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THE DISS PROJECT: DIRECT STEAM GENERATION IN PARABOLIC TROUGHS OPERATION AND MAINTENANCE EXPERIENCE UPDATE ON PROJECT STATUS

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ABSTRACT

The DISS (DIrect Solar Steam) project is a complete R+TD program aimed at developing a new generation of solar thermal power plants with direct steam generation (DSG) in the absorber tubes of parabolic trough collectors. During the first phase of the project (1996-1998), a life-size test facility was implemented at the Plataforma Solar de Almería (PSA) to investigate under real solar conditions the basic DSG processes and evaluate the open technical questions concerning this new technology. This paper updates DISS project status and explains O&M-related experience (e.g. main problems faced and solutions applied) with the PSA DISS test facility since January 1999.

NOMENCLATURE

DAS	Data acquisition system
DISS	Direct solar steam (the project)
DSG	Direct steam generation (the process)
PSA	Plataforma Solar de Almería
P	Pressure
T	Temperature

INTRODUCTION

Solar thermal power plants based on parabolic trough collectors are presently the most successful solar technology for electricity generation, as demonstrated by the SEGS plants in California. Direct steam generation in the absorber tubes is seen as a promising option to further the competitiveness of this technology. Replacement of the oil by direct steam generation results in lower investment and operating costs, as well as reduced environmental risk and fire hazards in case of leaks. Simultaneously, the performance can be improved by avoiding the thermodynamic losses associated with the oil - water/steam heat exchanger of the SEGS plants. In combination with further improvements of the collector field and overall system integration, a 26% reduction in the electricity cost seems to be achievable (Langenkamp, 1998).

Taking into consideration this expected benefit, a group of German and Spanish partners, with the financial support of the European Commission JOULE Programme, started in 1996 the DISS (Direct Solar Steam) project, which is an R+D program aimed at developing a new generation of solar thermal power plants with parabolic trough collectors. Expected improvements are based on three main factors:

1. Development and implementation of improved components for parabolic trough collectors (e.g. new, more economical absorber tubes with good optical and thermal properties; cheaper sun-tracking systems; better mirrors, etc...).
2. Development of the Direct Steam Generation (DSG) process to eliminate the oil used at the existing solar thermal plants as a heat carrier from the solar field to the power block. Since the DSG process is a promising way

to increase the overall efficiency of parabolic-trough solar thermal power plants, development of this new technology was defined as the main objective of the DISS project

3. Optimization of the overall plant O&M procedures and design to achieve a better coupling between the solar field and the power block.

During DISS-Phase I (1996-1998), a life-size test facility was designed and implemented at the Plataforma Solar de Almería (PSA), the largest European solar research center. At present, in the second phase of the DISS project (1999-2001), this test facility is in use to investigate the three basic DSG processes (i.e., Once-through, Recirculation and Injection) under real solar conditions to find out which would be the best for a commercial plant, thus gathering valuable experience for the design of future DSG-based power plants.

THE PSA DISS TEST FACILITY

The facility is composed of two subsystems, the Solar Field and the Balance of Plant (BOP). The solar field converts direct beam solar radiation into superheated steam, while the BOP condenses this superheated steam and sends it back to the solar field inlet.

The solar field is composed of a single North-South oriented row of 11 parabolic trough collectors connected in series, with a total length of 550 m and 3000 m^2 of reflecting mirrors. Each collector is composed of 4 parabolic trough modules, with the exception of Collectors 9 and 10, which have only two. Each module has a 12-m aperture and is 5.57 m long with a focal length of 1.71 m. The inner/outer absorber pipe diameters are 50/70 mm.

The collector row is divided into two sections by a water/steam separator:

- *The water evaporation section:* The first nine collectors of the row where the feed water is preheated and converted into saturated steam. Their tracking axes can be placed horizontal or tilted at either 2 or 4º to study the influence of the tilt on the two-phase flow pattern.
- *The steam superheat section*: The last two collectors in the row where the saturated steam delivered by the evaporating section is superheated.

Figure 1 shows the schematic diagram of the PSA DISS facility. The three main operating modes are:

	Solar field inlet	Solar field outlet
Mode 1:	Water at 40bar/210ºC	Steam at 30bar/300ºC
Mode 2:	Water at 68bar/270ºC	Steam at 60bar/350ºC
Mode 3:	Water at 108bar/300ºC	Steam at 100bar/375ºC

In the BOP, the superheated steam produced by the solar field is condensed in an air-cooled condenser and converted into feed water that is pumped back to the solar field inlet and the water injection system in a closed loop. The BOP is also provided with a deaerator and chemical dosing equipment. The water recirculation system consists of a water/steam separator and a pump that recirculates the water entering the separator to the solar field inlet.

There are water injectors at the solar field to allow system operation in any of the three basic DSG processes: Once-through, Injection and Recirculation. Figure 2 shows the basic scheme for each of these three processes. All the components of the DISS facility have been designed for flexible operation, so that any combination of the three basic DSG configurations is also possible.

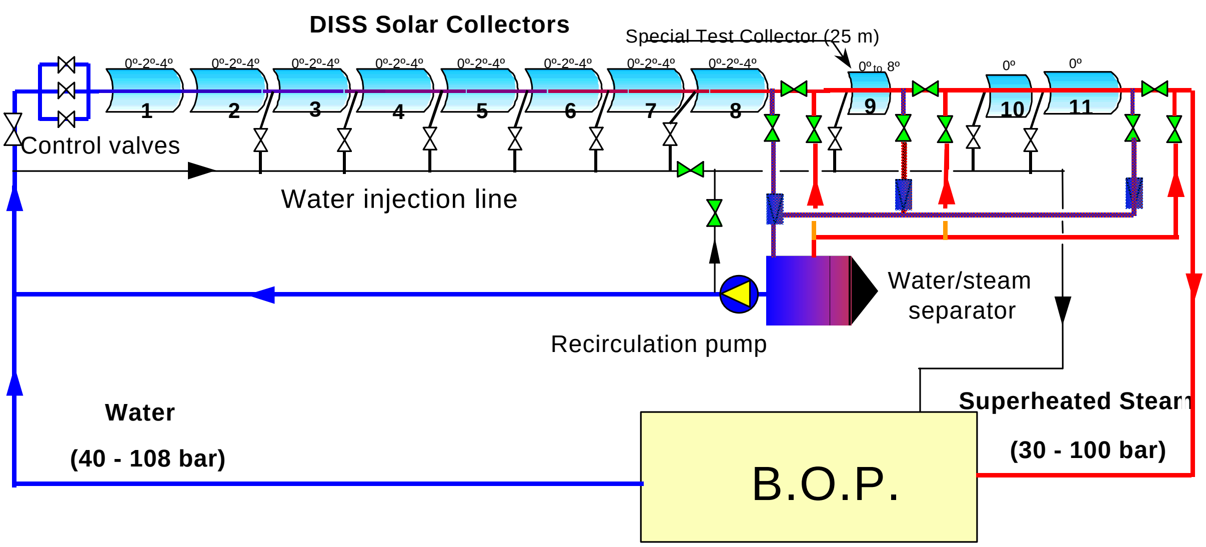

Figure 1. Actual diagram of the PSA DISS test facility

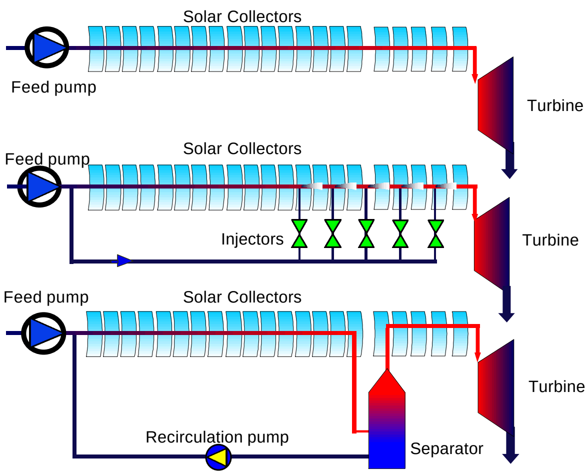

Figure 2. The three basic DSG processes (Once-through, Injection and Recirculation)

Figure 3 is a picture of the DISS facility in operation, with the absorber pipes in the focal line illuminated by the concentrated solar radiation reflected by the mirrors.

OPERATION AND MAINTENANCE EXPERIENCE

The PSA DISS test facility was operated for more than 2000 hours from January, 1999 to October, 2000. In spite of the technical problems faced during this period, many tests have been performed and valuable experience has been gained. This testing will continue until August 2001.

It should be remarked that the main problems faced so far were not in the DSG process itself, but the conventional equipment used for it (e.g. thermocouples installed on the absorber pipes, water recirculation pump and electronic cards). In the following paragraphs these problems and the action taken to solve them will be explained.

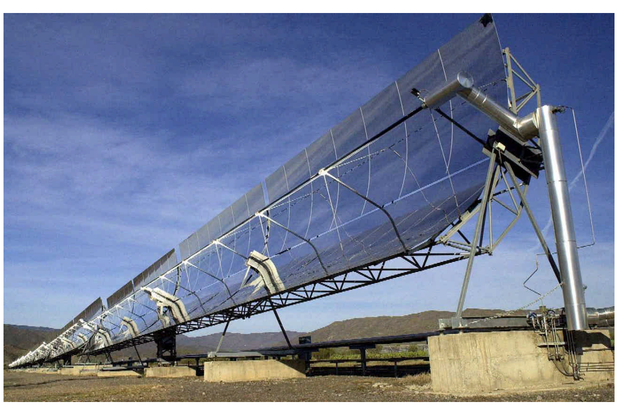

Figure 3. View of the PSA DISS solar field in operation

1. Local Controllers to Track the Sun

The DISS solar collectors are provided with an innovative sun-tracking system. The traditional controller based on sensors that detect the position of the sun has been replaced by a new system based on theoretical calculation of the solar coordinates. The algorithm used for this and the angle encoder used to measure the position of the collector rotation axis are the two basic elements of this system.

The local controller calculates the solar coordinates and the collector axis position necessary to reflect the beam solar radiation onto the absorber tube in the focal line of the parabolic reflector. If the position of the rotation axis, which is measured by a 2^{12}-bit angular encoder, is not right, the local controller activates the solenoid valves of the hydraulic-drive unit rotating it into the proper position.

During the last two years, the PSA team has continually improved the solar coordinate algorithm, increasing its accuracy. The latest version of this algorithm has been checked against the Multiyear Interactive Computer Almanac (MICA), which is a software product of the United States Naval Observatory (1998) and the results reported by Blanco (2000)] were highly accurate.

Though system performance seems to be good at present, there are still some small tracking errors. The test performed on October 27, 2000, showed a maximum peak error of less than 3.1 mrad over the day. Though this tracking error does not seem important enough to affect the optical efficiency of the solar collectors, the source is currently being sought in an attempt to remove it. The influence of several types of errors (e.g. mechanical, optical and geographical coordinates of the PSA site) has been studied. Preliminary conclusions achieved so far are:

- The steel structure of the DISS collectors is rigid enough and no error due to bending or torsion has been detected.
- The angular encoder must be, whenever possible, connected directly to the collector rotation axis. The use of a pendulum to determine the position of the axis is subject to problems due to mechanical inertia of the steel structure and oscillation of the pendulum.
- Resolution of the current angular encoders (2^{12} bits) seems to be too low. 2^{13}-bit encoders seem to be a better option for large parabolic trough concentrators (similar to the LS-3 size).
- The influence of a small error in the North-South alignment of the row of collectors is very important. Even a very small error (< 4.5 mrad) can cause a large error in collector position when this is done by mathematical calculation of the solar coordinates. On the other hand, large errors in the longitude and/or latitude of the site are required to provoke a significant positioning error. Figure 4 shows a comparison of the positioning errors produced by these three types of deviation.

2. System Start-Up and Shut-Down

One of the O&M problems initially faced at the DISS facility was the long start-up period needed to reach nominal operating conditions.

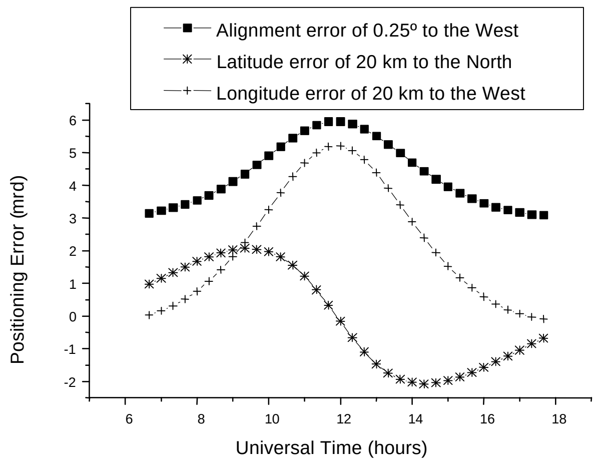

Figure 4. Positioning errors that would be produced by deviation in the North-South alignment of the DISS collector row, latitude and longitude of the PSA site

The number of steel parts in the solar field (more than 2000 meters of piping and 26 Tons of iron) required a long start-up time (about 6 hours) to achieve nominal steam pressure from system ambient temperature. Steam remaining in the solar field piping and vessels is condensed by overnight thermal loss, demanding a lot of thermal energy to heat the system up in the morning. This problem delayed the development of the planned DSG testing.

A dynamic simulation model of the DISS facility identified improvements that could shorten start-up and reduce thermal loss. Modifications in the initial piping layout and operating procedure and thermal insulation improvements were therefore implemented late in 1999, reducing start-up time by more than 50%. The shutdown procedure was also improved to shorten the time initially needed to stop daily operation.

The main modification in the piping layout was the implementation of a bypass to connect the solar field outlet to the water/steam separator (see Fig 1). Without the new bypass, only the first 9 collectors could be connected to the water/steam separator at start up, while the last 2 collectors would remain out of focus until saturated steam at nominal pressure was available at the separator. The bypass connecting the outlet of the row of collectors to the water/steam separator, made it possible to use the whole solar field to start up the facility and increase the temperature and pressure, thus partially overcoming the huge thermal inertia of the facility.

Figure 5 shows the main operation parameters during a dynamic test to adjust the outlet steam temperature control. The complete solar field was focussed at 9:15 hours to start up the facility. The outlet of the solar field was connected to the water/steam separator, which in turn was connected to the solar field inlet by means of the recirculation pump (see Fig 1). 60 bar Nominal pressure was reached at 11:23 and the outlet of the solar field was disconnected from the separator and connected to the BOP, so that the last two collectors began to deliver superheat steam. Nominal operation conditions were maintained during 8 hours and finally the shutdown took less than 15 minutes.

Nevertheless, thermal inertia will not be a major problem for a commercial DSG plant. The length of passive piping (i.e. pipes with thermal insulation) in the DISS solar field is five times greater than the length of active piping (absorber tubes) since there is only one row of collectors and there are long pipe headers connecting the BOP to the solar field inlet and outlet. A commercial plant would have many rows of collectors connected in parallel, so that the length of passive piping would be negligible compared to the total length of collector rows.

Pressure control between the BOP and the solar field was designed and implemented in 2000 to avoid formation of vacuum in the solar field piping due to condensation of the steam remaining in the pipes after shutdown. Water from the BOP is automatically fed into the solar field piping if the pressure falls below 1.1 bar (absolute).

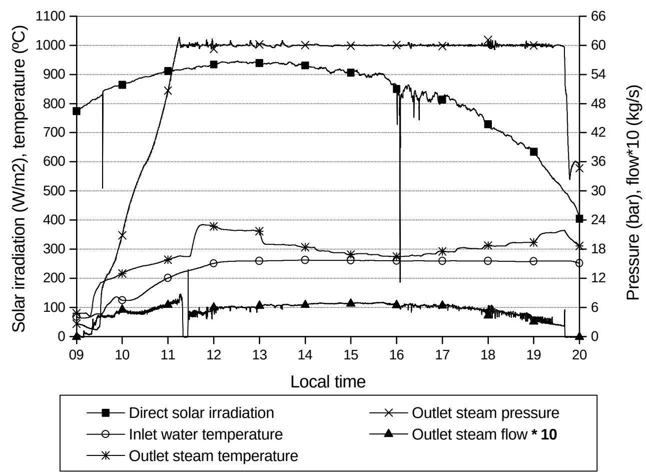

Figure 5. Operation at 60bar in *recirculation mode* on 20th of June 2000.

3. Water Recirculation Pump

A major O&M-related problem was the failure of Pump P-23, the water recirculation pump. Since May 4, 1999, the plunger packing has failed repeatedly, demonstrating that the initial design of this pump, which was specially designed and manufactured by the National Oilwell company (USA) for the DISS project, was inadequate.

Though the pump did not fail for the first few months of operation when operating pressure was kept below 70 bar, problems began to appear as soon as pressure increased to 90-100 bar. The repeated failure of this pump has delayed high-pressure testing. In December, 1999, the pump was checked by National Oilwell and they reported that the initial design of the packing set was wrong. So new parts were delivered by National Oilwell and tested at the PSA in April and May, 2000. Though there was no major problem at 30 bar or 60 bar (except for small leaks) the new packing failed again in July, 2000.

Though National Oilwell has repeatedly stated that the failure of the recirculation pump is not a major problem and promised to solve it, the pump is still unable to work at design conditions, thus delaying the DSG test plan.

4. Measurement of Temperature Profiles at The Absorber Pipes

There are two different types of absorber pipes in the DISS collectors, with and without a set of eight thermocouples on the steel pipe wall. This set of thermocouples is called the *"Test Cross Section"*, because during system operation, it is used to monitor the circumferential temperature profile around the steel absorber tube, the most critical parameter in the DSG process. 44 DISS absorber tubes are provided with such thermocouple sets. Figure 6 shows the *Test Cross-Section* thermocouple layout. Each individual thermocouple is installed in a 5-mm-deep hole in the pipe.

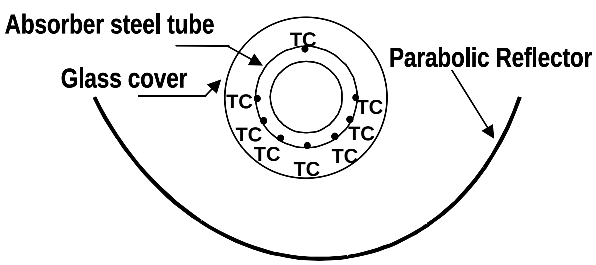

Figure 6. Test Cross-Section thermocouple layout

Temperature gradients measured in the Test Cross Sections during the first tests were much steeper than expected from theoretical calculations. it was found out that heat conduction through the stainless steel thermocouple casings was the cause of the error. Heat was being transferred from the solar-irradiated section to the casing of the thermocouple closest to the junction in its 5-mm bore in the steel tube wall, so that the temperature read by the DAS was not the temperature of the tube wall, but the temperature of the thermocouple junction end.

Once the problem had been identified, trials were performed to find a solution. Several ways to improve the thermal contact between the thermocouples and the tube wall were checked and the best result was obtained by soldering the thermocouples with a special induction generator. Small inductors were manufactured by the German company ELDEC to reach the thermocouples through a small, approx. 50-mm ø window opened in the glass absorber-tube sleeve, to solder the thermocouples.

Once the repair process had been fully defined, it was tried out using a spare absorber tube first and it was then carried out on nineteen DISS absorber tubes. The gap between the glass sleeve and the steel tube of the repaired absorber pipes was filled in with 50 mbar (absolute) of Krypton to avoid future degradation of the selective absorber-tube coating after repair.

Temperature profiles measured with the repaired thermocouples showed the expected maximum 12K to 17K temperature gradient between thermocouples in the same Test Cross Section, which fully agrees with the theoretical values calculated by simulation computer programs.

The lesson learned from this problem is that the thermal contact between a thermocouple and the surface to be measured must be perfect. Contact by pressure is insufficient if the thermocouple casing is subject to concentrated solar radiation.

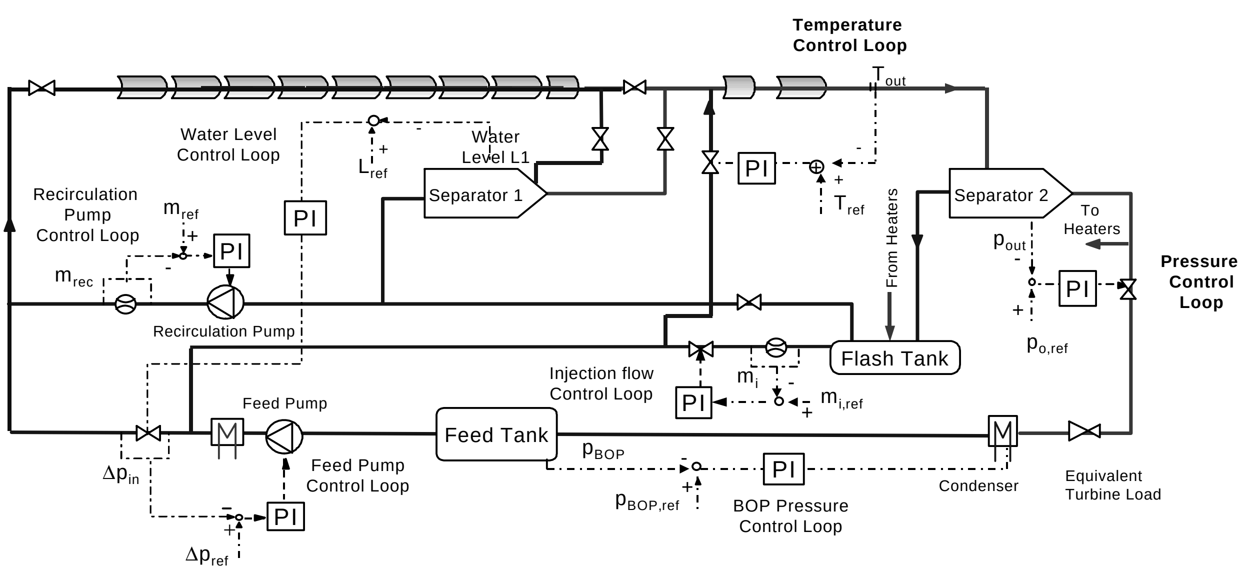

Figure 7. Control scheme for the *recirculation process*.

5. Steam Pressure/Temperature Control

Though the outlet steam pressure and temperature are the main variables that must be controlled in a DSG solar field, the complete control scheme for any of the three DSG basic operation modes (i.e. Once-.through, Injection and Recirculation) requires additional control loops (e.g. water pump, water-level in the water/steam separator, etc.). Figure 7 shows the complete scheme for *Recirculation*.

All the secondary control loops depicted in Figure 7 have been tuned and are working in automatic mode. The outlet-pressure PI-controller has already been tuned and is also working properly. Figure 8 shows how the outlet steam pressure and temperature were kept constant during a *recirculation mode* test on June 22, 2000 designed to adjust the temperature PI-control parameters. This controller was able to cope with variation of 100 W/m^2 in direct beam solar radiation. After 16:00 two changes were made in the temperature set point and control response was also good.

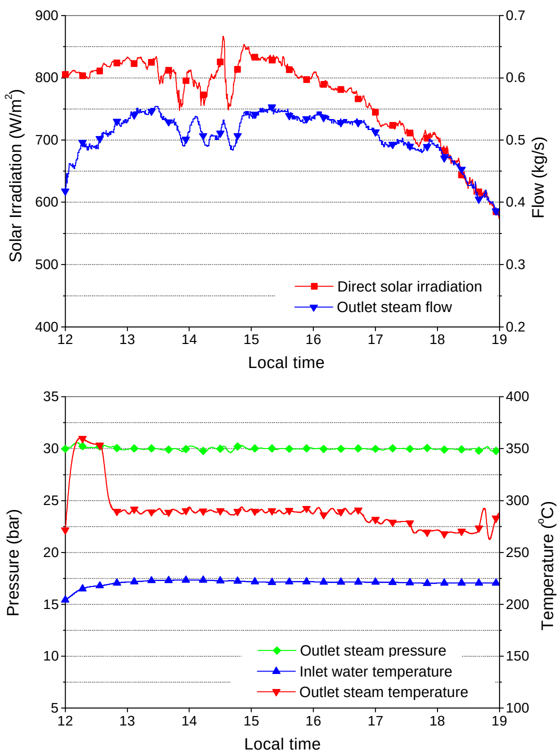

Figure 8. Operation in *recirculation mode* on June 22, 2000 with outlet temperature control from 12:45 to 18:30. Outlet pressure control and secondary controllers in automatic mode (Recirculation rate = 2).

The control scheme configuration for the *once through process* is quite similar. Secondary control loops are nearly the same. Only adjustment of some of the PI-parameters has been necessary. The outlet-steam pressure PI-controller is currently working in automatic mode and the scheme developed to control the outlet-steam temperature differs from the controller designed for recirculation mode. Preliminary tests have been carried out to calculate the parameters associated with the scheme based on a feed-forward controller in parallel with a PI-controller.

With the control schemes already implemented, DSG process stability is guaranteed for clear days and with short solar radiation transients. The tuning of the temperature controllers to cope with long solar radiation transients is still underway.

In addition to the steady-state tests, many transient tests have been performed at the DISS solar field to investigate its behavior under transient conditions. Very interesting results have been obtained from the transient tests performed at the DISS facility (Eck, 2001).

6. Optical Peak Efficiency of The DISS Collectors

Due to optical and geometric factors, there is a significant loss of energy in the solar collectors of a solar power plant during concentration of the solar radiation onto the absorber tubes. Optical efficiency calculation of the DISS collectors is therefore very important to evaluate the energetic behavior of the entire facility.

Optical efficiency tests have been performed with several DISS collectors to determine their optical efficiency at 0° angle of incidence (peak optical efficiency). Peak optical efficiency h_{opt} is the ratio between absorbed heat flow $\dot{Q}_{abs}$ and power irradiated $\dot{Q}_{irr}$ onto the collector, with no thermal loss at an angle of incidence of 0°.

$$h_{opt} = \dot{Q}_{abs} / \dot{Q}_{irr} \quad \text{(no thermal loss, incident angle = 0°)} \quad (1)$$

The absorbed heat is calculated on the basis of the mass flow M through the absorber tubes of the collector and the specific enthalpy gain of the working fluid between collector inlet (h_{in}) and collector outlet (h_{out}):

$$\dot{Q}_{abs} = M \cdot (h_{out} - h_{in}) \quad (2)$$

The irradiated power $\dot{Q}_{irr}$ is calculated using the irradiance Irr and the irradiated area A of the solar collector:

$$\dot{Q}_{irr} = Irr \cdot A \quad (3)$$

Area Irradiated A may be defined in different ways, which in turn lead to different optical peak efficiencies. Care must therefore be taken in defining the irradiated area in order to avoid misunderstanding when comparing efficiency data from different solar collectors. The most usual definition of Irradiated Area is the active irradiated mirror aperture area A_{mirror}. This is the sum of all partial aperture areas, which are calculated using the collector module mirror width Wp_{module} and the facet length L_{facet} of one mirror facet.

$$A = A_{mirror} = \sum Wp_{module} \cdot L_{facet} \quad (4)$$

During DISS collector optical efficiency testing, the following parameters were measured at steady state conditions: collector inlet temperature T_{in}, collector outlet temperature T_{out}, system pressure p, mass flux M and irradiance Irr. Using the inlet temperature, outlet temperature and system pressure, the inlet enthalpy $h_{in} = f(T_{in}, p)$ and outlet enthalpy $h_{out} = f(T_{out}, p)$ were determined from tables of thermodynamics and the above-mentioned peak optical efficiency was calculated.

Since cold water was used as the working fluid in the tests, heat loss was negligible. All tests were carried out in July with the advantage of small angles of incidence for the north-south aligned DISS collector row. However, a final correction factor was used for determining the optical efficiency at 0°.

Six DISS collectors were evaluated and the average peak optical efficiency was 68%. Average mirror reflectivity of the DISS collectors during all these tests was 87%. With cleaner mirrors (reflectivity 93%) and glass absorber-pipe sleeves, the above-mentioned efficiencies would increase about 5 points. An additional 2-point increase in optical efficiency could be achieved if the hydrogen-removing elements installed in the absorber pipes by the manufacturer were not protected from the concentrated solar radiation by aluminum plates that cover 2% of the tube length.

So, the tests performed at the DISS collectors have showed a peak optical efficiency of 75%, which is lower than the 80% peak optical efficiency of the SEGS plants (Harats, 1989). The lower absortivity and higher emisivity of the selective coating used at the DISS absorber pipes is the main reason for this difference. This higher emissivity provokes a slightly lower thermal efficiency also.

7. Other O&M Issues

7.1 Data Acquisition and Supervision Systems

The Control, Data Acquisition and Supervisory System implemented at the DISS facility is a distributed control system supplied by Elsag Bailey Hartmann & Braun, S.A. There are two operator workstations. One of them acts as server and is directly connected to the process control unit. Communication between the server and the process unit is over an RS-232C line. Due to the large amount of data running over this line, some internal DAS software parameters were modified to optimize system performance and eliminate interruptions caused by the impossibility of processing all the data in less than 1 second.

The DISS system has some peculiarities that make it's data acquisition system different from those usually implemented in commercial plants. There are over 2000 signals, including internal computation parameters. Process data are stored in electronic files every 5 seconds, leading to data-files of more than 200MB per day. It was found that the size of these files and the amount of information sent over the communications lines was affecting the normal execution of the operator graphic interface that runs on the same server and more RAM memory was installed to solve the problem.

Failures in the measuring device input circuit cards, communications and blocking of the system are frequent. Though the supplier, Elsag Bailey Hartmann & Braun S.A, has recommended in 2000 some improvements, they have not yet found a solution for the electronic circuit cards, which have a 5% yearly failure rate.

The original RS-232C interface will be replaced by an SCASI communications line and the two operator workstations installed in 1998 will be replaced by more powerful 927 MHz workstations, which are expected to solve the communications failures faced so far.

7.2 Ball-joints

One of the technical design problems of the DISS test facility was the unknown high-pressure and temperature performance of the ball joints connecting adjacent collector absorber tubes. Every collector absorber-tube outlet must be connected to the inlet of the absorber pipe of the following collector by a rotary connection allowing the solar collectors to rotate independently of each other while simultaneously compensating for the thermal expansion of the absorber pipes in both collectors.

Though 400ºC/25 bar ball joints had already replaced the original flexible bellows installed by LUZ at the SEGS plants in California, the DISS facility requires them to work at 400ºC and 125 bar, which had never been tested. A special design had therefore to be developed. The graphite sealing was optimized so that steam or water do not leak at the highest design temperature/pressure and the torque required to rotate the ball joint is low enough to avoid mechanical deformation of the steel collector structure.

The DISS ball-joints have performed very well and there have been no O&M problems during the first 23 months of operation.

UPDATE ON PROJECT STATUS

The PSA DISS facility was operated for more than 2000 hours during the first 23 months of the project. The most important conclusion derived from this is the certainty that direct solar steam generation is possible in parabolic trough collectors with horizontal absorber tubes. The PSA DISS facility has shown its usefulness for applied DSG research, identifying the critical issues that must be taken into account when designing a commercial DSG plant.

Unexpected problems concerning temperature measurement in the absorber pipes and water recirculation-pump failures, together with the need for a long training period in which the operating procedure was optimized, caused significant delays in the initial PSA DSG test plan. This delay has been partially recovered by CIEMAT and DLR by operating the facility Saturdays and Sundays and until sunset on work days. This intensive operation started on June 15, 2000, and will remain in force until the end of the project in August, 2001.

Another important remark is that the main problems faced in the project so far are not related to the DSG process itself, but to measuring devices (thermocouples) and other conventional equipment. Therefore, the technical and commercial feasibility of the DSG process must not be questioned because of that. Most of the problems have been solved. Only the failure of the National Oilwell water recirculation pump and the frequent failure of the Elsag Bailey Hartmann & Braun input circuit cards persist.

Two outstanding achievements have been good DISS high-pressure/temperature ball joint performance and measurement of the absorber-pipe temperature profiles. Experimental temperature measurements are in agreement with the simulation results predicted by computer models (Eck, 2001). Another good result is that the pressure drop measured in the DSG solar collectors is about 30% less than predicted by simulation models. Required pumping power is less than 10% of that in an equivalent HTF solar field, which increases overall plant efficiency.

Facility performance and O&M procedures have been significantly improved. 30-bar and 60-bar recirculation mode tests have shown good system stability and controllability, even under long solar transients. Taking into consideration the low recirculation rate required to assure stability and safe operation under solar transients, options for replacing standard water/steam separators with cheaper devices (e.g., cyclone, T-pipes, etc.) should be investigated.

Despite the encouraging results gathered so far in recirculation mode, demonstration of parallel-row operation is essential to fully validate the numerical models developed for DSG and to gain the confidence of potential investors, manufacturers and operators of future commercial DSG power plants. Therefore, implementation of a small DSG solar field composed of several parallel rows is being considered by the project Partners.

Concerning the original DISS-phase II test plan, tests with tilted collectors will probably be omitted in order to gain time for the completion of horizontal collector tests. The reasons for this are the following:

- Economics studies performed in other parabolic-trough collector projects show that tilted collectors are unlikely to go commercial.
- Tilted collector tests were planned because it was assumed that DSG in horizontal collectors would cause strong temperature gradients in the absorber tubes. However, experimental results show a safe operation of the DSG process with horizontal collectors.
- By omitting tilted collector tests there will be more time for the more important tests remaining, such as the startup and shutdown procedure optimization and testing and fine tuning of the control loops, which are the main project objective.

The above arguments do not mean that investigation of the DSG process with tilted collectors is no longer of interest, but that higher priority has now been given to the horizontal collector tests in order to assure that the main project objectives are achieved in the time remaining.

Parallel to DSG testing at the PSA DISS facility, options to integrate a DSG solar field into Rankine power cycles have been analyzed in DISS. This analysis (García, 2000) has pointed out the advantages of the DSG process over the traditional oil parabolic-trough systems (SEGS plants). In a regenerative Rankine cycle, DSG integration to produce steam at a steam turbine inlet temperature of 450ºC leads to a total conversion efficiency (solar to electricity) of 22.6%, while the efficiency of oil systems with a turbine inlet temperature of 375ºC (temperature imposed by the present oil stability limit) is 21,3%. With a DSG system, the steam turbine inlet temperature approaches the optimum for operation at T = 550ºC, achieving a total conversion efficiency of 23%. These conclusions show that efficiency of a solar thermal power plant can be significantly improved if a DSG solar field is used to deliver steam at 550ºC/100 bar, instead of 400ºC/100 bar. Therefore, steam temperatures of about 550ºC should be attempted.

Since the technology and components currently available for DSG solar fields do not allow temperatures/pressures over 400ºC/100bar, it therefore seems clear that two subjects must be investigated to enhance the integration of DSG into the energy market: advanced components for temperatures/pressures of up to 550ºC/100 bar, and possible options for replacement of conventional water/steam separators with cheaper components (e.g. cyclones, T-pipes, etc.). These will probably be the main objective of the next short-term activities planned by the DISS Partners.

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