.

# Experiences with industrial solar process steam generation in Jordan

Dirk Krüger, Michael Berger, Marwan Mokhtar, Lisa Willwerth, Christian Zahler, Mahmoud Al-Najami, and Klaus Hennecke

Citation: AIP Conference Proceedings **1850**, 180003 (2017); doi: 10.1063/1.4984570
View online: http://dx.doi.org/10.1063/1.4984570
View Table of Contents: http://aip.scitation.org/toc/apc/1850/1
Published by the American Institute of Physics

# Experiences with Industrial Solar Process Steam Generation in Jordan

Dirk Krüger[1a)], Michael Berger[2b)], Marwan Mokhtar[3], Lisa Willwerth[4], Christian Zahler[5], Mahmoud Al-Najami[6] and Klaus Hennecke[7]

*[1]Dipl.-Ing., Researcher. German Aerospace Center (DLR), Institute of Solar Research, Cologne, Germany. +49 2203 924129*
*[2] Dipl.-Phys., System Engineering. Industrial Solar GmbH, Emmy-Noether-Str. 2, 79110 Freiburg, Germany*
*[3] MSc., Research & Development. Industrial Solar GmbH, Emmy-Noether-Str. 2, 79110 Freiburg, Germany*
*[4] MSc., Researcher, German Aerospace Center (DLR), Institute of Solar Research, Cologne, Germany*
*[5] Dipl.-Phys., Managing Director. Industrial Solar GmbH, Emmy-Noether-Str. 2, 79110 Freiburg, Germany*
*[6] Dr., General Manager. RAM Pharmaceutical Industries Co. Ltd P.O.Box 211 - King Abdulla II Industr. Est. Sahab, 11512 Amman*
*[7] Dipl.-Ing., Researcher. German Aerospace Center (DLR), Institute of Solar Research, Cologne, Germany*

[a)]Corresponding author: dirk.krueger@dlr.de
[b)]michael.berger@industrial-solar.de

**Abstract.** At the Jordanian pharmaceuticals manufacturing company RAM Pharma a solar process heat supply has been constructed by Industrial Solar GmbH in March 2015 and operated since then (Figure 1). The collector field consists of 394 m² of linear Fresnel collectors supplying saturated steam to the steam network at RAM Pharma at about 6 bar gauge. In the frame of the SolSteam project funded by the German Federal Ministry for Economic Affairs and Energy (BMWi) the installation has been modified introducing an alternative way to separate water and steam by a cyclone. This paper describes the results of experiments with the cyclone and compares the operation with a steam drum. The steam production of the solar plant as well as the fuel demand of the steam boiler are continuously monitored and results are presented in this paper.

## TESTING OF DIRECT STEAM GENERATION PROCESSES

For direct steam generation in solar collectors typically the so-called recirculation process is used. The solar field is supplied with a surplus of liquid water, so that only a part of the entering water is evaporated in the absorbers. Behind the collector field the water/steam mixture will be separated. The separated steam will be delivered to the steam network, while the liquid part will be pumped back to the collector inlet. To replace the separated steam in the collector circuit, feed water is injected into the recirculated liquid water.

The separation of liquid water and steam can be accomplished by a steam drum [1]. The steam drum also serves as a buffer storage for up to 15 minutes of steam consumption, by accumulating steam in a pressure range from 7 $bar_g$ to 14 $bar_g$. Additionally, by changing the set point of the steam drum level, water can be drawn from or deposited in the steam drum quickly, when the amount of water mass changes quickly in the solar field due to transients like for example clouds. This solution has been implemented at the installation at RAM Pharma. A detailed technical description of the solar plant is given in [2]. Figure 1 shows the solar field and the steam drum in front of it.

*SolarPACES 2016*
AIP Conf. Proc. 1850, 180003-1–180003-8; doi: 10.1063/1.4984570
Published by AIP Publishing. 978-0-7354-1522-5/$30.00


**FIGURE 1.** Collector field and steam drum. a) Upper level switch, b) Level sensor, c) Lower level switch

## Operation with Steam Drum

The operation with the steam drum has proven to be stable. No superheating has been observed in the absorbers of the collectors. Superheating would indicate a dry-out of the absorbers, resulting in a severe non-uniform temperature distribution across the absorber diameter and accordingly high tensions possibly beyond allowed limits. During operation no strong noises or vibrations have been observed, which would be the case when steam hammer occur, even though the two-phase mix of steam and condensate flows downwards from the collector exit to the steam drum.

During start-up and shut-down of the solar field water movement from and to the solar field were well compensated by the steam drum. Operation of the solar field through the steam drum showed a very stable supply to the customer's steam network. During operation of the solar field the pressure in the steam network is even more constant than at times when only the conventional diesel fired steam boiler supplies steam.

As mentioned above, the steam drum not only worked as a separator, but also as a steam accumulator of roughly 15 min storage time, which additionally stabilized the operation during changing weather conditions or when the steam consumption in the factory changed quickly. Such rapid changes in the steam demand are common, when batch processes in the production are turned on or switched off.

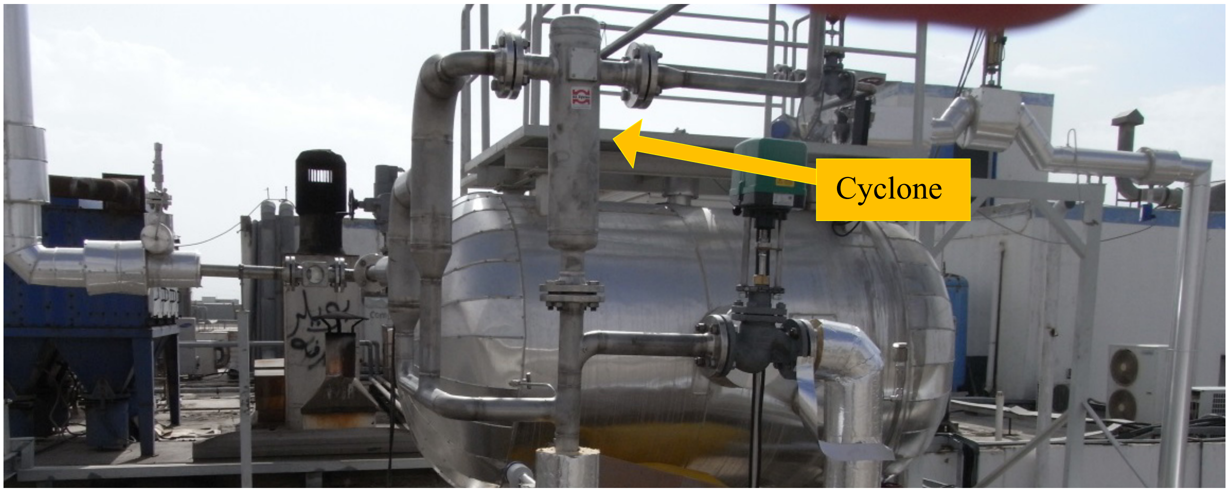


**FIGURE 2.** Cyclone in front of steam drum before the installation of thermal insulation

## Operation with Cyclone

While the steam drum is a very effective solution to ensure a reliable solar steam supply, it is an expensive component, when only compared to other separator technologies, if the storage property is not needed. Instead a cyclone can take over the task of separating liquid from steam. In a previous work a baffle separator and two different cyclones have been investigated and showed a good performance for one loop at the DISS test facility at the Plataforma Solar de Almeria (PSA) [3]. To investigate which effects the integration of a cyclone will have on the operation of a commercial process steam plant, a cyclone has been installed in parallel to the drum during October 2015 (Fig. 2) with a three way valve to switch between both operation modes. Cyclones are commonly used to dry steam, but typically with low liquid content in a wet steam flow. At this installation though, high amounts of water can enter the cyclone, as the solar field is typically run with excess water so that only a part of the water entering the solar field is evaporated and a great part remains liquid. Therefore, a series of two demisters has been installed ahead of the cyclone to separate the largest part of the liquid from the two-phase flow before entering the cyclone. In the cyclone the remaining liquid part is supposed to leave at the bottom of the cyclone, while the steam leaves at the right upper side (compare Fig. 2).

It is necessary to know about the water level below the cyclone to avoid that water rises until the cyclone is flooded and water reaches the consumer steam line. Also it must be avoided that steam reaches down to the recirculation pump. Therefore a level sensor and transmitter have been installed (LT in Fig. 3 and marked b) in Fig. 1) parallel to an enlarged vertical pipe from the rooftop down to the ground level, where the recirculation pump is installed. The level value is being used to regulate the position of the three way valve V-54. It is open (position 0% in Fig. 5) between cyclone and recirculation pump when the level is high and closes when the level gets low, thereby opening towards the steam drum. At the latter case water is taken from the steam drum which here is used as a standby vessel comparable to a feed water tank, because the recirculation pump must not be starved.

The challenge for operation with the cyclone is to prevent starvation of the recirculation pump on one side and flooding of the cyclone on the other. For security the level switches (EPD) I-97 and I-96 give a signal, whether they are in water or steam. To reduce the flow velocity in that pipe and to have more reaction time to control the level position, the pipe section between cyclone and lower level switch has been enlarged from 2” to 4” NPS. The upper level switch (I-97) is close to the bottom of the cyclone to indicate potential flooding of the cyclone, while the bottom level switch is directly underneath the lower range of the level measurement to indicate potential danger of starving the pump.

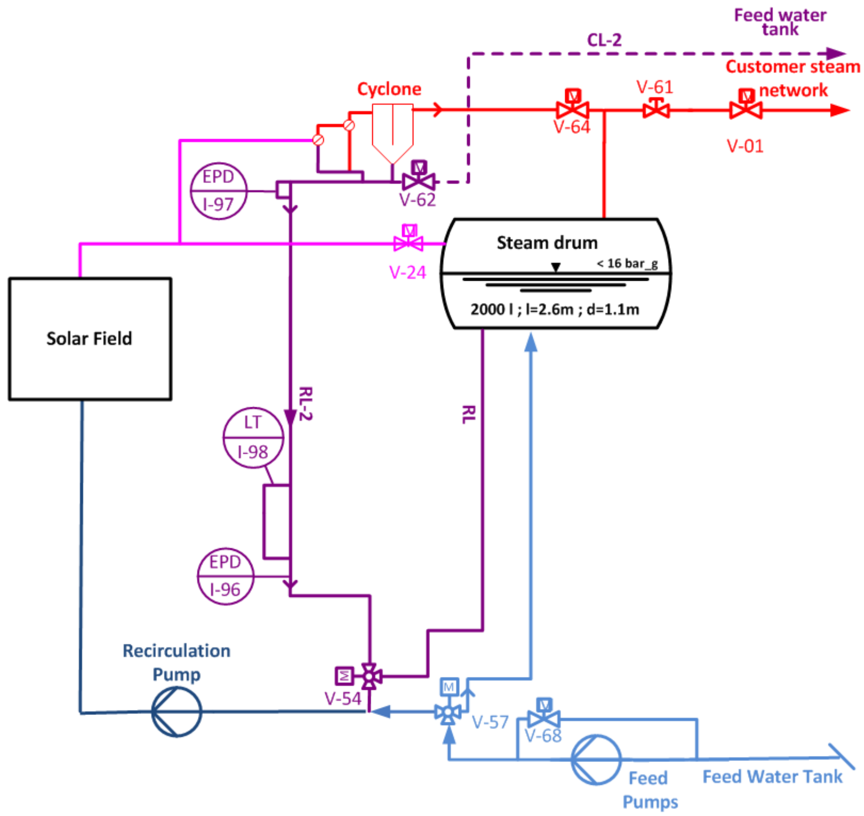


**FIGURE 3.** Valves and sensors around steam separation. With the three way valve V-54, a choice between cyclone or steam drum operation can be made.

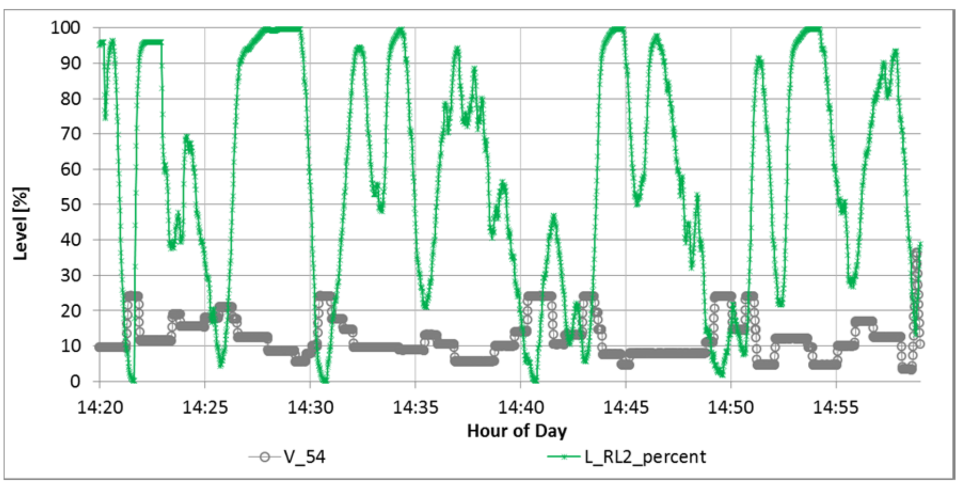


**FIGURE 4.** Water level in % of the level sensor height and the closing in % of the valve V-54

The operation of the cyclone has been tested on site on the 17th of April 2016. During one hour of continuous manual control the water level could be kept within the boundaries given by the two level switches.

Figure 4 shows a part of the test with the water level in % of the level sensor height (green curve) and the opening position in % of the three way valve V-54 (grey curve). Mostly the level even remained between the min and max values of the level sensor. At times when the water level reaches 100% the upper level switch has not been triggered meaning that the water level did not reach up to the cyclone.

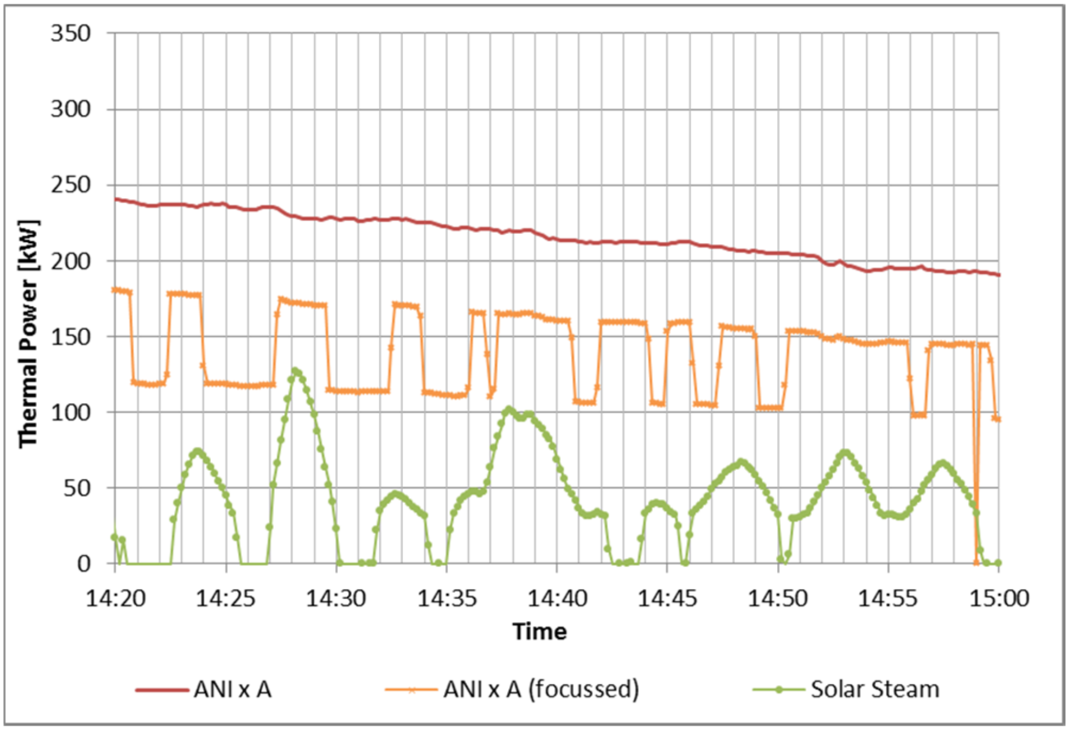


**FIGURE 5.** Thermal power during testing cyclone. The red curve shows ANI multiplied with the collector aperture area (A) of 394 m² in kW. The orange curve shows the ANI power on the mirrors in focus, which have been adapted to the steam demand of the factory within 25% and 75% of the overall mirror area (A). The green curve shows the measured amount of steam delivered to the consumer in kW after multiplying steam mass flow with the specific enthalpy difference between steam and feed water.

The testing has been performed during a day with fairly constant radiation (red curve, Fig. 5). The radiation is displayed as ANI which is the DNI multiplied with the cosine of the incident angle. The steam demand by the factory (green curve, Fig. 5) fluctuated severely between 0 and 120 kW thermal power. The solar field adapts to the actual power demand by turning some of the mirrors in or out of focus (orange curve, Fig. 5).

Nevertheless these fluctuations could be handled well and the water level remained between the boundaries given by the level switches. It is now planned to introduce an automatic control of the water level in the cyclone path.

## SOLAR STEAM DELIVERY TO PRODUCTION STEAM LINE

The solar field size at RAM Pharma is comparatively great compared to the consumption of the facility. Even days can be observed when the solar steam production is significantly above the consumption. Apart from demand this depends strongly on the season. In winter the solar gains are lower due to higher zenith angles of the sun. In Fig. 6 and 8 a winter and a summer day are displayed on which the DNI reaches about 700 W/m² around noon. The ANI is much lower though for the winter day as can be recognised by the orange curve representing the ANI multiplied by the aperture area in focus. The green lines represent the steam power delivered to the consumer. The dark line stands for the thermal power from the steam boiler and the light green line for the solar field power. Fossil power is calculated from measured fuel oil consumption assuming an efficiency of 75 %, and an energy equivalent of 10 kWh/l of diesel.

On the winter day the consumption is high during the whole day except for the time between 16:00 and 19:00 when there is a pause in production. Solar steam is supplied in intervals (see Fig. 7) because the solar field power is lower than consumption and because the control hysteresis of the steam valve V-01 causes it to close for a while. This way the solar energy is stored for a while and then released explaining also values of solar steam production above the ANI values multiplied with aperture. During the pauses the boiler takes up production.

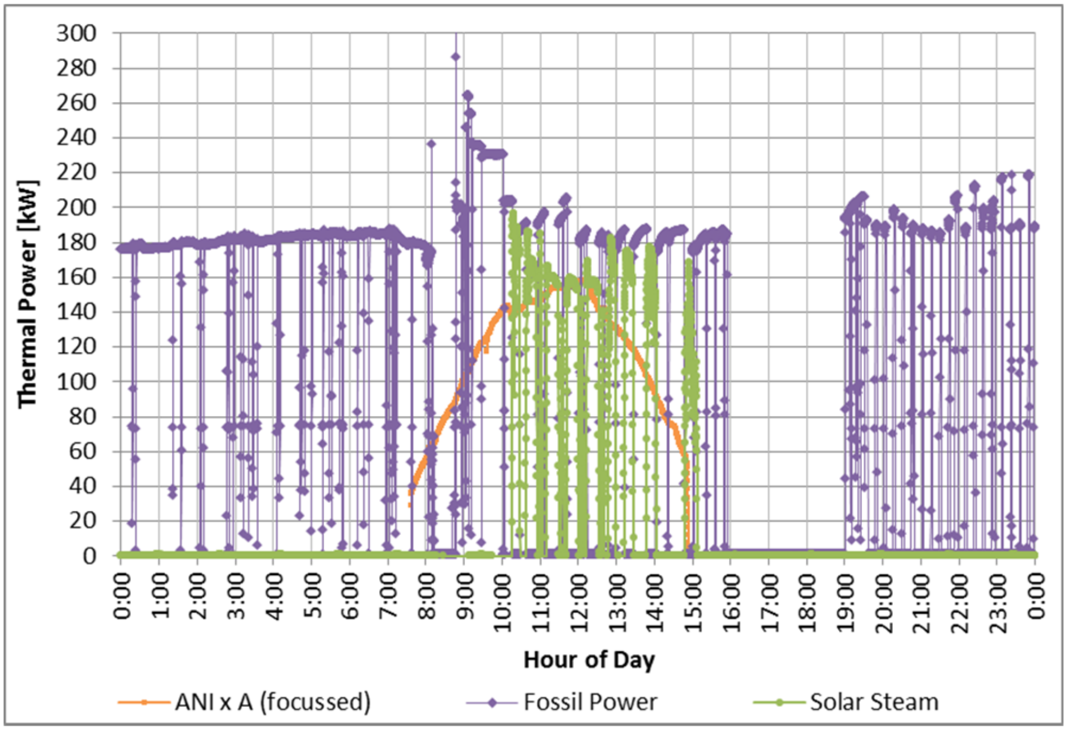


**FIGURE 6.** 25th of December, 24 hour thermal production

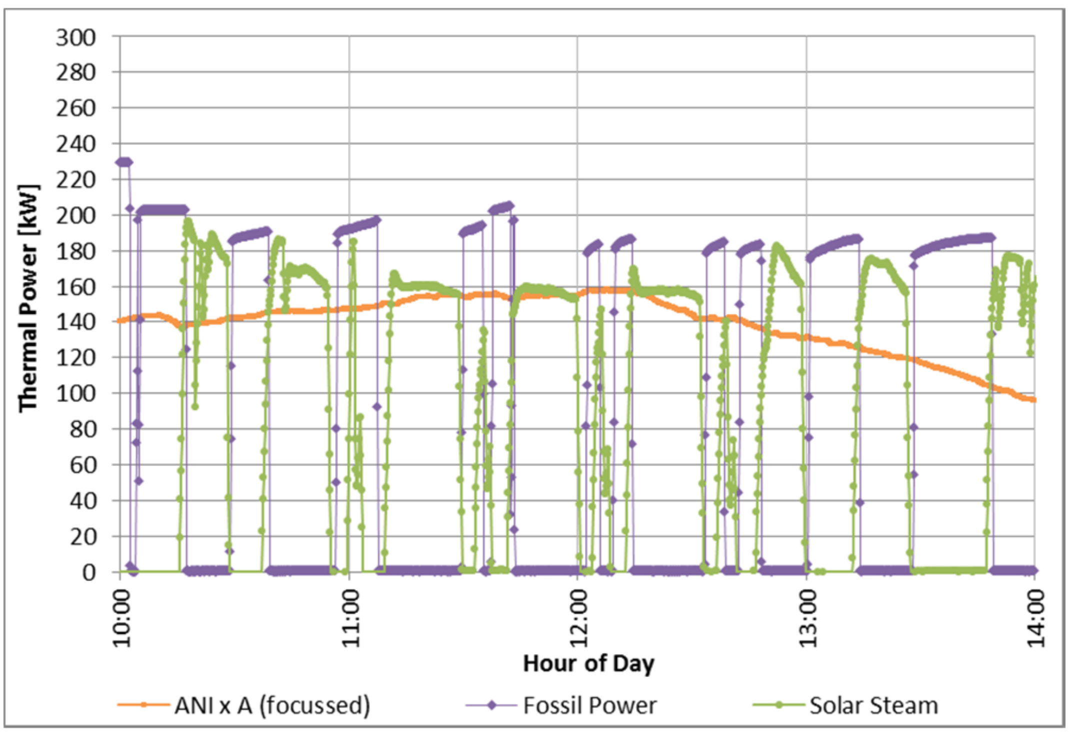


**FIGURE 7.** 25th of December, thermal production between 10 a.m. and 2 p.m..

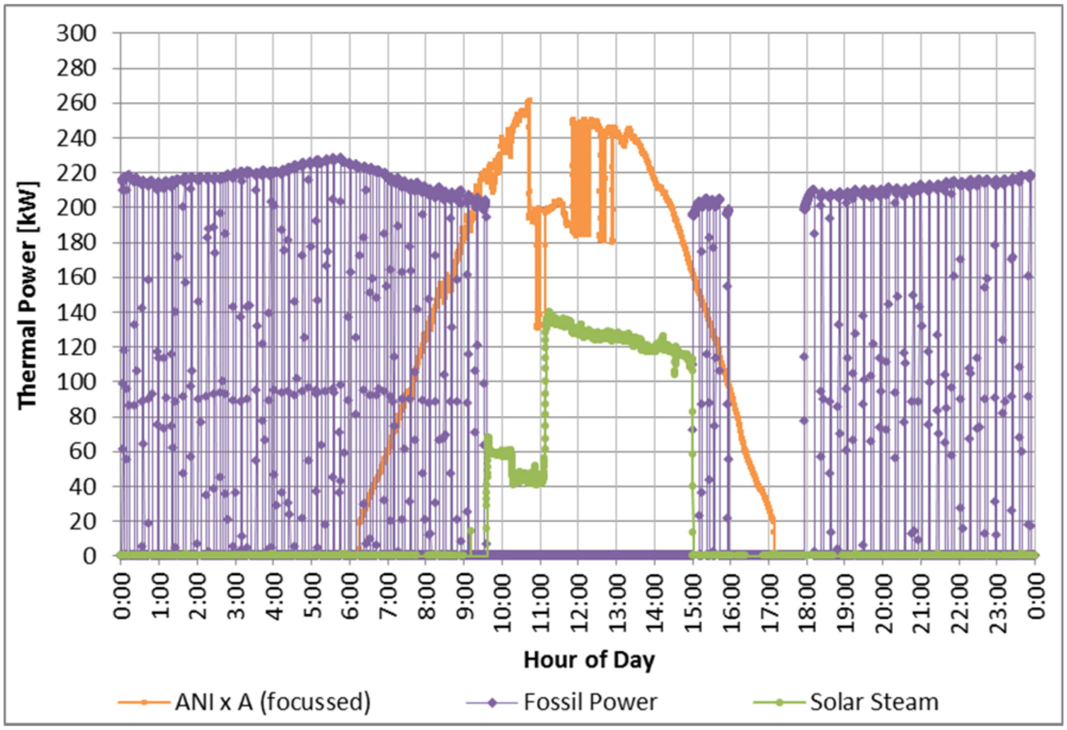


**FIGURE 8.** 7th of April, 24 hour thermal production

During the summer case in Fig. 8 a case of surplus of solar energy can well be observed. There is a constant demand during the night and the early morning. During the start-up phase of the solar system the boiler provides steam. Starting from 9:30 a.m. solar steam is provided until 3 p.m. (15:00). During this time all the energy is provided by the solar field. At noon the solar energy provided is greater than the demand so that some of the mirrors are defocussed recognisable in the dips of the curve ANI multiplied with the aperture in focus.

**TABLE 1.** Examples for daily thermal production

| | 25th of December | 7th of April |
|---|---|---|
| ANI | max. 400 W/m² | max. 685 W/m² |
| Energy from fuel oil [MJ] | 9110 | 4154 |
| Solar Energy in MJ | 1447 | 2018 |
| Savings of fuel oil in litre | 53 | 75 |
| Savings of fuel oil in % | 14 | 33 |
| | Higher steam demand than available solar power | Lower steam demand than available solar power |

## RESUME

Operating the solar field with a steam drum has proven to be very stable in automatic operation. The integration into the existing steam supply did not create any technical incidents or shutdown of the production which is often feared by operation personnel. Delivery of steam is smoothly shifted from solar field to boiler and vice versa.

First tests to move the liquid/steam mixture along a cyclone instead along the steam drum have shown successful with manual control of the related valves. Nevertheless to replace the steam drum another vessel needs to be available to take up water separated by the cyclone.

In a next step an automatic control shall be implemented and tested at the RAM Pharma installation.

## ACKNOWLEDGMENTS

The adaption and monitoring of the plant in 2016 and 2017 within the frame of the project "SolSteam" is being funded by the German Federal Ministry for Economic Affairs and Energy (BMWi) on the basis of a decision by the German Bundestag (Funding reference number: FKZ 0325545A-C).

The installation of the solar process steam plant has been funded by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

## REFERENCES

1. D. Krüger, N. Lichtenthäler, J. Dersch, H. Schenk, K. Hennecke, A. Anthrakidis, M. Rusack, A. Lokurlu, K. Saidi, M. Walder, S. Fischer and H. Wirth, "Solar steam supply: Initial operation of a plant", ISES Solar World Congress, Kassel, Germany, 28.8. – 2.9.2011.
2. M. Berger, M. Mokhtar, C. Zahler, M. Al-Najami, D. Krüger and K. Hennecke, „Solar Process Steam for a Pharmaceutical Company in Jordan" in SolarPACES 2015, 13. - 16. Oktober 2015, Cape Town, South Africa, AIP Conference Proceedings 1734.
3. M. Eck, H. Schmidt, M. Eickhoff and T. Hirsch "Field Test of Water-Steam Separators for Direct Steam Generation in Parabolic Troughs" at SolarPACES 2006, Sevilla, Spain.