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How Better are Propylene Glycol-based Nanofluids Compared to Propylene Glycol? A Study in Small, Jacketed Vessel

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ABSTRACT

Experimental studies on heat transfer in a jacketed vessel were carried out to test the performance of two nanofluid coolants, viz. $Mn_{0.47}Fe_{2.53}O_4$-propylene glycol (2 vol%) and CuO-propylene glycol (1 vol%) nanofluids, against pure propylene glycol. The flow rate of process fluid (Therminol-55®) flowing through the jacket was varied between 60-500 mL min^{-1}. In general, these nanofluids were able to reduce the outlet temperature of process fluid to values lower than that achieved using pure propylene glycol. These nanofluids are more effective at higher flow rates of process fluid due to their improved transport properties.

Key words: Propylene glycol nanofluid, manganese ferrite, cupric oxide, jacketed vessel, heat transfer performance

INTRODUCTION

Heat transfer operations are carried out in industries for various applications, including preheating, energy conservation, drying etc. (Bandrowski and Kaczmarzyk, 1978; Namkung and Cho, 2004; Raju *et al.*, 1994; Rajan *et al.*, 2006, 2007a, b, 2008a, b, 2010; Radford, 1997; Shigeru and Pei, 1984). Cooling may be carried out using gas or liquid. Gases have poor thermal conductivity compared to that of liquids and hence are used for heating or cooling only when required in processes. Thermal conductivity and viscosity are the most important properties of liquids that are used for cooling. Water satisfies these properties as liquid coolant, apart from being available at lower cost, compared to other liquid coolants. When cooling duty is to be carried at sub-zero temperatures, glycol-based coolants are used. Ethylene glycol-water mixture and propylene glycol-water mixtures are used for such conditions, with former possessing better thermo-physical properties than the later. However, the toxicity of ethylene glycol is detrimental to applications in food industry. Hence, propylene glycol is used as coolant for food-industry applications.

There are only limited studies on the thermo-physical properties of propylene glycol-based nanofluids (Suganthi *et al.*, 2013a, b; Aishwarya *et al.*, 2013; Prasher *et al.*, 2006). There are no published reports on the actual performance of propylene glycol-based nanofluid coolants in a heat exchanger. Hence, the present study was carried out to test the heat transfer performance of propylene glycol-based nanofluid coolants. The jacketed vessel has been chosen as the heat exchanger geometry owing to its application in reactors. Also, the geometry provides scope for carrying out heat transfer experiments in a variety of test conditions, though experiments on only one of such test conditions has been carried out here.

The nanofluids chosen for the study are 1 vol% CuO-propylene glycol and 2 vol% $Mn_{0.47}Fe_{2.53}O_4$-propylene glycol nanofluids. CuO-propylene glycol (1 vol%) has a viscosity much lower than that of propylene glycol while its thermal conductivity is higher by 27% compared to that of propylene glycol (Suganthi *et al.*, 2013b). $Mn_{0.47}Fe_{2.53}O_4$-propylene glycol nanofluids (2 vol%) too has lower viscosity than propylene glycol and a much larger enhancement in thermal conductivity (71%) than that of CuO-propylene glycol nanofluid (Aishwarya *et al.*, 2013). The study of heat transfer performance of these two propylene glycol-based nanofluids with marked difference in transport properties and comparison of their heat transfer characteristics with those of pure propylene glycol is expected to provide insights about the real advantage of better transport properties of nanofluids. Such a study can also be used to ascertain whether the improvement in transport properties is reflected as improvement in heat transfer performance.

METHODS

A jacketed vessel heat exchanger of volume 50 mL was used for testing. The outer surface of the jacket was insulated to prevent heat transfer between fluid in the jacket and atmosphere. The jacket was provided with a liquid inlet at the bottom and a liquid outlet at the top. Therminol55-® was used as the process fluid in the jacket. The outlet temperature of the process fluid was recorded using KS-1 sensor of thermal property meter (KD2-Pro, Decagon Devices, USA). Three different service fluids were used: (1) Propylene glycol and (2) CuO-propylene glycol nanofluid and (3) $Mn_{0.47}Fe_{2.53}O_4$-propylene glycol nanofluid. These service fluids were studied for their capability to cool the process fluid. The use of service fluid in the cylinder vessel of the heat exchanger allowed heat transfer experiments to be carried out using lower volumes of nanofluid. A schematic diagram of experimental set-up is shown in Fig. 1.

The properties of propylene glycol and various nanofluids at 25-28°C, used for carrying out the experiments are shown in Table 1.

Table 1: Properties of propylene glycol and nanofluids

Fluid	Thermal conductivity (W mK^{-1})	Viscosity (mNs m^{-2})
Pure propylene glycol	0.2000	40.8
1 vol% CuO-propylene glycol nanofluid	0.2551	26.8
2 vol% $Mn_{0.43}Fe_{2.57}O_4$-propylene glycol nanofluid	0.3430	30.9

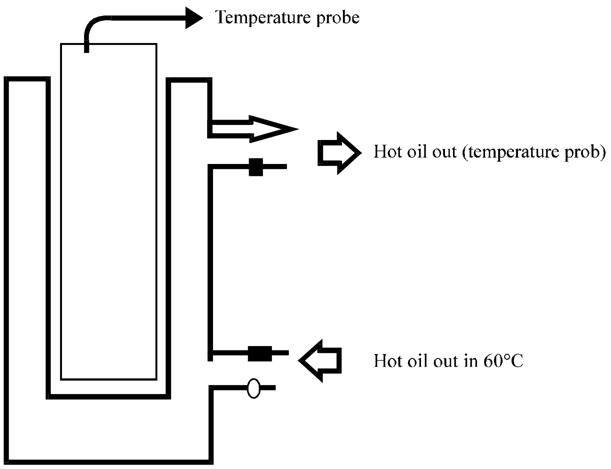

Fig. 1: Schematic diagram of jacketed vessel heat exchanger

The flow rate of process fluid tested for various fluids are shown in Table 2.

A typical experiment begins with filling the cylindrical portion of the vessel with the service fluid. The process fluid is supplied to the jacket at a fixed flow rate and at a fixed temperature, maintained using a constant temperature bath equipped with a digital temperature indicator and controller. The outlet temperature of process fluid was measured at different time points for about 3-10 min, to study response of the system.

RESULTS

A comparison of outlet temperature of process fluid while using propylene glycol and 2 vol% $Mn_{0.43}Fe_{2.57}O_4$-propylene glycol nanofluid as the service fluids are shown in Fig. 2-4 for the process

Table 2: Flow rates of process fluid used in the experiments

Service fluid	Process fluid	Flow rate of process fluid (mL min^{-1})
Pure propylene glycol	Therminol55-®	500, 380, 325, 300, 125, 60
1 vol% CuO-propylene glycol nanofluid	Therminol55-®	60, 300, 325
2 vol% $Mn_{0.43}Fe_{2.57}O_4$-propylene glycol nanofluid	Therminol55-®	500, 380, 125

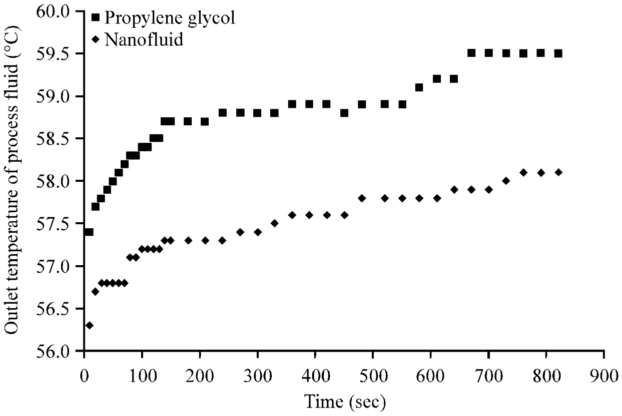

Fig. 2: Temporal variation of temperature of process fluid when cooled using propylene glycol and 2 vol% $Mn_{0.43}Fe_{2.57}O_4$-propylene glycol nanofluid. The process fluid was supplied at 60°C at a flow rate of 500 mL min^{-1}

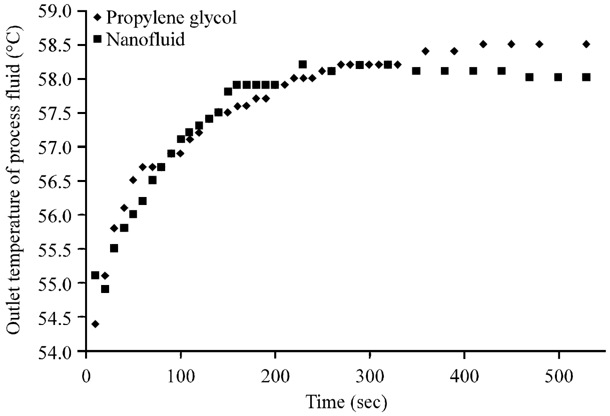

Fig. 3: Temporal variation of temperature of process fluid when cooled using propylene glycol and 2 vol% $Mn_{0.43}Fe_{2.57}O_4$-propylene glycol nanofluid. The process fluid was supplied at 60°C at a flow rate of 380 mL min^{-1}

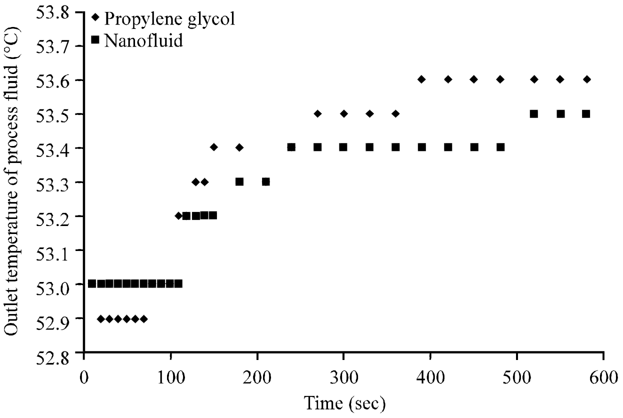

Fig. 4: Temporal variation of temperature of process fluid when cooled using propylene glycol and 2 vol% $Mn_{0.43}Fe_{2.57}O_4$-propylene glycol nanofluid. The process fluid was supplied at 60°C at a flow rate of 125 mL min^{-1}

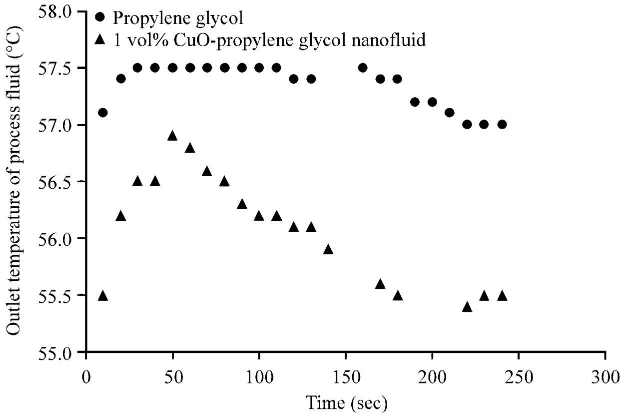

Fig. 5: Variation of outlet temperature of process fluid with time, when cooled by propylene glycol and CuO-propylene glycol coolants. The process fluid was supplied at the flow rate of 325 mL min^{-1}

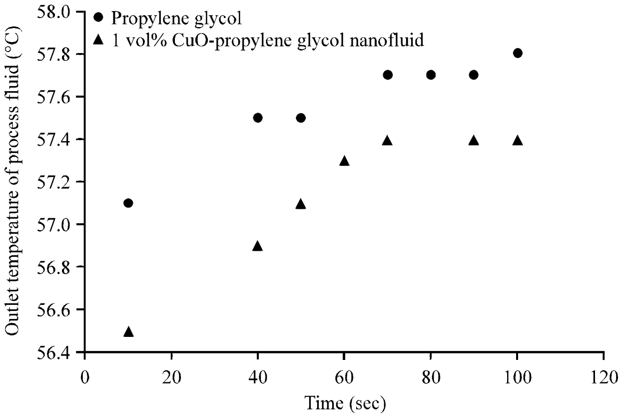

Fig. 6: Variation of outlet temperature of process fluid with time, when cooled by propylene glycol and CuO-propylene glycol coolants. The process fluid was supplied at the flow rate of 300 mL min^{-1}

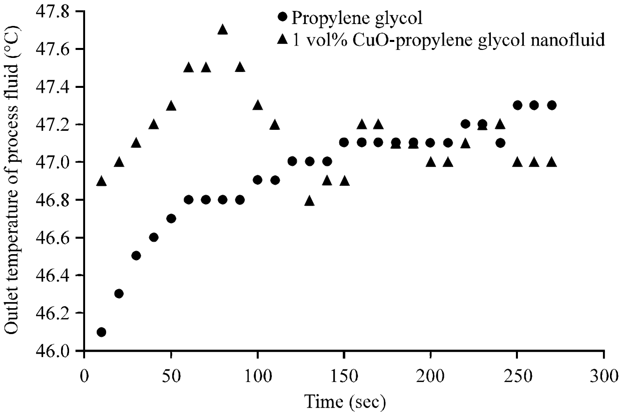

Fig. 7: Variation of outlet temperature of process fluid with time, when cooled by propylene glycol and CuO-propylene glycol coolants. The process fluid was supplied at the flow rate of 60 mL min^{-1}

fluid flow rates of 500, 300 and 125 mL min^{-1}, respectively. These figures depict the temporal-variation of temperature of process fluid at different flow rates, for the process fluid inlet temperature of 60°C.

The variation of outlet temperature of process fluid with time, when cooled by propylene glycol and CuO-propylene glycol coolants is shown for the process fluid flow rate of 325 mL min^{-1} in Fig. 5. Similar temporal profiles of process fluid temperature for other flow rates of process fluids are shown in Fig. 6-7. The temperature profile of process fluid, when cooled by different service fluids, is shown together in Fig. 2-7 for the purpose of ease of comparison and interpretation of results.

DISCUSSION

Performance comparison of propylene glycol and $Mn_{0.43}Fe_{2.57}O_4$-propylene glycol nanofluid: The temporal variation of outlet temperature of process stream supplied at 500 mL min^{-1}, shown in Fig. 2, for the case of cooling by propylene glycol and $Mn_{0.43}Fe_{2.57}O_4$-propylene glycol nanofluid indicates initial rapid increase in temperature with time, before saturation after about 600-700 sec. The constant outlet temperature of process fluid when cooled with propylene glycol was 59.5°C while that cooled with $Mn_{0.43}Fe_{2.57}O_4$-propylene glycol nanofluid was 58.2°C. Hence, it is clear that the outlet temperature of process fluid, when cooled by $Mn_{0.43}Fe_{2.57}O_4$-propylene glycol nanofluid, is lower by about 1.3°C when compared to the outlet temperature when cooled by pure propylene glycol.

Similar trends are observed when the process fluid was supplied at the rate of 380 mL min^{-1}. However, the difference between the outlet temperature of process stream when cooled by $Mn_{0.43}Fe_{2.57}O_4$-propylene glycol nanofluid was only 0.6°C when compared to the outlet temperature when cooled by pure propylene glycol. This difference is reduced to about 0.1°C, when the process stream was supplied at a flow rate of 125 mL min^{-1}.

The above results shows that the $Mn_{0.43}Fe_{2.57}O_4$-propylene glycol is a better coolant than propylene glycol at higher process fluid flow rate. This may be attributed to the fact that the residence time at higher process stream flow rate is low. Under these circumstances, the higher thermal conductivity of $Mn_{0.43}Fe_{2.57}O_4$-propylene glycol nanofluid enhances heat transfer rate, bringing down the outlet temperature of coolant more rapidly compared to that of pure propylene glycol alone.

Performance comparison of propylene glycol and CuO-propylene glycol nanofluid: It may be observed from Fig. 5 that the outlet temperature of process fluid increases initially with time, when cooled by propylene glycol and CuO-propylene glycol nanofluid, for the process fluid flow rate of 325 mL min^{-1}. The outlet temperature of process fluid saturates after certain time, with the temperature reached while cooling with CuO-propylene glycol nanofluid 1.5°C lower than that achieved with propylene glycol.

Similar results were observed for the process fluid flow rate of 300 mL min^{-1} as well. However, the difference in the outlet temperature of the process fluid when cooled by the two coolants is only 0.4°C. However, at the process fluid flow rate of 60 mL min^{-1}, the higher outlet temperatures occur while cooling with CuO-propylene glycol nanofluid when compared to cooling with propylene glycol alone. This shows that the CuO-propylene glycol is a better coolant than propylene glycol at reasonably higher process fluid flow rates.

CONCLUSION

The study of heat transfer performance of $Mn_{0.43}Fe_{2.57}O_4$-propylene glycol nanofluid, CuO-propylene glycol nanofluid and pure propylene glycol reveal that both $Mn_{0.43}Fe_{2.57}O_4$-propylene glycol and CuO-propylene glycol nanofluids perform better than propylene glycol. The better transport properties of these nanofluids, viz. higher thermal conductivity and lower viscosity compared to pure propylene glycol, contributes to their better performance. These nanofluids are more effective when the residence time of process fluid flowing through the jacket is lower. Further experimental studies are required to ascertain the heat transfer performance of these nanofluids in larger jacketed vessel geometry with continuous flow of both process and coolant streams.

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