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Studies of Acoustic Wave Propagation when Facing Obstacle

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Control of flame behaviour has a number of practical applications. This task is not trivial and a rapidly growing body of research related to this subject can be recently observed. A promising solution for such a problem could be a technology utilising the acoustic waves. One may expect that the acoustic excitation characterised by the same pressure level will interact with the flame differently, when the environment configuration in flame's close vicinity changes. Hence the issue related to the propagation of the acoustic waves in the presence of obstacles is worth of interest. The paper presents results of studies taken on acoustic field propagation when the acoustic excitation is carried with and without acoustic screen.

topics: acoustic wave, acoustic screen, wave propagation, sound pressure level

1. Introduction

The potential use of acoustic waves in flame quenching seems to be a promising approach that could be used as an alternative or supplement to available flame extinction methods, such as water mist [1–4], hot aerosols [5] or extinction powders [6, 7].

The available literature provides an interesting insight into the experimental study of flame behaviour under the action of acoustic oscillations [8–16]. Although the topic is interesting there are very few papers dedicated to the potential use of acoustic waves in the extinction of flames. McKinney and Dunn-Rankin [17] determined the extinction criteria for a burning linear fuel droplet stream exposed to the acoustic field. The authors found that the sound level (SL) required for the extinction event to occur increases with both oscillation frequency and droplets diameters. Beisner et al. [18] examined the use of single tone acoustic waves in the extinction of ignited Zippo lighter in microgravity environment. The results showed that it is easier to extinguish the flame in a microgravity environment than in a regular gravity field and that the flame extinction can be achieved more quickly for lower oscillation frequencies. Friedman and Stoliarov [19] analysed what conditions need to be meet for quenching of laminar diffusion line-flames. It was observed that the lower frequency is the lower SL is required to extinguish the flame. It was also shown that for the critical SL required to cause extinction of the flame the ratio between the modified Nusselt number and the Spalding B number remains unchanged regardless of the acoustic frequency. Bennewitz et al. [20] determined extinction criteria for single droplets located in the vicinity of a velocity antinode of acoustic standing wave generated inside a resonator tube. Similarly, as in the previous works authors found that the higher frequency is the higher extinction pressure is required to cause the extinction. Niegodajew et al. [21] utilised acoustic waves in quenching of gas burner flame. A low impact of the burner power on the acoustic extinction pressure was observed. It was also found that the quenching is caused due to the fuel stream deflection and flame displacement from its original position caused by the cumulative effect of oscillatory perturbations and acoustic mean flow.

All the above mentioned works were related to acoustically-driven extinction of the flame located either in the open environment [17–19, 21] or inside the resonator tube [20]. When concerning the use of acoustic waves as a fire suppression method one may expect that the closest environment of a flame would not be free of obstacles. In such a case an acoustic oscillations acting on a flame would differ from that generated in the open space and it is of interest to investigate how obstacles affect the

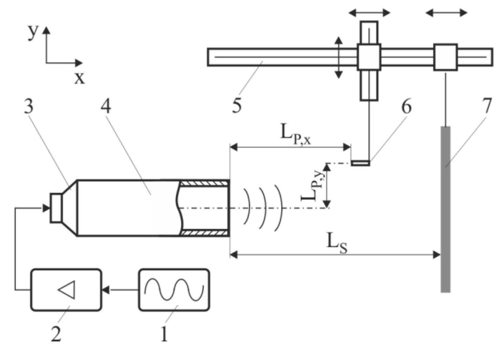

Fig. 1. Scheme of the experimental setup (a) and position of the pressure sensor and the screen (b) with respect to the outlet of the tube.

acoustic field. Hence, the purpose of present paper is to investigate how the acoustic field changes with varying distance between an acoustic source and an acoustic screen — being the simplest model of a single obstacle and therefore a case of fundamental studies.

2. Experimental setup

The experiment was performed with the use of setup schematically shown in Fig. 1. The generator TESLA RC OSCILLATOR BM 365U (1) produces a sine signal that is transduced through the amplifier Mosfet MDD. 2108M (2) to the loudspeaker SONY 1-825-378-11 (3) mounted on one end of the tube (4). Such a setup allows producing the traversing (progressive) acoustic wave in the region between the other side of the tube and the acoustic screen (7). The sound intensity was measured in the region between the tube and the screen with the use of SL probe Voltcraft SL-451 (6) mounted on a precise 2-dimensional traversing system (5). The SL probe's position will be hereafter defined with coordinates $L_{p,x}$ and $L_{p,y}$ (see Fig. 1b), where $L_{p,y} = 0$ determines the tube's axis position. The tube was made of steel and its length and inner diameter were 650 mm and 70 mm, respectively. The acoustic oscillations frequency was always fixed at 50 Hz. The acoustic screen was made of glass and its dimensions were 335 mm × 235 mm. The measurements were conducted in two configurations — with and without acoustic screen in order to assess its impact on the acoustic field.

3. Experimental results

Figure 2a illustrates the SL field (in the form of isolines of constant SLs expressed in decibels) for the case without the acoustic screen. As can be seen, the SL decreases with increasing both axial and radial direction from the tube outlet forming a circular shape — characteristic feature for the traversing wave leaving the nearly point acoustic source. Simultaneously isolines' radiuses increase with increasing distance leading to flattening of wave front. When placing the acoustic screen in the measuring section at a 160 mm distance (see Fig. 2b) the acoustic field changes noticeably. It is manifested by two qualitative effects. These are the shift and the elongation of the isolines in axial direction towards the acoustic screen. This effect is attributed to the wave reflection from the acoustic screen, leading to constructive interference and an increase in the SL level, in particular, influencing the region close to the tube axis.

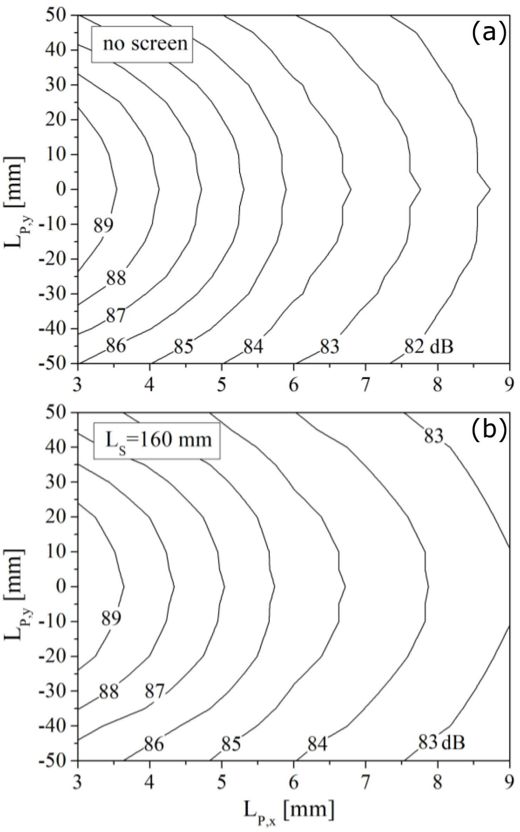

Fig. 2. Isolines of constant SL at the outlet of the tube without (a) and with (b) the screen located at L_s =160 mm.

To assess quantitatively the impact of the acoustic screen on the acoustic field, Fig. 3 shows SL profiles measured at three distances, i.e., $L_{p,x} = 30, 60$ and 90 mm and for three different configurations, i.e., without the screen and with the screen located at distance $L_S = 160$ mm and 200 mm.

When analysing consecutive profiles given in Fig. 3a–3c it is evident that with increasing distance from the tube outlet ($L_{p,x}$) wave front flattens significantly. For the smallest $L_{p,x}$ analysed (30 mm — see Fig. 3a), the impact of the screen on LS is evident only for the large values of $|L_{p,y}|$. When increasing measuring distance $L_{p,x}$, the presence of the screen leads to growth in SL comparing to the case when the wave is released to the open environment (+0.8 dB for $L_{p,x} = 60$ mm and +1.3 dB for $L_{p,x} = 90$ mm for $L_s = 160$ mm

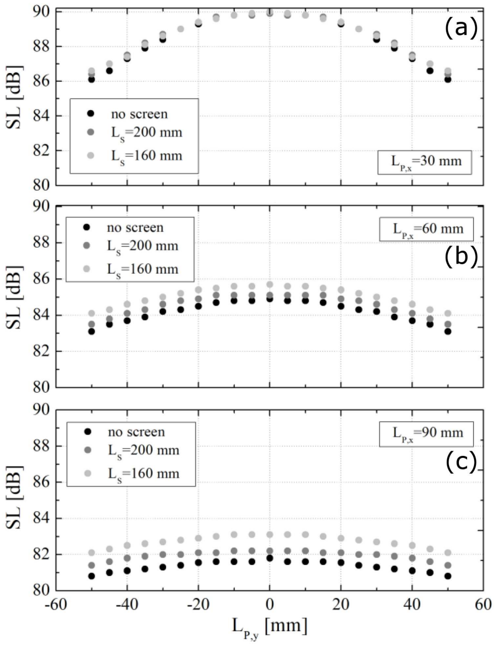

Fig. 3. SL at the tube outlet without (a) and with the screen distant 200 mm (b) and 160 mm (c) from the tube outlet.

regardless of $L_{p,y}$). An increase in SL can be also achieved by reducing the distance between the tube outlet and the screen — what is clearly visible in Figs. 3b and 3c.

3. Conclusions

The results shown in the present paper clearly indicate that when the acoustic screen is placed in the sound field, the sound level will increase. Even higher SL can be achieved by reducing the distance between the acoustic screen and the tube outlet. Therefore on one hand the expectation is that such a configuration will improve fire extinction. Hovever, this phenomenon depends not only on the SL but also on the so called non zero mean flow generated by the tube. Hence, on the other hand conclusion that improved SL will improve acoustically-driven extinction process without knowing the impact of the screen on the mean flow, cannot be stated. It is expected that screen will reduce the velocity of mean flow, therefore the further studies should focus on verifying this issue.

Regardless which parameter has a dominant character on the extinction, the results presented in this paper indicate that one cannot simply ignore presence of obstacles in the near vicinity of a flame, even if they are located directly behind.

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