Matching Index-of-Refraction for 3D Printing Model Using Mixture of Herb Essential Oil and Light Mineral Oil

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1. Introduction

Particle Image Velocimetry (PIV) and Laser Dopler Velocimetry (LDV) are the two major optical technologies used for flow field visualization in the latest fundamental thermal-hydraulics researches [1]. Those techniques seriously require minimizing optical distortions for enabling high quality data. Therefore, matching index of refraction (MIR) between model materials and working fluids are an essential part of minimizing measurement uncertainty.

This paper proposes to use 3-D Printing technology for manufacturing models for the MIR-based optical measurements. Because of the large flexibility in geometries and materials of the 3-D Printing, its application is obviously expected to provide tremendous advantages over the traditional MIR-based optical measurements. This study focuses on the 3-D printing models and investigates their (1) optical properties, (2) transparent printing techniques, and (3) index-matching fluids.

2. 3D Printing Model Materials

2.1 3D Printing Techniques and Model Materials

This study investigated five different combinations of manufacturing methods (based on 3-D printing) and transparent model,

A Selective Layer Sintering (SLS) model from Stratasys uses acrylic transparent material called VeroClear-RGD810 [2]. A Stereolithography (SLA) model from 3D Systems takes liquid material called ClearVue made from epoxy [2]. Vacuum casting based on the 3-D printing master is another way to make transparent models using a 3D printer and various plastic resins such as epoxy and urethane were used here.

2.2 Measurement of Optical Properties

The refractive indices (RIs) of the candidate models have been measured using an ellipsometer from Ellipso-technology [3]. Fig. 1 shows the RIs of the general transparent models along the wavelength. As shown in this figure, the RIs range from 1.4597 to 1.5547 at 532 nm wavelength.

A PIV laser generally uses light of 532nm in wavelength. Therefore, the RI at this wavelength should be importantly discussed. Table I compares two optical properties (RI and transparency) of the proposed candidate models. It shows that the SLA model has higher transparency than the SLS models. The models from the vacuum casting shows the highest transparency but the surface might be uneven.

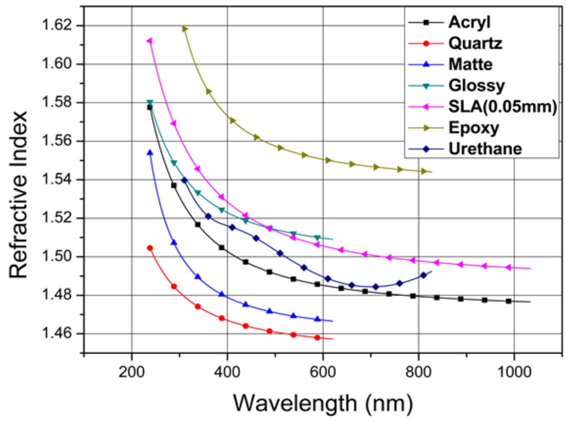

Fig. 1. Refractive Index of Transparent Model Materials

Table I: Refractive Index and Transparency of Candidate Model Materials

Model Material	RI(@532nm)	Transparency
SLS (Matte)	1.4695	+
SLS (Glossy)	1.5124	+
SLA	1.5105	+++
VC (Epoxy)	1.5547	+++
VC(Urethane)	1.4984	+++

3. Herb Essential Oil-Based Working Fluid

In order to match the RIs of 3-D printing models, the present study has extensively explored available working fluids. The following characteristics have been considered for fluid selection: (1) high RI (>1.47), (2) high transparency, (3) colorless, (4) high density, (5) low viscosity, (6) low toxicity, and (7) low cost.

3.1 Base Fluid: Herb Essential Oil

Through the immense literature survey, this study ended up with the Herb essential oils, which have high RIs and low toxicity. By screening more than 30 different Herb essential oils based on the above requirements, three candidates have been finally selected. Table II summarizes the physical properties of three essential oils. Their names are not specified here (named as A, B, C). Because of the high RI, low viscosity and high density, Oil B appears to be the best working fluid here.

Table II: Physical Properties of Herb Essential Oils

Type	Oil A	Oil B	Oil C
Index of Refraction	1.501	1.555	1.4835
Viscosity(cP)	37	2.37	1.99
Density(g/cm3)	-	0.985	0.889
Miscibility With Mineral Oil	O	O	O

3.2 Mixing Fluid: Light Mineral Oil

In order to lower and adjust the RIs of the Herb essential oils, light mineral oil were mixed here. All of the oil A, B, and C can be easily mixed with the mineral oil, which has relatively high RI and great transparency. This study has selected KF-70 oil (RI = 1.453) manufactured by Molytech because of its low viscosity [4]. Fig. 2 shows the RI (for mixture of Oil B and KF-70) versus mass fraction (for Oil B) in percentage.

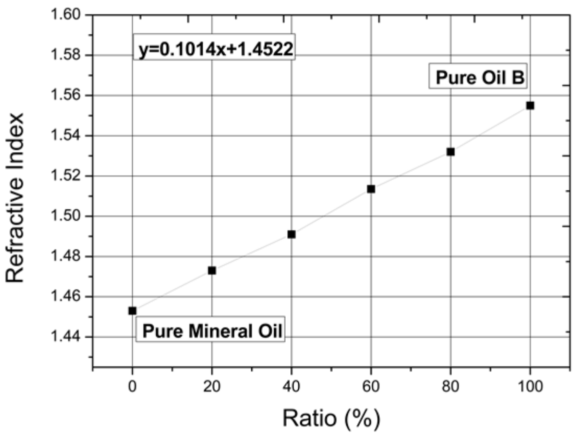

Fig. 2. Refractive Index of Oil B and Mineral Oil Mixture.

4. Matching-Index-of-Refraction Test

A simple MIR test has been conducted and the results are summarized below. The wire wrapped fuel models for a sodium fast reactor (SFR) were made of various model materials and manufacturing methods: (1) blowing (quartz), (2) SLA (CelarVue), (3) vacuum casting (urethane), and (4) vacuum casting (epoxy). In order to match the RIs, mineral oil (KF-70) has been properly mixed with Oil B based on the data shown in Fig. 2.

Fig. 3 shows the preliminary results of index matching. Water and air have been also used as working fluids as the reference. As shown in this figure, (1) quartz-pure mineral oil, (2) SLA-Oil B/mineral oil, and (3) vacuum casting (urethane)-Oil B/mineral oil show the best index matching results, in which the solid models in the liquid look to disappear. On the other hand, (1) SLA-air, (2) SLA-water, and (3) vacuum casting (epoxy)-Oil B/mineral oil show poor index matching. Chemical compatibility of the model and working fluid was also evaluated successfully. The above results indicate that except vacuum casting (epoxy), the candidate models proposed in Table I can be used for the optical measurements with MIR.

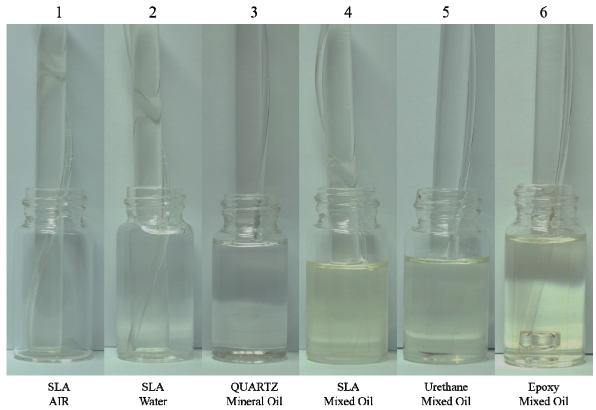

Fig. 3. MIR test using Mixed Oil

5. Summary and Conclusion

This study has extensively investigated the emerging 3-D printing technologies for use of MIR-based flow field visualization methods such as PIV and LDV. As a result, mixture of Herb essential oil and light mineral oil has been evaluated to be great working fluid due to its adequate properties. Using this combination, the RIs between 1.45 and 1.55 can be accurately matched, and most of the transparent materials are found to be ranged in here. Conclusively, the proposed MIR method are expected to provide large flexibility of model materials and geometries for laser based optical measurements.

Acknowledgement

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