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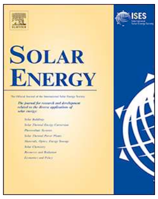

Experimental and dimensional study of the draining process in drainback solar thermal systems

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ABSTRACT

This study aims at analyzing the phenomenon of siphon draining occurring in drainback solar thermal systems. Although several experimental studies have been previously carried out, there is a lack of theoretical work in the literature. Since describing the draining process from a theoretical point of view should include complex phenomena as two-phase flow and stochastic events, a simpler representation is sought through dimensional analysis. The main physical parameters impacting the draining are at first identified with the equations of fluid mechanics before being individually assessed with experiments. The piping diameter, the type of fluid, the piping length, the drained volume of the circuit as well as the singular pressure losses are for this purpose varied throughout the experiments. A methodology for obtaining an empirical equation using dimensionless variables is finally developed, showing that the impact of all the studied parameters on the draining time could be accurately described for piping with an inner diameter of 10 and 16 mm.

1. Introduction

Drainback solar thermal systems are an old technology, with their main feature being the emptying of the heat transfer fluid (HTF) from the solar collector loop when the circulation pump is not in operation. This notably allows the use of water as HTF and prevents potentially damaging freezing or overheating events. An exhaustive presentation of the advantages and drawbacks associated with drainback solar thermal systems (DBS) can be found in Botpaev et al. (2016). One of the main threats related to water operated drainback systems is a faulty draining caused by a wrong system design or installation which might lead to severe frost damages. Some authors suggest the use of antifreeze mixtures to get rid of this issue (Frank et al., 2014; Mugnier et al., 2011). Indeed, half of the DBS proposed on the market are recommended to be operated with antifreeze (Botpaev and Vajen, 2014).

Drainback systems have to be cyclically filled and emptied. Both processes require careful system design and control and a few studies focusing on their specificities are available. Although some numerical works concerning drainback systems exist (Davidson et al., 1993; Gašpar and Michaľčonok, 2016), detailed numerical simulations of the filling and draining phases are not known to the authors. With regards to the filling, several experimental works were carried out to determine the minimal velocity required to achieve a complete filling, i.e. the establishment of a siphon (Kaiser et al., 2013; Kutscher et al., 1984; Mikkelsen, 1988). Botpaev (2017) derived from his investigations empirical correlations describing the minimum velocities required to fill the pipes both for smooth and corrugated piping as a function of the diameter. Additionally, the fluid temperature, the slope of the pipes and the type of fittings were varied and their impact assessed. Concerning the draining phase, despite its importance for the safety of the system, only few studies have so far focused on this process. In an early investigation, Kutscher et al. (1984) carried out experiments to determine the range of pipe diameters with a single open-end which would prevent the draining. The results indicated that pipes with an inner diameter lower than 1.4 cm might retain a standing water column due to the surface tension of water and thus hamper the draining. Nevertheless, this situation only applies to cases where reverse flow, i.e. opposite to circulation, is not possible in the solar collector loop, because of the use of a positive displacement pump for instance. In most drainback systems, siphon draining can occur. In order to initiate the draining, air might be able to penetrate inside the solar collector loop. Botpaev et al. (2016) summarized different technical solutions proposed in the literature for this purpose. An air gap between the end of the flow pipe and the water surface in the drainback tank or water

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Nomenclature

Abbreviations

DBS	drainback solar thermal system
HTF	heat transfer fluid

Variables

A	cross-sectional area normal to the fluid flow (m^2)
d	diameter of the piping (m)
f	friction factor (–)
g	gravitational acceleration (m/s^2)
h	absolute height of the fluid in the circuit (m)
H	maximal falling height of the fluid during siphon draining (m)
h_f	friction loss of the fluid when flowing in a circuit (m)
h_g	falling height of the fluid in siphon draining used for gravitational potential energy (m)
h_L	total head loss of the fluid when flowing in a circuit (m)
h_S	pressure loss of the fluid when flowing through a singularity (m)
k	local pressure loss coefficient of a singularity (–)
K	total local pressure loss coefficient (–)
L	wet length of the piping (m)
L_d	length of the circuit to be drained (m)
L_T	total length of the piping (m)
p	pressure (Pa)
Q	fluid flow rate (m^3/s)
Re	Reynolds number (–)
t	time (s)
t_d	draining duration (s)
v	cross-sectional average fluid velocity (m/s)
V	volume to be drained (m^3)

Greek letters

μ	fluid viscosity (Pa·s)
π	dimensionless variable (–)
ρ	fluid density (kg/m^3)

Indices

exp	experimental

storage, as exemplified in Fig. 1 (left) is a simple way of achieving air entrance. To avoid noises and bubble formation due to falling water during operation, most authors prefer ending the flow pipe immerged below the water surface. In this configuration, air penetration might be enabled with one or several hole(s) drilled in the flow pipe above the water surface. The hole might be closed with a motor valve or a check valve in some configurations. A last set of configurations consists in locating the air inlet at the apex of the solar collector loop. In this case, no siphon is present and the draining occurs as a "two columns draining", part of the fluid emptying through the flow pipe, part through the return pipe.

Beyond technical solutions to fulfil the draining, Botpaev et al. (2015, 2014) experimentally analyzed in their studies the draining process and notably the impact of different pump configurations on its course. Nonetheless, no systematic investigation of the parameters impacting siphon draining as well as no theoretical study was found in the literature. The present work aims at filling this gap. The theoretical background necessary to describe siphon draining is in a first step presented as well as the dimensional analysis method which is later used to model the impact of the relevant physical parameters on the draining time. The different experimental set-ups are then presented and the individual impact of the main considered parameters – piping diameter, type of fluid, piping length, drained volume of the circuit and singular pressure losses – is determined with the experiments. Finally, the methodology for deriving an empirical correlation describing the draining time over the range of the studied parameters is developed using dimensional analysis. The assessment of the draining time might be useful to optimize the control strategy of drainback systems, such as the minimum latency time separating a draining from the next filling, or in order to define the appropriate time step in numerical simulations.

2. Theoretical approach

2.1. Principles of fluid mechanics

The theoretical equations of fluid mechanics describing siphon draining are presented hereafter. On the one hand, the basic siphon draining phenomena of tank draining, shown in Fig. 1 (right), is presented. It can be considered stationary as the cross-sectional area of the tank is supposed to be large enough compared to the tube section. This

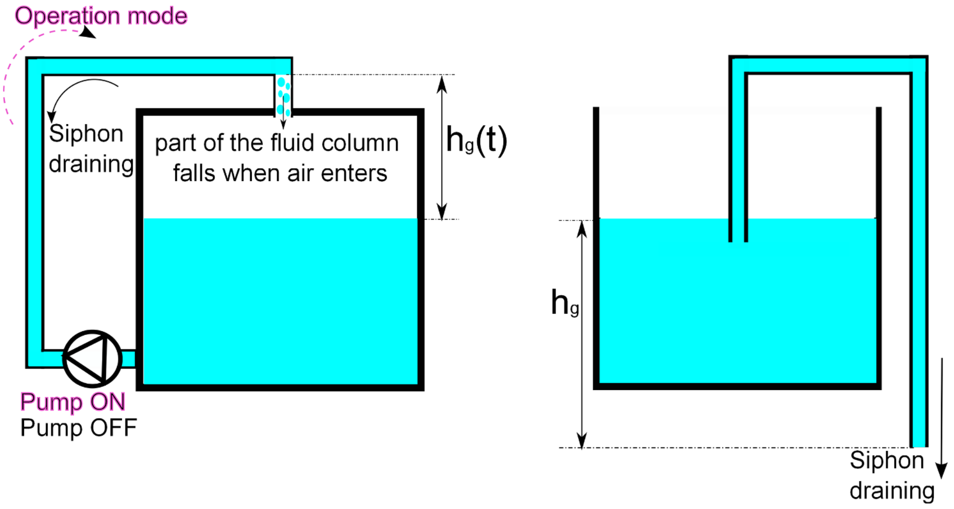

Fig. 1. Simplified schema of the siphon draining phenomena appearing in drainback solar thermal systems (left) or in a typical case of tank draining through siphon (right).