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Measurement of two-phase mixture level using an ultrasonic method

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Abstract

An ultrasonic method is developed for the measurement of a two-phase mixture level. The proposed approach can be used as a level measurement method in a reactor vessel or steam generator. A commercial ultrasonic method is used and modified for application under conditions such as high temperature and pressure, as well as severe surface fluctuation. The modifications are as follows: (1) The calculation method of the ultrasonic velocity is modified such that it can be predicted correctly under high temperature and pressure conditions considering the medium as a homogeneous mixture of air and steam; and (2) a waveguide is developed to reduce the loss of echo by the effects of attenuation and by the diffused reflection from the fluctuated surface of the water level. Finally, the developed method is verified under high temperature (211 °C) and pressure (1.95 MPa) conditions. It is concluded that the developed ultrasonic method measures the two-phase mixture level more accurately than the conventional methods at high temperature and pressure conditions as well as under conditions of surface fluctuation.

Keywords: Ultrasonic; Two-phase mixture level; Waveguide; Ultrasonic velocity

1. Introduction

During the accident at the TMI-2 nuclear power plant, low water level and inadequate core cooling (ICC) in the reactor vessel were not recognized for a long period of time because the TMI-2 level instrumentation system did not measure the real two-phase mixture level accurately. After the TMI-2 accident, accurate measurement of the actual mixture level in nuclear power plants has been emphasized. The measurement of water level under low temperature and pressure conditions without surface fluctuations is a relatively simple process. However, a rapid change of environmental conditions such as temperature and pressure precludes the use of these standard techniques in reactor applications. In addition, conditions at high temperature, which can cause a fluctuating surface and mist, make measurement of the exact two-phase mixture level more difficult [1,2].

In the present study, the ultrasonic method is selected among the various methods of level measurement. This method is further developed to measure the two-phase mixture level accurately and for application to a nuclear reactor or steam generator during abnormal conditions or accidents as well as normal conditions [3]. The commercial ultrasonic sensor is first tested to determine problems at various conditions such as high temperature and pressure, the existence of obstructs, mist, and so on. Then, in order to solve the identified problems, the commercial ultrasonic sensor for level measurement is modified with a particular focus on the calculation method of the ultrasonic velocity and waveguide development. Finally, the developed methods are verified at high

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Nomenclature

C_p	constant pressure specific heat [kJ/kg K]	T	temperature [°C]
C_v	constant volume specific heat [kJ/kg K]	t_r	round trip time [s]
H_{tank}	tank height [m]	v_0	ultrasonic velocity at 20 °C [m/s] (=344.1 m/s)
$L_{mixture}$	mixture level [m]	v	ultrasonic velocity [m/s]
M	molar mass [kg/kmol]	W_{air}	air mass fraction
P	pressure [kPa]	γ	specific heat ratio ($\gamma = C_p/C_v$)
R	gas constant [kJ/kg K]	ρ	density [kg/m^3]

temperature and pressure conditions up to 211 °C and 1.95 MPa, respectively, which corresponds to the pressure limitation of this facility.

2. Experimental facility

Two experimental facilities are manufactured in the present study; one is for pretests and development procedures and the other is for verification tests.

Fig. 1 shows a schematic of the experimental facility for pretests and development of the measurement system. The ultrasonic sensor employed in the facility is a XCT-8 made by Miltronics Co. (Canada). The ranges of measurable distance and temperature are 0.45–8 m and 40–150 °C, respectively. A signal processor (Multiranger plus by Miltronics), oscilloscope (HP infinium), and high pass filter are used to observe and record the raw signal. Temperature and pressure of the medium are measured using three K-type thermocouples and a pressure transmitter. An air supply system is provided to make the water surface fluctuate without boiling by a heater. The water in the tank is boiled with/without pressurization by a heater and a heater controller. There are two windows to observe the actual level. Experimental data are recorded using Data Acquisition System (DAS; HP 1431C and mainframe) and a computer.

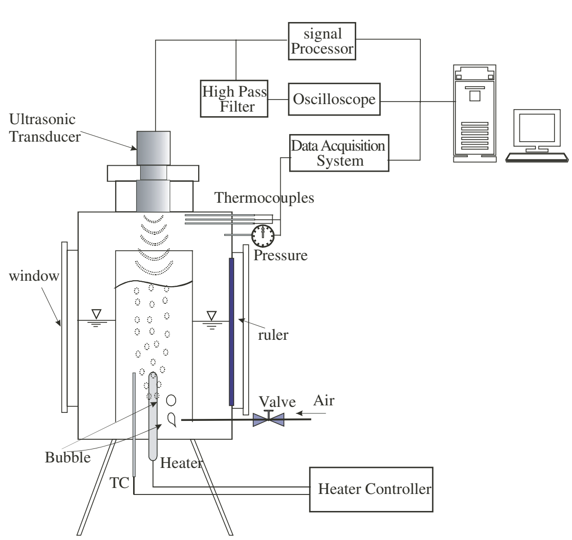

Fig. 1. Experimental facility for pretests and development procedures.

In order to verify the developed method under higher temperature and pressure, the second experimental facility is manufactured as shown in Fig. 2. The maximum operating pressure of this facility is 2.0 MPa and there are several windows to measure the actual level by visual observation. A Heater, heater controller, and air injection system are provided for the same purposes as those in the pretest. Temperature and pressure of the medium and water are measured using ten K-type thermocouples and two pressure transmitters. A waveguide is installed in the tank and the same ultrasonic sensor, processor, and data acquisition system as in the first facility are used. The uncertainties of the major measured parameters with regard to the instrumentation are summarized in Table 1.

3. Experimental work for development

3.1. Pretest results

From pretests performed up to 135 °C of temperature and 0.31 MPa of pressure, it is found that the level measured by the commercial sensor is different from the actual level as the temperature increases even when the sensor's correction method is used. The maximum deviations with and without this correction are 8.67% and 17.72% near the maximum temperature, respectively, as shown in Fig. 3. From the pretest performed up to 100 °C of temperature at constant pressure (0.1 MPa) and in the case of air inflow to the test section, more echo signals are lost as the water level fluctuates more severely, as shown in Fig. 4. As such, the ultrasonic method cannot be used under these conditions. Therefore, in order to use the ultrasonic method, the inaccuracy of the level measurement at high temperature and the loss of echo signal under severe surface fluctuation must be corrected.