CHARACTERIZATION OF ULTRASONIC HOMOGENIZERS FOR SHIPBUILDING INDUSTRY

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Abstract: *The article deals with analysis of a possible application of high-power ultrasound in the process of preparing homogeneous emulsions of fuel and water in order to improve combustion efficiency on ships and generaly in shipbuilding industry. On the basis of published literature it is known that under influence of the high-power ultrasound it is possible to disperse water droplets in waste oil or high viscosity liquid fuels (for example crude oil) and high quality emulsions can be obtained. Under influence of ultrasound it is possible to perform emulsification and homogenization of immiscible liquids in such way that even after long time period eventual component separation could be avoided. Evaporation of emulsified water reduces the combustion temperature and ensures better "contact" of the fuel droplets with the oxygen, which enhances the combustion by reduction of soot and NOx in exhaust gases.*

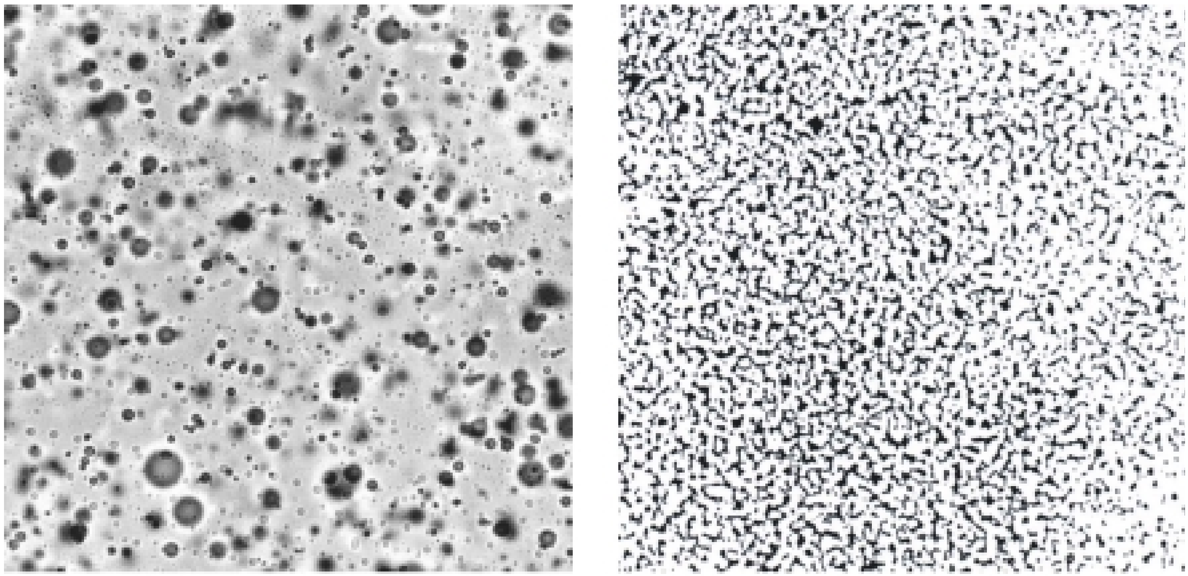
Key words: *high power ultrasonics, cavitation, homogenization*

1. INTRODUCTION

Homogenization of liquid fuels on ships can be useful due to the two main reasons [1,2,3]:

- because of unequal quality of the fuel heavy fractions are sedimented on the bottom of the fuel tank so necessity for storage tanks of such waste exists.
- homogenization of water in heavy fuels enhances combustion.

In both cases, the aim of the procedure is fuel fragmentation into small particles, (Fig. 1.) mixed with water droplets, which easily evaporates explosively in the heat and tear apart heavy fuel oil clusters. The "consequence" of such effect is much better combustion with increase of calorimetric value of the prepared emulsion. Preparing emulsions of diesel or crude oil with water is possible due to the physical phenomenon of ultrasonic cavitation which provokes oscillation of present cavitation nuclei. The size of such nuclei is strictly determined by the frequency of the applied ultrasonic energy. In order to ensure presence of cavitation effects in liquids, the required amount of ultrasonic energy in specially designed process chambers (called ultrasonic processors) most be provided. Knowledge of basic physical and chemical parameters of liquids that are involved in the emulsification and homogenisation process are presumed. Ultrasonic transducers are driven by ultrasonic generators that convert supply power into a high frequency voltage excitation of strictly determined frequency. When the ultrasonic field in the process chamber reaches sufficiently large negative pressures, the rarefaction of the liquids appears, and the distance between the molecules exceeds the critical value. At this moment the liquid will break down, and voids will be created, i.e. cavitation bubbles will form.



a) b)

Fig. 1. Droplet size distribution. Magnification 400x.

a) Crude oil, without insonification, 30 % of droplets have diameter bigger than 30 μm, 30 % have diameter between (20-30) μm, 40 % has diameter less then 20 μm.

b) Emulsion of crude oil with water (concentration 5 %). Insonification time 2 min. Mean droplets diameter is 7,34 μm, with standard deviation of 5,47 μm.

This effect is accompanied by the strong hydrodynamic movement in the liquid, intense emmiting of acoustic shock waves, (up to 1000 atm), local increase of the temperature (approximately to 10000 ^{o}C) at places where bubbles are formed. The described effects provoked by ultrasonic cavitation cause chemical and structural changes of liquids under treatment, which bring us to the emulsification, i.e. dispersion of one liquid into another. In such manner, with the help of ultrasound, homogeneous and stabile emulsions can be obtained. The possibility of creating fine and high-quality emulsions is the reason why the process of ultrasonic homogenization has already found wide application in the technology of chemical, pharmaceutical and food industry.

2. TECHNICAL SOLUTION

The technological process of ultrasonic homogenization is based on a specially constructed modular ultrasonic unit (Fig. 2) consisting of ultrasonic transducers, ultrasonic power generators, and a specially shaped process chamber [4,5,6]. The ultrasonic transducer has the shape of so called “sandwich” construction, made from piezoelectric ceramics (lead zirconate titanate), metal parts (front and rear) and with a quality bolt pre-stressed into the compact transducer with required resonant frequency. In order to define the necessary amount of acoustic power operating frequency, necessary acoustic intensity and insonification time must be balanced. The ultrasonic power generator are commonly manufactured as modular units with electrical power output up to 2 kW. If the required acoustic intensity (and the corresponding sound pressure) in the process chamber is ensured, special attention has to be paid to the insonification time. Industrial applications demand usage of flow-through chambers so there must be a balance between the liquid flow rate and the sonification time.

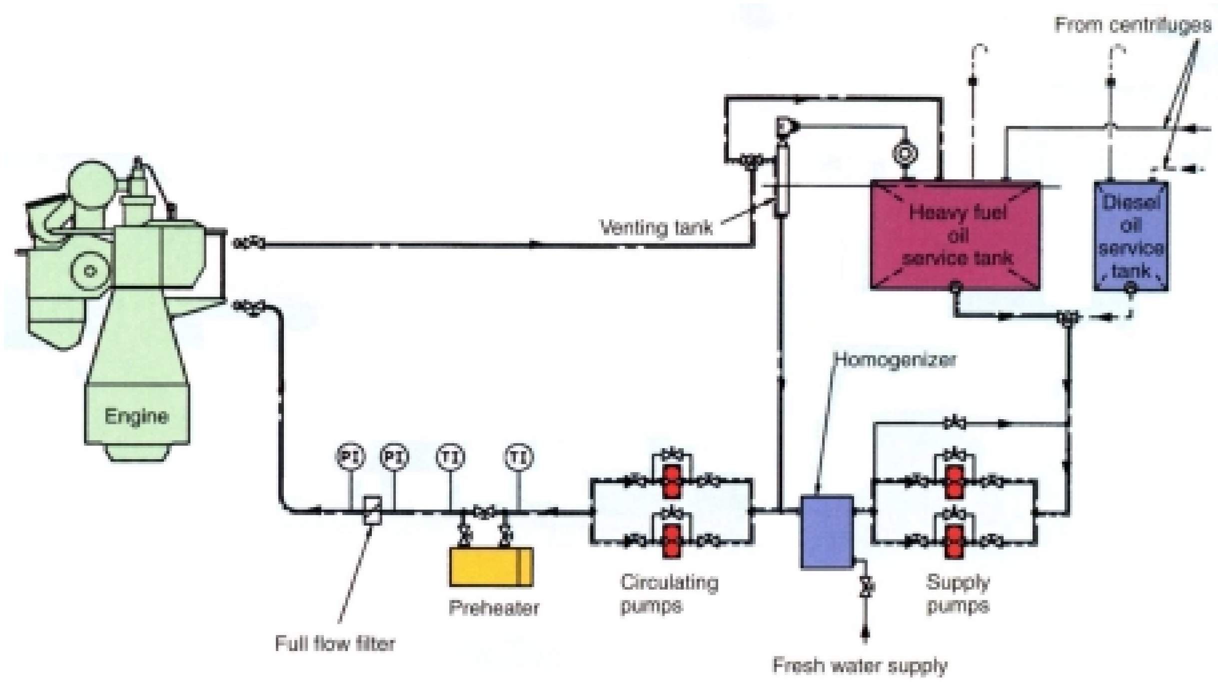


Fig. 2. Block scheme of the ship homogenizer (RESON A/S)

A too short sonification time can lead to insufficient mixing of liquids, while at a too long sonification time coagulation effects may occur. Only if high homogeneity of the emulsion or small diameter of liquid particles is needed an increase of the sonification time might be economically justified, but with conotrolled acoustic input parameters. Also, the quality of emulsification and homogenization processes depends upon the sound field inside the process chamber. It has been observed that in the standing wave field water/oil emulsions have smaller concentrations, when compared with ultrasonic fields with progressive waves. At the beginning of the emulsion preparation it is necessary to develop the critical value of the acoustic intensity I_C, which corresponds to the cavitation threshold of one component in the process. For preparation of water/fuel emulsions the boundary acoustic intensity is approx. 0,5 W/cm^2, while for fuel/water emulsions the cavitation threshold is almost doubled. For clean technical water at normal hydrostatic pressure and room temperature, the cavitation threshold is approximately equal to

$$I_C = \frac{p_c^2}{\rho\, c} = \frac{10^4}{3}\ \mathrm{W/m^2} = \frac{1}{3}\ \mathrm{W/cm^2} \tag{1}$$

where

p_c – critical sound pressure in (Pa),

$\rho\, c$ – characteristic acoustic impedance of the medium, in (kg/(m^2 s).

From (1), the critical sound pressure can be calculated as:

$$p_c = 0{,}7 \cdot 10^5\ \mathrm{Pa}\ \text{ or }\ L_c = 217\ \mathrm{dB\ ref.\ 1\ \mu Pa} \tag{2}$$

Parameters that affect cavitation threshold can be separated into two main groups:

a.) Parameters of the acoustic field - acoustic intensity *I*, and sound pressure *p*, sound attenuation α, operating frequency *f*.

b.) Physical and chemical characteristics of the emulsified liquid - liquid viscosity, ratio of specific densities of liquids, vapour pressure of liquid, surface tension of liquid, concentration and diffusion rate of dissolved gasses, static and external applied pressure, operating temperature.

By increasing ultrasonic frequency cavitation threshold also increases while dimensions of dispergated components decrease. In such conditions for a stable cavitation at frequencies around 20 kHz (continuous wave), in technical degassed water and without applied external pressure, the acoustic intensity is approx. 0,3 W/cm^2, while at the frequency around 100 kHz (CW), the necessary acoustic intensity is almost 1 W/cm^2. Selection of the lower ultrasonic frequency (20 kHz) has advantages and disadvantages with respect to the better quality of emulsion. By lowering the operating frequency coefficent of the electroacoustical efficiency of the transducer increases, the cavitation bubbles have greater diameter, the transducer and power generator are bigger and the level of noise around the unit is raised.

The process of emulsification and homogenization also depends upon the static pressure and applied external pressures. For degassed technical water is has been experimentally determined that if the ratio of sound pressure p_A and static pressure p_0 is 0,4, an optimal shock wave and cavitation erosion are formed.

Temperature of liquids also has significant influence on intensity of cavitation. Increasing temperature raises vapour pressure of the medium. As a direct consequence production of cavitation nuclei is multiplied. Temperature has a very complicated influence on the emulsion preparation process and therefore must be under control during the whole technological process. While at classic emulsion preparation rising of ambient temperature almost always has favourable influence to the process, the ultrasonic homogenization must be performed under optimal temperature range where cavitation activities are at maximum. For water and its solvents the temperature range lies between 35 ^oC and 50 ^oC, while for the oil or crude oil it is around 80 ^oC.

Liquid viscosity acts twofold on the emulsion preparation processes. Namely, an increase in viscosity is in fact an increase in natural cohesive forces between liquid molecules, therefore it follows that formation of cavities in such liquid demands a larger negative pressure in the rarefaction region. Also, the viscosity of liquid has influence on speed of acoustical streaming at the liquid/liquid interface where the emulsification process takes place. Big differences in viscosities of the two or more liquids involved in the emulsion preparation process are not suitable for production of good-quality and stable emulsions, while less viscuous liquids can be emulsified easier and quicker. Surface tension of liquids has very similar influence on the emulsion preparation process as liquid viscosity, and it is very important in the case where the emulsification process involves immiscible liquids. As cavitation effects take place in interfacial regions between liquids, by employing liquids of lower surface tension, might reduce cavitation threshold. But at onset of cavitation bubbles collapse at or near the interface, disrupt it, impel jets of one liquid into the other and form anemulsion of very high concentration. Emulsion preparation processes between immiscible liquids are usually very slow. In order to reduce liquid surface tension surface-active materials have been used. These materials, known as the various types of emulgators and stabilizators, are forming absorption layers at liquid surfaces that accelerate cavitation processes on lower ultrasonic energy levels.

3. CONCLUSION

Installation of ultrasonic homogenizers in power plants or ship power units for emulsification of dispersed water into heavy fuel enable better quality of combustion, increase the calorimetric value of prepared emulsion, reduce fuel costs and improve characteristics of exhaust gasses. By application on ships two additional goals can be acchieved:

- Usage of waste fuel (heavy fractions) that has sedimented at the bottom of fuel tanks, eliminates the need for storage tanks, and
- Emulsification of water into heavy fuel oil (maximum ratio 1:2 or 33 % of water in emulsion), ensures better calorimetric values of emulsion.

The emulsification of diesel or crude oil with technical water in such facilities can acchieve savings of up to 5 % of overall fuel costs, with reduced soot, 10 % less NOx and 25 % less CO_2 in exhaust gasses. Generally it can be said that ultrasonic homogenizers on ships should be used primarily for such installations where the NOx has to be controlled at levels well below of those prescribed by IMO (17 g/kWh) for main engines.

4. LITERATURE

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KARAKTERIZACIJA ULTRAZVUČNIH HOMOGENIZATORA ZA UPOTREBU U BRODOGRAĐEVNOJ INDUSTRIJI: *Osnovni cilj rada je analiza mogućnosti primjene ultrazvuka u priređivanju homogenih emulzija goriva i vode radi kvalitetnijeg sagorijevanja na brodovima i općenito u brodograđevnoj industriji. Poznato je da se djelovanjem ultrazvuka velike snage u otpadnim uljima ili u tekućim gorivima visokog viskoziteta (npr. mazut) mogu raspršiti kapljice vode i dobiti kvalitetne homogene emulzije. Pomoću ultrazvuka velike snage može se provesti emulzifikacija i homogenizacija nemiješajućih tekućina tako da nema odvajanja pojedinih komponenata niti nakon dužeg vremena. Ovim postupkom površina kapljica goriva bolje dolazi u dodir s kisikom, što omogućava kvalitetnije sagorijevanje, s povoljnijom karakteristikom dimnih plinova, smanjenjem čađi i NOx.*

Ključne riječi: *visokoenergetski ultrazvuk, kavitacija, homogenizacija*