European Union's Horizon2020 Research and Innovation
programme under grant agreement n°823802

SFERA-III 2nd Summer School
October, 5th- 6th, 2021
Almería (Spain)

Lecture:
Solar Steam Generation for SHIP Applications

Prepared by:
Eduardo Zarza Moya
PSA-CIEMAT
eduardo.zarza@psa.es

Content:

- Introduction
- HTF technology
- Flashing
- Direct Steam Generation

SHIP Applications at Medium Temperature

Steam is the most common fluid in the industry at medium temperature range

Industry	Process (es)	Temperature (ºC)	Medium
Food processing, beverages production, milk processing	Cooking, pasteurization, sterilization, tempering drying, heat treatment…	40 - 150	Steam, water, air
Textile	Blanching-dying, Drying, Pressing, Fixing, printing	40 - 180	Water, steam
Pulp and paper	Bleaching, de-linking, drying, pulp preparation…	60 - 200	Water, pressurized water, steam, air
Chemical and pharmaceutical	Distillation, evaporation, drying…	100 - 170	Water, steam, air
Leather products, rubber, plastic and glass manufacturing	Pre-tanning, drying and finishing, preheating, preparation, distillation, lamination…	50 - 200	Water, air, steam
…	…	…	…

SHIP Applications at Medium Temperature

There are three options to produce medium-temperature steam (125-450ºC) with solar energy.

They all are suitable for line-focus concentrating solar technologies (i.e., linear Fresnel and parabolic trough collectors).

- HTF (Heat Transfer Fluid) technology
- Flashing technology
- Direct Steam Generation technology

Content:

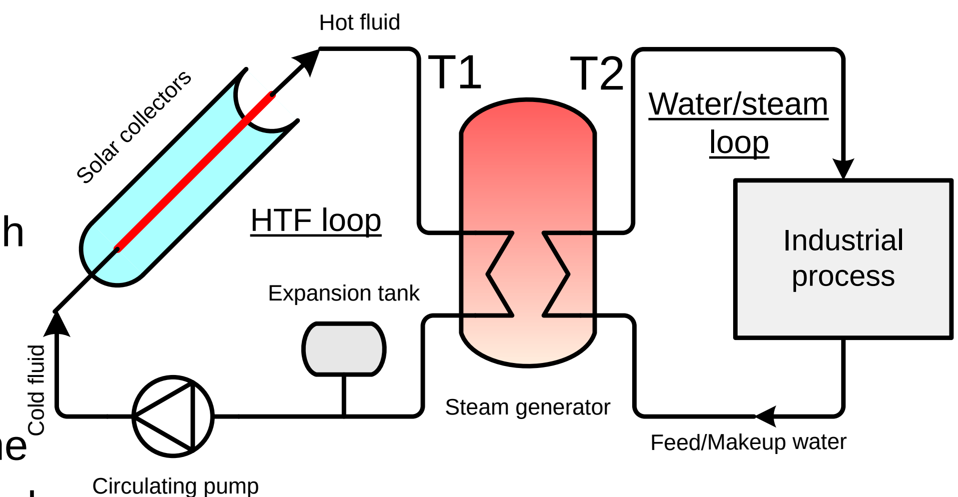
- Introduction
- HTF technology
- Flashing
- Direct Steam Generation

SHIP: Options for Steam Generation

Unfired boiler or Heat Transfer Fluid (HTF) technology

- Two separated loops
- A heat transfer fluid (HTF) loop, which delivers hot fluid from the solar collectors to an unfired boiler or steam generator and recirculates the fluid to the collectors through a circulating pump
- In the steam generator the hot fluid delivers the heat required to convert feed water in the secondary loop into saturated or superheated steam at the pressure and temperature required by the process
- The temperature of the hot fluid from the solar field, T1, must be at least 10-20ºC higher than that of the steam required by the process, T2.

T1 >T2

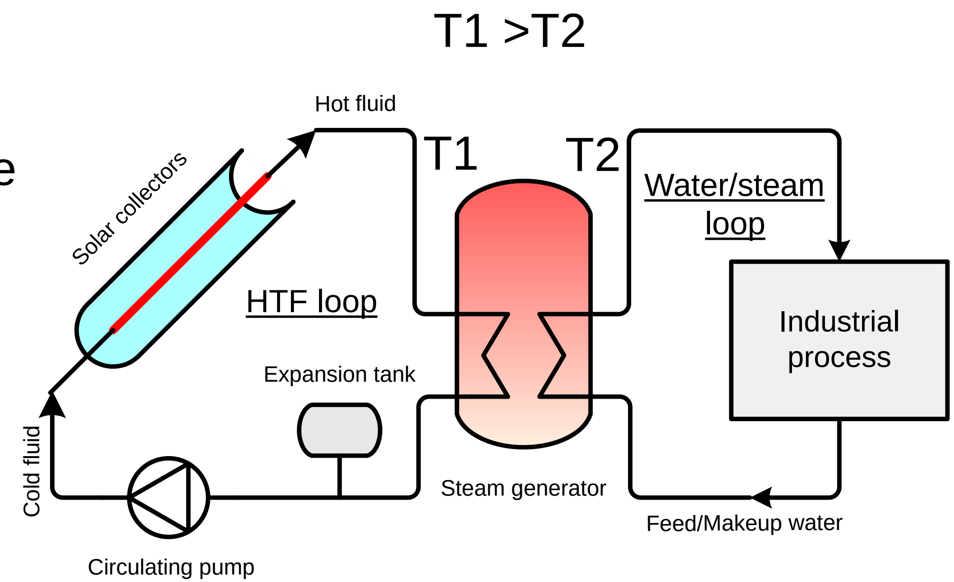


HTF based SHIP system

SHIP: Options for Steam Generation

Unfired boiler or Heat Transfer Fluid (HTF) technology

- The working fluid commonly used in the solar field for this indirect concept is thermal oil
- A nitrogen system is provided over the organic fluid to prevent oxidation and fire hazards
- An storage tank may be implemented to increase the number of operating hours
- An expansion tank is required at the solar field side to absorb the thermal expansion of the oil



HTF based SHIP system

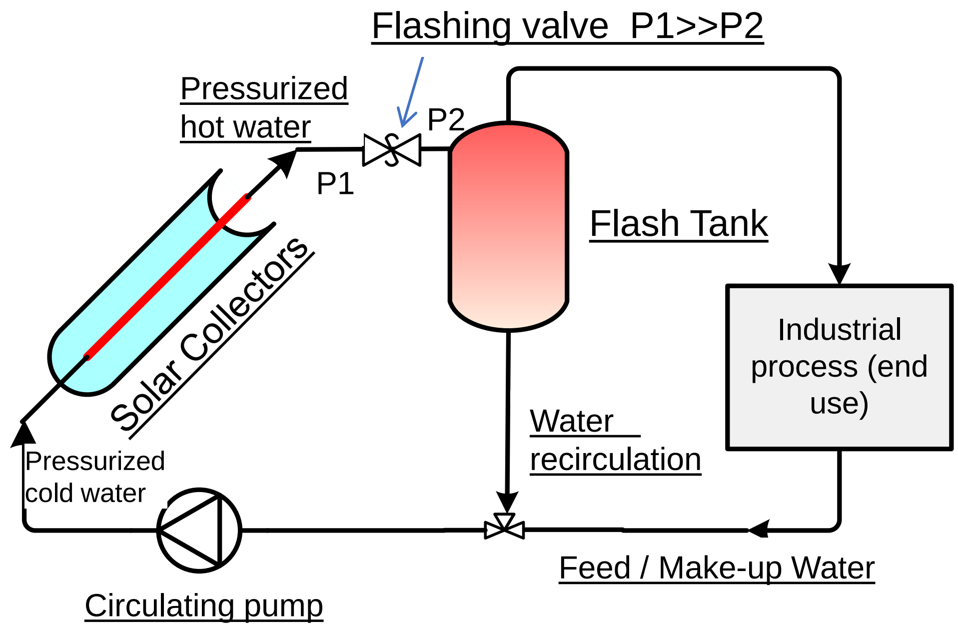
Content:

- Introduction
- HTF technology
- ☛ Flashing
- Direct Steam Generation

SHIP: Options for Steam Generation

Flash boiler

- Water from the flash boiler is pressurized and circulated through the solar field
- The water is pressurized and maintained at the required pressure by a circulating pump to prevent boiling within the collectors or piping
- When the pressurized heated water from the collector field enters the boiler flash chamber, due to the change in pressure in the vessel, a part of it is converted into saturated steam.

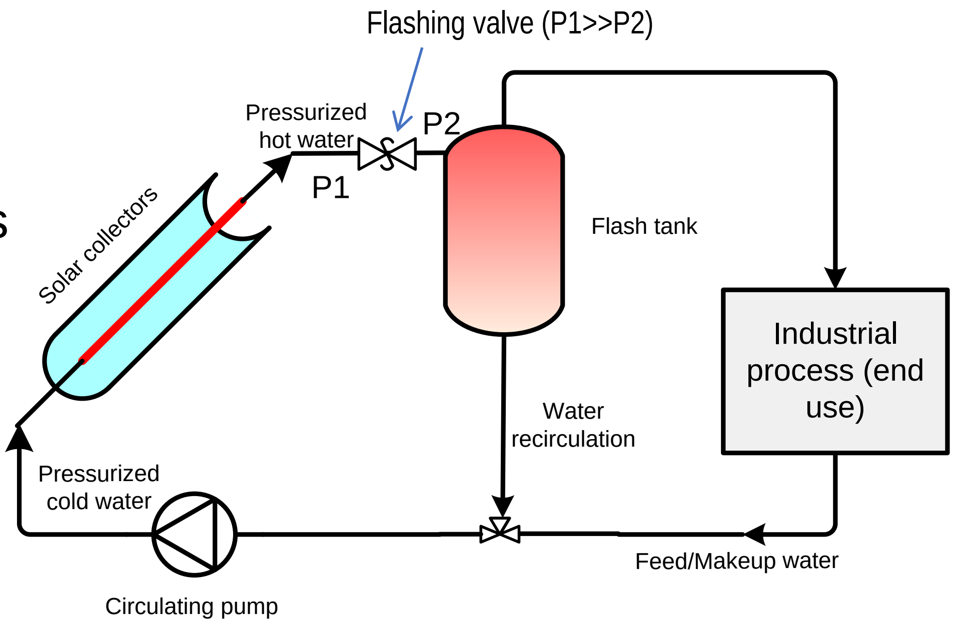


Flash boiler based SHIP system

SHIP: Options for Steam Generation

Flash boiler

- Saturated steam produced in the vessel is delivered to the steam mainstreams of the industrial process
- The rest of the water (liquid) is pumped back to the collector field
- Flashing is up to about 12%, depending on the temperature of the heated water and the pressure difference between the solar field and flash tank (P2-P1)



Flash boiler based SHIP system

Content:

- Introduction
- HTF technology
- Flashing
- Direct Steam Generation

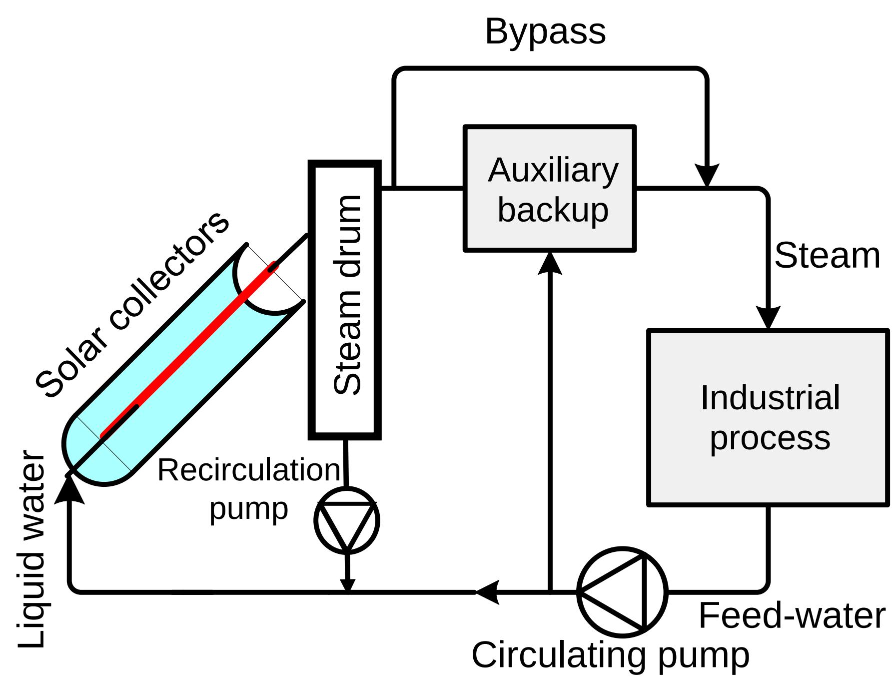
SHIP: Options for Steam Generation

Direct Steam Generation

- Steam is directly produced inside the receivers of the solar collectors (2 options)

✓ Water can be partially evaporated in the collector:

- ➢ Water is circulated through a steam drum where steam is separated from the liquid water
- ➢ Feed water is mixed with the recirculated water at a rate regulated by a level controller in the drum



Direct steam production in collectors with auxiliary backup <u>and partial evaporation in the solar field</u>

SHIP: Options for Steam Generation

Direct Steam Generation

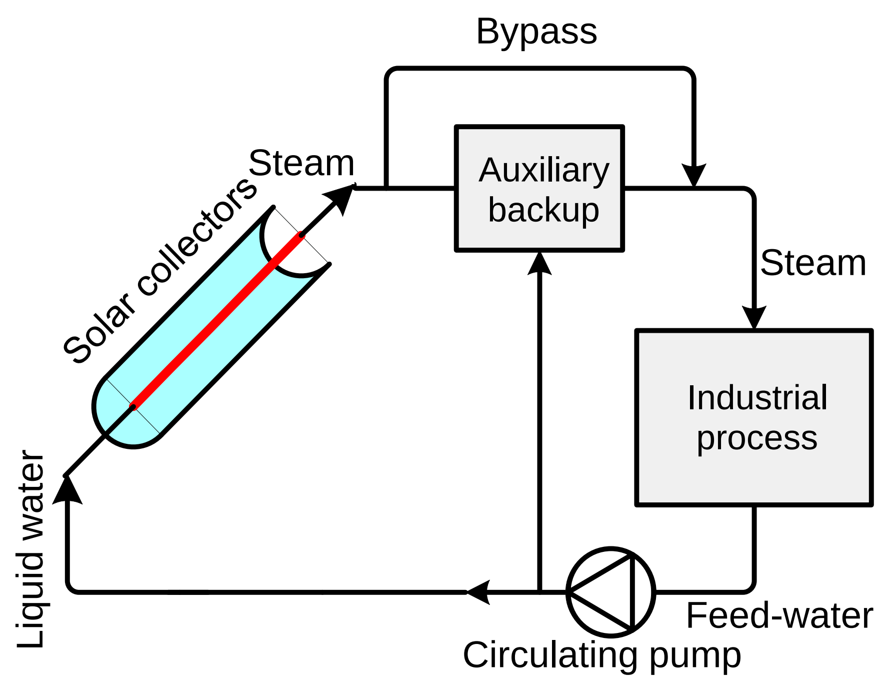
- Steam is directly produced inside the receivers of the solar collectors (2 options)

✓ Water can be partially evaporated in the collector:

- ➢ Water is circulated through a steam drum where steam is separated from the water
- ➢ Feed water is added to the recirculated water at a rate regulated by a level controller in the drum

✓ Water can be completely evaporated in the solar field

- ➢ Feed water is added directly to the collector field inlet



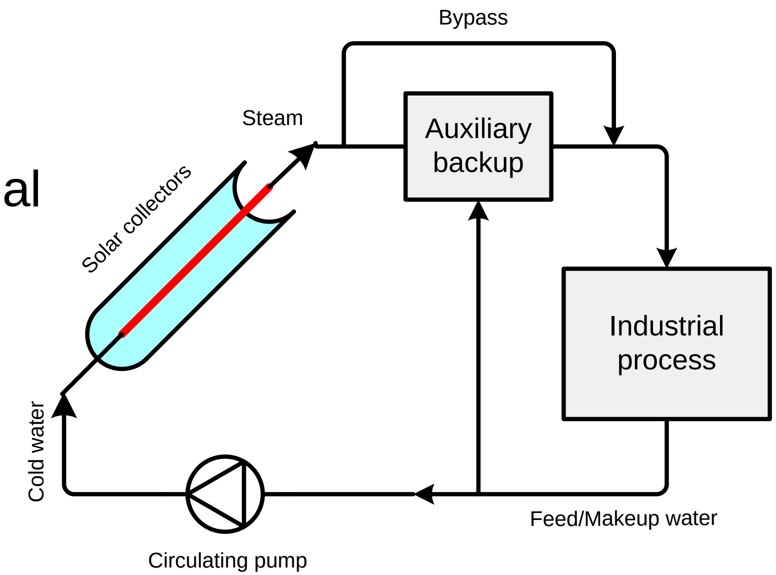
Direct steam production in collectors with auxiliary backup <u>and 100% evaporation at the solar field</u>

SHIP: Options for Steam Generation

Direct Steam Generation

➢ Advantages versus HTF option

- Environmental risks associated with thermal oil are eliminated (fires and leaks)
- Oil/steam heat exchanger is unnecessary
  - ➢ Overall plant efficiency is higher
  - ➢ Solar field requirement and investment is lower
  - ➢ Plant configuration is simplified
  - ➢ Auxiliary thermal oil systems are eliminated
- O&M costs are reduced
  - ➢ There is no oil/water heat exchanger
  - ➢ 3% of yearly oil make-up is avoided



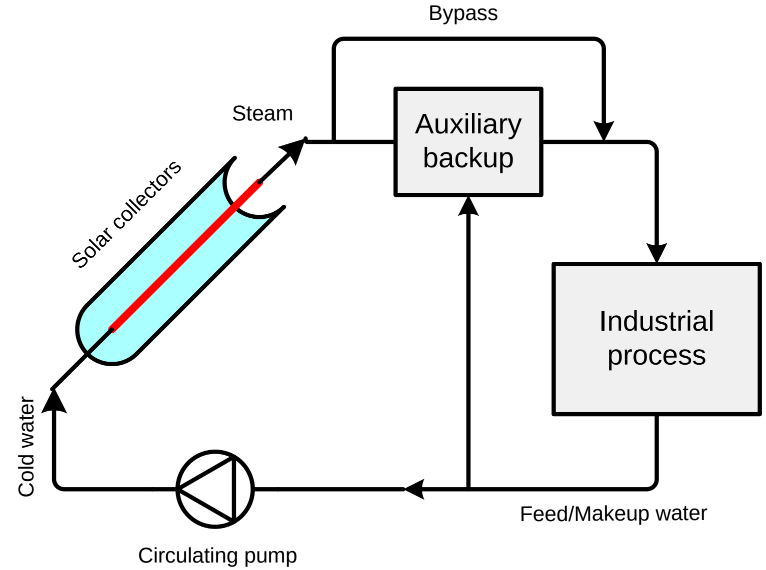
Direct steam production in collectors with auxiliary backup

SHIP: Options for Steam Generation

Direct Steam Generation

➢ **Disadvantages versus HTF option**

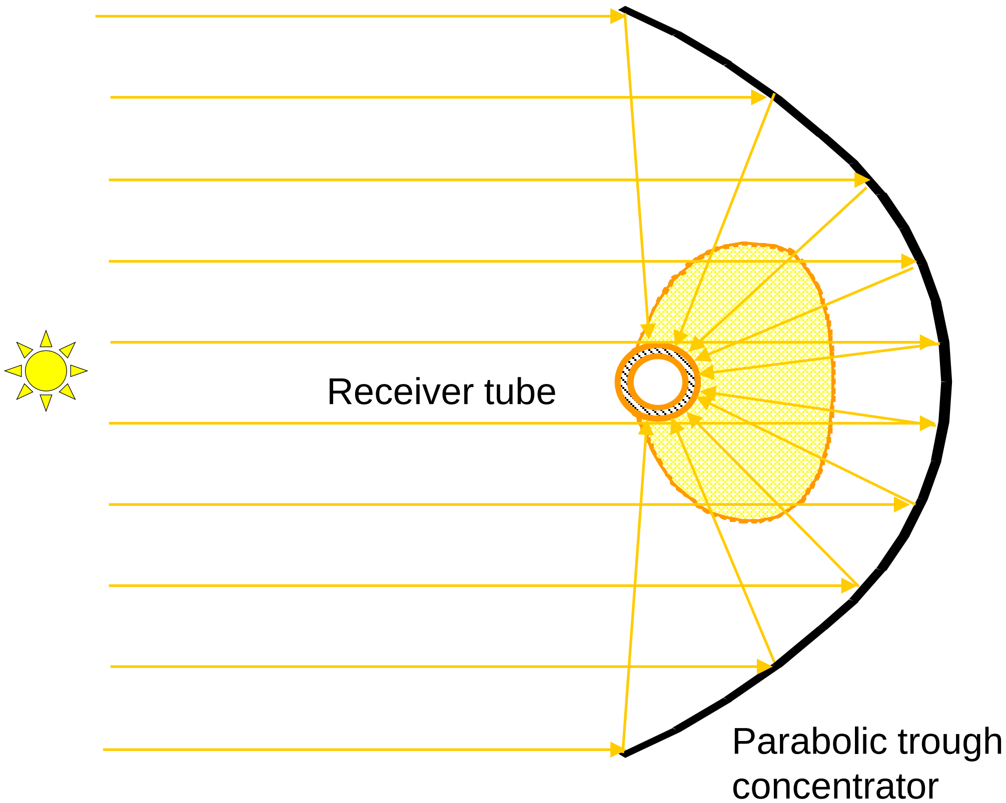
- Higher solar field operating pressure requires suitable hydraulic components, which increases costs
- Water may freeze in cold weather conditions
- Liquid water stratification problems

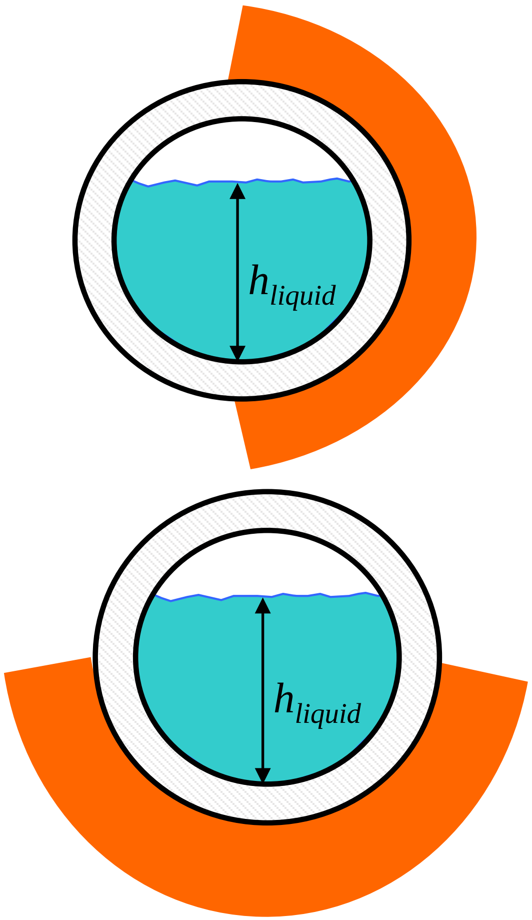


Direct steam production in collectors with auxiliary backup

Direct Steam Generation

Water stratification problems in Solar Fields with Direct Steam Generation



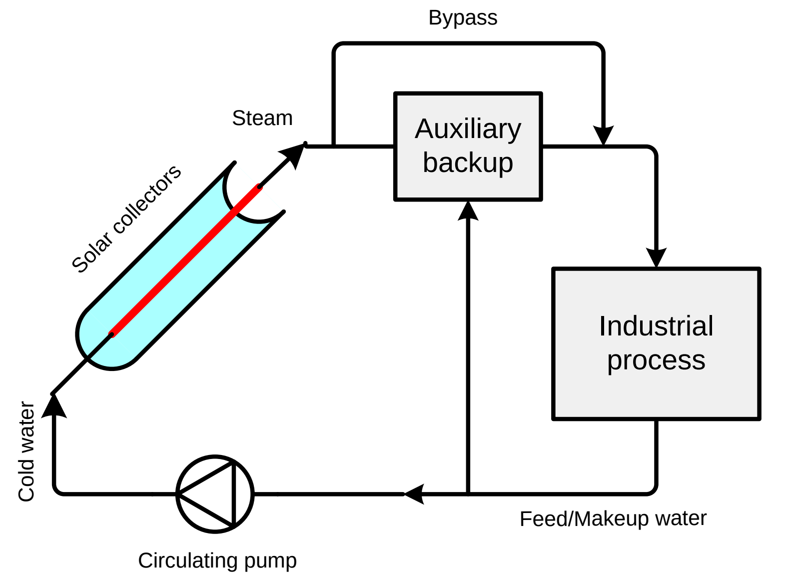


SHIP: Options for Steam Generation

Direct Steam Generation

➢Disadvantages versus thermal oil

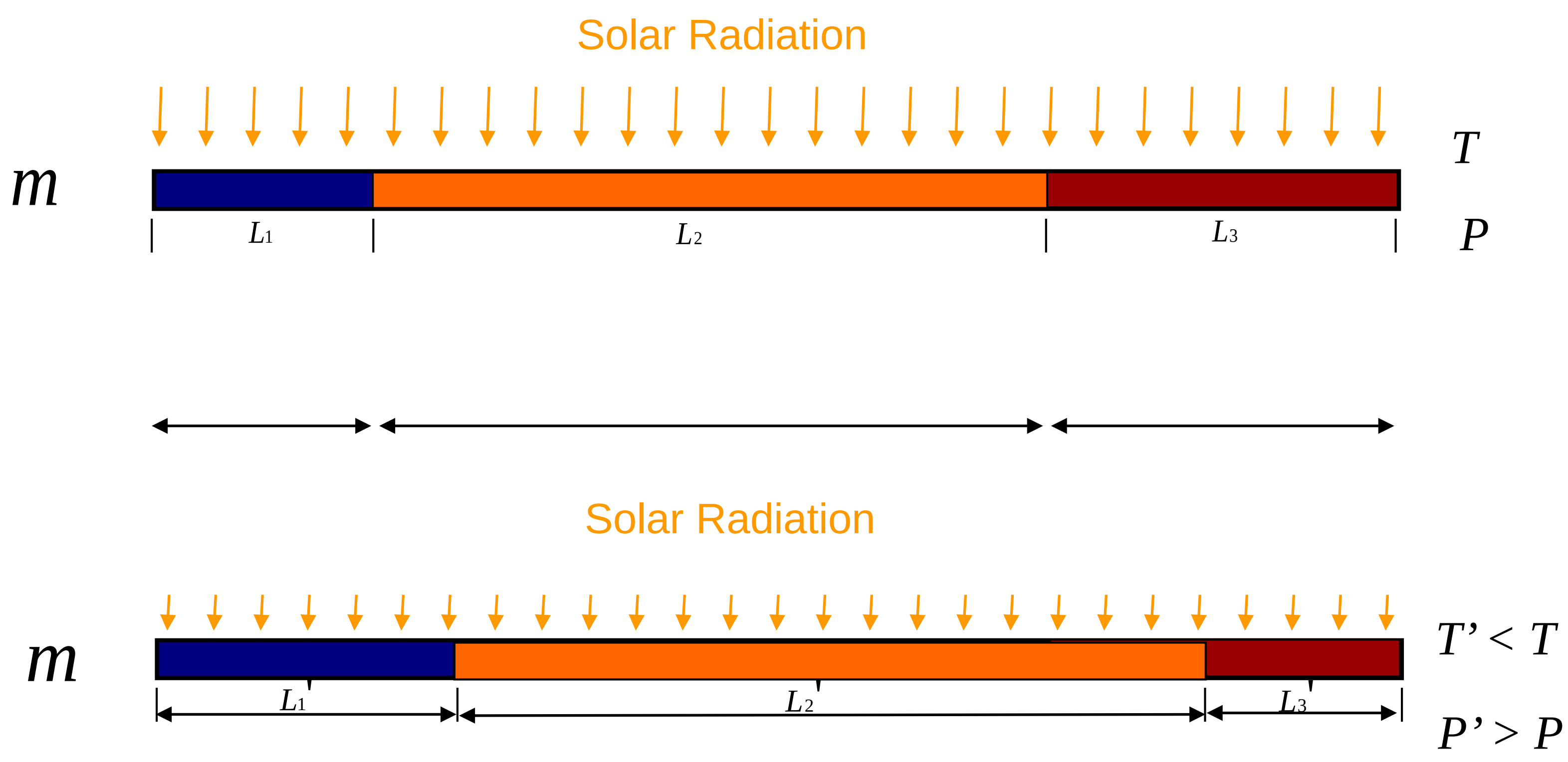
- Higher solar field operating pressure requires suitable hydraulic components, which increases costs
- Water may freeze in cold weather conditions
- Liquid water stratification problems
- Control systems required for the solar field are more complex and expensive (two-phase flow)



Direct steam production in collectors with auxiliary backup

Direct Steam Generation

Control-related problems in Solar Fields with Direct Steam Generation



SHIP: Options for Steam Generation Summary of pros and cons

Unfired boiler	Flash boiler	Direct steam generation
In case of using thermal oil: • Lower pressure in the solar field piping • High temperature steam • Most of the thermal oils currently available for T<350ºC have a low freezing point	• Same Fluid in the collector field may be used also in the process • No need of heat exchanger • Good heat transfer media (high C_p and high thermal conductivity)	• Same Fluid in the collector field may be used also in the process • No need of heat exchanger • Good heat transfer media • Phase change reduces flow rate required through solar collectors
In case of using thermal oil: • Fire risk due to leakages (need of ATEX specifications in some cases) • Expensive and pollutant • High viscosity at low temperature→high pressure losses→high pumping losses	• Risk of freezing in the collector field • Limited steam temperature because fluid temperature in the solar field >>>process steam temperature • Economical viability only if max. pressure < 30 bar • Very high pumping power	• Risk of freezing in the collector field • Uneven heat transfer in the receiver tubes with water stratification • Controllability of the process in solar field more complex

SHIP: Commercial examples

Source: Abengoa Solar

Plant /aplication:	Minera El Tesoro (Antofagasta), Chile
Solar field configuration:	**Unfired boiler based SHIP system**
Processes:	Steam (150°C) & hot water (80°C) for solvent extraction and electro-generation (processes to obtain copper cathodes)
Year:	2013
Solar collector type:	Abengoa-PT1 (2.3m x 6.1 m, T_{max} = 288ºC, C ~ 40) (Reflector : Aluminum/Steel)
Number of solar collector units:	1280
Total collectors area:	16742 m^2
Thermal power:	7 MW_{th}

SHIP: Commercial examples

Plant /application:	El Nasr plant (Cairo), Egypt
Solar field configuration:	**Flash boiler based SHIP system**
Processes:	Steam (173°C/8 bar) for a pharmaceutical industry
Year:	2004
Solar collector type:	IST(Abengoa)-PT1 (2.3m x 6.1 m, T_{max} = 288ºC, C ~ 40) (Reflector : Aluminum/Steel)
Total collectors area:	1900 m^2

SHIP: Commercial examples

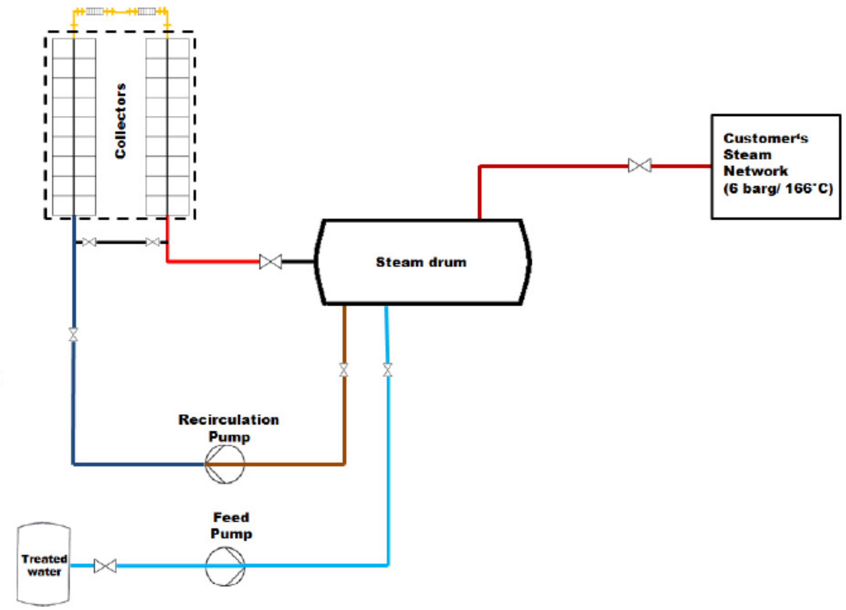


Figure 3. Conceptual P&I diagram of solar process heat installation at RAM Pharma

Source: Haagen et al. Energy Procedia 70 (2015), 621-625

Plant /application:	RAM Pharma (Sahab), Jordan
Solar field configuration:	**Direct steam generation**
Processes:	Steam (160°C/6 bar) for a pharmaceutical industry
Year:	2015
Solar collector type:	LF-11 Industrial Solar (22 m^2 per module)
Total collectors area:	396 m^2
Thermal power:	222 kW_{th}

SFERA-III
2nd Summer School
October, 5th- 6th, 2021
Almería (Spain)

End of Presentation

- Thank you for your attention
- Questions ?

Prepared by:
Eduardo Zarza Moya
PSA-CIEMAT
eduardo.zarza@psa.es