A Novel Method for the Synthesis of Binary Molten Salt Nanofluids Adding SiO₂ Nanoparticles

Joohyun Seo (✉ joohyunseo1@gmail.com)

The University of Texas at Arlington

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Dr. Joohyun Seo
Postdoctoral Research Associate
Neutron Reflectometry Team
Large Scale Structures Group
Neutron Scattering Division
Neutron Sciences Directorate

OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE U.S. DEPARTMENT OF ENERGY

Spallation Neutron Source
P.O. Box 2008
Oak Ridge, TN 37831-6454
Email: seoj@ornl.gov

October 21, 2020

Dear Sir/Madam:

Please find enclosed the manuscript, "A novel method for the synthesis of binary molten salt nanofluids adding SiO₂ nanoparticles" by Joohyun Seo, which I would like to submit for publication as a full-length article in *Nanoscale Research Letters*. To my knowledge, this is the first report showing the new synthesis method for mixing a molten salt eutectic and nanoparticles. I believe my findings would appeal to the readership of *Nanoscale Research Letters*. I confirm that this manuscript has not been published elsewhere and is not under consideration by another journal. I look forward to hearing from you at your earliest convenience. Thank you.

Sincerely,

Joohyun Seo

A handwritten signature in black ink, appearing to read "Joohyun Seo". The signature is fluid and cursive, with the first name "Joohyun" and the last name "Seo" clearly distinguishable.

Enclosures: One (1) copy of the manuscript

Highlights

The new method has been suggested for the synthesis of a binary molten salt eutectic adding nanoparticles (i.e. molten salt nanofluids).

A binary nitrate-based molten salt eutectic ($\text{NaNO}_3\text{-KNO}_3$, 60:40 wt.%) was used as a base salt and 10nm of SiO_2 nanoparticles were used to add it to a molten salt eutectic.

The results of a modulated differential scanning calorimeter (MDSC) made a comparison with the enhanced specific heat capacity from previous nanofluid synthesis methods.

A suggested novel synthesis process adding a Liquid-to-Liquid method can not only prevent unexpected errors in the sample preparation, but also enhance the specific heat capacity of molten salt nanofluids.

A novel method for the synthesis of binary molten salt nanofluids adding SiO₂ nanoparticles

Joohyun Seo^{a,b,*}

^aNeutron Scattering Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA

^bThe Department of Materials Science and Engineering, The University of Texas at Arlington,
Arlington, TX 76019, USA

Abstract

In this study, the new method has been suggested for the synthesis of a binary molten salt eutectic adding nanoparticles (i.e. molten salt nanofluids). Solar salt (i.e. NaNO₃-KNO₃, 60:40 by weight) adding 10nm of SiO₂ nanoparticles was prepared to measure the specific heat capacity of molten salt nanofluids by a modulated differential scanning calorimeter (MDSC). In previous studies the sample preparation of a molten salt eutectic follows the same procedure. Each chemical of a molten salt eutectic and nanoparticles is dissolved in an aqueous solution. These homogeneous salts are completely mixed by a sonication. Nano-mixtures are scrapped off the bottom surface of a vial after drying. However, there are complex steps in the process of getting fresh molten salt eutectic nanofluids before MDSC measurements. An unexpected result is able to occur due to phase change (i.e. solid-liquid-solid) at each step and then it has an affect on the specific heat capacity of molten salt nanofluids. A suggested novel method (i.e. Liquid-to-Liquid) can not only prevent unexpected errors (e.g. the possibility of contamination) by phase change in the sample preparation, but also enhance the specific heat capacity of molten salt nanofluids.

^aCurrent affiliation

^{*}Corresponding author

Email address: seoj@ornl.gov (Joohyun Seo)

1. Introduction

Solar energy is limitless and clean energy [1]. People convert solar energy into a usable form to generate electrical power [2]. Solar photovoltaic and solar thermal energy are used to produce electricity in the field [3]. Solar thermal is used as an energy source in concentrated solar power (CSP) systems [4]. CSP systems consist of heliostats (i.e. mirrors), thermal energy system (TES), and a heat transfer fluid (HTF) that is used as a working fluid. TES stores thermal energy for later use. Thermal energy can be not only used for 24 hours, but also used regardless of the weather conditions, cloudy, even after sunset thanks to TES's capability in CSP systems. According to a previous study [5], commercial CSP systems with TES are already in operation in several areas over the world. A capacity of CSP systems (MW), annual electricity generation (MWh), type of a HTF, TES storage type, TES capacity (hours), and type of CSP systems varies from area to area on purpose. TES capacity is from 5MW to 2000MW and TES hours of operation is from 2.5 hours to 24 hours. A HTF stores thermal energy that is obtained by heliostats and moves this energy to a turbine engine to generate power. CSP systems operate at high temperature due to a HTF's thermal stability. A molten salt eutectic is used as a working fluid in TES. A molten salt eutectic has some advantages such as low vapor pressure, non-toxic, and abundant [6-7]. It is not only less expensive, it allows a low material cost of CSP systems [6]. A molten salt eutectic's low vapor pressure can also reduce a potential risk of mechanical structures at high temperatures. A binary, ternary, and quaternary molten salt eutectic, such as $\text{NaNO}_3\text{-KNO}_3$ (60:40, wt.%), $\text{NaNO}_2\text{-NaNO}_3\text{-KNO}_3$ (40:7:45, wt.%), $\text{Ca(NO}_3)_2\text{-NaNO}_3\text{-KNO}_3$ (48:7:45, wt.%), $\text{LiNO}_3\text{-NaNO}_3\text{-KNO}_3$ (20:28:52, wt.%), $\text{LiNO}_3\text{-Ca(NO}_3)_2\text{-KNO}_3$ (30:10:60, wt.%), $\text{NaNO}_2\text{-LiNO}_3\text{-NaNO}_3\text{-KNO}_3$ (17.8:17.5:14.2:50.5, wt.%), $\text{Ca(NO}_3)_2\text{-LiNO}_3\text{-NaNO}_3\text{-KNO}_3\text{-CsNO}_3$ (19:8:6:23:44, wt.%), $\text{NaNO}_3\text{-LiNO}_3\text{-Ca(NO}_3)_2\text{-KNO}_3$ (20:10:10:60, wt.%), $\text{NaNO}_3\text{-LiNO}_3\text{-}$

Ca(NO₃)₂-KNO₃ (10:20:10:60, wt.%), NaNO₃-LiNO₃-2KNO₃ Mg(NO₃)₂ (15:18:31:36, wt.%), NaNO₃-LiNO₃-NaNO₂-KNO₃ (14:18:18:50, wt.%), and LiNO₃-NaNO₃-KNO₃ (29.6:13.2:57.2, wt.%), are used as TES material in CSP systems [8-16]. These molten salt eutectics' melting point is from 65°C to 220°C. Its melting point is higher than the traditional HTF (e.g. mineral oils) and then it has high thermal stability up to 600°C. The thermodynamic efficiency of CSP systems (e.g. Rankine and Stirling cycle) is increased due to a molten salt eutectic's high melting point. The specific heat capacity of these molten salt eutectics is from 1.091kJ/kg °C to 1.67kJ/kg °C in a liquid state. However, it is less than 2kJ/kg °C and then this property is inadequate to reduce a size of TES and initial capital cost of CSP systems.

Previous studies have been reported the enhanced specific heat capacity of a molten salt eutectic adding nanoparticles [17, 18-31]. Different types of a molten salt eutectic adding nanoparticles were prepared to measure its specific heat capacity in several studies [17]. These studies reported types of a molten salt eutectic, types of nanoparticles, concentration percent of nanoparticles, synthesis procedure, measurement techniques, enhancement, and nanoparticles' diameter and shape. Al₂O₃ nanoparticles (<50nm) were dispersed in Hitec Salt (NaNO₃-KNO₃-NaNO₂, 7:53:40 by mole ratio) at different concentrations (i.e. 0.016, 0.063, 0.125, 0.25, 0.5, 1, and 2 wt.%) [32]. The specific heat capacity of these nanofluids (nitrate-based salts) has increased by 6.5%, 7.8%, 9.6%, 12.7%, and 19.9% respectively. A ternary nitrate molten salt eutectic (KNO₃-Ca(NO₃)₂ 4H₂O-LiNO₃, 67:19:14 %) was mixed with CuO and MoS₂ nanoparticles (200nm) at 0.5%, 1%, and 2% concentration (wt.%) [33]. These ternary salts' specific heat capacity is 0.5kJ/kg °C-2.125kJ/kg °C when CuO nanoparticles were dispersed in salts. The highest value of results is 2.125kJ/kg °C at 0.5% concentration of nanoparticles. MoS₂ nanoparticles were dispersed in these salts and its specific heat capacity is from 0.5kJ/kg °C to

2.385kJ/kg °C. It shows the highest value, 2.385kJ/kg °C, at 0.5% concentration of nanoparticles. A binary carbonate molten salt eutectic ($\text{Li}_2\text{CO}_3\text{-K}_2\text{CO}_3$, 62:38 by mole ratio) was mixed with SiO_2 nanoparticles (1% wt.%) [34]. Different sizes (5nm, 10nm, 30nm, and 60nm) of SiO_2 nanoparticles were added to these salts. The specific heat capacity has risen from 23% to 26% at 1% concentration. A ternary carbonate molten salt eutectic ($\text{K}_2\text{CO}_3\text{-Li}_2\text{CO}_3\text{-Na}_2\text{CO}_3$, 4:4:2 wt.%) by adding SiO_2 nanoparticles (1% wt.%) was prepared to measure the specific heat capacity of these nanofluids [35]. 5nm, 20nm, 30nm, and 60nm of SiO_2 nanoparticles were added to this ternary carbonate salt. The specific heat capacity of ternary carbonate nanofluids has increased by 70.2%, 103.7%, 113.7%, and 116.8% respectively. A quaternary molten salt eutectic ($\text{BaCl}_2\text{-NaCl-CaCl}_2\text{-LiCl}$, 34:13:40:13 %) was mixed with SiO_2 nanoparticles (20nm-30nm) at 1% concentration [36]. These alkali chloride-based nanofluids' specific heat capacity has increased by 14.5%.

Solar salt, which is a binary nitrate-based molten salt eutectic ($\text{NaNO}_3\text{-KNO}_3$, 60:40 wt.%), is already used as a HTF in TES in CSP systems around the world, Gemasolar Thermosolar Plant, SunCan Dunhuang, Crescent Dunes, and Archimede [37]. Two types (i.e. power tower and parabolic trough) of technology were used to obtain solar thermal energy. CSP systems' operating temperature range is from 290°C to 565°C and TES capacity is from 8 hours to 15 hours. The capacity of CSP systems (i.e. turbine engine) with solar salt is 5MW-110MW. A melting point of his binary molten salt eutectic is 220°C and it has high thermal stability up to 590°C. The specific heat capacity is 1.52kJ/kg °C and then several studies have been made to enhance this specific heat capacity by adding nanoparticles [5]. Different types (i.e. SiO_2 , Al_2O_3 , $\text{SiO}_2/\text{Al}_2\text{O}_3$, and CuO) of nanoparticle were dispersed in a binary molten salt eutectic (i.e. solar salt). SiO_2 nanoparticles were added to salts at different concentration, 0.5%-1% by weight. Different sizes (i.e. 5nm, 7nm, 10nm, 12nm, 30nm, and 60nm) of SiO_2 nanoparticles were also used to add it to salts. The specific

heat capacity of nanofluids adding 5nm of SiO₂ nanoparticles has increased by 10% at 1% concentration [38]. Nanofluids' (added 7nm of SiO₂ nanoparticles) specific heat capacity has gone up by 0.8%-2.6% at 1% concentration [39-40]. The specific heat capacity of nanofluids adding 10nm of SiO₂ nanoparticles increased by 13% at 1% concentration [38]. Nanofluids adding 12nm of SiO₂ nanoparticles increased by 2%-25.03% at 0.5%, 1%, 1.5%, and 2% concentration respectively [41]. When 30nm and 60nm SiO₂ nanoparticles (1% concentration) were dispersed in salts, its specific heat capacity has increased by 21% and 28% respectively [38]. 13nm of Al₂O₃ nanoparticles were dispersed to salts at 1% concentration and then the specific heat capacity of these nanofluids increased by 2.8%-5.9% [39-40]. SiO₂/Al₂O₃ nanoparticles were added to salts. Its specific heat capacity has increased by 3.6%-18.6% at 1% concentration of SiO₂/Al₂O₃ nanoparticles (2nm-200nm) [39]. The specific heat capacity of nanofluids adding 7nm/13nm of SiO₂/Al₂O₃ nanoparticles increased by 1.5%-22.5% at 1% and 1.5% concentration respectively [40]. CuO nanoparticles (10nm-20nm) were dispersed in solar salt. Its specific heat capacity has risen by 4.55%-6.86% at 0.1% concentration and it has increased by 7.96%-11.48% at 0.5% concentration [42].

Previous studies have also been reported the synthesis of molten salt nanofluids [32-36, 38-44]. SiO₂, Al₂O₃, SiO₂/Al₂O₃ nanoparticles were added to a binary molten salt eutectic and mixed together by a twin-screw micro-compounder [39]. A different mixing time and screw speed was used to mix salts and nanoparticles all evenly. A binary molten salt eutectic was mixed with CuO nanoparticles [42]. Each single chemical of a molten salt eutectic and CuO particles were ground using a mortar and pestle and mixed them together. These mixed salts were melted to make it homogeneous and then it was ground again to mix them evenly after cooling down. Al₂O₃ nanoparticles were mixed with a ternary nitrate molten salt eutectic [32]. These were placed in a

stirring hot plate to melt it completely after mixing together. Well-mixed salts were obtained by grinding after cooling. Another synthesis was used in previous studies [33-36, 38, 40-41, 43]. Each single chemical of a ternary nitrate molten salt eutectic and nanoparticles (i.e. CuO and MoS₂) were dissolved in an aqueous solution (i.e. deionized water) [33]. A sonication was used to mix this solution well. Well-mixed solutions were put in a rotary evaporator for drying. A ternary carbonate molten salt eutectic and SiO₂ nanoparticles were mixed together [35]. Each chemical and nanoparticles were dissolved in distilled water and it was sonicated to mix it well. These solutions were placed in an electric thermostatic drying oven to obtain well-mixed salts adding nanoparticles in a solid state. SiO₂ nanoparticles were mixed with a binary carbonate molten salt eutectic and quaternary chloride molten salt eutectic [34, 36]. Each chemical of a molten salt eutectic and SiO₂ nanoparticles were dissolved in distilled water and these solutions were sonicated for mixing. Well-mixed solutions were put on a hot plate for drying. Homogeneous salts adding nanoparticles were obtained by drying on a hot plate. A binary nitrate molten salt eutectic (NaNO₃-KNO₃, 60:40 wt.%) was mixed with nanoparticles (i.e. SiO₂, Al₂O₃, and SiO₂/Al₂O₃) [38, 40-41, 43]. Each single chemical and nanoparticles were dissolved in distilled water and deionized water. These solutions, salts-nanoparticles-water, were sonicated for mixing and put it on a hot plate for drying. Well-mixed salts adding nanoparticles were obtained by this nanofluid synthesis procedure. However, phase change occurs at each step of the synthesis procedure. For example, each salt and nanoparticles are mixed in a solid state and put it in an aqueous solution (i.e. distilled water or deionized water). A heating appliance (e.g. hot plate) is used to dry well-mixed solutions, salts-nanoparticles-water. Well-mixed salts are obtained in a solid state again. It is a complicated process that can cause an unexpected result due to phase change (i.e. solid-liquid-solid) at each step. The frequency of phase change in the sample preparation impinges on the specific heat capacity of

molten salt nanofluids. For example, the chances of contamination in a sample and the effect of absorbed moisture on a sample.

In this study, I suggested the new synthesis method (i.e. Liquid-to-Liquid) for mixing a molten salt eutectic and nanoparticles. A binary nitrate-based molten salt eutectic ($\text{NaNO}_3\text{-KNO}_3$, 60:40 wt.%) was used as a base salt. 10nm of SiO_2 nanoparticles were used to add it to a molten salt eutectic. I compared a proposed synthesis method with other nanofluid synthesis procedures from previous studies. A modulated differential scanning calorimeter (MDSC) was used to measure the specific heat capacity of molten salt nanofluids. These results made a comparison with the enhanced specific heat capacity from previous nanofluid synthesis methods. A novel synthesis method can not only enhance the specific heat capacity, but also prevent an unexpected error in the sample preparation.

2. Sample preparation and experimental set-up

Nitrate-based molten salt eutectic nanofluids (Solar Salt, $\text{NaNO}_3\text{-KNO}_3$, 60:40 wt.% and nanoparticles) was synthesized using the sample preparation procedure such as dissolving in an aqueous solution, using a sonication, and drying in a hot plate as shown in table 1 [38, 40-41, 43]. Distilled water and deionized water were used as an aqueous solution to dissolve a salt eutectic and nanoparticles in a vial.

Table 1: Comparison of the synthesis procedure of molten salt nanofluids

Eutectic salt	Nano particle	Size (nm)	Concentration (wt.%)	Synthesis procedure	Ref.
$\text{NaNO}_3\text{-KNO}_3$ (60:40 wt.%)	SiO_2	5, 10, 30, and 60	1	Dissolving in an aqueous solution	[38]
	SiO_2	7	1	+ Using a sonication	[40]
	SiO_2	12	0.5, 1, 1.5, and 2	+ Drying in a hot plate	[41]
	Al_2O_3	13	0.9, 2.7, and 4.6 (vol.%)		[43]

A proposed synthesis method added specific steps to the previous sample preparation. In figure 1, each single chemical was placed on a hot plate at 100°C for 5 minutes. Each chemical's melting point is higher than 100°C . The purpose of this step is to remove the effect of absorbed moisture on each chemical before mixing. Each chemical (salts and nanoparticles) was mixed with solar salt's weight ratio and put it in a vial together. 198mg of salts and SiO_2 nanoparticles (2mg, 1 wt.%), were mixed together. These mixed salts were dissolved in 10ml of distilled water considering the solubility of each salt and nanoparticles at a given temperature [45]. 1mg of SiO_2

nanoparticles is completely dissolved in 10ml of distilled water (i.e. pH 7). 10ml of distilled water at 60°C can dissolve 2.5mg of SiO₂ nanoparticles. Thus, 10ml of distilled water were used to dissolve salts adding SiO₂ nanoparticles (i.e. 2mg). 10mg of distilled water are also enough to dissolve each salt (i.e. NaNO₃ and KNO₃) completely due to salts' high solubility. For example, 12200mg of NaNO₃ and 10600mg of KNO₃ can be dissolved in 10ml of distilled water at 60°C. These solutions were sonicated at 60°C for 30 minutes. Well-mixed solutions were put in a furnace at 200°C for 2 hours and it dried up completely during heating. A furnace distributes heat evenly and reduces an aggressive evaporation unlike a hot plate. Solar salt's melting point is 220°C. The furnace temperature was increased up to 300°C. A pipette was used to add a drop of nanofluids into a hermetic pan for a modulated differential scanning calorimeter (MDSC) measurement as shown in figure 2. A sample was loaded into a pan without phase change and it is a "Liquid-to-Liquid" loading method. According to previous studies [38, 40-41, 43], a sample was obtained by scraping off the bottom surface of a vial after drying in a hot plate unlike this. These bulk salts were loaded into a pan for MDSC measurements and bulk salts was melted again at high temperature. However, a sample was loaded directly into a pan using a Liquid-to-Liquid method in this study. Therefore, a proposed synthesis method reduced an unnecessary step that can cause unexpected errors (e.g. the possibility of contamination, the effect of absorbed moisture, and etc.) in the sample preparation.

Figure 1: Proposed synthesis procedure of molten salt nanofluids

Figure 2: Liquid-to-Liquid loading method to a pan in a furnace at 300°C

The specific heat capacity of each sample was calculated by a simple mixing rule (i.e. conventional theoretical model) as shown in equation 1 [46]:

$$C_{p,nf} = \frac{\rho_{np}V_{np}C_{p,np} + \rho_{mse}V_{mse}C_{p,mse}}{\rho_{np}V_{np} + \rho_{mse}V_{mse}} \quad (1)$$

where C_p is the specific heat capacity, ρ is density, and V is volume, respectively. Subscripts nf, np, and mse denote nanofluids, nanoparticle, and molten salt eutectic, respectively. A nitrate-based binary molten salt eutectic ($\text{NaNO}_3\text{-KNO}_3$, 60:40 wt.%) was mixed with 10nm of SiO_2 nanoparticles. A molten salt eutectic and its nanofluids adding nanoparticles were synthesized by a proposed method. A molten salt eutectic was first tested to confirm that it is in good agreement with the literature. Molten salt nanofluids (i.e. four samples) were tested to compare the results of a previous study [38]. A modulated differential scanning calorimeter (MDSC, Q20 TA Instrument) was used to measure the specific heat capacity of these samples. All samples were loaded in a pan. Those were hermetically sealed by a lid to prevent loss of salts during MDSC measurements at high temperatures.

3. Results and discussion

Figure 3 shows the results of the enhanced specific heat capacity of a binary molten salt eutectic and its nanofluids adding 10nm of SiO₂ nanoparticles (1% by weight) at 300°C (i.e. liquid state) in each synthesis method (i.e. Dudda's, dry mixing, and Liquid-to-Liquid). The following table 2 compares three types of the synthesis method. This table includes information regarding a salt eutectic, nanoparticles, its size and concentration (wt.%), and the enhancement of nanofluids on average. According to Dudda's synthesis method [38], salts (i.e. each salt) and SiO₂ nanoparticles were dissolved in 20ml of distilled water. These solutions were sonicated for 200 minutes at 60°C and it was placed on a hot plate at 200°C for 7 hours for drying distilled water completely. Dry salts adding nanoparticles were obtained by scraping off the bottom surface of a vial in a solid state. Each sample (i.e. dry salt mixture adding nanoparticles) was put on a hot plate at 200°C for 30 minutes before MDSC measurements to remove any moisture on a sample. In a dry mixing method, each salt (i.e. NaNO₃ and KNO₃) and SiO₂ nanoparticles were put on a hot plate at 100°C for 5 minutes to remove any additional moisture on each chemical. Salts and nanoparticles were mixed together in a vial without an aqueous solution. This vial was placed in a furnace at 300°C for 30 minutes to completely melt. Well-mixed salts adding nanoparticles were obtained by scraping off the bottom surface of a vial in a solid state. In a proposed synthesis method (i.e. Liquid-to-Liquid), each chemical was placed on a hot plate at 100°C for 5 minutes to remove any moisture on each material. 10ml of distilled water was used to dissolve salts and nanoparticles and these solutions were sonicated for 30 minutes 60°C for mixing well. A vial was placed in a furnace at 200°C for 2 hours for drying solutions completely. Liquid nanofluids were directly loaded in a pan using a Liquid-to-Liquid method in a furnace at 300°C. In figure 3, the specific heat capacity of a molten salt eutectic from all types is similar to the literature [6, 9]. The specific

heat capacity of molten salt nanofluids by Dudda's method is 1.57kJ/kg °C, 1.63kJ/kg °C, 1.58kJ/kg °C, and 1.65kJ/kg °C respectively. It shows 1.61kJ/kg °C on average. The results of all samples are higher than a molten salt eutectic. A dry mixing's enhanced specific heat capacity is 1.58kJ/kg °C, 1.60kJ/kg °C, 1.66kJ/kg °C, and 1.60kJ/kg °C respectively and the average is 1.61kJ/kg °C. All samples' specific heat capacity is still higher than the specific heat capacity of a molten salt eutectic. According to the results of a Liquid-to-Liquid method, the enhanced specific heat capacity is 2.11kJ/kg °C, 2.12kJ/kg °C, 2.14kJ/kg °C, and 1.99kJ/kg °C respectively. The average of the enhanced specific heat capacity is 2.1kJ/kg °C. These results are the highest value of three types of the synthesis method. In table 2, the specific heat capacity of Dudda's results has increased by 9.4% on average and a dry mixing method's values has risen by 2% on average. Thus, an aqueous solution (e.g. distilled water) is required to mix salts and nanoparticles well and a sonication helps to make a homogenous mixture (i.e. salts and nanoparticles). According to the results of a Liquid-to-Liquid method, the specific heat capacity of nanofluids has gone up by 30.5% on average. This enhancement is the highest among all three types of the synthesis method. Dropping liquid nano-mixtures into a pan has an effect on the enhanced specific heat capacity of nanofluids unlike scraping nano-mixtures in a solid state from Dudda's method and dry mixing method. Therefore, a proposed Liquid-to-Liquid synthesis method can not only reduce an unnecessary step in the sample preparation, but also improve the specific heat capacity of nanofluids.

Figure 3: Comparison of the enhanced specific heat capacity in each synthesis method

Table 2: Comparison of the synthesis method

Ref.	Salt	Nano	Size	Concen.	Synthesis method	Ave.
	eutectic	particle	(nm)	(wt.%)		Enhanced
						C _p (%)
	NaNO ₃ -	SiO ₂	10	1	Dissolving in distilled	
	KNO ₃				water	
Dudda's	(60:40 wt.%)				+ Using a sonication	9.4
[38]					+ Drying in a hot plate	
					+ Scraping off	
					+ Preheating	
Dry					Preheating	
mixing					+ Dry mixing	2.0
					(no solutions)	

		+ Drying in a furnace	
		+ Scraping off	
		Preheating	
Liquid-		+ Dissolving in distilled	
to-		water	30.5
Liquid		+ Using a sonication	
		+ Drying in a furnace	
		+ Dropping	
		(Liquid-to-Liquid)	

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4. Conclusions

Different types of a synthesis method are used to improve the specific heat capacity of molten salt nanofluids adding nanoparticles (i.e. $\text{NaNO}_3\text{-KNO}_3 + \text{SiO}_2$) in previous studies. Each of them has a different characteristic such as preheating a chemical, dissolving in an aqueous solution (i.e. distilled water), mixing by a sonication, drying in a hot plate, and scraping nano-mixtures in a solid state. All synthesis processes share one step that nano-mixtures are dissolved in distilled water (i.e. aqueous solution) and solutions are mixed by a sonication. A MDSC measurement has confirmed the effect of an aqueous solution on the enhanced specific heat capacity of nanofluids. The specific heat capacity of samples that were dissolved in distilled water is higher than dry mixing samples without an aqueous solution. However, this step alone is not sufficient enough to obtain better specific heat capacity than others. Dry nano-mixtures were obtained by scraping off the bottom surface of a vial in the last step of the sample preparation, but this step is simply unnecessary because phase change from liquid to solid occurs in this step. A hot plate is also used to completely dry solutions. A vial with solutions is placed on a hot plate, but thermal contact only occurs between the surface of a hot plate and the bottom surface of a vial. Thus, a hot plate cannot distribute heat evenly in solutions during drying. According to a proposed synthesis method (i.e. Liquid-to-Liquid), the effect of absorbed moisture on a single chemical was considered before mixing together. Each chemical (i.e. salts and nanoparticles) was placed on a hot plate considering the melting point of each material. Well-mixed salts and nanoparticles were dissolved in distilled water considering the solubility of salts (i.e. NaNO_3 and KNO_3) and SiO_2 nanoparticles at a given temperature. A furnace was used to dry solutions completely. It helped distribute heat evenly over all solutions in a vial unlike a hot plate. Nanofluids were directly loaded in a pan using a Liquid-to-Liquid method without scraping or phase change. The specific heat

capacity of these nanofluids has increased by 30.5% on average and it is the highest value among other synthesis methods. Therefore, a suggested novel synthesis process adding a Liquid-to-Liquid method can not only prevent unexpected errors by phase change in the sample preparation, but also enhance the specific heat capacity of molten salt nanofluids.

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Figures

Figure 1

Proposed synthesis procedure of molten salt nanofluids

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Proposed synthesis procedure of molten salt nanofluids

Figure 2

Liquid-to-Liquid loading method to a pan in a furnace at 300°C

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Liquid-to-Liquid loading method to a pan in a furnace at 300°C

Figure 3

Comparison of the enhanced specific heat capacity in each synthesis method

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Comparison of the enhanced specific heat capacity in each synthesis method