Introduction to stagnation control and stagnation prevention

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Outline

Introduction to stagnation / overheating

- Definition of terms

    ▪ Stagnation and Overheating

    ▪ Stagnation control and stagnation prevention

    ▪ Emptying behavior

Solutions for sound overheating / stagnation behavior in *FPC and ETC* solar process heat applications

    ▪ Concepts and measures to cope with plant stagnation (stagnation control)

    ▪ Concepts and measures to avoid plant stagnation (stagnation prevention)

    ▪ Stagnation prevention measures realized in the SolarBrew project

Definition of terms

Stagnation

- Stagnation describes the state of a solar thermal system, in which the flow in the collector loop is interrupted and solar radiation is further absorbed by the stagnating collector.

- Stagnation can be triggered by technical defects (e.g. failure of the solar pump), power outages or lack of heat demand. In these cases the collectors will reach its specific maximum absorber temperatures (= equilibrium or stagnation temperature). As a consequence evaporation of the collector fluid occurs and energy is transported very effectively from the collector to other system components and leads to high temperature loads.

Overheating

- A solar thermal system is overheating as soon as the design operating temperature is exceeded and until equilibrium (stagnation) temperature is reached.

- Overheating occurs if the energy delivery by the collectors exceeds the energy demand and heat storage capacity. If no precautions are taken, the collectors will then soon reach their equilibrium (stagnation) temperature.

Definition of terms

Stagnation control

- Stagnation control is necessary if stagnation is an accepted operation mode and hence includes measures to prevent the solar loop components from severe system damages caused by high temperature and pressure loads caused by stagnation.

  - good emptying behavior of the collectors and the entire collector field is favorable,

  - large expansion vessels are needed (able to absorb both liquid expansion and liquid expelled due to steam formation),

  - collector loop components and compound materials need to be maximum temperature resistant (dependent from collector loop characteristics)

  - Less temperature resistant components and compound materials need to be protected by means of (passive) cooling devices and/or special hydraulic settings

  - Stagnation control may operate independent from electrical supply or only low capacity uninterruptible power supply (UPS) is needed (e.g.: for solar loop control + motor operated control valve)

Definition of terms

Stagnation prevention

- Stagnation prevention is necessary if stagnation is **not** an accepted operation mode and hence includes measures to prevent a solar thermal system from stagnation.

  - good emptying behavior of the collectors and the entire collector field is favorable but not necessary,

  - small expansion vessels are sufficient (able to absorb liquid expansion only),

  - collector loop components and compound materials need to be temperature resistant up to a defined maximum <u>overheating temperature</u>.

  - Stagnation prevention relies on an active and working control and cooling device and hence is <u>dependent from electrical supply</u>. For proper stagnation prevention high capacity uninterruptible power supply (UPS) is needed (e.g.: for solar loop control + motor operated valves **+ pumps + active cooling devices**)
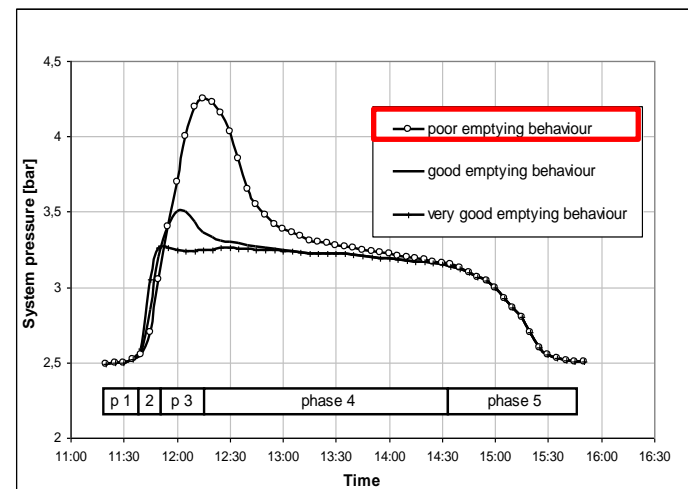
Definition of terms

Emptying behavior (collectors)

- Influence of internal collector piping arrangement on the emptying behavior

  - Collector examples with poor emptying behavior

normal operation of the collector

stagnation condition
evaporation in the collector
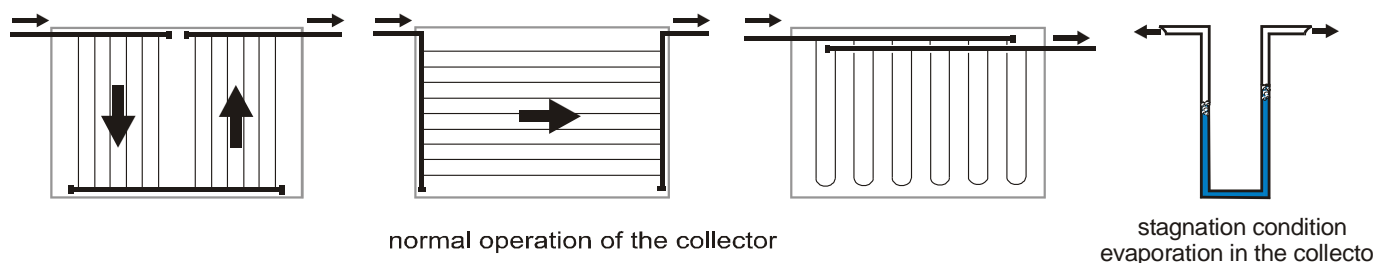
- In case of stagnation liquid remains trapped within the collector.

- → leads to high maximum steam power values **(100 – 200 W/m²)** and longer stress periods

- → saturated steam effectively transports energy throughout the system stressing system components also in quite distance from the collector field
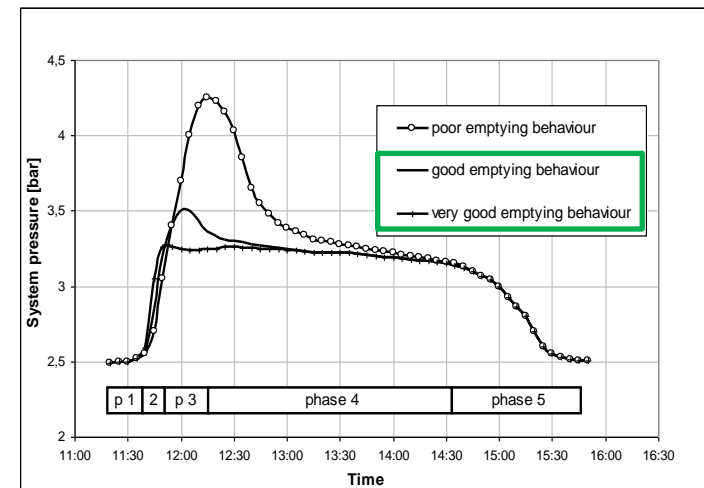
Definition of terms

Emptying behavior (collectors)

- Influence of internal collector piping arrangement on the emptying behavior

  - Collector examples with good emptying behavior

normal operation of the collector

stagnation condition
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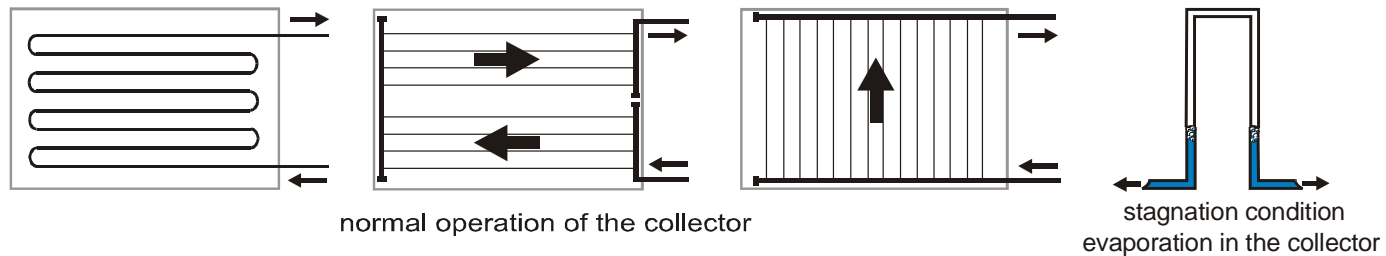
  - In case of stagnation liquid can be quickly displaced by steam

  - → leads to lower maximum steam power values **(50 W/m²)**

  - → system components in distance from the collector field are less stressed

Definition of terms

Emptying behavior (collector field)

- Influence of system hydraulics on the emptying behavior of collectors
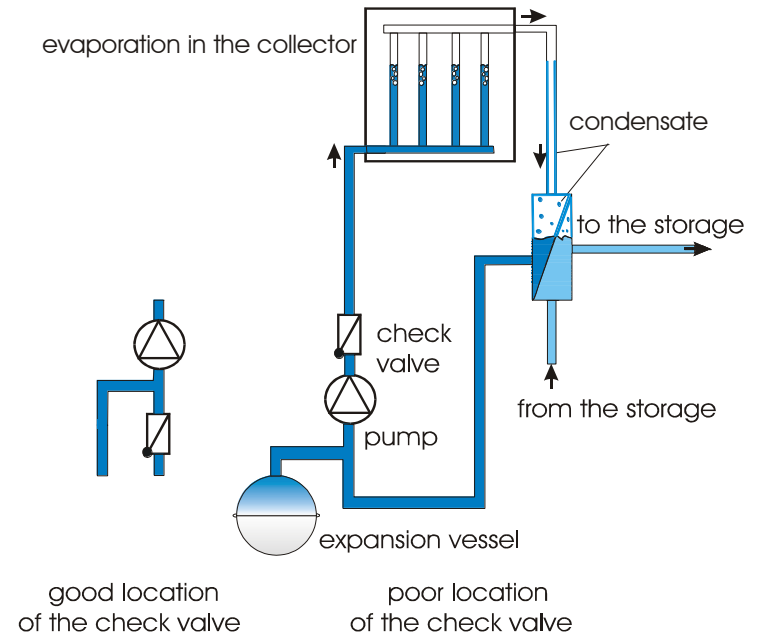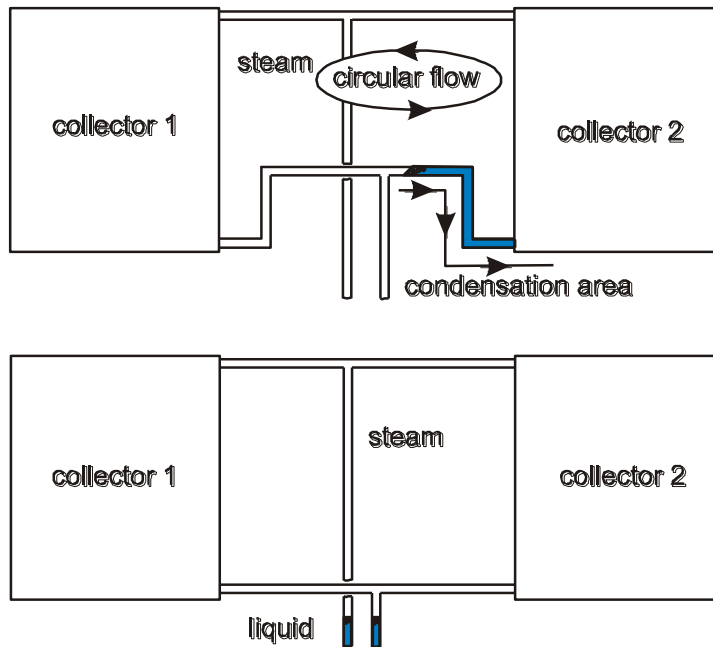
- Examples of the interconnection of two collectors which empty well with poor emptying behavior (top figure) and good emptying behavior (bottom figure) of the system.

- Good and poor arrangement of the components (check-valve!) of the primary solar circuit.

Stagnation control

Concepts and measures to cope with plant stagnation

- **large expansion vessels**

  - If stagnation is an accepted operating mode, the expansion vessels need to be designed to absorb both the liquid expansion as well as the **steam volume** at stagnation conditions.

  - 1) The steam volume for a solar thermal system can be calculated from the **maximum specific steam power – MSP (W/m²)** and mainly depends on the emptying behavior of the collectors used, the system filling pressure and the solar radiation.

    - MSP – good emptying behavior: ≤ 50 W/m²

    - MSP – bad emptying behavior (standard collectors): ≤ 120 - 140 W/m²

    - MSP – bad emptying behavior (advanced collectors): ≤ 200 W/m²

  - 2) **The maximum steam range** can be calculated from the MSP and the dissipation losses through the solar loop piping (around 25 to 30 W/m for pipes where the insulation thickness equals the outer tube diameter)

  - 3) From the maximum steam range **the maximum steam volume V_S** can be calculated (= volume of the collector fluid replaced by steam)

Stagnation control

Concepts and measures to cope with plant stagnation

- **large expansion vessels**

  ▪ The common procedure to calculate the nominal volume of the expansion vessel V_N has to be modified to:

$$V_N \geq \frac{V_M * n + V_V + V_S}{N}$$

$$n = \frac{\rho_{cold}}{\rho_{hot}} - 1 \approx 0.09$$

$$N = \frac{P_m - P_{diff} + 1 - (P_0 + 1)/0.9}{P_m - P_{diff} + 1} \leq 0.5$$

$$P_{diff} \approx H_{diff} * \rho_{cold} / 10000$$

|	
V_N	Nominal volume of the expansion vessel [l]
V_M	Entire volume of the heat transfer medium [l]
V_V	Spare liquid in the expansion vessel [l]
V_S	**Maximum steam volume [l]**
N	Expansion factor (approx. 0.09 to ~120 °C for 40% propylene glycol)
N	Maximum operational capacitance of the expansion vessel <= 0,5 [-]
P	Density of the heat transfer medium [kg/m³]
P_m	Maximum allowable pressure = opening pressure of the safety valve minus 20% [bar]
P_0	Preset pressure in the expansion vessel [bar]
H_{diff}	Altitude of expansion vessel minus altitude of safety valve [m]
P_{diff}	Pressure difference corresponding to Hdiff [bar]

*Pressures are above atmospheric (bar_{gauge}).

Stagnation control

Concepts and measures to cope with plant stagnation

- **passive cooling devices: air cooler**

  - for smaller solar thermal systems (< 50m²) with bad emptying behavior, a simple automatically controlled air cooler (e.g. finned tubes) in the primary solar circuit can limit the steam volume <u>in case of stagnation</u>

  - operates independent from electrical supply
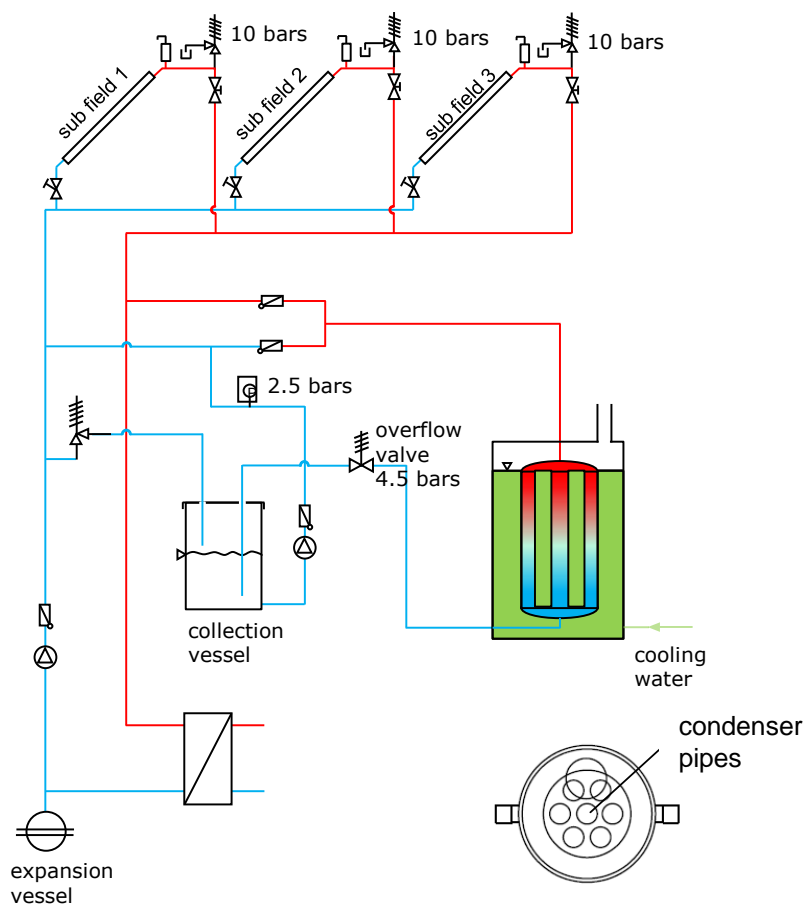
  - only for small solar thermal applications
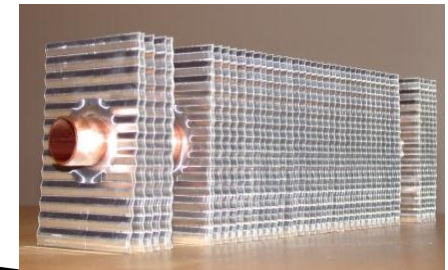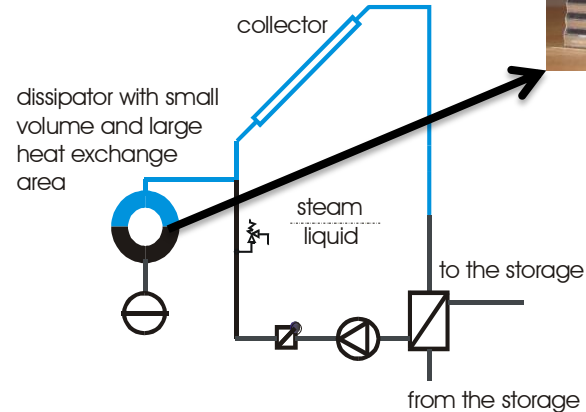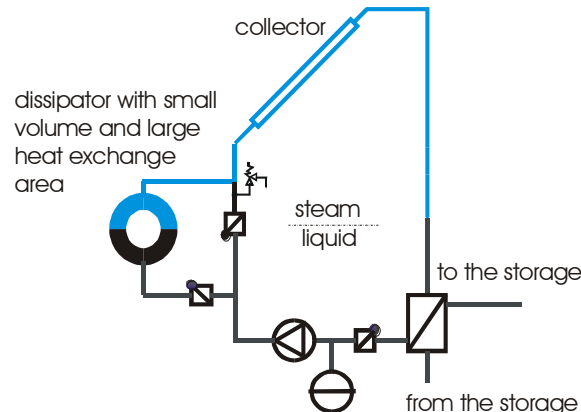
Cooling capacity ≈ 750 – 1,000 W/m

Stagnation control

Concepts and measures to cope with plant stagnation

- **(pressure-controlled) evaporative cooling device**

- In case of stagnation the overflow valve opens due to system overpressure and the medium is pushed through the cooler.

- In the cooler the medium is condensed and cooled down below 100°C before the liquid medium enters the (atmospheric) collection vessel.

- As soon as the system pressure goes below a defined pressure (e.g. 2.5 bars), a filling pump automatically re-fills the system.

- The concept works independent from the electrical supply

- Good emptying behavior of the system is favorable

- The expansion vessels in the solar primary loop need to be designed for liquid expansion + steam volume

- Little practical experience (one demonstration in Austria with 500m²)

Stagnation control

Concepts and measures to cope with plant stagnation

- **System "Ritter XL Solar**
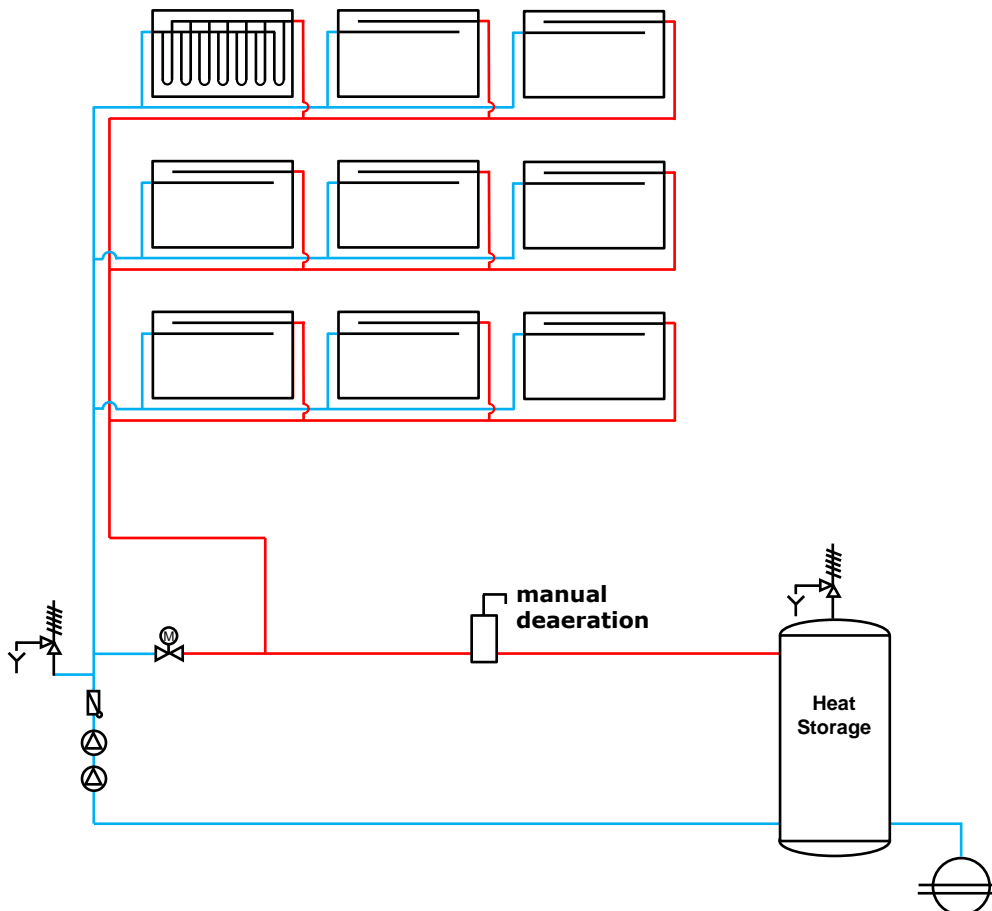
- In case of stagnation the motor-operated ball valve opens (e.g. if max. temperature in the storage is reached) and the system is emptied via both the return and the supply line.

- In this special arrangement from Ritter XL Solar no temperature-sensitive components are harmed in the entire solar loop and no system separation is necessary (water-based system).

- The system is refilled automatically by the expansion equipment (pressure holding system or expansion vessels)

- A low capacity (and hence cheap) UPS is needed to operate the controller and the motor-valve in case of power outages.

- The expansion equipment for the entire system need to be designed for liquid expansion + steam volume

Stagnation prevention

Concepts and measures to avoid plant stagnation

- **active cooler solutions: water/water HEX**
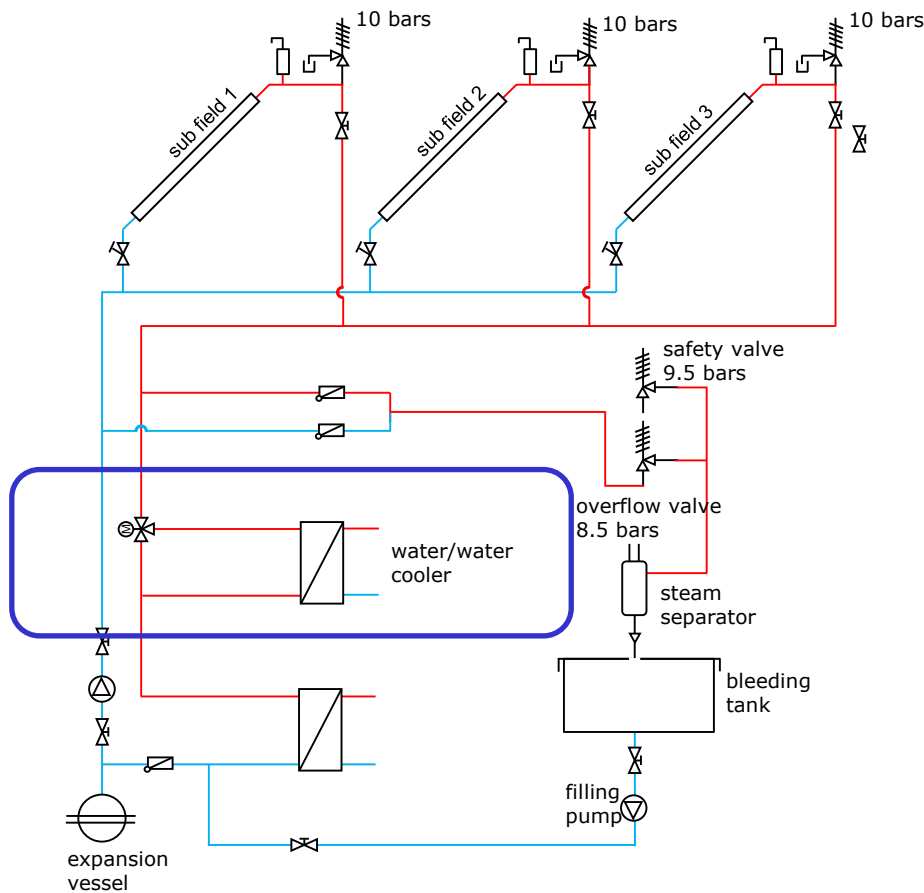
- In case of system overheating a water cooler (water/water HEX) is activated by the control system as soon as a max. temp. is detected in the solar supply loop.

- In case of emergency an overflow valve opens and medium passes a steam separator before the liquid medium is released to a bleeding tank.

- As soon as plant pressure is lower than the activation pressure of the overflow valve, the system can be re-filled again (filling pump).

- A medium capacity UPS is needed to operate the controller, a motor-valve and the pump on the cooling water side in case of power outages.

- Cheap solution

- High demand for resources (cooling water)

- The expansion equipment need to be designed for liquid expansion only

Stagnation prevention

Concepts and measures to avoid plant stagnation
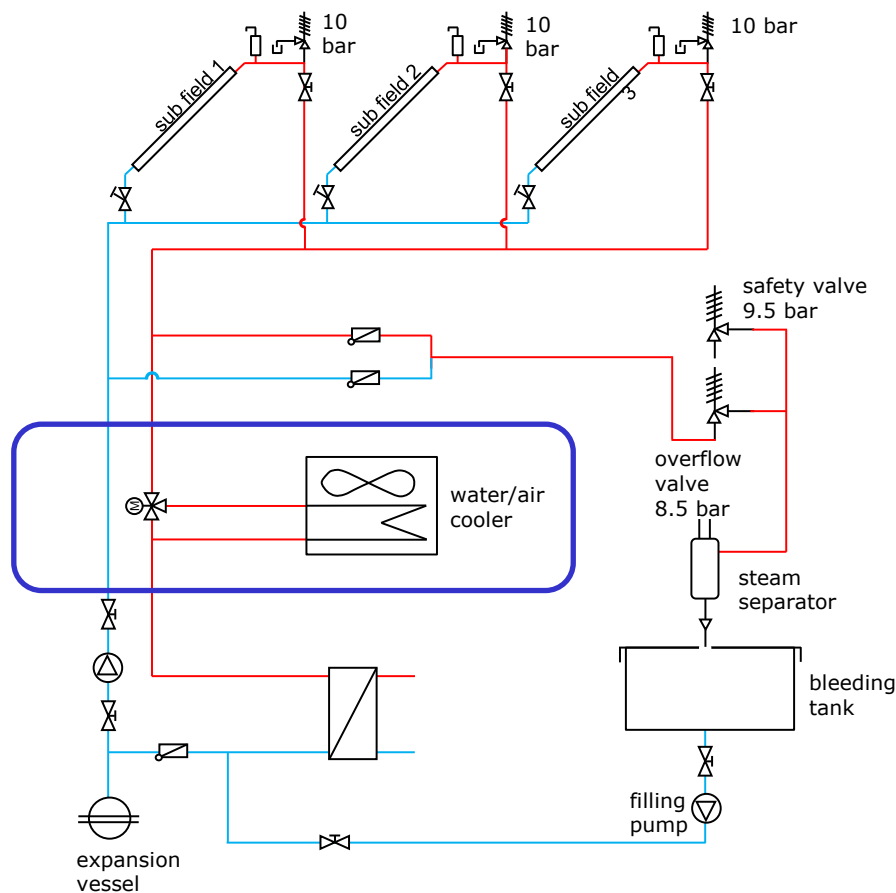
- **active cooler solutions: water/air HEX**

- In case of system overheating an air cooler (water/air HEX) is activated by the control system as soon as a max. temp. is detected in the solar supply line.

- In case of emergency an overflow valve opens and medium passes a steam separator before the liquid medium is released to a bleeding tank.

- As soon as plant pressure is lower than the activation pressure of the overflow valve, the system can be re-filled again (filling pump).

- A high capacity UPS is needed to operate the controller, a motor-valve and the air cooler in case of power outages.

- Expensive air cooler needed and high parasitic electricity demand for operation

- The expansion equipment need to be designed for liquid expansion only

Stagnation prevention

Concepts and measures to avoid plant stagnation

- **Drain-back solutions**

DB-Tank
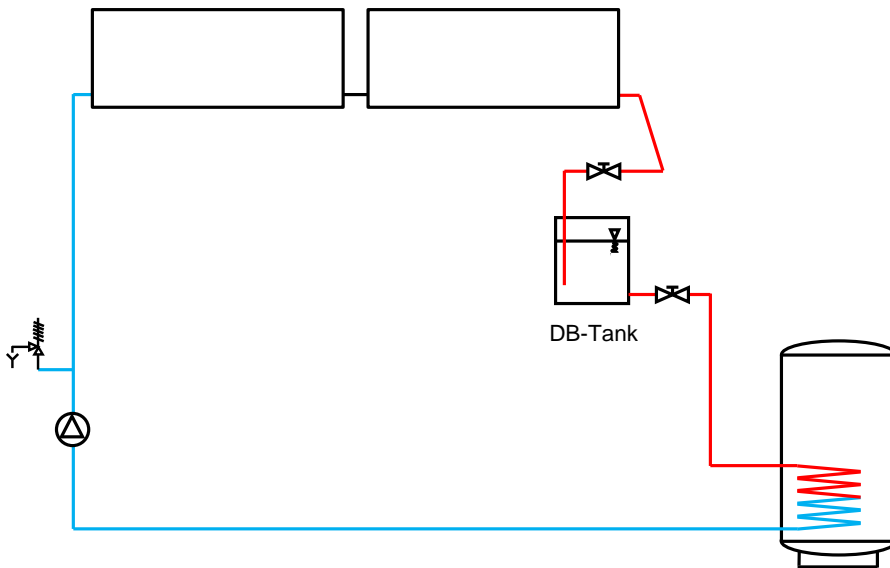
- In case of system overheating the solar loop pump stops (e.g. temperature controlled) and the entire collector field is drained automatically.

- The drained collector fluid is collected in a drain back tank from where the system can be re-filled again by the solar loop pump.

- Perfect emptying behavior is required (the entire collector field wiring to the drain back tank need to be routed downwards)

- The concept works independent from the electrical supply

- No separate expansion equipment - liquid expansion is absorbed by the DB-tank

- No practical experiences in large scale solar process heat applications so far

Stagnation prevention

Example SolarBrew

- 1,500m² flat plate collectors

- 200m³ pressurized storage tank

- Expansion vessels in solar primary and secondary loop designed to absorb liquid expansion only.

- Stagnation prevention is done by means of 1) night cooling and 2) active water/water HX

- A pressure controlled safety valve opens if all other proceeding measures fail (due to malfunction, power outages, etc...).
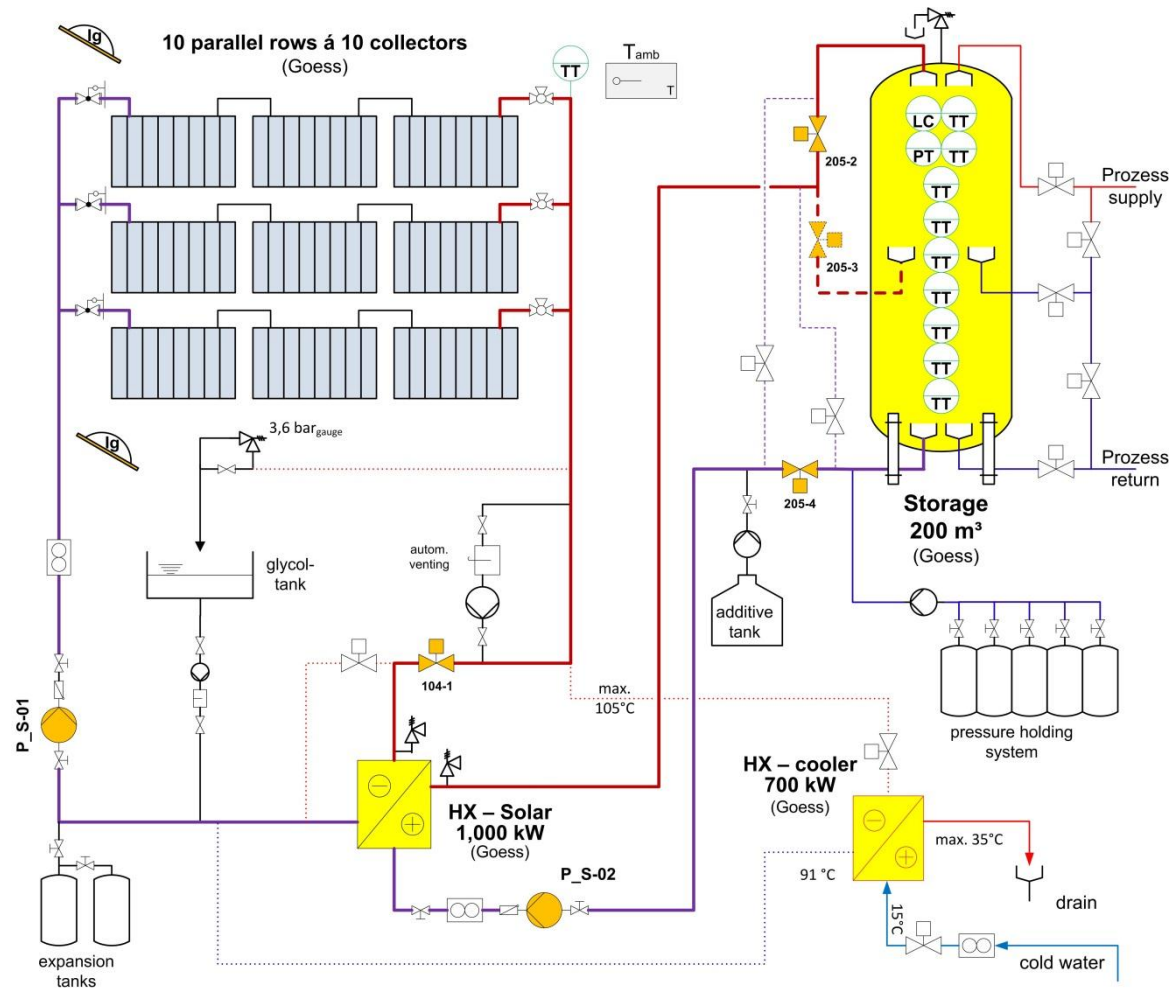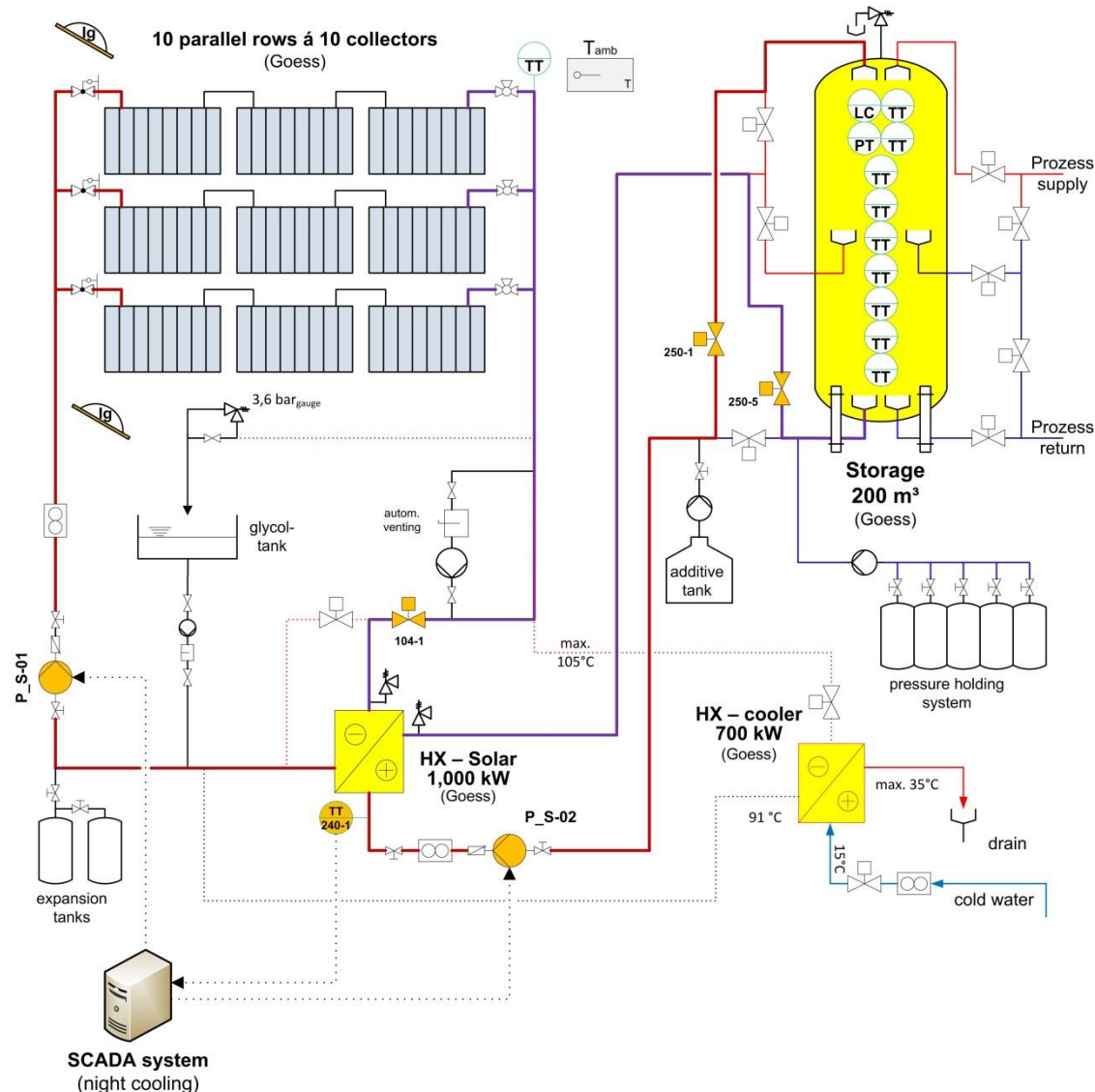
Stagnation prevention

Example SolarBrew

1) night cooling

- Manual or automatic start via SCADA system

- valves 250-1, 250-5 and 104-1 open and the pumps in secondary (P_S-02) and primary (P_S-01) loop start

- Night cooling function is switched off either after a pre-defined time (e.g. 240 minutes) or automatically as soon as the temperature TT_240-1 falls below a certain value (e.g. 60°C).

- Outlook: predictive control considering weather forecasts and production schedules

10 parallel rows á 10 collectors (Goess)

T_{amb}

3,6 bar$_{gauge}$

glycol-tank

autom. venting

P_S-01

additive tank

max. 105°C

250-1

250-5

Storage 200 m³ (Goess)

Prozess supply

Prozess return

pressure holding system

104-1

HX – Solar 1,000 kW (Goess)

TT 240-1

P_S-02

HX – cooler 700 kW (Goess)

max. 35°C

91 °C

15°C

drain

cold water

expansion tanks

SCADA system (night cooling)

Stagnation prevention

Example SolarBrew

2) Water cooler

- Was cheapest option in the course of the decision finding process

- Cooling mode temperature-controlled by SCADA system

- As soon as one of the three following criteria is fulfilled (adaptable) the motor-operated valves 136 and 303 are automatically opened and solar secondary pump (P_S-02) is switched off:

  - TSH 141-1 >105°

  - T storage top > 102°C

  - T storage bottom >80°C
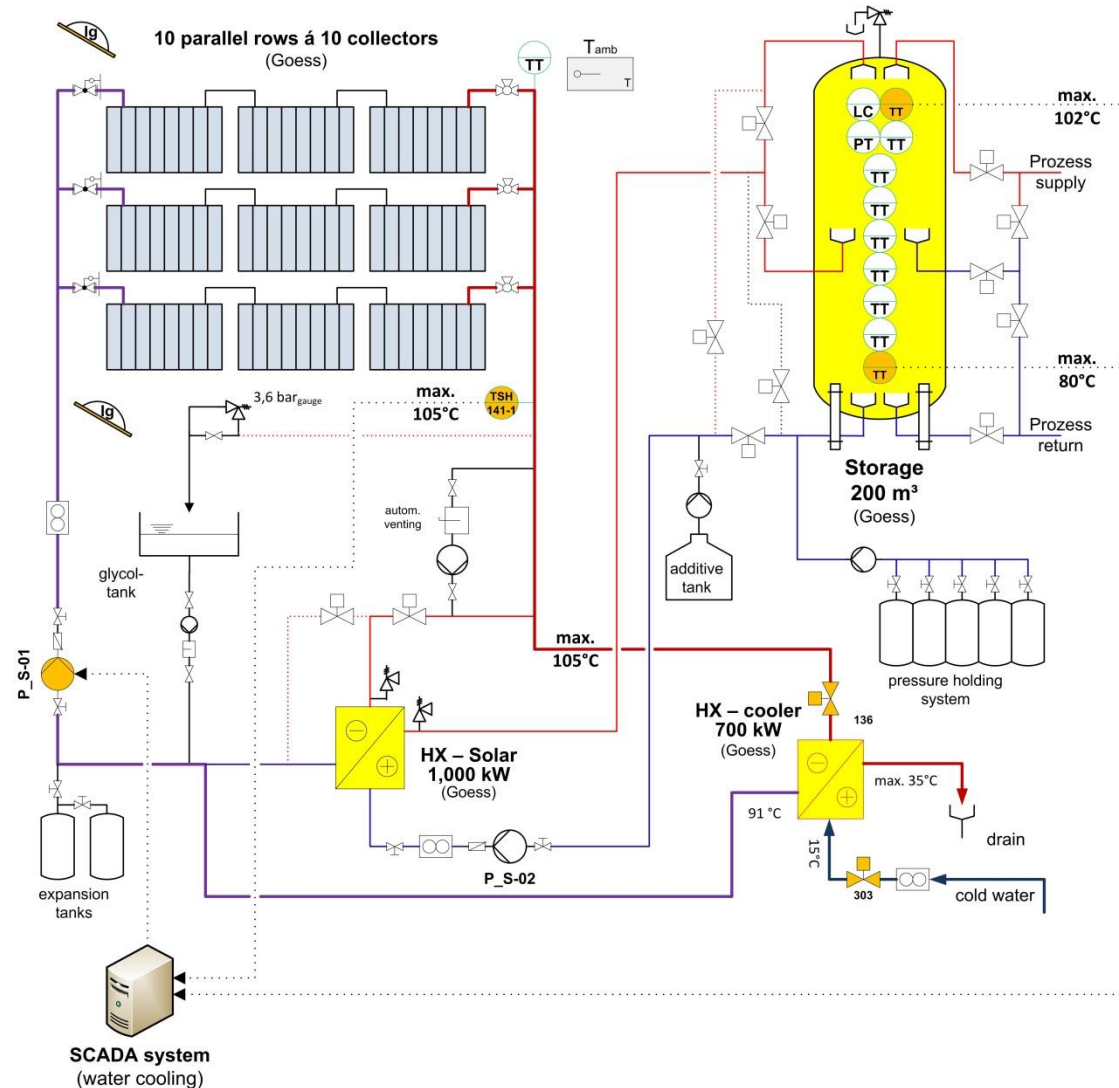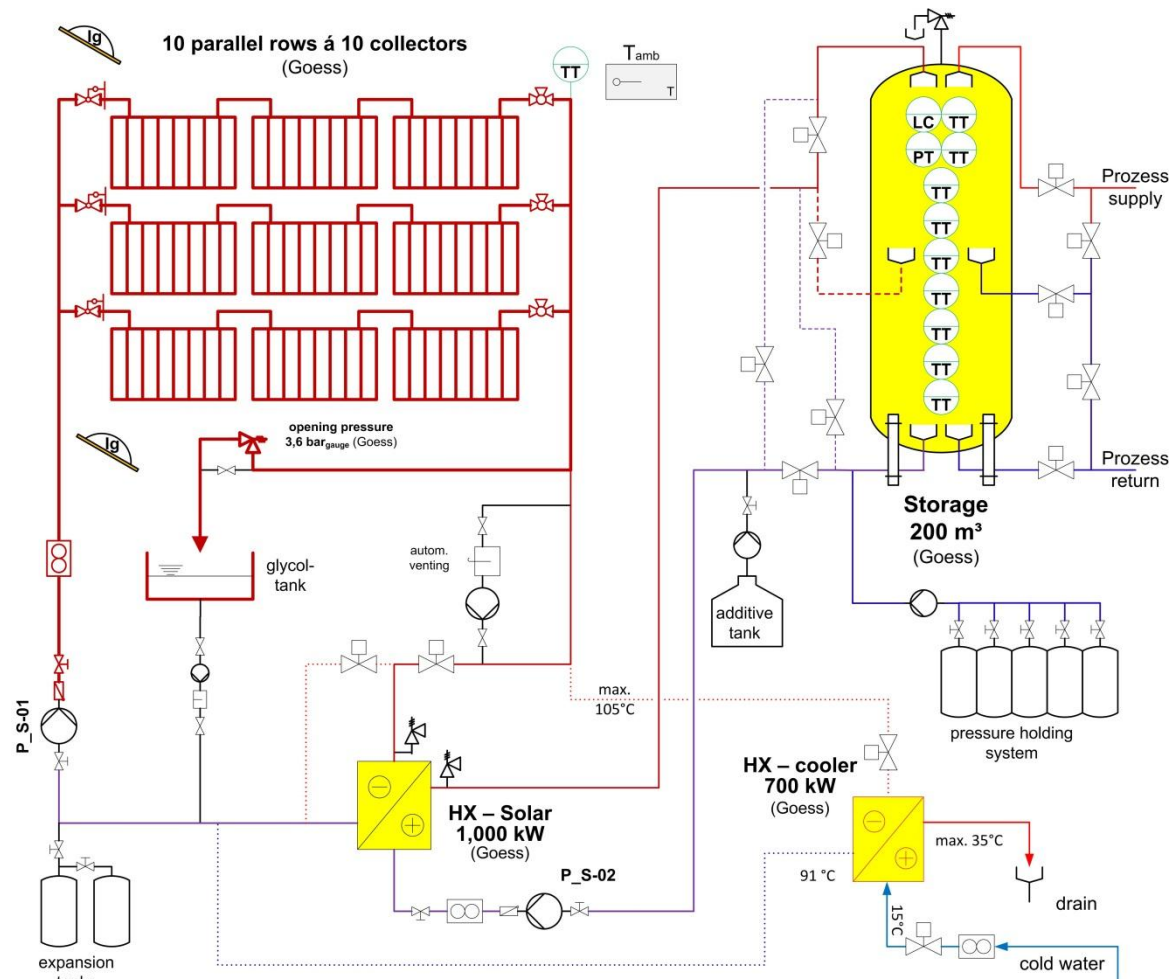
Stagnation prevention

Example SolarBrew

3) pressure controlled safety valve

- The relief valve in the solar primary supply loop opens at relatively low pressure (3.6 bar_{gauge}) and medium is directly released into a glycol tank (loss of medium)

- The low opening pressure limits the maximum stagnation temperature but high steam power can be expected because of bad emptying behavior of the collectors

- After stagnation the system has to be refilled with a manually operated pump and lost collector fluid has to be re-added.

Summary

Measures for stagnation control and stagnation prevention

	Stagnation control	Stagnation prevention
Passive measures	large expansion vessels	
	air cooler – e.g. finned tubes (small systems only <50 m²)	drain back systems
	evaporative cooler (medium systems only <500 m²)	
	passive heat sink in solar loop e.g. water storage	
Active measures	NO or low capacity UPS (uninterruptible power supply) needed	Low to high capacity UPS needed
		active re-cooler in solar loop e.g. • water cooler (external water / water heat exchanger) • electrical re-cooling devices (dry air cooler, compression cooler)
		night cooling
safety valve characteristics	(usually) high opening pressure	(usually) low opening pressure
expansion vessels characteristics	large volume (water expansion + steam)	small volume (water expansion only)
emptying behavior of the solar loop	Good emptying behavior is favorable	Good emptying behavior is favorable but not high priority

Conclusions

For FPC and ETC several (proven) concepts for stagnation control and stagnation prevention are available

Especially for large SHIP applications (>100m²) with longer stand-stills over weekends, frequent maintenance periods, etc. measures for stagnation prevention actively avoid high temperature and pressure stress of the system

- maintenance-free operation can be ensured

- solar loop system components need to meet the requirements for overheating conditions only

- expansion vessels need to absorb liquid expansion only

- temperature and pressure stress of the system is limited and hence system life time is affected in a positive way (condensation pressure shocks are avoided)

- degradation of the collector fluid additives (glycol) is avoided

- active coolers and UPS as backup are needed

- need for electricity and / or other resources (e.g.: cooling water)

- in case of drain back systems special system design is necessary which need to be further developed for large scale SHIP applications

Conclusions

With **night cooling** active cooling of the system can be actively reduced

- → predictive control for night cooling considering weather forecasts and production schedules needed (…to be developed…)

Night cooling should be implemented in the **design of** the needed **storage capacity**

- E.g.: production schedule is 5 days per week, batch heat load during the week – which storage capacity is appropriate?

- → proposed storage design: storage capacity should be sufficient to store maximum solar heat gains over the weekend **less** heat which can be dissipated through night cooling (…further theoretical and empirical work to be done…)

Conclusions

Ritter XL Solar provides one concept for stagnation protection for large ETC fields which can cope with high temperatures while stagnation

- no active cooling device needed

- system operating with water and hence no degradation of collector fluid additives (glycol)

- no temperature-sensitive components and no system separation (HX) needed

- only low capacity UPS as backup needed

- minor parasitic electricity consumption and no need for other cooling medium

- special system design and expertise is needed

- solar collector field components (from the collectors to the motor-operated valves) need to meet the requirements for stagnation conditions (T_{stag} = 338°C)

- the entire water based system need to be protected against frost (heating demand in winter)

Thank you for your attention!

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