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Experimental arguments in favour of heat transfer in compressible fluids by Pressure Gradient Elastic Waves

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ABSTRACT

The results of extensive scientific research show that sound has an effect on thermal processes in gases. The Ranque and Hartmann-Sprenger effects belong to this class of phenomena. Existing conventional theories cannot explain the heat transfer processes in devices based on these effects.

The concept of Pressure Gradient Elastic Waves provides a physical description of heat transfer in these processes. Pressure Gradient Elastic Waves are waves of sound type. These waves arise in compressible fluids (in gases) as a result of the existence of a pressure gradient within the volume of the gas, and in the presence of initial density fluctuations (under the influence of sound). Under these conditions the pressure forces act on micro volumes having density fluctuations along the pressure gradient vector. However the resultant forces act on fluctuations of rarefaction and on fluctuations of compression in opposite directions. The compression front of Pressure Gradient Elastic Wave propagates in the direction of increasing pressure, while the rarefaction front propagates in the opposite direction i.e. in the direction of reducing pressure. Thus these waves carry energy from the low pressure zone to the high pressure zone. This heat transfer manifests itself in the heating of the wall bounding the high pressure zone and in the cooling of the low pressure region.

The article presents the results of experiments performed by the author on a short vortex chamber and on Sprenger heat tubes. The maximum possible extent of heating and cooling are estimated. It is shown that conventional theories, previously used to explain the Ranque and Hartmann-Sprenger effects, fundamentally cannot explain the results obtained.

1. Introduction

Much research has been published on the effect of sound on thermal processes in gases (on heating [1], on drying [2] and on cooling [3]). The temporary lack of an adequate understanding of the physical basis of these processes has resulted in them being attributed to a sequence of physical paradoxes. The Ranque [4] and Hartmann-Sprenger [5,6] temperature effects must be attributed to the same class of phenomena. Different concepts have been proposed to explain these effects. Adiabatic pressure reduction during the acceleration of the jets in the nozzles has been considered a source of gas cooling in devices utilizing these effects. The heating process was explained by the viscous friction of gas jets or (in the Hartmann-Sprenger effect) by shock waves. The micro-refrigeration processes (or interaction of vortexes) were also considered. Hot and cold micro-volumes obtained from these processes were then separated according to this concept. However until now there were no theories that adequately described thermal processes occurring in devices utilizing these effects [7,8].

More recently the temperature separation phenomenon in a short vortex chamber [9–11] was discovered. In this device compressed air was pumped at room temperature from the side peripheral wall toward the centre of the vortex chamber. These experiments revealed that the highest temperature of the periphery was 465 °C and the lowest temperature of the central zone was −45 °C. These results cannot be explained on the basis of the concepts outlined above.

The temperature separation modes in all of the above devices are always accompanied by a loud noise. H. Sprenger [6], M. Goldshtik [12], and M. Kurosaka [13] have all emphasized that sound affects the temperature separation process inside vortex tubes. Moreover, despite the fact that the gas flow conditions in the vortex tubes and in the Hartmann sound generator are radically different, Sprenger suggested [6] that the thermal effects in both devices have the same physical nature. Based on the work described in this paper (the analysis of temperature effects in the devices described above) it is concluded that Sprenger's assumption is correct. How-

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ever his assertion that the rotation of the gas in a vortex tube is not necessary is not supported. Instead it is found that rotation is necessary to create a pressure gradient.

In Refs. [9–11] the concept of Pressure Gradient Elastic Waves (PGEW) was been proposed and demonstrated. A PGEW is a special kind of elastic wave arising in compressible fluids (gases) with a pressure gradient, in the presence of initial density fluctuations. The most important property of PGEWs is that they transfer energy from a region of low pressure to a region of high pressure. This heat transfer is not dependent on the temperature gradient.

The concept of PGEWs is new and unexpected and has yet to be accepted and verified by the scientific community at large.

Nevertheless, the results of experiments, which cannot be explained on the basis of existing conventional theories, confirm the concept of PGEWs.

2. Pressure Gradient Elastic Wave

2.1. Fundamentals

This section briefly describes the concept of PGEWs. In doing so it utilizes the following four broadly accepted fundamentals:

- *Any effect on a gas, leading to appearance of a pressure gradient, can be modeled by the field of volume forces.*
- *A zone of density fluctuation in a gas can be represented as a micro-volume on whose boundaries pressure forces act.*
- *Pressure forces are "rapidly acting" forces having the rate of change faster than the sound velocity.*
- *Any disturbance associated with the gas density fluctuations generates an elastic wave (the Huygens' Principle for gases).*

Consider a rapid density fluctuation arising in a gas in the presence of a pressure gradient. The density of a gas changes from $\rho_s(r)$ to $\rho_s(r) \pm \Delta\rho$ *where* $\pm\Delta\rho$ is the amplitude of the fluctuations. Considering the balance of forces on the boundaries of a micro volume (the area fluctuations), it is seen that the pressure gradient creates a resultant force acting on this area of fluctuation. The expression for the acceleration $\boldsymbol{u}(r)$, which determines the magnitude of additional force acting on the area of initial density fluctuation, is given in Ref. [10].

$$\boldsymbol{u}(r) = \boldsymbol{u_f}(r)\frac{\Delta\rho}{\rho_s(r) + \Delta\rho}$$

where $\boldsymbol{u_f}\,(r)$ is the acceleration, which characterizes the volume forces (for example, for the rotation with constant angular velocity ω, $\boldsymbol{u_f}(r) = \omega^2 r$). The greater the value of the pressure gradient (defined by the acceleration $\boldsymbol{u_f}\,(r)$), and the greater the amplitude $\Delta\rho$ of the initial density fluctuation, the greater is the magnitude of this resultant force acting on the area of fluctuation. If the value of $\Delta\rho$ is positive (compression) then the force acts in the direction of increasing pressure and further compresses the zone of initial compression. If $\Delta\rho$ is negative (rarefaction) then the force acts in the direction of decreasing pressure and reduces the pressure generated by the field further extending the zone of initial rarefaction. The pressure forces are "rapidly acting" forces. The initial fluctuation develops with the speed of sound. During this process the rapidly acting pressure forces act on the zone of fluctuation, creating a secondary density disturbance.

In accordance with Huygens' Principle (as mentioned above) the secondary density disturbance in the zones of initial fluctuation must create a secondary elastic wave. This wave is described by the wave equation and propagates with the speed of sound. The principle of wave superposition makes it possible to consider this wave separately. In addition to the above, unique properties are revealed. This allows us to highlight this secondary wave in a *separate kind of elastic wave in gases* – the **Pressure Gradient Elastic Wave**.

As can be seen from the above arguments the existence of PGEWs follows naturally from established physical principles and does not require additional evidence. However, in the recent paper [14] the propagation of sound inside a gas centrifuge is modelled. It is concluded that the elastic waves in a gas having a pressure gradient exhibit unique characteristics, dramatically different from the properties of sound waves under normal conditions. This article can serve as a theoretical confirmation.

2.2. Properties of Pressure Gradient Elastic Wave

The PGEW properties listed below arise from the expressions published in articles [9,10] and are based on the two necessary conditions: the existence of initial density fluctuations and the existence of a pressure gradient.

- Regardless of the direction in which the initial sound wave propagates, the PGEW is always directed along the vector of pressure gradient.
- The compression front and rarefaction front of PGEWs propagate in opposite directions: the compression front propagates to the direction of pressure increasing and the rarefaction front to the direction of pressure decreasing. The compression front carries the real heat and the rarefaction front carries the real cold.
- In a limited volume, PGEWs cannot be reflected and move in the opposite direction when it reaches the wall due to the waves interference. For the same reason, the PGEW cannot pass through the zone of the extremum of the pressure gradient (for example, through the centre of rotation) and is dissipated in this region.
- The PGEW cools the wall (or region) positioned in the low pressure zone and heats the wall positioned in the high pressure zone.

The feeding of heat transfer agents to the respective zones could enable heat transfer, which is independent of the temperature gradient. That is, it could potentially enable the development of a new type of heat pump.

3. The results of the experiments (a critical review)

In this section conventional explanations for the Ranque and Hartmann-Sprenger temperature effects are discussed.

The experimental installations used were described in detail, along with the characteristics of sensors and their accuracy in Refs. [9,10].

3.1. The thermodynamic processes

3.1.1. Micro-cooling cycles

Micro-cooling cycles have been proposed as the source of heating and cooling in vortex tubes (the Ranque effect). Hot and cold micro-volumes are formed as a result of various processes inside vortex layer and then the micro-volumes are separated.

The temperature separation phenomenon, discovered and investigated in short vortex chamber [9,10], disproves this concept. Fig. 1 shows schematically the modified (simplified) vortex chamber. This simplified vortex chamber differs from the full installation in that outlet header has been removed. Air enters to the chamber tangentially through the nozzles mounted on the cylindrical side wall 2.