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Evaluation of a large solar thermal drainback system for hay bales drying

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Abstract

In this paper, over one year of measurement data of a 127 m² drainback solar thermal system for hay drying is analysed. The study shows that high temperatures in the solar collector loop lead to partial boiling when the system starts, slowing down the filling process. More severe, due to siphon establishment, the flow rate drops and the efficiency of the field is impacted anytime the collector outlet temperature exceeds 83 °C. The existing system is then modelled with the simulation software TRNSYS 16, based on measured data. Four other hydraulic designs are as well modelled and simulated for a comparative analysis. Three use the drainback principle and one represents a “conventional” pressurized system. As expected the results demonstrate that the drainback with load-side heat exchanger has the best thermal performance and the “conventional” system the worst one. The energy yield of the drainback design with collector-side heat exchanger is comparable to the one of the “conventional” system. The parasitic electricity consumption of the solar collector loop pump is also calculated. It varies significantly depending on the system, the most demanding one being the drainback without siphon formation, with a total consumption more than doubled compared to the same system with siphon formation.

Nomenclature:

C_p	specific heat, J kg^{-1} K^{-1}
$E(X)$	expected value, s
E_{pump}	solar collector loop pump energy consumption, kWh
$f_{sav,therm}$	fractional thermal energy savings
H	pump head, m
h_l	head losses between two points of a piping system, Pa
P_1	power consumed by the pump, W
p_{atm}	atmospheric pressure, Pa
P_H	pump hydraulic power, W
p_{top}	pressure at the highest point of the hydraulics, Pa
Q_{aux}	auxiliary heater energy consumption, kWh
Q_{coll}	collector field energy production, kWh
Q_{ref}	energy consumption for the reference system, kWh
t_{fill}	filling time, s
$\dot{V}$	volume flow rate, m³ s^{-1}
ΔH	height between water surface in the storage and highest point of the hydraulics, m
η_{tot}	total pump efficiency
ρ	density, kg m^{-3}
g	gravitational acceleration, m s^{-2}
σ	standard deviation, s

Keywords: *Drainback system, Solar process heat*

1. Introduction

In order to decrease the overall costs of solar thermal systems, one option is to use the drainback configuration, which enables the reduction of both initial investment and maintenance costs (Mugnier et al., 2011). For the solar thermal branch, this target is a priority, as the growth of the solar thermal market has been flattening out during the past years, and Europe is especially stricken by this tendency (Mauthner et al., 2015). For large systems, notably dedicated to process heat or district heating, the use of the drainback technology is rarely documented in the literature and the specificities of their functioning barely addressed (Botpaev et al., in press). Bokhoven et al. (2001) and Mugnier et al. (2011) are so far the main resources dealing with large drainback systems. This paper aims at providing more knowledge on their functioning but also at highlighting their specificities compared to “conventional” pressurized glycol systems. For this purpose, extensive measurement data from an existing large drainback system for hay bales drying are analysed. After presenting the system, the focus is on the filling and draining phases, two specific features of drainback systems. The operation of the system is also studied and especially the impacts of siphon formation on the solar thermal energy yield. Finally,

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five different collector loop configurations are modelled and their energy performances compared. For smaller, single-family house systems, such detailed simulations and comparisons were already carried out by Goumaz and Duff (1981).

2. The studied system

The studied solar drainback system (DBS) is located at a farm in Frankenhausen in Germany. This DBS was built to supply heat for the drying of hay bales during the summer season. It is designed to cover the drying needs of around 300 bales per year, which corresponds to an annual load of 29 MWh. Additionally, it also covers part of the domestic hot water (DHW) and space heating demands of the farm buildings the yearlong and especially during the winter period. The collector field is showed in Fig. 1. It is composed of ten "Solar Roof" flat plate solar thermal collectors from the company Wagner GmbH. They are connected in parallel according to the Tichelmann principle. The total collector field aperture area is 127 m² (138 m² gross area).

Fig. 1: The collector field of the studied drainback system.

The collector field is connected without heat exchanger to two serially coupled heat stores constructed by the company Fsave Solartechnik GmbH. They have a total volume of 42 m³ and are made of polypropylene (PP). The use of polymers presents several advantages – ease of transport and installation, low thermal conductivity, potential for low costs – but requires the storage to remain unpressurized. This is achieved in a simple manner with the drainback configuration with load-side heat exchanger. In order to avoid any pressure variation, the system needs to be open, i.e. the storages are vented to the atmosphere. For the charge and discharge, no stratification device is installed, but horizontal lances are used to reduce the velocity of the heat transfer fluid (HTF) entering and exiting the storages. As no heat exchanger is applied in the solar collector loop and because of the drainback design, pure water is used as HTF. A single Wilo-Top-S 30/10 pump is installed and serves both as filling and circulation pump. Additionally, a motor valve connected to an air vent opens to trigger the draining phase once the pump stops. In Fig. 2 is presented a detailed hydraulic scheme of the above described system. The hay bales drying process is connected to the storage via a water-to-air heat exchanger. It enables the drying of 20 hay bales simultaneously. During a drying cycle, the relative humidity of the bales is decreased from approx. 30 % to 10 %, depending on the harvesting conditions. An auxiliary wood burner is connected to the storages with an external heat exchanger. The same heat exchanger is used for heat and DHW delivery to the farm buildings.

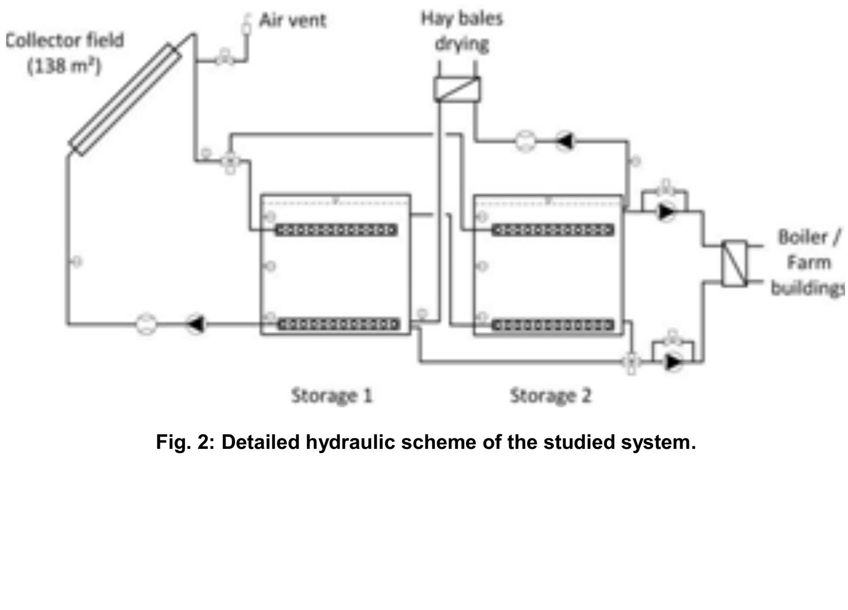

Fig. 2: Detailed hydraulic scheme of the studied system.

The system has been in operation since spring 2012. In August 2014 additional measuring devices were installed, as well as a data logging system. Calibrated temperature sensors were mounted as well as a pyranometer to measure the total irradiation on the collector plane. Fig. 3 presents the energy yield of the collector field over the previous year. In total, with a specific measured radiation of 951 kWh m^{-2} a^{-1}, the collector field delivered about 292 kWh m^{-2} a^{-1} of heat. These values are low as almost two months of data are missing over this period. If only the drying period is considered, between Mai and September, the production amounted to 218 kWh m^{-2}.

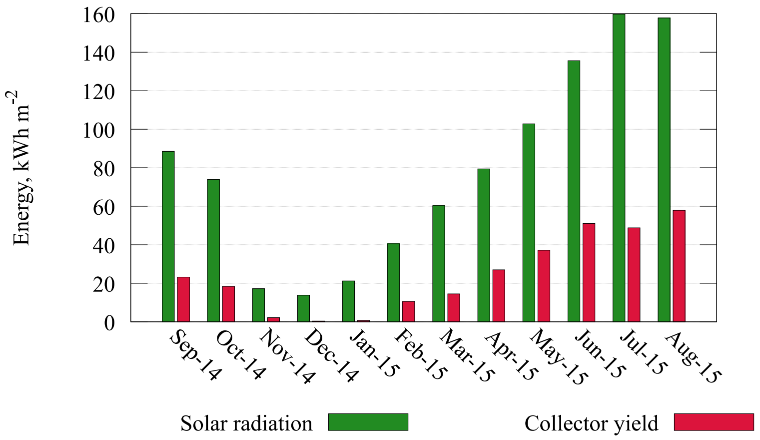

Fig. 3: Measured solar radiation in the collector plane and energy yield from the solar collector field (per m² absorber area) between September 2014 and August 2015. Due to maintenance and monitoring issues 14 days of data are missing in November, 16 between February and March, 12 in April, 12 in May and 3 in June.

3. The filling and draining processes

For a comprehensive analysis of the functioning of DBS, Botpaev et al. (2014) proposed to distinguish the filling and draining phases from the operation phase, the latter being shared by any solar thermal system. In order to better understand the specificities of these two phases in the context of large systems they are examined in detail. The previous work from Jordan et al. (2015) is here extended with additional measurement data, totalling more than 600 complete filling and 300 draining phases. The aim is to identify the phenomena which impact the filling and draining processes of large solar drainback systems.

One should also recall, as stated in Jordan et al. (2015) that the studied system is operated with a so called siphon formation (Fig. 4, left), meaning that water completely fills the flow pipe. Another design, without siphon formation (also called trickle-down design, Fig. 4, right) is also possible and its impact is simulated in section 5. Further details about these configurations can be found in Botpaev et al. (in press).

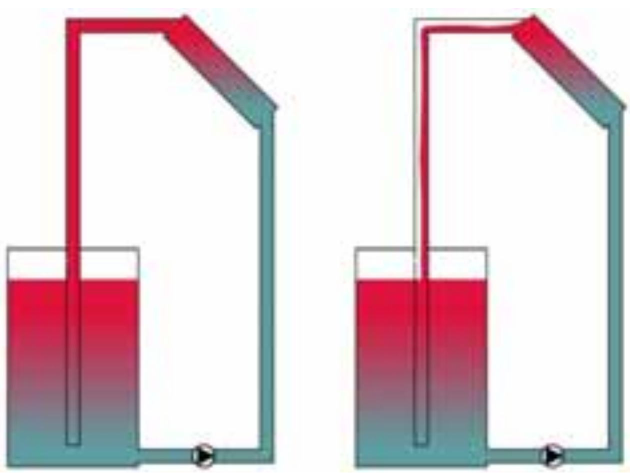

Fig. 4: DBS with siphon formation (left) and without (right). The latter is characterized by the presence of a two-phase flow (air and water) in the flow pipe.

In Fig. 5 and Fig. 6 are shown the relative frequency distribution of the studied filling and draining processes.

Each point has an accuracy of ± 10 s, due to a temporal resolution of the logging device of 10 s. Moreover, from Fig. 7 it appears that the end of the filling phase cannot always be accurately determined, as the flow rate does not always clearly stabilises as the flow rate in case (b) highlights. It was arbitrarily chosen to end a filling phase at the moment when the flow rates does not fluctuate of more than ± 5 % over the next 30 s.

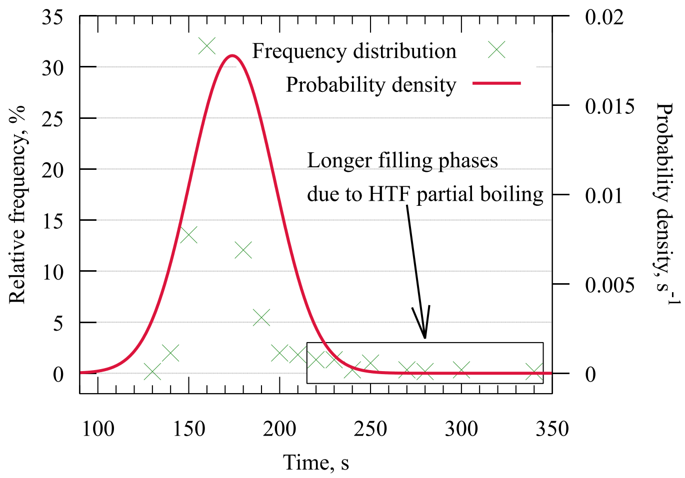

Fig. 5: Frequency distribution and probability density associated to the normal distribution for 605 filling processes. The parameters of the density curve are σ = 22.5, *E(X)* = 170.7.

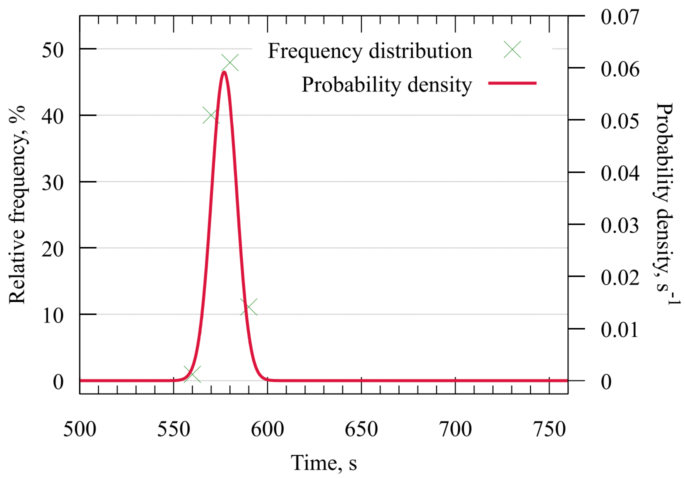

Fig. 6: Frequency distribution and probability density associated to the normal distribution for 315 draining processes. The parameters of the density curve are σ = 6.7, *E(X)* = 576.9.

From the results, it can be seen that the length of the draining phase is rather constant independently from operation conditions, with a standard deviation of 6.7 s (1.2 % of the draining time), in the range of the measurement inaccuracy (Fig. 6). Regarding the filling, the deviation is larger, at 22.5 s (13.1 % of the filling time). This can be explained by the inherent inaccuracy of the measurements as stated previously, but also by the occurrence of longer filling phases lasting up to 340 s, as shown in Fig. 5. A detailed analysis of these longer fillings reveals that they might be caused by a partial boiling of the incoming HTF when inlet temperatures and/or irradiation level are high at the moment of the filling. This conclusion is drawn from Fig. 7. Compared to a "normal" filling process (a), the longer one (b) is characterized by a quick and sharp increase of the collector field outlet temperature shortly after the start of the filling, almost reaching 100 °C. First of all one can notice that the temperature increase in the outlet pipe takes place less than 20 s after the start of the filling, the theoretical minimum time for the fluid to reach the first collector with a flow rate of 1.39 litre s^{-1} (conservative value as the flow rate is fluctuating quite fast during the filling phase). A plausible explanation is that some water should remain in the riser pipe. When the pump starts, it is pushed into the collectors and vaporizes. Secondly it demonstrates that some of the HTF boils in the collector field. This partial boiling most certainly slows down the filling process by increasing the pressure drop in the field. Each significantly longer filling phase is characterized by the same boiling phenomenon. Unfortunately, a lack of sensors did not allow getting more details of where exactly in the field the boiling takes place.

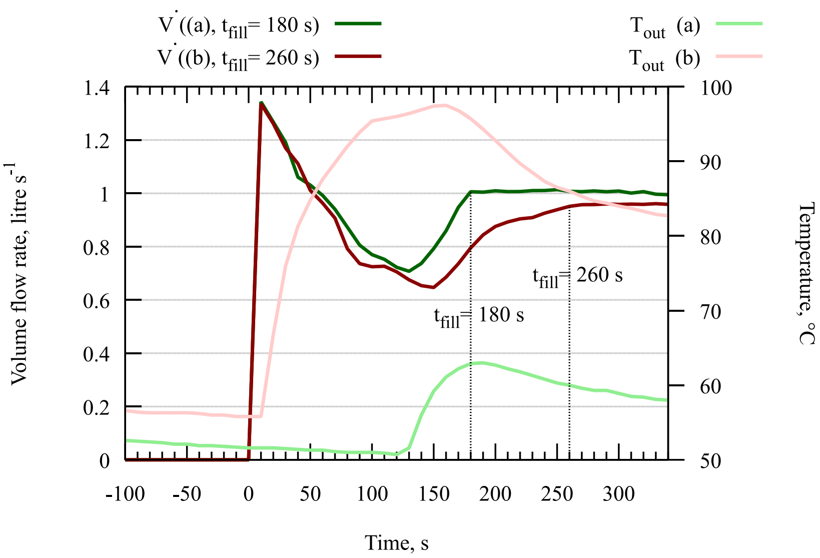

Fig. 7: Flow rate and outlet temperature profiles of two filling processes, one lasting 180 s and one 260 s. t = 0 corresponds to the start of the pump.

In the studied system, the partial boiling of the incoming HTF in the collectors does not appear to prevent the filling process. However depending on the location of the boiling in the field and the position of the collector field temperature sensor, one could imagine a situation where the threshold collector temperature is reached and detected by the sensor (in the studied system 95 °C) thus stopping the pump and causing the system to stagnate. Kratz and van Dam (1999) stated that large drainback fields are difficult to properly fill as siphon creation favours the filling of some rows at the expense of others. This effect contributes to degrade the efficiency of the system as some rows might remain non-filled. The boiling described here might enhance this uncomplete filling as rows where boiling occurs might be even more penalized.

From this analysis it can be concluded that a control strategy for the filling a DBS is always a matter of compromise. The start filling temperature difference should not be too low otherwise the first daily fillings are not stable, i.e. the collectors are cooled down by the incoming HTF which in turns stops the pump. In Frankenhausen, it often happens that the first filling of the day is shortly followed by a draining because of the cooling effect. On the contrary, if the start temperature difference is too high, there is the risk that an already quite warm incoming fluid (in case of relatively high temperatures in the storage) starts to boil. Gößlinghoff (2010) proposed in a patent to fill each parallel row of a drainback collector field successively with the use of motor-valves. Due to the boiling effect highlighted here, such a lengthy filling strategy could in practice not be very effective.

Finally, the power consumption of the pump situated in the solar collector loop was measured during the filling phase. Contrary to what is sometimes mentioned, the power required by the pump during the filling process is on average slightly lower than during operation, with 280 W against 285 W.

4. DBS and underpressure

Having a non-pressurized system vented to the atmosphere presents some advantages such as the reduction of the number of components (no expansion vessel, no safety valve) and the possibility to use of polymer materials. Nevertheless a system with siphon formation requires a careful design especially considering the risk of boiling. Indeed, from a fluid mechanics perspective, when applying an energy balance to the HTF between the highest point of the solar collector loop hydraulics and the end of the flow pipe assuming a turbulent regime, a steady flow and the fluid incompressible, one obtains the following equation (Crowe, 2009):

$$p_{top} = p_{atm} - \rho g \Delta H + h_l \qquad \text{(eq. 1)}$$

Equation 1 shows that the pressure at the top of the hydraulics might be lower than atmospheric pressure due to a siphon-like effect. It also explains that in order to reduce this potential underpressure one might either decrease the height difference between the water level in the storage and the highest point of the hydraulics (*ΔH*) or increase the head losses in the flow pipe (h_l). Kratz and van Dam (1999) proposed to use a "trickling-down" flow in the flow pipe also for large solar DBS, avoiding the formation of the siphon. In the drainback configuration with load-side heat exchanger, this issue is particularly relevant as *ΔH* can be quite important depending on the respective location of the collectors and the storage. In Frankenhausen *ΔH* is equal to 6.5 m. A first approximate modelling of the pressure drops in the solar collector loop showed that with a flow rate of 0.99 litre s^{-1} (3500 kg h^{-1}) a negative pressure relatively to atmospheric pressure should occur in the solar collector loop. To examine the actual impact of this undesired phenomenon on the performance of the system, two consecutive sunny days with high collector outlet temperatures are presented in Fig. 8.

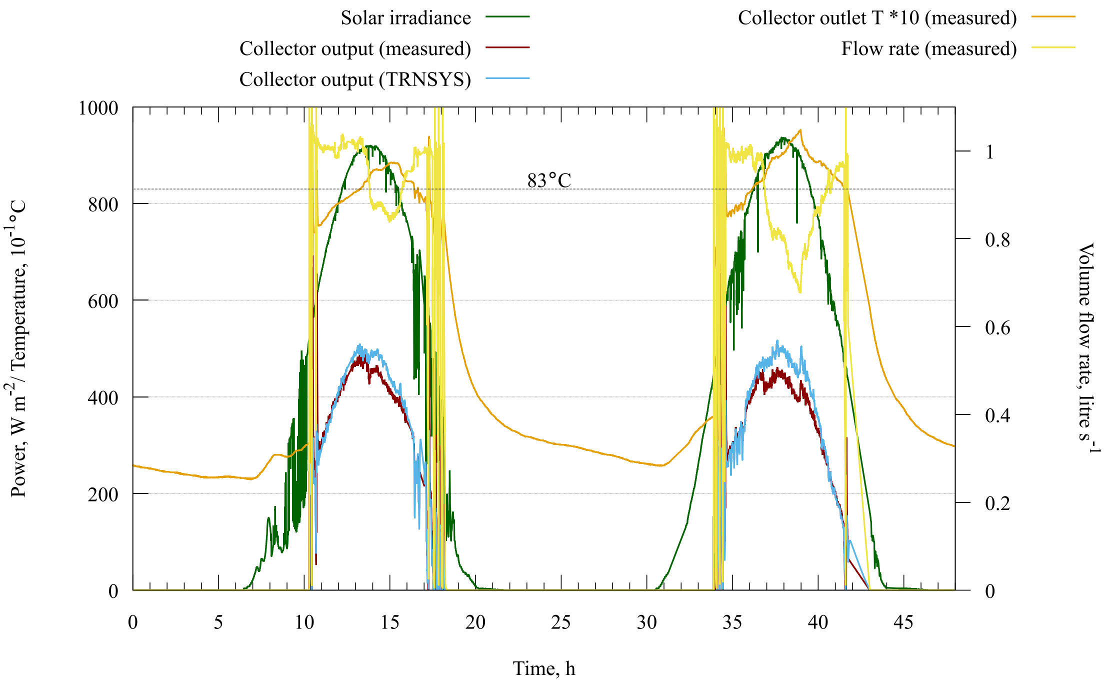

Fig. 8: Measured and calculated collector field power output over two consecutive sunny days in August 2015, with collector outlet temperatures above 83°C.

From the figure it appears that once the outlet temperature of the collector reaches a certain threshold, the flow rate sharply decreases and remains lower than during "normal" operating conditions. From Fig. 9, one can notice that this threshold temperature is around 83 °C and that after this point, the flow rate decreases linearly from 0.028 litre s^{-1} (100 litre h^{-1}) for each degree kelvin the collector field outlet temperature increases. A comparison of a TRNSYS simulation of the solar collector loop power output with actual measured data for these two days also shows that nonetheless drops the flow rate, but the efficiency of the collectors is also affected. While the relative deviation between measured and simulated power output is in a range of ± 5 % during periods when the outlet temperature is lower than the threshold temperature, this deviation reaches up to 15 % after the threshold is passed. It was however not possible to precisely determine the impact of the boiling on the collector efficiency, due to insufficient measurement data. A detailed CFD modelling would be necessary to understand how the heat transfer between the absorber and the collector HTF is affected by partial boiling. However it was not the goal of this paper.

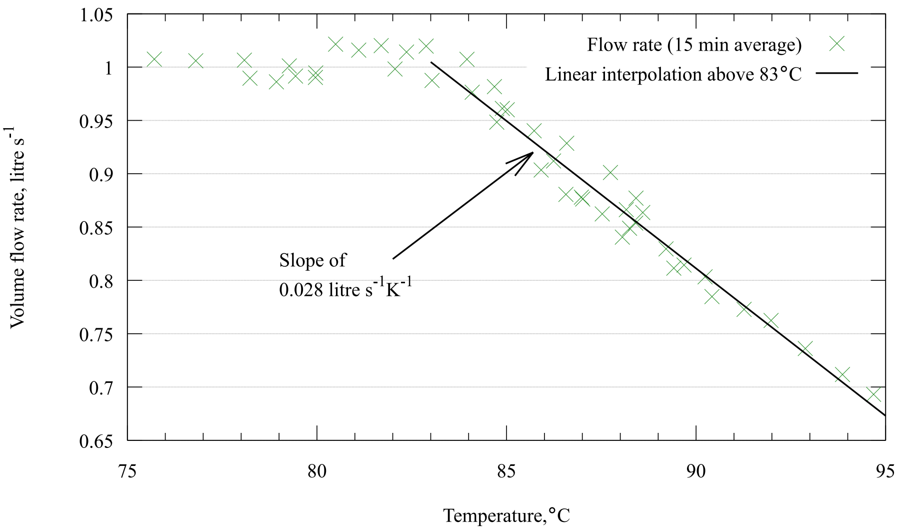

Fig. 9: Solar collector loop flow rate as a function of the collector field outlet temperature during steady irradiation periods for the two days shown in Fig. 8 (15 minutes average values).

5. System simulations

In order to compare the performance of the DBS installed in Frankenhausen with other designs, the actual system was modelled with the use of the simulation software TRNSYS 16. Some parameters were then changed in order to simulate other system designs. In Tab. 1 are summarized the five different system designs simulated. They are based on the work from Botpaev et al. (in press). The parameters of the model were configurated in order to represent as closely as possible the real system. The system was simulated over the period going from the 1st of May to the 30th of September, which corresponds to the hay drying season. The total drying load was adjusted to meet the 29 MWh required to dry 300 bales a year and the total DHW load during the period was set according to measurement data to 6.5 MWh. The load profiles were also extracted from measurement data and slightly adjusted for each simulation in order to reach the same loads in all cases. The weather data applied were extracted from hourly data for Kassel, Germany, a city located 10 km south from Frankenhausen.

Tab. 1: Description of the simulated systems and their main specificities.

System number	Description	Siphon	HTF	Pump capacity, W	Collector-side heat exchanger	Other specificity
1	Actual system: DBS with load-side heat exchanger	Yes	Water	285	No	Decreasing flow rate above 83°C outlet temperature
2	DBS with load-side heat exchanger without siphon formation	No	Water	585	No	
3	"Conventional" system	N/A	Antifreeze mixture	375	Yes	
4	DBS with collector-side heat exchanger	Yes	Water	285	Yes	Additional drainback tank (DBT)
5	DBS with collector-side heat exchanger and glycol	Yes	Antifreeze mixture	375	Yes	Additional DBT

In order to take into account some specificities of a DBS, the boiling effect described before was simulated with a flow rate decreasing above a collector outlet temperature of 83 °C, according to the profile from section 4. When a DBT is present, it was considered that it could be installed high enough to avoid a critical underpressure. Moreover, the collectors were considered with a varying heat capacity depending whether they are or not filled with HTF. The efficiency parameters of the collector were taken from data from the manufacturer. Some studies highlighted that the type of HTF used has an impact on the efficiency coefficients of a collector (Bava et al., 2014). This effect was however not considered in the simulations, therefore the same collector coefficients were used both with water and a mixture of glycol and water as HTFs.

Concerning the flow rate and the pumping power, the pump in the solar collector loop was run at a fixed speed as in the actual system. For simplification the HTF properties were taken at a temperature of 60 °C and pumping energy needs and flow rates were also assumed constant (except for the actual system above 83 °C) and calculated for this temperature. For water, data were extracted from Verein Deutscher Ingenieure (2006). When a mixture of glycol and water was used, the data were taken from Tyforop Chemie GmbH (2009) for a volume concentration of glycol in the mixture of 40 %. In all cases, the capacity flow rate ($\dot{V}\rho C_p$) was kept constant in the solar collector loop. Moreover in systems with a collector-side heat exchanger, an overall heat transfer coefficient of 5000 W K^{-1} was considered for the heat exchanger. Given the short length of the filling phase compared to the operation phase and the minimal difference of power required by the pump between these two phases (see section 2) the power consumption difference was neglected.

In order to determine the pump capacity required in the solar collector primary loop for each case, measured values for the actual system and the total pump efficiency given by equation 2 (Grundfos, 2004) were used.

$$\eta_{tot} = \frac{P_H}{P_1} = \frac{\rho g \dot{V} H}{P_1} \quad \text{(eq. 2)}$$

The hydraulics of system 1 was modelled in a spreadsheet and calibrated according to measurement data. In its actual working conditions the total efficiency of the pump amounts to 16 %. To estimate the pumping power required by the other systems, the same hydraulics was assumed in all cases (same pipe diameters). With the help of the model, the working point of each system was calculated. It was then assumed that for this working point a pump of 16 % overall efficiency could be found. Compared to the actual system, the results show that the systems running with glycol require 32 % more pumping power and the needs of the DBS without siphon formation are 106 % higher.

To compare the thermal performance of the systems, the fractional thermal energy savings $f_{sav,therm}$ defined in eq. 3 is used (Letz et al., 2009).

$$f_{sav,therm} = 1 - \frac{Q_{aux}}{Q_{ref}} \quad \text{(eq. 3)}$$

Q_{aux} designates the energy supplied by the auxiliary wood boiler and Q_{ref} the sum of the different heating loads of the reference system, i.e. the hay drying load, the DHW load and the losses of the two heat stores. The auxiliary wood boiler is also assumed to be the boiler in the reference case, therefore the boiler efficiency is considered equal in both the reference and the simulated systems.

Finally, the main control strategies applied are the following:

- The control of the solar collector loop pump differs depending whether the system is drainback or not. It starts when the difference between the collector temperature and the temperature at the bottom of storage 1 (see Fig. 2) is higher than 12 K respectively higher than 7 K and stops in both cases when it drops below 3 K.
- Storage 2 has priority when the collectors are in use and is loaded as long as the collector temperature is higher than the temperature at its top. If this is not the case, storage 1 is loaded.
- The water returning from the DHW load is directed to the bottom of storage 2 as long as its temperature is higher than the temperature at the top of storage 1. Otherwise it flows at the bottom of storage 1.

The results of the simulations (Tab. 2) show that the system performing thermally the best is the DBS without siphon formation in the flow pipe (2). This is due to the fact that system 1 is penalized due to a lower boiling point in the collector field, which in return affects Q_{coll}. Over the period the collector outlet temperature of system 1 is above the threshold temperature (83 °C) during 27 hours, which corresponds to 3.4 % of the total running time of the solar pump. However to achieve this slightly better performance the energy consumption of the pump in system 2 is more than doubled (108 % increased) due to the fact that the pump continuously needs to overcome the height difference between the storage and the collector field.

The conventional system (3) is thermally performing worst as it is penalised by the presence of the heat exchanger and the use of glycol. Compared to system 1, $f_{sav,therm}$ is 3.9 % lower and the energy required by the pump to circulate the HTF is 46 % higher.

The most widespread drainback design on the market is the DBS with collector-side heat exchanger and an additional DBT (Botpaev and Vajen, 2014). Systems 4 and 5 aim at reproducing these designs, one using water as HTF (4) and the other one a mixture of glycol and water (5). It is indeed nowadays a very common trend to use glycol instead of pure water in DBS (Botpaev and Vajen, 2014). Both systems are performing very similarly to the conventional system. When comparing the two HTF, the difference in thermal performance is negligible, but the system with glycol (5) requires 32 % more electrical energy than the one with water (4) to circulate the HTF in the solar primary loop, due to higher friction losses.

Finally a configuration with a load-side heat exchanger and an additional DBT to avoid the underpressure could also be thought of but was not simulated here as such a design would increase the static pressure in the storages, which is not feasible with the PP storages used in Frankenhausen.

Tab. 2: Simulation results for the different studied systems over the drying period.

System	Q_{aux}, kWh	Q_{ref}, kWh	Q_{coll}, kWh	Q_{coll}, kWh m^{-2}	$f_{sav,therm}$, %	Solar collector loop pump running time, h	E_{pump}, kWh	E_{pump}/Q_{coll}, %
1	13137	39752	27878	219	67.0	787	223	0.8
2	12463	39754	28349	223	68.6	799	467	1.6
3	14646	39700	26082	205	63.1	876	328	1.3
4	14542	39627	26547	209	63.3	905	257	1.0
5	14512	39638	26488	208	63.4	907	340	1.3

6. Discussion and additional knowledge gained from the monitoring

The simulation results show that the two DBS without collector-side heat exchanger performs thermally slightly better than the others. They are therefore the recommended designs when the conditions are favourable, especially when the boiling risk does not exist.

When comparing other systems (notably 3, 4 and 5) the thermal performances are very similar. In these cases one decision criteria could be the pumping energy. Overall, the study showed that the pumping energy can vary quite significantly, from one system to the other. The conventional system requires 46 % more energy over the period than system 1, while the consumption of the DBS without siphon (2) is as much as 108 % higher. With today's efficient pumps sold on the European market, the relative consumption of the pumps between the different systems would not change (assuming that the same efficiency for the different working points can be achieved with actual pumps, which is in reality not the case). In terms of absolute consumption nevertheless choosing one configuration compared to the other has nowadays a much lower impact. For system 1 for instance, with a pump having a total efficiency of 35 %, which is realistic considering today's pumps, the total consumption over the period would drop from 223 kWh down to 102 kWh, which corresponds to 0.4 % of the total solar energy gain.

The results presented here are specific to the studied system and its design. It would be difficult to find a system with similar load profiles, control strategies, impact of the partial boiling on the flow rate, etc. However, they aim at showing some trends of how different DBS system designs would comparatively perform but also how DBS perform against conventional systems. Furthermore, the results might be conservative, as some authors recommend to decrease the collector efficiency when the glycol concentration in the HTF increases (Bava et al., 2014), which was not considered here. In this situation, the conventional system would be further penalized compared to DBS using water as HTF. Finally, the comparison is limited in this paper to the energy performance of the systems. One should additionally carry out a detailed cost analysis to get the whole picture of the respective advantages and drawbacks of each system against the others.

The monitoring of the field over more than a year also gave the opportunity to gain additional knowledge about the design of the system. As it was already mentioned in Jordan et al. (2015) the position in the storage of the sensor controlling the pump is very important. The tank outlet manifold and the sensor should be positioned at the same height. In Frankenhausen, the sensor is slightly lower than the outlet which causes some energy loses, as the pump is running longer as it should. Between September 2014 and August 2015, the measured losses amount to 16.5 kWh m^{-2} a^{-1} of absorber area, which corresponds to 5.6 % of the total production of the collector field.

Finally a last issue which was encountered with the system is the deposit of lime. Its presence in the water was responsible for the blocking of the heat exchanger between the wood burner and the storage. To solve this problem, the water in the heat stores was then demineralised.

7. Conclusions

In this work several aspects of the functioning of a large drainback system for hay drying have been studied. Extensive measurement data demonstrated that the filling phase might be slowed down when the incoming HTF starts to boil in some parts of the collector field. In Frankenhausen the result is an increase of the length of the filling phase, but on even larger fields the consequences could be worse. Partial filling or early draining could result. To minimize this issue, the position of the collector field temperature sensor appears to be fundamental. The draining phase is on the contrary not significantly impacted by varying operating conditions.

Boiling is also an issue especially with the load-side heat exchanger configuration. In the studied case water starts to boil in the collector around 83 °C because of the underpressure created by the siphon formation. This phenomenon does not completely prevent the functioning of the solar collector loop but reduces the flow rate of 0.028 litre s^{-1} per degree kelvin above 83 °C and degrades the collector efficiency. The degradation is not quantified in this paper.

In a next step, different DBS designs and one “conventional” system have been simulated based on the configuration and the loads of the existing system in Frankenhausen. The simulations ran between May and September, the drying period. The results show that from a thermal point of view the fractional energy savings are 3.9 % higher with the applied drainback design compared to a “conventional” system. This improvement could reach 5.5 % if no boiling occurred in the collector field. This would however be reached at the expense of the pump electrical energy consumption, which would more than double, but still amounting to less than 2 % of the solar thermal energy gain. Overall, when considering pumping energy, resorting to water as HTF is always beneficial. If the system in Frankenhausen had a “conventional” design, the pump would require 46 % more energy. From a thermal perspective it was also shown that a DBS with collector-side heat exchanger performs very similarly to a “conventional” system.

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8. References

Bava, F., Furbo, S., Brunger, A., 2014. Correction of collector efficiency depending on fluid type, flow rate and collector tilt. IEA-SHC Tech sheet 45.A.1.

Bokhoven, T.P., van Dam, J., Kratz, P., 2001. Recent experience with large solar thermal systems in the Netherlands. Solar Energy 71 (5), 347–352.

Botpaev, R., Louvet, Y., Perers, B., Furbo, S., Vajen, K., in press. Drainback Solar Thermal Systems: A Review. Solar Energy.

Botpaev, R., Orozaliev, J., Vajen, K., 2014. Experimental Investigation of the Filling and Draining Processes of the Drainback System (Part 1). Energy Procedia 57, 2467–2476.

Botpaev, R., Vajen, K., 2014. Drainback systems: market overview, in: Konferenzband 11. Internationale Konferenz für solares Heizen und Kühlen, Gleisdorf, Austria.

Crowe, C.T., 2009. Engineering fluid mechanics, 9th ed. Wiley, Hoboken, NJ.

Gößlinghoff, C.-H., 2010. Solaranlage mit Drain-Back-System und ein Verfahren zum Betreiben einer solchen F24J 2/46.

Goumaz, J.Y., Duff, W.S., 1981. Comparison of drain-back and dual liquid solar heating and domestic hot water systems, in: Proceedings of the International Solar Energy Society Congress, pp. 372–379.

Grundfos, 2004. Pump Handbook, Bjerringbro, Denmark.

Jordan, U., Louvet, Y., Jaradat, M., Addy, J., Fleig, D., Vajen, K., 2015. Erfahrungen mit einem offenen Sorptionskreislauf zur Trocknung von Prozessluft in Kombination mit einer Drain-Back-Solaranlage, in: 25. Symposium Thermische Solarenergie. 6. bis 8. Mai 2015, Kloster Banz, Bad Staffelstein. OTTI, Ostbayer. Technologie-Transfer-Inst, Regensburg.

Kratz, P., van Dam, J., 1999. Method for starting a system of multiple solar collectors F24J 2/42.

Letz, T., Bales, C., Perers, B., 2009. A new concept for combisystems characterization. The FSC method. Solar Energy 83 (9), 1540–1549.

Mauthner, F., Weiss, W., Spörk-Dür, M., 2015. Solar Heat Worldwide Markets and Contribution to the Energy Supply 2013. AEE Intec, IEA SHC, Gleisdorf, Austria.

Mugnier, D., Casals, L., Siré, R., Le Denn, A., 2011. Drainback systems as an efficient and safe solution for solar DHW installations: practical experience, in: Proceedings of the ISES Solar World Congress 2011, pp. 621–632.

Tyforop Chemie GmbH, 2009. Tyfocor® L. Concentrate for long-term antifreeze and corrosion protection of heating and cooling circuits, solar and heat pump systems, Hamburg, Germany.

Verein Deutscher Ingenieure, 2006. VDI-Wärmeatlas. [Berechnungsunterlagen für Druckverlust, Wärme- und Stoffübertragung], 10th ed. Springer, Berlin, Heidelberg.