Measurement of liquid film thickness using near infrared imagery with application to film condensation

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1. Introduction

Film condensation occurs in various industry included nuclear power plant. Film condensation heat transfer is related to the safety and efficiency and accurate analysis of heat transfer is required. Thermal resistance of condensate film is major parameter to analyze the film condensation heat transfer. Therefore film condensation heat transfer strongly depends on film thickness of condensate. Film thickness is an unknown parameter in analyzing heat transfer in force convection film condensation [1].

Several studies on the measurement of liquid film thickness in separated two-phase flow have been conducted. Kang (1992) developed the flash-wire probe technique to measure film thickness during air-water laminar flow. [2] The technique has high accuracy, however the probe installed into film disturbs the flow characteristic of condensate film. Recently, Dupont et al. (2013) proposed a new technique using near-infrared (NIR) imagery to measure liquid water film thickness [3]. They used principle of intrinsic optical absorption properties of water in the NIR range. They calculated film thickness from intensity of the reflected on the wall and attenuated light into film. Advantages of the method are non-intrusive measurement mechanism and high spatial resolution.

In this study, an experimental facility of film condensation is designed and constructed. A feasibility test to apply the NIR measurement technique of film thickness to forced convection film condensation using air-water separated flow is conducted.

2. Measurement technique of film thickness

Fig. 1 represents the measurement principle of the NIR method. The NIR camera measures intensity of the reflected light on the wall, which is attenuated in the condensate. The optical components consist of the infrared lamp with the maximum power of 1 kW, the spherical mirror, the aspherical lens, spherical lens and filter with center wavelength of 1250 nm. The spherical mirror and the aspherical lens to collect the light and spherical lens to illuminate the uniform light to the water film. The filter is used to consider the specific wavelength. The emitted light through the optical components is absorbed at the film interface and absorbed to water film. A reflected light at the wall is back toward the NIR camera. The various fraction of the attenuated light as film configuration is calibrated to thickness. The position of optical components is shown as fig. 2.

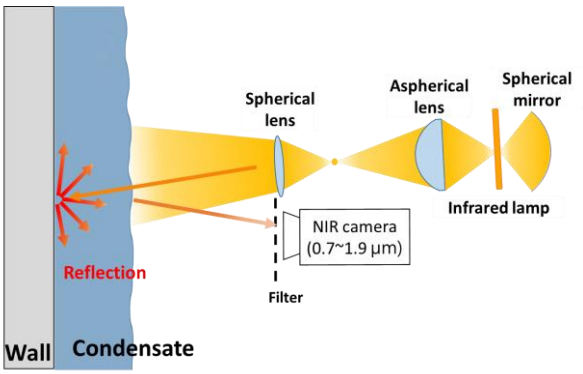

Fig. 1. Schematic of measurement technique using near-infrared camera

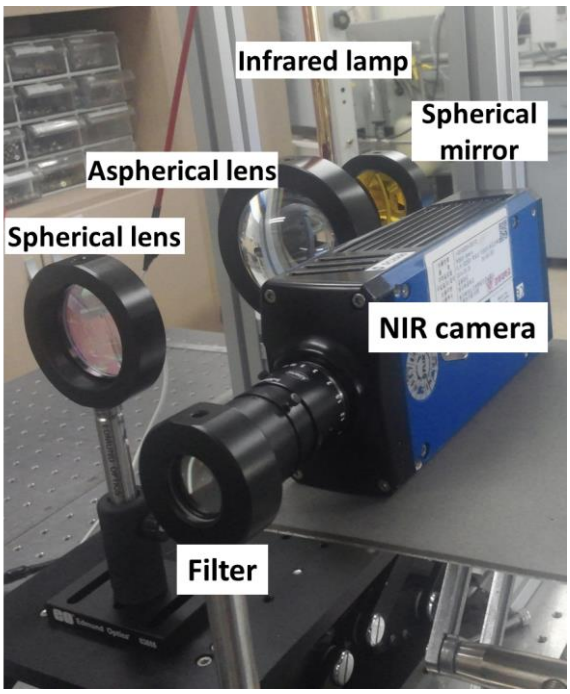

Fig. 2. Aligned optical set up.

3. Experimental facility

The experimental facility is designed to apply the measurement technique of film thickness during forced convection film condensation. The design goal for experimental facility are as follows:

1) constant wall temperature can be maintained,
2) heat flux measurements on the wall is allowed,
3) the test section is inclined from vertical to horizontal position,
4) NIR method apply to measure film thickness measurement of the condensate flow.

The schematic of the experimental facility is shown in Fig. 3. The experimental facility consists of the test section, the steam generator, the air blower, the condensate reservoir tank, the water tank and the water film feeding system.

The main test section is a 730-mm long, 85-mm wide and 20-mm high rectangular duct made of polycarbonate with low thermal conductivity. The sample for film condensation heat transfer is a 500-mm long, 85-mm wide and 15-mm thick rectangular plate made of aluminum to condensate and it is posited on the test section.

The sample is cooled using the coolant with below saturation temperature. Surface temperature of the sample is controlled according to mass flow rate and temperature of coolant. Steam from the steam generator is condensed on the cooled surface. The steam generated from the steam generator is injected into the main test section through the honeycomb and the screen. The honeycomb and the screen play a role in aligning flow direction forming uniform velocity, respectively. Condensate film generated in the test section is accumulated in the condensate reservoir tank. The insulator of 10-mm thick glass wool is installed on the test section to reduce heat loss. NIR-transparent sapphire windows are installed in test section to apply NIR technique for the measurement film thickness.

The flow rates of steam, air and coolant are measured using a KTVP-750 vortex mass flow meter, an orifice flowmeter, a rotameter. The temperature of aluminum sample, the coolant inlet, outlet and the injection water from water tank and the test section are measured by T-type thermocouple. Pressure is measured at inside the test section. Condensation heat flux is measured using the temperature different between the coolant inlet and outlet using the following equation.

$$q''_{conden} = \dot{m}_{coolant} c_p (T_{out} - T_{in}) \quad (1)$$

4. Feasibility test

The feasibility is conducted to validate the application of the NIR method using adiabatic water-air separated flow without film condensation. The facility for the feasibility test is modified to form water film on the sample. An air from the air blower is substituted for the steam to forced convection of air-water separated flow. Water was supplied to the test section using the water injection system into the test section.

From the feasibility test, the intensity of the attenuated light on wetted surface according to various air velocity and water mass flow rate is obtained. The characteristic of flow as the conditions of fluid is understood.

5. Summary

In present study, the condensation experimental facility was constructed to apply the NIR technique to film thickness measurement. A set of feasibility test of liquid film thickness method using the NIR method are conducted under air-water mixture condition.

The present NIR measurement technique will be used to study fundament film condensation.

REFERENCES

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[3] J. Dupont, G. Mignot and H. M. Prasser, “Near infrared liquid water film thickness measurement technique and 2-D mapping”, NURETH-15, Pisa, Italy, May 12-17, 2013

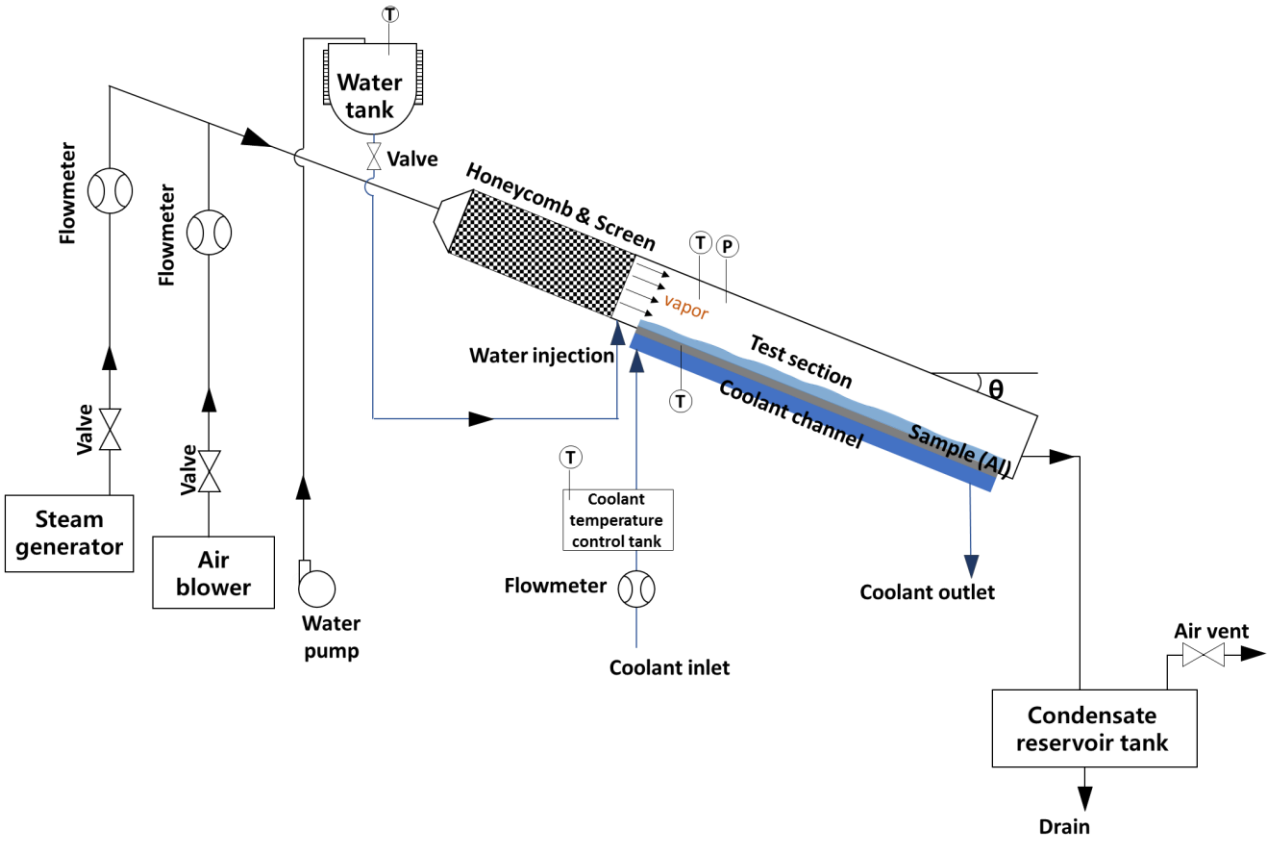

Fig. 3. Schematic of the condensation experimental facility