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CSP plant thermal-hydraulic simulation

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Abstract

In the frame of the development of new solar plants and their innovative components, our research activities focus on theoretical elaborations and simulation to support basic design and assistance to manufacturing. The aim is to describe the use of Relap5 code [1] for analyzing the thermal-hydraulic behavior of a CSP Plant based on parabolic through collectors. Here a fluid dynamic simulation of the Test Plant, situated at Casaccia Research Center, will be evaluated.
For the first simulation, the filling and draining phase of the circuit has been considered. It has been simulated a time period corresponding to the plant starting with the switch on of the pump, the filling of the circuit, a steady state condition and the pump switching off until the complete draining of the circuit. This studies have been performed in different collectors configurations and different logics of the operation valves in order to define the better system control and the better operating procedure.

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Keywords: CSP Plant; simulation; Relap5 code; parabolic trhough; solar collector

1. Introduction

The present work consists in a fluid dynamic simulation of the PCS Test Plant modified with the introduction of a new collector. This work has been developed inside the MATS (Multipurpose Applications by Thermodynamic Solar) Project financed by the 7th Framework Program [4]. The project aims at promoting the exploitation of concentrated solar energy through small and middle scale facilities, suitable to fulfill local requirements of power and heat, and easily to back-up with the renewable fuels locally already available or that can be expressly produced.

More in detail, the MATS project is focused on the innovative CSP technology developed by ENEA as an improvement of its Solar Thermodynamic technology based on molten salts as heat transfer fluid.

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2. Applied methodology

For simulating the thermal-hydraulic behavior of the CSP Plant both in steady state and transient conditions, the RELAP5 (Reactor Loss of coolant Analysis Program) code has been used. The RELAP5 code is based on non-homogeneous and non-equilibrium model for the two-phase systems that is solved by a fast, partially implicit numerical scheme to permit economical calculations of system transients [1]. In order to fit it for a different fluid from light and heavy water, a specific subroutine of RELAP5 code has been modified and thermo-physical property tables have been developed for molten salt mixture and have been inserted in the code. After the code modification, a comprehensive assessment and validation of the new fluid property tables have been carried out and it has been based on experimental data recorded on the PCS facility electric heater [2].

In Fig. 1 it is represented the PCS scheme with a loop of 200 m consisting in the new solar collector (100 m), that will be installed in the MATS solar plant, collector A and the old collectors B and C (50 m each).

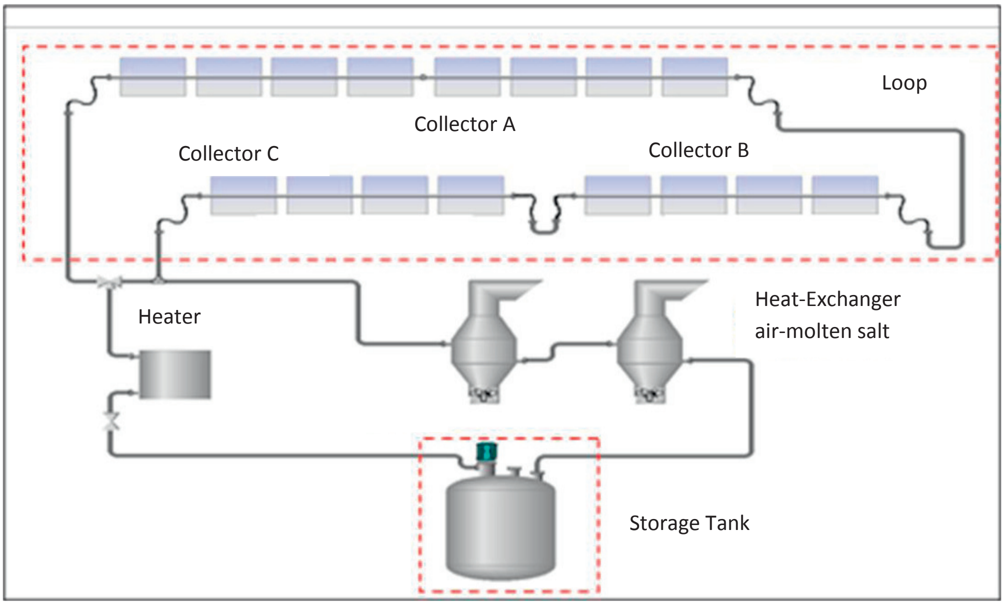


Fig. 1. PCS Plant Scheme (200m loop).

2.1. Modelling

The Relap5 code is a mono-dimensional code based on some particular elements used to simulate the thermo-fluid-dynamic behavior of the hydraulic circuit.

The first step of the simulation is the nodalization of the system, defining all the hydraulic characteristics of the circuit such as pipe's geometrical data, elevations, concentrated and distributed losses coefficients and so on. In the following list there are the elements used in the nodalization:

- Pipe: used for those portions of the system without branches;
- Branch: used to model interconnected piping networks. The component has been used to fix more than one input condition for a pipe, in fact it collects more input and has only one output;
- Time dependent volume: connects two different volume systems and can be used when mass flow or velocity of fluid is known and fixes the temperature and pressure conditions;
- Valve: used to regulate flow by varying the flow area at a specific location in a flow stream
- Pump: provides information for the hydrodynamic and pump-fluid interaction models;
- Junction: used to connect other components such as two pipes.

The Fig. 2 illustrates the nodalization scheme of the modified PCS plant. In detail it is possible to note that the hydraulic circuit has been simulated with pipe components each including more volumes and the storage tank has been simulated with two parallel pipes with some transversal junctions (Fig. 3).

About the pump model, the homologous curves have been inserted in the input file. These curves are related at the use with molten salt and have been calculated from the characteristic curves of the pump already installed in the original PCS Plant. The homologous curves are calculated only for the first quadrant, the only available data, for the other three quadrants have been taken the standard curves. The Fig. 4 represents the homologous curves of the pump used in the simulation.

The operating point of the pump has the sequent value (Table 1):

Table 1. An example of a table.

Mass Flow (kg/s)	Head H (bar)	Velocity (rad/s)	Torque C (Nm)	Density (kg/m^3)
5.9	4.518	204.1	20.578	1772

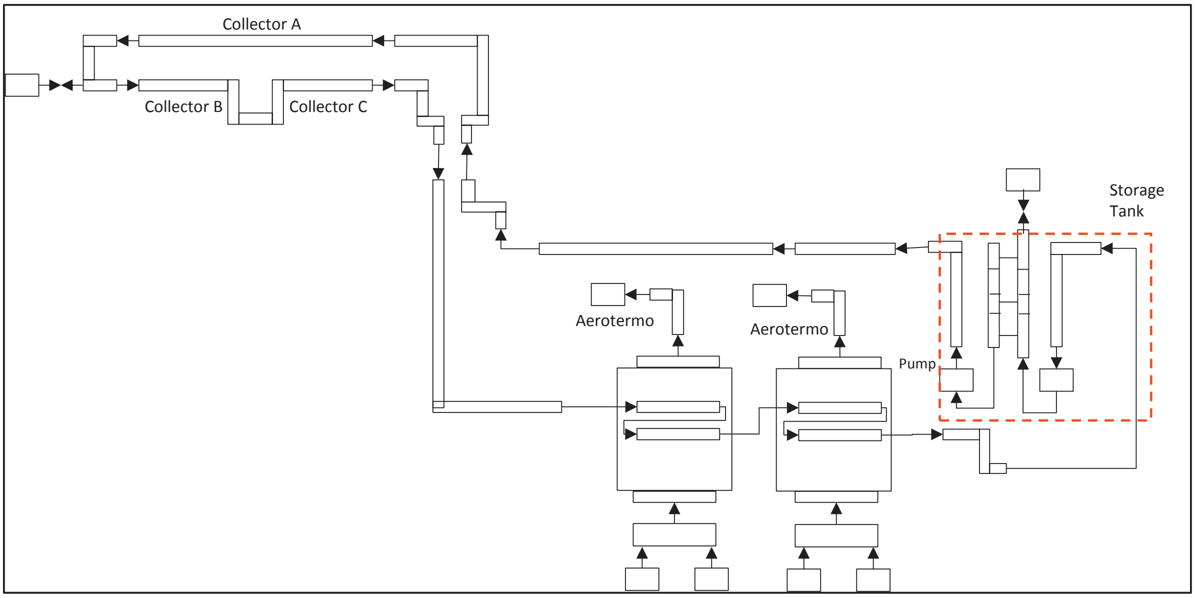


Fig. 2 Nodalization of the new PCS Plant

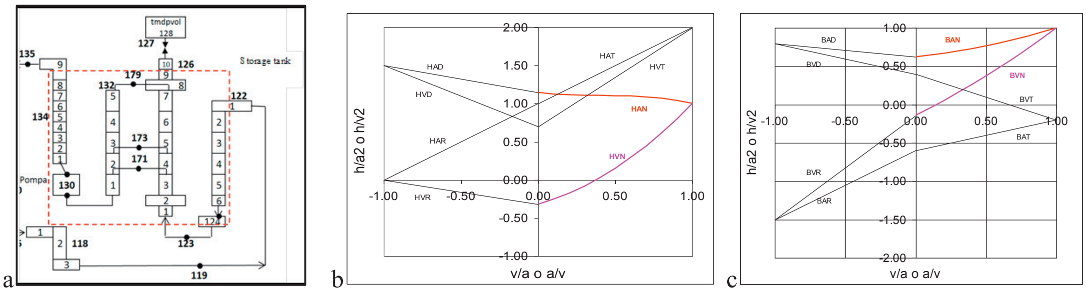


Fig. 3 a)Nodalization of the new storage tank b)Pump homologous head and c) torque curves

3. Hidrodynamic simulation

For the simulation, the filling and draining phase of the circuit has been considered. It has been simulated a time period corresponding to the plant starting with the switch on of the pump, the filling of the circuit, a steady state condition and the pump switching off until the complete draining of the circuit.

In this first phase of the simulation work it has been considered only the fluid dynamics of the plant without the thermal exchange.

At the beginning of the simulation all the molten salt is in the storage tank with a temperature of 320°C and a level of 1.95 m, all the remaining circuit is full of air at atmospheric pressure and temperature equal to 270°C. After 100 s the pump switch on and in 10 s the velocity is equal to 199 rad/s (1900 rpm), in this way the molten salt fills the entire circuit with a mass flow rate at the steady state condition equal to 6.43 kg/s (Fig. 4).

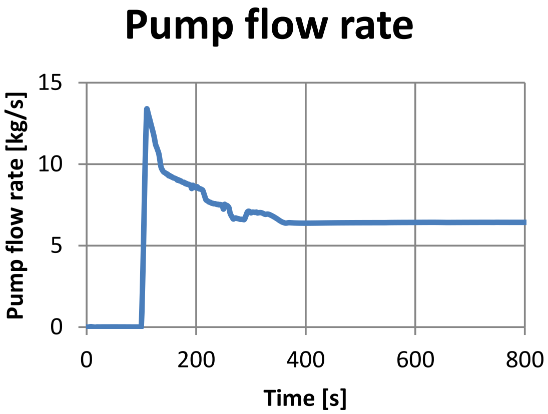


Fig. 4 Pump mass flow rate

After 5000 s the pump switch off and in 10 s the velocity is equal to 0 rad/s; in this last phase until the end of simulation the entire circuit is emptied and the salt accumulates in the storage tank.

The circuit draining simulation is important in order to check if the design of the piping layout is done correctly and any salt remains somewhere in the circuit, in fact in this case the salt could freeze without the use of any auxiliary electric heating system.

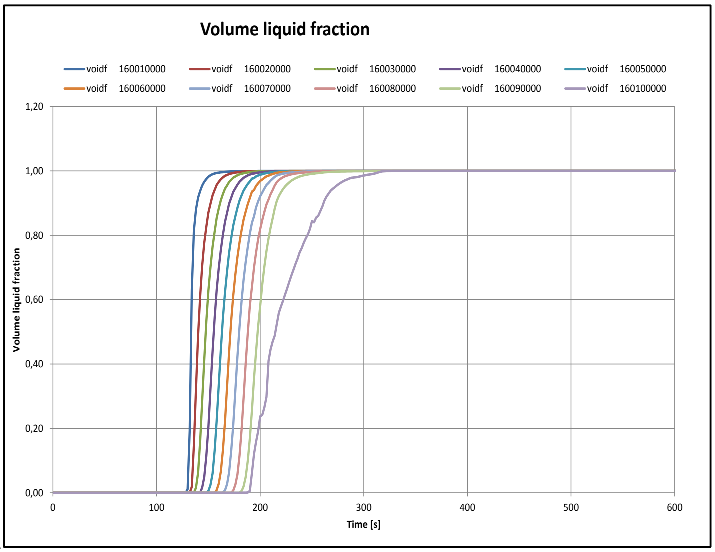
This simulation is also important for the definition of the operating procedures during the draining phase; in order to analyze these procedures two different positions of the collectors during this operation have been considered. In the first one all the collectors are in 90° degree position, they look the sky, in the second case the collector A is at 0°, the collector B is at 15° and the collector C is at 0° in respect to the horizontal position.

3.1. First configuration

In this first case all the collectors are in the upper position (90° in respect to the horizontal position), so they are higher than the vent valve situated between the collectors A and B.

Initially the circuit is empty of salt, after 100 s the molten salt starts to filling the circuit. The collector A is completed filled (void liquid fraction equal to 1), at about 300 s while the last collector, C, at about 500 s (Fig. 5, Fig. 6).

a



b

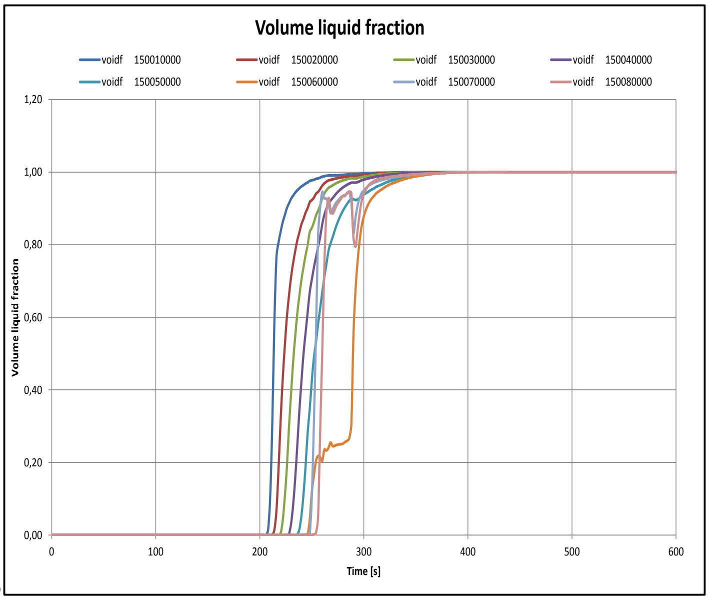


Fig. 5 Filling phase of the collector a) A and b) B

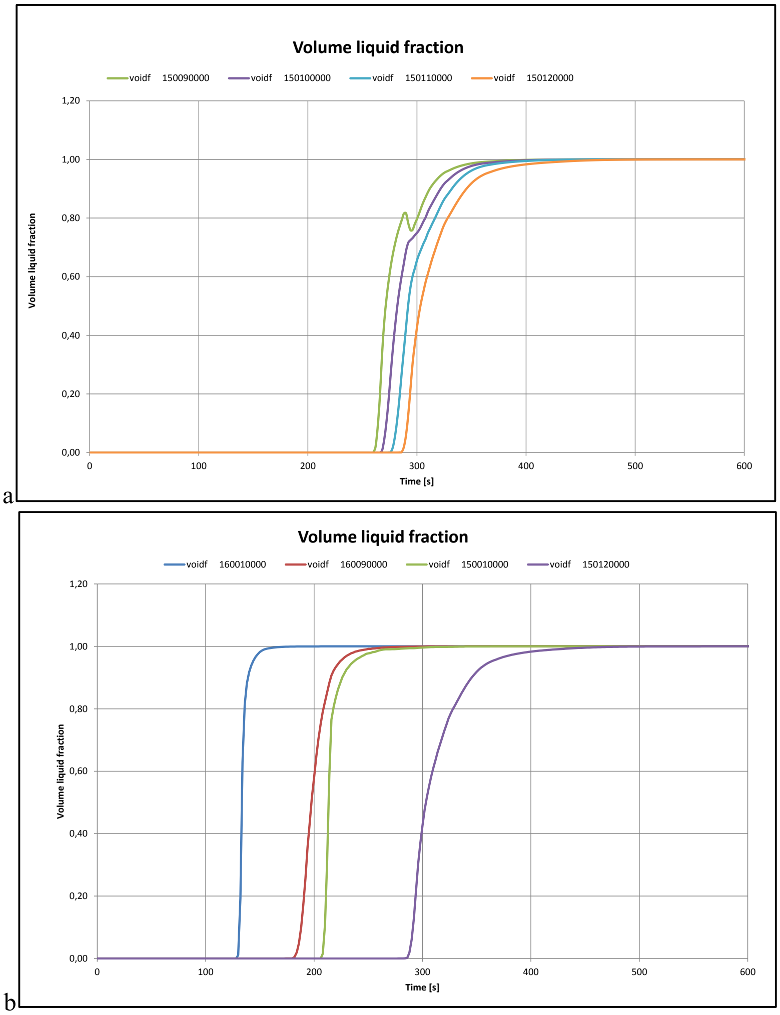


Fig. 6 a) Filling phase of the collector C b) Comparison between the filling phase of the collectors in series

In the Fig. 6b it is possible to note the same phase in the two solar collectors arranged in series (A and B+C), so when the first, A, is full the second starts to fill; also the second collector requires more time to completely fill compared to the first because of the higher load losses.

After a steady state period the pump is switched off, at 5000 s. At this moment in order to simply the draining of molten salt into the storage tank, it is necessary to open the two vent valves (valve 129 and valve 127), on the piping between collector A and B and on the tank, in this way air enters into the piping and permits the salt draining.

The collector A is drained in about 750 s (Fig. 7a) almost the same time for the old collectors B and C (Fig. 7b and Fig. 8a). The different behavior depend on the pressure drop in the piping downstream.

The molten salt remains in the pipe (corresponding to the siphon) between the collectors B and C and the element just after the siphon (1500800) starts to emptying with about 500s of delay.

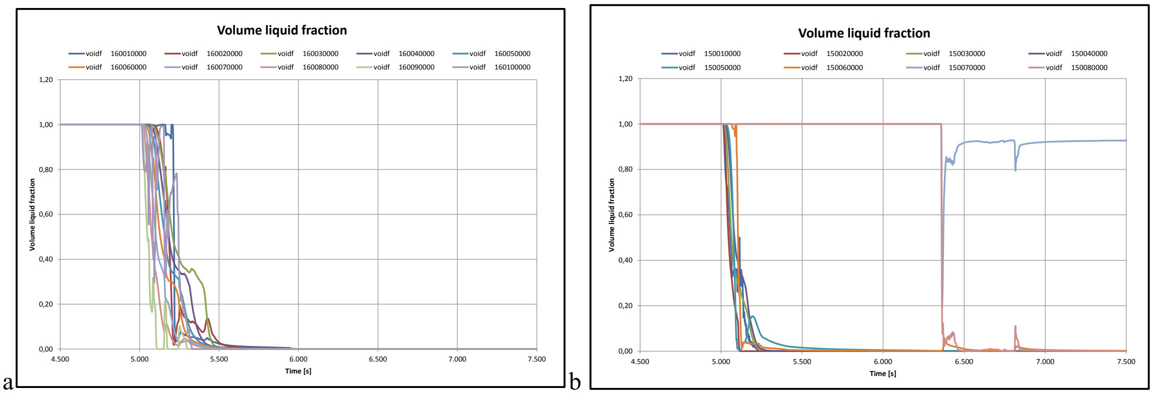


Fig. 7 Draining phase in the collector a) A and b) B

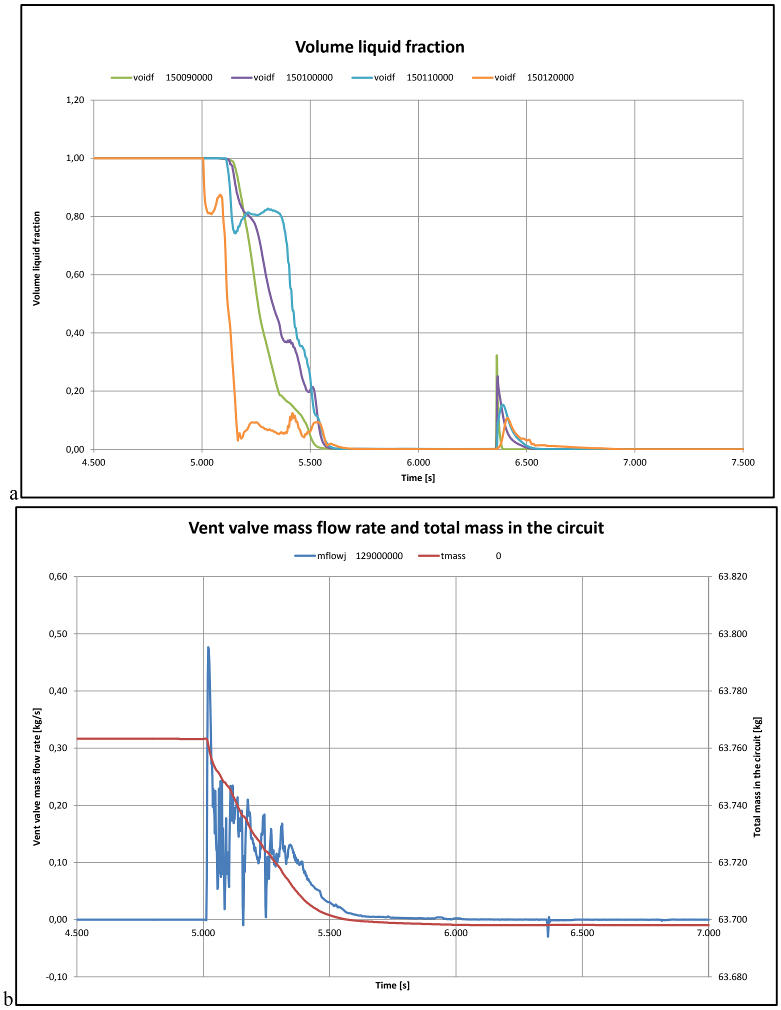


Fig. 8 a)Draining phase in the collector C b) Vent valve mass flow rate and total mass in the circuit

Since the air intake is opened the molten salt starts to coming out from the same valve (Fig. 8b), and the total mass of the circuit decreases of about 100 kg that correspond at the molten salt mass in the flex hoses and piping between the collectors A and B.

3.2. Second configuration

In the second configuration the collector A is positioned at 0° (horizontal position), instead the collector B is at 15° and the collector C is at 0° like the collector A. In this way the high of the collector is less than the previous configuration and the draining process would be simplified.

The transient simulation is the same of the first configuration so it is possible to compare the result during the draining phase.

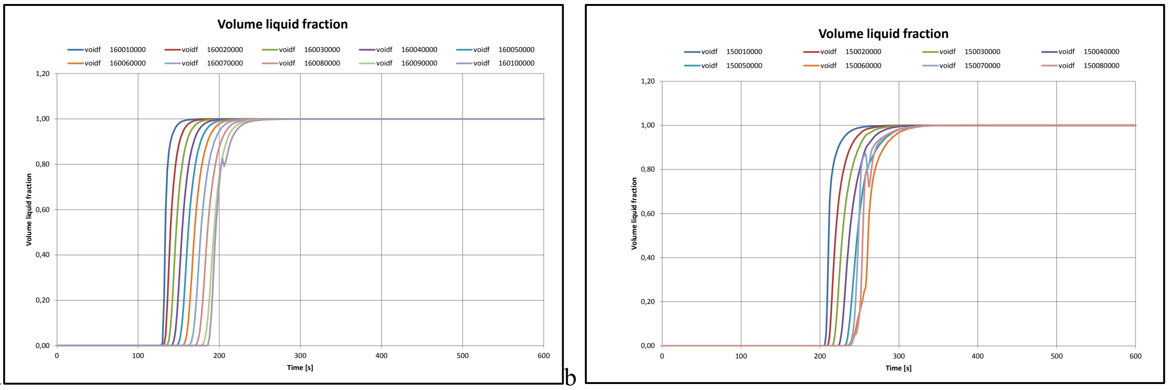
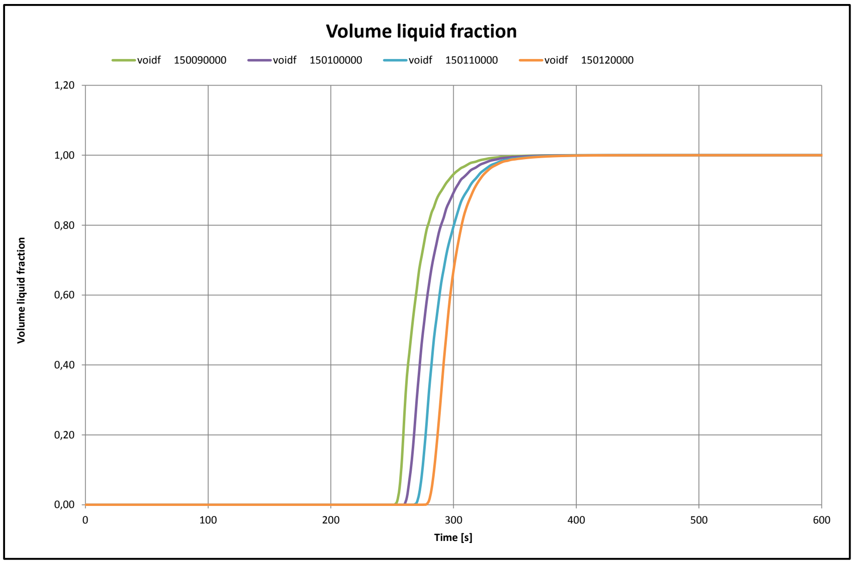
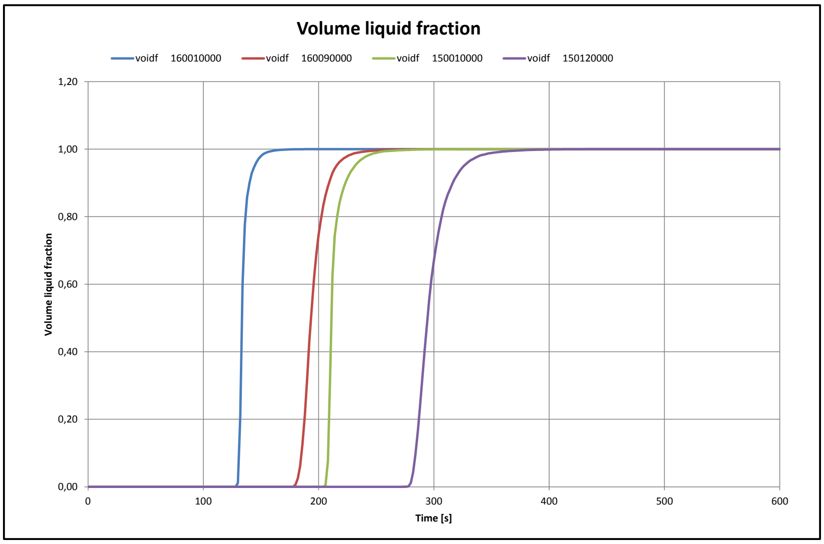
a b


Fig. 9 Filling phase of the collector a) A and b) B



a



b

Fig. 10 a) Filling phase of the collector C b) Comparison between the filling phase of the collectors in series

Like the previous configuration, the circuit is empty of salts, after 100s the salts start to filling the circuit. The collector A is completely filled at about 280s while the last collector, C, at about 400s earlier than the first case (Fig.9 and Fig. 10).

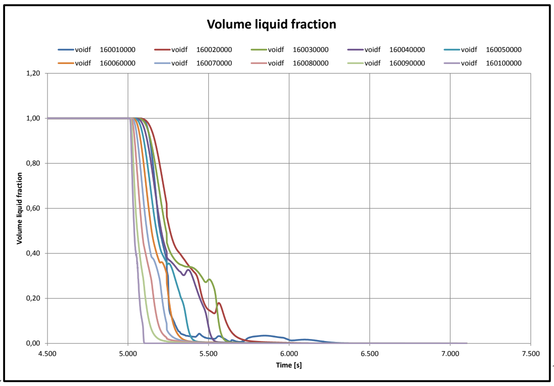
In Fig.10b it is possible to note the same phase in the two solar collectors arranged in series (A and B+C) and comparing with the pervious case, all the circuit fills in 100s less.

The simulation continues like the previous configuration, so at t=5000s the pump is switched off and the two vent valves are opened.

The collector A is drained in about 1250s (Fig.11a) instead the collectors B and C are drained in less time (about 250s) (Fig. 11b and Fig.12a).

The molten salts remain in the pipe (corresponding to the siphon) between the collectors B and C and the element just after the siphon (150080000) starts to emptying with about 250s of delay; respect to the first configuration, this second case is more suitable for the management of the draining phase that is a critical phase for the solidification of the molten salts.

a



b

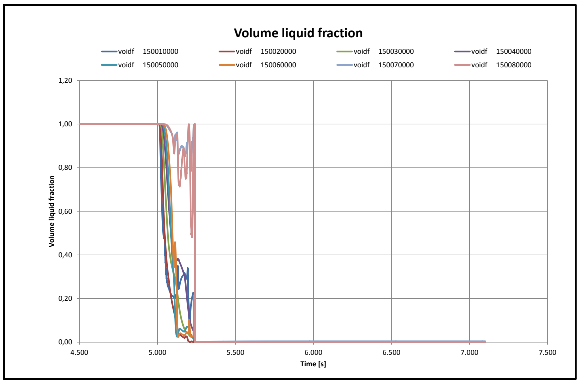


Fig. 11 Draining phase in the collector a) A and b) B

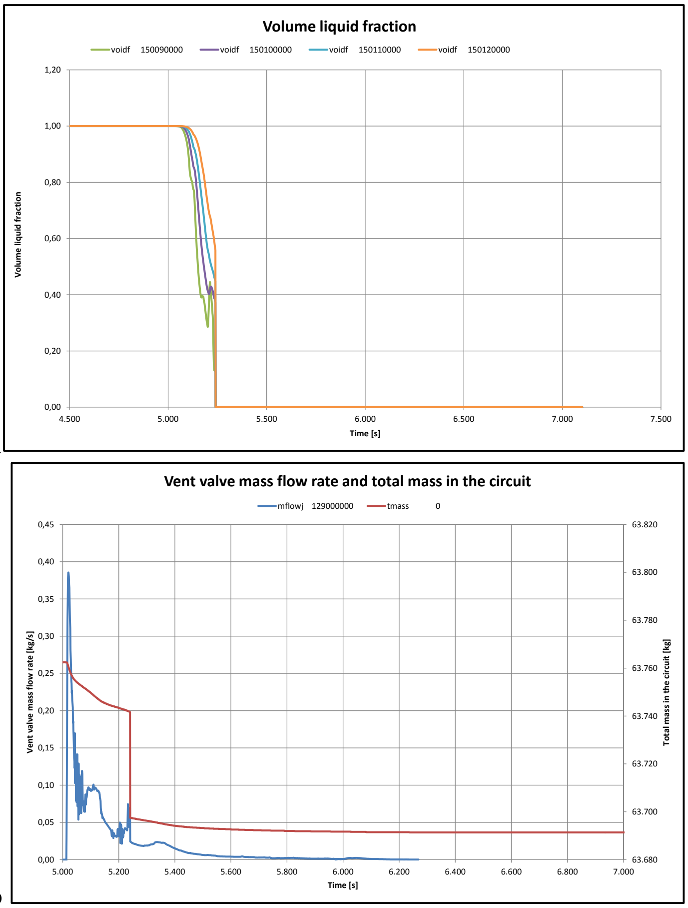


Fig. 12 a)Draining phase in the collector C b) Vent valve mass flow rate and total mass in the circuit

4. Conclusion

In the present work it has been realized a simulation tool using RELAP5 Code in order to simulate the behavior of a CSP Plant present in Research Center of Casaccia within the MATS Project (the MATS Plant doesn't work already).

The tool simulates the hydrodynamic of the plant in order to manage the draining phase that is critical due to the high solidification temperature of the molten salts.

In the future it will be possible to validate the result showed in this paper for what concerns the PCS Plant simulation and furthermore it will be possible to simulate all the daily operation with the solar irradiation in order to analyze the plant in normal operating condition.

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