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Experimental campaign and numerical analyses of thermal storage concrete modules

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ABSTRACT

A three-stage study on the behaviour of storage plants employing concrete with upgraded thermo-mechanical characteristics is here developed. The first stage defines the experimental campaign on a mixing at improved conductivity, via the SolTeCa experimental system, with review of the storage elements geometry, location of thermocouples and cycling procedures. The experimental results, obtained by ENEA *via* a comparison with appropriately performed numerical calculations, are interpreted during the second stage. Finally, a first design of a new equipment for the thermal cycling of storage elements up to 400 °C is proposed, based on *Joule-effect* heating. The numerical results are reported, in order to understand the thermal dynamics as well as the induced thermo-mechanical effects on concrete elements.

1. Introduction

Nowadays the integration of thermal energy storage (TES) systems within concentrated solar power (CSP) plants is considered to be one of the key factors for providing low cost electricity from solar power. Increasing interest has focused on very different solar plant layouts, storage principles, materials used and operating strategies, as reported by e.g. Gil et al. (2010) and Medrano et al. (2010). TES units can be used also for solar control walls or different services in high performance buildings to reduce costs and save energy from fossil fuels (Winter et al., 1991; Kuravi et al., 2013; Tatsidjodoung et al., 2013). Compared to other expensive ceramic materials, concrete has already demonstrated to give suitable and economically feasible TES solutions by sensible heat (Laing et al., 2008, 2011, 2012), properly designed for high temperature (Neville, 1963; Bazant and Kaplan, 1996; Laing et al., 2006; Guo et al., 2010; Giannuzzi et al., 2012; Giannuzzi and Mele, 2012; Giannuzzi et al., 2013; John et al., 2013; Ozger et al., 2013; Skinner et al., 2014; Mazzucco et al., 2014; Salomoni et al., 2014). Designing a concrete module and determining its operating conditions is not an easy task due to the fluid dynamics and heat transfer phenomena involved in the storage process between heat transfer fluid (HTF), piping and storage material (Giannuzzi and Mele, 2012; Giannuzzi et al., 2013). A new experimental campaign to evaluate the performance of concrete storage elements, realized with an appropriate mixing developed by the University of Trento, Italy, has been planned to examine the geometric characteristics of the storage elements and the applied measurements equipment. The experimental data acquired by ENEA have been compared with the results from Finite Element simulations and interpreted in order to understand the limits of applicability for such instruments as well as to evidence possible anomalies in the experimental outcomes; particularly, the coupled pipe-concrete thermo-mechanical response has been evaluated, as well as first durability assessments given. An apparatus for thermal cycling up to 400 °C and above has been additionally designed, so disengaging from the limits imposed by the silicon oil and from some technical difficulties arisen in a previous experimental campaign. A *Joule-effect* heating procedure has been hence adopted, with subsequent cooling via compressed air, easily automatable without any specific care related to service safety.

2. Experimental campaign on a mix with improved conductivity within a circuit with silicon oil

2.1. The SolTeCa experimental system

The experimental plant at ENEA Casaccia (Fig. 1) named *SolTeCa1* is

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Fig. 1. Storage elements of SolTeCa1 experimental plant.

dedicated to study concrete storage, which receives and gives heat through the heat-transfer fluid Alusil TR 50. Heat is provided to the fluid via a circulation thermostat able to maintain a constant delivery temperature and to regulate the fluid velocity at fixed values. Concrete in the discharge phase gives heat to the fluid, previously cooled at adequate temperature. To control the heat exchanges system, the fluid capacity is adjusted through valves and checked via a flowmeter. The system temperatures are surveyed through thermocouples and controlled by the thermostat itself. A centrifugal pump, integrated in the circulation thermostat, guarantees the motion of the fluid.

The plant is characterized by 2 new concrete samples with improved mixing to be tested and a length of 1000 mm to substitute the four existing samples. As reported in the next Section, the new samples have been appropriately instrumented so to produce results comparable with those from the old samples. The heating and cooling system are the same, as well as flowmeter and thermostat. The piping and samples insulation have been improved to further reduce energy losses.

2.2. Definition of experimental sections and data acquisition points

In the first test 4 samples were put in series, as shown in the sketch of Fig. 2, the first and the fourth being instrumented in the middle, whereas at 250 mm and 720 mm from the edges for the new samples (configuration 2, *SolTeCa2*), as if all the four samples of the previous test were instrumented in the middle: in fact, the sections at 250 mm of the new samples geometrically correspond to the middle sections of the first and fourth sample for configuration 1 (*SolTeCa1*), whereas the sections at 750 mm correspond to the middle ones of the second and third sample. Hence the advantage is twofold: to be able to compare temperature values at 250 mm with those in the middle of the first and fourth sample, and to investigate concrete behaviour on the sections at 750 mm. The increased length (1 m) can make the pipe-concrete interaction more critical, due to longitudinal thermal dilations.

2.3. Temperature range and test duration

On the basis of the experience developed in the first experimental campaign *SolTeCa1* and taking into account the physical characteristics of the new adopted mixing produced by the University of Trento, the temperatures delivered in Test-1 (degassing) and Test-2 (charge and discharge) are depicted in Fig. 3. The temperature increase in the degassing test is performed through two steps (80 and 160 °C) so to reduce the risk of concrete damage. For the charge and discharge cycles it has been chosen to vary the oil temperature between 180 and 240 °C, as in *SolTeCa1*, having verified that the silicon oil has not degraded. For further details the reader is referred to (Crescenzi et al., 2013).

3. Analysis and interpretation of the experimental tests

In agreement with ENEA, it has been chosen to numerically simulate the first Test-2 cycle of charge and discharge, being more complex than the degassing one. The test is characterized as follows (Fig. 3):

- first steady state at 180 °C, followed by transient heating in which the oil reaches 240 °C in 26 min, with clockwise circulation within the storage elements

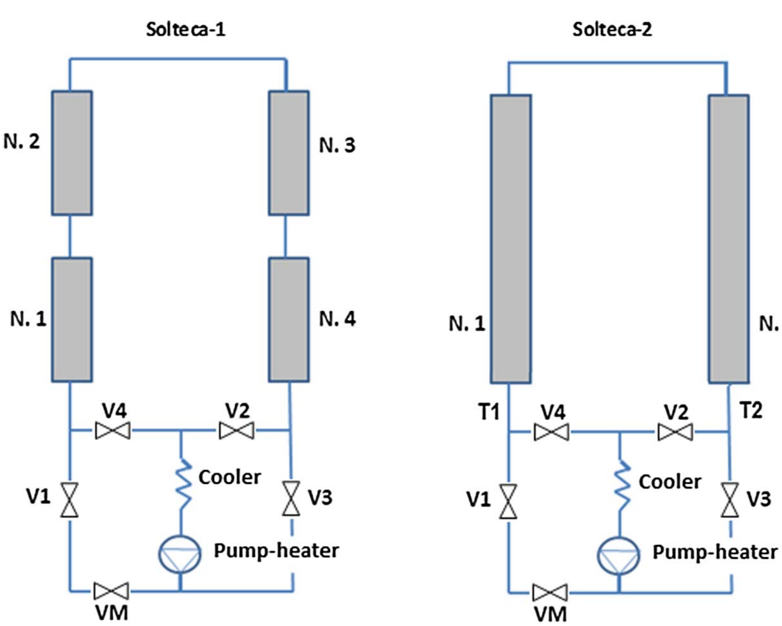

Fig. 2. Sketch of *SolTeCa* plant in configuration 1 and 2.