PROBLEMS

Relatively early during the construction period difficulties came up twice with flooding of the plant caused by heavy rainfalls.
During the first case the sodium heat transfer system hall was flooded by muddy water appr. 2.0 m high covering all installed components up to this level (tubing system, storage vessels, sodium pump housing etc.) Because of the fact that the water also entered the tubing all corresponding components had to be disassembled, cleaned and installed again. Only this caused a time slippage of approximately 3 weeks. The effects of a second flooding during the functional test period could be minimized by a quick and unconventional manpower action (manually pumping, sealing etc.) during 24 hours and therefore caused a time slippage of one week only.

Much greater difficulties had been caused by several sodium leakages in the cold storage vessel. During the first plant start-up period (middle of 1981) the first small leakage in the sodium cold storage vessel bottom was found. An outside surface inspection indicated only one crack starter probably from a bad welding seam in the inside of the vessel. The subsequent repair was performed by relatively simple measures in only one week. An additional outside inspection (by ultrasonic) of the cold storage vessel bottom in January 1982 showed new crack starters thus a preventive repair was decided. Again the repair measures were limited (repair caps from outside) because the vessel could not be drained from sodium and no access into the vessel was possible. Unfortunately this repair did not succeed more than six months when again leaks occured in the same area. Very detailed studies of international experts in 1982 found the failure causes in

. the non-optimal design of the vessel "incoming pipes" together with the inner deflaction plates
. the relatively high superimposed stresses caused by the deflaction plate/ bottom weld and the installation of the repair caps
. unqualified welding in the deflaction plate region.

The only possibility to repair this vessel thoroughly was defined by the experts group and included

. cleaning of the complete vessel inside
. exchange and modification of the complete lower vessel section
. heat treatment of the complete repaired vessel.

This work was completed by applying highest accuracy and quality control requirements in March 1983.

Some minor difficulties occured in the power conversion system because of several interruptions in the commissioning of the PCS (caused by bad weather, difficulties in heliostat computer systems, tank repair activities etc.). Therefore and because there are no redundant systems installed the adjustment of the steam motor was complicated and very time consuming.

GENERAL

Since the acceptance and take-over by the DFVLR in autumn 1981 the CRS plant is being operated in a two-years plant testing, operation and evaluation period. There, a fund of practical knowledge and experience have already been provided which will prove useful in the further development and application of this technology.

Pa Pö Zewen

THE KUWAIT SOLAR THERMAL POWER STATION: OPERATIONAL EXPERIENCES WITH THE STATION AND THE AGRICULTURAL APPLICATION

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ABSTRACT

A 100 KW solar thermal-electric power station has been operating in Sulaibyah, Kuwait since June 1981. The station consists of 56 point focusing parabolic dishes, a thermal storage tank and an organic Rankine Cycle using Toluene as working medium and provides both electric and thermal energy for agricultural applications including greenhouses, desalination facilities, irrigation systems and brackish water pumps. No electric grid is available so that the station has to work as a stand-alone plant. Operation has measured the plant subsystem performance, evaluated the operating and maintenance requirements and tested the equipment reliability.

KEYWORDS

Solar thermal-electric power station, Organic Rankine Cycle, Toluene, reverse osmosis desalination, multistage flash desalination, point focusing parabolic dish

1. INTRODUCTION

The principal objective of this project is to examine the feasibility of using solar energy to generate electric power for possible applications in areas where conventional techniques of electricity supply do not exist. This examination was made at an agricultural area, located in the Kuwait desert of Sulaibyah where no electric grid exists and where a solar thermal power station of the parabolic dish type generates electricity and thermal power for typical agricultural users, e. g. brackish water pumps, irrigation systems, water desalination and water storage systems as well as special greenhouses for hot, arid zones.

The solar thermal power station is the direct result of the mutual cooperation between Kuwait and the Federal Republic of Germany as manifest in the bilateral agreement signed between the Ministry of Research and Technology of the Federal Republic of Germany and the National Committee of Technology of the State of Kuwait. The project was executed by Messerschmitt-Bölkow-Blohm (MBB) on behalf of the German Party and the Kuwait Institute for Scientific Research (KISR) on behalf of the Kuwaiti Party. The Sulaibyah solar thermal-electric power station includes a solar collector, an energy storage and an energy conversion subsystem. The collector field (Fig. 1) consists of 1000 m^2 of point focusing parabolic dishes arranged in 4 east-west oriented loops, each containing 14 dishes. The collector reflective surfaces are back-silvered glass facets and the concentration ratio is about 210. The surface receivers are coated with a black painting. A heat transfer oil, Diphyl, is pumped through the receivers at a flow rate controlled to obtain the desired outlet temperature of 340 °C. The energy storage is a small thermocline tank if 15 cubic meter of oil, large enough to provide for one hour of turbine generator operation. From the thermal storage the hot oil is circulated through a heat exchanger unit to vaporize the organic working fluid Toluene. Energy conversion is accomplished by a Rankine cycle turbine manufactured by Linde. Nominal gross generator output is appr. 120 KW; net electrical production of the solar power station is 100 KW.

The power station is operated by the Kuwait Institute for Scientific Research. Operational objectives are:
- to pump brackish water from 70 m depth to several reservoirs located at ground level. The submersible motor pump, used for this task, has a capacity of 250 igpm and a motor rating of 22 KW
- to power several pumps of the irrigation system which includes a brackish water storage of 440 cbm, a fresh water storage of 240 cbm and a mixed water storage of 30 m^3
- to power a reverse osmosis desalination unit which can deliver 36 cbm of fresh water/day (Fig. 2)
- to provide electricity for operating and cooling of several greenhouses.

In the actually running phase of the project a multistage flash desalination unit shall be connected to the power station, which will get as thermal input more than 1 MWh/day from the waste heat of the energy conversion system and which will deliver 20 cbm of fresh water in addition to the fresh water produced by the R.O. desalination unit.

2. PLANT PERFORMANCE

SYSTEM

The solar thermal power station is designed for a design point of 960 W/m^2 insolation. Taking into account the weather data of the site, the major part of the year, the collector fields thermal output is not sufficient for the ECS operation with nominal power. The average direct solar insolation reaches peak values of 700 - 820 W/m^2, so that an average power output of appr. 70-80 kW_e can be expected.

Figure 3 shows the system behaviour for a clear day with high direct solar insolation. The collector field piping must be warmed up every day after the nightly shut-down period. During this warming-up period, no usable thermal energy is produced but electric energy for the tracking and the pumping required. These losses would be a minimum if the time spent for warming-up is as short as possible. The shortest time period for warming-up the collector field piping is appr. 40 minutes depending of the starting time in the early or late morning. During the 40 minutes the heat transfer fluid is continuously pumped through the collector field piping and the buffer tank. As soon as the temperature of the buffer tank reaches 240 °C, the thermal storage device charging procedure starts. During normal operation, the storage tank is warmed up near its upper design temperature of about 340 °C, so that the storage tank is nearly fully charged. The normal procedure requires now the warming-up of the energy conversion system which needs again a time period of appr. 40 minutes. If the ECS is operated together with a fully charged

thermal storage tank it is possible to operate it with nominal power output. In this case the highest efficiency value is reached. The thermal losses of the storage tank will be a minimum if the time period the storage is at its upper temperature is as short as possible. Therefore the normal procedure is to discharge the tank the same day of charging.

A collector field start is only meaningful if the direct insolation level is at least 500 W/m^2, and with increasing tendency. As long as the insolation into the parabolic dishes is beyond a certain level, the output temperature of the heat transfer fluid is maintained. If in the afternoon the minimum flow rate is reached the output temperature begins to drop rapidly and the collector field has to be shut-down. The ECS-starting occurs normally between 10 and 11 a.m., and the ECS-shut-down is normally between 16 and 17 p.m., depending on the weather conditions. Because weather conditions of the next day are not known, the thermal storage tank is never fully discharged.

The operational data accumulated so far show that the system can be operated on a very regular basis and can convert solar energy into electric energy with an efficiency of up to 9 % depending on the weather conditions.

COLLECTOR FIELD

Compared with other power stations the Kuwait SSPS shows a rather high reflectivity loss. The reflectivity factor is actually measured between 0.9 and 0.85 if the mirrors are cleaned. The exact reasons for this degradation is not completely known. The environment at the site can only be incriminated partly for this degradation. The main reason has to be found in the manufacturing process of the reflector, because samples located at the site, which were there since 1979 in dust and sandstorms, show still a very high reflectivity (91 %).Therefore the manufacturing process for future applications had to be reviewed and corrected.

The absorbers are coated with two different coatings: Pyromark 2500, and Thermolack 500. This was due to the fact that at the time of the plant erection, the long term behaviour of both coatings was not known. Therefore half of the absorbers were coated with Thermolack 500, and half with Pyromark 2500. Clearly Pyromark 2500 demonstrated a better performance, not only for the values at the beginning, but also for the status after 2 years in operation. Due to the high soiling conditions of the collector mirrors the collector field had to be washed every 4 weeks during summertime and every second month during wintertime. The collector field is protected by a 2.5 m high wall against sandstorms. No observation was made that the collector row directly exposed to the wind was more affected by dust and foreign particles. All experiences with the 2.5 m high wall are very positive. The overall subsystem performance is shown in fig. 4.

THERMAL STORAGE

Several tests were performed by heating the thermal storage to a fixed initial temperature and observing the temperature change of the sensors over a period of several days. The results are shown in fig. 5. The highest cooling rate occurs at the top of the tank and at the bottom. Using these curves, an estimate could be made over the heat losses from the storage tank. The result is appr. 100 KWh/24 hours. If the tank is fully charged with about 700 KWh, that would represent a loss of about 14 %.

POWER CONVERSION

The performance of the power conversion system was evaluated by several tests in 1981. Figure 6 shows a typical test run and the achieved cycle data. The gross efficiency at the output design point is 17 %, and the average power requirements for the power conversion system are appr. 12 KW.

HEAT TRANSFER FLUID

Due to the relative high operating temperature in which the heat transfer oil Diphyl must continuously operate, regular chemical analyses were made to check the fluid and its thermal stability. The manufacturer indicates 400 oC as highest allowable operating temperature. After 2 years in operation the chemical results show that actually the maximum usable temperature is appr. at 385 oC. If the oil is overheated the chemical components (Diphyl is an eutectic mixture of 27 % Diphenyl and 73 % Diphenyloxyd) start to separate.

3. OPERATIONAL EXPERIENCES

MANPOWER NEEDS

In general, it can be said that the manpower amount for the operation and maintenance of the power station is very low. The power station works and needs only one operator for supervision. This fact is the result of the efforts during the design phase to build a fully automatic system. Distributed collector systems are easy to handle. The power station is in routine operation and is operated as often the customer wants it. The positive experience during the operation so far is a proof of the basic validity of the system concept for solar energy collection.

MAINTENANCE NEEDS

The maintenance needs concern mainly the following activities:
- continuous inspection of all components of the power station (collectors, pumps, manometers, flowmeters, temperature pick-ups, indicators, valves, insulation, turbine, oil-system)
- periodical and routine revisions in order to obtain a perfect functioning of the installation. This activity is performed by a maintenance team which is composed by KISR/MBB/Linde people being at the site every 4 to 5 months during the test campaigns.

The maintenance manpower amounts to 1 fulltime technician for the continuous inspection. The periodical and routine revision manpower is covered by the test campaign manpower. The exchange or repair of components concerned mainly the following parts:
- electrical parts as transistors, fuses, PT 100, servo motors, power supplies, plugs, encoders, lamps
- mechanical parts as filters, valves, protection covers.

The amount for the exchange and the repair of mechanical parts was much less than for electrical parts. In general all plastic materials, which are exposed to the high solar insolation and to the duststorms are not appropriate for the environmental conditions at the site.

IMPROVEMENT NEEDS

The experience gained showed that some improvements should be implemented in order to improve the performance of the power plant further. The following items shall be implemented in the future.
- Improve insulation of collector junction boxes
- Investigate a new type of collector surface to improve optical performance over a longer period of time
- More frequent cleaning of collector surfaces to maintain a better optical performance of collector

- A simplified protection shield at the base of the absorber, to prevent possible damages to temperature sensors from improper focusing
- Coating of all absorbers with Pyromark.

4. ACHIEVED RESULTS

The results reported here represent the concerted effort of KISR and MBB to achieve the scope of the project. The following statements can be made:
- the results show that the power needs for a remote, agricultural area, can be provided by solar energy
- the amount of both electric and thermal energy generated by the power station is compatible with the energy needs of the site
- the collector field needs more attention with respect to the reflectivity losses of the mirror surface
- the storage and the power conversion systems are functioning satisfactory
- in spite of the remoteness of the location all maintenance activities could be performed
- the positive experiences with this plant and similar plants have proven the basic validity of distributed solar systems for solar energy collection and this type of applications.

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6. FIGURES

Fig. 1 Collector Field (56 Parabolic Dishes)

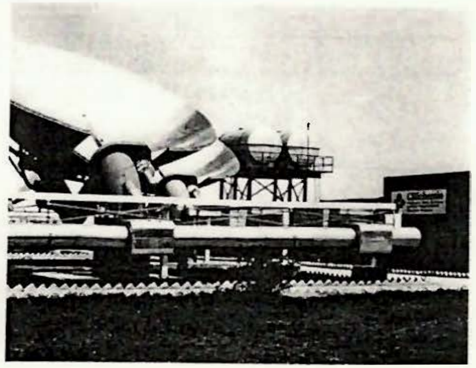

Fig. 2 R.O. Desalination Unit and Fresh Water Reservoirs

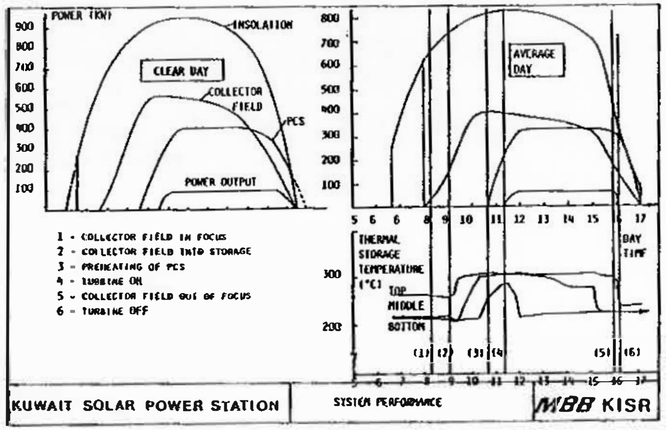

Fig. 3

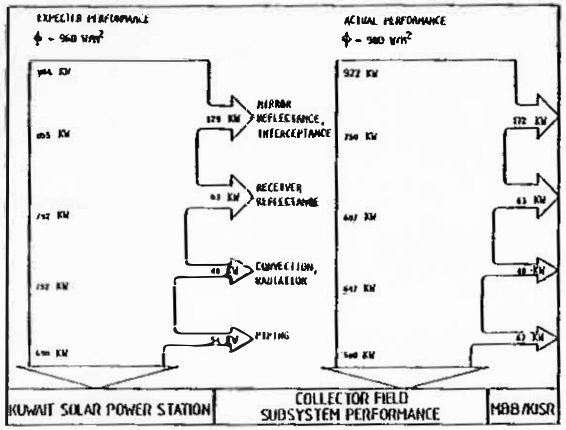

Fig. 4

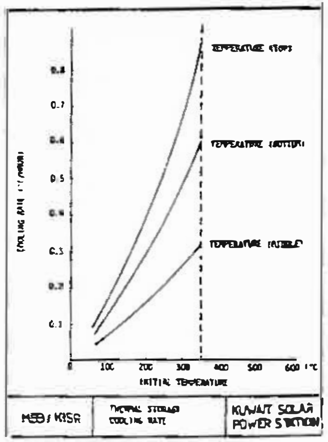

Fig. 5

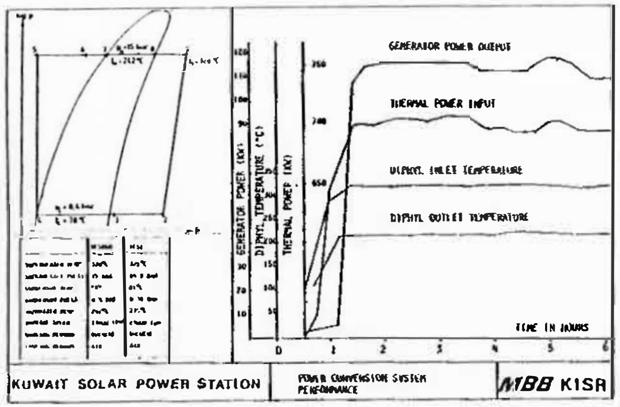

Fig. 6

EFFECT OF INTERMITTENT SOLAR IRRADIATION ON THE OPTIMUM OPERATION OF CONCENTRATION SOLAR COLLECTOR OF HORIZONTAL COAXIAL CYLINDERS FOR THERMAL POWER GENERATION

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ABSTRACT

A procedure is developed to determine the optimum design and operation parameters of solar energy collector systems combined with heat engine, considering the effect of intermittent solar irradiation. The system considered is horizontal coaxial cylinders using sensible heat transfer medium and phase change storage. The design and operation parameters considered in the calculation are the concentration ratio, the storage temperature, the flow rate of heat transfer medium, the heat capacity of the absorber tube, the percentage of sunshine and the sunshine period. The calculation is carried out for the periodic change and the irregular change of insolation and the results are compared with those for the steady insolation.

KEYWORDS

Optimum operation; solar collector; horizontal coaxial cylinders; unsteady insolation; solar thermal power; final conversion efficiency.

INTRODUCTION

The consideration of unsteady insolation is indispensable for the operation of the solar collector system. In this study the effect of the unsteady insolation on the optimum design and operation of concentration collector system of horizontal coaxial cylinders, which is connected to heat engine, is treated. The heat transfer medium considered is air. The concentration solar collector of horizontal and evacuated coaxial cylinders is considered. The standard dimensions adopted for the calculation trial are as follows; the outer diameter of the absorber tube: 0.04m, the tube thickness: 2mm, the tube length: 5m. As the solar beam radiation, the value of $0.837 KW/m^2$ is adopted. The heat capacity of the absorber tube and the parameter which expresses the characteristic of insolation are taken into consideration, too.

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