A Study of Oil Viscosity Mental Model

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Abstract. There is no study regarding on how to learn viscosity of the liquid (e.g. oil) by interconnecting macroscopic, sub-microscopic and symbolic levels. Therefore, the purpose of this research was to study the mental model of the oil viscosity. Intermolecular attractive force of oil constituent on the sub-microscopic level is depicted in the form of mental models. In this research, the viscosity data for some types of oil was measured by using Hoppler method. Viscosity of mineral oil SAE 20W-50, mineral oil SAE 15W-40 and synthetic oil SAE 10W-40 were 1.75, 1.31, and 1.03 Pa s, and the densities of these oils were 908.64, 885.04, and 877.02 kg/m³, respectively. The results showed that the greater density of the mineral oil that is assumed to be composed of linear chains of hydrocarbons, the longer the chain of hydrocarbon linear. Consequently, there are stronger the London force and greater the oil viscosity. The density and viscosity of synthetic oil are lower than that of both mineral oils. Synthetic oil structurally forms polymers with large branching. This structure affects a lower synthetic oil viscosity. This study contributes to construct a mental model of pre-service chemistry teachers.

1. Introduction
The property that characterizes a fluid’s resistance to flow is its viscosity, \( \eta \), eta [1]. Viscous fluid tends to adhere to solid surfaces that contact with fluid. The fluid that flows easily - such as water or kerosene- has less viscous than thick fluid, such as honey or lubricating oil. One of viscosity concept application is oil lubricating as engine lubricant. The viscosity of oil is considered in reducing the frictional forces generated by the machine moving and contacted each other, to prevent attrition, especially in piston area. According to the oil viscosity, it is known oil identifier code, SAE (Society of Automotive Engineers). The numbers followed that code, showing the level of the oil viscosity. For example lubricating oil with SAE 10W-30, it means that oil has a viscosity SAE 10W in low temperature and SAE 30 in high temperature [2]. The greater number that follows to the oil code indicates more viscous the oil. SAE 30 motor oil is more viscous than SAE 10 motor oil [3].

Application of viscosity concept in oil as engine lubricant is very interesting to be used as a context in studying liquid viscosity. Viscosity is one of the topics studied by pre-service chemistry teachers in physical chemistry lecture. So far, there is no study regarding on how to learn viscosity of the liquid (such as oil) by interconnecting the three levels of representation: macroscopic, sub-microscopic and symbolic levels. The ability of students to interconnect the three levels of chemical representation reflects their mental model [4]. An internal representation of cognitive constructed by someone, including a visual-pictorial component and propositional components to understand or to give a
rational explanation of a real-world phenomenon, imaginary situations, events, or processes that their structures reflect perceived structure of the situations, events or process is called mental model [5, 6].

Pre-service chemistry teachers are expected to interconnect the three levels of chemical representation in order to have a holistic understanding of the chemistry. In learning chemistry, pre-service chemistry teachers also study physical chemistry. However, the results of the study that conducted by Nyachwaya & Wood showed that most physical chemistry textbooks omitted discussion on how to interconnect mathematical representations to the macroscopic level or sub-microscopic level [7]. The use of multiple representations to interconnect macroscopic, symbolic and sub-microscopic level was very minimal, not more than 1% of the overall picture in the text. It was also found in student’s activity in the laboratory in physical chemistry lecture. The lack in using multiple representations is certainly an impact on the construction of student mental models.

Based on the above explanation, it should be an effort how to design a lesson on this topic by interconnecting the three levels of chemical representation. As an initial step, it has been studied viscosity of the liquid mental models, such as oil. Therefore, the purpose of this research was to study the mental model of the oil viscosity. Mental model describes intermolecular attractive force of oil constituent on the sub-microscopic level. This study contributes to construct a mental model of pre-service chemistry teachers.

2. Methods

Viscosity data of various types of oil was obtained by using Hoppler method (falling ball method). Materials were mineral motor oil SAE 20W-50, mineral motor oil SAE 15W-40 and synthetic motor oil SAE 10W-40. Apparatus were a 100 ml cylinder, a solid glass ball, a ruler, a stopwatch, a clipper, an analytical balance, a digital thermometer and a pycnometer.

Firstly, the third types of oil measuring in the same temperature. Secondly, the density of solid glass balls and oil was determined. Thirdly, cylinder was marked at a distance of 5 cm from the oil surface. Furthermore, oil was poured into a cylinder. Solid glass ball was dropped into the oil and the transmission time of solid glass ball in a distance of 5 cm from the surface of oil will be recorded. These steps were carried out to a distance of 10 cm and 15 cm from the oil surface. Data obtained from the optimization procedure laboratory were studied descriptively with explanation at the submicroscopic and symbolic levels.

3. Results and Discussion

Table 1 shows the results data in measuring oil viscosity. It was time measured for a solid glass balls in the oils at a certain distance along with its viscosity. The radius of solid glass balls used was 0.78 cm.

| Oil SAE         | The density of oil (kg m\(^{-3}\)) | The density of glass ball (kg m\(^{-3}\)) | The time for ball (seconds) | Oil Viscosity (Pa. s) | The Average of oil viscosity (Pa. s) |
|-----------------|------------------------------------|------------------------------------------|-----------------------------|-----------------------|-------------------------------------|
| 20W-50 (oil 1)  | 908.64                             | 2250.629                                 | 0.55                        | 0.85                  | 1.5                                 | 1.96                                | 1.51                                | 1.78                                | 1.75                                |
| 15W-40 (oil 2)  | 885.04                             | 2250.629                                 | 0.37                        | 0.70                  | 1.1                                 | 1.34                                | 1.27                                | 1.32                                | 1.31                                |
| 10W-40 (oil 3)  | 877.02                             | 2250.629                                 | 0.30                        | 0.50                  | 0.9                                 | 1.09                                | 0.91                                | 1.09                                | 1.03                                |

3.1. Mental Model of Oil Viscosity

Oil can be grouped into two majors, mineral oil and synthetic oil. Mineral oils are the chemical components obtained from crude oil (petroleum crude oil). Crude oil is classified as paraffinic or
Naphthenic. Paraffinic crude oil contains lots of linear and branched hydrocarbons. Naphthenic crude oil contains few of the long-chain "wax-like" hydrocarbon components which carbon atoms linked in rings. These rings are known as cyclo-paraffins. Paraffinic and Naphthenic structure are presented in Figure 1.

![Figure 1. Structure of paraffinic and naphthenic](image1.png)

According to Figure 1, the structure of oil constituents affects to the stronger of intermolecular forces among oil constituents. The closer distance between molecules so that intermolecular forces of hydrocarbon even greater. Cyclo-paraffinic has stronger intermolecular forces than paraffinic because of its structure. It forms rigid structure. Aromatic compound has more stable structure than others because of electron delocalization.

3.1.1. Mineral Oil SAE 20W-50 and SAE 15W-40

In macroscopic models mineral oil SAE 20W-50 (oil motor 1) more viscous than oil mineral SAE 15W-40 (oil motor 2). Table 1 shows that oil motor 1 has density (908.64 kg m⁻³) greater than oil motor 2 (density was 885 kg m⁻³). Based on this phenomenon, hydrocarbon constituents in both mineral oil are assumed in the form of linear hydrocarbons. Hydrocarbon constituent mineral oil 1 is longer than mineral oil 2.

Oil lubricating is composed by hydrocarbon C₂₀₋₇₀ [9]. The mineral oil SAE 20W-50 is assumed to be composed by linear hydrocarbon dotriacontane, C₃₂H₆₆. In sub-microscopic, intermolecular forces occurred between dotriacontane constituents of mineral oil 1 through London forces. The hydrogen atoms of an alkyl group at dotriacontene molecule will interact with hydrogen atoms from other molecules dotriacontane. Visualization intermolecular forces on the sub-microscopic level between dotriacontane molecules through London forces is shown in figure 2.

![Figure 2. Mental model of mineral oil SAE 20W-50](image2.png)

In the meantime for mineral oil SAE 15W-40, it is composed by linear hydrocarbon hentriacontane, C₃₃H₆₈. There are intermolecular forces between hentriacontane molecules through London forces too. The hydrogen atoms of an alkyl group at hentriacontane molecule will interact with hydrogen atoms from other molecules of hentriacontane. Figure 3 shows a visualization of
intermolecular forces between hentriacontane molecules through London forces at the sub-microscopic level.

The longer chain hydrocarbon constituent mineral oil and the closer the distance of the molecules affect intermolecular forces (London forces) even bigger. As a result, the increasing friction occurs between the ball and mineral oil and its viscosity also grow. Viscosity of the both oil is increasing with the increase in the value of SAE. It was supported by the average viscosity data obtained in this experiment. Viscosity of mineral oil SAE 20W-50 was 1.75 Pa s and 1.31 Pa s for mineral oil SAE 15W-40.

3.1.2. Synthetic Oil SAE 10W-40
Poly-Alp-Olefins (PAO) are constituent components of synthetic oil that more widely used by industrial synthetic lubricants (oil) in the United States and Europe [8]. Motor-oils today can be designed and manufactured therefore the performance closely matches PAO in most commercially significant in applications [10]. PAO has a double bond and forms polymer. PAO synthesized through two stages (sequence) of linear Alpha-Olefins derived from ethylene. The first stage is the synthesis of oligomers with the aid of a catalyst, for example BF₃. The second stage is the hydrogenation of the double bond in the oligomers in order to produce a more stable structure (not easily oxidized). The polymer formed is estimated to have a relative molecular mass of ≤ 10,000 [11]. Figure 4 shows the structure of PAO [8].

![Figure 4. PAO Structure](image)

Synthetic oil SAE 10W-40 is less viscous than others. The result of this experiment showed that density of synthetic oil (877.02 kg m⁻³) was lower than others. Synthetic oil was assumed contains PAO, Poly-Alp-Alpha-Decene. It forms polymer (C₁₀H₂₀)n. Synthetic oil structurally forms polymers with large branching. This structure affects the decrease of molecule orientation and weaker of intermolecular forces. Finally, the decrease friction occurs between the ball and this synthetic oil. Furthermore, visualization of this molecule structure in the trimmers-form (C₁₀H₂₀)₃ is presented in Figure 5.
The lowest SAE of this synthetic oil than others was supported by the average of viscosity data that obtained in this experiment. It is shown in the table 1. The mental models of various types of oil with different SAE is an internal representation of researchers cognitive in the form of visualization components intermolecular forces that occurs in the oil and propositional components as well as the definition of mental models synthesized from several experts [5, 6]. The components contained in each type of oil are an analogy to explain the observed phenomena. This is agreement with those of Coll’s [12] that mental models used to produce a simpler concept, to provide stimulation and support for the visualization and provide explanations for scientific phenomena.

3.2. Different Types Oil Viscosity to the Time Solid Glass Ball at a Certain Distance
Furthermore, the result data was obtained in measuring oil viscosity and the explanation in sub-microscopic level (intermolecular forces oil constituent) can be expressed in mathematical modelling. This graph shows the relationship of the viscosity of various types of oil to the time solid glass ball at a certain distance from the surface of the oil.

![Figure 5](image.png)

**Figure 5.** Mental model of synthetic oil SAE 10W-40

![Figure 6](image.png)

**Figure 6.** Graph relationship viscosity of various types of oil to the time dropping solid glass ball at a distance of 15 cm from the surface of the oil

Figure 6 shows that viscosity of mineral oil 1, mineral oil 2 and synthetic oil were 1.78 Pa s, 1.32 Pa s and 1.09 Pa s. The time for solid glass ball at a distance of 15 cm from the surface of the oil at the oil temperature of 26.6°C for all three kinds of oil are 1.5 seconds (mineral oil 1), 1.1 seconds (mineral oil 2) and 0.9 seconds (synthetic oil). The bigger viscosity of fluids (the fluid more viscous) the greater time of a ball dropping in the fluids. However, the value of the various types of motor oil viscosity in this research is not the same because of differences in the value of the density of motor oil. This suggests that oil constituent and its molecular structure can vary. The density of motor oil SAE 15W-40 by this research at oil temperature 26.6°C is 885.04 kg / m³ with a viscosity of 1.31 Pa s. The density of motor oil SAE 15W-40 by Vis科普edia data at temperature 26.6°C is between 878.7 kg / m³ and 872.5 kg / m³ with viscosity between 0.15531 and 0.28723 Pa s [13]. Meanwhile, motor oil viscosity SAE 40 according to V & P Scientific Inc. is 0.65 to 0.9 Pa s at temperature 21.11°C [14].

The oil temperature in this research was controlled to be the same. The increasing oil temperature affects a number of energy absorbed by the oil so that it can break the interactions that occur in the oil.
Movement of oil particles is more quickly when the temperature is increased. As a result, intermolecular attractive force and friction occurs between the oil and the ball will decrease. Then, oil viscosity will decrease too. Anyway the higher the temperature the smaller liquid viscosity. If the viscosity is smaller, then the time of the glass ball at a certain distance will be smaller. Therefore, it can be concluded that the temperature is inversely proportional to viscosity.

Based on this study, the thickness phenomenon of oil which indicated by the viscosity SAE grades can be explained by using the concept of intermolecular forces and molecular structure. Pre-service chemistry teachers understanding of these concepts may affect to the construction of their mental models about oil viscosity. This opinion is the same as Tumay’s [5] that the ability to construct and use mental models can impact the conceptualization learners about chemistry concepts. Therefore, the study of oil viscosity mental models is very useful to the construction of mental models and increased understanding of pre-service chemistry teachers on this matter. In order to conduct knowledge into long-term memory, students should be encouraged to use mental models in order to see how to connect all three levels of representation [15]. The efforts to develop a basic understanding of chemistry concepts, learners should be able to interconnect their understanding of the symbolic level to the macroscopic level and the sub-microscopic level [16, 17]. It certainly needs to be supported by the pattern of teaching facilities are useful for generating discussion connectedness between levels of representation [18].

4. Conclusion

Study of oil viscosity mental models was expressed in visualization of intermolecular forces that occur between oil constituents. Oil that has bigger SAE macroscopically is more viscous, indicating a strong intermolecular attractive force. The longer hydrocarbon chain constituent of mineral oil, the greater London forces, therefore the viscosity of the oil increases. Synthetic oil structurally forms polymers with large branching. This structure affects a lower synthetic oil viscosity. The results of this study can be followed by designing a fluid viscosity by interconnecting of the three levels of representation as improving mental models and increasing concept understanding of pre-services chemistry teachers.

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References

[1] Levine I R 2009 Physical Chemistry (New York : Mc-Graw Hill) pp 479-87
[2] Thibault R 2001 Machinery Lubrication1 (Tulsa : Noria Corporation) pp 3–6
[3] George N J, Obianwu V I, Akpan A E and Obot I B 2010 Arch. Phys. Res. I pp 103-11
[4] Chittleborough G D 2004 Ph. D. Thesis (Australia : Curtin University of Technology).
[5] Tumay H 2014 Chem. Educ. Res. Pract. 15 pp 366-79.
[6] Wang C Y and Barrow L H 2010 Res. Sci. Educ. 41 pp 561-86
[7] Nyachwaya J M and Wood N B 2014 Chem. Educ. Res. Pract. 15 pp 720-8
[8] Culpon D H and Mead T C 1992 Lubricationed Oberender F G (New York : Texaco Inc) p1
[9] Ahmed N S and Nassar A M 2011 Tribology Fundamentals and Advancements (In Tech) p 250
[10] Balabin R M and Safieva R Z 2008 Fuel 87 pp 2745-52
[11] Song W and Heilmans W J U.S. Patent No. 7129197
[12] Coll R K 2009 Educ. Quim pp 18-31
[13] Viscopedia Engine Oil see http://www.viscopedia.com/viscosity-tables/substances/engine-oil/
[14] V&P Scientific, inc. Viscosity Tables see http://www.vp-scientific.com?Viscosity_Tables.htm .
[15] Jansoon N,Coll R K and Somsook E 2009 Int. J. Env. Sci. Educ. 4(2) pp 147-68
[16] Bain K, Moon A, Mack M R and Towns M H 2014 Chem. Educ. Res. Pract. 15 pp 320–35
[17] Hernandez G E, Criswell B A, Kirk N J, Sauder D G and Rushton G T 2014 Chem. Educ. Res.
Pract. 15 pp 354-65

[18] Becker N, Stanford C, Towns M and Cole R 2015 Chem. Educ. Res. Pract. 16 pp 769-85