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THE APPLICATION OF SURFACE ACOUSTIC WAVES FOR THE STUDY OF LIQUIDS[1]

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Specific design of surface acoustic wave (SAW) sensor is used for the measurements of the SAW attenuation as a function of the engine oil wearing, temperature, acid-water and ethanol-water concentration respectively. The solid state application of this sensor is presented.

I. INTRODUCTION

The large interest was devoted to the construction of surface wave acoustic microsensors recently [1]. They are used for the measurement of a wide range of physical and chemical values.

It is well know that the interaction of ultrasound with the liquid can give very important informations concerning the molecular liquid structure. Physical parameter, very sensitive to these changes, is ultrasonic attenuation [2-4]. It seems to be reasonable to use the SAW attenuation changes for the same type of experiments because of specific features of surface acoustic waves (SAW) propagation, when SAW is in the contact with liquid.

In our work we deal with the utilization of immersion SAW sensor for the diagnostic of various liquids. The physical principles of the liquid sensor action are based on the following assumptions [5]. All types of surface waves in crystals are shear waves, it means that the particle displacement in the wave front has two or three components. In many cases, one component is perpendicular to the

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surface, and one or two "in-plane" components are presented. These specific wave motions are the reason of energy losses, if SAW is in the contact with a liquid. The perpendicular component of the wave motion provokes the conversion of one part of the SAW energy to the compressional waves generated into a liquid volume, which is in the contact with the crystal surface.

The second reason of the SAW energy losses is connected with the "viscous coupling" due to the fact that the SAW velocity along the crystal surface exceeds the velocity of ultrasound in the liquid.

II. METHOD

The experimental arrangement is illustrated in Fig.1. The interdigital transducer (IDT) has been prepared of the polished surface of YZ $LiNbO_3$. The opposite side of the same SAW-line has been plunged in to the investigated liquid. The Matec model 7700 has been used for the measurements of the SAW attenuation.

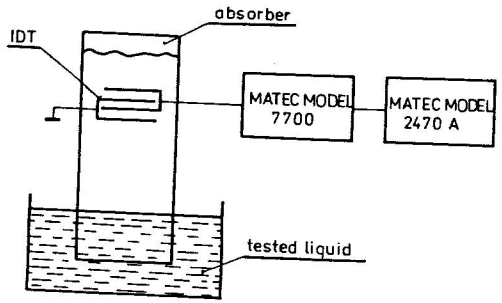

Fig. 1. The experimental arrangement and sensor design.

The advantage of such experimental arrangement is in very easy application of measured liquid to the sensor. The proper level of the SAW attenuation has been set by the depth of sensor immersion to the studied liquid. Because the SAW attenuation depends on the immersion depth, the constant depth of a sensor draft has been used for the comparative measurements of the attenuation. The power value has been set constant too. The temperature has been stabilized.

The measurements of the viscosity have been made at the same temperature with rotating viscosimeter Rheotest 2.1.

III. RESULTS AND DISCUSSION

The first domain of applications of the above described sensor is in the study of the diesel engine oil wearing. It is well know that the viscosity is very important parameter for the oil quality judging. The classic measurements of the viscosity are very complicated (cleaning of viscosimeters). The SAW attenuation, which is proportional to the square root of the viscosity, gives the possibility of "easy matching" in the viscosity measurements [5].

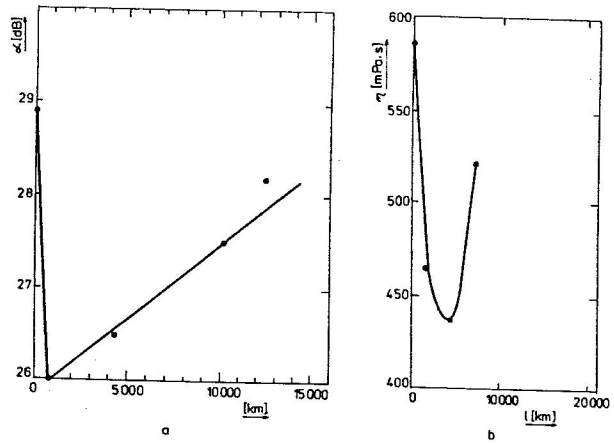

Fig. 2 *a*. The SAW attenuation versus oil age in km. The oil after the general repair of the locomotive engine. *b*. The dynamic viscosity versus oil age in km. The oil before the general repair of the same engine.

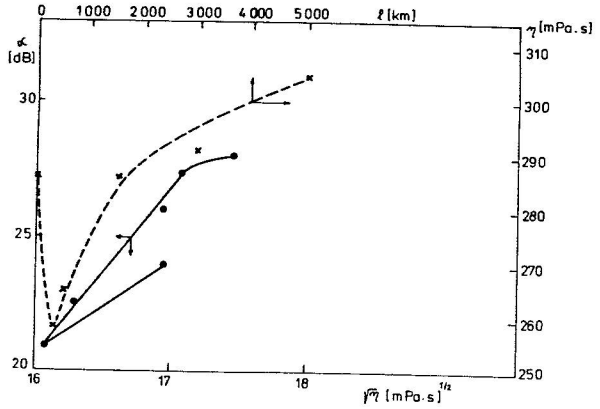

Fig. 3. The viscosity and SAW attenuation versus different parameters for the bus oil.

The oil samples have been taken from the standard diesel engines used in locomotives ans buses respectively. The results shown in the Fig.2 are obtained by using of the oil taken from the locomotive before (*b*) and after (*a*) the general repair respectively. Results obtained by using of the Fig.3. The measurements of the oil impurities amount have been measured simultaneously by a bridge TRIBO - 1. The results are shown in Fig.4*a* (locomotive) and 4*b* (bus).

Three interesting region are observed during the traffic cycle. After a few thousands of kilometers the viscosity strongly falls, then, practically linearly rises and after about 2000 km the slow curve bending begins (see Fig.3). The reason of

the viscosity fall is probably in the presence of the diesel oil in the oil. This fact has been supported by decreasing og the oil flash point (above 20 °C.

The next increase of the viscosity is probably connected with the presence of high molecular ingredients appearing in the combustion process. This fact has been supported by measurements of impurity amount which monotonously increases with oil aging and finally it is constant. It is interesting that the final value of the viscosity and the SAW attenuation after the working cycle has been practically the same as in the virgin sample. The same type of the oil viscosity dependence has been observed for the same kind of the oil taken from other locomotive. The viscosity fall has been studied by the intensive ultrasound irradiation. In decreasing and linear part of the viscosity curve, as shown in Fig.3, no changes have been observed. The 2 dB attenuation change has been observed after the irradiation (30 min.) between irradiated and nonirradiated sample for 34000 km old oil. It seems to be clear that the viscosity fall is not caused by the wrong state of the engine and the explanation of the observed dependence must be found in the working cycle of the diesel engine.

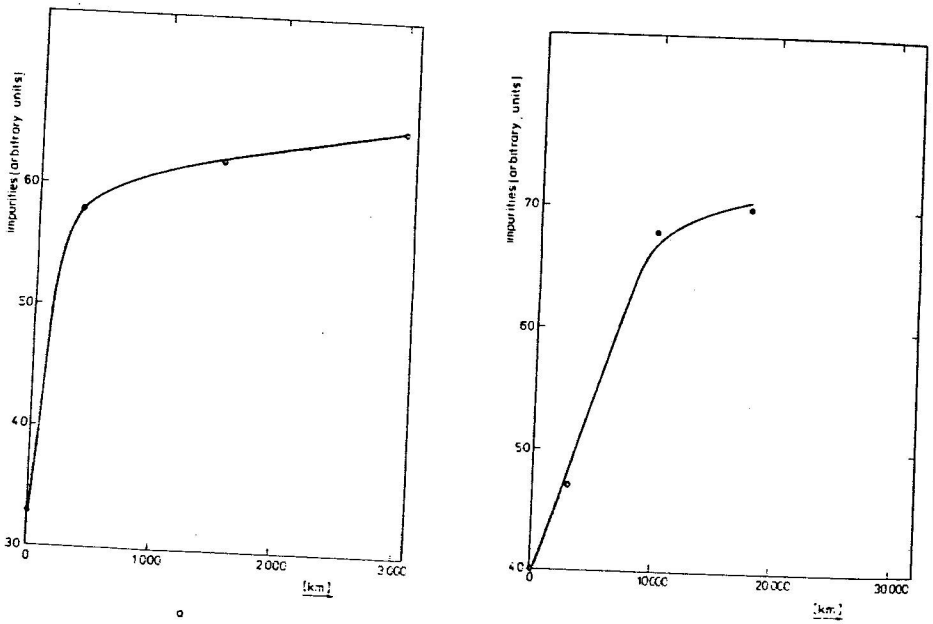

Fig. 4. *a*. The dependence of the impurity amount versus oil age in km (buss). *b*. The dependence of the impurity amount versus oil age in km (locomotive).

We have measured the temperature dependencies of the SAW attenuation for the same oils. We present curves describing the pure oil (Fig.5*a*) and the oil after the working cycle (Fig.5*b*). It is clearly seen that the curve describing the used oil is much more complex, which can be caused by the presence of impurities from the combustion process.

The study of the dissociation degree of ionic liquids has been the next domain

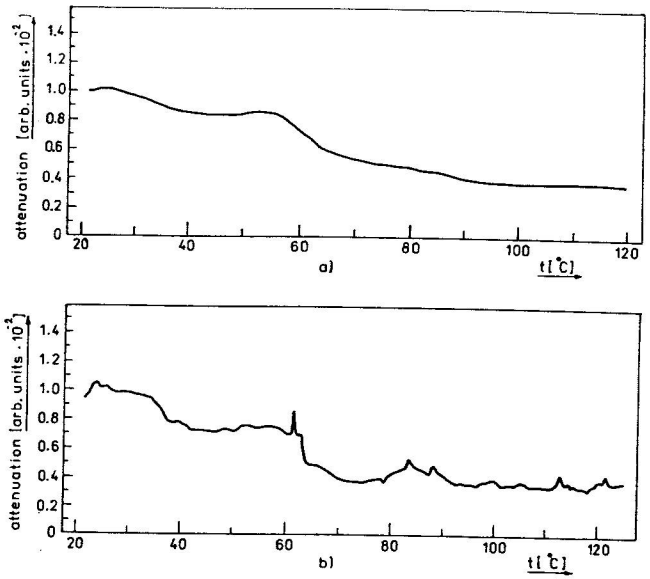

Fig. 5. The temperature dependence of the SAW attenuation in the locomotive oil (*a*) -virgin sample of the oil. *b* -the oil after the working cycle.

in which we used immersion sensor. In this type of experiments we test the aqueous solution of hydrochloric acid. The results are illustrated in the Fig.6. The curve a presents the attenuation versus volume of acid dependence, which reaches the maximum at about 0.5 ml of the acid and then slowly decreases with the increasing of acid amount. Very interesting is the high sensitivity of such acid presence detection. It is seen from the plot that the attenuation change about 1 dB corresponds to the addition of 0.05 ml of the concentrated acid to 400 ml of destiled water in the linear part of the curve.

The very similar experiments concerning water-ethanol solution at 23 °C give the same type of the attenuation dependence. The results are shown in the Fig.7. The maximum appeared at the 50 volume percent of ethanol is probably connected with the internal structure of ethanol-water solution and namely with the existence of the hydrogen bond. The equilibrium between molecules bonded by hydrogen bond in spatial net and "free" molecules is reached at the constant temperature. This maximum is shefted on the "bonded water" side. The following addition of ethanol influences on the location of molecules in the water net cavities. High polarity of O-H bonds improve the structure. This fact then can explain the attenuation rising (up to 50 volume percent of ethanol). It is probable to attain that this process can be accompanied by relaxation effects in the ethanol molecule. The addition of ethanol fulfills the cavities and the next increasing of its concentration destructs the spatial net and increases the amount of "free" water molecules and the attenuation falls.

Finally we describe one "liquid free" utilization of the above mentioned probe.

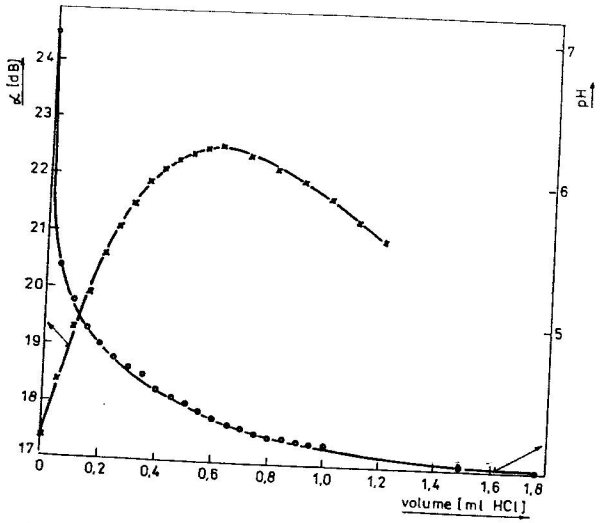

Fig. 6. The dependence of the SAW attenuation and ph versus HCl concentration. Corresponding axes are marked by arrows.

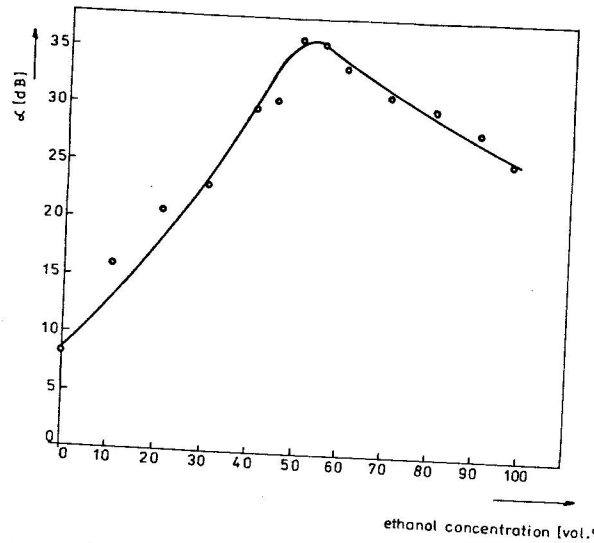

Fig. 7. The dependence of the SAW attenuation as a function of ethanol concentration.

The sensor has been placed on the surface of the paraffin. The temperature dependence of the SAW attenuation has been measured. The results are shown in Fig.8. It is clearly seen that at about 37 °C the large increase of the attenuation began. The inflection point (maximum of relaxation activity, see for instance Ref.3) is nearly 40 °C which is in in very good agreement with the value 41 °C given by factory as a softening point. Thus this experimental arrangement can be

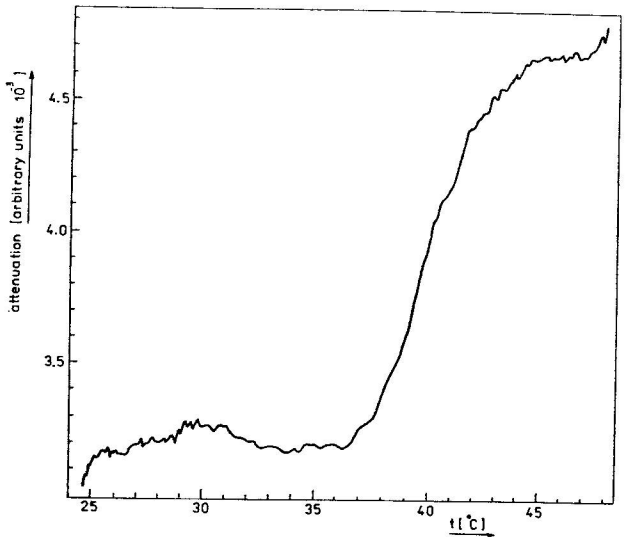

Fig. 8. The dependence of the SAW attenuation as a function of the temperature in parraffin.

with success used for the measurements of significant thermal point in solid state too.

IV. CONCLUSION

It is clearly seen from the presented results that the measurements of SAW attenuation can give important informations concerning quality of some technical liquids in the sense of their aging. Very interesting is the using of SAW sensor for the study of dissociation degree. The dependence of SAW attenuation versus acid concentration is nearly linear in sufficiently large domain of small acid concentrations, where the classic ph measurements are not too sensitive. The measurements of the softening point of parraffin open interesting utilization of above mentioned sensor for the study of significant thermal point of polymeric substances.

The "easy matching" is between the main advantages of presented sensor.

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