Transmission characteristics of ultrasonic waves in fine particles of phase-change material-water slurry

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ABSTRACT

Phase Change Material Slurry (PCMS) consists of multi-component and multi-phase suspensions. The micro-emulsion phase change material slurry (MEPCMS) is composed of paraffin as a phase change material, water as a carrier fluid, and surfactant as an emulsifier. This type of PCMS is known as a candidate of functional thermal fluids, which show very high energy density, and allow to save pumping [1]. The micro-emulsion phase change material slurry is a multi-phase fluid with a temperature shift from 15°C to 60°C. A sound speed measurement device is used to measure the sound velocity in the MEPCMS. In the present study, the paraffin melts, and the MEPCMS is totally in a liquid condition. The PCMS in the present study is composed of several kinds of paraffin (C18H36). The major component of the PCMS is trisuccinate C18H36O6.

The appearance of the MEPCMS has a milky-white color. The polymer surfactant having hydrophilic units in the water side and hydrophobic units in the paraffin side acts as an emulsifier or a covering film separating the PCMS from water. The PCMS particles and water are immiscible each other [5].

The density of the paraffin has significant temperature dependence. Generally, the density of the paraffin with linear chain structure depends on the previous history of pressure and temperature [6]. The density of the PCMS in the present experiment was done as shown in Fig.1. It is shown in the literature [4], [5] that the density and the volume of the dispersed phase exert a strong influence on the sound speed. The morphology of the PCMS as a dispersed phase is some complicated, but the present result does not consider its complexity like shape and size distribution of the PCMS particles.

INTRODUCTION

Phase Change Material Slurries (PCMS) are composed of multi-component and multi-phase suspensions. These PCMS as functional thermal fluids are researched and developed, which show high energy density and high pumping energy saving. However, the flow behavior has been observed with this type of PCMS, however, the opacity of this type of PCMS distorts to visualize the flow pattern. In order to use a high-speed camera in the study, the Measurement of velocity in the MEPCMS is important to obtain an accurate sound speed in a PCMS layer. Often the sound speed is experimentally determined by a method of the Time of Flight (TOF). Sound speed measurement systems available on the market are based on this principle. This principle is sensitive to the geometrical dilatation when temperature change occurs. The sound speed measurement is useful to specify a substance. The settlement of phase state of a PCMS in a PCMS can be made by a DTF [4].

COMPOSITION OF THE MICRO-EMULSION

The micro-emulsion phase change material slurry (MEPCMS) used in the present experiment is composed of 30 % (mass percent) of paraffin, 65 % of water and 5 % of surfactant. This PCMS is known as a candidate of functional thermal fluids, which shows very high energy density and low pumping energy per transmitted heat [1]. Fine paraffin particles are distributed in their diameter range from 0.1 μm to 1.2 μm (its average diameter of 0.5 μm). The particle frequency shows a lognormal function against particle diameter. The PCMS is solid when the temperature of MEPCMS is below its melting point of 47°C. Above this temperature, the paraffin melts, and the MEPCMS is totally in a liquid condition. The PCMS in the present study is composed of several kinds of paraffin (C18H36). Its major component of the PCMS is trisuccinate C18H36O6.

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DIFFERENTIAL TIME OF FLIGHT

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SOUND SPEED MEASUREMENT DEVICE USING THE DIFFERENTIAL TIME OF FLIGHT (DTF)

To avoid measuring error due to the geometrical dilatation when temperature change occurs, the principle of sound speed measurement in the present study is based on the Differential Time of Flight (DTF) [8]. The measurement of the sound speed is performed in multiple steps. An ultrasonic transducer is placed at a known distance from a reflecting wall. The transducer emits a burst of beam, which is reflected by the wall and returns back to the transducer. The time of the reflected echo after the emission (dt) is recorded on an oscilloscope. After the first measurement, we shift the position of the transducer with a micrometric screw (dx). The difference of the TOF between two measurements corresponds to two times the displacement of the transducer. The present measurement repeats this operation several times and obtains dxdt curve. The sound speed is given by the slope of this curve. The slope and its accuracy are determined by a classic least square method, as given in [7].

The container packed with the MEPCMS is composed of a plexiglass cylinder with a volume of about 2 liters. A micrometric screw is mounted on the top of its container to control and measure the displacement of the ultrasonic transducer. The reflecting wall is in stainless steel sheet. The height from the transducer and the reflected wall is around 7 cm. A mixing element with two propellers is located inside the container with the aim to avoid stratification of the sample. The prototype offers the possibility to test different frequency of US beam.

The validation of the present measuring method was confirmed using a distilled water. The ultrasonic signal, emit by a function generator device Tabor 8550, is a burst of 2 periods with an amplitude of 16 V peak to peak. The frequency of repetition is adjustable. The echo signal was observed by an Iwatsu DS-8814 digital oscilloscope. The temperature is measured with a thermocouple with an accuracy of 0.1 K. Measurements are made at different temperature and the obtained data is compared with values obtained by Grosso and Mader modified by Povey [4]. Results are shown in Fig.3. Systematic errors seem to occur for the performed validation's measures at three frequency, 2nd and 8 MHz. In the case of 4 MHz, measuring results of the sound speed show a lower random error. At this stage of the development of the DTF, the frequency of 4 MHz seems to be most appropriate for the measurement.

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MICRO-EMULSION SLURRY SOUND SPEED

The US signal attenuation of the MEPCMS layer is too strong to use the same signal (4 MHz - 16 V peak to peak) in the present measurement. Because of the paraffin particle diameter, scattering of the beam is more probable than absorption of the signal by the PCM particle. It is the reason why we finally chose the signal frequency for the US signal, from 4 to 2 MHz for measuring the MEPCMS. The penetration of the beam is stronger when reducing the frequency. The chosen amplitude for the US beam was 150 V. The signal is control and emit by a UVP instrument. One series of measurements was performed with an increase in the temperature of the MEPCMS, starting from the ambient temperature. The other series was done during the cooling process, starting with a temperature above the solidification point of the PCM. Every measurement was done after a stabilization of the temperature. Results of these measurements are shown in the Fig. 4.

Because the container is not hermetic, some evaporation of water can occur. In the present experiment, the water content in the MEPCMS can decrease during the measurement. The water content in the sample was 57% at the end of the measurement.

CONCLUSION

An acoustic measurement of MEPCMS was performed in the aim to avoid measurement error of the data in temperature variation when temperature change occurs. The method is based on the Differential method of Time of Flight DTF. Measurement in a distilled water showed reasonable results with a high accuracy. This method was applied to the measurement of MEPCMS at various temperatures. It must be done to avoid water evaporation from the MEPCMS during measurement. Some doubt appears concerning the capacity of the MEPCMS to take the same form when it is cooled down from a temperature above the melting point. Sound speed in MEPCMS is an important property for the parameter of thermal material. For example, to characterize the phase state in multi-phase media, to measure the acoustic properties, the MEPCMS layer by a Ultrasonic Doppler method.

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REFERENCES

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