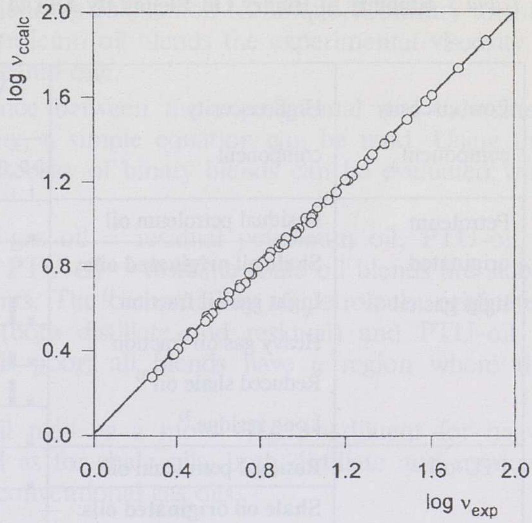


Fig. 9. Experimental and "corrected" calculated values of kinematic viscosity (mm^2/s) for PTU-oil – residual petroleum oil blends. Volume fraction high viscosity oil (φ_H) varies from 0.10 to 0.90

Stability of Blends. From the results obtained, it follows that when the conventional petroleum originated light gas oil is blended with residual petroleum oil, the blends are stable at every ratio of components (Table 3).

Contrary to this, the compatibility of petroleum originated light gas oil and shale oil originated oils, both distillate and residual, is poor. Petroleum originated light gas oil – shale oil originated light gas oil fraction blends are unstable, when the volume fraction of high viscosity component is below 0.40. Petroleum originated light gas oil – reduced shale oil blends settle into two layers, when the volume fraction of the high viscosity component is below 0.47. When the petroleum originated light gas oil is blended with the long residue from shale oil distillation, the blends are unstable at the region where φ_H = 0.65–0.85.

PTU-oil – residual petroleum oil and PTU-oil – shale oil originated distillate oil blends are stable at every ratio of components. Contrary to this, the compatibility of PTU-oil and residual shale oils is poor.

When the PTU-oil is blended with reduced shale oil, the blends have a region of poor stability at φ_H = 0.87–0.93. PTU-oil – shale oil long residue blends are unstable at the region where φ_H = 0.67–0.83.

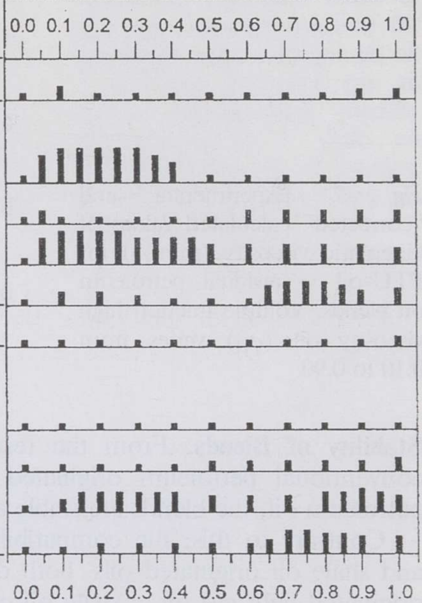
Results of this study lead to an important conclusion: the aromatic-rich PTU-oil may be a more effective diluent for heavy petroleum residues, as well as for shale oils, than petroleum originated conventional gas oils.

In comparison to petroleum originated gas oil – shale oil blends, for PTU-oil – shale oil binary blends, the resulting kinematic viscosity is always lower, and the region of poor stability of blends narrows down.

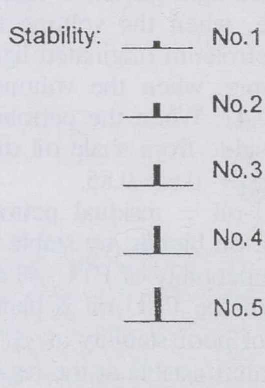
Using the approach described both in this and in our previous papers [1, 9], blending tables for various petroleum oil – shale oil blends may be compiled.

Table 3. **Stability of Binary Oil Blends By ASTM D 4740 Spot Test**

Low viscosity component	High viscosity component	Volume fraction of high viscosity component
Petroleum originated light gas oil	Residual petroleum oil	
	Shale oil originated oils:	
	Light gas oil fraction [1)]	
	Heavy gas oil fraction	
	Reduced shale oil [2)]	
	Long residue [3)]	
PTU-oil	Residual petroleum oil	
	Shale oil originated oils:	
	Light gas oil fraction	
	Heavy gas oil fraction	
	Reduced shale oil [4)]	
	Long residue [5)]	



Region of unstability at φ_H:
1) 0.03–0.40
2) 0.04–0.47
3) 0.65–0.85
4) 0.87–0.93
5) 0.67–0.83



Conclusions

1. The kinematic viscosity of so-called PTU-oil – shale oil binary blends can be evaluated by the standard blending calculation technique accepted for hydrocarbon oil blends.

2. When the low viscosity component is the petroleum originated light gas oil and the high viscosity component is a residual petroleum oil or shale oil originated oil, both distillate and residual, the experimental values of blend kinematic viscosity are always higher than the calculated ones, which are obtained by the standard blending calculation technique. Contrary to this, for PTU-oil – residual petroleum oil blends the experimental viscosity is always lower than the calculated one.
3. For evaluation the difference between the experimental and calculated values of kinematic viscosity, a simple equation can be used. Using this approach, the kinematic viscosity of binary blends can be evaluated with great accuracy.
4. Petroleum originated light gas oil – residual petroleum oil, PTU-oil – residual petroleum oil and PTU-oil – distillate shale oil blends are stable at every ratio of components. The compatibility of petroleum originated light gas oil – shale oil (both distillate and residual) and PTU-oil – residual shale oil blends is poor; all blends have a region where the stability is poor.
5. The aromatic-rich PTU-oil may be a more effective diluent for heavy petroleum residues, as well as for shale oils, both distillate and residual, than petroleum originated conventional gas oils.

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