Experimental research on Friction factor of glycerol based DES

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1. Introduction

Last 20 years, many researches have been carried out to apply Ionic Liquids(ILs). ILs are the solvent that only consist of ions, ILs synthesize can be categorized into two sections. First, eutectic mixing with metal halide and organic salt. Secondly, include at least one discontinuous anion[1]. While the need for organic solvents increases, but the high costs of ILs, these days DES[3] (Deep Eutectic Solvent) which is similar object to ILs is emphasizing and also introduced on Abbot et al(2003). Basically, DES is mixture of two or more of compound, mixture has less melting point than each compounds[4,5]. Moreover, DES is prepared by mixing salt and HBD(Hydrogen Bond Donor), it hydrogen bonds with salt anion. DES can be made by various kinds of salt(organic and inorganic) and HBD[2]. DES's physical, chemical properties are similar with[6] existing ILs. However, DSE has more sustainable advantage than ILs not just synthesize method, low cost, non-toxic but also environmental and economic advantage[6,7.8]. In this experiment, mixture of CHCl and glycerol will be used as 1:2 molar ratio. This fixed condition was used because many properties of this mixture has been researched and experimented. Lately, in many application fields there are reports about application of DES, one of them used CHCl based DES which used CHCl as a functional additive for starch-based plastics[9]. This experiment is basic research of heat transfer fluid for solar heat or 4th generation of nuclear power.CHCl based DES is used for catalyst to produce bio diesel fuel from low grade palm oil[10,11], and for electrolyte in electrochemical processes such as deposition of certain metals and electroless plating of metals[12,13]. And also, it used for eutectic solvent for epoxide hydrolysis using an enzyme-catalyst[14]. Glycerol is just solvent defined as polyol and used in many industrial applications, especially broadly on food and pharmaceutical industrials. But, it also have disadvantages because it is low solubility on organic compound and its limited use in organic transformation due to the inherent reactivity of polyols[15]. To overcome these disadvantages, many efforts are executing on various way to improve glycerol's physical, chemical properties[15,16]. One of these methods is manufacture DES consisting glycerol as HBD. While, glycerol is usually used on food and pharmaceutical industrial, in this experiment, using DES based on glycerol, the experiment about dynamic characteristics as a heat transfer medium was conducted. In chapter 2, describe about methodology and preparation using in this experiment. And in chapter 3, describe about experimental result.

2. Preparations and Methods

2.1 Manufacturing DES

In this chapter, the manufacturing method how to make Glyceline which is DES, mixture by CHCl and Glycerol, 1:2 molar ratio will be mentioned. Also, after measuring Glyceline's properties such as density and viscosity, through comparing with other researches, verify the quality of manufactured DES. By using 1:2 molar ratio of CHCl as a salt and Glycerol as a HBD, put them all together in the beaker or flask. Then using the heated stirrer, DES has made by mixing condition of 75℃, 600RPM for 2hours. In this manufacturing method, only except molar ratio of CHCl and glycerol, other conditions such as temperature, number of rotations, and time could be changed. Chemical formula of CHCl is $C5H14ClNO$, melting point is 302℃, molecular mass is 139.62 g/mol. Chemical formula of Glycerol is $C3H8O2$, melting point is 17.8℃, molecular mass is 92.094g/mol. Following, manufacturing 2kg of Glyceline, mass ratio of CHCl and Glycerol is 862.363g : 1137.637g.

Fig. 1. Glyceline manufacture process and result

After manufacturing Glyceline, it needs to be confirmed that it is manufactured properly. Therefore, after measuring density and viscosity of manufactured Glyceline, then compared with Glyceline's properties which were known by M. K. Alomar et al(2016)[17].

Density can be simply calculated by measuring volume and mass. After putting Glyceline on the reservoir which can measure the volume, measure the mass by maintaining constantly on the target temperature Then, calculate density by dividing measured mass by volume. Calculated density value through this test is figure 2.

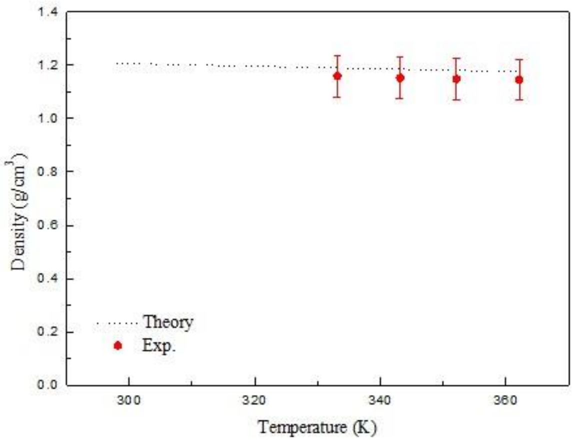

Fig. 2. Result of manufactured Glyceline density measurement

Density of manufactured Glyceline for the main experiment is calculated average 2.5% lower than the theory value. If reflecting the uncertainty of measuring volume by using reservoir and measuring mass by using scales, theory value is in measurement error range. Accordingly, manufactured Glyceline for the main experiment is judged properly manufactured.

Viscosity was measured directly by using viscometer. Quality specification of used viscometer is this. Viscometer model name is 'CL-1', measurement range is 1~ 2,000,000 cP. Accuracy of this viscometer is ±1% (Newtonian fluid), reproducibility is 0.5% (Newtonian fluid), operating temperature range is -5 ~ 100℃. Result of viscosity measurement is figure 3. It was measured on 334K, error between theory value is 3.708%.

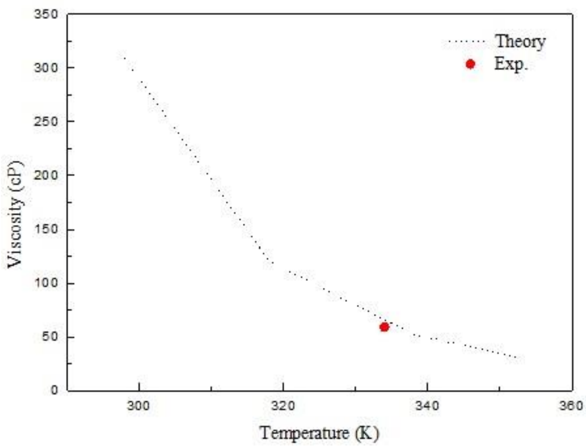

Fig. 3. Result of manufactured Glyceline viscosity measurement

To verify of appropriates of manufactured Glyceline, measure the density and viscosity, after comparing with theory value, density has 2.5% error and viscosity has 3.708% error. The reason why there occurs a little error is during manufacturing DES uncertainty of measuring mass causes uncertainty of molar ratio. However, density and viscosity of manufactured Glyceline has a little gap between the theory value, through that this DES manufactured appropriately to carry out this experiment.

2.2 Experimental apparatus

Purpose of this study is measuring DES's dynamic characteristics such as friction factor available as molten salt. Therefore, to accomplish the main purpose experimental device has designed and built like figure 4. By using the pump(PM-101, PM-102), we construct the device by making the fluid flow from Reservoir to test section, then circulates back to reservoir. During dynamic characteristics experiment, calculate the DES's friction factor by using the data from differential pressure gauge which installed in test section and flux from flow meter which installed following the pump. Chiller is used for making reservoir's temperature steady by chilling the DES which heated through test section then it inflows back to reservoir. The valve following flow meter is built to control the flux.

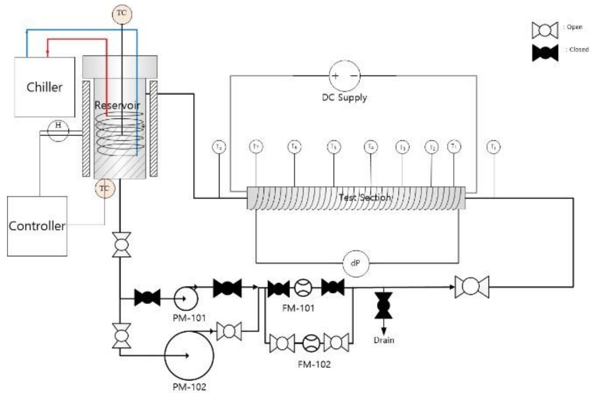

Fig. 4. Experimental apparatus schematic

Now, flow meter, differential pressure transmitter, thermocouple has been fixed. Flow meter is produced by Badger Meter Co,. Ltd., the model name is IND OG1"-S-S-ILR740-1-V. Flow meter's measurement Range is 5.7 ~ 170 LPM. Differential pressure gauge is produced by SCS Co,. Ltd., the model name is DWSH00.3MPH. The measurement range is 0 ~ 300 kPa. Thermocouple that used in this experimental apparatus is produced by OMEGA, the model name is CHROMEGA™-ALOMEGA™ XL Sheath, and K-type thermocouple

3. Result

In this section, through the experimental apparatus above, introduce the result of DES friction factor.

3.1 Measurement of Friction factor

Experimental procedure of measuring friction factor by using Glycelne manufactured in chapter 2. Put DES on the reservoir and circulates DES while keeping the steady temperature and same flux. After measuring the flux and differential pressure at this moment, calculate friction facor according to the Reynolds number change, and compared with the Poiseuille friction factor and Blasius friction factor, which are theoretical valuesof the friction factor for water in a circular tube. Following equation shows how to calculate Reynolds number by following equation.

$$Re = \frac{\rho\, v\, d}{\mu}$$

In this equation, ρ is density of DES(kg/m3), is v velocity of DES, d is diameter of circular tube, and μ is viscosity of DES. Desnsity, viscosity, and diameter is constant number on the fixed temperature in this equation. Accordingly, the velocity by measuring the flux can calculate Reynolds number. The friction factor can be calculated by using measured differential pressure and Darcy's formula. Darcy's formula is following equation..

$$\Delta P = f \frac{L}{D}\frac{1}{2}\rho v^2$$

ΔP is the differential pressure between inlet and outlet of test section, L is the length of test section, and D is the inner diameter of test section. Therefore, The friction factor can be calculated by using differential pressure that measured, flux and following equation.

$$f = \Delta P \frac{D}{L}\frac{2}{\rho v^2}$$

By comparing the friction factor calculated through the equation above and the theory value of the water in circular tube's friction factor, compare water and DES's dynamic characteristics. Friction factor on laminar region follows Poiseuille friction factor equation.

$$f = \frac{64}{Re}$$

Also, on the turbulent region, it follows Blasius friction factor equation.

$$f = 0.3164\, Re^{-0.25}$$

The appropriateness of experimental apparatus was evaluated by measuring water's friction factor and compare with the theory value, before using DES. Experimental result by using water is figure 5. Experimental result by using water confirmed that measured friction factor and the theory value matches exactly. Through this result, this experimental apparatus is designed and constructed appropriately.

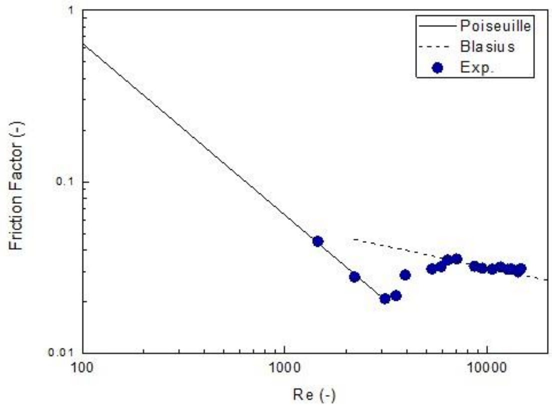

Fig. 5. Result of friction factor measuring experiment by using water

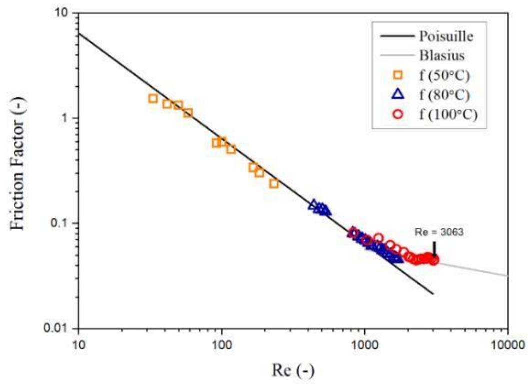

Fig. 6. Friction factor measurement result by using Glyceline

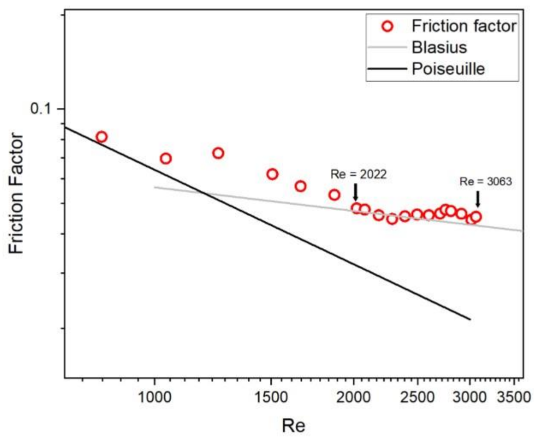

Fig.7. Friction factor measurement result by using Glyceline on turbulent region

Then the same experiment was carried out by using Glyceline. When Glyceline is steady on 50°C, 80°C, 100°C, then measured differential pressure. Then figure 6 and 7 shows the result of friction factor. Because of the viscosity, there were a limit flow through the temperature. As figure 6 expresses the limitation Reynolds number through the temperature. The experiment was carried out until the Reynolds number is 3063. As figures 6 shows, the value of differential pressure increases linearly following Reynolds number. It shows that Glyceline is a Newtonian fluid. And as figure 7 shows, around Reynolds number is around 1000, it looks like transition region has started. Figure 7 shows the enlargement of transition region. Accordingly, the experimental friction factor value matches with Poiseuille friction factor and Blasius friction factor. The maximum error of the measured friction factor is 15%.

4. Conclsuion

The dynamic characteristics of DES, which is considered as an alternative to Ionic liquids, was conducted as an experimental study. The study was conducted by selecting Glyceline as DES, and carried out on laminar and turbulent region. Through the test, Glyceline was confirmed that it is a Newtonian fluid. In the laminar region, friction factor matched almost the same as the Poiseuille friction factor and in the turbulent region, it matched almost the same as the Blasius friction factor. The fact that Glyceline's dynamic characteristics are much similar to water has known already, therefore, by applying the theoretical value for water, the dynamic characteristics of Glyceline could be judged. There was a difference on transition region. For water case, transition region that from laminar to turbulent was about Reynolds number 2000~2400. But for Glyceline, transition region was about Reynolds number 1000~3000. In conclusion, Glyceline and water both follows Newtonian fluid property, but the difference from water and Glyceline is that the transition region from laminar to turbulent.

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