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Preliminary research: The CO_2 flow rate sensor based on acoustic measurement using ultrasound signal

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ABSTRAK

Pada penelitian pendahuluan telah berhasil dibangun sensor pendeteksi laju aliran campuran gas (N_2 dan CO_2) dengan menggunakan pengukuran akustik. Detektor ini terdiri dari speaker sebagai pemancar gelombang ultrasonik dan 3 mikrofon sebagai penerima gelombang ultrasonik. Besaran fisis yang diukur dalam pengujian sistem deteksi ini adalah perbedaan fasa gelombang ultrasonik yang ditangkap oleh mikrofon kiri dan kanan. Laju aliran campuran gas akan mempengaruhi nilai perbedaan fasa antara mikrofon kiri dan kanan. Dengan meningkatnya laju aliran campuran gas, perbedaan fasa antara kedua mikrofon akan meningkat. Kisaran laju alir yang diuji adalah antara 0 dan 0,8 l/menit, dengan konsentrasi 20% CO_2 pada campuran gas N_2 dan CO_2. Dalam pengujian sistem deteksi ini, kesalahan absolutnya adalah 2,4 × 10^{-2} l/menit.

Kata kunci: laju alir, akustik, beda fasa, ultrasonik

ABSTRACT

In preliminary research, a sensor for detecting the flow rate of the gas mixture (N_2 and CO_2) has been successfully built using acoustic measurements. This detector consists of a speaker as a transmitter of ultrasonic waves, and 3 microphones as a receiver of the ultrasonic waves. The quantity measured in this detection system test is the phase difference of the ultrasonic waves captured by the left and right microphones. The flow rate of the gas mixture will affect the phase difference value between the left and right microphones. With the increase of the flow rate of the gas mixture, the phase difference between the two microphones will increase. The flowrate range tested was between 0 and 0.8 l/min, with a concentration of 20% CO_2 in the gas mixture of N_2 and CO_2. In testing this detection system, the absolute error is 2,4×10^{-2} l/min.

Keywords: *flow rate, acoustic, phase difference, ultrasound.*

1. INTRODUCTION

A flowmeter is a device used to measure the flow of liquids, gases, or a mixture of the two. Flow measurements are performed in applications in the food industry, oil and gas plants, and chemical / pharmaceutical plants [1]. There are several commonly used flow measurement methods, including differential pressure, electromagnetic, Coriolis, and ultrasonic. These four measurement methods have their respective advantages / disadvantages [1]. In this research focuses on the measurement of gas flow using the ultrasonic method.

In the measurement of gas flow, the ultrasonic method has an important advantage, this method can measure all mixtures of gases and gases over a wide pressure range. The ultrasonic method is also capable of measuring bidirectional and possibly non-intrusive flow without loss of pressure [2]. Flow meters with the ultrasonic method have been used for more than 20 years, especially in industrial warehouses. Measurements are made to measure the volumetric flow of liquids, gases and vapors[3].

Several different ultrasonic methods can be used to calculate flow rates. Figure 1 shows five different non-invasive methods that can be used [4]. Two main methods of Ultrasonic flow measurement, namely transit time and tag cross correlation [2].

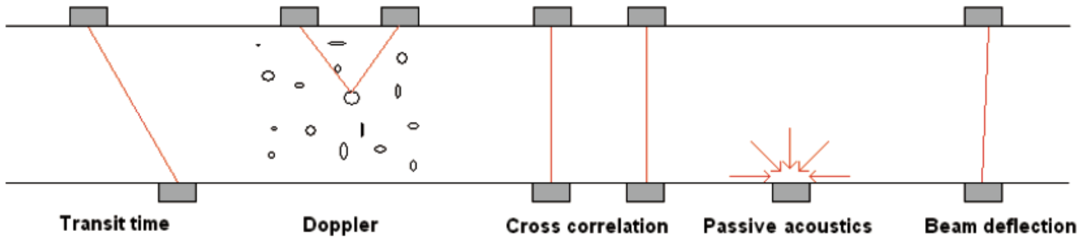


Figure 1. Ultrasonic method for calculate flow rates [4]

The transit time method uses two ultrasonic transducers which function as ultrasonic transmitters and receivers which are placed upstream and downstream respectively on the pipe [4], as shown in Figure 2. The liquid / gas flow causes the difference between the upstream and downstream transit times of the bundle. The measurement of this transit time difference gives the flow velocity [3].

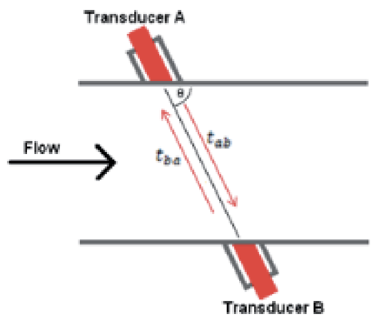


Figure 2. The Transit-time method[2]

The tag cross-correlation method, using two pairs of transducers positioned at a distance from each other in the direction of fluid flow and positioned to transmit through the pipe, as shown in the figure 3 [1]. The ultrasonic signal is transmitted by upstream and downstream transducers, the ultrasonic signal passes through the pipe which is modulated by vortices or vortices which naturally occur in the flow. The result is two very similar waveforms (Figure 11) having distinct peaks replaced by a time factor. This time factor is directly proportional to the distance between the pairs of transducers and inversely proportional to the flow velocity [5].

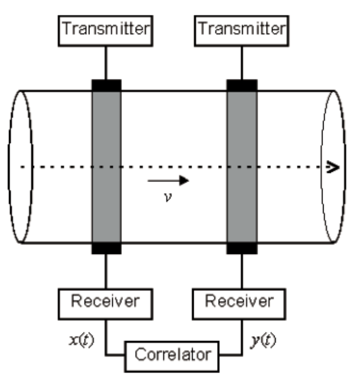


Figure 3. The tag cross correlation method [6]

The use of the ultrasonic method using the speed of sound can also be used to determine gas properties such as composition or density. This is often another major advantage of the ultrasonic method, as the properties of the gas can be combined with the measured flow rate to produce mass or energy flow or be used in place of a gas analyzer [7].This research built a CO_2 gas flow rate sensor with low cost and simple manufacture. This flow rate sensor consists of a speaker as the source of ultrasonic waves and three microphones as a sensor for detecting the ultrasonic signal. The gas flow can be determined from the phase difference of the microphone. The gas flow affects the speed of the ultrasonic signal propagating through the measurement system. The difference between when the left microphone receives the ultrasound signal and when the right microphone receives the ultrasound signal will affect the phase difference between the ultrasound signals from the two microphones. Besides the gas flow rate, the gas concentration also affects the speed of the ultrasonic signal propagating through the measuring system. In this study, the concentration value of CO_2 gas in the mixture was fixed, while the amount of flow was varied.

2. METHODOLOGY

In this research, there were three steps such as: 1) making the design of the sensor, 2) making the sensor according to the previously design, 3) testing the sensor at the using gas mixture of CO_2 and N_2.

1. Design of Sensor

The sensor was made from a brass tube with a diameter of 2.5 cm and a length of 40 cm. There were 3 microphones installed on the sensor which will work to receive the ultrasonic waves transmitted by the speaker. The speaker was installed in front of the microphone in the middle, it can be seen in Figure 4.

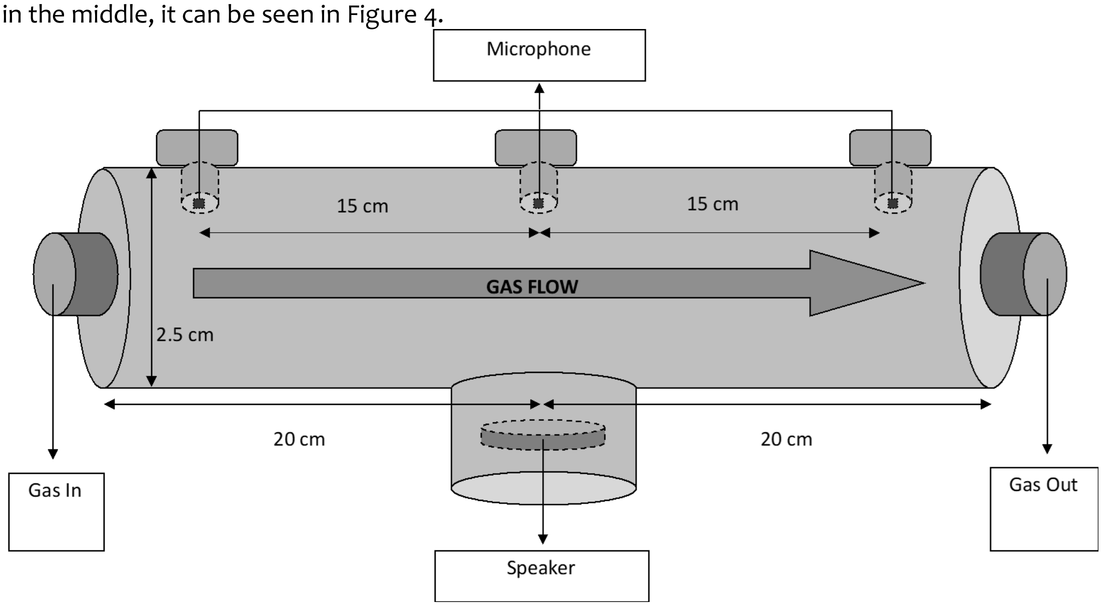


Figure 4. Design of sensor

In this research, flowrate measurements were determined using the acoustic method with ultrasonic signal. The detection of the flow of CO_2 gas in the gas mixture was carried out using a speaker as an ultrasonic signal transmitter and 3 microphones to pick up the ultrasonic signal. Ultrasonic signal was transmitted by speakers at 25 kHz of the frequency. The quantity measured by measuring the flow of CO_2 gas in this method is the phase difference between the waves picked up by the microphones.

2. Operation procedure of the CO_2 gas flow rate detection system

The operation procedure of the CO_2 gas flow detection can be schematically seen in Figure 5. The N2 and CO2 gas was mixed in a gas mixing device, the concentration of CO2 in the gas mixture is 20%. In the first stage of the gas mixing stage, nitrogen gas flowed into the gas mixing device until the pressure gauge indicated a pressure of 0.8 bar, after the pressure gauge showed the amount of pressure for N2, the gas mixing device was locked. Then, in the same way, 0.2 bar of CO2 gas flowed into the gas mixing chamber until the pressure gauge indicated a pressure level of 1 bar.

The gas mixture in the gas mixing device flowed to the sensor through a flow meter, where at the same time the loudspeakers supplied using a frequency generator at a frequency of 25 kHz. As the gas passes through the microphone, the microphone receives an ultrasonic signal and is displayed on the oscilloscope. The signal captured by the microphone is filtered using an active bandpass filter circuit so that the output voltage generated by the microphone has been amplified before being displayed on the oscilloscope. The signals displayed by the left and right microphones displayed on the oscilloscope and the phase difference between the two determining signals. This phase difference represents the flow of gaseous CO_2.

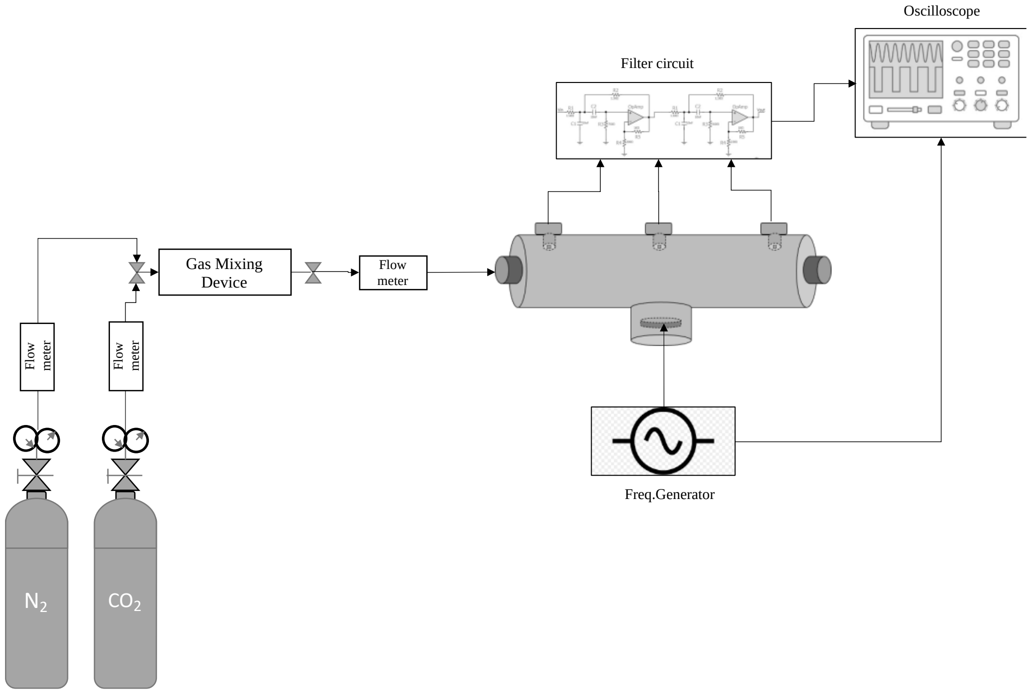


Figure 5. Schematic diagram of operation procedure

3. RESULT AND DISCUSSION

Figure 6 show the sensor made according to the design of Figure 4. Figure 7 (a) and Figure 7 (b), respectively, show the position of the speaker and microphone before installation. The speaker and microphone guaranteed to be right in the middle of the bolt and sturdy (not loose/not shaken), as this will affect the measurement results later.

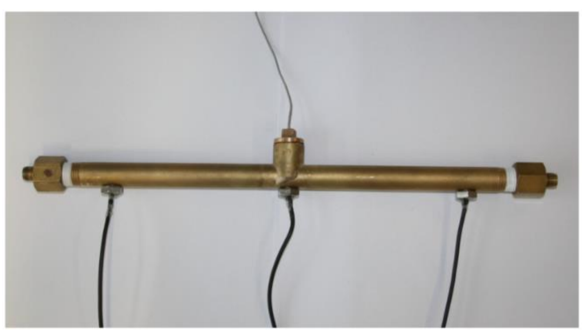
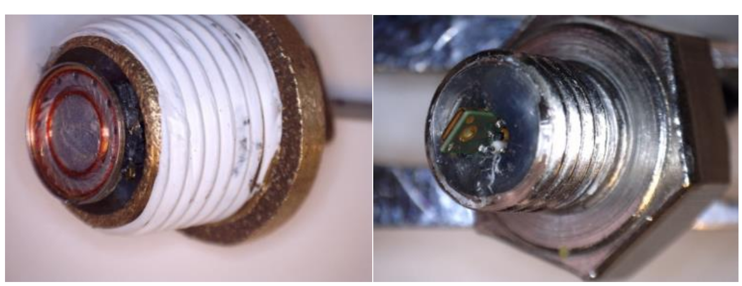


Figure 6. Photo of Sensor



(a) (b)

Figure 7.(a) Speaker (b) Microphone

As explained previously, this sensor designed to detect the flowrate of CO_2 which passes through the sensor system, with the phase difference which was representative of the flow rate of CO_2 gas in the sensor system. The sensor test performed by varying the flow rate of CO_2 gas that passes through the sensor with the fixed concentration of CO_2 gas. The variation in flow rate used was from 0,1 l/min to 0,8 l/min with 20% of CO_2 concentration in the gas mixture of N_2 and CO_2. The results of the sensor tests can be seen in Figure 8.

In Figure 8, it can be seen that the flow of CO_2 affects the phase difference of the microphone. If the flowrate increases, it causes an increase in the phase difference of the microphone. The flowrate affects the time between the ultrasonic signal received by the left microphone and the right microphone was different, the phase of the received ultrasonic signal also would be different.

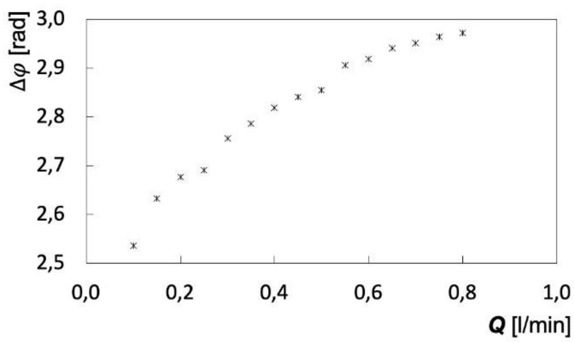


Figure 8. The result of flowrate detection

The validation of the measurement results was carried out by determining the relation between the input and the output of the sensor via the inverse function of the experimental results, where the inverse function can be compared between the theoretically obtained flow rate (inverted model) with the actual size of the debit. The graph of the inverse function from the experimental results can be seen in Figure 9.

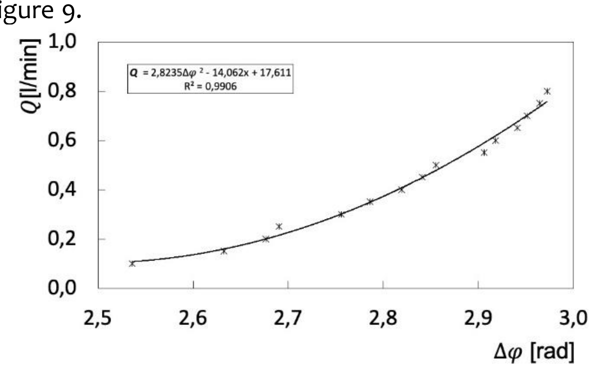


Figure 9. The inverse graph from the experimental results

From Figure 6, the equation of the relationship between the microphone phase difference and the flowrate of CO_2 can be seen in the following equation:

$$Q = 2{,}8235\Delta\varphi^2 - 14{,}062\Delta\varphi + 17{,}611 \quad (1)$$

where Q is the flow rate of the gas, and $\Delta\varphi$ is the phase difference produced by the microphone.

The validation results obtained from Equation 1 by comparing the CO_2 gas flow rate (measurement) with the CO_2 gas flow rate (theoretical), the absolute and relative error values for the flow detection are 2.4×10^{-2} l/min and 5.6%. Based on the absolute and relative error value of this sensor measurement is relatively low, it can be said that the sensor can work well to detect the flowrate of CO_2 gas flow in the gas mixture. The results obtained have a high level of conformity with a correlation coefficient of 0.9906. Absolute error and relative error graphs of the sensor measurements can be seen in Figures 10 (a) and 10 (b).

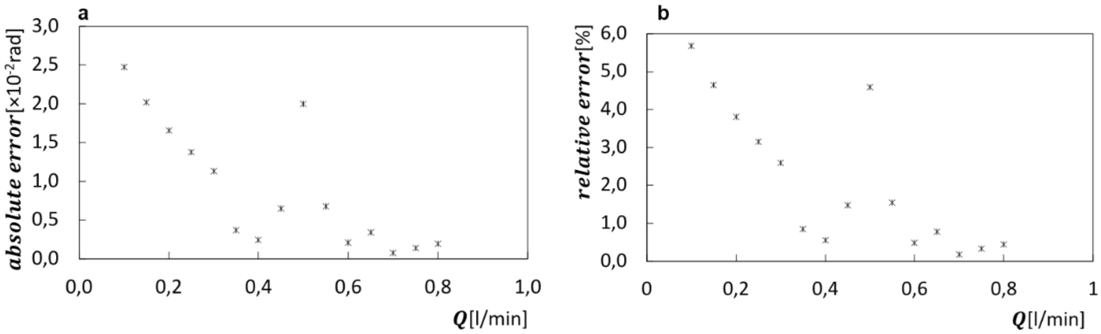


Figure 10. a. The absolute error of experiment, **b.** The relative error of experiment

4. CONCLUSION

In this preliminary research, the detection of the flowrate of CO_2 gas in a mixture of N_2 and CO_2 gases based on an acoustic measurement using ultrasound was carried out successfully. This detector consists of a speaker as the ultrasonic wave transmitter and 3 microphones as the ultrasonic wave receiver. The quantity measured in this detection system test was the phase difference of the ultrasonic waves picked up by the left and right microphones. The flow rate of the gas mixture affects the phase difference value between the left and right microphones. As the flow rate of the gas mixture increases, the phase difference between the two microphones will increase. The tests were carried out in a flow range of 0 to 0.8 l / min, with a concentration of 20% CO_2 in the gas mixture of N_2 and CO_2. When testing this detection system, the absolute error is 2.4×10^{-2} l/min.

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