A-41　課題番号　2010A-A23　利用装置名　ＴＮＲＦ

# キャピラリーチューブ内の減圧沸騰を伴う冷媒二相流の可視化とボイド率分布の計測

## Visualization and Void Fraction Measurement of Decompressed Boiling Flow in a Capillary Tube


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## Background

Capillary tube is often used in a refrigerator as an expansion tool of refrigerant. In order to design a tube diameter and length, it is necessary to estimate pressure difference for given mass flow rate and inlet condition. Since refrigerant usually flows into capillary tube as a subcooled liquid, and evaporates due to decompression by frictional pressure loss, it is required to clarify the boiling inception point and gas-liquid two-phase flow characteristics.

## Purpose

- To specify the boiling inception point
- To clarify boiling two-phase flow behavior on which intense centrifugal force is acting

## Conclusion

- Onset of boiling could be measured from void fraction distribution obtained by image processing.
- Radial liquid distribution was successfully obtained by a CT method using a radiograph as sinogram.
- It could be estimated that flow pattern transition of gas-liquid two-phase flow from intermittent to annular flow was occurred with void fraction of about 0.45.

## Experimental outline

### Visualization object

Refrigerant flow of HFC 134a ($C_2H_2F_4$) in a cupper capillary tube (3.0 mm OD × 1.5 mm ID × 19 mm coil dia.)

### Attenuation coefficient

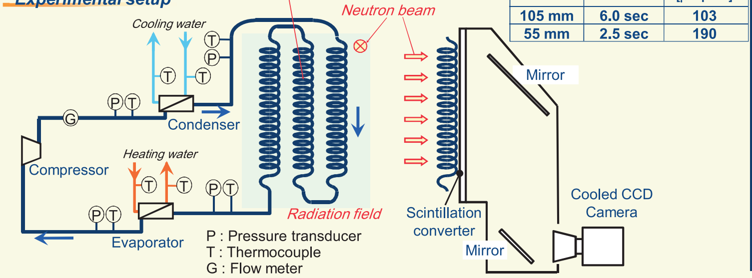
μ = 0.485 cm$^{-1}$ (liquid at 40 ℃)　　μ = 0.923 cm$^{-1}$

### Imaging condition

1024 × 1024 pixels
16 bit intensity level

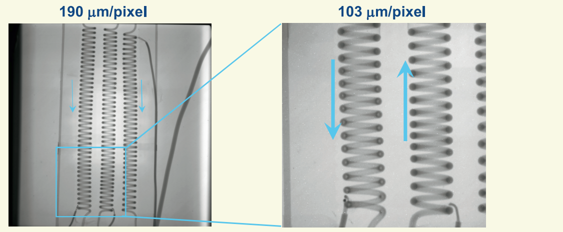
| Camera lens | Exposure time | Spatial resolution [μm/pixel] |
|---|---|---|
| 105 mm | 6.0 sec | 103 |
| 55 mm | 2.5 sec | 190 |

### Experimental setup




## Visualized image

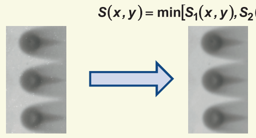
### Original image



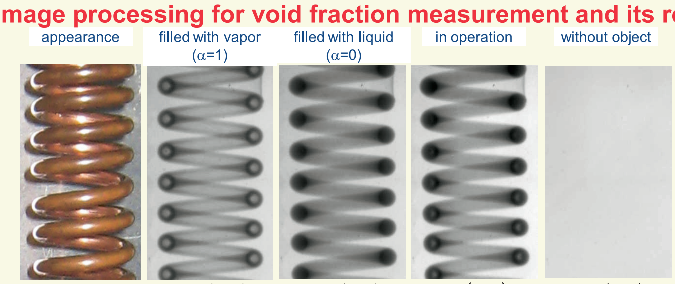

### Noise reduction

White spot noise was reduced by a minimum filter among three images for the same condition.

$S(x,y) = \min[S_1(x,y), S_2(x,y), S_3(x,y)]$



## Image processing for void fraction measurement and its results

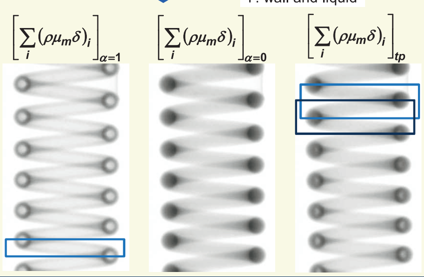



$S_{\alpha=1}(x,y)$　　$S_{\alpha=0}(x,y)$　　$S_{tp}(x,y)$　　$S_{w/o}(x,y)$

$$\sum_i (\rho\mu_m\delta)_i = \ln\frac{S_{w/o}(x,y)-O}{S(x,y)-O}$$

i : wall and liquid

$\left[\sum_i(\rho\mu_m\delta)_i\right]_{\alpha=1}$　　$\left[\sum_i(\rho\mu_m\delta)_i\right]_{\alpha=0}$　　$\left[\sum_i(\rho\mu_m\delta)_i\right]_{tp}$



### Brightness of radiographs

$$S_{tp}(x,y) = G(x,y)\exp[-\rho_w\mu_{mw}\delta_w(x,y) - \rho_l\mu_{ml}\delta_c(x,y)\{1-\alpha(x,y)\}] + O(x,y)$$

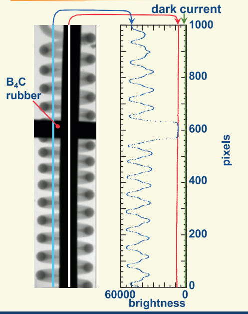
$$S_{\alpha=1}(x,y) = G(x,y)\exp[-\rho_w\mu_{mw}\delta_w(x,y)] + O(x,y)$$

$$S_{\alpha=0}(x,y) = G(x,y)\exp[-\rho_w\mu_{mw}\delta_w(x,y) - \rho_l\mu_{ml}\delta_c(x,y)] + O(x,y)$$

$$S_{w/o}(x,y) = G(x,y) + O(x,y)$$

The value of $O(x,y)$ was evaluated by umbra method using a rubber tape with $B_4C$.
A constant value $O$ was used, since the value was quite lower than measured brightness.

### Offset estimation

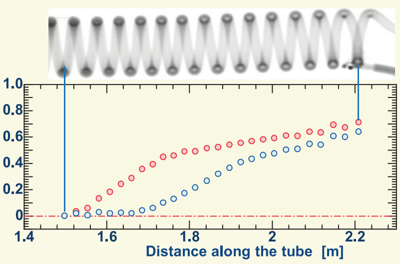



### Volumetric average void fraction

$$\bar{\alpha} = 1 - \frac{\sum_A\left[\sum_i(\rho\mu_m\delta)_i\right]_{tp} - \sum_A\left[\sum_i(\rho\mu_m\delta)_i\right]_{\alpha=1}}{\sum_A\left[\sum_i(\rho\mu_m\delta)_i\right]_{\alpha=0} - \sum_A\left[\sum_i(\rho\mu_m\delta)_i\right]_{\alpha=1}}$$

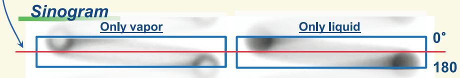
| | Inlet condition | Exit condition |
|---|---|---|
| Run #1 ○ (red) | 1.09 MPa, 29.8 ℃<br>$\Delta T_{sub}$=12.8 K, $P_{sat}$(T)=0.766 MPa | 0.327 MPa<br>$x_{eq}$ = 0.190 |
| Run #2 ○ (blue) | 1.82 MPa, 40.2 ℃<br>$\Delta T_{sub}$=23.2 K, $P_{sat}$(T)=1.02 MPa | 0.467 MPa<br>$x_{eq}$ = 0.202 |

$\Delta T_{sub}$ : subcooling degree , $P_{sat}$(T) : saturation pressure at $T$,
$x_{eq}$ : thermal equilibrium quality



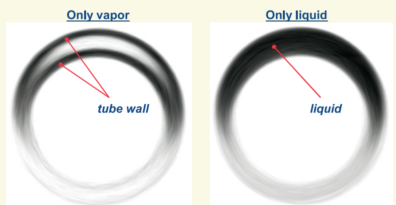

### Measurement of cross-sectional void fraction distribution by CT-method

#### Sinogram

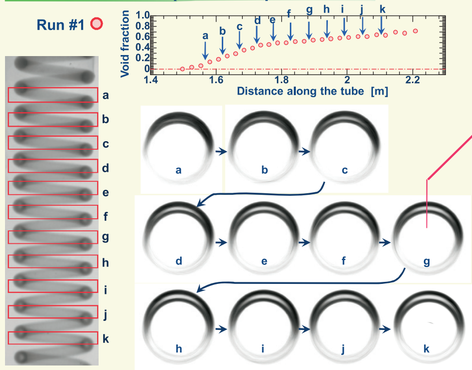



This distribution can be available as a sinogram for half rotation.

#### Reconstructed results




#### Measurement example for two-phase flow




#### Attenuation distribution in radial direction