Self-Organization and thermal Energy Transport in Transitional Thermal Plasma Plume

Ludek Krejci¹, Vladimir Dolinek¹, Pavel Sopuch¹, Václav Níkula², Jan Hlina²
¹Institute of Thermomechanics AS CR, Dolejškova 5, 182 00 Praha 8, Czech Republic
²Institute of Electrotechnical Engineering AS CR, Dolejškova 5, 182 00 Praha 8, Czech Rep.

Abstract

In the paper we want to point that understanding the nature of self-organizing phenomena we may gain a more penetrating insight into the complex events passing in the thermal plasma plumes in the course of their transition to turbulence. We will demonstrate that relatively simple experiments may reveal the role of the self-organization in the evolution of the plume transition process as well as in the transport of heat taking place there at the same time.

1. Introduction

Thermal energy needed for the realization of many prospective high temperature technologies is frequently supplied from transitional – neither laminar nor turbulent – thermal plasma plumes. And the most important events responsible for efficient plume energy utilization are complex thermal and dynamic phenomena taking place in the plume initial – core – region. When it comes to taking advantage of them we must have a thorough comprehension of the mechanism controlling them unconditionally. Our attention must be drawn to core shear layer vortex system instability, playing the crucial role in the onset of the transition process and to the plasma column oscillations induced by them, first of all [1], [2]. The correlations between the spectral signatures of these dynamic phenomena and the curious core heat transport events, which appear in the course of the next process stages, allow to distinguish two scenarios in further process evolution [3], [4]. In the first case the coupling of the plasma column swinging with a mode of the arc chamber cavity acoustical oscillations results in the plume self-sustained – “stabilized” – resonant oscillations; the second type of the scenario belongs to unstable, “flapping” plumes.

The type of the process scenario depends evidently [5] on the arc current and arc chamber cavity length values. These facts reflect sensitively and unambiguously appropriate thermodynamic portraits of the plume transition process represented by the core cusp stagnation point heat flux – arc heater exit average enthalpy relationships [3] – [6].

Such a particular relationship offers also a striking insights not only into the nature of the plasma plume transition, but also into the mechanisms controlling the heat and mass transport taking place in the plume core. When a certain transition process is reproduced experimentally, the thermodynamic portraits of these reproductions – reflecting the behavior of differently activated non-linear processes in essence – constitute a remarkable branch system. These branches coincide in a common thermodynamic state and diverge and coincide several times again in the course of the transition process – in the course of the mass flow rate increase, in tangibility. Such a behavior indicates, that the self-organization is the clue event
controlling the thermal plasma plume transition to turbulence, most probably; the thermodynamic states appearing there, where the distinctive process branches coincide represent the “milestones” of such a process course. The presence of self-organization suggests also, that the non-equilibrium thermodynamics must play an important role here.

In the following we want to describe briefly these particulars controlling the evolution of the plasma plume transition process and the transport of heat taking place under such conditions.

2. Experiments and their results

The description of the experimental equipment and the metodics used may be found elsewhere e.g. in [1], thus, we will give only the facts needed for understanding the text. The experiments have been performed in argon plasma plumes generated by a cascaded arc heater. The transition dynamics has been observed under different flow conditions at constant arc currents 120, 150 and 200 A, argon flow rates varied from 10 to 150 l/min. The plasma plumes issued from arc chambers of 24, 44 and 66 mm length through an exit ring anode orifice of 8 mm diameter. The particular thermal effects appeared in the plume core have been reflected by the stagnation point heat flux data measured in the core cusp region at the distance of 15 mm from the arc heater outlet plane as well as by corresponding arc heater exit average enthalpy data. The resulting thermodynamic portraits of the core transition processes in a typical “flapping” as well as in two “resonance stabilized” plumes are presented in Fig. 1 – 2. These strange pictures reveal the behavior of the thermal energy transport processes taking place in the plumes generated by the same arc heater working parameters – by the arc current 150 A and by the argon mass flow rates 10 – 150 l/min In the first case the plume issued from the arc chamber 24 mm length, in the second one form the chamber of 66 mm length. The portraits were obtained in the course of a series of experiments carried out over a period of 6 months. As this takes place, there exists a spread of initial values of the arc heater exit average enthalpy caused by the different conditions of process activation. As the plume transition evolves, the distinct branches of it, leaving these initial conditions coincide in the first and

![Graph showing heat flux to the probe vs. exit average enthalpy for different experiments.](image)

*Figure 1 – Thermodynamic portraits of the plasma plume transition*
subsequently in additional governing thermodynamic states. If we take into account that the measuring and data processing systems present the heat flux data obtained with 4 percent relative error and the arc heater exit average enthalpies obtained with 6 percent relative error, the process governing states are surprisingly well “embedded” in the process portrait. And in the cases of resonance stabilized transition studied – Fig. 2 and Fig. 3 – these process “milestones” mark the apparently wavy courses of distinct process branches. In the case of the “flapping” plume – Fig. 1 – the core experiences only two governing states and in the last – pre-turbulent – stage it seems that the individual branches are already immune from the controlling effect of process self-organization.

Unfortunately, seemingly reasonable phenomenological understanding as well as any mathematical models of the self-organization in a plasma plume do not exist for the time being. However, the process thermodynamic portraits obtained enable one to gather directly important particulars concerning the effect of self-organization on the transport of heat.
through the plume. If we simply “transform” our portraits into the core stagnation point heat flux – plume “net” power at the arc heater exit relationships – Fig. 6, we acquire a new striking meaning of the matter. The relationships obtained for the resonance-stabilized plume suggest, that the core heat flux varies almost directly with the plume power. The course of this relationship is changing abruptly as soon as a new dominant state appears. The emergence of thermodynamic “milestones” in the course of plume core transition simultaneously with the “unusual” thermal effects taking place there indicates at the same time that the redistribution – or separation – of energy dissipated in the plume causes these effects probably. The process evolution is also little affected by the process “activation” conditions. On the other hand, in the case of the “flapping” plume – Fig. 1 – exiting from short arc chambers – the evolution of the core heat transport in the third – pre-turbulent – stage of the plume transition process evolves quite randomly. Figures 1 – 6 give also a direct indication of the reproducibilities of the heat transfer data attained under the conditions of our experiments.

Figure 4 – Transformed thermodynamic portraits of the plasma plume transition

Figure 5 – Transformed thermodynamic portraits of the plasma plume transition

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3. References


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