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Detection of, and compensation for error inducing thin layer deposits on an ultrasonic densitometer for liquids

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Abstract – *A pulse echo ultrasonic densitometer can measure the acoustic impedance of a liquid by listening to the echo of an acoustic pulse reflected from the densitometer probe and liquid interface. The density of the liquid is obtained by dividing the acoustic impedance of the liquid and the speed of sound through the liquid. However, thin layer deposits, also known as fouling, on the probe at the liquid interface introduce errors in the assessment of the liquid's acoustic impedance and hence in the density estimation. In this paper, we simulate the situation with different types of contaminations at different fouling layer thickness and show that when performing a discrete Fourier transform (DFT) on the echo, the presence of the contaminating layer can be detected while the correct liquid density can be estimated.*

I. INTRODUCTION

The density of liquids used in certain industrial processes is important information to assure the quality of the end product. Let us for example consider mouthwash. Particular mouthwashes consist of water, glycerin and alcohol in specific amount. Mixing them by volume might lead to improper mixing since, for instance, water might already have been absorbed by the alcohol and glycerin prior to the mixing. Measurement of the liquids' density along with volumetric flow or simply mass flow resolves the issue. Additionally to minimize the total uncertainty in the process, a balance check can be performed subsequently to mixing using mass flow information [1]. Measuring the mass flow or the combination of volumetric flow and density of the flowing liquids is hence important to some industrial applications.

There are several meter types capable of estimating mass flow, each with its own advantages and weaknesses. One type is an ultrasonic mass flow meter which combines a standard ultrasonic flow meter and an ultrasonic densitometer [2]. The ultrasonic densitometer can be incorporated into one of the flow meter's transducers, thus not adding any additional transducers. Although one can find patents for ultrasonic mass flow meter dating from the 1950's, they are not a production item. Several issues have afflicted the ultrasonic densitometers. This paper presents the theory behind the pulse echo ultrasonic densitometer and follows with its drawbacks. The published solutions to some of those drawbacks are discussed. The fouling issue is presented and a solution introduced. A simulation setup reveals the problem and supports the proposed solution.

The concept behind the pulse-echo ultrasonic densitometer relies on the reflection of sound from the interface that joins the probe and the liquid. The coefficient of reflection R is the

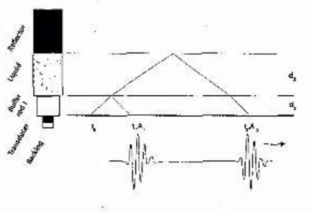

Fig. 1. Experimental setup and lattice diagram

ratio of the amplitude of the reflected wave A_r at the interface to the amplitude of incident wave A_i such that $R = A_r/A_i$. R, for normally incident ultrasonic pulse, is also

$$R = \frac{z_l - z_p}{z_p + z_l} \tag{1}$$

where z_p and z_l are the characteristic acoustic impedance of the probe and liquid respectively [3]. The acoustic impedance for progressive plane waves is defined as the product ρc with ρ being the density of the medium and c the speed of sound through the medium. This model is for continuous waves but has been used in pulse-echo techniques [4-7]. If A_i and z_p are previously known while A_r is measured then the acoustic impedance of the liquid z_l can be calculated. The density of the liquid ρ_l is simply z_l/c_l. c_l, the speed of sound in the liquid, is obtained by placing a reflector within the liquid at a known distance d. The part of the pulse transmitted into the liquid reflects back from the reflector and c_l is the ratio $2d$ to the time separating the two echoes. Fig.1 shows an illustration of this setup with its lattice diagram and the received signal.

Beyond this simple idea, there are issues that have slowed the introduction of the ultrasonic densitometer into the field. The amplitude of the emitted pulse A_i can vary, influencing directly the amplitude of the echo A_r. This can occur with a

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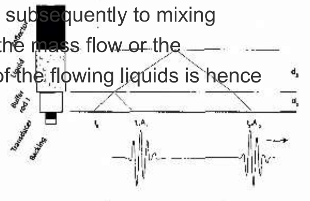

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