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PHYSICOCHEMICAL CHARACTERIZATION OF THE FUEL BY THE ULTRASOUND METHOD

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Abstract

A physical medium, whatever its nature, solid, liquid or gaseous is characterized by physicochemical parameter which are unique to it and which differentiate it from any other medium. But it can also be characterized and differentiated by its acoustic parameters: it's like two sides of the same coin. It is on these hypotheses that we suggest designing an ultrasonic measurement bench allowing the physicochemical characterization of a medium from its ultrasonic parameters. The work therefore consists in characterizing a certain number of fuel samples using the standard characterization benches to determine their physical parameter (viscosity, viscosity index, density, pour point, flash point, % Nitrogen, % Zinc) and to characterize the same samples by the ultrasound characterization bench to determine their ultrasonic parameter (celerity, compressibility, absorption, attenuation, transfer function, acoustic impedance).

Two databases are thus constituted for the samples: a physical database and an acoustic database. Subsequently to determine the physical parameter of any unknown sample belonging to the same medium, it suffices to determine its ultrasonic parameter. We thus replace all the characterization benches, physical and chemical (as many bans and reagents as parameters) by a single and unique characterization bench: ultrasound characterization bench below.

The aim is to proceed at the physicochemical characterization of the various oil wells in the HASSI MESSAOUD zone petroleum of Algeria in order to design with the hydraulics' department of the university the appropriate extraction pumps at each well. Since it was difficult to obtain samples of the wells in question, we have treated engine oils which have the same characterization parameters as fuel.

Key words: Fuel extraction, Characterization, Physicochemical parameter, Ultrasound's parameter, Measuring bench, Databases

1. INTRODUCTION

Characterization of a medium is a stylistic device which can provide further information on the properties and characteristics of this medium. To use or act on a physical medium, it is essential to characterize it by determining its physical properties. There are many conventional techniques for characterization based on various physical and chemical fundamentals (Mason, 1998). The ultrasonic technique is a non-destructive analysis and innovative method which aims the characterization of a medium by new approaches for its microstructures whatever its state is: solid, liquid or gaseous.

Recent advances in digital technology have made this technique a tool alternative to physicochemical techniques in the analysis of various fields ranging from food to medical via materials and biomaterials. So this non-destructive technology appears as a well-agreed method of quality control of food products and solutions. It is more appropriate to the requirements for quality control standards and process automation control (Workman Jr. et al, 2001).These ultrasonic

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methods, well established and their interpretations in various industrial applications have received increased attention of specialists for their use as analytical tools in the process of analytical chemistry (Workman Jr. et al., 1999; Hauptmann et al., 1998; Urick, 1947). Ultrasonic velocity; attenuation; reflection coefficient; compressibility, acoustic impedance of the medium etc are measurable parameters related to fundamental physical properties media in general and liquids and food in particular. They are of considerable interest in the quality control of finished products and consumer products (Povey, 1999; Mc Clements, 1997; Povey, 1997). These references have been cited just to show the multiple and numerous uses of ultrasonic parameters in the industry, chemistry and foodindustry.

It is from this perspective that we try through this very experimental work to deal with an ultrasonic technical quality of an industrial oil or fuel.

Indeed the quality of fuel and industrial oils is of great importance for the reliability, endurance and service life of the engines and machines that use them. Any damage caused to the engine by low quality of oil, is manifested in addition gradually, so that you cannot realize it immediately.

An oil that does not meet the standards affects the quality of lubrication and damages the engine that uses it. It is imperative to determine the physicochemical characteristics of the product and ensure they meet quality requirement standards.

So we try to determine experimentally the physico-chemical parameter (Viscosity, Viscosity Index, Density, Pour Point, flash point,% Nitrogen, %Zinc) of a motor and industrial oil from its ultrasonic parameter (speed, compressibility, peak to peak attenuation, attenuation signal: transmission / signal reception, transfer function etc).

This work conducted in collaboration with the laboratory of Rheology hydraulic department at the University of Science and Technology USTO (MB), the metrological service of the national oil company, has the objective of make available to the laboratory of these employees a single, reliable characterization equips that will allow them to conduct the physico-chemical characterization of their products (oils, fuels), and they avoid the use of multiple banks and the use of expensive chemical reagents and sensitive. The bench thus allows, once designed to not to need conventional characterization benches, and proceed to the identification of any sample submitted for his test by taking its ultrasonic identification.

2. THEORETICAL BASIS

2.1. Ultrasonic Signal for a Single Sensor Receptor

We consider in this case study that the wave propagation is a linear space-time stationary process. The convolution model allows us to write the signal issued by a sensor in the propagation medium according to the following equation:

$$y_r(t) = h_m(t) * s_e(t) + n(t) \tag{1}$$

where: the symbol * represents the convolution product, $h_m(t)$ - the transfer function of the propagation medium between the ultrasonic transmitter and an ultrasonic receiver, $s_e(t)$ - the wave form transmitted by the ultrasonic transmitter, $n(t)$ - the additive random noise which is assumed Gaussian, white, centered and independent of the signal.

Function $h_m(t)$ takes into account the propagation of the elastic wave throughout its path, and this wave is altered by the nature of the medium. We consider in the continuation of the work that the transfer function of ultrasonic propagation medium $h_m(t)$ is characterized by an attenuation a_m and a shift τ_m. In these conditions $h_m(t)$ becomes:

$$h_m(t) = a_m \delta(t - \tau_m) \tag{2}$$

where: $\delta(t)$ - the Dirac impulse.

By combining equations (1) and (2) we obtain:

$$y_r(t) = a_m s_e(t - \tau_m) + n(t) \tag{3}$$

2.2. Transmitted Wave Form

We will assume that the ultrasonic waves emitted by the source correspond to pulses which are defined as a damped sinusoid given by the equation:

$$s(t) = A \exp(-at) \sin(2\pi ft) \tag{4}$$

where: A - the amplitude of sinusoidal signal produced at emission.

The amplitude *A* gradually decreases at an exponential rate. The damping ratio α determines the length of the wave generated by the emitting transducer which oscillates at the frequency *f*. Figure 1 shows temporal and spectral emission signal.

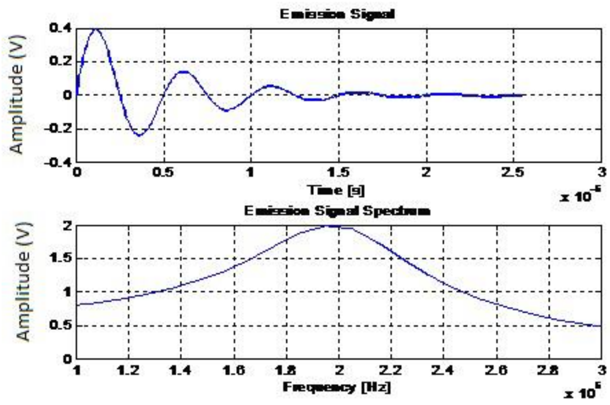

Fig. 1. Simulated transmitted waveform.

2.3. Energy of a Signal Acquired by a Sensor

The energy associated with the waves received by a sensor is defined by the following expression:

$$E = \sum_{t=1}^{M} \left| a_m . s_e(t) \right|^2 \tag{5}$$

where: M - the number of time samples acquired.

The energy parameter E is used as an indicator of the presence of foreign bodies. Indeed, the presence of foreign elements in the basic medium leads to a reduction of the amplitude A and therefore causes a reduction of energy E. The energy lost by an ultrasonic wave propagating through a medium is justified by the following relationship:

$$A_{receiver} = A\exp(\mu d) \tag{6}$$

where: μ - absorption coefficient of the medium, A - amplitude of the signal, d - length of the medium.

3. PROCESS

The principle consists in using N samples of industrial oils (for our case we took N = 5). For each sample, we proceed to its physicochemical characterization by conventional characterization bench. We so determine for each sample its viscosity, Viscosity Index, density, pour point, flash point, % of nitrogen, and its % of zinc. In parallel with the ultrasound bench, the following ultrasound parameters are determined for each sample: velocity, peak-to-peak attenuation, compressibility, absorption coefficient, acoustic impedance and transfer function.

Two databases were thus created for the samples studied. An ultrasound base (base 1) which contains their ultrasound parameter and a physicochemical base (base 2) which contains their physicochemical parameters, see figure 2.

3.1. Ultrasonic Characterization Bench

Figure 3 shows the experimental bench used, both for the constitution of the base 1 elements (basic ultrasonic parameter samples of the product), for measuring physicochemical parameter of an unknown sample.

The ultrasonic transmitter sends an electrical pulse of short duration to the emitting transducer which transforms it into an ultrasonic wave of frequency equal to 10 MHz The receiving transducer receives the wave which translates it into an electrical signal.

During its path, the ultrasonic wave interacts with the sample to be characterized; this interaction is reflected in the electrical signal. The oscilloscope digitizes the electrical signal and sends it to the computer (PC) via a GPIB (General Purpose Interface Bus). The signal thus undergoes scan and save on the PC various treatments in order to extract the desired information on the environmental status.

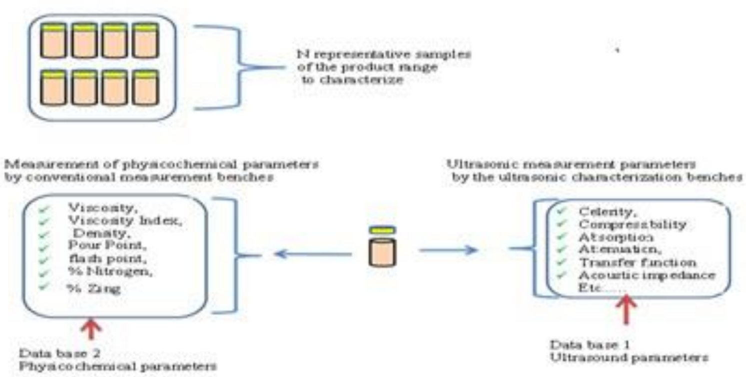

Fig. 2. Principle of the method.

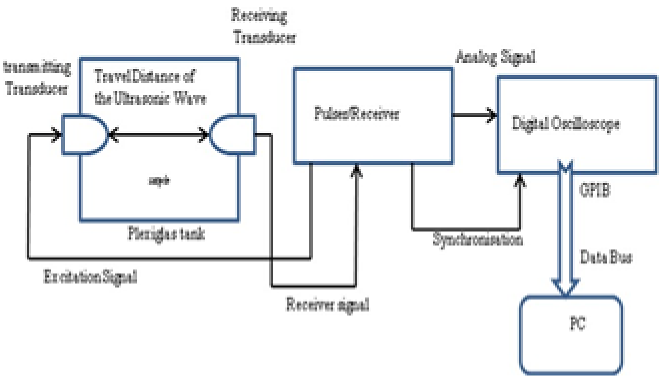

Fig. 3. *Ultrasonic characterization bench.*

The ultrasonic bench used for this work is composed by:

- Two ultrasonic transducers (10MHz) Panametrics V327SU
- Impulse generator Panametrics5052PR
- Digital oscilloscope FlukePM3384B
- Plexiglass container size 20x10x5(cm)
- Processing unit

3.2. Experiments and Results

In order to constitute elements of the two bases 1 and 2 we have selected five representative samples of oils of almost all motor oils on the market range. For each oil, we have determined experimentally, at room temperature, its physicochemical parameter by standard characterization benches and ultrasonic parameter by the ultrasonic characterization bench.

Physicochemical Parameters. The physicochemical parameters to be measured for each of the samples comose:

- Viscosity
- Viscosity index
- Density
- Pour point this parameter is very important in defining the drilling of crude pumping feasibility
- Flash point in closed couple
- % Nitrogen
- % Zinc

Ultrasound Parameters. The ultrasound parameters to be measured compose:

- Celerity
- Attenuation
- Absorption coefficient
- Compressibility
- Average value

The ultrasound parameters to be measured for each of the samples were determined from treatments carried on the ultrasonic signal transmission and reception for each sample considered.

These signals were obtained using two frequency ultrasonic sensors 10 MHz and each operating in transmission mode. We are obtained the elements of the two databases represented by table 1 and table 2.

Compatibility of results should be considered satisfactory, taking into account the fact of up to three plastically deformable materials interaction, for which elastic-plastic with hardening models are applied.

Table 1. *Base.1. Ultrasound's parameters.*

Samples	Celerity *(m/s)*	***(%)*** Attenuation *Pic to Pic*	% attenuation amplitude $Emax_{out}/Emax_{in}$	Compressibility Pa^{-1}	Average value *H(f)*
Chelia 20W40	1387.4	33.71	15.169	0.00046068	0.002479
Chelia 15W40	1367.9	17.31	6.104	0.0004613	0.0028505
Naftilia 15W40	1374.3	20.85	20.179	0.00045845	0.0028233
Total 20W50	1390.2	33.02	17.649	0.00046065	0.0024761
Naftilia 20W40	1381.5	29.53	7.874	0.00046046	0.0004604

Table 2 *Base.2. Physicochemical's parameters.*

Viscosity, pa/s	Viscosity index	Density g/cm^3	Pour point ℃	Flash point ℃	% Nitrogen	% Zinc
0.2408	93	0.848	-9	230	0.0140	0.055
0.1164	105	0.871	-15	225	0.0700	0.1015
0.1686	106	0.850	-16	222	0.0292	0.038
0.3452	116	0.855	-21	221	0.7200	0.780
0.2153	118	0.824	-20	210	0.0427	0.056

3.3. *Numerical modelling*

Based on these results, figure 4 shows the evolution of the physicochemical parameters of the samples as a function of the viscosity index of the medium.

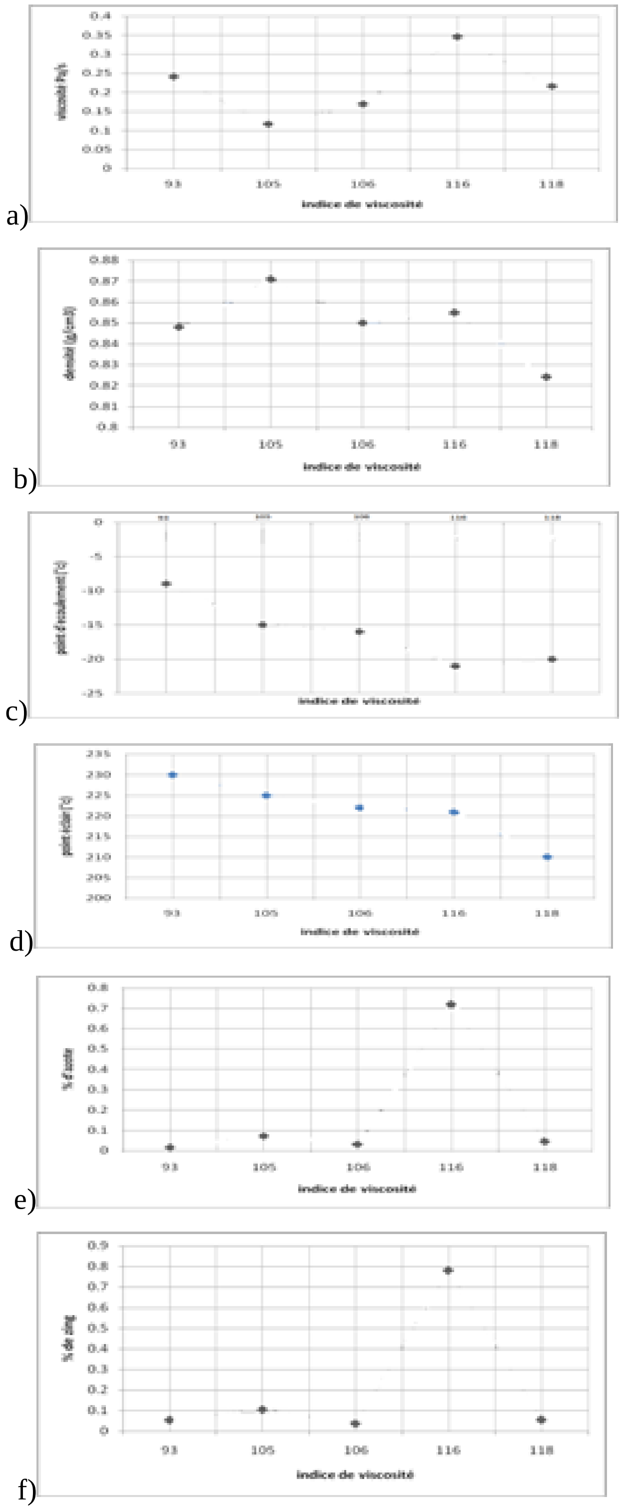

Fig. 4. *Evolutions of the physicochemical parameter of the samples according to their viscosity index: a) viscosity, b) density, c) pour point, d) flash point , e) % of Nitrogen , f) % of Zinc.*

Figures 5 represent the evolution of the ultrasonic parameter of the samples as a function of the same viscosity index of the medium.

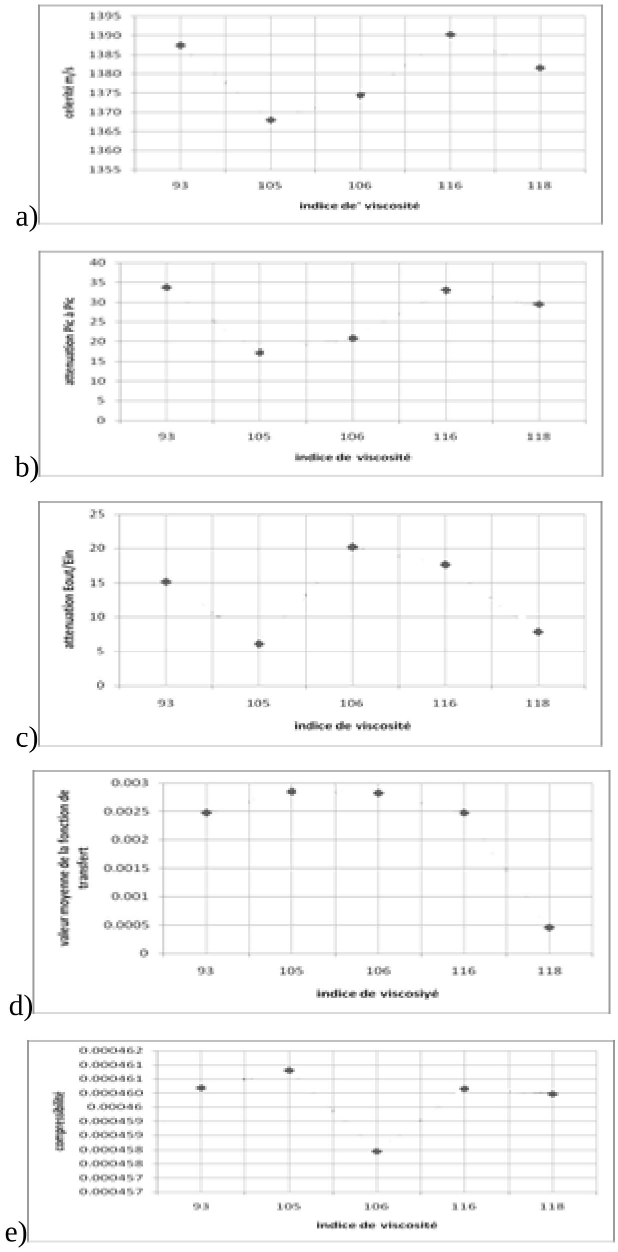

Fig. 5. *Evolutions of the ultrasound parameter of the samples according to their viscosity index: a) speed, b) attenuation, c) attenuation Emaxout/Emaxin, d) compressibility, e)average value from the transfer function.*

When we analyze the curves, we see that each sample has its own values proper for the physicochemical parameter and for the ultrasonic parameter. Each sample is therefore linked to unique physicochemical and ultrasonic values. So there is a narrow link between the physicochemical characterization of a medium and its ultrasonic characterization: and it is precisely this link that is used to deduce the physicochemical characterization of the medium from its ultrasonic characterization.

We put the curves on the same page to observe the parallelism and the shape the evolution of the curves for the physicochemical parameter and those of the ultrasonic parameter. We notice precisely that this evolution is almost identical between the viscosity and the ultrasonic speed; for the others if the variation is not identical they still have similar trends.

4. THE PROCESS OF PHYSICOCHEMICAL CHARACTERIZATION OF THE BENCH FOR AN UNKNOWN SAMPLE

We have chosen the viscosity index of the medium as parameters common to the two databases; first for its importance as a physicochemical parameter of the environment then to have a common link which allows us to link the two bases between them; the basis of ultrasound parameter and the basis of physicochemical parameter see figure 6a and figure 6b. Step 1 was identification relative to the base 1, as shown in figure 6a. The bench characterizes the sample by deducting all ultrasonic parameter that will identify with the data it has in its base 1 (ultrasonic base) to infer its viscosity index. Step 2 was identification relative to the base 2, as shown in figure 6b. From this viscosity index, the bench identified, in the base two (physicochemical data) and proceed the other physicochemical parameter which characterize the unknown sample.

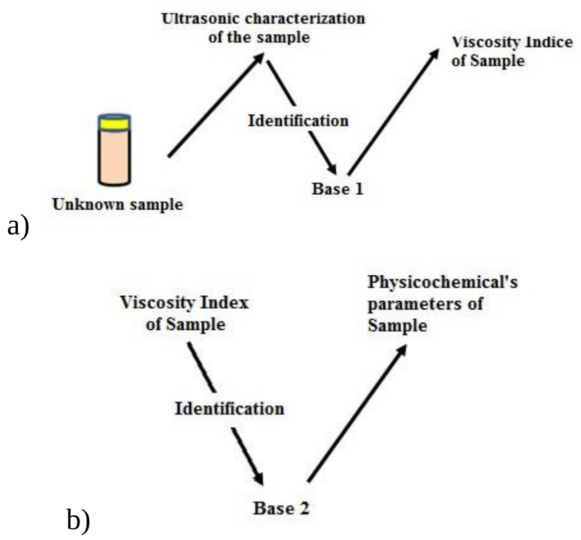

Fig. 6. Identification relative to the base 1 (Ultrasound parameter) (a) and identification relative to the base 2 (Physicochemical parameter) (b).

5. TESTS OF THE BENCH

We presented the characterization bench samples of unknown oils (5W40 and Chelia10W40 total) still at room temperature, and for which we have determined in advance the physicochemical parameter with conventional characterizations benches mentioned above. Table 3 and table 4 give the comparative values obtained by the ultrasonic characterization bench, and those obtained by conventional characterization benches.

Table 3. *Sample 1: Total5W40. Comparative values of physicochemical parameters.*

Physicochemical parameters	By ultrasound characterization bench	By classicals caracterization bench
Viscosity, pa/s	0.18251	0.2212
Viscosity Index	130	120
Density, g/cm^3	0.801	0.840
Pour Point, °C	-23°C	-28°C
Flash Point, °C	215°C	225°C
% Nitrogen	701	725
% zinc	722	750

Table 4. *Sample 2: Chelia10W40. Comparative values of physicochemical parameters.*

Physicochemical parameters	By ultrasound characterization bench	By classicals caracterization bench
Viscosity, pa/s	0.19522	0.1699
Viscosity Index	111	119
Density, g/cm^3	0.814	0.831
Pour Point, °C	-19	-22
Flash Point, °C	220	205
% Nitrogen	710	520
% zinc	750	560

If we analyze the values of the physicochemical parameter obtained by the ultrasound characterization bench on the test samples, we note that they are very near to those obtained by the conventional characterization benches (table 3 and table 4); mostly for the important parameters which are: viscosity, viscosity index and density.

For the basic parameter which is the viscosity index, it is this parameter which is the common link between the two databases, the base of the physical domain and the base of the electrical domain, and it is this parameter from which all the other physicochemical parameter are obtained, it is obtained with an error of approximately 7%: which is very good precision for the use of the ultrasonic bench for the application for which it is designed (see abstract).

6. CONCLUSIONS

For characterize a physical environment, any type of environment, it is necessary to determine its physicochemical parameter. We know that these parameters are obtained by physical characterization benches and chemical reagents, as many benches and reagents as parameters.

The objective of this work is to optimize this number of benches and to save the use of chemical reagents which require specific storage conditions at and dates of limited use.

It is in this perspective that we had the idea of designing a single bench of ultrasonic characterization whose function is to replace all these multiple benches

The values of the physicochemical parameter determined from the ultrasonic bench must be identical at the limit very near to those of conventional benches.

By analyzing the test values (tables 3 and table 4) the parameters obtained by the ultrasonic bench are very significant compared to the values obtained by conventional benches. There is an error of around 3 to 17% in excluding the percentage for Nitrogen and Zinc for the second sample.

Which is very promising and encouraging to explore the originality of this idea and the economy it can generate.

As perspectives, to increase the reliability of the designed bench and the precision of the values obtained by this bench compared to conventional experimental values, the following two axes:

- By working at frequencies well above 10MHz, 50MHz for example.
- And by enriching the ultrasound database (base 1) with additional electrical and ultrasound parameter. This enrichment is possible due to the application of other types of signal processing and algorithms capable of providing additional information from the signals acquired for the different samples.

REFERENCES

Hauptmann, P., Lucklum, R., Puttmer, A., Henning, B., 1998, Ultrasonic sensors for process monitoring and chemical analysis: state-of-the-art and trends, *Sensors and Actuators A*, 67, 32-48.

Mason, T.J., 1998, Power ultrasound in food processing The way forward, in: Povey, M.J.W., Mason, T.J., Eds., *Ultrasound in food processing*, Blackie Academic & Professional, London, 103-126.

Mc. Clements, D.J., 1997, Ultrasonic characterization of foods and drinks: Principles, methods, and applications, *Critical Reviews in Food Science and Nutrition*, 37, 1- 46.

Povey, M.J.W., 1997, *Ultrsonic Techniques for Fluids Characterization*, Academic Press, San Diego, 141-175.

Povey, M.J.W., 1999, Ultrasonic determination of the properties of food dispersions, *Seminars in Food Analysis*, 4, 95-111.

Urick, R. J., 1947, A sound velocity method for determining the compressibility of finely divided substances, *Journal of Applied Physics*, 18, 983-987.

Workman Jr., J., Veltkamp, D.J., Doherty, S., Anderson, B.B., Creasy, K.E., Koch, M., Tatera, J.F., Robinson, A.L., Bond, L., Burgess, L.W., Beckerman, G.N., Ultman, A.H., Darsey, G.P. Mozaynei, F., Bamberger, J.A., Greenwood, M.S., 1999, Process analytical chemistry, *Analytical Chemistry*, 71, 158-161.

Workman Jr., J., Creasy, K.E., Doberty, S., Bone, L., Koch, M., Ulman, A., Veltkamp, D.J., 2001, Process analytical chemistry, *Analytical Chemistry*, 73, 2705-2718.

FIZYKOCHEMICZNA CHARAKTERYZACJA PALIW METODĄ ULTRADŹWIĘKOWĄ

Streszczenie

Każde medium fizyczne, bez względu na to czy jest to ciało stałe, płyn czy gaz, jest charakteryzowane przez parametry fizykochemiczne, które są dla niego unikalne i różne od innych ośrodków. Ale może ono być także charakteryzowane przez akustyczne parametery, które są również unikalne. Te dwie charakterystyki są jak dwie strony tej samej monety. Na podstawie tej hipotezy w pracy zaproponowano projekt urządzenia pomiarowego umożliwiającego fizykochemiczną charakteryzację medium na podstawie parametrów ultradźwiękowych. Określono charakterystyki wybranych paliw wykorzystując standardowe metody wyznaczania parametrów fizycznych (lepkość, wskaźnik lepkości, gęstość, temperatura płynięcia, punkt zapłonu, %azotu, %cynku). Te same próbki scharakteryzowano przez wyznaczenie ich parametrów ultradźwiękowych (ściśliwość, wchłanianie, osłabienie, funkcja przejścia, impedancja akustyczna).
Sformułowano dwie bazy danych: fizyczną i akustyczną. W dalszej kolejności przyjęto, że w celu wyznaczenia parametrów fizycznych dowolnej próbki z tego samego medium, wystarczy określić jego parametry ultradźwiękowe. Dlatego zastąpiono bazy parametrów fizycznych i chemicznych jedną bazą parametrów ultradźwiękowych. Celem tych prac była bardziej zaawansowana charakteryzacja olei w zakładach HASSI MESSAOUD w Algerii w celu zaprojektowania odpowiednich pomp wydobywczych dla każdego szybu naftowego. W związku z trudnościami w zdobyciu próbek z badanych szybów, w pracy wykorzystano oleje silnikowe o podobnych charakterystykach.

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