

APPLICATION OF ULTRASONIC METHOD FOR MEASURING THE SOUND VELOCITY IN A MEDIUM TO DETERMINE THE TEMPERATURE CHANGE AND FLUCTUATIONS

Christian Halper, Jan Ilko & Miroslav Rusko



Authors' data: Ing. Halper, C[hristian]*; doc. Ing. PhD. Rusko, M[iroslav]**; Ing. Ilko, J[an]**, *MEDON GmbH, Olbendorf, Austria, **Slovak University of Technology in Bratislava, UIBE, Trnava, Slovakia, christian.halper@medon.at, jan.ilko@stuba.sk, miroslav.rusko@stuba.sk

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Abstract

There are application in technology processes where the fast determination of the temperature changes is important to achieve a stable process. The standard temperature sensors has a specific time-period to provide the information about the real temperature of the media. To get a fast response there is a possibility to use an ultrasonic method to determine the change and the real temperature as well. The goal of this study is to test the response time, correlation and reliability of ultrasonic measurement method for determination of water temperature as a part of further drinking water studies and analysis.

Keywords: temperature; ultrasonic; measurement; monitoring

1. Introduction

The sound velocity of a media is addicted to the media temperature. This fact can be used for temperature change determination or measuring of the temperature as well. For technological applications where the temperature of media is rapidly changing in time is the ultrasonic method a good way to get the fast response for the further controlling of the process. Big advantage of this method is by the fast response also the fact that the ultrasonic monitors allow a measuring from outside – so-called clamp on system. The ultrasonic sensors are able to measure in a range of -30 to +200 °C. There are solutions how to extend this range from cryo-temperatures up to 400 °C. This is called Wave-Injector.

Such method could find its place also in environmental applications. There are authors who are dealing with similar aspects in frame of their work [5], [6], [7].

2. Theory

Of the many sensing materials available, piezoelectric sensors offer a number of advantages [1]. From the value of the velocity of sound it is possible to compute the temperature [9]. A temperature measuring apparatus, shown on the Fig. 1, measures the temperature of a medium according to the propagation time of ultrasonic waves propagated for a predetermined distance through the medium. The apparatus has a transmitter 11, 12 for transmitting ultrasonic waves having a fixed frequency at predetermined timing and a receiver 13, 14, 15 for receiving the ultrasonic waves and providing a received signal. A delay time detector 24 detects, in response to the received signal, a delay time between the transmission and reception of the ultrasonic waves and a wave number calculator 21 calculates an integral wave number according to the delay time and a period of the ultrasonic waves [3].

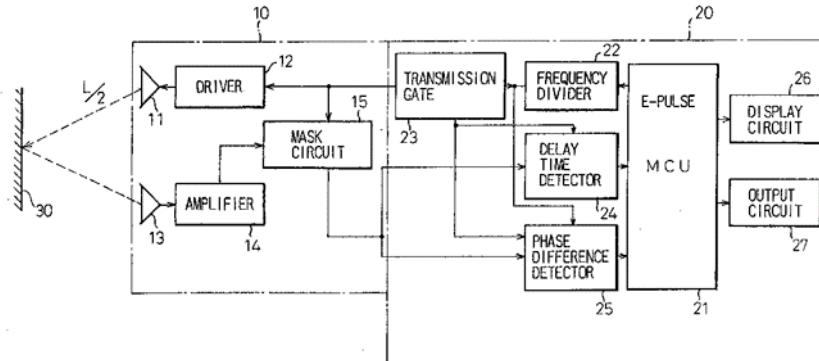


Fig. 1. Ultrasonic monitor principle [3].

For some applications the response of the fast temperature sensor is insufficient either the response is several seconds. Moreover, it is the response of the sensor itself. In real technological applications are the sensors put in a sleeve designed for the process where the temperature to be measured. For example there are sensors like LM34 where the real temperature is reached in 3 seconds like shown on the Fig. 2. Producer declare the response in the datasheet. In the Texas Instruments Datasheet for an LM34 (or LM35) in a TO92 package, they give a graph of thermal response in a stirred oil bath [4].

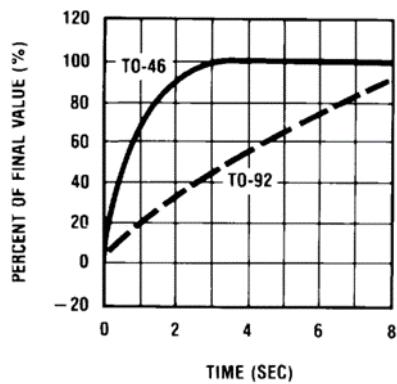


Fig. 2. Thermal Response in Stirred Oil Bath [13].

3. Dependence of sound speed from the temperature

The speed of sound in water depends on temperature, salinity and pressure. At a temperature of 25 °C, for example, the speed is 1496 m/s. In sea water, sound propagates 4.5 times faster than in air. With the increase of any of the factors mentioned (temperature, salinity, pressure), the speed of sound in the water increases. With all the causes, the average speed of sound propagation in fresh water is about 1450 m/s, and in the sea - about 1500 m/s [14]. In all liquids, with the exception of water, the ad. Compressibility with increasing temperature, whereby the density decreases. The speed of sound decreases approximately linearly with increasing temperature. The water occupies a special position in the liquids; here is the ad. Compressibility initially reduced up to a temperature rise to about 60 °C and only then increases. The speed of sound in water therefore initially has a positive temperature coefficient, which becomes negative when it exceeds 74 °C. Thus, the speed increases to a maximum value of 1557 m/s at 74 °C. Above this temperature, the speed of sound decreases [8].

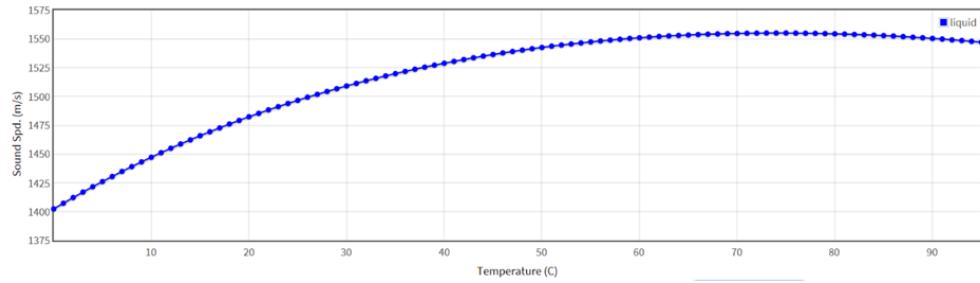


Fig. 3. Function of temperature of water to sound speed at atmospheric pressure [11].

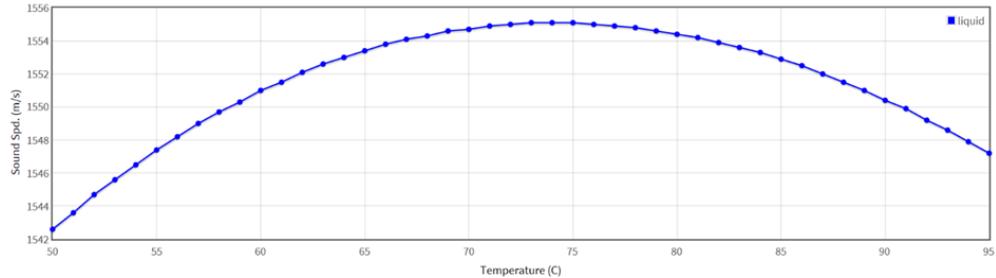


Fig. 4. Function of temperature of water to sound speed at atmospheric pressure in range of 50 - 95 °C [12].

4. Practice

The goal of the measurement was to see the correlation between the sound speed and the temperature of fluid (water) and the time of response. We used one ultrasonic flow monitor from a german producer with two temperature inputs (Fig. 5). For sound speed measurement has been used ultrasonic sensors with 1 MHz operating frequency. The temperature measurement was done with two paired Pt100 sensors (Fig. 6).



Fig. 5. Ultrasonic flow monitor F601 [2].

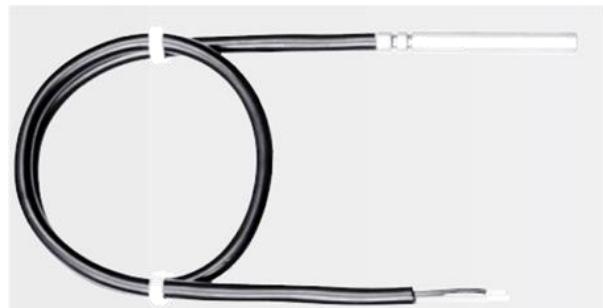


Fig. 6. Temperature sensor Pt 100 [10].



Fig. 7. Measurement assembly.

5. Measurement assemblies

There have been done two measurements.

- The first one was to compare the reaction of temperature sensor insitu with temperature sensor exsitu and the sound speed change of the medium. The measurement assembly is shown on the fig. 7. **Test 1**.
- The second measurement has been performed with two temperature sensors put into the medium and the sound speed monitor. For this measurement was taken a tube with a diameter of 110 mm. **Test 2**.

Test 1: The first measurement was performed with one temperature sensor (T1) in the media and the second sensor (T2) outside to see the time response on the temperature change, as mentioned above. The setting of the controll unit is shown on the following table (Table 1).

General		
Physical quantity	Unit	A
Transducer serial no.		CDQ1NZ746749
Parameters		
Physical quantity	Unit	A
Measurement task		Sound speed
Function		n/a
Measuring point		3
Outer diameter	mm	33.60
Pipe wall material		Stainless steel
Pipe wall thickness	mm	2.00
Pipe wall roughness	mm	0.00
Roughness	mm	0.00 (Typical)
Fluid type		Liquid
Fluid		Water
Fluid temperature	°C	25.00
Fluid sound speed	m/s	1496.55
Cable length	m	0
Measurement		
Physical quantity	Unit	A
Channel activated		Yes
Sound paths		2
Transducer distance	mm	4.00

Table 1. Flow monitor control unit setup during Test 1.

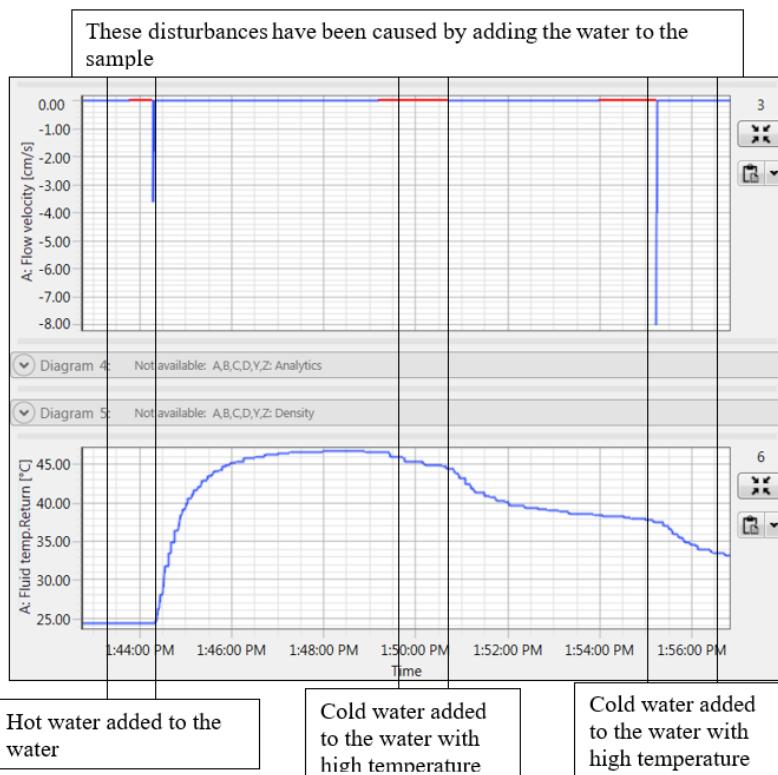


Fig. 8. Process of media temperature changing during the test 1.

The collected data have been exported to xls – see Table 2.

TEST 1	Sound speed [m/s]	Aux, temp [°C]	Fluid temp [°C]	T-Diff [°C]
7/17/2018 1:44:20 PM	1516,7513	23,00	24,30	1,30
7/17/2018 1:44:30 PM	1515,6481	22,80	28,10	5,30
7/17/2018 1:44:40 PM	1515,0974	22,70	33,40	10,70
7/17/2018 1:44:50 PM	1514,5682	22,70	36,40	13,70
7/17/2018 1:45:00 PM	1514,2531	25,70	39,20	13,50
7/17/2018 1:45:10 PM	1513,8198	33,50	41,10	7,60
7/17/2018 1:45:20 PM	1514,0007	39,10	42,10	3,00
7/17/2018 1:45:30 PM	1513,4451	42,90	43,50	0,60
7/17/2018 1:45:40 PM	1513,5037	44,80	44,10	-0,70
7/17/2018 1:45:50 PM	1513,2167	46,90	44,70	-2,20
7/17/2018 1:46:00 PM	1513,2736	48,40	45,20	-3,20
7/17/2018 1:46:10 PM	1513,3082	49,20	45,30	-3,90
7/17/2018 1:46:20 PM	1512,9294	49,80	45,80	-4,00
7/17/2018 1:46:30 PM	1512,9211	50,50	45,80	-4,70
7/17/2018 1:46:40 PM	1512,9133	51,10	46,00	-5,10
7/17/2018 1:46:50 PM	1512,8199	51,10	46,30	-4,80
7/17/2018 1:47:00 PM	1512,5710	51,30	46,30	-5,00
7/17/2018 1:47:10 PM	1512,6099	51,50	46,40	-5,10
7/17/2018 1:47:20 PM	1512,5538	51,50	46,50	-5,00
7/17/2018 1:47:30 PM	1512,2006	51,70	46,50	-5,20
7/17/2018 1:47:40 PM	1512,1123	51,70	46,60	-5,10
7/17/2018 1:47:50 PM	1511,8711	51,70	46,60	-5,10
7/17/2018 1:48:00 PM	1512,5986	51,70	46,70	-5,00
7/17/2018 1:48:10 PM	1512,0269	51,70	46,70	-5,00
7/17/2018 1:48:20 PM	1511,9932	51,60	46,70	-4,90
7/17/2018 1:48:30 PM	1511,9890	51,60	46,70	-4,90
7/17/2018 1:48:40 PM	1511,8707	51,50	46,70	-4,80
7/17/2018 1:48:50 PM	1512,0460	51,40	46,70	-4,70
7/17/2018 1:49:00 PM	1511,7501	50,10	46,60	-3,50
7/17/2018 1:49:10 PM	1511,1442	47,70	46,60	-1,10
7/17/2018 1:50:50 PM	1504,5839	37,10	43,90	6,80
7/17/2018 1:51:00 PM	1505,2888	36,60	43,10	6,50
7/17/2018 1:51:10 PM	1505,9424	37,40	42,40	5,00
7/17/2018 1:51:20 PM	1505,5277	38,50	41,40	2,90
7/17/2018 1:51:30 PM	1505,5288	38,50	40,80	2,30
7/17/2018 1:51:40 PM	1505,5920	39,00	40,70	1,70
7/17/2018 1:51:50 PM	1504,9001	39,50	40,20	0,70
7/17/2018 1:52:00 PM	1505,2567	39,50	40,10	0,60
7/17/2018 1:52:10 PM	1504,8490	39,60	39,70	0,10
7/17/2018 1:52:20 PM	1504,9227	39,70	39,60	-0,10
7/17/2018 1:52:30 PM	1504,5078	39,70	39,30	-0,40
7/17/2018 1:52:40 PM	1505,1230	39,80	39,20	-0,60
7/17/2018 1:52:50 PM	1504,6708	39,90	39,10	-0,80
TEST 1	Sound speed [m/s]	Aux, temp [°C]	Fluid temp [°C]	T-Diff [°C]

7/17/2018 1:53:00 PM	1504,6887	39,90	39,00	-0,90
7/17/2018 1:53:10 PM	1504,6481	39,90	38,90	-1,00
7/17/2018 1:53:20 PM	1504,3978	39,90	38,60	-1,30
7/17/2018 1:53:30 PM	1504,1068	39,90	38,60	-1,30
7/17/2018 1:53:40 PM	1504,4713	39,90	38,50	-1,40
7/17/2018 1:53:50 PM	1504,1632	39,90	38,50	-1,40
7/17/2018 1:54:00 PM	1504,5262	39,80	38,40	-1,40
7/17/2018 1:55:20 PM	1493,0122	34,20	37,50	3,30
7/17/2018 1:55:30 PM	1493,0046	34,10	36,50	2,40
7/17/2018 1:55:40 PM	1493,2284	33,60	35,90	2,30
7/17/2018 1:55:50 PM	1493,7861	33,10	34,90	1,80
7/17/2018 1:56:00 PM	1493,5598	33,00	34,50	1,50
7/17/2018 1:56:10 PM	1493,4324	32,80	34,00	1,20
7/17/2018 1:56:20 PM	1494,4509	32,80	34,00	1,20
7/17/2018 1:56:30 PM	1494,1292	32,80	33,50	0,70
7/17/2018 1:56:40 PM	1493,2693	32,80	33,40	0,60
7/17/2018 1:56:50 PM	1493,4330	32,70	33,10	0,40
7/17/2018 1:57:00 PM	1493,5544	32,70	33,10	0,40
7/17/2018 1:57:10 PM	1493,3602	32,70	33,00	0,30
7/17/2018 1:57:20 PM	1493,2382	32,70	32,90	0,20
7/17/2018 1:57:30 PM	1493,0513	32,70	32,80	0,10
7/17/2018 1:57:40 PM	1493,3098	32,70	32,60	-0,10
7/17/2018 1:57:50 PM	1493,3494	32,70	32,60	-0,10
7/17/2018 1:58:00 PM	1493,3732	32,70	32,50	-0,20
7/17/2018 1:58:10 PM	1492,8188	32,70	32,50	-0,20
7/17/2018 1:58:20 PM	1493,0105	32,70	32,40	-0,30
7/17/2018 1:58:30 PM	1492,8381	32,70	32,40	-0,30
7/17/2018 1:58:40 PM	1492,7958	32,70	32,30	-0,40
7/17/2018 1:58:50 PM	1492,5940	32,70	32,30	-0,40
7/17/2018 1:59:00 PM	1493,0725	32,70	32,20	-0,50
7/17/2018 1:59:10 PM	1492,8896	32,70	32,20	-0,50
7/17/2018 1:59:20 PM	1492,7566	32,70	32,10	-0,60
7/17/2018 1:59:30 PM	1492,4844	32,70	32,10	-0,60

Table 2. Collected data in reduced intervals from 1 second sampling to 10 seconds intervals.

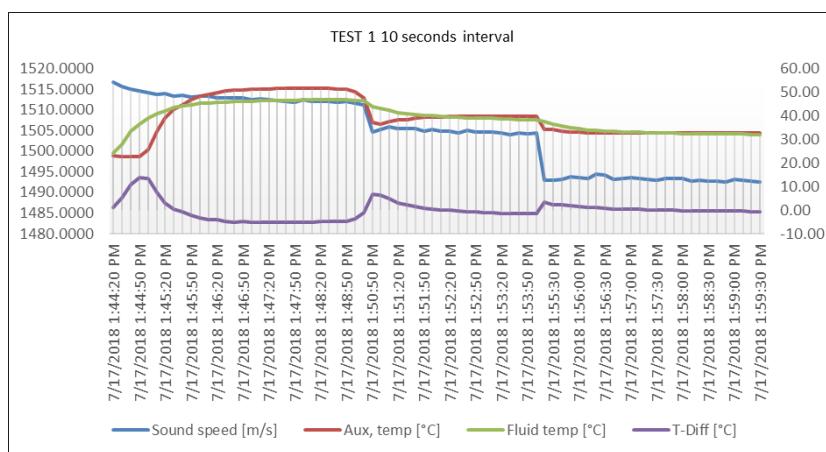


Fig. 9. Trend of the temperatures and sound velocity in Test 1.

Test 2: The second measurement was performed with both temperature sensors (T1, T2) in the medium. The setting of the control unit is shown on the following table (Table 3).

General		
Physical quantity	Unit	A
Transducer serial no.		CDM1EZ778779
Parameters		
Physical quantity	Unit	A
Measurement task		Sound speed
Function		n/a
Measuring point		3
Outer diameter	mm	110.00
Pipe wall material		PVC
Pipe wall thickness	mm	3.40
Pipe wall roughness	mm	0.00
Roughness	mm	0.00 (Typical)
Fluid type		Liquid
Fluid		Water
Fluid temperature	°C	25.00
Fluid sound speed	m/s	1496.55
Cable length	m	0

Measurement		
Physical quantity	Unit	A
Channel activated		Yes
Sound paths		2
Transducer distance	mm	18.50

Table 3. Flow monitor control unit setup during Test 2.

For the second test was taken a PVC tube with diameter of 110 mm.

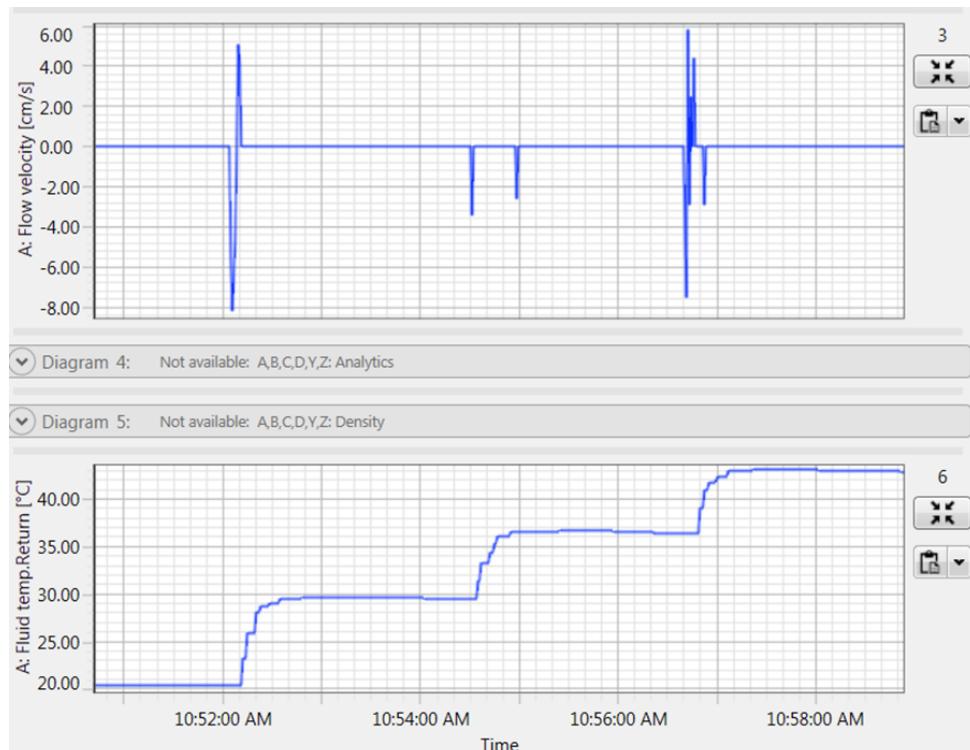


Fig. 10. Process of media temperature changing during the test 2.

The collected data have been exported to xls – see Table 4.

TEST 2	Sound speed [m/s]	T _{avg} [°C]	T1 [°C]	T2 [°C]	T-Diff [°C]
7/18/2018 10:50:50 AM	1480,36	20,20	20,10	20,30	0,20
7/18/2018 10:51:00 AM	1480,39	20,20	20,10	20,30	0,20
7/18/2018 10:51:10 AM	1480,45	20,25	20,20	20,30	0,10
7/18/2018 10:51:20 AM	1480,35	20,25	20,20	20,30	0,10
7/18/2018 10:51:30 AM	1480,41	20,25	20,20	20,30	0,10
7/18/2018 10:51:40 AM	1480,42	20,25	20,20	20,30	0,10
7/18/2018 10:51:50 AM	1480,33	20,25	20,20	20,30	0,10
7/18/2018 10:52:00 AM	1480,51	20,25	20,20	20,30	0,10
7/18/2018 10:52:10 AM	1499,45	21,25	22,20	20,30	-1,90
7/18/2018 10:52:20 AM	1506,65	27,85	27,60	28,10	0,50
7/18/2018 10:52:30 AM	1505,16	29,05	29,10	29,00	-0,10
7/18/2018 10:52:40 AM	1505,28	29,50	29,50	29,50	0,00
7/18/2018 10:52:50 AM	1504,89	29,60	29,60	29,60	0,00
7/18/2018 10:53:00 AM	1505,26	29,65	29,70	29,60	-0,10
7/18/2018 10:53:10 AM	1505,11	29,70	29,70	29,70	0,00
7/18/2018 10:53:20 AM	1504,80	29,70	29,70	29,70	0,00
7/18/2018 10:53:30 AM	1504,88	29,65	29,70	29,60	-0,10
7/18/2018 10:53:40 AM	1505,19	29,65	29,70	29,60	-0,10
7/18/2018 10:53:50 AM	1504,75	29,65	29,70	29,60	-0,10
7/18/2018 10:54:00 AM	1504,98	29,65	29,70	29,60	-0,10
7/18/2018 10:54:10 AM	1504,83	29,60	29,70	29,50	-0,20
7/18/2018 10:54:20 AM	1504,77	29,60	29,70	29,50	-0,20
7/18/2018 10:54:30 AM	1514,80	29,60	29,70	29,50	-0,20
7/18/2018 10:54:40 AM	1520,34	35,30	37,30	33,30	-4,00
7/18/2018 10:54:50 AM	1520,34	36,70	37,30	36,10	-1,20
7/18/2018 10:55:00 AM	1519,13	36,85	37,20	36,50	-0,70
7/18/2018 10:55:10 AM	1518,93	36,70	36,80	36,60	-0,20
7/18/2018 10:55:20 AM	1519,00	36,70	36,80	36,60	-0,20
7/18/2018 10:55:30 AM	1518,90	36,75	36,80	36,70	-0,10
7/18/2018 10:55:40 AM	1518,97	36,75	36,80	36,70	-0,10
7/18/2018 10:55:50 AM	1518,72	36,80	36,90	36,70	-0,20
7/18/2018 10:56:00 AM	1518,61	36,75	36,90	36,60	-0,30
7/18/2018 10:56:10 AM	1518,43	36,70	36,80	36,60	-0,20
7/18/2018 10:56:20 AM	1518,40	36,65	36,80	36,50	-0,30
7/18/2018 10:56:30 AM	1518,26	36,55	36,70	36,40	-0,30
7/18/2018 10:56:40 AM	1518,07	36,55	36,70	36,40	-0,30
7/18/2018 10:56:50 AM	1531,35	40,85	42,70	39,00	-3,70
7/18/2018 10:57:00 AM	1529,66	43,20	44,10	42,30	-1,80
7/18/2018 10:57:10 AM	1529,18	43,60	44,20	43,00	-1,20
7/18/2018 10:57:20 AM	1528,61	43,30	43,60	43,00	-0,60
7/18/2018 10:57:30 AM	1528,45	43,30	43,50	43,10	-0,40
7/18/2018 10:57:40 AM	1528,36	43,20	43,30	43,10	-0,20
7/18/2018 10:57:50 AM	1528,54	43,10	43,10	43,10	0,00
7/18/2018 10:58:00 AM	1528,24	43,10	43,10	43,10	0,00
7/18/2018 10:58:10 AM	1528,08	43,00	43,00	43,00	0,00

7/18/2018 10:58:20 AM	1528,13	43,00	43,00	43,00	0,00
7/18/2018 10:58:30 AM	1528,18	42,95	43,00	42,90	-0,10
7/18/2018 10:58:40 AM	1527,73	42,90	42,90	42,90	0,00
7/18/2018 10:58:50 AM	1528,03	42,90	42,90	42,90	0,00

Table 4. Collected data in reduced intervals from 1 second sampling to 10 seconds intervals.

For the analysis and the conclusion, the data from specified intervals has been taken. The data are in the Table 5 and Fig. 11, 12, 13.

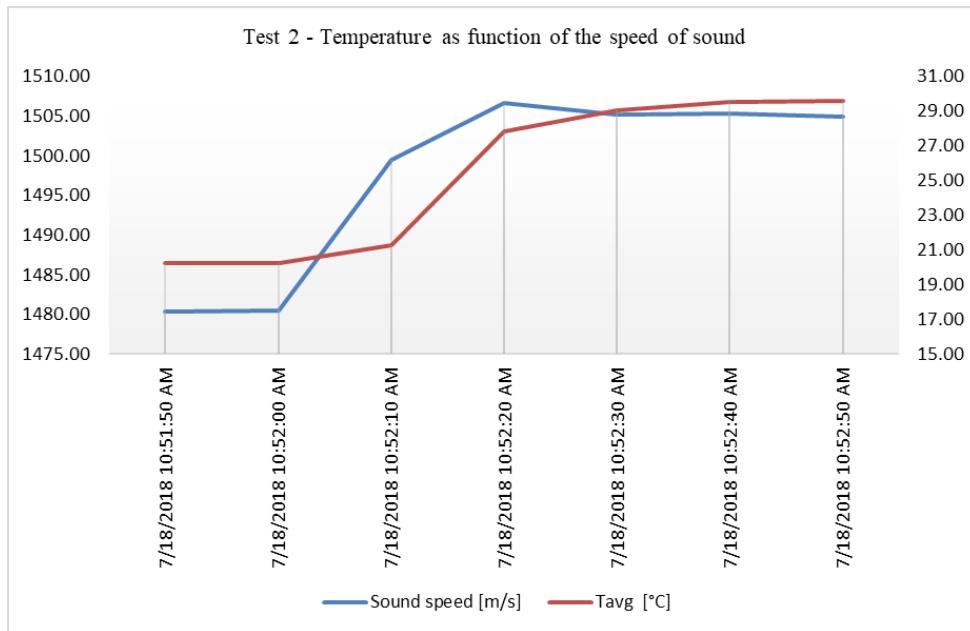


Fig. 11. Trend of the temperatures and sound velocity in Test 2.

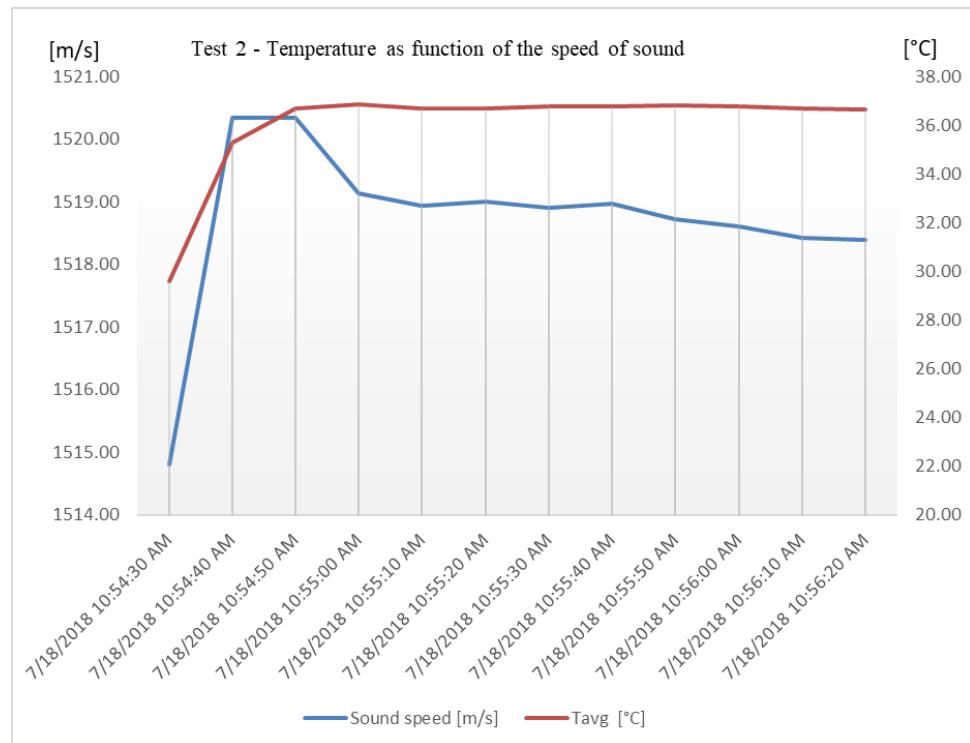


Fig. 12. Trend of the temperatures and sound velocity in Test 2.

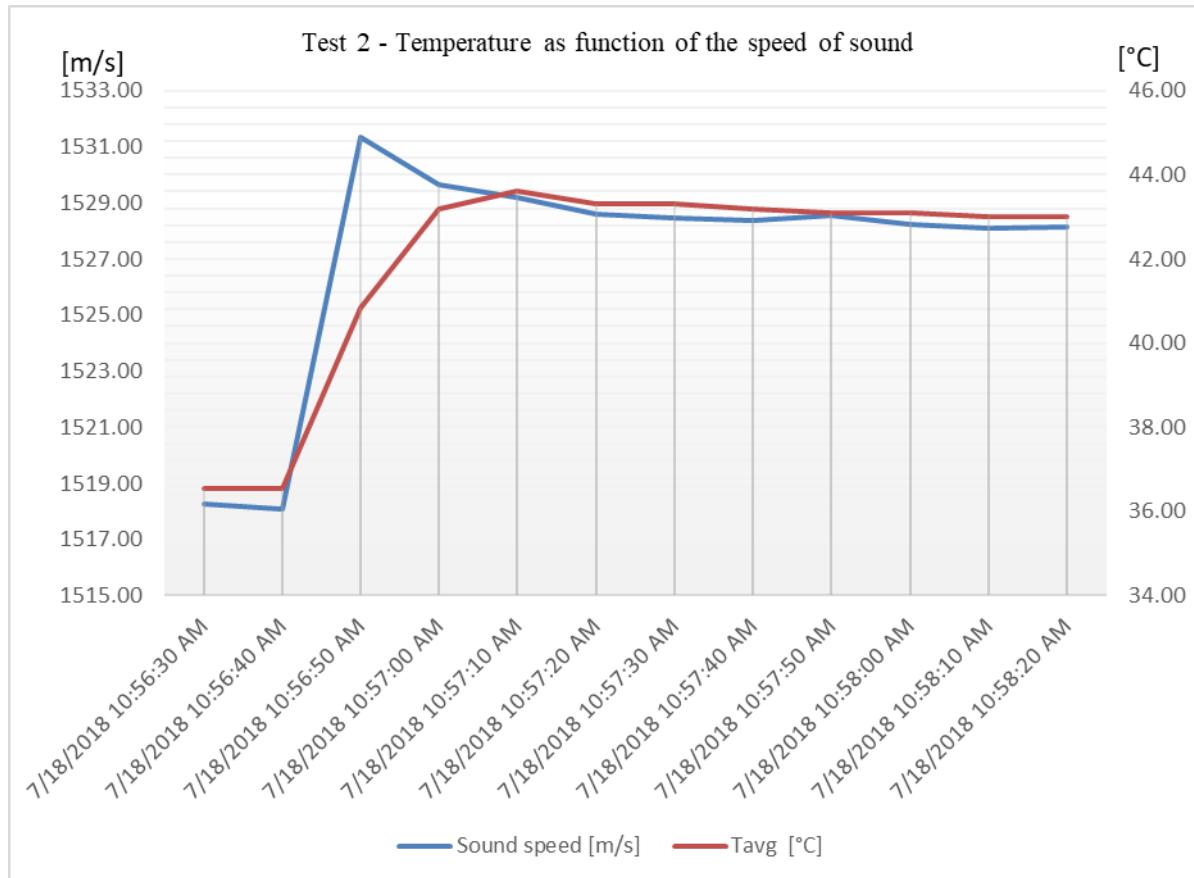


Fig. 13. Trend of the temperatures and sound velocity in Test 2.

6. Conclusion

The purpose of the test was to apply a method to monitor the change of drinking water temperature in accuracy of 1 °C due to the risk of increasing the number of bacteria in drinking water at Celsius degree temperature increase. With ultrasound devices the desired accuracy can be achieved. The sound velocity depends on the pressure of the monitored media. The media pressure should be simultaneously monitored either it has a minor effect on the final result. Water temperature monitoring, resp. changing of the temperature over the sound speed brings the advantage of the response rate to the change in the process. Temperature sensors have a certain delay that is caused by encapsulation of the sensor, in some cases from materials in which the temperature response is much slower. This can cause instability in the control process and to avoid it, the algorithmic processes in the control systems must have a certain delay. Temperature monitoring can be used in technological processes for different types of media. In view of the response rate mentioned above, it is possible to accelerate the process and thereby increase its efficiency.

Results of this study will be a part of next research in drinking water monitoring and analysis. The study will be provided as a technical concept for bacteria grow study in drinking water linings and supplying systems.

7. Acknowledgments

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8. References

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