SPECIFICS OF THE ATOMIZATION AND EVAPORATION PROCESSES THROUGH THE APPLICATION OF PULSE COMBUSTION

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Abstract: The application field of the pulse combustion can be extended in several domains, especially in agriculture, where it can be used for plants protection against freezing by controlling the parameters of the pulsating gas flow. There are presented the results of the experimental research regarding the influence of the pulsating gas flow over the water atomization and evaporation processes. It is shown that the gas temperature can be controlled by water injection in the resonance exhaust tube; the influence over the pulsating combustion process is insignificant. It was revealed that water evaporation process is more efficient when the unsteady flow (pulsating) is used than in the case of the steady flow. Consequently, the water evaporation area is shorter.

1. Introduction

The focus of the later years on the analysis of the various flow control methods and of the transfer processes is motivated by the requirements to increase the efficiency of energy transformation and utilization, to eliminate the environment pollution and to reduce the cost of the thermo – energetic equipment and systems.

A promising direction in the field of mass and heat transfer process control or augmentation is the application of the high amplitude acoustical fields, or the pulse fluid fluxes [1]. High intensity oscillating fluxes can be efficiently generated in Helmholtz resonator type devices, operating in the fluid flow resonance regime. The resonance flow regime in a Helmholtz resonator can be achieved through the forced entrainment by a piston placed in the resonator section, at a frequency equal to the resonating frequency of the resonator [2], or through the pulse combustion adjustment in a self – oscillating regime [3].

The pulsating burned gas fluxes of temperatures over 1000 C, provided by the pulse combustion installations are usually in the 40 – 200 Hz frequency range, with a velocity amplitude at the resonating tube of 100 m/s and a sound pressure of 90 – 180 dB.

These performances, as well as their high thermal volumetric load (50 x 10^6 W/m^3), reduced sizes and simplicity, autonomous combustion air aspiration, as well as operation with the air excess coefficient of 1.0, render the pulse combustion installations attractive for the improvement of various technological processes, especially for the high energy consumption ones, such as the pulverization drying or incineration processes [3].

An important problem for agriculture is the elimination, or the diminishing of the material losses induced by the late autumn, or early spring freezing. The most commonly used method to do this is to compensate the heat losses through placing various thermal devices in the near proximity of the ground, to heat up the cold air. The high energy consumption and the high cost of such devices are the main disadvantages of such a protection system.

This paper analyzes the possibilities of using pulse combustion chambers as a protection system of plants against freezing through the compensation method. Also, due to the high velocity (over 100m/s in amplitude) and to the oscillatory character of the gas flux at the resonance tube exhaust, the installation can achieve the intensive mixing of the high temperature air layers existing at higher distances above the ground with the cold air immediately near the ground.

The high energy consumption for plant protection achieved through the traditional thermal devices is due to the large heat losses owing to the convective transport of the high temperature air near the heat source away from the protection zone.

By using the pulse combustion as the thermal energy source, this phenomenon can be eliminated or, at least, reduced [4].

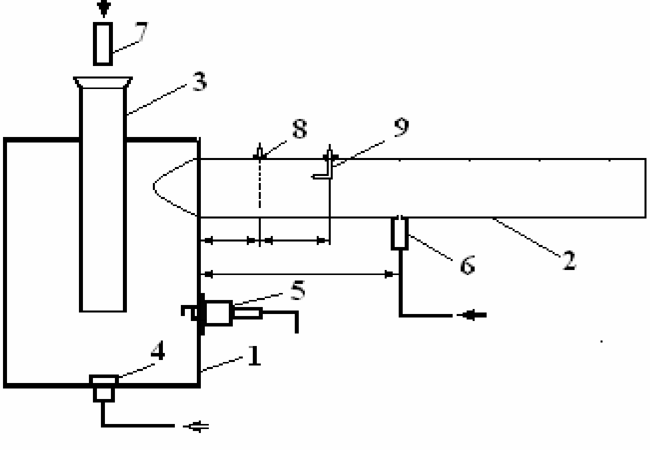
The use of the hot gas cooling method through evaporation is beneficial and can ensure a higher efficiency of the protection system both by the increase in the humidity content of the surrounding air, and by forming a fog layer on the protected field.

The purpose of this paper is to study the specifics of the atomization and evaporation of the water jet injected in the gas flux in the resonance tube, and their effect on the pulse combustion device characteristics.

2. The installation and the research method

For the experimental study if the water evaporation process, a combustion chamber with a resonance tube placed tangentially has been selected [5].The constructive schematic of the installation is presented in Figure 1.The, dimensioning of the *50kW* combustion installation, propane –butane fuelled, was made through the successive approximation method, and by using experimentally measured values of the combustion chamber parameters. The constructive parameters of the installation are: *combustion chamber volume –* $1.329 \, x \cdot 10^{-3} \, m^3$*, resonance tube diameter –* $48.5 \, x \cdot 10^{-3} \, m$*, resonance tube length – 1.1 m.*

During the experimental research studies, the resonance tube length L_{tr} and the aerodynamic vane length L_{sa} have been modified. The resonance tube length was varied in the range $L_{tr} = (0.8 - 2.0)$ m by adding or removing segments to the resonance tube of designed length of $L_{tr} = 1.10$ *m.* The aerodynamic vane vane was varied in a similar manner. For the gaseous fuel (butane) injection an injector with five, *1.2 mm* diameter orifices aligned with an axis forming a 60^0 angle with the injector axis was used. The fuel injector was placed co-axially with respect to the aerodynamic vane. The fuel injection pressure was varied in the range *20 – 80 kPa*, and the fuel mass flow rate in the range $G_c = (0.4 - 1.1)G_{cn}$, where G_{cn} is the nominal fuel mass flow rate. The fuel mass flow rate was measured by a calibrated rotary meter. The air mass flow rate required for combustion was evaluated through the burned gas composition analysis, or through using the mass balance equation, $G_a = G_{pa} - G_c$, where G_{pa} is the combustion products mean mass flow rate. The G_{pa} mass flow rate was measured through a Pitot – Prandtl tube.



1- combustion chamber
2 - resonance tube
3 - aerodynamic valve
4 - fuel injector
5 - spark plug
6 - water injector
7 - starting air injector
8, 9-thermocouples

Fig. 1 - The constructive schematics of the pulse combustion installation

The combustion products temperature and the resonance tube surface temperature were measured using *chromel-alumel* thermocouples *(*type K) of 0.8 mm diameter, covered with ceramic tubes of *2.4 mm* external diameter. The thermocouples were mounted on the resonance tube exterior wall, with a *30 mm* distance between each two consecutive ones along the tube. The thermocouples meant for measuring the gas flux temperature were placed on a special mounting device, such that they could be placed inside the resonance tube at the desired distance.

The water injection was made normally to the gas flow, at a *640 mm* distance from the resonance tube inlet. For the injection of water, a jet injector of nozzle diameter of $d_j = (1.0 - 4.0)$ mm was used. The jet mass flow rate was measured with a calibrated rotary meter.

The pressure and velocity oscillations amplitude and frequency were measured using piezoelectric pressure transducers of type *LX-610A*. The recording and the analysis of the pulse spectrum was performed by means of an electronic oscilloscope and a spectral analyzer. For the burned gas composition analysis a *Testo 350* equipment was used.

3. Results and analysis

In a first research stage, the pulse combustion regime stability was analyzed with respect to the resonance tube length and the fuel mass flow rate. It was found that for the designed resonance tube length of $L_{tr}=1.10\ m$, combustion occurs at an equivalence ratio close to $\varphi = 1.0$. In the stable pulse combustion regime the frequency is independent of the fuel mass flow rate in the investigated range, except for the pressure oscillation amplitude.

The oscillation amplitude continuously decreases from $P_{am} = 22.0\ kPa$ at a fuel mass flow rate of $G_c= 1.09\cdot10^{-3}\ kg/s$ to $P_{am} = 6.4\ kPa$ at a fuel mass flow rate of $G_c=0.43\cdot10^{-3}\ kg/s$. The fuel mass flow rate value of $G_c=0.42\cdot10^{-3}\ kg/s$ represents the minimum fuel mass flow rate where the pulse combustion regime is still possible. The analysis of the pulse spectrum shown in Figure 2 indicates that the combustion chamber operates at a base frequency f_1, given by the expression:

$$f_1 = \frac{a_{nc}}{2\pi}\cdot\sqrt{\frac{\rho_{nc}\cdot f_{tr}}{\rho_{tr}\cdot V_c\cdot l_{tr}}}\ ,\ [Hz]$$

where: a_{nc}- sound velocity [m/s]; ρ_{nc},ρ_{tr} – density of mixture in the combustion chamber and resonance exhaust tube, respectively [kg/m^3]; V_c – volume of the combustion chamber [m^3]; f_{tr} – cross section of the resonance exhaust tube [m^2]; l_{tr} – length of the resonance exhaust tube [m].

The pulse spectrum also shows peaks at frequencies equal to $2f_1$ and $3f_1$, but the pressure oscillation amplitude at these frequencies is smaller compared to the base frequency.

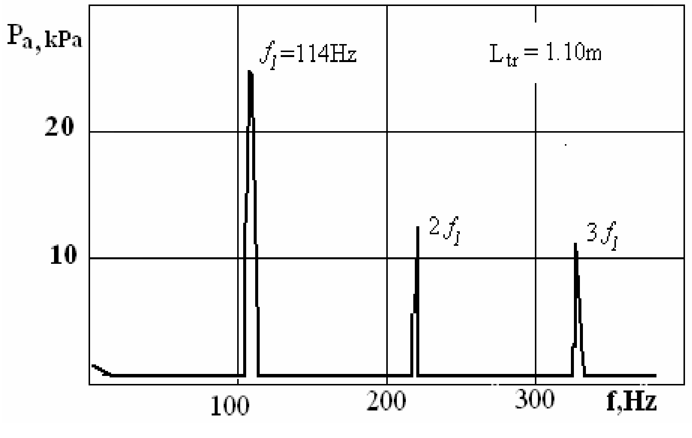


Fig. 2 - Pressure oscillation spectrum

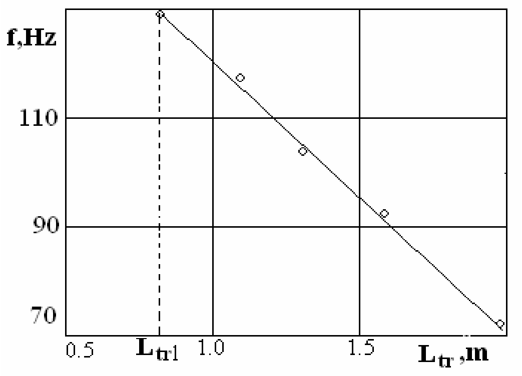


Fig. 3 - The resonance tube effect on the base frequency

In Figure 3 the effect of the resonance tube length on the base harmonics frequency is presented. It is important to note that although the base frequency appears for any resonance tube length, the pressure oscillation amplitude decreases both for $L_{tr} > 1.10\ m$ and for $L_{tr} < 1.10\ m$. For $L_{tr} > 1.10\ m$, the pressure oscillation amplitude decreases with the decrease of the L_{tr} length for each of the three frequencies. This can be explained by the increase in the hydrodynamic resistance of the resonance tube. For the range $L_{tr} = (0.8 – 1.10)\ m$ as L_{tr} decreases, the base frequency oscillations amplitude decreases, but $2f_1$ and the $3f_1$ frequency oscillations amplitude is increasing. The reason for this effect is the modification of the combustion regime. The combustion products analysis has shown that as L_{tr} is decreasing, the combustion dosage coefficient (the equivalence ratio reciprocal) also decreases, reaching a value of $\psi = 0.4$ for a length of $L_{tr} = 0.8m$. The installation operation in a pulse combustion regime for values $L_{trt} < 0.8m$ is impossible.

The effect of the pulse hot gas flux on atomization droplet size was experimentally studied earlier [6]. It was found that due to the fast evaporation of the droplets, the measurement of the droplets for reduced water jet mass flow rates ($G_j < 25\ l/h$) is impossible.

To eliminate the evaporation effect on the droplet size measurement in the paper, the jet atomization process in a pulse flux generated by a piston Helmholtz resonator research method was used. The resonator chamber diameter was of *88 mm*, the resonance tube diameter of *22 mm*, and the tube length of *1.0 m*. The pulsating air flux velocity amplitude at the exhaust of the resonance tube was varied in the range *50 – 130 m/s* by varying the piston oscillation frequency. The droplet size measurement was made through the impact method.

In Figure 4 the effect of the air flux velocity amplitude at the exhaust of the resonance tube on the Sauter D_{32} droplet diameter is presented as an example. The jet injection normal to the pulsing air flux was achieved through a $d_j = 2\ mm$ diameter nozzle, placed at a *30 mm* distance from the resonance tube exhaust. The droplet diameter was measured at a *600 mm* distance from the jet injection position.

In comparison to the jet atomization in a continuous flux, under quasi – similar conditions [7, 8] a smaller size of the droplets generated in the pulse flux can be noted. The Sauter D_{32} diameter of the droplets measured in reference [6] is affected by the evaporation process. However, the droplet's D_{32} is larger than that recorded in the present paper. An explanation for this can be the large difference between the water jet injected in the hot gas pulse flux and the cold air jet, of $dj = 14\ mm$, respectively of $d_j = 2\ mm$.

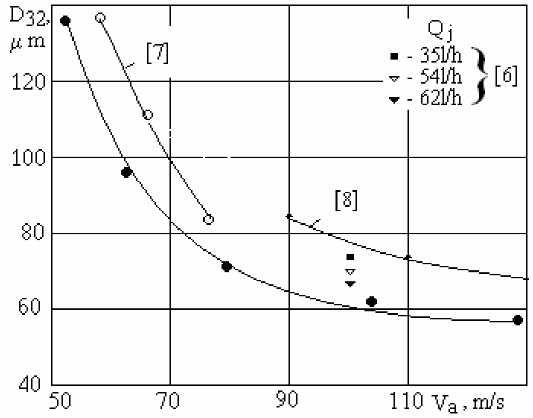


Fig. 4 - The effect of amplitude on the Sauter D_{32} diameter. $G_j = 18$ l/h

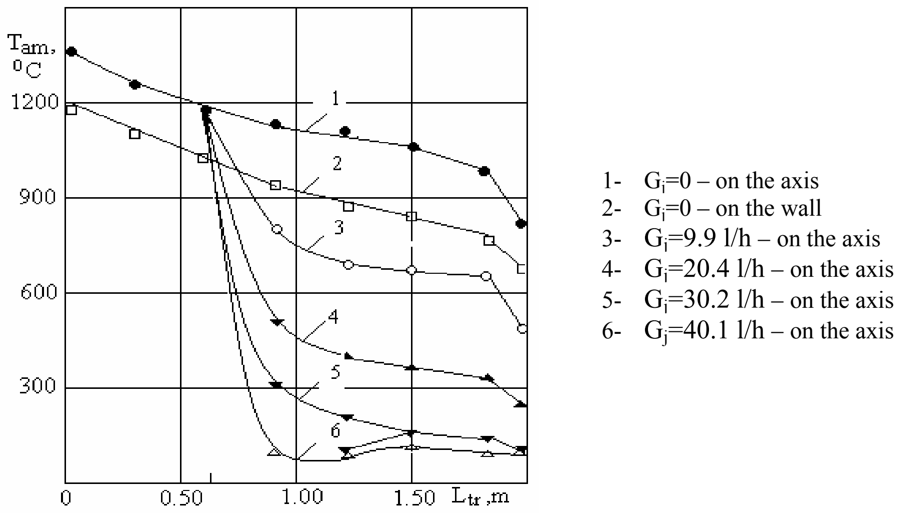


Fig. 5 - The temperature distribution on the resonance tube diameter

The water jet injection in the resonance tube was carried on normally to the gas flux direction, at a *640 mm* distance from the combustion chamber, on condition that the flame length does not exceed this length. It is important to note that the flame length was evaluated at the installation nominal power evaluation.

In a first research phase, the gas cooling effect was tested using a resonance tube of *1.10 m* length, because the installation parameters at this length, L_{tr}, are optimal. It was found, however, that a *0.46 m* length is insufficient for the complete water jet evaporation. For this reason, the experimental research focused on the evaporation process in the $L_{tr} = 2.0\ m$ installation, maintaining the water injection position.

In Figure 5, the gas temperature distribution along the resonance tube axis for various water jet mass flow rates is presented. The figure also shows the temperature distribution at the resonance tube surface. The maximum difference between the gas and the wall temperature is found in the central region, while the smallest occurs close to the open end of the tube. A sudden drop in the burned gas temperature can also be observed. This is due to the cold air entering the resonance tube during the gas flux reversal phase. The phenomenon remains present in the case of water injection in the gas flux. The effect is less obvious for mass flow rates at which on a liquid film is formed on the resonance tube surface (curve 6).

The liquid film formation on the resonance tube effect was used in references [9,10] to determine the efficiency of the evaporation process of the water in the gas flux generated by the pulse combustion installation when compared to the evaporation in a continuous flux. It was found that the water jet evaporation rate increases 35% [9], or 107% [10]. A similar result as that mentioned in [9] was also obtained here through the analysis of the thermal balance of the installation. The distance and the temperature for which the evaporation process ends were determined from the temperature pattern in the temperature stabilization point. Thus, it was found that as the water jet mass flow rate increases, the length of the complete evaporation zone is also increasing, and the temperature of the gas – vapor mixture decreases. The increase of the evaporation zone with the increase of the water mass flow rate is explained by the increase of the droplet sizes and the fast reduction in the temperature difference between gaseous and the liquid phases. In comparison to the liquid jet evaporation in continuous flux [11], the length of the complete evaporation zone reduces by a factor of 2 to 3. The analysis of the results presented in Figure 5 shows that the jet complete evaporation zone length when the liquid film does not form on the inner surface of the resonance tube changes in the range *(0.6 – 1.0) m.* To ensure the complete evaporation in the $L_{tr} = 1.10$ m resonance tube length installation, the water jet was injected at a distance of *0.1m* from the combustion chamber. The results of the temperature field measurements were similar to the results obtained for $L_{tr} = 2.0\ m.$

During the research studies, it was observed that the liquid jet injection affects the operation regime of the pulse combustion installation. The effect of the jet mass flow rate on the combustion chamber pressure oscillation base frequency for $L_{tr} = 1.10\ m$ and for two injection positions at *0.64 m*, and *0.1 m* respectively, is shown in Figure 6.

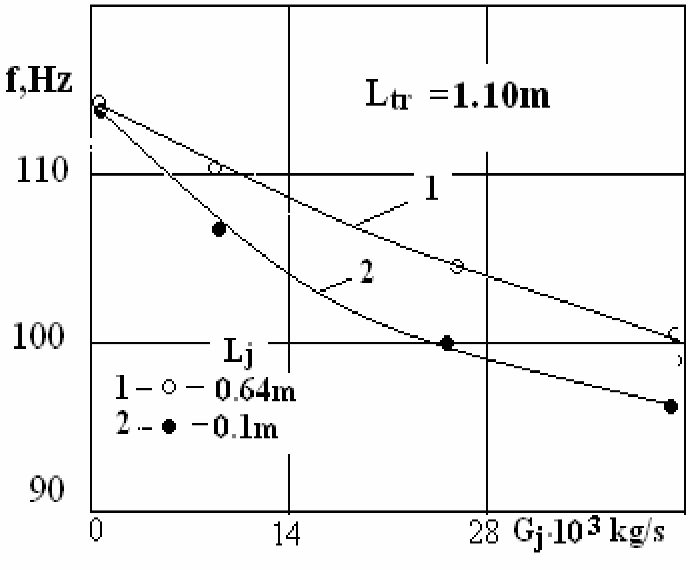


Fig. 6 - The effect of the jet mass flow rate on the pressure oscillations frequency

In the case of liquid jet injection in the resonance tube, the frequency of the pulse combustion process decreases with the increase in the jet mass flow rate. This effect becomes more significant as the length of the resonance tube region where a gas – vapor mixture is flowing increases. (case $L_j = 0.1\ m$). The effect of the liquid jet injection in the resonance tube can be explained by the increase in the gas flux mass

The application area of the results of this paper can be extended to other fields, such as the bio – pesticide aerosol generation, the pharmaceutical product drying and the drying of products that require for preparation thermal agents with controlled temperature.

4. Conclusion

During the experimental research presented herein, the regime parameters of the pulse combustion chamber with a tangentially placed resonance tube were determined, as well as the variation range of the geometrical parameters within the installation exhibits stable operation. The specifics of the liquid jet atomization process in a pulse flux unaffected by the evaporation process have been analyzed. The atomization and evaporation process intensification effect, when compared to their occurrence in a continuous flux has been appraised. The effect of the liquid jet injection in the resonance tube over the pressure oscillations in the combustion chamber was also observed.

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