PASSIVE COOLING SYSTEMS

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1 Introduction

Passive Cooling Systems (PCS') are engineering solutions to perform the function of heat transfer using the temperature difference between hot and cold sources to generate the driving force. They are, therefore, autonomous systems, independent of external energy sources. Most of the designs consists of heat exchangers connected by a hydraulic circuit. Because they don't need active components to operate, PCS' have the advantages of lower costs and higher reliability. Nowadays, PCS' find large applicability in cooling functions of electronic components and in the nuclear industry. Indeed, the high reliability make these systems particularly relevant to nuclear installations, especially after the events of Fukushima[1]

PCS' can be classified as single-phase and two-phase systems. There is a third class which operate at very high temperatures and pressures: the supercritical systems, which are single-phase with characteristics of two-phase systems. Many fossil fuel fired power plants use supercritical water because of the high efficiency of the thermal cycle. While conventional cycles

[1]Nuclear accident caused by a strong seismic event succeeded by a tsunami in the east coast of Japan.

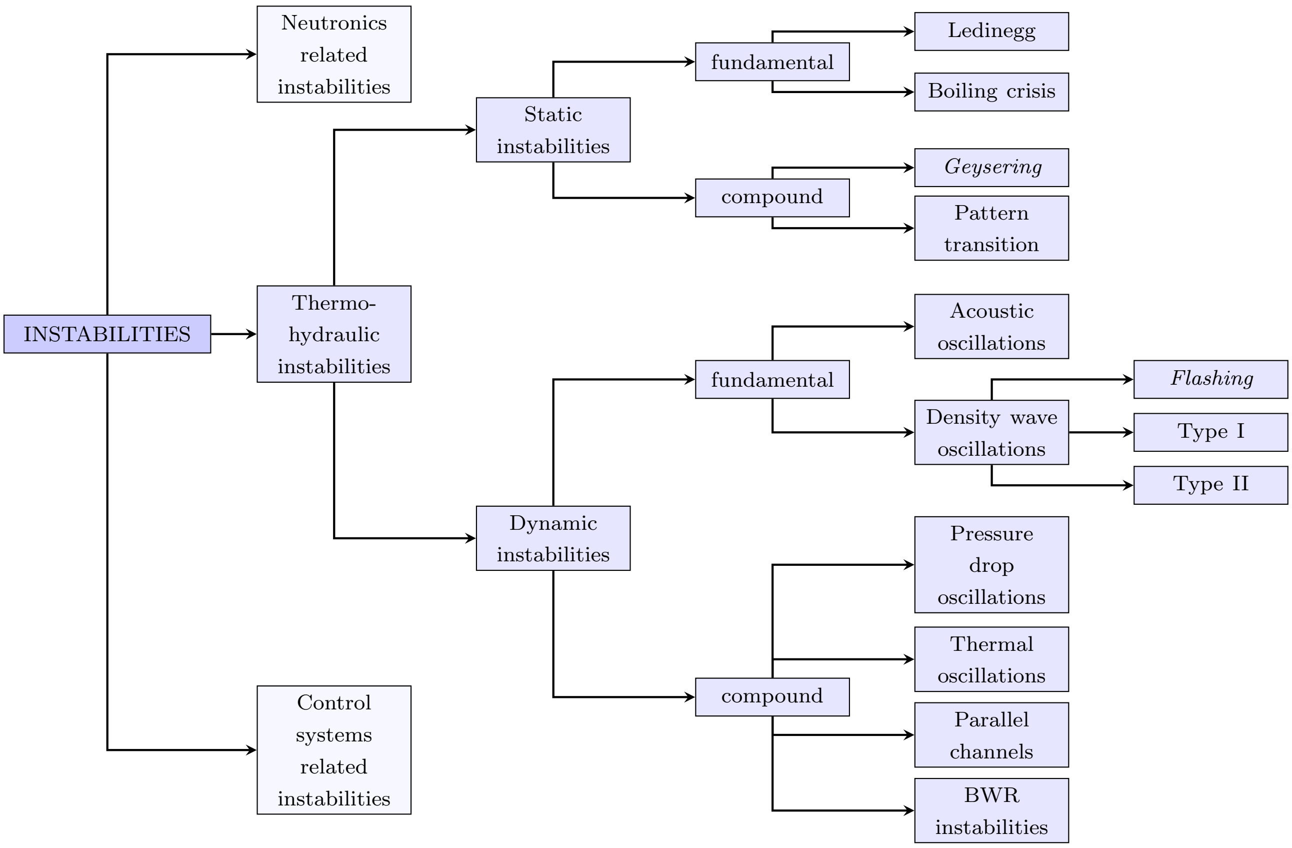

Figure 1: Instability types according to Prasad et al. [3].

may have efficiencies up to 36%, supercritical cycles may provide up to 50% efficiency [4]. Additionally, the design of passive systems with supercritical fluids is favored by the high density gradients close to pseudo-critical points[2]. One of the design of Generation IV nuclear reactors[3] consists of a reactor cooled by supercritical water, possibly in a passive system.

Nevertheless, independent of the type, all PCS' have the disadvantage of being subjected to instabilities, which may lead to inadmissible levels of vibrations and generate high temperature spots in the circuit. Although two-phase systems are much more susceptible to instabilities, there are conditions in which single-phase systems can be unstable.

2 Stability in a PCS

The interplay between buoyancy forces and friction drag after a perturbation may generate increasing oscillations in the system's transient properties. In this case, the PCS is unstable and the instability is a dynamic type one. In fact, instabilities of cooling circuits can be of many different types. Boure et al. [1] is one of the first works to provide a classification of instabilities in two-phase systems (including active systems) and is the basis for the classification used today by many authors for natural circulation loops, both single and two-phase. Their work presents 10 types of instabilities, divided into two main classes: static and dynamic instabilities. Prasad et al. [3] identified the types studied by Boure et al. [1] as thermo-hydraulic instabilities, and added two other groups aside this: the instabilities associated to control systems and the ones associated to neutron kinetics (see fig. 1).

2.1 Stability in a single-phase PCS

In a work published on 1975, Creveling et al. [2] estate that, in previous works, instabilities in single-phase natural circulation loops were only reported for systems operating at conditions close to the pseudo-critical point. They mention, however, analytical results published between 1966 and 1967 which concluded that there are conditions under which subcritical single-phase systems present instabilities. Motivated by this evidence, Creveling et al. [2] were the first work to show experimental results with unstable behavior in a conventional (subcritical) single-phase natural circulation loop. Today there is a wide knowledge about instabilities in single-phase systems. For example, Vijayan et al. [5] estate that stability in such systems depend on the

- Grashof and Stanton numbers[4];
- flow regime;
- heater and cooler orientation;
- length scales of the loop (height, total length, heater and cooler lengths etc.).

There are many experimental and numerical results available today which reproduce instabilities, both static and dynamic, in several geometries of conventional single-phase natural circulation loops. Natural convection flows without phase change in closed circuits occur in many types of nuclear installations, like in most of pressurized reactors in case of loss of reactor coolant pumps, and it is also the type of flow during start up of boiling water reactors.

References

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[2] For each isobaric curve above the thermodynamic critical pressure, there is a supercritical temperature which defines a pseudo-critical point in this isobaric at which the specific heat at constant pressure exhibits a maximum value.

[3] www.gen-4.org

[4] These non-dimensional numbers are presented in a modified form by Vijayan et al. [5]