

Experimental investigation of the filling and draining processes of drainback systems (Part 2)

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Abstract

This paper presents the results from experimental investigations of the filling and draining processes of drainback systems (DBS). An experimental setup of DBS with transparent hydraulic components was built for these purposes. Three experiments have been carried out, evaluated and summarized: (1) impact of an air vent in combination with an air channel on draining and filling processes, (2) influence of the pump's speed on the filling process, and (3) effect of the water level in the drainback tank on operation conditions. Some results of these investigations are:

- A general method to measure the duration of the filling process for DBS is developed
- Two types of draining processes "syphon draining" vs. "two columns draining" are compared
- Air entrainments into the drainback tank due to splashing and vortex effects are analyzed

Other results with explanations of the processes are presented in this paper. A familiarization with a previous publication- part 1 (Botpaev et al. 2013) is not required for a comprehensive reading of this work.

Key words: drainback system, drainback tank, draining, filling, syphon draining.

1. Introduction

Drainback systems (DBS) can provide a simple protection against overheating and freezing of the applied heat carrier. A safe operation of the system is reached due to alternating of three operating stages, namely filling, operation mode and draining. Each stage is very important for a safe and smooth functioning of the system. DBS do not only offer reliable freeze and overheating protection, but also a low level of maintenance, saving time for inspections, controlling and "replacements". Fewer components in hydraulics make the system simpler and economically feasible. DBS are not susceptible to failure due to air entrainment, whereas it might be a typical problem for pressurized solar thermal systems. Nevertheless, DBS are widely spread only in a few countries such as Netherland, Norway and Belgium. An insignificant mistake during the installation can disturb the operation, which can lead to a damage of the system. Therefore, the understanding of the filling/draining processes is crucial for a proper operation. The previous paper from Botpaev et al. 2013 considered the basic principles of operation of drainback systems. A siphon effect plays an essential role for the filling and draining processes. During the filling it compensates the elevation head supporting the pump(s), whereas for the draining it is the driving force and the basis of functioning. A siphon effect also makes horizontal piping suitable for a safe draining, which always occurs in a reverse direction to circulation. A height of hydrostatic pressure difference between the flow and return side above 10 mm is enough to initiate the draining. The present paper contains further experiments on filling and draining of DBS which are understandable even without familiarization with previous work (part 1).

2. Description of experiments

The draining of the heat carrier from the collector is known already for many decades. Nevertheless there are

a lot of recently published patents which are suggesting that improvements are still sought for DBS (Newman et al. 2011, Humphreys Michael 2012). Different approaches seem to be envisioned to ensure a reliable filling and draining. In order to initiate the draining process of DBS, a hydrostatic pressure difference between return and flow pipe is required. For this purposes systems of some companies are equipped with a motor driven valve (e.g. Bunksolar, Agritec), which is permanently closed in operation mode. This valve is typically installed on a so called air channel, which connects the air gap in the drainback storage or the surroundings with the solar flow side. The end of the flow side, where the heat carrier reaches the drainback storage, is always located below the water level in this storage. Under such circumstances an automatic self-draining is impossible, due to the absence of a hydrostatic pressure difference between flow and return pipes. The applied motor driven valve serves to provide a driving force for the draining. If the power supply is interrupted or the pumps are shut-down, the motor driven valve opens automatically. This facilitates a partly draining of the flow side and creates a hydrostatic pressure difference, necessary for further draining. A comparable approach with an air channel was already patented by Busch D., Mitlacher W. (Patent Nr.DE 2753 756 A1) 35 years ago. They proposed to use the air channel, which connects the top of the hydraulic with atmosphere through the drainback vessel. The open solar thermal drainback system according to this invention did not need any protection against high pressures and temperatures. The open cycle increases however the risk of corrosion. Therefore a closed system, sealed from surroundings is preferable in practice otherwise corrosion resistant materials should be applied. One similar approach of DBS with some modification is presented in the scope of the first experiment. A closed drainback system with an air channel was evaluated. Besides the air channel, the system has an automatic air vent, which is positioned at the top of the hydraulics. Depending on the water level inside the vent, it opens or closes automatically and does not require any additional energy supply. The air vent is connected with the air gap of the heat storage via the air channel. Thus, the air can be partly released through the vent to the drainback tank during the filling and used again for accelerating of the draining process. The hydraulic schema of the experimental setup is presented in Fig.1.

Another experiment is performed to show the difference of the filling strategies. Some attempts were undertaken in the past by different scientists in order to figure out the minimal required velocity of the fluid for the filling. However, there are no studies on the filling behaviour of the DBS above this criterion. The present experiments aimed at correlating the filling time with the adjusted flow rate. The filling time is defined as the duration from the start of the pumps up to the appearance of the operation state, so when the air is more or less completely removed from the piping, in particular in the downcomer to the drainback volume. Either one booster pump or two small pumps conneted in series are used in the DBS. Two pumps are in operation only during the filling process, afterwards one of the pumps can be shut off. Thus, the optimal flow rate could be adjusted separately for the filling process and the operation mode. VDI 6002 (2014) recommends to keep the velocity of the circulating fluid above 0.4 m/s in order to eliminate air from the solar loop. Is it also recommendable during the filling process? The variation of the pump's speed and its influence on the filling process is considered in the second experiment.

In addition to the variation of the pump's speed, the influence of the water level in the drainback tank is investigated in a third test. Typically after night break, the solar collectors must heat the whole circulation fluid in the loop, including in the drainback reservoir, before the heat should be delivered to the heat storage. The system is in operation, but no energy is transferred to the heat storage, as long as the whole fluid in the drainback tank is not heated up. This leads to a delay of energy delivering which depends on the water amount in the drainback tank. From this point of view, a full drainback reservoir is not desired, due to additional thermal capacity of the water. On the other hand, a low level in the drainback tank might cause a negative air entrainment into the circulating fluid. Air bubbles in the system not only decrease its efficiency, but accelerate the degradation of the components. According to ASHRAE (1990), the drainback tank should be 3/4 to 7/8 full when the system is off, while in operation the level should not drop below 1/8. "Levels outside these ranges signify potential problems" warns the ASHRAE society. The depth of air entrainment by the different water levels in the drainback tank and different flow rates is measured, established and analysed in this third experiment.

3. Experimental setup

The schematic diagram of the experimental setup with the location of the components along is presented in

Fig.1. Two types of drainback systems were considered: one with heat storage as drainback reservoir and one with an additional drainback tank. Pipes and some hydraulic components were transparent for visual assessments of the processes. Pure water was colored red and used as the circulating fluid in the loop. The measurement equipment comprised magnetic-inductive flow meters, manometers and an Agilent data acquisition system. The setup was not heated and operated at ambient temperature at all times.

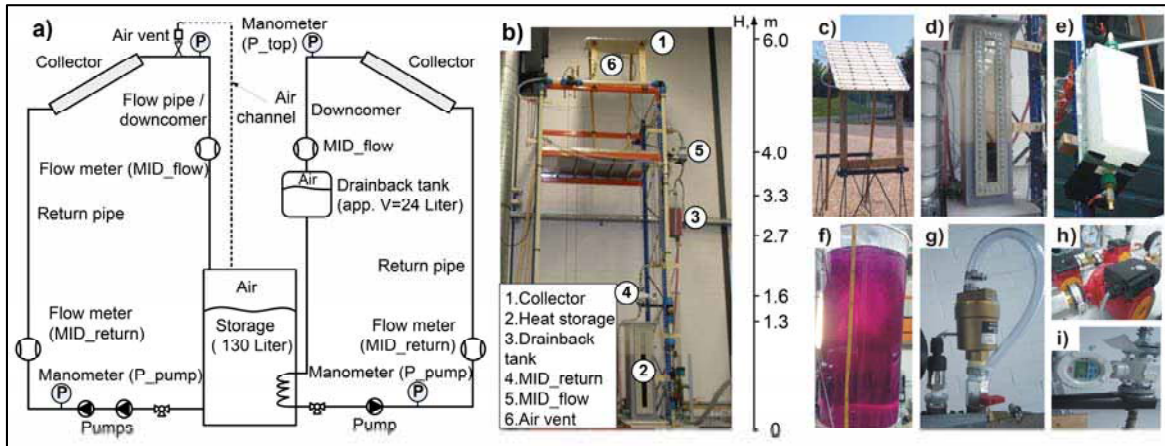


Fig. 1: Hydraulic scheme (a) of the experimental setup (b) and hydraulic components (c-i)

The experimental setup with total height of 6 m consists of the following components:

- *Solar collector and piping (Fig.1,c).* The model is based on the dimensions of an existing drainback collector (Braun collector), but was assembled with shorter length. The collector consists of a meander absorber, made from PVC pipes ($\varnothing 10\text{mm}$ inside) and fixed on a wooden plate. The tilt angle of the collector was 60° during the experiments. The aperture area is approximately 1.2 m^2 (BxH, $1\text{ m} \times 1.2\text{ m}$). The piping to and from collector were constructed with PVC ($\varnothing 19\text{ mm}$ inside) material. The PVC pipes have almost the same absolute roughness as standard copper pipes.
- *Storage (Fig.1,d).* Both type of the 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 $320 \times 320 \times 1300\text{ mm}$ (LxBxH) with a total volume of about 130 liters. One centimeter of the water column in the heat storage corresponds to approximately one liter 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 inside with a heat exchanger coil, two others for the direct integration of the solar loop, and the last one for the air vent.
- *Drainback reservoir (Fig.1,e,f).* Two different drainback tanks were applied. The first drainback tank (Fig.1,e) in form of a rectangular cuboid was welded from PP-H plastic. The dimensions of this tank are $200 \times 200 \times 600\text{ mm}$ (LxBxH), which correspond to a volume of 24 liters. The thickness of the plastic allows to observe the processes. The tank contains a wall inside, which divides its volume into two zones. The zones are connected with each other at the top and at the bottom of the drainback tank. There are two connections at the top and one at the bottom of the drainback tank. The variations of the top connections will be used in the third experiment. Additionally a drainback tank (Fig.1,f) in cylindrical form was bonded from transparent Plexiglas pipe ($\varnothing \text{OD/ID } 300/292\text{ mm}$) and plates by adhesive. The dimensions of this tank are $300 \times 650\text{ mm}$ (BxH), which corresponds to a volume of 43 liters.
- *Air vent with air channel (Fig.1,g).* Automatic air vent AE 30 of Spirax Sacro was applied. At start-up the air vent is open allowing air to pass through the main valve. As soon as circulating fluid reaches the vent the float is raised and a lever mechanism closes the valve. The air vent is connected with the air gap at the top of the heat storage via an air channel (PVC pipe). Thus, the system is supposed to be sealed from the surroundings. The impact of the air vent with air channel on the filling and draining processes will be tested.
- *Pumps (Fig.1,h).* 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 the

operating the solar loop either with single pump Grundfos 25-120 or two small Grundfos Solar 15-80 pumps. The latter pumps had two adjustable speed levels: min and max.

- Measurement's acquisition.* The data acquisition system Agilent 34970A was used for monitoring, gathering and evaluation of the measurement data. Manometers and flow meters were the main sensors of the experimental setup. Muntwyler (2005) reported that some flow meters can cancel the draining processes, therefore magnetic-inductive flow meters (MID) were applied (Fig.1,i). The chosen MID - ABB Process Master 311 are capable to measure the flow rate in both directions. An additional advantage of the MID flow meter is its 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 1.6 m, the second one in the flow pipe above the drainback tank at 4.0 m. Two digital manometers from JUMO GmbH & CO.KG were placed on the highest point of the hydraulic and after the pumps. Some simple manometers were also applied for controlling purposes.

4. Measurements and analyses

Three experiments mentioned above were performed to figure out specificities of the filling and draining processes under certain operating conditions. Each test was repeated at least three times in order to eliminate the measurement errors and biases. The drainback system with an air vent, an air channel and storage as drainback reservoir was used for the first experiment (Fig.2, a), the same hydraulics without the air vent and the channel for the second one (Fig.2, b), whereas the system with an additional drainback tank was investigated in the third test (Fig.2, c). A measurement concept was developed with two magnetic-inductive flow meters, one in the return side and other one in the downcomer. This approach allows to estimate exactly the duration of the filling process and/or to determine the presence of the air bubbles in circulating fluid. Both flow meters measure the same flow rate, therefore they display identical values if the solar loop is completely filled with water. Once a mix flow air-water passes through this sensor fluctuating values are displayed. Thus, a comparison of the flow rates of both MID provides accordingly a comprehension of the flow inside the loop. The pressure at the top and behind the pumps was measured by manometers. The aim of the first experiment is to analyze the influence of the suggested air vent in combination with an air channel on the filling and draining processes of the DBS. The second experiment was conducted to compare the filling strategies by means of varying the speed of the pumps. The third one investigated the impact of the water level in the drainback reservoir on operation conditions of the DBS.

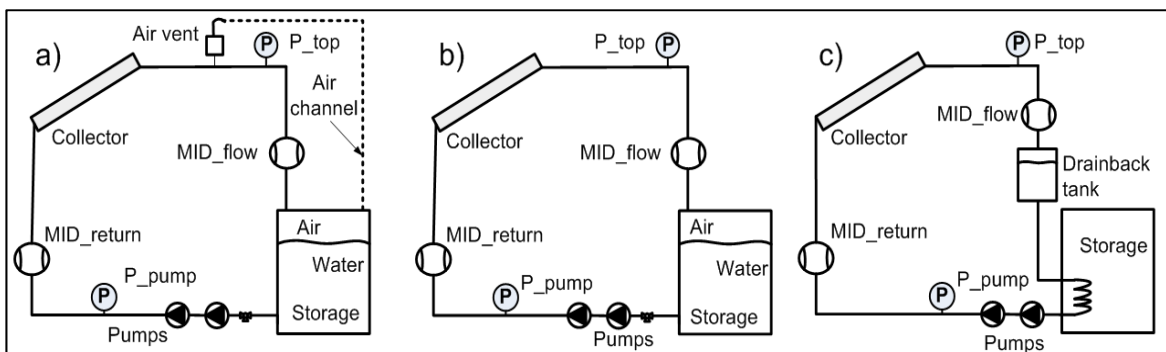


Fig. 2: Hydraulic scheme of the drainback system during the first (a), the second (b) and the third experiment (c)

Experiment 1- Impact of an air vent in combination with air channel on filling and draining processes. Both serially connected pumps were adjusted to maximal speed level. The diameter of flow and return piping was 19 mm. The flow pipe from the collector to the heat storage ends above the water level in the heat storage. The air vent is coupled with the air gap in the heat storage via the air channel. The proposed air vent regulates the filling and draining processes, and does not need additional energy supply as motor driven valve. The operation of the drainback system is presented in Fig.3. The flow rate curves (dotted and continuous line) are drawn in black colour, and the pressure in blue. The X-axis, which reflects the time in seconds was additionally split into several stages and designated with capital letters (A-H). Each stage will be discussed separately.

AB (approx. from $t=0$ to $t=9$ s) - the system is not in operation. Both flow meters recorded zero flow rates. The absolute pressure at the top of the system (P_{top}) is 1 bar, while the pressure behind the pumps (P_{pump}) is slightly above 1 bar due to a water column in the heat storage of about 50 cm.

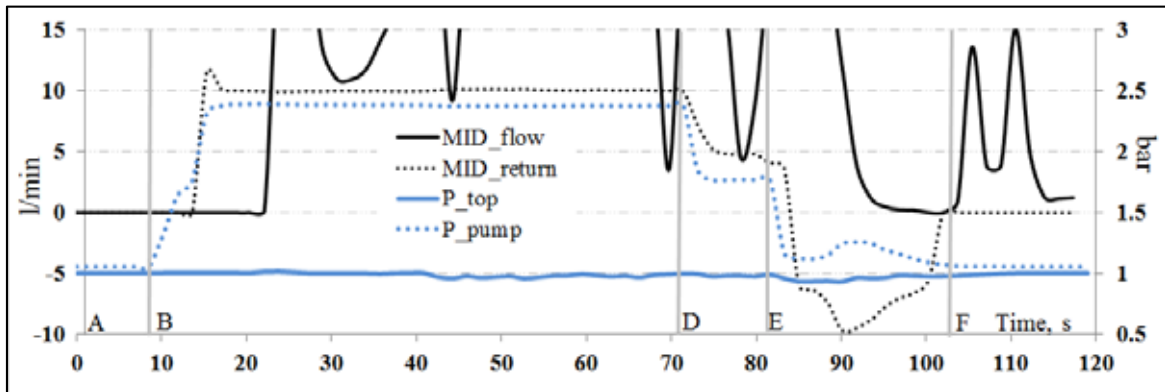


Fig. 3: Filling and draining processes of the drainback system with heat storage as drainback reservoir and with air vent. MID_flow, MID_return (left Y-axis) - the flow rates in the flow and return sides, P_{top} , P_{pump} (right Y-axis) the absolute pressure on the top of the hydraulics and behind the pumps.

BD - the filling and operation mode. Two serially connected pumps are started at time B. The pumps filled the solar return pipe within 10 seconds. Behind a spike (MID_{return} at $t=17$ s) which is normal for DBS, the flow rate in the return pipe stabilizes to 10 l/min, while the MID_{flow} (from 24 s) registers fluctuating values above the range of the diagram. The main reason for such fluctuations is a permanent air entrainment through the air vent. Even the air vent supposed to be closed, whenever the water flow reaches it (approx. at $t=22$ sec.), the observation showed opposite. The vent stayed open during the whole operation period. The functionality of the air vent was disturbed due to underpressure at the top of the system, which is typical for unpressurized DBS (Botpaev et al. 2013). In order to be closed automatically, a certain minimal positive pressure difference with atmosphere is required. Instead of this overpressure at the top of the hydraulics a vacuum pressure was created. The open vent and underpressure lead to air suction from the heat storage into the solar flow side through the vent. It can be exactly seen as a slightly cyclic drop of the pressure on the top, which in the next time step again increased up to atmosphere pressure, due to sucked air from the heat storage. The observation confirms the full flow in the return pipe inclusive in collector, while in the downcomer a partially filled pipe has been observed during this test. It has to be emphasized that observation of the operation mode during hours shows the same tendency of mix air-water flow in the downcomer, but for better visualization purposes the duration of this mode was reduced to 1 minute in this experiment. The proposed solution with an air vent at the top did not facilitate the filling process at all; moreover it prevented the desired water flow in the flow pipe. The syphon was not established during the filling due to permanent air suction at the top. On the contrary, the same hydraulics without air vent could be completely filled under the same operation conditions as mentioned in Botpaev et al. 2013.

DE - operation mode with one pump. After shutting down one pump at time D (approx. after 71 s), the values of all sensors, besides P_{top} are rapidly reduced and stabilized. As a consequence of the open vent and underpressure at the top, the air continued to flow from the heat storage through the vent to the flow pipe. In turn, the water flow delivered the air again to the heat storage, forming a circulation of the air through the downcomer side (hesitation of MID_{flow}). This operation condition causes an increase of electricity consumption by the pumps.

EF- draining process. The pump was turned-off at time E (approx. 82 s). The circulation continued the next few seconds, afterwards stopped. As expected, the air vent works as siphon/vacuum breaker. The air penetrating through the vent breaks the circulation fluid into two water columns in the flow and return pipe. The water line in the flow pipe drained into the heat storage directly. The air in the flow did not enabled proper measurements by MID_{flow} , thus the flow rate curve lies partly above the diagram's range and is not accessible for analyses. The fluid flow in the return pipe reverses its original direction and drained in opposite way, due to gravity. A split of the flow into two columns makes the draining easier and faster. The draining process with air vent took approximately 18 s (from 86 s to 104 s), whereas for the same system without air vent and air channel continued approx. 37 s (Botpaev et al. 2013). The presented draining approach - "two columns draining", in contrary to "siphon draining" mentioned in the first part is better

suited for DBS with large diameter (above $\varnothing 25\text{mm}$) and complex hydraulics (a lot of horizontal pipes in downcomer).

Experiment 2 - Influence of pump’s speed on the filling process.

A drainback system with heat storage as drainback reservoir was applied in this experiment (Fig.2,b). The circulation of water in the solar loop is maintained by two serially connected pumps. The filling process under different variation of the pump’s speed was monitored during these experiments. The velocity of the circulating fluid laid in the range of 0.2 to 0.7 m/s. Filling processes with different flow rates are presented in Fig. 4. Each graph has a heading, which gives information on the speed adjustment of the pumps in the solar loop. For instance “1max-2min” means that first pump was operated at maximal speed, while the second one at minimal. The last graph shows the filling process with only one pump “1off-2max”. The filling process is considered to be complete, once both MID flow rates show the same value and the underpressure at the top is stabilized.

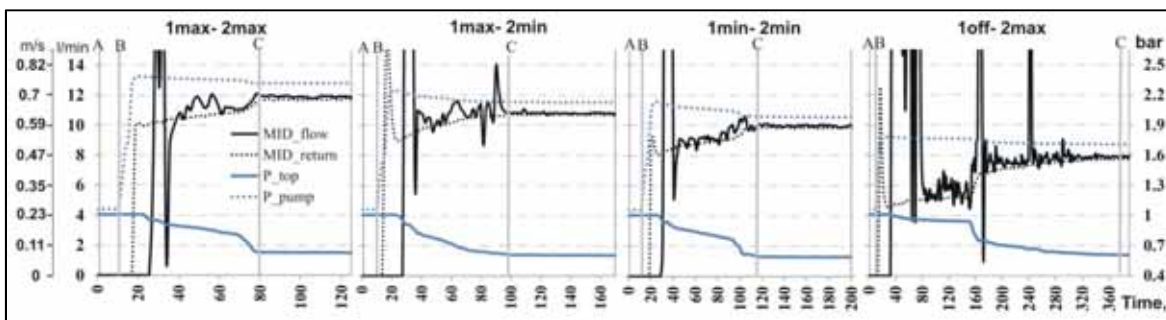


Fig. 4: Filling process of the drainback system with heat storage as drainback reservoir under variation of both pump’s speed. No air vent and air channel is in the hydraulics. The diameter of flow and return piping is 19 mm

AB - the system is not in operation.

BC – the filling process. Observations showed that the solar return pipe is filled completely regardless of the flow rate. On the contrary, the filling of the flow pipe depends mainly on the velocity of the fluid. Operation of two pumps on the maximal speed levels “1max-2max” demonstrated the shortest filling time (approx. 70 s, B=10 s, C=80 s). In case of “1max-2min” the filling time was measured 88 s, whereas for “1min-2min” it was 105 s. A deviation of the filling time up to 12 s from the presented average was occurred for each adjustment of the pumps speed. The experiment with one pump on the minimal speed level (the fluid velocity is approx. 0.2 m/s, not on Fig.4) showed that the downcomer cannot be completely filled at all. The fluctuation of the curve MID_flow was observed here during several hours, afterwards the experiment was terminated. The results of these experiments are summarized in the Tab.1.

Tab. 1: Duration of the filling mode depending on the flow velocity

Pump adjustment	1max-2max	1max-2min	1min-2min	1off-2max	1off-2min
Filling time [s]	70	88	105	362	Not filled
Average flow rate [l/min]	10.6	10.3	8.9	7.6	3.4
Filling time *average flow rate, [l]	12.4	15.1	15.7	45.9	-

As expected, the experiments show an increase of the filling time with reduction of flow rate. Interesting behaviour in this trend is a deterioration of the process, which implies the replacement of the air from collector loop into the upper part of the heat storage. It becomes more difficult for the flow to push the air pocket (joining of several air bubbles) into the heat storage with reduced flow rate. Therefore there is a visible step-by-step increase of the flow rate in the case “1off-2 max”, related to gradual disappearance of air pocket/bubbles in the flow side and a continuous filling process. Obviously, the low flow rate lead by itself to an increase of the filling time, but the main delay is caused by “weakening” of the replacement process of large bubbles/pockets. An integral of the MID_return curve in interval BC (simplified as a product of the average flow rate in BC range and the duration of the filling process) could be used as an expression of intensity of the “air cleaning” process. A numerical integration (Tab.1, last row) indicates an activation of

the air replacement process with increasing of the flow rate. Thus, it is important to fill the solar loop with high velocity, and after establishment of the stationary mode the flow rate can be adjusted to the desired value.

Experiment 3 - Impact of the water level in the drainback tank on operation conditions (Fig.2,c). A single pump Grundfos 25-120, as well both Grundfos Solar 15-80 were applied. The system is closed, without integrated air vent and air channel. The diameters of flow and return piping were 19 mm.

The drainback reservoir is the only component which is filled with air and circulation fluid at the same time during operation. In Fig.5 are presented some operation conditions of the drainback system with respect to the drainback tank. On the left side is shown the cuboid drainback reservoir when the solar circuit is not in operation. The completely filled drainback tank is illustrated on the right side. The experiments with a completely full drainback vessel did not reveal any operation disturbance. The filling and draining processes occurred in a good manner. It is to notice that experiments were carried out for the circulating fluid at a constant temperature of 20°C, thus thermal expansion was not considered.

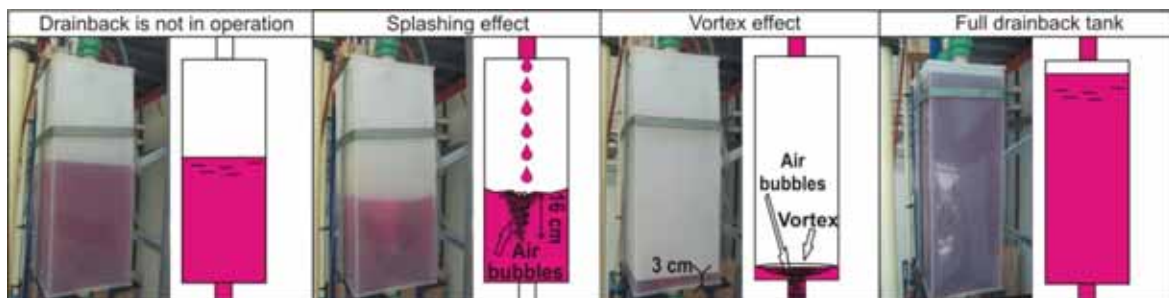


Fig. 5: Operation conditions of the drainback system with respect to the drainback tank

In the middle are demonstrated some processes-phenomena, as “splashing” and “vortex” effect. A Vortex appears if the drainback tank operates with low water level inside. The vortex is similar to what is usually observed by drainage of water from a bathtub or a kitchen sink. Spinning air bubbles were observed in the flow pipe below the rectangular drainback tank, as consequences of the vortex effect. In order to visualize the “pure” vortex effect and to eliminate the influence of splashing, a special construction of a cuboid tank with two zones was developed and applied. The inlet pipe to the drainback tank was located at the top of the first zone, whereas the outlet pipe was at the bottom of the second zone. The two zones are divided by a border wall, with opening at the top and at the bottom. Therefore the vortex effect was separated from splashing and occurred only in the second zone. The minimal water level in the drainback tank, causing the vortex was experimentally measured at a level of 3 cm.

Another observed phenomena is the splashing effect. The circulating water trickles from the top through the air gap into the drainback reservoir. The falling fluid reaches the surface of the water in the drainback tank a few seconds later. At the time of the impact, the kinetic and potential energy of the fluid is converted into splashing and bubbling of water. The splashing process causes a penetration of air into the water contained inside the drainback reservoir, as presented in Fig.5. As it can be seen, the depth of air entrainment was about 16 cm for a flow velocity of 0.7 m/s. Air bubbles move from the depth of the drainback tank upward, due to their lower density. If the water level in the tank is lower than the depth of air entrainment, air bubbles might be captured by the circulating fluid at the outlet of the reservoir. Circulating fluid with air bubbles is not desirable for the system and leads to negative consequences as noise, degradation of the components, higher electricity consumption and fast aging of the pumps. Thus it is significant to avoid penetration of these air bubbles into the circulating fluid. The minimal water level in the drainback vessel, which guaranteed no air capture by the outgoing fluid for this cuboid tank with a fluid velocity 0.7 m/s, was measured at a level of 12 cm. For water levels in this drainback tank below 12 cm, air bubbles were permanently sucked into the outlet pipe from the tank. It is significant to note the difference between the maximal depth (16 cm) of air penetration into the 45 % full drainback tank and measured water level without air capture by outgoing fluid 12 cm. Four cm difference indicates that the water level in the tank also affects the penetration depth of the air, otherwise the bubbles must be captured and delivered through the loop by the fluid at water levels below 16 cm.

The influence of the water level will be described below using a second drainback tank. The second tank is

made of plexiglas in a cylindrical shape with a total height of 65 cm. Some simple experiments were carried out to determine the depth of the air entrainment depending on the height of the water level in the drainback tank. The filling of the tank was varied between 30 % up to 90 %. Thirty percent full tank means that the height of the water in the tank from its bottom is 20 cm, whereas the rest upper volume is an air layer of 45 cm. For each investigated water level, the flow rate was gradually increased up to 30 l/min. The results of these experiments are shown in Fig.6. As predicted: the higher the flow rate, the deeper the air entrainment in the drainback tank. Such tendency appeared in all conducted experiments. The depth of air penetration for a certain flow rate is not the same at different filling levels of the drainback tank. As less water in the tank, as shallower air bubbles penetrate for a certain flow regime. For instance the difference of the height of the “air diving” for 90 % (Fig.6, DBT_90 % curve) and 65 % (Fig.6, DBT_65 % curve) full drainback tank is about 5 cm at a flow rate of 30 l/min. The interpolated depth of air penetration at flow rate of 0.7 m/s for 45% filled cylindrical drainback tank was 15 cm, whereas 16 cm was measured for the first cuboid drainback tank (Fig.6, red dot). The values are very similar, that shows the strong influence of the flow velocity on the entrainment depth. The operation state of the drainback tank 45% filled, corresponding to a water level of 30 cm, demonstrated that some single bubbles are sucked through the outlet of the tank by maximal flow rate of 30 l/min. Further decrease of the flow rate leads to the reduction of the air penetration depth, and thus the air capturing problem on outlet was eliminated. The depth of air penetration in this experiment was measured due to simplicity from the bottom, whereas for previous tests (drainback tank 65%, 80%, and 90% filled) from the top, that is why different measurement uncertainties have to be taken into account. This might be a reason of the curve behaviour with 45% filled drainback tank in Fig. 6, which was coloured with blue. The last series of experiments were conducted for a 30 % filled drainback tank (20 cm water level). It is to emphasize that the air bubbles overcame the whole water column in the drainback tank and circulated further down to the lowest point of the hydraulics. This was valid for flow regimes with fluid velocities from 0.45 up to 1 m/s. Air bubbles gathered inside horizontal pipes, pumps and heat exchanger at the lowest point. Sometimes bubbles were visible in the return pipe, but their appearance were cyclic in spite of a permanent capturing on outlet from drainback tank. Depth of air penetration reaches 20 cm for the operation conditions recommended by VDI 6002 (2014).

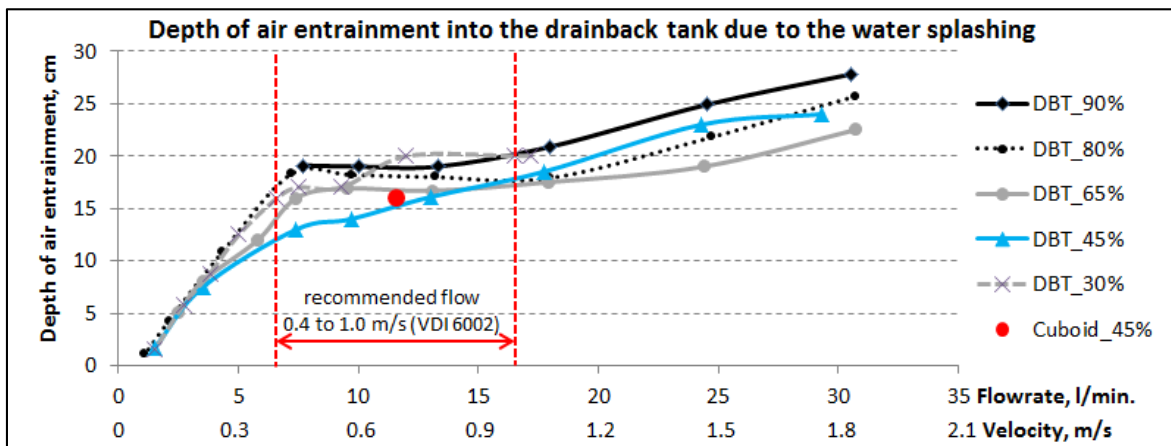


Fig. 6: Depth of air entrainment into the drainback tank for different levels of filling

It is important to emphasize the observation of the intensity/volume of entrained air bubbles in correlation with the flow rate. In Fig.7 are depicted nine operation states of the drainback tank (80 % full), under different flow regimes. The flow rate decreases in the picture from the left to the right. The photos of the experiments are presented in the upper part of the Fig.7. Some original photos do not allow to recognize the entrained air bubbles, therefore each photo below is the same own observations. The water is coloured with red, whereas the air is drawn by small black circles. The bottom of each drainback tank is signed with the velocity of the circulating fluid, determining the flow regime. The first picture from the right has the maximal flow rate of about 30 l/m (1.8 m/s), which causes air entrainment of high intensity. It is to notice that almost the whole amount of the upper part of the water volume contains air bubbles. A reduction of the flow rate leads at the same time to the decrease of air amount entrained in the tank. For a velocity of the circulating fluid of 0.4 m/s only a few tens of bubbles were clearly seen in the tank. The entrained air bubbles became “countable”, as their amount was significantly decreased. However, the depth of air penetration was nearly

the same, as for the previous three experiments with 1.1, 0.8 and 0.6 m/s. Further reduction of the flow rate demonstrated the appearance of a larger amount of bubbles in the tank due to splashing, but the depth of their entrainment was several centimeter less than in the previous one with 0.4 m/s. The same tendency of a significant reduction of air penetration intensity was also confirmed for a DBT 65 % filled. An explanation for this phenomena might be a change of the water profile of the falling fluid in the air. A transformation of the cross section of the falling stream leads to a change of the contact pressure between incoming fluid and the water surface. Thus, splashing of the water occurs in a different manner, which does not cause an intensive air penetration.

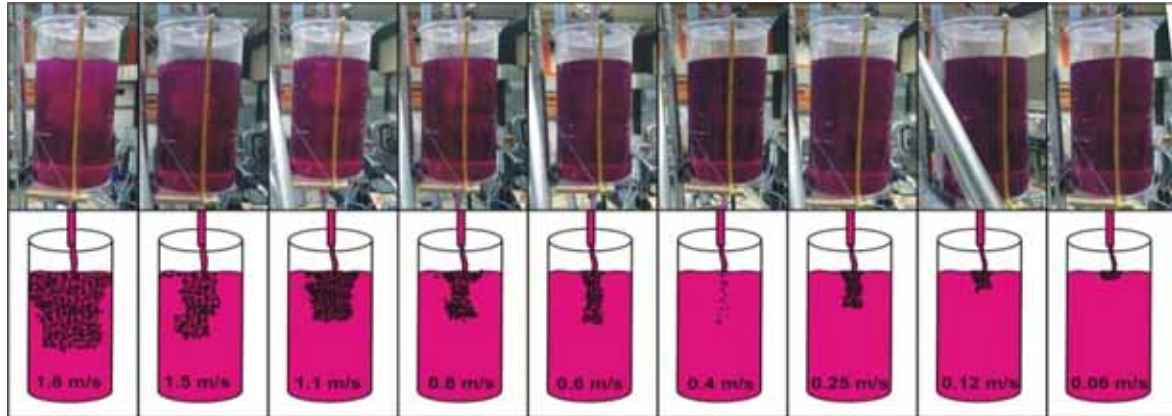


Fig. 7: Intensity of the entrained air bubbles into the 80% full cylindrical drainback tank

It can be concluded that the depth of the air entrainment depends on many parameters such as the shape of the drainback tank, its level of filling, the operation velocity of the circulating fluid, and the height of the air layer inside. The positions of the inlet and outlet pipes of the drainback tank are another factor which should be taken into consideration. The splashing of the water is to be avoided by transforming the falling fluid energy into something else, for instance to redirect the flow towards the wall. Such kind of measure can be applied to eliminate both noise and air entrainment.

5. Conclusions

The filling and draining processes of drainback systems were experimentally investigated. Two types of drainback systems, one with a heat storage as drainback reservoir and one with a separately mounted drainback tank were considered. An air vent at the top connected with the air gap in the heat storage by means of an air channel was additionally tested. Almost all components of the experimental system were transparent, that gave the chance to observe the processes.

The behaviour of the filling process with the air vent is different from the behaviour of a system without it. The full flow operation was not achieved with the air vent. The return side was completely filled, whereas a partly filled pipe was observed in the downcomer. The reason for such operation behaviour is a restriction of the air vent's functionality. The air vent was not able to close automatically during the operation of the drainback system, due to underpressure at the top. Thus, a permanent air entrainment through the air vent from the drainback tank was observed and registered by an MID flow sensor. Draining process was occurred in a different manner as well. There was no "siphon draining" anymore, which enables the water column in the flow side to be lifted by the water column in the return pipe. On the contrary, the circulation fluid was broken into two water columns due to air entrainment at the top. "Two columns draining" was observed: one water column was drained through the flow and the other one through the return pipe. The duration of the draining process was reduced by a factor of 2 in comparison to the system without air vent as mentioned in (Botpaev et al. 2013). It can be concluded that the use of an air vent at the top in association with an air channel is not sufficient for the filling, but fosters the draining process of the drainback system, in particular with complex hydraulics and large pipe diameters.

The filling of the closed solar drainback system without air vent was conducted with different flow rates. The filling velocity was varied in the range of 0.2 to 0.7 m/s. Experiments showed the tendency of a reduction of the filling time with an increase of filling velocity, providing simultaneously a full flow in the loop. The

main reason of this increase of time is not that a certain volume is filled faster with a high flow rate, but the forming of a siphon in the flow side. High velocities ensure a quick replacement of air in the pipes, whereas small velocities lead sometimes to the appearance of air pockets. Air pockets require more time to be completely removed from the loop into the drainback vessel. The high velocity of the filling fluid over 0.59 m/s guarantees that the air is completely pushed from the upper part of hydraulics and pushed into the drainback tank in less than 2 minutes. These velocities facilitate the establishment of the full flow in the downcomer, providing the siphon effect. By decreasing of the velocity from 0.59 to 0.47 m/s, the duration of the filling process increases by a factor of three. Further decreasing to 0.2 m/s disabled the full flow operation at all. Thus, the filling process above the lowest boundary of the velocity (flow rate) is desired for assurance of a full flow. An air replacement process during the filling was expressed by a product of an average filling velocity with a filling time. A continuous intensification of the "air cleaning" process (replacement of air in solar loop by fluid) with an increase of the flow rate was calculated.

Besides the flow rate and the air channel, the water level in a drainback reservoir has an impact on the operation conditions. No disturbance was observed during the filling and draining of the system with a full drainback tank for a constant temperature of the circulation fluid of approx. 20°C. A low water level in the drainback vessel caused in contrast an air entrainment into the solar loop. Two effects, vortex and splashing, were observed, that lead to air entrainment. Vortex effect occurs when the water level in the drainback reservoir dropped below 3 cm. The spinning air bubbles in the fluid in the outlet pipe are a consequence of the vortex. Splashing effect of the falling water might cause as well air penetrations into the outlet pipe. The depth of air entrainment is expected to be up to 20 cm for the operation conditions recommended by VDI 6002. A comparable depth of air penetration was measured for both, rectangular and cylindrical tank, at a velocity of 0.7 m/s (16 cm vs. 15-19 cm). This approved a strong influence of the velocity on the depth of the air penetration. A special construction of the drainback tank, in particular two zones, allowed investigating both effects separately. The splashing depends on many parameters such as the velocity of the circulating fluid, the location of the pipes, the shape of the tank, the height of the water level etc., and should be considered. Higher velocities of the circulating fluid induce deeper air bubbles into the tank while splashing. On the contrary low velocities lead to less deep penetration. The volume of the air bubbles in the tank is not always proportional to the flow rate. As it was experimentally demonstrated, a slow velocity can lead to more intensive air penetration compared to higher flow operation. Further experiments on filling and draining processes of DBS might be carried out to clarify these problems.

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