IEA SHC Task 49

SolarPACES Annex IV

Solar Process Heat for Production and Advanced Applications

"Best practice" Series of Case Study Reports from Demonstration Projects

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1 Introduction

Throughout the world, many new technologies and projects are currently being undertaken to assist in the reduction of fossil fuel consumption. While the focus has been in the electrical and transport sector, significant progress has been made in the realm of renewable heat and more specifically, solar heat for industrial processes.

While still in its infancy, solar process heat (SPH) projects have been and continue to be deployed worldwide. Many of these are small in nature, serving just a fraction of the overall onsite thermal energy demand, but serve as a good demonstration of the techologies' technical feasibility and potential fuel savings. Some larger projects, most noteably a metal mining operation in Chile, home to the largest process heat plant, are able to satisify nearly all of the thermal demand. A good, though not all encompassing, database of currently operating solar process heat plants can be found at www.ship-plants.info. Within this database, 188 solar thermal projects are detailed, including location, industrial sector, type of solar collector implemented, and its respective integration point. Some conservative estimates put the current installed solar process heat projects above 500, as a significant number of projects have been erected in Asia, namely China and India, but are yet to be included into the database.

The most prominent industrial sector which has taken advantage of the near infinite solar resource is Food and Beverage (FB). To date, 79 of the 188 list projects have been built in this sector. This is primarly due to temporal similarities between industrial FB processes and solar availability, and their required processes temperatures which solar thermal collectors can achieve. Nearly half of these collectors have been flate plate, followed closely by vacuum tube and parabolic trough, with the fewest being air collectors. Many of these projects have been small, due to their demonstrative nature, but a third have had solar fields larger than 500 m^2 (~300 kW_{th}), helping to lower project specific costs while offsetting more fossil fuel and thus carbon dioxide emission.

A sample of solar process heat projects currently in the database are exhibited in the following chapters, spanning the beverage, natural gas, mining, and metal treatment sectors. These case studies include a detailed plant layout, integration scheme, and other pertinent information to provide a deeper understanding of the intricices of such projects. Through this knowledge, such projects can be replicated in other regions and industires to rapidly advance the future of solar process heat and reduce fossil fuel consumption and carbon emissions.

2 Solar preheating of natural gas

Enersolve GmbH is a company that has realized several solar heating plants for gas pressure regulation stations (GPRS). For the economic transportation of natural gas over long distances the gas needs to be under high pressure. Therefore, GPRS are implemented to reduce the pressure before being supplied to the end-consumer. By reducing the pressure of natural gas, the temperature is reduced due to the Joule-Thomson-Effect, which can cause freezing of the GPRS components and thus a safety risk. To avoid freezing, a remarkable amount of energy is needed to preheat the gas before its expansion. Enersolve has realized several projects where the natural gas is partially preheated by solar energy. In Großseelheim, Germany such a solar heating plant with 355 m^2 flat plate collectors was integrated in a GPRS. Figure 1 shows the installed collector field close to the GPRS (building left).

Figure 1: Field of flat plate collectors close to the GPRS building (Source: Enersolve)

Before the solar heating system was installed the required heat was supplied by a cascade of conventional burners using natural gas as fuel. A water-glycol mixture is presently used as heat transfer fluid within the solar loop. The energy storage is an ambient pressure short-term water storage with a volume of 25 m³ that was built into a standard cargo container. A schematic hydraulic plan for the integration of the solar system is shown in Figure 2.

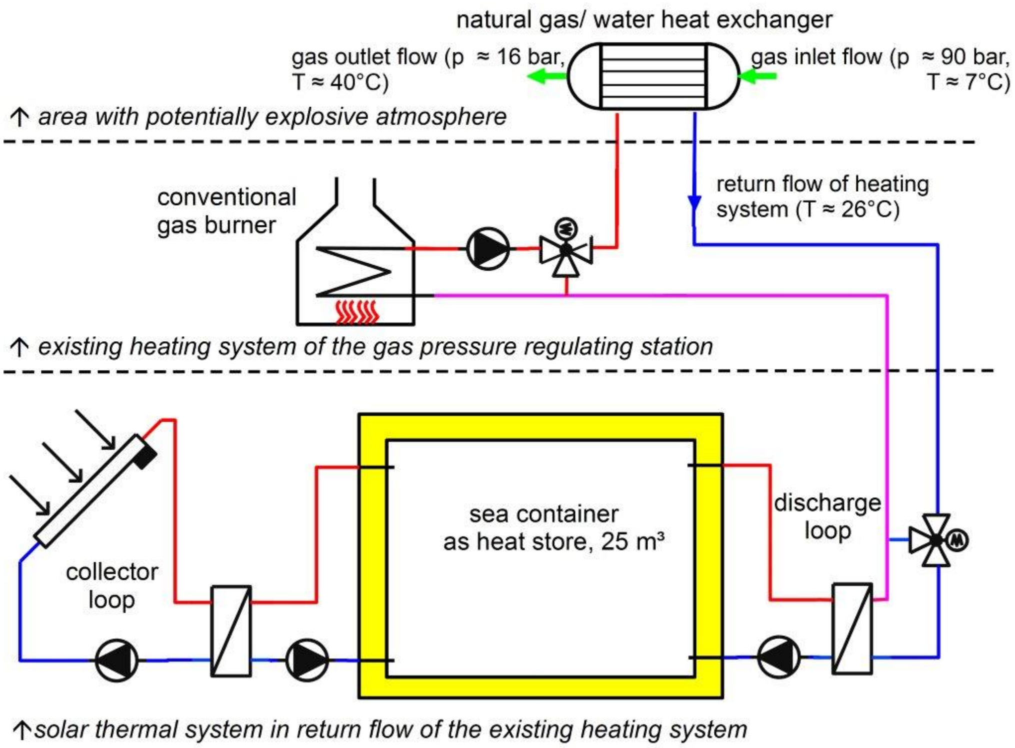

Figure 2: schematic hydraulic plan for the integrated solar system (Source: Enersolve)

The storage is heated by the collectors and if the storage temperature exceeds the return line temperature of the conventional heating system, the heat will be integrated into the process. The solar heat is used to increase the temperature of the return line. If the storage temperature reaches the set temperature of 60 °C, the conventional gas burners are shut off completely. The total investment cost of the solar system was about 165.000 €. It has an annual solar heat delivery of 190 MWh/a which corresponds to a total solar fraction of 15 % for the system.

3 Solar barrel washing in a winery

The company Golan Winery Limited is located in Katzrin, Israel/Syria. It was founded 1982 and has become Israel's third largest winery with 150 employees and produces over 6 million bottles of wine a year. The company uses a solar heating system for preheating of barrel washing water with temperature levels from 18..85 °C. The solar heating system was planned and installed by TIGI Limited. The installed collector gross area is about 244 m² and is roof mounted. The installed collector field is shown in Figure 3.

Figure 3: roof mounted solar system at Golan Winery (Source: TIGI Limited)

A water-glycol mixture is used as heat transfer fluid within the solar loop. The storage has a volume of 30 m³ and is implemented for short-term use. The annually global irradiation on the tilted collector surface is about 2050 kWh/m²*a with typical collector temperatures of 70 °C at the inlet and 90 °C at the collector outlet. In term of a stagnation, a passive overheating prevention device (OPD) is installed direct at the collector level. The OPD-System is based on a closed loop heat pipe and is a part of the new collector type invented by TIGI Limited. The new collector is named as Honeycomb Collector and it uses the technology of transparent insulation to reduce heat losses. Figure 4 shows the principle of using transparent insulation.

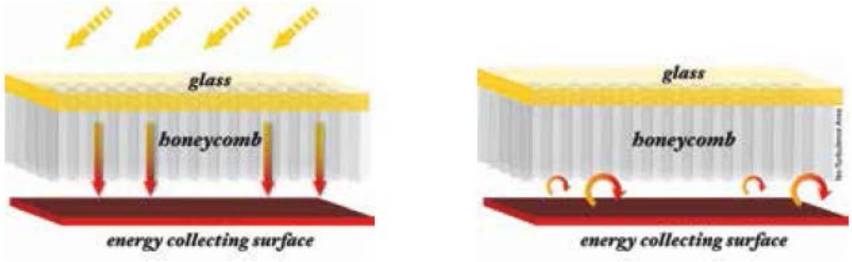

Figure 4: The Principle of Using Transparent Insulation (Source: TIGI Limited)

Sunlight passes through the transparent insulation, heating the absorber (left). The transparent insulation layer suppresses convection heat losses (right).
Before the solar heating system was installed the hot water was supplied by a conventional hot water boiler using oil as fuel. The solar heat is integrated into the conventional hot water storage on the supply level. As described before the solar heat is used to preheat cold brewing water from 18..85 °C. In Figure 5 the hydraulic scheme of the solar system is shown.

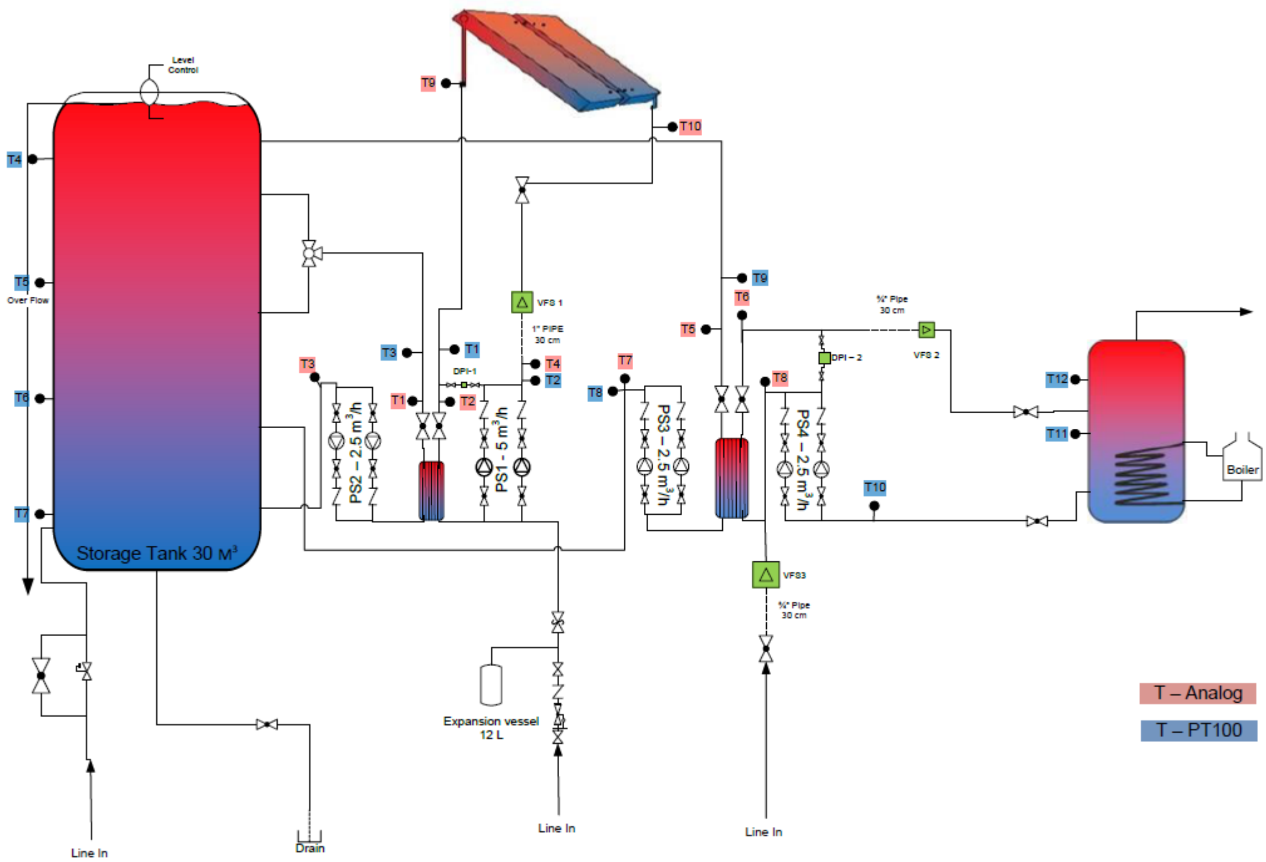

Figure 5: Golan Winery Hydraulic Scheme (Source: TIGI Limited)

The solar heated water is fed into the hot water buffer storage of the winery, which is needed for washing barrels and tanks. The total investment cost of the whole solar heating system was about 200,000 €, leading to solar heat generation costs of 32.4 €/MWh, with a projected annual solar heat of 247 MWh/a. The solar system will supply about 70 % of the yearly energy needed for the washing processes.

4 Solar mashing and feed water heating at a brewery

Breweries have a significant low temperature demand and often a high potential for process optimization. Manufacturing of malt and beer requires tremendous amounts of electrical and thermal energy. According to Mauthner et al. (2014), the entire heat demand of breweries and malting plants can be supplied at temperature levels between 25 °C and 105 °C, with processes like malt drying, bottle cleaning, pasteurization or mashing, all very promising for SPH.
Sector specific SPH concepts for this sector have been developed and a number of successful SPH projects have been carried out recently. Figure 6 shows a flat-plate collector field at the Goess Brewery in Leoben, Austria, which was installed in June 2013.

Figure 6: Flat-plate collector field with 1,500 m² at the Goess Brewery (Source: AEE INTEC)

Two steam supplied vessels (mash tuns) were retrofitted with internal plate heat exchangers to allow the mash tuns to be heated with hot water instead of steam. This hot water supply is fed by waste district heat from a biomass plant as well as from the large-scale SPH installation (100 collectors with 1,500 m² gross area, about 1 MW_{th} peak power). The collector field feeds a 200 m³ pressurized water buffer storage, which was installed outside the brewery (cp. yellow cylinder in the background of Figure 6). Additionally, a vapor condenser recovers the waste steam occurring during start-up of the wort boiling process and the produced water is added to the hot water network. Figure 7 shows the system concept of the SPH plant.

The collector loop contains a water/glycol mixture and charges the solar buffer storage via a charging heat exchanger. External stratified charging is done depending on the charging flow temperature level and the temperature within the storage. Non-return valves eliminate losses due to natural convection through the collectors and the charging loop at night. To prevent the charging loop from freezing on cold winter mornings, the charging heat exchanger is automatically bypassed until the whole collector loop has been heated up. Stagnation (i.e. steam production in the field when the solar supply exceeds the demand) is prevented in two ways: First, night cooling is implemented, i.e. hot water from the storage top can be pumped through the collectors at night to cool the storage. If necessary, additionally a water/water heat exchanger can cool down the collector field.

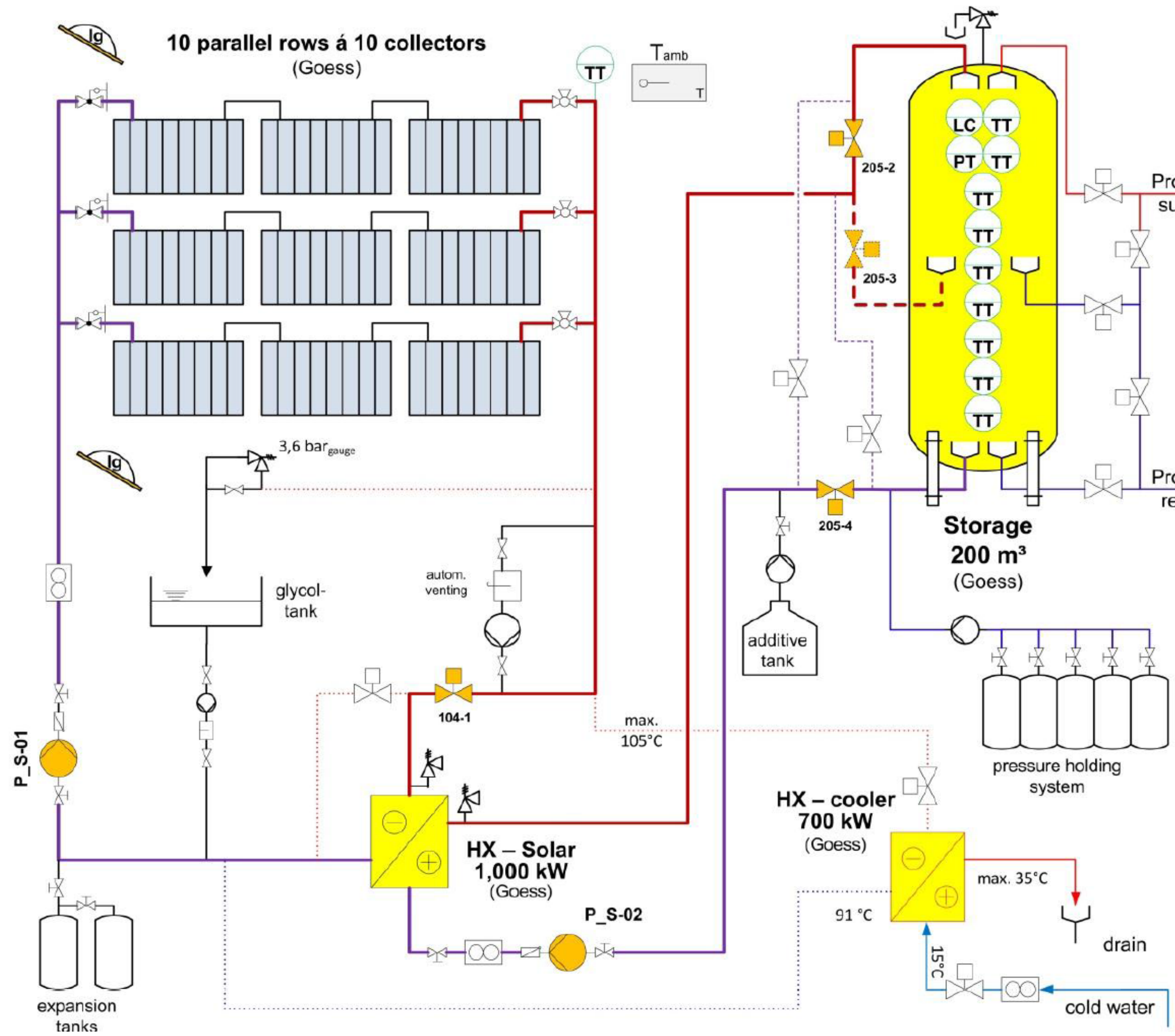

Figure 7: System concept of the SPH installation at Goess Brewery (Source: AEE INTEC)

Figure 8 shows the solar heat integration into the retrofitted mash tuns. The mashing process requires consecutive temperature increase from initially 58 °C to finally 78 °C in three steps. If solar heat above these temperatures is available, heat from the buffer is pumped through the retrofitted plate heat exchangers. The return flow from the process back to the storage is stratified according to the temperature level. If the temperature in the solar energy storage is not high enough to supply the entire mashing process, but still higher than the process return temperature, the solar heat is further heated in-line by waste heat from the biomass plant. If the temperature within the solar buffer is too low, the buffer is bypassed and the mash tuns are supplied by waste heat only. If both systems cannot supply either the temperature or the energy quantity needed, the existing steam supply system acts as parallel backup.

Simulations indicate that almost 30 % of the heat demand for mashing can be supplied by SPH and the remaining process heat demand can be covered by waste heat from biomass. In sum, around 1,570 MWh of natural gas per year, corresponding to 38,000 tons of CO_2 equivalents can be saved in future by this hybrid system (Mauthner et al. 2014).

The system is expected to have relatively low annual specific solar gains of 280 kWh/m²a due to the for standard flat-plates comparably high supply temperatures. The overall invest including the integration was 550 EUR/m², including approx. 50 % subsidies.

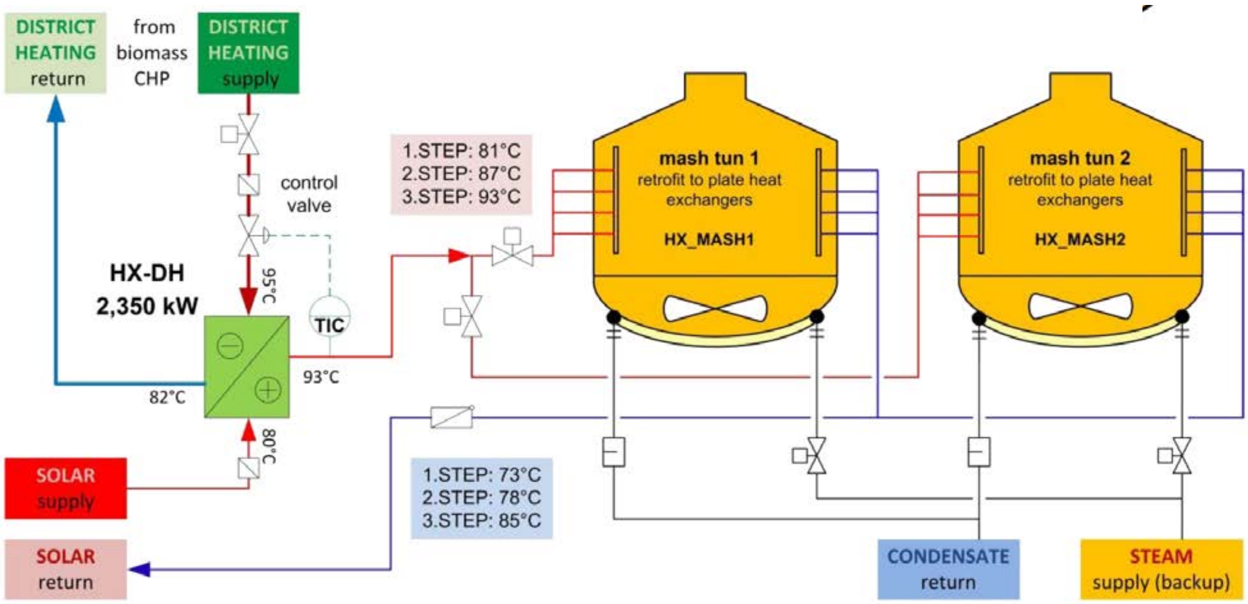

Figure 8: Solar heat and biomass district heat integration into the mash tuns of Goess brewery (Mauthner et al. 2014)

5 Solar bath heating for pretreatment of automobile components

The company Wheels India Limited in Padi, Chennai, India is a manufacturer for metal vehicle wheels in the automotive supply industry and was established in 1962. It uses evacuated tube collectors for heating and maintaining the baths temperatures for pretreatment of automobile components before being painted. The plant shown in Figure 9 was mounted on the trussed factory roof and has a collector area of 1,365 m². It was designed, delivered and commissioned by Aspiration Energy P Ltd, India.

Figure 9: Evacuated tube collectors on the roof of Wheels India in Padi, Chennai, with a collector gross area of 1,365m² (Source: IEA SHC Task49 & SoPro India)

In detail, the heat demanding processes consist of four tanks or baths which are used for cleaning the wheels after casting. The first tank is a hot water tank at 55 °C, the second tank is a knock-off degreaser tank at 70 °C, the third and fourth tanks are degreaser tanks at 60 °C. A furnace oil boiler was used as conventional heat supply. Therefore, the company used about 3,000 liters of furnace oil per day (~33 MWh_{th}/day), which leading to daily energy costs of approximately 2,000 €. The solar thermal system was designed to replace furnace oil usage and reduce carbon dioxide emission by 280 tonnes annually. The solar thermal system consists of four separate systems, each for one specific heat demanding process. This is shown in Figure 10.

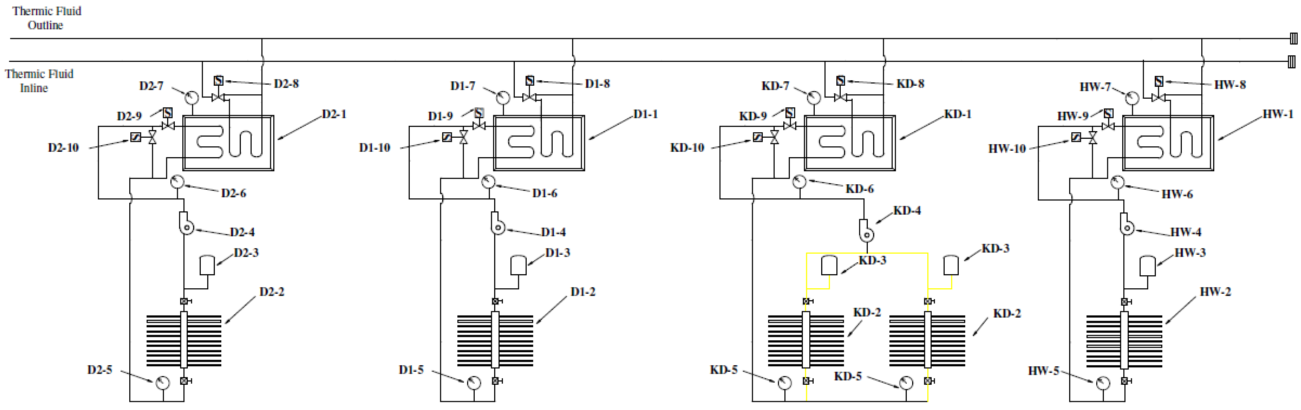

Figure 10: Four separate solar thermal systems installed for each heat demanding process. (from left to right) System 4, System 3, System 2, System 1. (Source: Aspiration Energy)

For the solar system, evacuated glass tube collectors (ETC) were used, each with a manifold in the center, and on both sides 40 evacuated glass tubes. It is rated at 6 $kW_{th}$with 13 m² aperture area. In total 105 ETC's were installed with a gross area of 1,365 m².

System 1: 20 ETC's connected to hot water tank at 55 °C
System 2: 44 ETC's connected to knock-off degreaser tank at 70 °C
System 3: 16 ETC's connected to degreaser tank I at 60 °C
System 4: 25 ETC's connected to degreaser tank II at 60 °C

The collectors are connected in series except system 2, where two series of 22 ETC collectors are connected in parallel.

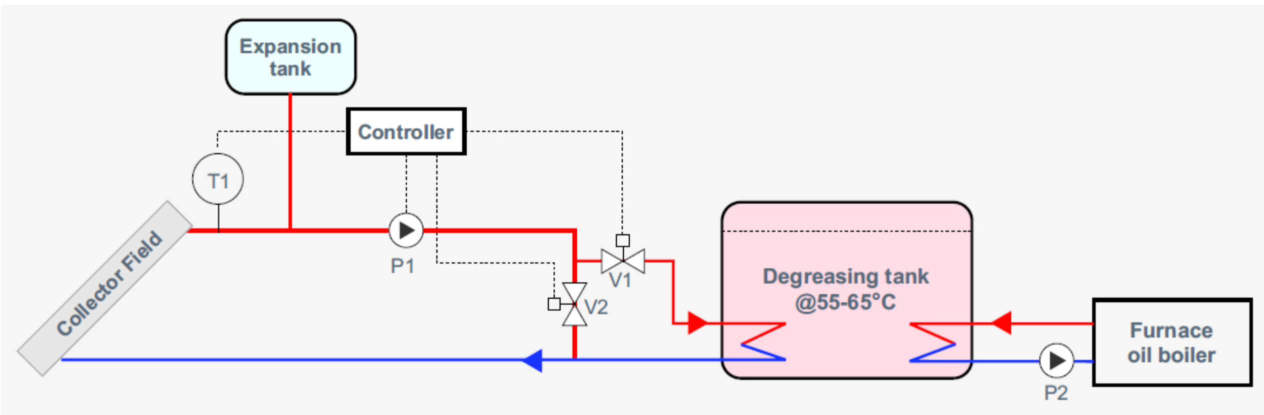

Figure 11: Hydraulic scheme of solar water heating system at Wheels India ltd. (Source: Aspiration Energy)

The tubes of the ETC's are filled with a heat transfer fluid (water-glycol mixture) and the solar heat is transferred by a heat exchanger to the demineralized (DM) water loop. The DM water is used as a heat transfer fluid and circulates in closed loops to transfer the solar heat to the degreasing tanks by immersed coils, acting as heat exchangers. The tanks are used as storages, therefore no other storages are needed. The solar system is not pressurized and an open expansion tank is used to balance the expansion of the DM water. A hydraulic scheme of the solar water heating system is shown in Figure 11.

Typical operation of the system:
The controller starts pump P1 every morning at 7 am. If it is a rainy day, the operation time of the pump can manually be postponed. As long as the temperature T1 (collector output) is below 60 °C, valve V1 is closed and valve V2 open to bypass the tank. If the temperature is above 60 °C, V1 is open and V2 is closed to deliver the solar heat to the tank. If the tank temperature is below 55 °C, the furnace oil boiler heats the bath via a thermic fluid circuit.
The temperature values of collector inlet and outlet are recorded periodically, which are used for calculating the fuel savings. Other data such as pressure, tank temperature and totalizer readings are also noted.
The solar thermal energy delivered to the tanks is calculated with about 995 MWh/a. This corresponds to 730 kWh/m² to the gross collector area per year. The solar yield is calculated by assuming an average temperature difference of collector inlet/outlet and a fixed heat flow over 6 hours per day for 300 days per year within the solar circuits. As mentioned before the solar heating system saves about 280 tonnes CO_2 per annum and about 380 liters a day of furnace oil. The total investment costs for the solar system was about 260,000 € minus subsidies and tax benefit. This corresponds to about 190 €/m² for the gross collector area. The project worked under the RESCO (Renewable Energy Service Company) model. This means that Aspiration Energy invested in the solar system and receives 70 % of the monthly savings over 5 years. If Wheels India would have invested in the solar system and not used the RESCO model, the payback time would have been about 2 years.

6 Large scale solar mining plant

During the last years, mining industries have installed several very large-scale SPH plants and more projects are being planned. The currently largest SPH system worldwide is the Minera Gabriela Mistral, pictured from a bird's view in Figure 12.
Mining requires very high investments, which makes the sector very risk sensitive and conservative about applying new technologies. However, there is a need for its reduction in CO_2 emissions, since customers increasingly care about the carbon footprint of their supply chain. Adding to that, the sector sees an important advantage of SPH in the fact that solar heating costs are highly predictable over the lifetime of a SPH plant (unlike fossil fuels), which highly reduces investment risks.
Minera Gabriela Mistral is producing copper. There, energy is mainly needed for breaking up the ore, transport, pumps, as well as for electrolytic copper winning. Copper mines are usually very remote, so that its energy supply is delivered by oil/diesel tanker trucks. By electrolysis, copper of high purity is deposited on plates. For this, a copper solution is heated in a bath between 46 °C and 51 °C. Prior to the installation of the SPH plant, the mine used 8,000 m³ of oil per year to produce 120,000 tons of copper.
The SPH plant at Minera Gabriela Mistral has an aperture area of 39,300 m² and a heat storage of 4,000 m³. It was commissioned in October 2013 and has a thermal peak power of 27.5 MW_{th}. The system delivers heat for electrolytic copper winning to the Gaby copper mine, which belongs to the state-owned mining company Codelco.

Figure 12: Flat-plate collector field of 39,300 m² at Codelco's "Minera Gabriela Mistral" in the Atacama Desert, Chile (Source: ArconSunmark)

The plant is located 100 km south of the city Calama, in a region with almost no rainfall and regular sand storms. Regardless of the harsh environment, the Atacama Desert is pre-destined for SPH, since the high altitude of between 2,000 m and 4,000 m above sea level leads to 90 %very clear days. Additionally, the Atacama Desert is located near the equator between 18° and 25° southern latitude, leading to very little annual variation in irradiance. The primary (collector) loop of the plant works at 85 °C flow and 55 °C return flow, the secondary loop at 80 °C / 60 °C. The 80 °C flow temperature is needed to heat the baths. The secondary solar loop is directly connected to the fossil boiler heating network. Due to the storage, the SPH system supplies heat for 24 hours. The collectors are cleaned by an innovative automated dry cleaning device and their tilt is seasonally adjusted to ensure maximum solar gains. The system annually delivers 50 GWh of heat, with an extremely high specific solar gain of 1,272 kWh/m²a. It covers 85 % of the energy needed for electro winning, equal to savings of 20,000 l oil per day or 250 road tankers annually. The remaining heat demand is delivered by the existing oil burner.

Sunmark Solutions installed Minera Gabriela Mistral as a turn-key project. The project was realized by the project developer Energía Llaima SpA, who organized financing of the plant. Energía Llaima is contracted by Codelco, who only buy the solar heat actually produced. This way, Codelco did not have to take any risks, neither technically nor economically, nor did they have to put any effort into realization of the project (Slavin 2015).

7 Solar heating plant for metal treatment processes

The company Zehnder is producing radiators, heat pumps, and other heating components in Gränichen, Switzerland with about 250 employees working five to six days per week. The company has a heating demand of approx. 1,670 MWh per year, which was previously covered with heating oil and liquefied petroleum gas (LPG).
The radiators are pre-treated in baths at a temperature around 60 °C before they are coated. About 40 % of the heating demand of Zehnder is from these baths. Figure 13 shows the solar collector field of the company, which was commissioned in July 2012. The field is orientated along the roof edge with about 25° turned towards the south-east. The collectors are sloped 45° and unshaded. Since the production hall was newly constructed before the collectors were installed, the necessary sub-structure for the collectors had already been considered beforehand.

Figure 13: Field of 80 high performance evacuated tube collectors with CPC reflectors on the roof of Zehnder in Gränichen, Switzerland, with a gross area of 394 m² (Source: Ritter XL Solar)

Figure 14 shows the integration of the plant into the hydraulic system. Solar heat is directly integrated into the heating network of the new production hall, so the collector field works like an additional boiler. The installation is a so called Aqua System, operating with water only as the heat carrier fluid. No heat exchanger between collector loop and heating network is necessary. Depending on the current power of the field, the solar loop is either used as return flow boost for the boilers or to deliver the set flow temperature of 85 °C to heat the baths.
Because the baths itself can be used as a buffer, only a very small storage tank of 5 m³ is installed. This storage acts as a hydraulic separator, compensating the different mass flows through the solar loop, the boilers and the baths.

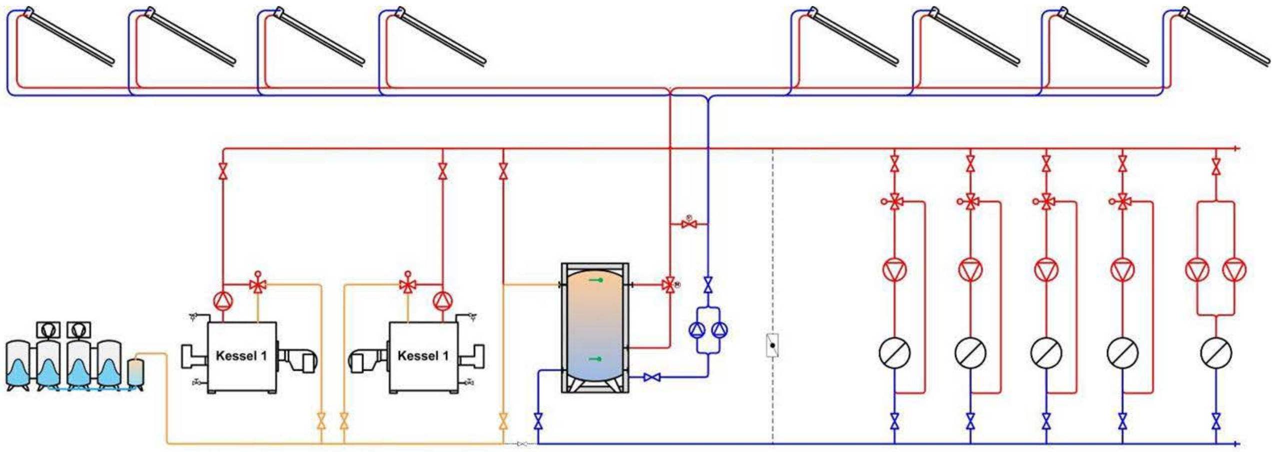

Figure 14: Integration of the evacuated tube collector field into the heating network parallel to the existing boilers (Source: Ritter XL Solar)

Ritter XL Solar states that on very good summer days the plant covers the whole heating demand of the baths. Annually, the solar fraction of this process is 30 %. Alternatively, the heating of the production hall can be supplied by solar when required.
Considering all material and installation costs of the system including the steel sub-structure for

mounting, the solar plant had specific investment costs of about 1000 EUR/m², not including subsidies. Thanks to a grant from the Swiss Federal Office of Energy, the plant is expected to have a payback period slightly above five years.

According to Ritter XL, the simulated specific yield of the system is 400 kWh/m²a, summing up to an annual gain 158 MWh/a, which means annual savings in LPG of about 200 MWh. The system is turnkey and was installed under Guaranteed Solar Results contracting. In this case, this means if the system delivers less than 90 % of the simulated annual energy gain as a mean value over the first three years, the solar company is paying the costs of the fuel not saved. In the first two years of operation, the measured solar gains matched the simulated system gains very well.

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