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Study of errors in ultrasonic heat meter measurements caused by impurities of water based on ultrasonic attenuation*

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Abstract: Impurity is one of the main factors that affect the measurement accuracy of an ultrasonic heat meter. To study the effects of different impurity species and concentrations on the accuracy of heat meters, flow tests were carried out for the suspending of calcium carbonate and yellow mud. By analyzing the attenuation characteristics of the ultrasound amplitude in different impurity concentrations and species, the influence of the impurities on the heat meter measurement accuracy is evaluated. In order to avoid the inaccuracy caused by the sediment of the reflective bottom surface, a vortex generator is put ahead of the reflective surface. According to the test, the calcium carbonate suspension with a mass concentration of 1%, which influences the heat meter accuracy severely, is used as the flow media. The influence of the vortex generator on the calcium carbonate suspension flow field in the heat meter body is studied with numerical simulations. The results of this paper provide some theoretical guide on improving the heat meter measurement accuracy when the water contains impurities.

Key words: impurities, ultrasonic heat meter, amplitude attenuation, measuring error, experiment study

Introduction

With the development of China's energy conservation and emission reduction, new requirements are put forward for heat metering. The Chinese State Council promulgated a policy of "Speed up the development of energy saving and environmental protection industry", which indicates clearly that China must implement the policy of household heat metering in new buildings and promote heat metering and energy efficiency renovations in the existing residential heating system. Ultrasonic heat meters are widely applied in China for its predominant advantages such as high accuracy, no moving parts, small pressure loss, easy installation and maintenance. But because of the poor heating water quality in China, the solid impurity in the water is one of the main problems that influence the heat metering accuracy. The ultrasonic wave propagation and attenuation in the water containing impurities is the basis of exploring the influence of impurities on the errors of the ultrasonic heat meter measurements and of improving the ultrasonic measurement accuracy under actual working conditions.

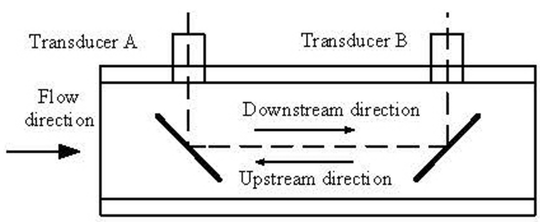

Fig.1 Schematic diagram of the flow measurement

Ultrasonic heat meter involves the calculation of the velocity of the fluid by measuring the time diffe-

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rence of the ultrasonic wave transmission in the downstream and the upstream. The structure of the U-type ultrasonic heat meter is shown in Fig.1. Two reflective surfaces are in symmetrical positions, and the angle between the eflective surface and the horizontal line is 45^{o}. Transducers A and B can not only emit ultrasonic pulses, but also receive ultrasonic signals, When the transducer A is in the state of emitting, the transducer B is in the state of receiving, the downstream transmission time t_1 can thus be determined, when the transducer B is in the state of emitting, the transducer A is in the state of receiving, we can determine the upstream transmission time t_2 So the transmission time difference between the downstream and the upstream Δt is $t_2 - t_1$. If the transmission velocity of the ultrasound in a static fluid is constant, the velocity of the fluid can be obtained as

$$\Delta t = \frac{2Lv_l}{c^2} \tag{1}$$

where c is the ultrasonic velocity in the medium, L the propagation distance in the flow direction, v_l the average linear velocity of the flow.

When the ultrasonic wave travels in the medium, the wave energy decreases gradually with the increase of the transmission distances, and this phenomenon is called the ultrasonic attenuation, which includes the diffusion attenuation, the scattering attenuation and the absorption attenuation. The diffusion attenuation is mainly due to the non-planar sound wave propagation, which only depends on the geometry of the sound source rather than the transmission medium. The scattering attenuation is mainly due to the impurity in the water, which makes some parts of the sound waves to scatter and is influenced by the shape, the size, the quantity of the scattering particle, as well as the nature of the scattering particles and the medium. The absorption attenuation is mainly due to the internal friction between the particles caused by the medium viscosity, so that a part of sound energy turns into heat energy. Besides, the heat conduction and the relaxation caused by the microscopic process also lead to the sound energy consumption. When the water contains impurities, because of the influence of gravity and the interactions between the impurity particles and the fluid, the distribution of impurities is often uneven. Thus the ultrasonic attenuation mechanism is very complicated in the water containing impurities. The ultrasonic signal intensity, the transmission depth and the amplitude are affected by the impurities, so the waveform changes and the measurement accuracy is decreased.

The ultrasonic attenuation in the fluid containing impurities was extensively studied. Spelt et al.[1] used an effective-medium model to predict the attenuation in solid-liquid systems. Carlson and Martinsson[2] presented a simple theoretical model to predict the sound attenuation due to particles. Baudoin et al.[3] improved the coupled phase theory to consider the polydisperse suspensions using an effective medium and the self-consistent theory. Galaz et al.[4] performed two-dimensional finite-difference time domain simulations in suspensions of polystyrene, which were validated by experiments. Richards et al.[5] developed a reverberation technique for measuring the ultrasonic absorption. In the field of ultrasonic flow metering, Inoue et al.[6] improved the precision of the time difference ultrasonic flow meter measurement by changing the incident angle of the ultrasonic pulse, Ruppel and Peters[7] found a unique assignment between the flow pattern and the error shift in an experimental study. An initial process based on the cross-correlation method was developed by Brassier et al.[8], which validated the choice of the high working frequency. Wang and Tang[9] reduced the errors caused by the inertia delay and the amplitude attenuation by a novel method. A two path ultrasonic gas flowmeter was designed by Chen et al.[10] to eliminate the influence caused by the inherent switch time. Takamoto et al.[11] developed a very small ultrasonic flowmeter for liquids, which can be used to measure the liquid flow rate below 1 ml/min. Liu et al.[12], Liu et al.[13], Liu[14], Lynnworth and Liu[15] also made some progress in the heat meter accuracy improving research. Impurities in the fluid can seriously influence the measurement accuracy of an ultrasonic heat meter, but the influence of impurities on the measurement error is not well studied. In this paper, we study the errors of the heat meter measurement and the variations of the ultrasonic wave amplitude caused by different impurities in the fluid, both theoretically and experimentally.

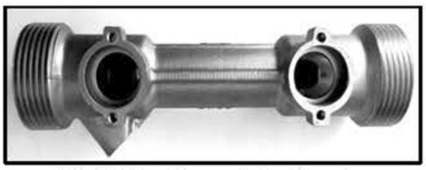

Fig.2 The ultrasonic heat meter

Fig.3 Outline of flow test device