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Experimental Investigation of the Filling and Draining processes of drainback systems (part 3)

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Abstract

An experimental setup was constructed for the investigation of the filling and draining processes of a drainback system. Corrugated stainless steel (CSS) pipes in combination with transparent plastic hydraulic components (collector, heat storage) were applied in this study. CSS pipes are flexible, economically feasible and easy to install. However, sagging and the corrugated shape might be obstacles for a complete filling and proper draining. Therefore, several experiments with different diameters of CSS pipes (DN 12, DN 16, DN 20, DN 32) were performed. The recommended lower threshold of the flow rate for siphon establishment in hydraulics with CSS pipes has been experimentally obtained. Regarding the draining process a typical profile comprising of the emptying time and maximal draining flow rate is summarized. It is showed that the draining proceeds always in the same way (profile, emptying time) for the same hydraulics regardless of the adjusted flow rate during operation. The impact of the pumps on the draining process is also demonstrated. Finally a burst test was conducted, that proved a safe operation even by phase change of the remaining water. Conclusions are presented in details in this paper.

Keywords: *Drainback, drain-back, drain back, filling, siphon*

1. Introduction

Drainback solar thermal systems (DBS) offer failsafe freeze and overheating protections. High reliability of DBS is achieved due to three alternating stages: filling, operation and draining of the solar fluid. Each stage has its own functional purposes and requires a deep understanding of their specific peculiarities. Insignificant mistakes during design and installation might cause a fatal damage of the drainback system. Despite presence of some general recommendations towards optimal design and construction of DBS, there is a lack of publications concerning the filling and draining issues. Therefore an experimental setup was constructed for investigation of the existing knowledge gap. Different experiments were conducted and presented in the previous papers (parts 1, 2). Former both publications focused on experimental investigation of the drainback hydraulics, where smooth pipes were applied. In particular polyvinyl chloride (PVC) pipes were installed due to their transparency, which allowed the observation of the filling and draining processes. It has been shown that a siphon effect is essential for the filling process, which compensates the lift head to be overcome by the pump. The presence of an air vent at the top of the hydraulics modifies the filling and consequently the draining processes. A hydrostatic pressure difference between flow and return side is the driving force and of vital importance for a failsafe draining. In the scope of the present paper further findings on filling and draining behaviors are summarized. It is to emphasize that this paper is clearly understandable without familiarization with previous parts, despite their identical heading. The aim of the present investigation is to evaluate both operation stages (filling and draining) for the DBS with corrugated stainless steel (CSS) pipes. CSS pipes are flexible, economically feasible, compact for transportation and easy to install. However, sagging and the corrugated shape might be obstacles for a complete filling and proper draining. There are drainback systems which can be found on the market with CSS pipes, whereas some manufactures

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recommend restricting the solar piping to conventional copper pipes (Botpaev and Vajen, 2014a).

A schematic representation of both types of pipes is shown in Fig. 1, whereas the main dimensions are summarized in Tab. 1. The wave-shape of the CSS pipe is clearly visible in the longitudinal cross section of this pipe. Concerning other parameters it can be emphasized that the specific weight of CSS pipes is significantly lower, due to at least five times thinner pipe walls. Simultaneously, CSS pipes have a slightly larger top surface area and volume in comparison with copper pipes of identical sizes. It is not less important to notice, that CSS pipes obtain much higher pressure losses than copper pipes, but their cost on the market is slightly cheaper than conventional "red" pipes.

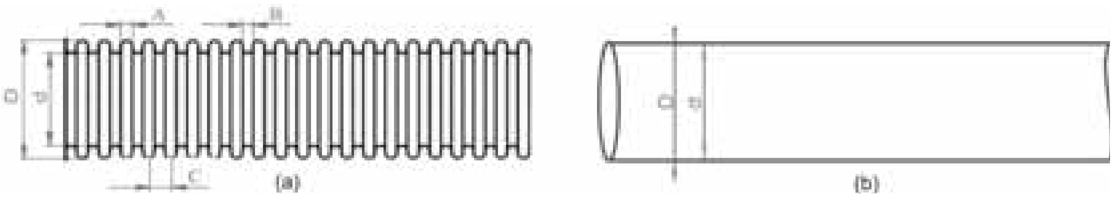

Fig. 1: Profiles of the (a) corrugated stainless steel and (b) copper pipes

Tab. 1: Dimensions of CSS and copper pipes as presented in Fig.1 (FlexxSys 2015; German pipe 2015)

	DN	A	B	C	D	d	Wall thickness	Weight	Top surface area	Volume
		mm	mm	mm	mm	mm	mm	kg/m	m²/m	l/m
CSS pipes	12	2.41	1.71	4.12	16.5	12.6	0.18	0.086	0.072	0.168
	16	2.81	1.81	4.62	21.4	16.5	0.18	0.127	0.099	0.283
	20	2.51	2.31	4.82	26.2	20.5	0.18	0.174	0.138	0.437
	25	3.11	2.21	5.3	31.7	25.6	0.2	0.261	0.155	0.644
	32	3.11	1.72	4.82	41.1	34.6	0.2	0.345	0.228	1.125
Copper pipes	6				8	6	1	0.20	0.025	0.028
	15				18	16	1	0.48	0.057	0.201
	20				22	20	1	0.59	0.069	0.314
	25				28	25	1.5	1.11	0.088	0.491
	32				35	32	1.5	1.41	0.11	0.804

2. Description of experiments

The main advantage of CSS pipes is their flexibility, which allows flexible arrangement of the pipes without additional fittings and bending machine. Their competitive cost and compactness for transportation increased popularity among solar thermal system's plumbers; therefore CSS pipes have become a standard piping solution in solar thermal systems. Drainback systems however, require additional attention during design and installation due to the unique three stage operation modes. The complete hydraulics of the solar collector loop, including piping, should be completely filled after each pump activation; on the other hand the upper part of the hydraulics should be failsafe emptied when the pump is turned off. The latter is of vital importance in summer to avoid possible stagnation in collectors as well as in winter to prevent pipe failure. Can CSS pipes fulfill these specific drainback requirements?

The wave-shape profile of CSS pipes seems to be an obstacle for DBS, as the grooves inside retain water. Additionally these grooves can be a barrier for the air replacement from the hydraulics during the filling. Therefore the filling and draining properties of single samples of CSS and copper pipes were evaluated in a first step. The applied table experimental setup is shown in Fig.2. This setup consists of the following instruments and measuring devices: a "Sartorius" terminal connected to a weighing platform (accuracy ±0.1 g), a "Laserliner" digital spirit level (accuracy ±0.1° at 0° and 90°, and ±0.2° between 1° to 89°) for measurements of the tilt angle and a standard camera (not presented) to record the dynamic of the draining process. Six pipe samples: CSS pipes DN 12, DN 16, DN 20, DN 32 and copper pipes DN 6 and DN 20 of one meter each were tested. Each sample was fixed on a straight metal profile in

Fig. 2: Experimental setup for the filling and draining tests of CSS and copper pipes

order to maintain their linearity avoiding pipe sagging. Samples were weighed, then filled completely with water and drained at different tilt angles: 0° (horizontal), 2°, 5°, 10° and 90° (vertical). These slopes have been chosen based on a previous study summarizing the minimal recommended tilt angles for the piping in DBS (Botpaev and Vajen, 2014a). The pipes were differently filled: in vertical position from the top and from the upper edge of slightly sloped pipes. Afterward the pipes were shaken in order to test if air was still remaining in the tubes. The dynamics of the draining process was analyzed as well, through continuous weighing of the samples. Reduction of the sample's weight was recorded with a standard camera for an hour. Based on the results of this first set of experiments, quantitative draining features of CSS pipes in comparison with copper pipes were elucidated.

In a second stage the CSS pipes were integrated into an existing drainback experimental setup (Fig. 3). CSS pipes were installed in the flow side, whereas transparent PVC pipes were chosen for the return pipes. Two types of drainback systems were considered: one with heat storage as drainback reservoir and one with an additional drainback tank. Some hydraulic components were transparent for visual assesments of the processes. Pure water was colored red and used as the circulating fluid in the loop. The measuring equipment comprised magnetic-inductive flow meters, manometers and an Agilent data acquisition system. The system operated at ambient temperature during all conducted experiments.

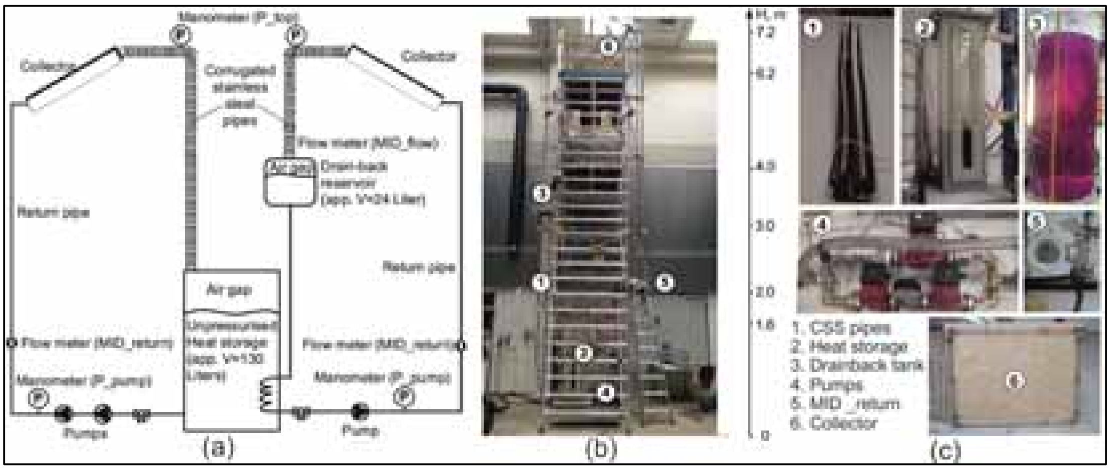

Fig. 3: Hydraulic scheme (a) of the experimental setup (b) and hydraulic components (c)

The experimental setup with a total height of 7.2 m (Fig.3, in the middle) consists of the following components:

- *Solar collector and piping.* Two parallel-connected heat-pipe collectors were hydraulically reproduced with vertical PVC (Ø38mm inside) pipes, which were mounted on a wooden board (1.7 m x 1.4 m). The tilt angle of the collector was 60° during the experiments. The piping to the collector (return side) was constructed with PVC (Ø19 mm inside) pipes, whereas CSS pipes (DN 12, DN 16, DN 20 and DN 32) were applied for the flow side. CSS pipes with a length of approx.

8.2 m were mounted in the flow side as a single piece, connected with fittings to the collector outlet and the heat storage inlet.

- *Heat storage.* Both types of drainback systems were connected to the same heat storage. The unpressurised storage was made from PP-H plastic in a cubic form. The inside dimensions are 320 mm x 320 mm x 1300 mm (LxBxH) with a total volume of about 130 litres. One centimetre of water column in the heat storage corresponds to one litre of water. On the front side of the heat storage a sight glass made of a polycarbonate plate was mounted. The heat storage has five connections - two of them connected to a heat exchanger coil located inside the tank, two others for the direct integration of the solar loop, and the last one is an air vent.
- *Drainback tank.* A drainback tank with a cylindrical form was bonded from a transparent Plexiglas pipe (Ø OD/ID 300/292 mm) and plates with an adhesive. The dimensions of this tank are 300 mm x 650 mm (BXH), which corresponds to a volume of 43 litres.
- *Pumps*. There are two possibilities to force the circulation in the solar loop of the experimental setup: either with one pump or with two pumps connected in series. Connection in series of two identical pumps doubles the head, allowing overcoming of the vertical lift head. A set of valves allows operating the solar loop either with a single pump Grundfos 25-120 or two small Grundfos Solar 15-80 pumps. The latter has two adjustable speed levels: min and max.
- *Measurements acquisition.* The data acquisition system Agilent 34970A was used for monitoring, gathering and evaluation of the measured data. Manometers and flow meters were the main sensors of the experimental setup. Muntwyler (2005) reported that some flow meters can cancel the draining proccesses, therefore magnetic-inductive flow meters (MID) were applied. The chosen MIDs - ABB Process Master 311 (accuracy ±0.4 %) are capable of measuring the flow rate in both directions. An additional advantage of MID flow meters is their ability to determine the presence of air bubbles in the flow. As long as air entrainment occurs in the stream, the sensor delivers fluctuating values of the flow rate. One flow meter was mounted in the return pipe directly above the heat storage at a height of 2 m, the second one in the flow pipe above the drainback tank at 4 m. Two digital manometers from JUMO GmbH & COKG were placed at the highest point of the hydraulics (accuracy ±0.8 kPa) and after the pumps (accuracy ±1.3 kPa). Some simple manometers were also applied for controlling purposes.

Several tests concerning the filling and draining processes were conducted and evaluated. The filling process was performed under different variations of the pump speed. The process of air replacement by water during the filling was analyzed by integrating the flow rate curve over the duration of the filling process. This test was conducted for two different hydraulic configurations, which were completely identical besides the arrangement of the CSS pipes in the flow side. The flow side piping of the first hydraulics was arranged vertically with one horizontal part at the level of the heat storage, whereas the second hydraulics had an additional horizontal part at the level between the collector and the heat storage. The length of the CSS pipes, however, was the same in both hydraulics. The course of the draining process under different operation strategies (high flow or low flow) was also analyzed. The impact of pump configuration (e.g. one pump vs. two), which are responsible for an additional pressure drop during the draining.

Finally some burst tests have been presented in order to estimate the freezing threat in CSS and copper pipes. A conventional freezing unit was applied for these experiments. In Fig. 4 is presented the interior of the

Fig. 4: The inner part of the freezer with the samples inside

mentioned freezer with the samples inside. Cables of installed NiCr-Ni thermoelements and isolating material are also shown; however they were used for other experiments which are beyond the scope of this paper. The pipe samples (CSS and copper) were filled with water and frozen, afterwards simply observed. The filling inclination was varied in accordance with obtained results from the first experiment, in order to find out its impact on the pipes while freezing.

3. Measurements and analyses

The results of the experiments are summarized in the present chapter, in the same order as they were described above. At the beginning the results of the filling and draining tests of the samples are analyzed, afterward the filling and draining processes of the setup are explained and finally the burst test is briefly described.

Experiment 1 – filling and draining properties of the CSS and copper pipe samples. Several simple experiments were performed to determine the filling and draining properties of the CSS in comparison to copper pipes. The samples were fixed on a straight metal profile to keep the linearity avoiding pipe sagging. Then the samples were filled, at the beginning in vertical position from the top, while the bottom was closed with a cap. Once the water level was close to the top, the samples were gently shaken, in order to remove the remaining air in the pipes. Observation, however, showed a full filling of the pipes without "shaking". Only copper pipes DN 6, had some difficulties by the filling due to prevailing surface tension. When the samples were filled in near horizontal position, some air was captured in the grooves, and could only be removed by placing the samples vertically. Further the filled pipe samples were adjusted to the desirable tilt angle, weighed, afterward the caps on both ends were removed, and the draining process launched. The draining profiles of the smooth copper DN 20 (Fig. 5, left) and CSS pipes DN 16 (Fig. 5, right) are presented in the Fig.5. Both graphs are scaled identically for better visual comparison of the draining dynamics of the smooth and "wave-shape" pipes. As expected the copper pipes drained completely by tilt angles steeper than 2°, whereas at a slope of 2° a small amount of water remained due to surface tension. For the same reason the copper pipe placed in horizontal position captures a considerably larger amount of water about 54 g, that represent 18 % of the water mass of the completely filled pipe sample. In CSS pipes as proposed a small amount of water always remains at all slopes range due to its special shape with grooves. It has to be emphasized that a comparable water mass remains both in horizontal as well as in vertical pipes. Moreover in vertical pipes after draining remains significantly larger amount of water than at flat slopes. This is a distinguished feature of CSS pipes, which retain water after the draining even in vertical position. Considering the dynamic of the draining for CSS and copper pipes at 0°, it can be noticed that the main volume of water flows out within 30 seconds from copper pipes, whereas about 3 minutes are required for CSS pipes.

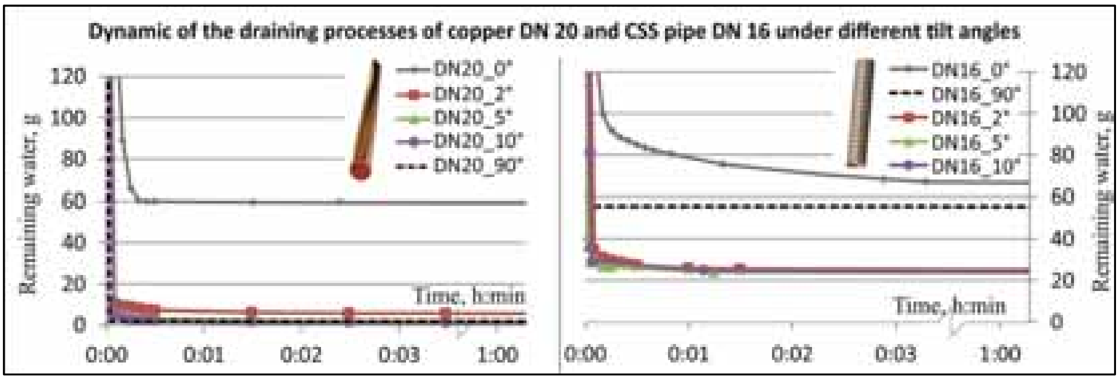

Fig. 5: Draining processes of a copper DN 20 (left) and CSS DN 16 pipe (right)

The draining processes of other samples show almost similar courses over the time, therefore only the measurements of remaining water after one hour are summarized in Tab. 2. The first columns in the table provide general information on the samples and the weighed water mass required to fill the pipes completely. This weight was considered in the next column as 100 %, in order to calculate the relative amount of remaining water after draining. The following columns present the remaining water mass after 1 hour of draining in absolute values (gram) and in percent.

Tab. 2: Remaining water mass in copper and CSS pipes after 1 hour of draining

DN		Water content in the fully filled pipe		Remaining water mass in the pipe after 1 hour					
				0°		2°	5°	10°	90°
		g	%	g	%		g	g	g
Cu	6	33.0·(1±1%)	100	13.1±0.3	40	4.7±0.1	1.9±0.1	0.7±0.1	0±0.1
	20	310.5·(1±1%)	100	54.4±1.1	18	5.3±0.1	1.7±0.1	0.2±0.1	0±0.1
CSS	12	156.8·(1±1%)	100	90.3±1.8	58	27.5±0.6	21.9±0.4	20.5±0.4	41.4±0.8
	16	265.4·(1±1%)	100	64.5±1.3	24	24.0±0.5	23.0±0.5	22.0±0.4	55.6±1.1
	20	412.7·(1±1%)	100	53.7±1.1	13	31.7±0.6	30.4±0.6	29.6±0.6	88.9±1.8
	32	1086.6·(1±1%)	100	50.5±1.0	5	49.2±1.1	45.8±0.9	45.3±0.9	168.0±3.4

The percentage values of the remaining water, as presented in Tab.2, are illustrated in Fig.6. The graph shows the relative amount of remaining water one hour after the start of the draining process. Referring to Fig.6, it can be seen that the smaller the diameter, the more water (percentage values) remains inside. Moreover, a comparable water amount remains in the pipe regardless of the tilt angle for corrugated stainless steel pipes diameter larger than DN 16 (≥ DN 16). The latter statement is true, except in the case of a vertically positioned CSS pipe. When perpendicular to the horizontal, 15-26% of the water content remains in CSS pipes after the draining process, which should be considered during installation. On the contrary, smooth copper pipes empty completely as expected in a vertical arrangement. The "poor" emptying properties of the smooth horizontal pipes might be caused due to an insufficient initial hydrostatic pressure, which is the driving force of the draining. It is to emphasize that the draining of horizontal pipes in a real system proceeds in another way, where inertia of the flowing water and significantly larger hydrostatic pressure difference is present. Therefore, the emptying test of the presented experiment with 0° tilt angle should be considered as the worst draining case, as demonstrated in Botpaev et al. (2014) a horizontal arrangement of the smooth pipes does not affect the draining process of DBS. Similarly, better draining properties under the influence of inertia and hydrostatic pressure might be assumed for CSS pipes; however it is not possible in reality to arrange CSS pipes in such a lineal way, as it was done here by fixing them to a metal profile. Summarizing this first set of experiments, it has to be repeated that water always remains in the CSS pipes regardless of the slope. Furthermore, it should be noted that in vertical CSS pipes remains a significantly larger amount of water than in sloped one.

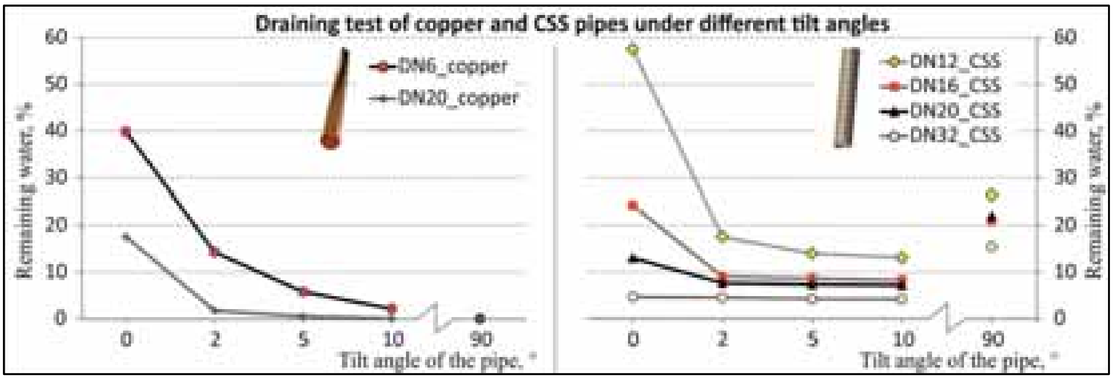

Fig. 6: Remaining water in copper and CSS pipes after one hour of draining process

Experiment 2 – filling and draining processes of a DBS with corrugated stainless steel pipes. The second set of experiments was performed with a second experimental setup, which was introduced above in Fig. 3. CSS pipes were integrated into an existing experimental setup, replacing PVC pipes in the flow side. The filling process of the system is presented in the Fig. 7, which similarly proceeds as the filling process of the same system with smooth pipes. The flow rate curve is drawn in black color, whereas the pressure is depicted in blue. The X-axis, which reflects the time in seconds was additionally split into several stages and designated with capital letters (A-C). The time interval between B and C represents the duration of the filling process with a typical spike of the flow rate at the beginning (red point). At the end of the filling process at time C all parameters such as the flow rate, the pressure after the pump and at the top are stabilized, indicating complete air replacement by water in the hydraulics. The underpressure at the top (blue curve) shows a siphon establishment in the loop. The area under the MID_return curve over the length of the filling process, colored grey, is used to characterize the air replacement process in the solar loop (Botpaev and Vajen, 2014b). The speed of the installed pumps was varied and for each pump configuration the filling process was evaluated. Two identical but slightly modified hydraulics, the first one with one horizontal pipe arrangement of the flow side piping and the second with two (as described above) were applied.

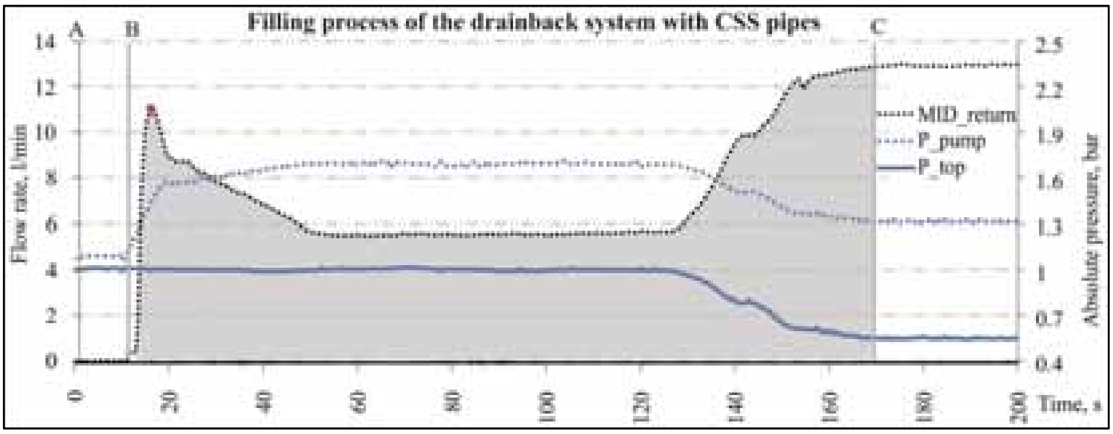

Fig. 7: The filling process of the drainback system with CSS pipes

In Fig.8 is presented the evaluation of the filling process with the above described integral method. The red point in the graph corresponds to the filling case depicted in Fig. 7, where the minimal flow rate after the spike is 5.4 l/min and the grey area under MID_return amounts to 19 l. Based on the rules for error propagation, the uncertainty of the integral is estimated and presented in the graph for two flow rates (9.7 and 25.1 l/min). The absolute uncertainties are increasing at higher flow rates, due to the impact of the uncertainty on the filling time. In spite of relatively good repeatability conditions of the experiments, there is obviously no reproducibility of the results for experiments with adjusted pump speed at minimal flow rate below 6 l/min for both hydraulic configurations (1- with one, 2- with two horizontal pipe arrangements). The filling time for these flow rates is not predictable, as the amount of water required for the filling (integral) varies significantly. The experiments with a minimal flow rate above 6 l/min show a good reproducibility of the results. It appears that a comparable amount of water should flow through the loop in order to completely remove the air in the upper part of the hydraulics independently of the flow rate. This means that the intensity of the air transport process remains identical in CSS pipe, although the filling flow rate increases. The bend of the curve (near 6 l/min) can be considered as a tipping point, a recommended lower threshold of the flow rate for a proper filling process of DBS with CSS DN 20 pipes. Above this threshold, a good reproducibility of the filling time is guaranted; the control unit of the solar thermal system can therefore be precisely adjusted. A further rise of velocity causes an increase of pressure losses in the pipes (Fig.8, right Y-axis), without intensification of the air transport process; therefore the filling around the threshold minimizes the pump energy consumption without hampering the filling process.

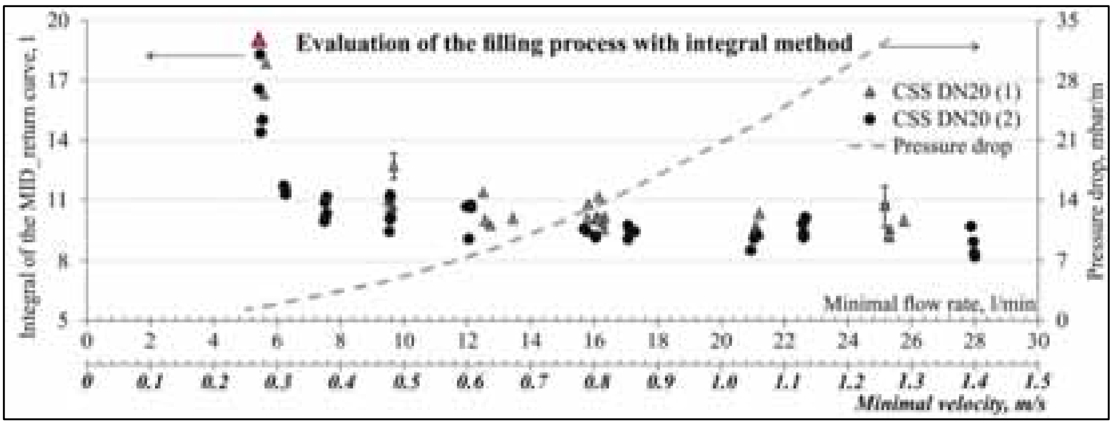

Fig. 8: Evaluation of the filling process with integral method

In Tab. 3 are summarized the values of the threshold flow rate for other CSS pipe diameters. These values were obtained based on the evaluation of two slightly modified hydraulics, as in the previous case. It is to be emphasized that the threshold for the CSS pipe DN 32 was indistinct due to lack of measurements data.

Tab. 3: Recommended lower threshold values for the filling process

CSS Pipe	DN 12	DN 16	DN 20	DN 32
Diameter of the CSS pipe, mm	12.6	16.5	20.5	34.6
Recommended lower flow rate threshold, l/min	0.85±0.01	4.00±0.04	6.00±0.06	35±2
Recommended minimum flow velocity, m/s	0.1·(1±1%)	0.3·(1±1%)	0.3·(1±1%)	0.6·(1±6%)

The minimum flow velocities in Tab.3 are calculated considering the minimal diameter (d on Fig. 1) of the CSS pipes. It should be noted that these values besides for DN 32 are smaller than the recommended minimum flow velocities in VDI 6002 (2014). This standard issued by the Association of German Engineers suggests to keep the minimum flow velocity at 0.4 m/s in order to transport the air from the hydraulics. However, this velocity is not sufficient for the filling of drainback systems with CSS pipes DN 32.

Some additional remarks about observations and calculations during the filling tests:

- There is a recommended lower flow rate threshold, which guarantees a full filling of the hydraulics. At this value occurs a predictable air replacement processes. Further growth of the flow rate lead to an increase of the pressure losses and a decrease of the filling time, but the intensity of the air transport process remains the same.
- Flow rates above 5 l/min cause vibrations in CSS pipe DN 12 followed by a strong rumble. The vibrations were observed also for other CSS pipe diameters, however without noise. It means that the distance between the bindings should be optimised also for vertical CSS pipes, in order to minimize the vibrations. In particular a transition zone vertical to horizontal and inverse have been carefully considered.
- The pressure losses in CSS pipes are approximately three times (depending on flow rate) higher than in smooth pipes.

In Fig. 9 is shown the dynamic of the flow rate during the draining process. Five experiments were carried out for the same hydraulics with different pump configurations as schematically shown at the top of the graph. For instance in experiment 1010 the draining occurred through both parallel lines, whereas in 1016 only through the large single pump, and during experiments 1102, 1006 and 1013 through the two serially connected pumps. The X-axis is a timeline of the process in seconds. The Y-axis is a flow rate measured by MID_return. Positive values correspond to the direction of the circulation during operation mode, whereas the draining process occurs in the opposite way therefore depicted in a negative range. Capital letters (C-F) at the bottom of the graph highlight the transitions between some characteristic operating stages of drainback systems. The time interval between C and D is the operating mode, at time D the pump is turned off, however due to inertia the circulation continues with a decreasing flow rate during a couple of seconds, at time E the circulation ceases, afterwards starts the draining process in opposite direction.

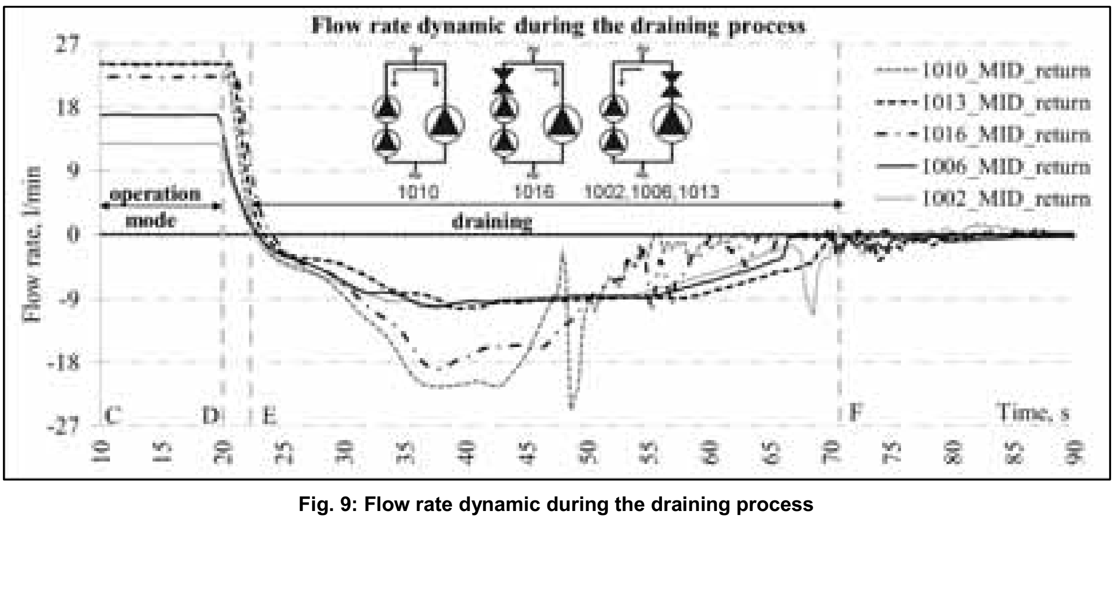

Fig. 9: Flow rate dynamic during the draining process

Pump represents a local pressure loss during the draining process. The value of the pressure loss depends on the pump(s) type and their hydraulic connection (serial or parallel). Obviously two parallel lines of pumps obtained the minimal pressure drop, whereas two pumps connected in series the maximal pressure drop. The pressure drop impacts the draining profile significantly. As presented in Fig. 9 the maximal amplitude of the flow rate during the draining process is twice larger in experiment 1010 (21.5 l/min) than for pump configuration adjusted in experiments 1002, 1006 and 1013 (9.3 l/min). Beside the maximal amplitude of the flow rate, this configuration ensures a minimal draining time which is also important. Furthermore it has to be emphasized that the draining process occurs in the same way for the same hydraulics regardless of the previous operation conditions (high flow, low flow or matched flow). It is visible that the profile of the flow rate curve (duration, amplitude) during the draining is identical for experiments 1002, 1006 and 1013, despite different flow rates during the operating mode. The flow rate during the draining even exceeded the flow rate during operation mode, as presented in the case of experiment 1016.

Some remarks about observations and calculations during the draining tests:

- The draining process proceeds always in the same profile, with identical amplitude and duration, for a certain DB hydraulics regardless of the flow rate during operation.
- The pump(s) represent(s) a relative significant pressure drop for the draining process, which impact the profile, duration of the draining process and its maximal amplitude.
- Small volumes of water always remain in CSS pipes after the draining process regardless of the tilt angle of the pipes. Furthermore in vertical pipes with large diameters more water remains than in sloped CSS pipes.
- The smaller the diameter of CSS pipes, the more water (in percentages to the full pipe) remains inside
- Vibration can occur during the draining for significantly high flow rates.

Experiment 3- burst test. In this last test, samples of different CSS pipes have been frozen in a freezing unit. Several tens of freezing and defrosting cycles have been carried out with CSS and copper pipes in horizontal position with different filling levels up to 50 %. They did not reveal any burst or visual damage of the samples. Fully filled copper pipes burst after the first freezing cycle, whereas CSS are elongated after the first freezing but are not burst. It can be concluded that remaining water in CSS pipes (partly filled) after draining does not present any danger for the pipes even after phase change of the heat transfer fluid. The only negative aspect is an energetic issue as the remaining water which transforms into ice needs to be melted at the start of the system.

4. Summary and conclusions

Experimental investigations of the filling and draining processes of drainback systems have been undertaken. The behaviour of these processes was evaluated for DBS with corrugated stainless pipes as solar collector loop piping. CSS pipes are widely used by assemblers of solar thermal systems as they are flexible, economically feasible, compact for transportation and easy to install. Because of specific design and installation requirements, the use of CSS pipe in combination with DBS was investigated in this study. In a first step, the filling and draining properties of several CSS and copper samples were investigated. The results show that CSS pipes are suited for the filling process, despite their distinguished shape with grooves. These grooves retain some fluid after the draining process, therefore water always remains in CSS pipes regardless of their tilt angle. Moreover, CSS pipes vertically positioned hold more water than identical samples with 2°, 5° or 10° slope, which is not the case for copper pipes. Indeed, Smooth pipes empty completely at angles steeper than 2°. Further experiments were conducted with a complete drainback setup. The suggested integral method was used to evaluate the filling process. The recommended lower value of the flow rate for CSS pipes with different diameters was obtained. This value is a threshold, above which a repeatable filling process with a predictable filling time is ensured. Further rise of the flow rate above this threshold during the filling is however not desirable as it causes additional pressure losses, without improvement of the air transport mechanism. Besides for DN 32 pipes, the obtained thresholds are in line with the minimum flow velocity recommended in VDI 6002. The draining experiments confirmed that the draining profile including amplitude and the draining time proceed always in the same way for a given hydraulics regardless of the flow rate during operation. The pressure drop through the pump(s) impacts the draining profile, so it is desirable to install pump(s) allowing back flow, but also with a minimal pressure drop. Finally burst tests approved the applicability of CSS pipes for DBS, however a sufficient number of fastening points for both vertical and horizontal pipes is required, in order to avoid sagging and vibration of the pipes.

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