# Chapter 4
# Numerical and Experimental Study of Abnormal Thermo–Mechanical Effects in Supercritical Fluid

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## ABSTRACT

*At least three regions can be distinguished on the phase diagram where one-phase fluid has abnormal thermo-mechanical properties: (1) the region above the thermodynamic critical point, strictly the supercritical fluid (SCF); (2) the region close to the coexistence curve; and (3) the region where (d2p/dv2) S<0. This chapter is devoted to the experimental and numerical study of abnormal effects in (1) and (3) regions. The calculations are carried out with the use of equations of Navier-Stokes, mass conservation, energy balance, and van der Waals or perfect gas equation of state. Two basic characteristic features of the SCF near the critical point, the accelerated temperature rise in the bulk heated from boundaries (so-called "piston effect") and very slow relaxation of the generated inhomogeneities of thermodynamic parameters are studied. For region (3) the abnormal regimes of propagation of the shock and rarefaction waves after decay of a discontinuity are found.*

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## INTRODUCTION

The development of supercritical engineering demands detailed knowledge on characteristic features of heat transfer near the thermodynamic critical point and the use of this knowledge for developing new methods of control of the processes in SCF-devices, such as devices for chemical extraction and separation processes, and so on. The use of SCF in rocket and space engineering demands to study the anomalous heat transfer in the inhomogeneous SCF in weightlessness and under the action of overloading as well as various gravity conditions for using the perspective SCF engineering for the exploration of the Moon and Mars. In all these cases it is important to know how we can control the heat transfer processes.

The study of heat transfer in the SCF was intensively carried out in the last two decades primarily owing to the space experiments onboard MIR station with ALICE-1/2 instruments (Straub et al., 1995; Garrabos et al., 1998; Garrabos et al., 2001; Garrabos et al., 2007; Zappoli et al., 2015; Deng et al., 2017) and ground-based preparation of the KRIT space experiment on the ISS (Polezhaev et al., 2008; Gorbunov et al., 2018). It was found that when the fluid in a closed domain is heated from the boundaries the temperature of the fluid bulk progressively rises to reach a thermal equilibrium. The fluid near the heated wall expands and the fluid bulk compresses. Thus, the process looks like a compression of the bulk with the near wall fluid and it was named as a "piston effect".

The temperature-density inhomogeneity in SCF in weightlessness appears when the fluid is heated or cooled from the walls, and/or as a result of heating the bulk with a laser beam or chemical reactions. The space experiments show that the temperature-density inhomogeneity is a long-lived structure (Wilkinson et al, 1998). In some cases, it is necessary to level out the temperature-density inhomogeneity and in other cases it should be made stronger (forced temperature-density stratification).

The heat transfer process in a compressible fluid, in particular in SCF fluids, has a wave nature. This means that it is very important to know the characteristic features of propagation of infinitely small, finite amplitude, and shock waves depending on various thermodynamic conditions. In particular when $(d^2p/dv^2)_S>0$ after the distortion of initial pressure and density drop (like as in a shock tube) the abrupt compression shock wave moves in the low-pressure fluid with supersonic speed whereas the smooth rarefaction wave propagates through the high-pressure fluid. However, when $(d^2p/dv^2)_S<0$ the shock rarefaction wave moves through the high-pressure fluid with a supersonic speed whereas the smooth compression wave moves in the low-pressure fluid with the sound velocity (Borisov et al., 1983). It is natural to assume that the behavior of infinitely small and finite amplitude waves also has specific features. The region in the vicinity of the phase equilibrium line is also can be considered as an abnormal region.

So, it can be distinguished at least three abnormal regions where the heat transfer process is complicated by the peculiarities of thermo-mechanical effects associated with abnormal behavior of the waves of thermodynamic parameters.

In this chapter we consider the approaches for the assessment of the location and areas of the abnormal regions and present the results of numerical studies of characteristic features of the heat transfer process and wave behavior within the regions.

## PHASE DIAGRAM AND ABNORMAL REGIONS

Let us consider a fluid whose equation of state has the form: