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POSITION DETECTION OF AN ANALYTE PHASE IN THE LIQUID CHROMATOGRAPHY COLUMN USING A CLAMP-ON ULTRASONIC MONITOR

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ABSTRACT
In this study are results of an experimental analyte phase position detection in a liquid chromatograph column. To perform this experiment, a liquid chromatograph was used, with ethylacetate as the analyte and the ultrasonic portable flow monitor type Fluxus G608, primarily intended for measuring gas and liquid flows in industry. The experiment was based on measuring of different values of speed of sound during the movement of ethylacetate through the adsorbent column. The measurement results confirmed the possibility of using the given method to determine the position of the analyte in the chromatographic column.

Key words: *Liquid chromatography, analyte phase position, ultrasonic clamp-on detection.*

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Introduction

The liquid chromatography uses a columns with solid filaments. The goal of these study was to perform several experiments to qualify, if there is possibility to localize the position of an analyte in the chromatography column. The next experiment was to find out, if there is posibility to detect mechanical defects of the solid phase inside the column. These experiments were done in a laboratory with liquid chromatograph and ultrasonic flow monitor, which provide along the values of actual flow of different media the value of sound speed in the fluid and the diagnostic parameters as well.

Information

Liquid chromatography is one of the most versatile technologies in the life sciences.[1] Laboratories belonging to many different areas, such as toxicology, clinical chemistry, forensics, doping, and environmental and food analyses are interested in cost-effective methodologies, with reduced analysis time.[2] Recent developments in chromatographic supports and instrumentation for liquid chromatography (LC) are enabling rapid and highly efficient separations.[3]The utilization of silica monolithic capillary columns is particularly attractive because micrometer-size macropores in the silica monolith allow simple column modification using only small amount of liposome dispersions.[4] In recent years, monoliths have been used in various fields of chemistry such as support for heterogeneous catalysis, enzymatic reactions and most importantly, as chromatographic stationary phases. Fast analysis and the relatively short running times they provide increases the work productivity in several fields such as in the analysis of prohibited drugs and their metabolites, environmental pollutants, food additives, biological samples.[5]

Materials and Methods

For the measurements the liquid chromatograph Teledyne Isco Combi Flash RF+ was used. This type of chromatograph is shown in the Figure 1.

Figure 1. Liquid chromathograph Teledyne Isco Combi Flash RF+.[6]

Combi Flash Rf + - For more advanced needs, the Combi Flash Rf + is a 1-200 mL/min (delivery flow rate), 200 psi system that forms a binary gradient by automatically selecting two solvents from four inlets. This configuration has an automatic, self-cleaning injection valve for sample introduction, and full-spectrum UV (200-400 nm) or UV-vis (200-800 nm) detection with secondary wavelength monitoring. An internal air pump is used for post-run column air purging, active solvent level sensing, and waste full bottle detection.[7] For the analyte position detection was used the ultrasonic clamp-on flow meter Fluxus G608 FLEXIM. The model is shown in the Figure 2. For our experiments, the fluid sound speed measurement was used, which is the parameter provided by the flow meter flexim with other measurement data, simultaneously.

Clamp-on ultrasonic systems determine the volume flow according to the transit-time difference method. Since the ultrasonic signal that is irradiated into the pipe is carried by the medium flowing

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inside, a time delay occurs between the acoustic transit time both with and against the flow of direction. This time delay can be measured very accurately. The measuring transmitter calculates the volume flow rate based on the parameters input for the pipe geometry and the physical properties of the medium stored in the internal database. The non-invasive acoustic measuring method is inertia-free and is characterized by very high measuring dynamics in both flow directions. Clamp-on ultrasonic transducers are mounted on the outside of the pipe at a specific distance from each other which allows the meter to determine the acoustic velocity in the medium. This depends on the density. Combining density determination through measurement of the transit time and flow recording through transit-time difference measurement results in the mass flow rate. A particularly practical use for the non-invasive measuring technique is the fact that the current output of liquid-based thermal consumers, e.g. heating or cooling systems, can be easily recorded.[8]

Figure 2. FLUXUS G608 ultrasonic flow monitor.[9]

Figure 3. Ultrasonic sensor mounted on a pipe surface.[10]

The experiment was carried out on a column with 80 g of silicagel with a diameter of 35 mm and a polypropylene wall of about 1,5 mm. We equilibrated the column with ethyl acetate and chose methyl-isobutylketone as the analyte. For this diameter of column we choosed the FSQ-type ultrasonic sensor. The sensor is a sharewave type and allows to send and detect the ultrasonic signals.

Research

We placed the sensors on a 35 mm diameter silica gel column as shown in Figure4. We equilibrated the column with ethylacetate and then injected the analyte at a flow rate of 30 ml/min. We did five experiments as shown in the table 1. Methyl-isobutyl-ketone was supposed to simulate any chemical molecule (for example a medicament).

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Figure 4. Ultrasonic sensors mounted on the chromatography column.

Mounting of the sensor is shown in the Figure 5. The mounting is done by so called fastening shoes, where the sensor is positioned in and the chains for mounting on a pipe.

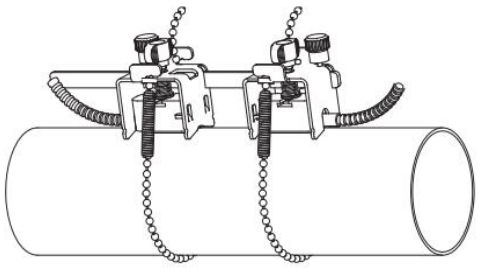

Figure 5. Mounting of ultrasonic sensor on a pipe surface.[11]

Table 1. List of experiments with parameters.

Exper.	flow [ml/min]	MF	Injection	Flow meter setting in SoundPath-1 cfg
1	30	ethylacetate	2 ml methylisobutylketon	OD:36.5 mm, WT=1 mm, c=1000 m/s
2	30	ethylacetate	10 ml methylisobutylketon	OD:36.5 mm, WT=1 mm, c=1000 m/s
3	30	ethylacetate	10 ml methylisobutylketon	OD:36.5 mm, WT=10 mm, c=1000 m/s
4	30	program 3x(2 min-etac/2min DCM)		OD:36.5 mm, WT=10 mm, c=1000 m/s
5	30	ethylacetate	no inj., column purged 60 min by air	OD:36.5 mm, WT=10 mm, c=1000 m/s

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Experiment 1–Injection of two ml of methylisobutylketon to column. No sound speed difference has been detected at the display. The concentration has been to low to make any detectable effect to the sound speed of the fluid in the column. The logged data is in the Table 2.

Table 2. Logged data with the Sound speed and the diagnostic values.

Date	Sound speed [m.s^{-1}]	Amplitude [%]	Amplification [dB]	Quality [%]	SCNR [dB]	SNR [dB]
3.26.2024 9:29:00 AM	1322,21	32,00	101,32	89,00	27,00	7,00
3.26.2024 9:29:01 AM	1322,21	32,00	101,32	89,00	27,00	7,00
3.26.2024 9:29:02 AM	1322,21	32,00	101,32	89,00	27,00	7,00
3.26.2024 9:29:03 AM	1322,85	32,00	101,32	98,00	28,00	6,00
3.26.2024 9:29:04 AM	1322,85	32,00	101,32	98,00	28,00	6,00
3.26.2024 9:29:05 AM	1322,85	32,00	101,32	98,00	28,00	6,00
3.26.2024 9:29:06 AM	1322,61	32,00	101,32	93,00	29,00	6,00
3.26.2024 9:29:07 AM	1322,61	32,00	101,32	93,00	29,00	6,00
3.26.2024 9:29:08 AM	1322,61	32,00	101,32	93,00	29,00	6,00
3.26.2024 9:29:09 AM	1322,74	32,00	101,32	93,00	26,00	7,00
3.26.2024 9:29:10 AM	1322,74	32,00	101,32	93,00	26,00	7,00
3.26.2024 9:29:11 AM	1322,74	32,00	101,32	93,00	26,00	7,00
3.26.2024 9:29:12 AM	1322,74	32,00	101,32	93,00	26,00	7,00
3.26.2024 9:29:13 AM	1323,35	31,00	102,81	98,00	31,00	7,00
3.26.2024 9:29:14 AM	1323,35	31,00	102,81	98,00	31,00	7,00
3.26.2024 9:29:15 AM	1323,73	32,00	101,32	95,00	28,00	8,00
3.26.2024 9:29:16 AM	1323,73	32,00	101,32	95,00	28,00	8,00
3.26.2024 9:29:17 AM	1323,42	32,00	101,32	82,00	28,00	8,00
3.26.2024 9:29:18 AM	1323,42	32,00	101,32	82,00	28,00	8,00
3.26.2024 9:29:19 AM	1322,56	32,00	101,32	94,00	27,00	8,00
3.26.2024 9:29:20 AM	1322,56	32,00	101,32	94,00	27,00	8,00
3.26.2024 9:29:21 AM	1322,78	32,00	101,32	95,00	30,00	9,00
3.26.2024 9:29:22 AM	1322,78	32,00	101,32	95,00	30,00	9,00
3.26.2024 9:29:23 AM	1322,91	34,00	98,34	90,00	28,00	8,00
3.26.2024 9:29:24 AM	1322,91	34,00	98,34	90,00	28,00	8,00
3.26.2024 9:29:25 AM	1321,88	32,00	101,32	99,00	27,00	8,00
3.26.2024 9:29:26 AM	1321,88	32,00	101,32	99,00	27,00	8,00
3.26.2024 9:29:27 AM	1322,60	32,00	101,32	99,00	25,00	9,00
3.26.2024 9:29:28 AM	1322,60	32,00	101,32	99,00	25,00	9,00
3.26.2024 9:29:29 AM	1322,53	32,00	101,32	93,00	27,00	9,00
3.26.2024 9:29:30 AM	1322,19	33,00	99,83	95,00	28,00	8,00
3.26.2024 9:29:31 AM	1322,19	33,00	99,83	95,00	28,00	8,00
3.26.2024 9:29:32 AM	1322,26	32,00	101,32	95,00	25,00	8,00
3.26.2024 9:29:33 AM	1322,26	32,00	101,32	95,00	25,00	8,00
3.26.2024 9:29:34 AM	1321,38	32,00	101,32	96,00	26,00	8,00
3.26.2024 9:29:35 AM	1321,38	32,00	101,32	96,00	26,00	8,00
3.26.2024 9:29:36 AM	1321,79	32,00	101,32	92,00	24,00	8,00
3.26.2024 9:29:37 AM	1321,79	32,00	101,32	92,00	24,00	8,00
3.26.2024 9:29:38 AM	1322,39	31,00	102,81	96,00	27,00	8,00

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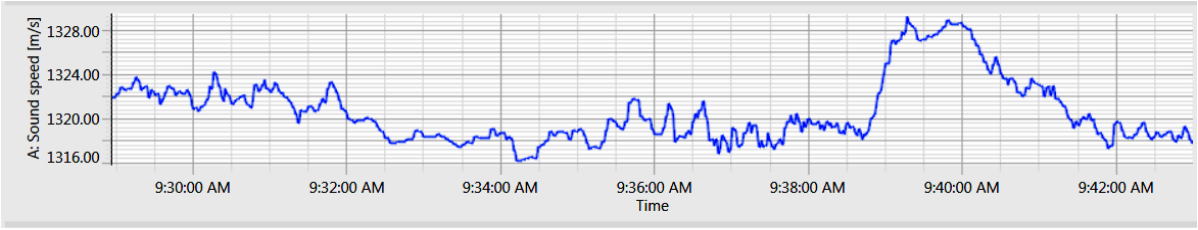
3.26.2024 9:29:39 AM	1322,39	31,00	102,81	96,00	27,00	8,00
3.26.2024 9:29:40 AM	1322,99	32,00	101,32	95,00	24,00	8,00
3.26.2024 9:29:41 AM	1322,99	32,00	101,32	95,00	24,00	8,00
3.26.2024 9:29:42 AM	1322,90	32,00	101,32	90,00	27,00	8,00
3.26.2024 9:29:43 AM	1322,77	32,00	101,32	94,00	25,00	8,00
3.26.2024 9:29:44 AM	1322,77	32,00	101,32	94,00	25,00	8,00

Experiment 2 - 9:38 injection, the sound speed increased from 1319 $m.s^{-1}$to 1328 $m.s^{-1}$in peak maximum. The trend of changing of the soundspeed monitored by the ultrasonic flow meter after injection of 10 ml of methyl-isobutylketon to column and wall thickness parameter set to 1 mm is shown in the Graph 1.



Graph 1. The trend of changing of the soundspeed in the chromatography column.

The stored sound speed values from the time of injection are shown in the Table 3.

Table 3. Logged data with the sound speed and the diagnostic values after injection of 10 ml of methyl-isobutylketon to column and wall thickness parameter set to 1 mm.

Date	Sound speed [$m.s^{-1}$]	Amplitude [%]	Amplification [dB]	Quality [%]	SCNR [dB]	SNR [dB]
3.26.2024 9:38:00 AM	1319,95	32,00	101,32	95,00	26,00	7,00
3.26.2024 9:38:01 AM	1319,95	32,00	101,32	95,00	26,00	7,00
3.26.2024 9:38:02 AM	1319,55	32,00	101,32	96,00	28,00	7,00
3.26.2024 9:38:03 AM	1319,55	32,00	101,32	96,00	28,00	7,00
3.26.2024 9:38:04 AM	1319,55	32,00	101,32	96,00	28,00	7,00
3.26.2024 9:38:05 AM	1319,52	32,00	101,32	97,00	27,00	7,00
3.26.2024 9:38:06 AM	1319,52	32,00	101,32	97,00	27,00	7,00
3.26.2024 9:38:07 AM	1319,74	32,00	101,32	92,00	29,00	8,00
3.26.2024 9:38:08 AM	1319,74	32,00	101,32	92,00	29,00	8,00
3.26.2024 9:38:09 AM	1319,07	32,00	101,32	91,00	24,00	8,00
3.26.2024 9:38:10 AM	1319,35	32,00	101,32	93,00	26,00	7,00
3.26.2024 9:38:11 AM	1319,35	32,00	101,32	93,00	26,00	7,00
3.26.2024 9:38:12 AM	1318,92	32,00	101,32	100,00	26,00	7,00
3.26.2024 9:38:13 AM	1319,45	32,00	101,32	95,00	27,00	7,00
3.26.2024 9:38:14 AM	1319,71	32,00	101,32	98,00	26,00	7,00
3.26.2024 9:38:15 AM	1319,71	32,00	101,32	98,00	26,00	7,00
3.26.2024 9:38:16 AM	1319,45	32,00	101,32	95,00	24,00	7,00
3.26.2024 9:38:17 AM	1319,61	32,00	101,32	99,00	26,00	7,00
3.26.2024 9:38:18 AM	1319,14	31,00	102,81	94,00	28,00	7,00
3.26.2024 9:38:19 AM	1319,32	32,00	101,32	98,00	27,00	7,00
3.26.2024 9:38:20 AM	1319,32	32,00	101,32	98,00	27,00	7,00

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3.26.2024 9:38:21 AM	1319,34	32,00	101,32	94,00	26,00	7,00
3.26.2024 9:38:22 AM	1319,62	31,00	102,81	94,00	26,00	7,00
3.26.2024 9:38:23 AM	1319,23	32,00	101,32	98,00	29,00	7,00
3.26.2024 9:38:24 AM	1318,75	32,00	101,32	98,00	24,00	7,00
3.26.2024 9:38:25 AM	1318,75	32,00	101,32	98,00	24,00	7,00
3.26.2024 9:38:26 AM	1318,74	32,00	101,32	94,00	24,00	6,00
3.26.2024 9:38:27 AM	1318,97	32,00	101,32	98,00	28,00	6,00
3.26.2024 9:38:28 AM	1318,61	32,00	101,32	98,00	27,00	6,00
3.26.2024 9:38:29 AM	1319,38	32,00	101,32	94,00	28,00	6,00
3.26.2024 9:38:30 AM	1319,66	31,00	102,81	98,00	30,00	6,00
3.26.2024 9:38:31 AM	1319,66	31,00	102,81	98,00	30,00	6,00
3.26.2024 9:38:32 AM	1319,16	32,00	101,32	96,00	27,00	6,00
3.26.2024 9:38:33 AM	1319,15	32,00	101,32	96,00	30,00	6,00
3.26.2024 9:38:34 AM	1319,31	32,00	101,32	95,00	28,00	7,00
3.26.2024 9:38:35 AM	1319,31	32,00	101,32	95,00	28,00	7,00
3.26.2024 9:38:36 AM	1318,78	32,00	101,32	96,00	31,00	7,00
3.26.2024 9:38:37 AM	1318,60	33,00	99,83	98,00	31,00	7,00
3.26.2024 9:38:38 AM	1318,52	33,00	99,83	98,00	29,00	7,00
3.26.2024 9:38:39 AM	1319,06	32,00	101,32	98,00	26,00	8,00
3.26.2024 9:38:40 AM	1319,06	32,00	101,32	98,00	26,00	8,00
3.26.2024 9:38:41 AM	1318,44	33,00	99,83	78,00	28,00	8,00
3.26.2024 9:38:42 AM	1318,19	33,00	99,83	95,00	28,00	8,00
3.26.2024 9:38:43 AM	1318,60	33,00	99,83	98,00	25,00	8,00
3.26.2024 9:38:44 AM	1318,48	32,00	101,32	96,00	29,00	9,00
3.26.2024 9:38:45 AM	1318,73	33,00	99,83	99,00	29,00	9,00
3.26.2024 9:38:46 AM	1318,73	33,00	99,83	99,00	29,00	9,00
3.26.2024 9:38:47 AM	1319,10	33,00	99,83	93,00	25,00	9,00
3.26.2024 9:38:48 AM	1319,70	33,00	99,83	97,00	23,00	9,00
3.26.2024 9:38:49 AM	1320,05	32,00	101,32	93,00	25,00	8,00
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3.26.2024 9:38:51 AM	1320,36	32,00	101,32	91,00	25,00	8,00
3.26.2024 9:38:52 AM	1320,57	32,00	101,32	96,00	25,00	8,00
3.26.2024 9:38:53 AM	1321,38	32,00	101,32	98,00	26,00	8,00
3.26.2024 9:38:54 AM	1322,14	33,00	99,83	90,00	25,00	8,00
3.26.2024 9:38:55 AM	1322,42	31,00	102,81	83,00	25,00	8,00
3.26.2024 9:38:56 AM	1322,42	31,00	102,81	83,00	25,00	8,00
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3.26.2024 9:38:58 AM	1323,60	33,00	99,83	84,00	24,00	8,00
3.26.2024 9:38:59 AM	1324,17	33,00	99,83	98,00	26,00	7,00
3.26.2024 9:39:00 AM	1324,99	32,00	101,32	95,00	25,00	6,00
3.26.2024 9:39:01 AM	1324,99	32,00	101,32	95,00	25,00	6,00
3.26.2024 9:39:02 AM	1324,97	32,00	101,32	92,00	24,00	5,00
3.26.2024 9:39:03 AM	1325,02	32,00	101,32	95,00	25,00	5,00
3.26.2024 9:39:04 AM	1326,61	33,00	99,83	92,00	29,00	5,00

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3.26.2024 9:39:05 AM	1327,13	32,00	101,32	98,00	31,00	5,00
3.26.2024 9:39:06 AM	1327,13	32,00	101,32	98,00	31,00	5,00
3.26.2024 9:39:07 AM	1327,03	32,00	101,32	97,00	26,00	6,00
3.26.2024 9:39:08 AM	1326,79	32,00	101,32	97,00	24,00	6,00
3.26.2024 9:39:09 AM	1327,11	31,00	102,81	97,00	28,00	6,00
3.26.2024 9:39:10 AM	1327,11	31,00	102,81	97,00	28,00	6,00
3.26.2024 9:39:11 AM	1327,05	32,00	101,32	99,00	27,00	6,00
3.26.2024 9:39:12 AM	1327,22	32,00	101,32	99,00	27,00	6,00
3.26.2024 9:39:13 AM	1327,83	32,00	101,32	95,00	27,00	6,00
3.26.2024 9:39:14 AM	1327,60	31,00	102,81	97,00	28,00	6,00
3.26.2024 9:39:15 AM	1327,60	31,00	102,81	97,00	28,00	6,00
3.26.2024 9:39:16 AM	1328,09	32,00	101,32	95,00	26,00	6,00
3.26.2024 9:39:17 AM	1329,21	32,00	101,32	96,00	29,00	7,00
3.26.2024 9:39:18 AM	1328,74	32,00	101,32	97,00	28,00	7,00
3.26.2024 9:39:19 AM	1328,55	32,00	101,32	99,00	26,00	7,00
3.26.2024 9:39:20 AM	1328,55	32,00	101,32	99,00	26,00	7,00
3.26.2024 9:39:21 AM	1328,35	32,00	101,32	97,00	26,00	7,00
3.26.2024 9:39:22 AM	1328,30	33,00	99,83	96,00	30,00	7,00
3.26.2024 9:39:23 AM	1328,20	33,00	99,83	98,00	28,00	8,00
3.26.2024 9:39:24 AM	1327,89	32,00	101,32	98,00	26,00	8,00
3.26.2024 9:39:25 AM	1327,14	33,00	99,83	94,00	27,00	8,00
3.26.2024 9:39:26 AM	1327,14	33,00	99,83	94,00	27,00	8,00
3.26.2024 9:39:27 AM	1327,06	33,00	99,83	97,00	26,00	8,00
3.26.2024 9:39:28 AM	1327,06	33,00	99,83	97,00	26,00	8,00
3.26.2024 9:39:29 AM	1327,24	32,00	101,32	91,00	25,00	8,00
3.26.2024 9:39:30 AM	1327,24	32,00	101,32	91,00	25,00	8,00
3.26.2024 9:39:31 AM	1327,18	32,00	101,32	91,00	24,00	8,00
3.26.2024 9:39:32 AM	1327,18	32,00	101,32	91,00	24,00	8,00
3.26.2024 9:39:33 AM	1327,53	31,00	102,81	94,00	24,00	8,00
3.26.2024 9:39:34 AM	1327,53	31,00	102,81	94,00	24,00	8,00
3.26.2024 9:39:35 AM	1327,45	31,00	102,81	94,00	27,00	7,00
3.26.2024 9:39:36 AM	1327,45	31,00	102,81	94,00	27,00	7,00
3.26.2024 9:39:37 AM	1327,45	31,00	102,81	94,00	27,00	7,00
3.26.2024 9:39:38 AM	1327,67	30,00	104,30	97,00	27,00	7,00
3.26.2024 9:39:39 AM	1327,67	30,00	104,30	97,00	27,00	7,00
3.26.2024 9:39:40 AM	1327,67	30,00	104,30	97,00	27,00	7,00
3.26.2024 9:39:41 AM	1327,67	30,00	104,30	97,00	27,00	7,00
3.26.2024 9:39:42 AM	1327,98	31,00	102,81	97,00	29,00	7,00
3.26.2024 9:39:43 AM	1327,98	31,00	102,81	97,00	29,00	7,00
3.26.2024 9:39:44 AM	1327,98	31,00	102,81	97,00	29,00	7,00
3.26.2024 9:39:45 AM	1328,32	31,00	102,81	84,00	25,00	6,00
3.26.2024 9:39:46 AM	1328,32	31,00	102,81	84,00	25,00	6,00
3.26.2024 9:39:47 AM	1328,32	31,00	102,81	84,00	25,00	6,00
3.26.2024 9:39:48 AM	1328,87	29,00	105,79	94,00	27,00	6,00
3.26.2024 9:39:49 AM	1328,87	29,00	105,79	94,00	27,00	6,00

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3.26.2024 9:39:50 AM	1328,87	29,00	105,79	94,00	27,00	6,00
3.26.2024 9:39:51 AM	1328,58	30,00	104,30	91,00	25,00	5,00
3.26.2024 9:39:52 AM	1328,58	30,00	104,30	91,00	25,00	5,00
3.26.2024 9:39:53 AM	1328,58	30,00	104,30	91,00	25,00	5,00
3.26.2024 9:39:54 AM	1328,58	30,00	104,30	91,00	25,00	5,00
3.26.2024 9:39:55 AM	1328,55	30,00	104,30	98,00	27,00	6,00
3.26.2024 9:39:56 AM	1328,55	30,00	104,30	98,00	27,00	6,00
3.26.2024 9:39:57 AM	1328,55	30,00	104,30	98,00	27,00	6,00
3.26.2024 9:39:58 AM	1328,73	32,00	101,32	90,00	27,00	5,00
3.26.2024 9:39:59 AM	1328,73	32,00	101,32	90,00	27,00	5,00
3.26.2024 9:40:00 AM	1328,73	32,00	101,32	90,00	27,00	5,00
3.26.2024 9:40:01 AM	1328,30	32,00	101,32	95,00	29,00	5,00
3.26.2024 9:40:02 AM	1328,30	32,00	101,32	95,00	29,00	5,00
3.26.2024 9:40:03 AM	1328,30	32,00	101,32	95,00	29,00	5,00
3.26.2024 9:40:04 AM	1328,06	32,00	101,32	95,00	26,00	5,00
3.26.2024 9:40:05 AM	1328,06	32,00	101,32	95,00	26,00	5,00
3.26.2024 9:40:06 AM	1328,06	32,00	101,32	95,00	26,00	5,00
3.26.2024 9:40:07 AM	1328,06	32,00	101,32	95,00	26,00	5,00
3.26.2024 9:40:08 AM	1327,24	32,00	101,32	96,00	28,00	6,00
3.26.2024 9:40:09 AM	1327,24	32,00	101,32	96,00	28,00	6,00
3.26.2024 9:40:10 AM	1327,24	32,00	101,32	96,00	28,00	6,00
3.26.2024 9:40:11 AM	1326,59	32,00	101,32	98,00	27,00	6,00
3.26.2024 9:40:12 AM	1326,59	32,00	101,32	98,00	27,00	6,00
3.26.2024 9:40:13 AM	1326,59	32,00	101,32	98,00	27,00	6,00
3.26.2024 9:40:14 AM	1325,83	31,00	102,81	98,00	26,00	7,00
3.26.2024 9:40:15 AM	1325,83	31,00	102,81	98,00	26,00	7,00
3.26.2024 9:40:16 AM	1325,83	31,00	102,81	98,00	26,00	7,00
3.26.2024 9:40:17 AM	1325,08	32,00	101,32	97,00	25,00	7,00
3.26.2024 9:40:18 AM	1325,08	32,00	101,32	97,00	25,00	7,00
3.26.2024 9:40:19 AM	1325,08	32,00	101,32	97,00	25,00	7,00
3.26.2024 9:40:20 AM	1324,49	31,00	102,81	93,00	24,00	8,00
3.26.2024 9:40:21 AM	1324,49	31,00	102,81	93,00	24,00	8,00
3.26.2024 9:40:22 AM	1324,13	32,00	101,32	90,00	24,00	8,00
3.26.2024 9:40:23 AM	1324,13	32,00	101,32	90,00	24,00	8,00
3.26.2024 9:40:24 AM	1324,88	31,00	102,81	93,00	26,00	8,00
3.26.2024 9:40:25 AM	1324,88	31,00	102,81	93,00	26,00	8,00
3.26.2024 9:40:26 AM	1325,58	32,00	101,32	81,00	25,00	8,00
3.26.2024 9:40:27 AM	1325,58	32,00	101,32	81,00	25,00	8,00
3.26.2024 9:40:28 AM	1324,89	32,00	101,32	92,00	25,00	8,00
3.26.2024 9:40:29 AM	1324,89	32,00	101,32	92,00	25,00	8,00
3.26.2024 9:40:30 AM	1324,07	32,00	101,32	92,00	25,00	8,00
3.26.2024 9:40:31 AM	1324,07	32,00	101,32	92,00	25,00	8,00
3.26.2024 9:40:32 AM	1323,60	32,00	101,32	93,00	23,00	8,00
3.26.2024 9:40:33 AM	1323,60	32,00	101,32	93,00	23,00	8,00
3.26.2024 9:40:34 AM	1323,59	32,00	101,32	98,00	24,00	8,00

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3.26.2024 9:40:35 AM	1323,59	32,00	101,32	98,00	24,00	8,00
3.26.2024 9:40:36 AM	1323,06	32,00	101,32	98,00	26,00	8,00
3.26.2024 9:40:37 AM	1323,68	32,00	101,32	96,00	23,00	8,00
3.26.2024 9:40:38 AM	1323,68	32,00	101,32	96,00	23,00	8,00
3.26.2024 9:40:39 AM	1323,60	32,00	101,32	96,00	24,00	8,00
3.26.2024 9:40:40 AM	1323,60	32,00	101,32	96,00	24,00	8,00
3.26.2024 9:40:41 AM	1323,32	31,00	102,81	93,00	25,00	8,00
3.26.2024 9:40:42 AM	1323,32	31,00	102,81	93,00	25,00	8,00
3.26.2024 9:40:43 AM	1322,40	32,00	101,32	96,00	21,00	8,00
3.26.2024 9:40:44 AM	1322,40	32,00	101,32	96,00	21,00	8,00
3.26.2024 9:40:45 AM	1322,43	31,00	102,81	93,00	28,00	8,00
3.26.2024 9:40:46 AM	1322,43	31,00	102,81	93,00	28,00	8,00
3.26.2024 9:40:47 AM	1322,00	32,00	101,32	97,00	25,00	8,00
3.26.2024 9:40:48 AM	1322,00	32,00	101,32	97,00	25,00	8,00
3.26.2024 9:40:49 AM	1322,16	33,00	99,83	90,00	26,00	8,00
3.26.2024 9:40:50 AM	1322,81	31,00	102,81	96,00	27,00	8,00
3.26.2024 9:40:51 AM	1322,81	31,00	102,81	96,00	27,00	8,00
3.26.2024 9:40:52 AM	1322,69	32,00	101,32	93,00	25,00	8,00
3.26.2024 9:40:53 AM	1322,69	32,00	101,32	93,00	25,00	8,00
3.26.2024 9:40:54 AM	1323,67	32,00	101,32	90,00	31,00	8,00
3.26.2024 9:40:55 AM	1323,67	32,00	101,32	90,00	31,00	8,00
3.26.2024 9:40:56 AM	1323,27	32,00	101,32	96,00	26,00	8,00
3.26.2024 9:40:57 AM	1323,27	32,00	101,32	96,00	26,00	8,00
3.26.2024 9:40:58 AM	1323,22	33,00	99,83	90,00	24,00	8,00
3.26.2024 9:40:59 AM	1323,22	33,00	99,83	90,00	24,00	8,00
3.26.2024 9:41:00 AM	1323,03	31,00	102,81	96,00	26,00	8,00
3.26.2024 9:41:01 AM	1323,03	31,00	102,81	96,00	26,00	8,00
3.26.2024 9:41:02 AM	1322,93	32,00	101,32	96,00	27,00	8,00
3.26.2024 9:41:03 AM	1322,93	32,00	101,32	96,00	27,00	8,00
3.26.2024 9:41:04 AM	1322,08	32,00	101,32	97,00	25,00	8,00
3.26.2024 9:41:05 AM	1322,08	32,00	101,32	97,00	25,00	8,00
3.26.2024 9:41:06 AM	1322,81	32,00	101,32	94,00	27,00	8,00
3.26.2024 9:41:07 AM	1322,81	32,00	101,32	94,00	27,00	8,00
3.26.2024 9:41:08 AM	1322,95	32,00	101,32	95,00	24,00	8,00
3.26.2024 9:41:09 AM	1322,14	32,00	101,32	97,00	25,00	8,00
3.26.2024 9:41:10 AM	1322,14	32,00	101,32	97,00	25,00	8,00
3.26.2024 9:41:11 AM	1322,91	32,00	101,32	86,00	26,00	8,00
3.26.2024 9:41:12 AM	1322,91	32,00	101,32	86,00	26,00	8,00
3.26.2024 9:41:13 AM	1321,83	32,00	101,32	93,00	25,00	9,00
3.26.2024 9:41:14 AM	1321,83	32,00	101,32	93,00	25,00	9,00
3.26.2024 9:41:15 AM	1321,86	32,00	101,32	97,00	29,00	9,00
3.26.2024 9:41:16 AM	1321,86	32,00	101,32	97,00	29,00	9,00
3.26.2024 9:41:17 AM	1321,50	32,00	101,32	93,00	27,00	8,00
3.26.2024 9:41:18 AM	1321,50	32,00	101,32	93,00	27,00	8,00
3.26.2024 9:41:19 AM	1321,11	32,00	101,32	97,00	25,00	8,00

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3.26.2024 9:41:20 AM	1321,11	32,00	101,32	97,00	25,00	8,00
3.26.2024 9:41:21 AM	1320,58	32,00	101,32	89,00	24,00	8,00
3.26.2024 9:41:22 AM	1320,11	31,00	102,81	84,00	24,00	8,00
3.26.2024 9:41:23 AM	1320,11	31,00	102,81	84,00	24,00	8,00
3.26.2024 9:41:24 AM	1319,90	31,00	102,81	97,00	27,00	9,00
3.26.2024 9:41:25 AM	1319,90	31,00	102,81	97,00	27,00	9,00
3.26.2024 9:41:26 AM	1319,20	33,00	99,83	87,00	24,00	9,00
3.26.2024 9:41:27 AM	1319,20	33,00	99,83	87,00	24,00	9,00
3.26.2024 9:41:28 AM	1319,69	32,00	101,32	98,00	27,00	9,00
3.26.2024 9:41:29 AM	1319,69	32,00	101,32	98,00	27,00	9,00
3.26.2024 9:41:30 AM	1319,44	32,00	101,32	92,00	22,00	9,00
3.26.2024 9:41:31 AM	1319,44	32,00	101,32	92,00	22,00	9,00
3.26.2024 9:41:32 AM	1319,94	32,00	101,32	90,00	28,00	9,00
3.26.2024 9:41:33 AM	1319,94	32,00	101,32	90,00	28,00	9,00
3.26.2024 9:41:34 AM	1320,21	32,00	101,32	98,00	26,00	9,00
3.26.2024 9:41:35 AM	1319,98	32,00	101,32	98,00	27,00	9,00
3.26.2024 9:41:36 AM	1319,98	32,00	101,32	98,00	27,00	9,00
3.26.2024 9:41:37 AM	1319,98	32,00	101,32	98,00	27,00	9,00
3.26.2024 9:41:38 AM	1320,45	32,00	101,32	91,00	25,00	9,00
3.26.2024 9:41:39 AM	1320,45	32,00	101,32	91,00	25,00	9,00
3.26.2024 9:41:40 AM	1319,81	33,00	99,83	95,00	30,00	9,00
3.26.2024 9:41:41 AM	1319,81	33,00	99,83	95,00	30,00	9,00
3.26.2024 9:41:42 AM	1320,02	32,00	101,32	95,00	25,00	9,00
3.26.2024 9:41:43 AM	1319,14	32,00	101,32	98,00	25,00	9,00
3.26.2024 9:41:44 AM	1319,14	32,00	101,32	98,00	25,00	9,00
3.26.2024 9:41:45 AM	1318,57	32,00	101,32	96,00	26,00	9,00
3.26.2024 9:41:46 AM	1318,57	32,00	101,32	96,00	26,00	9,00
3.26.2024 9:41:47 AM	1318,74	32,00	101,32	97,00	22,00	8,00
3.26.2024 9:41:48 AM	1318,74	32,00	101,32	97,00	22,00	8,00
3.26.2024 9:41:49 AM	1318,27	31,00	102,81	85,00	23,00	8,00
3.26.2024 9:41:50 AM	1318,27	31,00	102,81	85,00	23,00	8,00
3.26.2024 9:41:51 AM	1318,03	31,00	102,81	91,00	26,00	8,00
3.26.2024 9:41:52 AM	1318,03	31,00	102,81	91,00	26,00	8,00
3.26.2024 9:41:53 AM	1317,28	32,00	101,32	99,00	27,00	8,00

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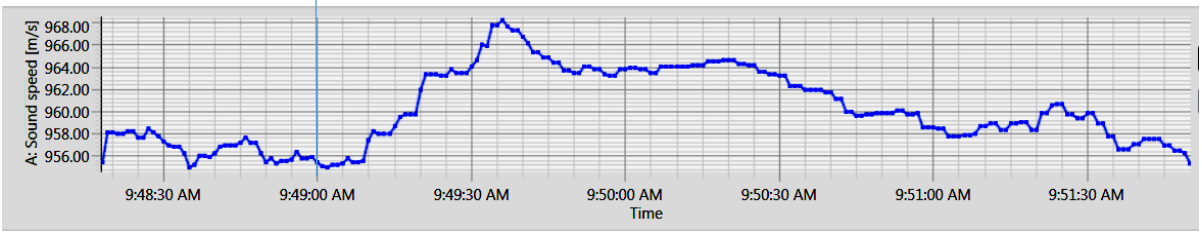
Experiment 3 - 9:49 injection, the sound speed increased from 955 $m.s^{-1}$to 967 $m.s^{-1}$in peak maximum. The trend of changing of the soundspeed monitored by the ultrasonic flow meter after injection of 10 ml of methyl-isobutylketon to column and wall thickness parameter set to 10 mm is shown in the Graph 2.



Graph 2. The trend of changing of the soundspeed in the chromatography column during experiment 3.

The stored sound speed values from the time of injection are shown in the Table 4.

Table 4. Logged data with the sound speed and the diagnostic values after injection of 10 ml of methyl-isobutylketon to column and wall thickness parameter set to 10 mm.

Date	Sound speed [$m.s^{-1}$]	Amplitude [%]	Amplification [dB]	Quality [%]	SCNR [dB]	SNR [dB]
3.26.2024 9:48:41 AM	956,80	32,00	101,32	95,00	27,00	9,00
3.26.2024 9:48:42 AM	956,95	32,00	101,32	98,00	29,00	9,00
3.26.2024 9:48:43 AM	956,95	32,00	101,32	98,00	29,00	9,00
3.26.2024 9:48:59 AM	955,91	32,00	101,32	90,00	26,00	9,00
3.26.2024 9:49:00 AM	955,43	32,00	101,32	95,00	31,00	9,00
3.26.2024 9:49:01 AM	955,08	32,00	101,32	96,00	28,00	9,00
3.26.2024 9:49:02 AM	954,92	33,00	99,83	96,00	28,00	9,00
3.26.2024 9:49:03 AM	955,18	32,00	101,32	95,00	29,00	9,00
3.26.2024 9:49:04 AM	955,18	32,00	101,32	95,00	29,00	9,00
3.26.2024 9:49:05 AM	955,32	33,00	99,83	85,00	28,00	9,00
3.26.2024 9:49:06 AM	955,75	32,00	101,32	97,00	31,00	10,00
3.26.2024 9:49:07 AM	955,44	34,00	98,34	94,00	29,00	10,00
3.26.2024 9:49:08 AM	955,44	34,00	98,34	94,00	29,00	10,00
3.26.2024 9:49:09 AM	955,52	34,00	98,34	93,00	28,00	10,00
3.26.2024 9:49:10 AM	957,38	32,00	101,32	96,00	29,00	10,00
3.26.2024 9:49:11 AM	958,23	32,00	101,32	97,00	28,00	10,00
3.26.2024 9:49:12 AM	958,00	32,00	101,32	95,00	30,00	10,00
3.26.2024 9:49:13 AM	958,06	33,00	99,83	93,00	29,00	10,00
3.26.2024 9:49:14 AM	958,06	33,00	99,83	93,00	29,00	10,00
3.26.2024 9:49:15 AM	958,71	33,00	99,83	95,00	29,00	10,00
3.26.2024 9:49:16 AM	959,48	32,00	101,32	95,00	28,00	9,00
3.26.2024 9:49:17 AM	959,76	32,00	101,32	98,00	30,00	9,00
3.26.2024 9:49:18 AM	959,76	32,00	101,32	98,00	30,00	9,00
3.26.2024 9:49:19 AM	959,73	32,00	101,32	95,00	27,00	9,00
3.26.2024 9:49:20 AM	961,93	32,00	101,32	87,00	29,00	9,00
3.26.2024 9:49:21 AM	963,31	32,00	101,32	97,00	28,00	9,00
3.26.2024 9:49:22 AM	963,43	32,00	101,32	91,00	30,00	9,00
3.26.2024 9:49:23 AM	963,42	32,00	101,32	92,00	29,00	9,00

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3.26.2024 9:49:24 AM	963,27	31,00	102,81	94,00	28,00	9,00
3.26.2024 9:49:25 AM	963,27	31,00	102,81	94,00	28,00	9,00
3.26.2024 9:49:26 AM	963,87	32,00	101,32	95,00	30,00	9,00
3.26.2024 9:49:27 AM	963,50	33,00	99,83	95,00	28,00	9,00
3.26.2024 9:49:28 AM	963,50	33,00	99,83	95,00	28,00	9,00
3.26.2024 9:49:29 AM	963,45	33,00	99,83	91,00	27,00	9,00
3.26.2024 9:49:30 AM	964,06	33,00	99,83	92,00	25,00	9,00
3.26.2024 9:49:31 AM	964,67	31,00	102,81	96,00	29,00	9,00
3.26.2024 9:49:32 AM	966,09	32,00	101,32	98,00	23,00	9,00
3.26.2024 9:49:33 AM	965,99	31,00	102,81	85,00	25,00	8,00
3.26.2024 9:49:34 AM	967,77	30,00	104,30	85,00	28,00	8,00
3.26.2024 9:49:35 AM	967,77	30,00	104,30	85,00	28,00	8,00
3.26.2024 9:49:36 AM	968,23	30,00	104,30	95,00	24,00	8,00
3.26.2024 9:49:37 AM	967,70	30,00	104,30	89,00	27,00	8,00
3.26.2024 9:49:38 AM	967,38	32,00	101,32	93,00	26,00	8,00
3.26.2024 9:49:39 AM	967,38	32,00	101,32	93,00	26,00	8,00
3.26.2024 9:49:40 AM	966,78	32,00	101,32	94,00	27,00	8,00
3.26.2024 9:49:41 AM	966,12	31,00	102,81	82,00	28,00	8,00
3.26.2024 9:49:42 AM	965,33	31,00	102,81	94,00	25,00	8,00
3.26.2024 9:49:43 AM	965,33	31,00	102,81	94,00	25,00	8,00
3.26.2024 9:49:44 AM	964,90	32,00	101,32	95,00	25,00	8,00
3.26.2024 9:49:45 AM	964,90	32,00	101,32	95,00	25,00	8,00
3.26.2024 9:49:46 AM	964,45	32,00	101,32	97,00	29,00	8,00
3.26.2024 9:49:47 AM	964,45	32,00	101,32	97,00	29,00	8,00
3.26.2024 9:49:48 AM	963,73	33,00	99,83	95,00	30,00	8,00
3.26.2024 9:49:49 AM	963,73	33,00	99,83	95,00	30,00	8,00
3.26.2024 9:49:50 AM	963,49	33,00	99,83	94,00	30,00	8,00
3.26.2024 9:49:51 AM	963,49	33,00	99,83	94,00	30,00	8,00
3.26.2024 9:49:52 AM	964,10	32,00	101,32	96,00	28,00	8,00
3.26.2024 9:49:53 AM	964,10	32,00	101,32	96,00	28,00	8,00
3.26.2024 9:49:54 AM	963,88	32,00	101,32	98,00	28,00	9,00
3.26.2024 9:49:55 AM	963,88	32,00	101,32	98,00	28,00	9,00
3.26.2024 9:49:56 AM	963,36	33,00	99,83	85,00	28,00	8,00
3.26.2024 9:49:57 AM	963,28	32,00	101,32	93,00	28,00	8,00
3.26.2024 9:49:58 AM	963,28	32,00	101,32	93,00	28,00	8,00
3.26.2024 9:49:59 AM	963,78	32,00	101,32	90,00	27,00	8,00
3.26.2024 9:50:00 AM	963,78	32,00	101,32	90,00	27,00	8,00
3.26.2024 9:50:01 AM	964,01	32,00	101,32	98,00	30,00	8,00
3.26.2024 9:50:02 AM	964,01	32,00	101,32	98,00	30,00	8,00
3.26.2024 9:50:03 AM	963,82	32,00	101,32	93,00	28,00	8,00
3.26.2024 9:50:04 AM	963,82	32,00	101,32	93,00	28,00	8,00
3.26.2024 9:50:05 AM	963,51	32,00	101,32	95,00	26,00	8,00
3.26.2024 9:50:06 AM	963,51	32,00	101,32	95,00	26,00	8,00
3.26.2024 9:50:07 AM	964,03	31,00	102,81	91,00	25,00	8,00
3.26.2024 9:50:08 AM	964,03	31,00	102,81	91,00	25,00	8,00

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3.26.2024 9:50:09 AM	964,03	31,00	102,81	91,00	25,00	8,00
3.26.2024 9:50:10 AM	964,02	30,00	104,30	96,00	30,00	7,00
3.26.2024 9:50:11 AM	964,02	30,00	104,30	96,00	30,00	7,00
3.26.2024 9:50:12 AM	964,02	30,00	104,30	96,00	30,00	7,00
3.26.2024 9:50:13 AM	964,21	31,00	102,81	92,00	29,00	7,00
3.26.2024 9:50:14 AM	964,21	31,00	102,81	92,00	29,00	7,00
3.26.2024 9:50:15 AM	964,21	31,00	102,81	92,00	29,00	7,00
3.26.2024 9:50:16 AM	964,57	32,00	101,32	94,00	32,00	7,00
3.26.2024 9:50:17 AM	964,57	32,00	101,32	94,00	32,00	7,00
3.26.2024 9:50:18 AM	964,57	32,00	101,32	94,00	32,00	7,00
3.26.2024 9:50:19 AM	964,62	31,00	102,81	97,00	29,00	7,00
3.26.2024 9:50:20 AM	964,62	31,00	102,81	97,00	29,00	7,00
3.26.2024 9:50:21 AM	964,62	31,00	102,81	97,00	29,00	7,00
3.26.2024 9:50:22 AM	964,28	32,00	101,32	94,00	25,00	8,00
3.26.2024 9:50:23 AM	964,28	32,00	101,32	94,00	25,00	8,00
3.26.2024 9:50:24 AM	964,21	32,00	101,32	99,00	25,00	8,00
3.26.2024 9:50:25 AM	964,21	32,00	101,32	99,00	25,00	8,00
3.26.2024 9:50:26 AM	963,55	32,00	101,32	95,00	29,00	8,00
3.26.2024 9:50:27 AM	963,55	32,00	101,32	95,00	29,00	8,00
3.26.2024 9:50:28 AM	963,35	32,00	101,32	95,00	29,00	8,00
3.26.2024 9:50:29 AM	963,35	32,00	101,32	95,00	29,00	8,00
3.26.2024 9:50:30 AM	963,21	32,00	101,32	87,00	23,00	8,00
3.26.2024 9:50:31 AM	963,21	32,00	101,32	87,00	23,00	8,00
3.26.2024 9:50:32 AM	962,35	31,00	102,81	95,00	30,00	7,00
3.26.2024 9:50:33 AM	962,35	31,00	102,81	95,00	30,00	7,00
3.26.2024 9:50:34 AM	962,35	31,00	102,81	95,00	30,00	7,00
3.26.2024 9:50:35 AM	961,99	30,00	104,30	99,00	27,00	7,00
3.26.2024 9:50:36 AM	961,99	30,00	104,30	99,00	27,00	7,00
3.26.2024 9:50:37 AM	961,99	30,00	104,30	99,00	27,00	7,00
3.26.2024 9:50:38 AM	961,99	30,00	104,30	99,00	27,00	7,00
3.26.2024 9:50:39 AM	961,79	31,00	102,81	98,00	27,00	7,00
3.26.2024 9:50:40 AM	961,79	31,00	102,81	98,00	27,00	7,00
3.26.2024 9:50:41 AM	961,16	32,00	101,32	99,00	29,00	8,00
3.26.2024 9:50:42 AM	961,16	32,00	101,32	99,00	29,00	8,00
3.26.2024 9:50:43 AM	960,05	32,00	101,32	93,00	26,00	8,00
3.26.2024 9:50:44 AM	960,05	32,00	101,32	93,00	26,00	8,00
3.26.2024 9:50:45 AM	959,61	32,00	101,32	97,00	27,00	8,00
3.26.2024 9:50:46 AM	959,61	32,00	101,32	97,00	27,00	8,00
3.26.2024 9:50:47 AM	959,78	32,00	101,32	93,00	30,00	8,00
3.26.2024 9:50:48 AM	959,78	32,00	101,32	93,00	30,00	8,00
3.26.2024 9:50:49 AM	959,92	32,00	101,32	98,00	26,00	8,00
3.26.2024 9:50:50 AM	959,92	32,00	101,32	98,00	26,00	8,00
3.26.2024 9:50:51 AM	959,86	32,00	101,32	94,00	24,00	8,00
3.26.2024 9:50:52 AM	959,86	32,00	101,32	94,00	24,00	8,00
3.26.2024 9:50:53 AM	960,10	31,00	102,81	96,00	28,00	8,00

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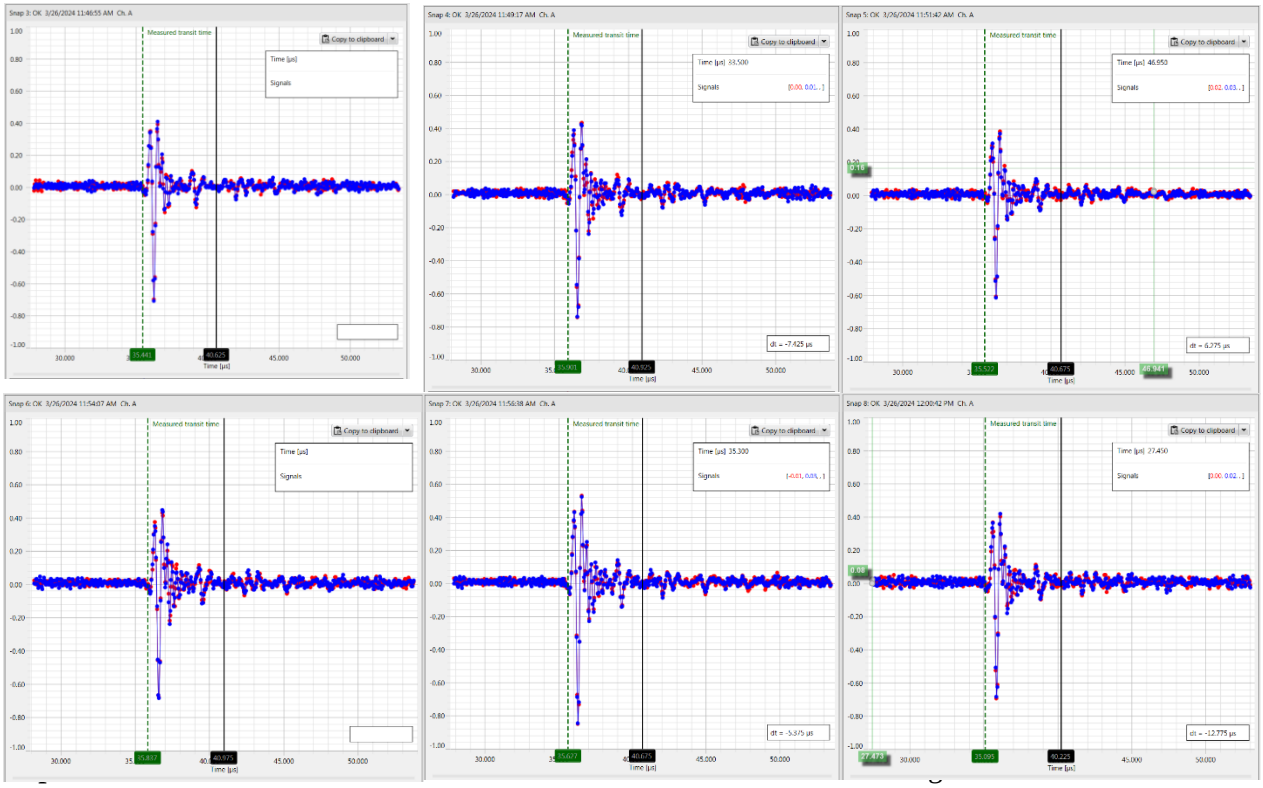
3.26.2024 9:50:54 AM	960,10	31,00	102,81	96,00	28,00	8,00
3.26.2024 9:50:55 AM	959,76	31,00	102,81	98,00	27,00	8,00
3.26.2024 9:50:56 AM	959,76	31,00	102,81	98,00	27,00	8,00
3.26.2024 9:50:57 AM	959,85	32,00	101,32	92,00	28,00	8,00
3.26.2024 9:50:58 AM	958,58	31,00	102,81	94,00	26,00	8,00
3.26.2024 9:50:59 AM	958,58	31,00	102,81	94,00	26,00	8,00

Experiment 4 - We watched an echo or snap-picture change after each MF change but there was no change of the signal form as seen in the Graphs 3-8.



Discussion

It should be emphasized that this method is suitable for monitoring higher concentrations. Five experiments were performed:

- The goal was to determine whether it is possible to monitor the deformations of the silica gel deposit inside the column (cavities, channels) using ultrasonic probes. It didn't work.
- In preparative chromatography, the column load is 1:100 (in schools), but in industry it is also 1:10 (ie 8 g of analyte per 80 g, so we are close to our 10 ml of Methylisobutylketone per 80 g of silica gel.
- Using this method, we would be able to monitor that if the silica gel is incorrectly poured into the column, then where the peak broadening occurs, whether at the top, bottom, or inside. Whether near the distributor.... the shape of the peak on the probes above and below would be compared (does it look symmetrical...).
- In case something crystallized inside the column, we might have a tool to prove it. That is, to watch how it dissolves.
- During repeated chromatography, the front of the column - the beginning becomes clogged with impurities, and thus the resistance/pressure also increases. This way we could monitor the clogging of the column.

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Conclusion

The detection of the position of the analyte in the column using the ultrasonic signal was successful. Using this method, it is possible to determine the position of the analyte even in larger columns, which will help in the localization of the analyte in the columns using the speed of sound in the medium. The ultrasonic detector/sensors as we used them are suitable for measuring larger concentrations in the column. Silica gel significantly dampens the ultrasonic signal, but for one pass (i.e. without reflection), such a setup can be used for API monitoring in a column. An ultrasonic detector could be used behind a column or a flow cell. The advantage would be the ability to monitor substances that cannot normally be seen on an ultrasonic detector (sugars, aliphatics, inorganics...) But with such a detector, it would be advisable to have a PT100 installed there, because US is highly dependent on temperature. The dependence of the speed of sound on temperature can be linear with an increasing or decreasing tendency, but it can also have a maximum or minimum over a range of temperatures, which could work negatively for determining concentrations (but is OK for detection/monitoring).An interesting idea arose to mount the sensors on the outside of the entire reactor, the bottom part, and thus measure the concentration in the solution (for example, in thickening, the limitation is duplication, vortex in the boiler, agitator in the middle, the sensors would have to be on a straight wall, so only for larger volumes).We were unable to measure defects in the column (visually visible cracks) using the ultrasonic sensors. An alternative for measuring cracks in the column could be a defectometer that also works on the principle of ultrasound. Or a different sonar. Another option that could be used to measure the defect in the column is to stretch the coil on the column and measure the change in electromagnetic induction.

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