Experimental study
Measurement of sonic speed of drilling muds under shear stress

Short version

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Introduction

Investigations for the speed of the sound of drilling muds was carried out so far under static conditions [1] and [2].
Major limitations of the results for the practical result from the used piezoceramic transducers and the vibration generation technology.

In particular, the following points for the evaluation of the technical suitability are not optimal in above mentioned investigations:

-adverse selection of the frequency
-too small diameter of the piezo disk
-low power of the transmitters
-single pulse to excite
-no shear stress of muds

Apparatus

The measurement of sound velocity and damping took place at IBJ technology with other acoustic and electric parameters and under realistic conditions with shear stress of the muds. Changing circular rotations of the muds were realized with a stirrer.

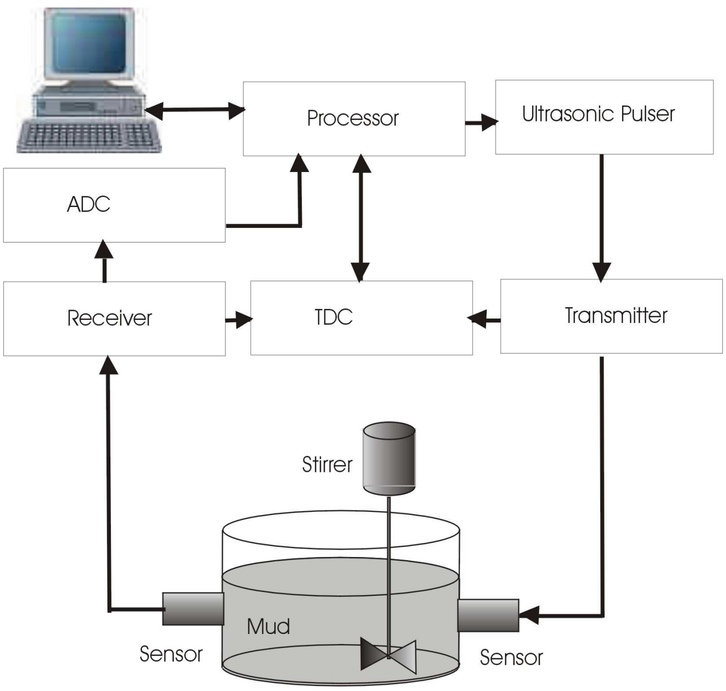
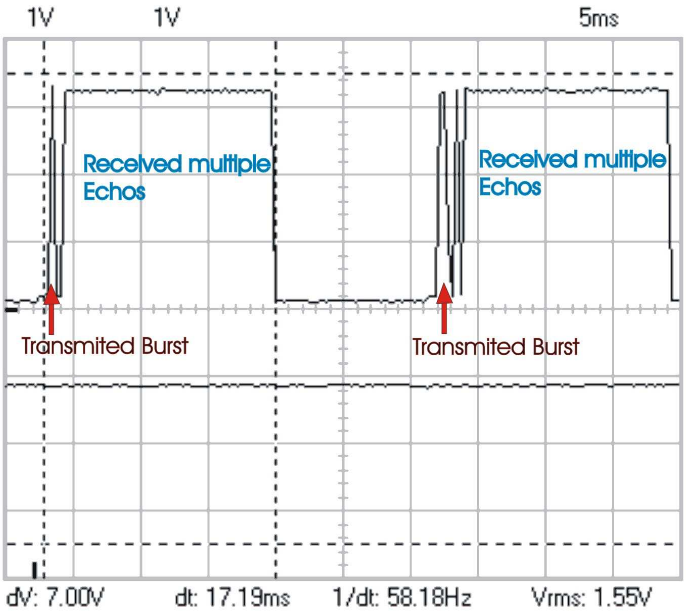


Figure 1: Apparatus

Figure (1) shows the experimental setup with a PC-controlled processor that monitors the variable burst pulse generation. Is the transit time between the transmitter and receiver with a standard deviation (time measurement) of approximately 50 ns with a TDC is determined.
The amplitude of the envelope at certain times of the multiple reflections between the transmitter and receiver with an ADC is calculated by determining the damping. In addition, even the length of multiple reflections is determined. These represent the penetration depth of the ultrasonic signals in the mud.

As a criterion for the penetration depth, the reliably trigger enabled signal level is taken for determining maturity. Figure (2) shows the principle of measurement of the penetration depth.

This depth is greater than a multiple of the real distance between the transmitter and receiver can be assumed by a practical measurement.



The penetration depth of process water (soapy water between the single muds) is in image (2). The distance of the transmission burst is 28 ms. The amplification of the received pulses of ultrasound was chosen so that multiple echoes not per the new transmitter into range. The process water, a penetration depth is achieved by 17,19 ms, corresponds to about 25 m or 984 inch.

Figure 2: depth of penetration in process water

Implementation

The first investigations for the time being confined to water-based muds. Similar behavior was found for the water-based and oil-based sludge in [1]. The absolute sound speeds are about 200 to 250 m/s lower.

4 mud densities (11,3 lb/gal, 12 bl/gal, 15,6 bl/gal and 20,2 bl/gal) were produced for the experimental investigations. The blends consist of water, barite, bentonite, and methyl cellulose.
Further additives like pot ash, salt, xanthan gum, starch, etc were not admitted.
The mixture for the water-based mud with 12 bl/gal was, for example, as follows:

Water	65,33 mass %
Bentonite	3,73 mass %
Barite	29,84 mass %
Methyl cellulose	1,10 mass %

Results

Of course the absolute sound speeds are also influenced by the salinity and temperature. Decides for the practicality, however, is the penetration depth in the mud and the behaviour under shear load through the rotating drill string.
Table 1 shows the measurement results without shear load below.

Mud Density		Basis	Sound Speed	Penetration		
				Time	Length	
1,35 kg/l	11,3 lb/gal	Bentonite	1505,93 m/s	3,09 ms	465 cm	181 inch
1,44 kg/l	12,0 lb/gal	Barite	1505,14 m/s	9,41 ms	1416 cm	552 inch
1,87 kg/l	15,6 lb/gal	Barite	1498,36 m/s	7,22 ms	1082 cm	422 inch
2,42 kg/l	20,2 lb/gal	Barite	1449,67 m/s	4,42 ms	641 cm	250 inch

Table 1: Static penetration and sound speed

The following tables show the measurement results with dynamic shear stress (strirrer rotation in rpm).

Mud Density	Penetration		
	50 rpm #	300 rpm #	500 rpm #
11,3 lb/gal*		157 inch	
12,0 lb/gal	615 inch	587 inch	143 inch**
15,6 lb/gal	320 inch	347 inch	333 inch
20,2 lb/gal	198 inch	164 inch	119 inch

#Rotation

*Basis: Bentonite

** Stirrer trompe, air trapped in the Sound path. The resulting Σ of the speed of sound is the Path length in the air small.

Table 2: Dynamic penetration

Table 2 shows the dynamic penetration depth in different stirrer rotations per minute. The results for 20.2 lb/gal are constant without averaging Very much, because the viscosity of the mud is the highest. Thus, the flow conditions are Very much constant and little turbulence.
Please note this is for all studies with the same constant reinforcement work was. The signal-to noise ratio would have approved a 20 to 40 dB higher gain of the received signal.

Mud Density		Ultrasound Speed			
	50 rpm #	300 rpm #	500 rpm #	#Rotation
11,3 lb/gal *		1505,42 m/s		*Basis: Bentonite
12,0 lb/gal	1505,13 m/s	1505,15 m/s	1433.65 m/s**	** Stirrer trompe, air trapped in the Sound path. The resulting Σ of the speed of sound is the Path length in the air small.
15,6 lb/gal	1499,88 m/s	1499.05 m/s	1498.97 m/s	
20,2 lb/gal	1451,54 m/s	1452,12 m/s	1452,60 m/s	

Table 3: ultrasound speed under shear stress

Table 3 are shown in dynamic ultrasonic speeds. For mud densities up to 15, lb/gal minor changes of the speed detected these amounted to less the maximum up to 1 m/s.
At a density of the mud of 20, lb/gal, signified a proportional monotonically increasing velocity was measured. This increase amounted to around 2, m/s at 500 rpm.

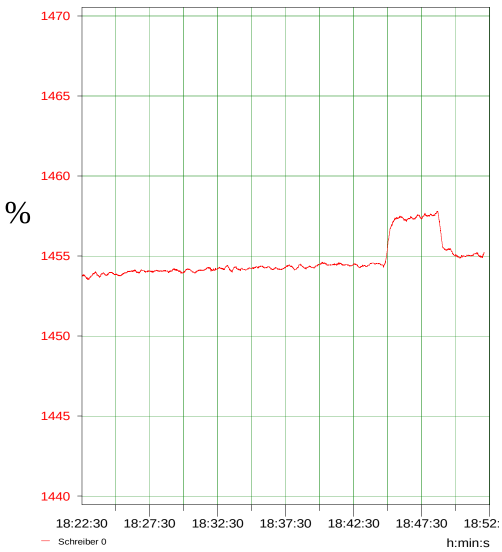


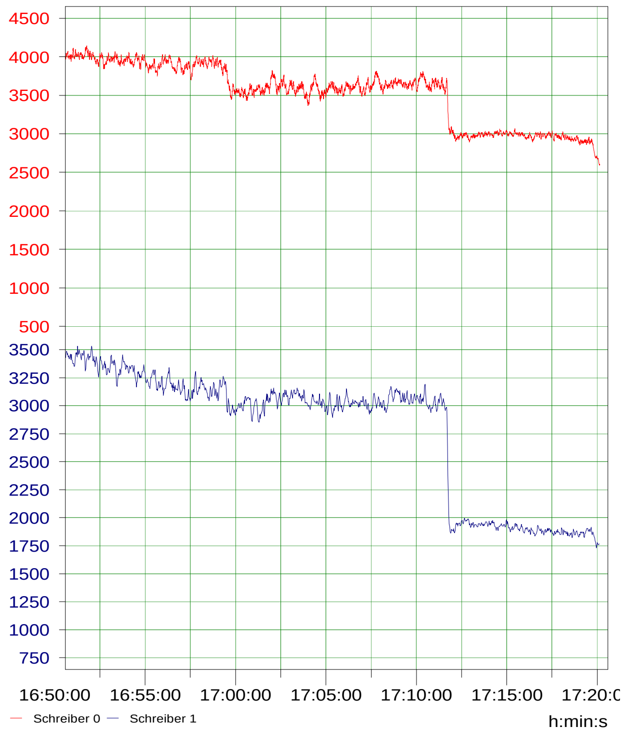
Figure 3 shows the significant increase in the speed of sound by shear stress.
The slight increase of the curve is based on the influence of temperature.
The influence of the shear stress on the speed moves in the 0,1 area and is for the kick detection without meaning. A change of in temperature of 1° Celsius has even greater influence on the change of speed.

Figure 3: Boost the speed

Penetration depth and Non-Newtonian behavior

The penetration rises at first monotonous after a standstill of the stirrer. The example of 12 bl/gal it was ms after 10 min over 10 ms.
Then with a low rotation speed of about 50 rpm shear forces applied rpm, the penetration depth remains essentially at this size (9.96 ms).
At about 500 rpm, the depth of half breaks together 4,8 ms with a variation of +-2 ms. The speed of sound drops further, it formed a stirring trompe between the sensors. Thus, the results are affected significantly. Too small values for the speed and depth are determined.
With increasing time the penetration depth on 3 +-1ms (without averaging, real-time sampling). The speed remains relatively constant with the error by the trompe 1419 m/s.
The mud 15.6 lb/gal starts at 1506,17 m/s and 0,83 ms penetration depth after a rest period of 24 hours without moving. More recently turning over 300 rpm monotonically in the subsequent peace on 5,16 ms penetration depth and the speed drops to 1501,63 m/s.
The depth of penetration into the drilling mud under shear stress increases from 49 inch to 302 inch.

Thus, the drilling mud shows the behavior of a Bingham fluid.



The envelopes of the multiple echoes were recorded with the ADC. In the time range of the first multiple echoes until about 2 ms a decrease of the absorption of ultrasonic waves in the drilling mud witnessed as the drilling mud with the density of 20.2 lb/gal. She reflected in increase in the amplitude, so the following display (Figure 4) shows the dependence of the measured amplitudes at different speeds. This was reduced from 300 rpm 50 rpm (from 17: 00), and then click zero rpm (from 17:12).
A higher speed causes a higher amplitude, or smaller absorption of ultrasonic waves.

Figure 4: ultrasonic amplitude as a function of Speed

Measurement without fluid

The ultrasonic transducers are designed so the they in fluid and gas can measure (Fig. 5). With the used open experiment measurement can be demonstrated with gas only with air. The speed of sound drops when draining on 357 m/s. Due to the high resolution of 1 cm/s, even small changes in speed can be measured by dissolved gases. At a rate of 28 ms, a Very much fast display of real values is achieved even with a moving average from a variety of values.

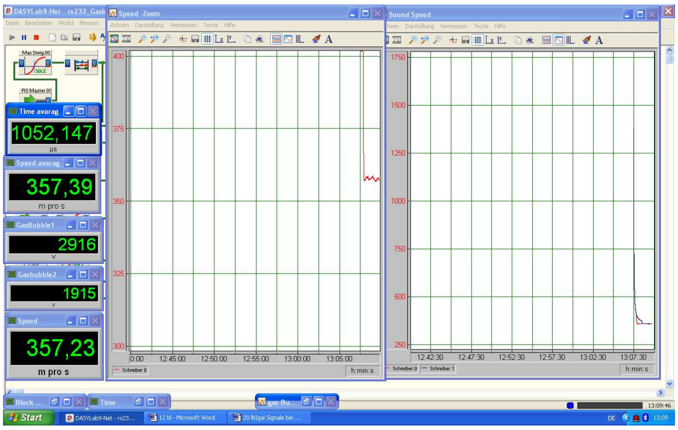


Figure 5 Change of the mud

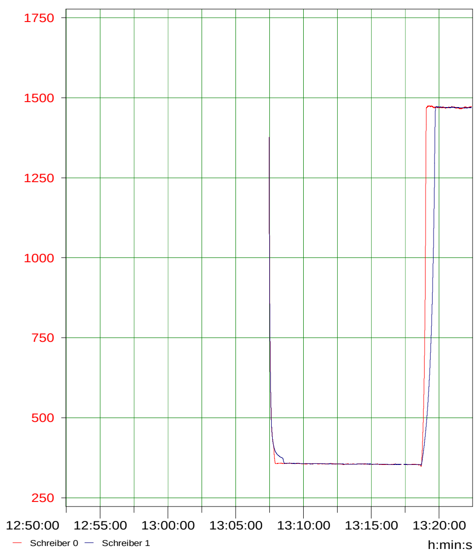


Figure 6 change the speed air-mud

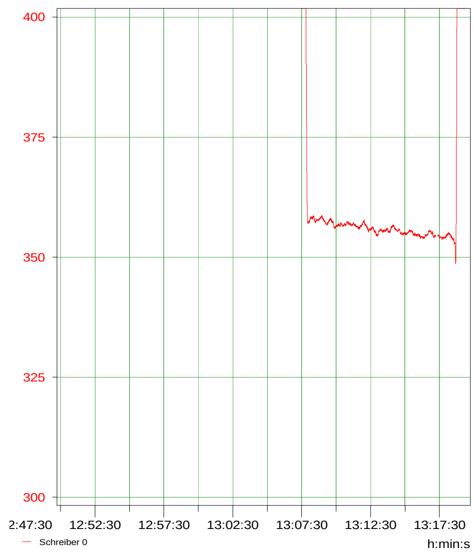


Figure 7 zoom speed in air

Figure 6 shows the speed of sound in the phase of emptying and new filling with drilling mud. Figure 7 shows the zoom ultra sound velocity in air.

The measurement of the velocity of gaseous and liquid hydrocarbons inflows cannot be determined with this open experiment.

In the literature, there are about A few calculations and practical studies.
The solubility of methane in diesel oil is in [3] consider.
The effect of gas solubility is considered in [4].
The sound velocity of fluid-fluid mixtures and fluid-gas mixtures under pressure is investigated in [5].
Reflections on the sound speed in liquid-gas mixtures' water-air and water-steam are to find in [6].

Conclusions

The measurement of the speed of sound is practical with the concept of the Ultrasonic sensors. Interference by rotating drill strands are not to be expected. The depth and range of the sensors safely exceeds the damping of the mud. Even in the most absorbing mud (20.2 lb/gal), the penetration depth is 10 x the distance of the sensor.

With an AGC (automatic gain control), the penetration depth in the drilling mud 20.2 can lb/gal on the 2 or 3 be lifted times. Thus one is 30 to 50 times security across the entire range. The absorption of ultrasound has no disturbing effect on a measurement of velocity or velocity high mud densities and viscosities at the selected frequencies of ultrasound and the transmission burst.

The measurement of the flow of drilling mud is possible also with all commonly used drilling sludge and diameters of pipelines.

It is measurable not disturbing increase of noise during the operation of the stirrer.

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