A Mach-Zehnder interferometer-based study of evaporation of binary mixtures in Hele-Shaw cells

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Evaporation applications (heat pipes, refrigeration) are using pure liquids. Abe et al [2003] have shown that carefully chosen mixtures can drastically improve the efficiency of heat pipes.

=> Study efficiency of evaporation of binary mixtures
Contents

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Data analysis
  Fourier Image Processing
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Mach-Zehnder Interferometer + Hele-Shaw

Hele-Shaw Gap: 0.5mm
Distance liquid surface-Nitrogen jet: 8mm
Nitrogen speed: 0 to 1m/s
Ethanol concentration: 17.7%
Measurements at 1 fps
Principle of Finite Fringe Interferometry

Homogeneous refractive index field $\Rightarrow$ Parallel Fringes

Refractive index gradient $\Rightarrow$ Bend Fringes $=$ Phase Shift

$\Rightarrow$ Measure phase shift and translate into refractive index difference through formula: $\Delta n = \lambda \Delta \varphi / 2\pi t$
Fourier Based Image Processing

Nitrogen

Water-Ethanol Mixture

(a)
Preliminary Results
Occasional bubbles or large gradients create phase residues, which necessitate a 2D unwrapping algorithm

=> Goldstein's Method
Goldstein's Branch Cut Method

Unwrapping path should avoid encircling unbalanced residues

Extra mask to prevent unwrapping across interface

Unwrap both zones also in time
Time evolution
Vibration compensation

Necessary to do some vibration compensation

Keep phase differences in air = 0

Large vibrations might decouple air phase from liquid phase

Keep phase differences at bottom = 0

Passing structures bias results

Keep phase between two consecutive images at most of the pixels = 0

Makes smooth movies, but physical?
Results

1 ln/min N2

Time elapsed: 00 hours 02 minutes 15 seconds

0 ln/min N2

Time elapsed: 00 hours 01 minutes 50 seconds
Interpretation of Results

Refractive index changes => due to temperature changes or concentration changes?
Interpretation of Results

Mass Concentration [%]

Temperature of Water [°C]
Temperature influence

Experiments on pure ethanol to estimate error

Maximum underestimation of concentration difference is 0.38%
Different Ethanol Concentrations

Relative Concentration [%]

8% Ethanol

20.8% Ethanol

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Conclusions

Mach-Zehnder interferometry is a good tool to study the evaporation of binary mixtures.
Vibration compensation is necessary but how to make it physically relevant?

Preferential evaporation of ethanol creates a dense watery boundary layer which is unstable and creates fingering.
Temperature influence leads to underestimation of concentration gradients in the flow.
Future Improvements

Characterise instabilities and their origin: wavelength, propagation speed, extract concentration/density profiles

Dependence of these parameters on experimental parameters

Characterise efficiency of evaporation versus concentration of ethanol

Perform simultaneous thermal measurements: liquid crystals, infrared camera, multi-wavelength interferometry, ...
Thank you for your attention