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Preparation and investigation on density and surface tension of quaternary bromides for concentrating solar power

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ABSTRACT

In order to improve the unsteady high temperature heat transfer performance of receivers in solar thermal power stations the receivers should be optimized further. High temperature could help to optimize heat transfer of the receiver. Based the selection of heat pipes and bromides this work prepared six samples of quaternary bromides with different composition ratios of KBr, LiBr, NaBr, and $CaBr_2$ and their density and surface tension were measured and analyzed. Experimental results show that density of quaternary bromides shows very good linearity with salt temperature, and density of quaternary bromides is higher than that of Solar salt at a same temperature. Also, quaternary bromide NO.2 has maximum density, and quaternary bromide NO.3 has minimum thermal expansion coefficient while quaternary bromide NO.6 has the minimum density and maximum thermal expansion coefficient at the same temperature. In addition, quaternary bromide NO.1 has a maximum surface tension and fitting curve slope at a same temperature among the six samples of quaternary bromides. Their density and surface tension were fitted with linear fit with their temperature respectively. Furthermore, that the composition ratio has evident influence on the density and surface tension of quaternary bromides has been concluded.

1. Introduction

A concentrating solar power (CSP) system is usually a large-scale way of solar energy to generate electricity, where a key problem is the coupled unsteady heat transfer from solar radiation to high temperature heat transfer fluid (HTF). Heat pipes with Alkali metals as HTF are of efficient heat transfer elements, which have been employed in CSP to improve the heat transfer [1–4]. However, Alkali metals heat pipes in case of fracture may cause fire or even serious explosion, which may bring about big economic losses and heavy casualties. Molten inorganic salts(Molten salts) as efficient HTFs have also been widely used to enhance heat transfer in the concentrating power tower receiver and the thermal energy storage (TES) system in CSP system [5], which is of low vapor pressure, wide operating temperature range, low cost and to be inert in comparison to Alkali metals. Thus employing molten salts as the working fluid of heat pipes would promote the heat transfer stability and safety of receivers in CSP system.

Molten salts that have been evaluated experimentally and analytically for CSP include mainly nitrates, Chlorides and carbonates. Currently, Multi-component salt went to the center of efficient heat transfer material development due to the mismatch of melting point, working temperature and temperature range, decomposition temperature of single salt. Density and surface tension are two fundamental thermo-physical properties of HTF as the working fluid of heat pipes, which have direct influence on the comprehensive heat transfer performance-the larger the density and surface tension are, the higher the heat transfer power is and the lower the heat transfer resistance of heat pipes is. Several nitrates, carbonates and chlorides have been developed and their density and surface tension have been studied extensively by authors [6–18]. However, these salts have either high melting point or low decomposition temperature or density, which is unsuitable for heat pipes.

It is found that molten bromide mixtures can satisfy high working temperature, density and surface tension. Decomposition temperature of quaternary bromides with different component ratios of NaBr, KBr, $CaBr_2$ and LiBr is proved to be up to 900 °C while their melting point is as low as 300 °C [19]. It is difficult to find a suitable molten salt serving as the working fluid of high temperature heat pipes. Density and surface tension are two fundamental thermo-physical properties of molten salt as the

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working fluid of heat pipes. Data of density and surface tension of quaternary bromide mixtures are rare and have ever been measured specially. In the present work density and surface tension of quaternary bromides with different component ratios of NaBr, KBr, $CaBr_2$ and LiBr were measured. The Purpose of this work intends to provide data for selection of molten salt for heat pipes in concentrating solar power system. This work provides basic data of density and surface tension for molten salt selection used for heat pipes in concentrating solar power systems. The results of density, thermal expansion coefficient and surface tension of quaternary bromides would be presented and discussed in the following.

2. Experimental

2.1. Preparations of quaternary bromides

Materials used in the presented experiments are sodium bromide (AR), potassium bromide (AR), lithium bromide (AR) and calcium bromide (AR), which are all from the manufacturer: Tianjin Zhiyuan ChemicalReagen Co. Ltd. All bromides were treated by dehydration before the preparations. 6 quaternary bromide mixtures were prepared based on the different mass proportions of NaBr-KBr-LiBr-CaBr, as shown in Table 1. The mass of mixed bromides were weighed by using a precision balance with a precision of 0.1 mg produced by Mettler Toledo Instrument Company. The bromides were mixed well by a high-speed disintegrator. The prepared samples were stored in a drying box kept at 200 °C for experiments.

2.2. Density measurement

Density is an important thermo-physical property of molten salts and has great significance in practical and theoretical research. In order to eliminate the influence resulted from the surface tension the density of the molten quaternary bromides is measured by the improved Archimedean principle [20] in the present work. The crucible is made of high pure alumina with purity of 99.9% and the density probe is made of 316 L stainless steel in present experiments which have extremely low reactivity with bromide salts with the protection of inert gas - Helium. An accurate density of molten salts prepared can be obtained according Eq. (1) as follows:

$$\rho = \frac{M_1 - M_2}{V_\rho} \quad (1)$$

Where M_1 is the weight of the probe when the surface of the melt is at position 1, M_2 is the weight of the probe at position 2, while V_ρ is the volume of the probe between position 1 and 2. V_ρ is measured in advance with the same method by using density-known molten salts at different temperature.

Schematic diagrams of the density probe and the experimental apparatus are show in Figs. 1 and 2.

Table 1
mass ratio of quaternary bromides.

NO.	Mass fraction, %			
	NaBr	KBr	$CaBr_2$	LiBr
1	5	25	15	55
2	5	27	18	50
3	8	31	16	45
4	11	35	14	40
5	14	39	12	35
6	17	43	10	30

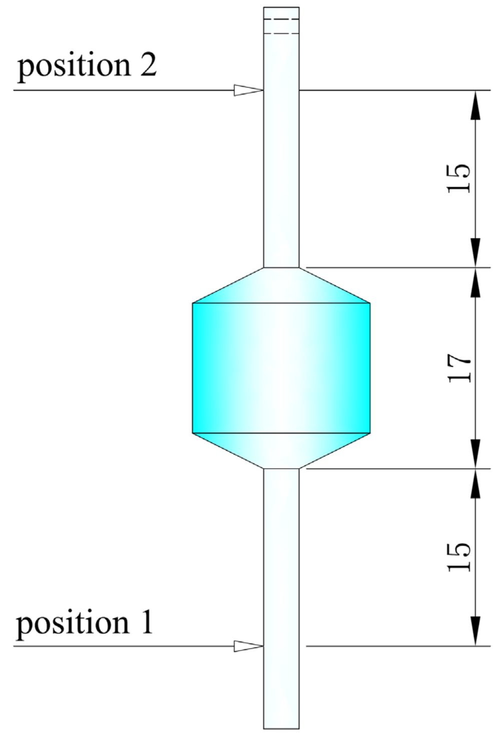

Fig. 1. Schematic diagram of the density probe.

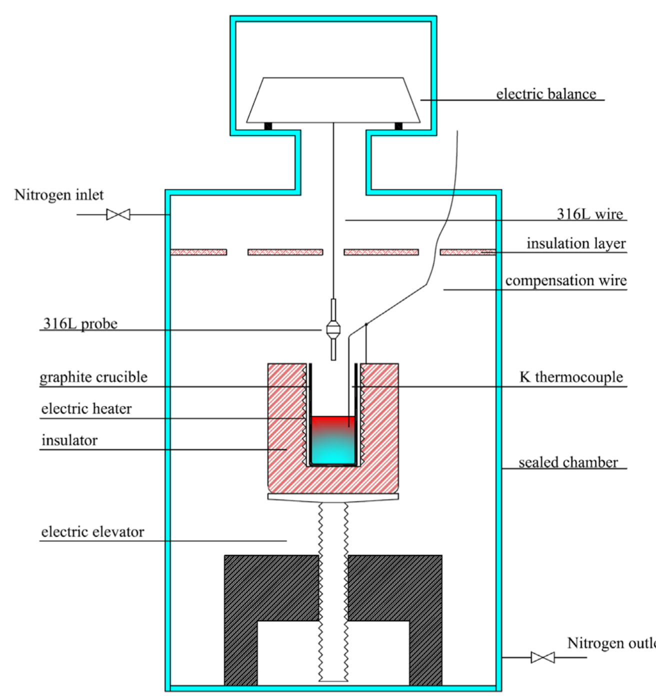

Fig. 2. Schematic diagram of the experimental apparatus.

An electric balance with an accuracy of 0.1 mg is used to measure the weight of the probe. The relative error is measurement of density is estimated to be with ±0.1%。.

2.3. Surface tension measurement

The Pull-Off method originating from the du Noüy Ring method is employed to measure the surface tension of the molten salts, which is based on the measurement of maximum equilibrium force to pull a probe out of the molten salts. The surface tension