SIMULATIONS OF A LARGE SCALE SOLAR THERMAL POWER PLANT IN TURKEY USING CONCENTRATING PARABOLIC TROUGH COLLECTORS

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SIMULATIONS OF A LARGE SCALE SOLAR THERMAL POWER PLANT IN TURKEY USING CONCENTRATING PARABOLIC TROUGH COLLECTORS

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ABSTRACT

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In this study, the theoretical performance of a concentrating solar thermal electric system (CSTES) using a field of parabolic trough collectors (PTC) is investigated. The commercial software TRNSYS and the Solar Thermal Electric Components (STEC) library are used to model the overall system design and for simulations. The model was constructed using data from the literature for an existing 30-MW solar electric generating system (SEGS VI) using PTC's in Kramer Junction, California. The CSTES consists of a PTC loop that drives a Rankine cycle with superheat and reheat, 2-stage high and 5-stage low pressure turbines, 5-feedwater heaters and a dearator. As a first approximation, the model did not include significant storage or back-up heating. The model's predictions were benchmarked against published data for the system in California for a summer day. Good agreement between the model's predictions and published data were found, with errors usually less than 10%. Annual simulations were run using weather data for both California and Antalya, Turkey. The monthly outputs for the system in California and Antalya are compared both in terms of absolute monthly outputs and in terms of ratios of minimum to maximum monthly outputs. The system in Antalya is found to produce30 % less energy annually than the system in California. The ratio of the minimum (December) to maximum (July) monthly energy produced in Antalya is 0.04.

Keywords: Concentrating solar, thermal power, parabolic trough collector, simulation.

ÖZ

TÜRKİYE'DE BÜYÜK ÖLÇEKLİ GÜNEŞ ENERJİSİ SİSTEMLERİNİN PARABOLİK OLUKLU KOLLEKTÖRLER KULLANILARAK SİMÜLASYONU

Usta,Yasemin
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Bu çalışmada parabolik oluklu kolektörler kullanılarak yoğunlaştırılmış güneş enerjisi sistemlerinin teorik performansı incelenmiştir. Sistemin tümünün tasarımında ve simülasyonunda TRNSYS yazılımı ve ona bağlı STEC kütüphanesi kullanılmıştır. Kaliforniya Kramer Junction'da güneş enerjisi ile 30 MW değerinde elektrik üretimi yapan sistem örnek alınmıştır. Sistem parabolik oluklu kollektörler ve buna bağlı ısıtıcı ve ön ısıtıcı, beş adet besleme suyu ısıtıcısı yüksek basınç ve alçak basınç türbinlerini ve bir adet açık çevrim ısıtıcısı ile Rankine çevrimini oluşturmaktadır. Ilk olarak sistemde bir depolama yada ek ısıtma sistemi kullanılmamıştır.Sistemin yaz ayları için elde edilmiş sonuçları Kaliforniya'daki sistem sonuçları ile karşılaştırılmıştır. Sonuçlar karşılaştırıldığında %10 dan daha az hata görülmüştür. Kaliforniya ve Antalya'nın koşulları uygulanarak sistem bir yıl için simüle edildi. Kaliforniya ve Antalya'nın aylık verileri minimum ve maksimum oranları karşılaştırıldı. Antalya'da kurulan sistemin yıllık toplamda %30 daha az enerji ürettiği belirlenmiştir. Antalya'nın aralık ayındaki minimum enerjisinin maksimum enerjisine oranı 0.04 olarak bulunmuştur.

Anahtar Kelimeler: Yoğunlaştırılmış güneş enerjisi, parabolic oluklu kolektörler, ve simulasyonu.

To my husband and my family

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TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

LIST OF SYMBOLS

C	capacitance
E	the equation of time [min]
h	specific enthalpy(kJ kg^{-1})
H	enthalpy(kJ)
K	incidence Angle Modifier
L_{st}	standard meridian for the local time zone(deg)
L_{loc}	the longtitude of the location (deg)
m	mass (kg)
$\dot{m}$	mass flowrate(kg h^{-1})
n	day number of the year
P	pressure(bar)
Q	heat transfer (kJ)
θz	zenith angle (deg)
ω	hour angle (deg)
T	temperature(^oC)
UA	overall heat transfer factor(kJ $h^{-1}K^{-1}$)
$\dot{W}$	mechanical power (MW)
ΔT	temperature difference (K)

Greek Symbols

ϕ	latitude
δ	declination angle(deg)
ε	effectiveness
η	isentropic efficiency

Subscripts

htf	heat transfer fluid
in	inlet
max	maximum
min	minimum
REF	reference
out	outlet

Abbreviations

CSP	concentrating solar power
DNI	direct normal irradiance
FWH	feedwater heater
HCE	heat transfer element
HTF	heat transfer fluid
HP	high pressure
LP	low pressure
NTU	number of transfer units
PTC	parabolic trough collector
SEGS	solar energy generating systems
STEC	solar thermal electric component
TMY	typical meteorogical year
SCA	solar collector area

CHAPTER I

INTRODUCTION

1.1. Background Information

Serious environmental problems and finite fossil resources result in the need for new sustainable electricity generation options, which take advantage of renewable energies and are economical. Solar energy has many benefits including environmental protection, economic growth, job creation, and diversity of fuel supply. Solar energy technologies can be deployed rapidly, and have the potential for global technology transfer and innovation. The total (annual) solar energy striking the earth's surface is 10,000 times annual global energy consumption [1,2].

Solar energy has been used since B.C. for heating and mechanical applications. More than two thousand years ago, in 212 B.C., Archimedes concentrated the sun's rays using mirrors. In 1615, a"solar powered motor" was invented by Salomon De Caux and was the first recorded mechanical application of the Sun's energy. Public institutions and initiatives continue facilitate the development of solar conversion technologies and yield an alternative to traditional energy sources, such as coal and oil [3].

Turkey is a developing country with an increasing energy demand. Solar resources and large areas are widely available in the western and southeastern parts of Turkey. Solar energy research in Turkey began in the 1960s as an alternative energy [4,5]. Water heating has been used in Turkey since 1975 [6]. The Turkish government supports the development of this technology strongly.

Solar resources can be converting into a useful form of energy by different types of solar energy systems. Three of the most basic system types are shown as a block diagram in Figure 1.1.

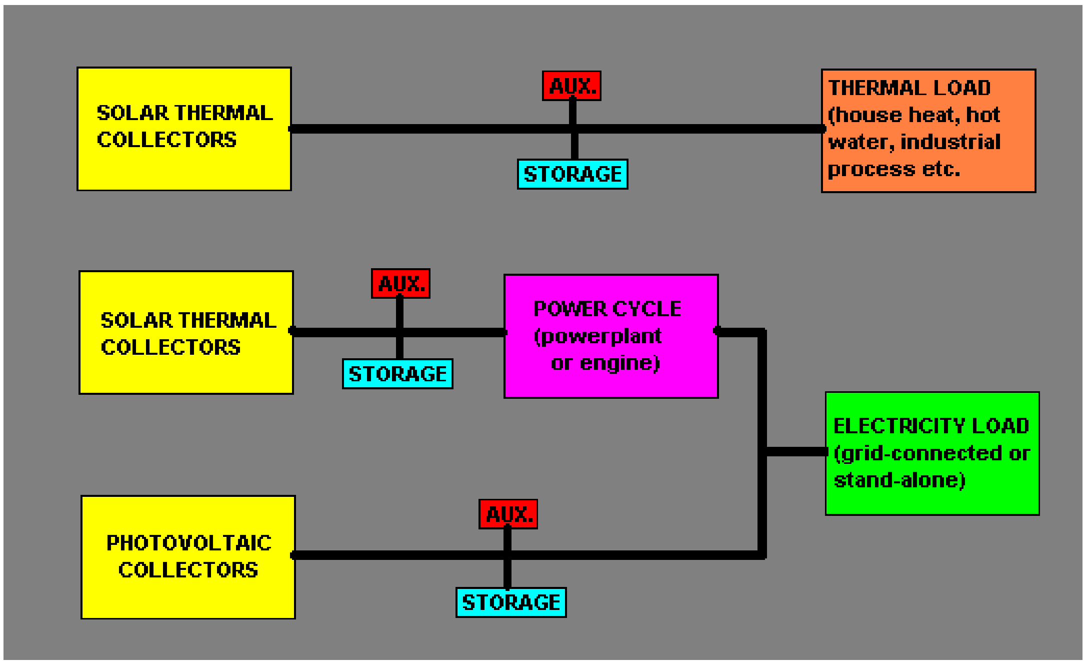

Figure 1.1 Diagram of basic solar energy conversion systems [7]

Heat for industrial process, water heating and house heating requires a thermal energy source. Solar energy is used as a source to supply a thermal load. There are two methods which are used to change solar energy into electricity. The first method is that solar energy is collected as heat then changed into electricity using a traditional power plant or heat engine. The second method is that solar energy is collected and converted directly into electricity using photovoltaic cells [5,7].

As a result, solar energy is used for both industrial and residential purposes both nationwide and worldwide. There is a strong need for advanced solar energy systems that are environmental benign and more efficient so that solar energy systems can be more competitive with traditional energy systems.

1.2. Current Solar-Thermal Power Situation

Solar energy is available over the entire globe. Some regions intercept more solar energy than other regions because of the relative motion of the sun with respect to the earth and variations in cloud cover. Solar energy conversion systems which are constructed in high insolation areas are more efficient. Figure 1.2 shows high insolation areas and these areas cover mainly desert zones and include many developing countries. The same amount of heat or electricity can be obtained anywhere on the globe but in areas with low insolation the size of the collectors needs to be increased. The amount, quality, and timing of solar energy are the most important factors for solar energy system design [7].

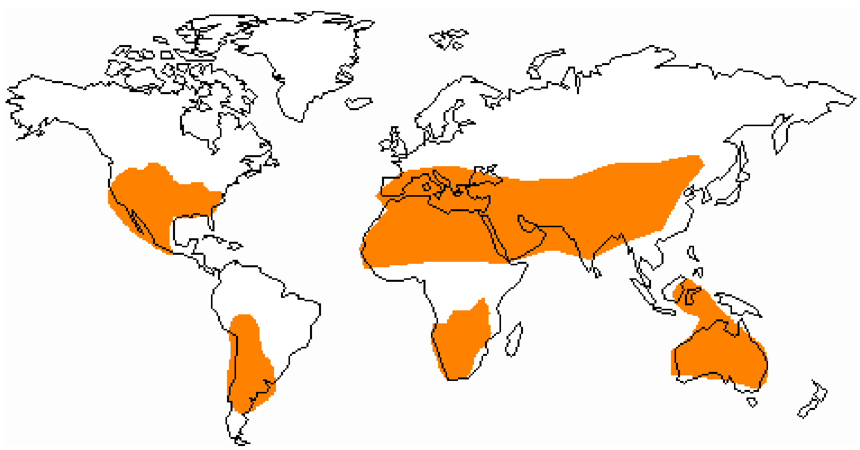

Figure 1.2 Areas of the World with High Insolation [7]

Global solar irradiance is the total amount of solar radiation and includes both direct and diffuse radiation. While non-concentrating solar energy conversion technologies can use both direct and indirect radiation, concentrating solar energy conversion technologies can only use direct irradiance.

Concentrating solar power (CSP) herein refers specifically to solar thermal technologies that obtain high temperature heat by concentrating solar energy. The sun's energy is converted to electric power using various concentrating mirror configurations. The plants consist of two parts, one which are the collectors that concentrate sunlight to heat a heat transfer fluid to a high temperature and the other which converts the thermal energy in the hot heat transfer fluid to electricity.

Producing electricity from solar thermal technologies requires four main elements: 1) concentrator; 2) receiver, 3) heat transfer fluid; and 4) power conversion system. The three most common collector types for CSP are power towers, dish, and parabolic trough collectors (PTC).

Solar power towers consist of "heliostat" mirrors that generate electric power from sunlight by focusing concentrated solar radiation on a tower-mounted heat exchanger (receiver). These plants have a 30 to 400 MW capacity for utility-scale applications [1,3,7,8].Figure 1.3 shows a photo of a power tower system.

Figure 1.3 Power Tower System [9]

Parabolic Dish Collectors (or dish engine systems) consist of "dish parabolic-shaped" mirrors used as a reflector. These mirrors concentrate and focus the sun's rays onto a receiver which is mounted at the focal point. These systems firstly convert the thermal energy to mechanical energy then to electrical energy. Dish/engine systems are different from other conventional solar thermal energy technologies as they do not use a heat transfer fluid loop to connect the collector to the heat engine. Their concentrators are mounted on a structure with a two-axis tracking system to follow the sun. The collected heat is typically utilized directly by a heat engine mounted on the receiver moving with the dish structure. 25 kW of electricity can be generated from each individual system. The capacity can easily be increased by connecting dishes together [1,3,7,9,10]. Figure 1.4 shows a photo of parabolic dish collector.

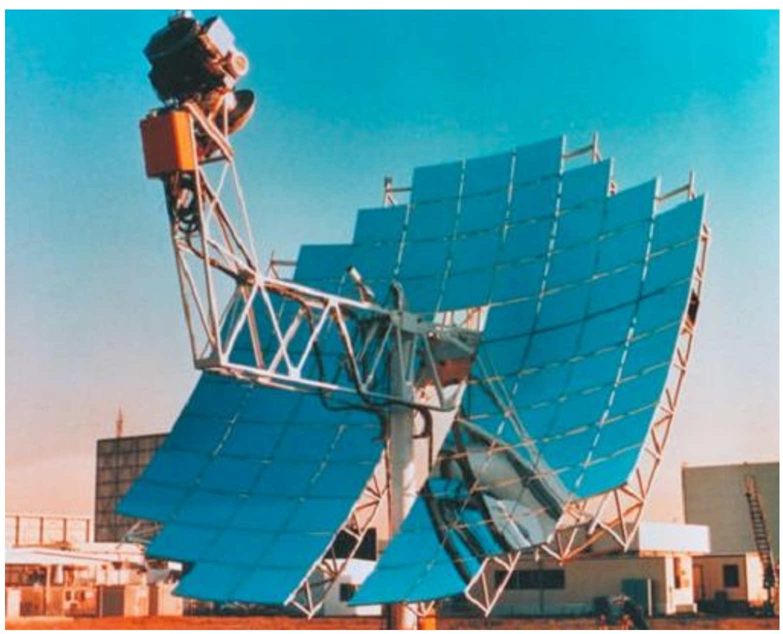

Figure 1.4 Parabolic Dish Collector [9]

Parabolic Trough Collectors (PTC) consists of rows of trough-shaped mirrors which concentrate solar insolation to a receiver tube placed along the focal axis of each trough. The solar field is composed of many troughs which are placed in parallel rows. The troughs are aligned along a north-south axis and track the sun from east to west during the day. The focused radiation raises the temperature of the heat-transfer fluid, which is used to generate steam.

The steam is then used to power a turbine-generator to produce electricity [1,3,5,7,11]. Figure 1.5 shows a photo of parabolic trough collector field.

Figure 1.5 Parabolic Trough Collector Field [9]

Concentrating solar thermal systems can be used for a wide range of different applications including electricity production and heating. Different systems can produce different temperatures. The maximum temperature scales with the system’s concentration factor (C), defined as the ratio of the aperture area to the absorber area. Parabolic trough, parabolic dish and power tower technologies can reach maximum temperatures of 400 ^{0}C, 750 ^{0}C, and 1000 ^{0}C respectively. Additionally, PTC's are also appropriate for delivering process heat and driving thermally powered cooling cycles. Both the dish and tower systems use 2-axis tracking while the PTC uses single axis tracking. Of the three, only PTC's have been commercialized with an installed capacity of 354 MW, which are the LUZ plants built from 1984 to 1991 in California. Solar towers and dish engines have been tested in a series of demonstration projects. For all three types hybrid operation where a fossil fuel is used as a secondary energy source is possible [1].

These technologies need further research to overcome non-technical and technical barriers. The main non-technical barriers are financial or legal and include grid access, financing, obtaining permits to build and operate, approval of environmental impact assessments, and power purchase agreements.

Concentrating solar power technologies are more appropriate for plant sizes of 10 MW electric or larger. These technologies offer the lowest –cost solar electricity. Recent technologies cost $3 per watt and 12¢ per kilowatt-hour (kWh) of solar power. Hybrid systems, which are a combination of concentrating solar power plants with coal plants or natural gas combined cycles, can reduce costs to $1.5 per watt [12].

Turkey is a developing country with an increasing energy demand. Over the period of 1975-2008 the average electricity demand increased annually by 8.3% [13]. About 81% of the electricity demand of Turkey in 2007 was met by coal, lignite, fuel oil, or LPG. Natural gas, which is imported from neighboring countries, is about 61.2% [14]. About 19% of the electricity is supplied from wind and geothermal, etc. In 2016-2017 electricity demand in Turkey is predicted to exceed the supply [15].

CHAPTER 2

SURVEY OF LITERATURE AND OBJECTIVES

2.1 Overview of Solar Thermal Energy Generating Systems

Solar Energy Generating Systems (SEGS) I through IX parabolic trough plants were built in the Mojave Desert in southern California between 1985 and 1991. The systems have a total capacity of 354 MW. The first two systems are rated at 14MW and 30MW, Systems III through VII are rated at 30MW each, and the final two SEGS plants are rated at 80MW each. Luz International Company designed, built, and sold the nine SEGS plants and as of 2006 these plants have performed well over their first 20 to 25 years of operation. Other parabolic trough collector projects are also planned and some of them are active, including a 64 MW plant in Nevada and 50 MW plants in Spain [16]. Basic characteristics of the SEGS (III,IV,V,VI,VII) plants at the Kramer Junction site are listed in Table 2.1.

Table 2.1 Characteristics of SEGS plants at Kramer Junction [16]

Plant	Startup Year	Capacity (net)	Design Solar Field Supply Temperature	Collector Technology*	Solar Field Size
III	1987	30 MW	349 [C]	LS-2	230,300 m^2
IV	1987	30 MW	349 [C]	LS-2	230,300 m^2
V	1988	30 MW	349 [C]	LS-2/LS-3	250,560 m^2
VI	1988	30 MW	390 [C]	LS-2	188,000 m^2
VII	1989	30 MW	390 [C]	LS-2/LS-3	194,280 m^2

Figure 2.1 Solar Collector Assembly

Several long parallel rows of collectors comprise a solar field assembly ((Figure 2.1). The trough parts of the collectors are curved glass mirrors that focus direct radiation from the sun onto a heat collection element. These collectors track the sun by rotating around a north-south axis. The troughs concentration ratio is 71:1 for LS-2 and 80:1 for LS-3 [11].

2.2 Sun-Earth Geometric Relations

The angles between the sun and a horizontal plane relative to the earth describe important solar geometric relationships [17]. The angle of incidence (θ) in Figure 2.2 shows the angle between beam (also called direct) radiation and the normal to that surface. The angle of incidence describes the position of the sun in the sky relative to a surface. Throughout the day and year the angle of incidence will vary and the performance of the collectors will be affected.

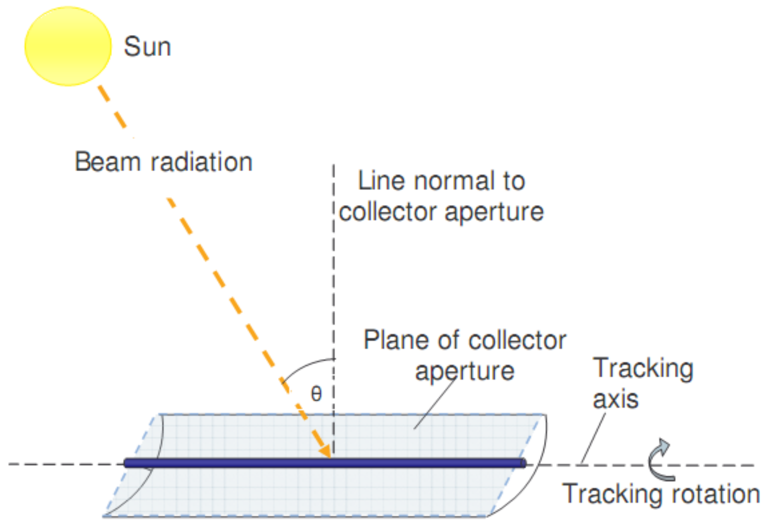

Figure 2.2 Angle of Incidence on a Parabolic Trough Collector [16]

The declination angle (δ), shown in Figure 2.3, shows the angular position of the sun at solar noon with respect to the plane of the equator. The declination angle will change throughout the year over a range of $-23.45° \leq \delta \leq 23.45°$.

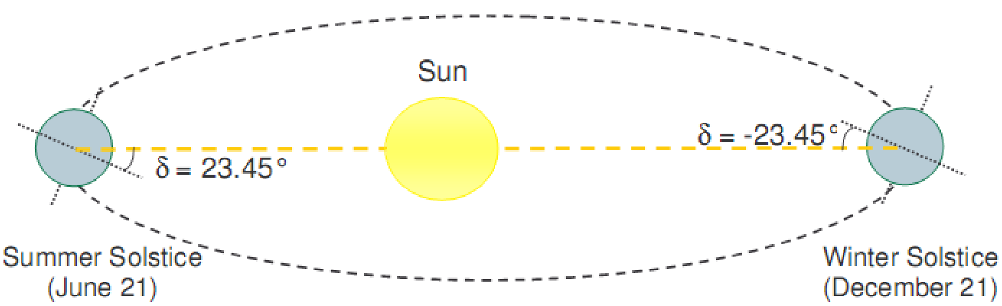

Figure 2.3 Declination Angle due to the Earth [16]

The following expression for declination angle was developed by P.I. Cooper in 1969 [17]

$$\delta = 23.45 \sin\left(360 \frac{284+n}{365}\right) \tag{2.1}$$

Here n is the day number of the year and varies from 1 (corresponding to January 1) to 365 (corresponding to December 31). Figure 2.4 shows the variation of the declination angle throughout the year.

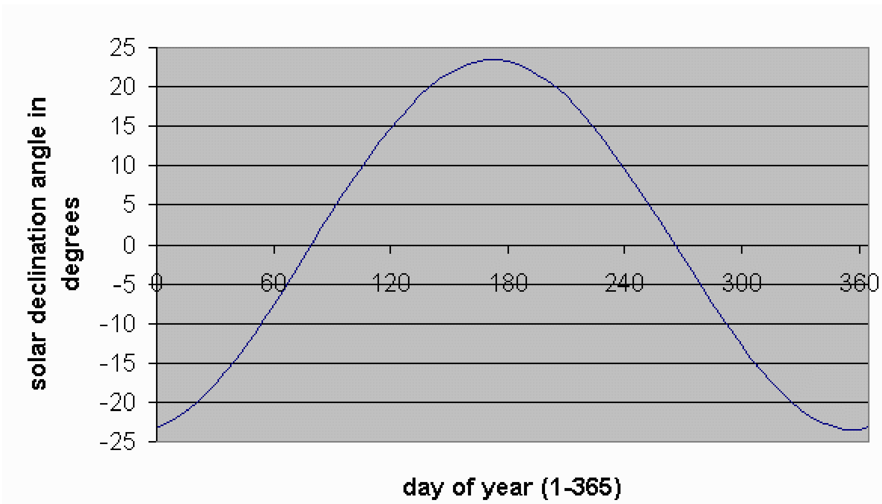

Figure 2.4 Solar Declination vs. day of year from Equation 2.1

Two types of times are used in solar engineering: solar time and standard time. Solar time is measured with respect to the sun's position. When the center of the sun is on an observer's meridian (at its highest point during the day), the observer's local solar time is zero and it is solar noon. However, standard time is based on a standard meridian for a time zone that may lie to the east or west of the local meridian. Standard time is also called "clock time" as it is the time shown on a common clock [17,18]. The difference in minutes between solar time and standard time is

Solar time- Standart time= 4 (L_{st}-L_{loc}) + E (2.2)

where;

L_{st} = Standard meridian for the local time zone[deg]

L_{loc} = The longtitude of the location [deg]

E = The equation of time [min]

The equation of time used here, in minutes, comes from Spencer [17]

E = 229.2(0.000075+0.001868Cos B-0.032077Sin B

-0.014615Cos 2B- 0.04089 Sin 2B) (2.3)

where;

$$B = \frac{360}{365}(n-1)[deg] \quad (2.4)$$

n = day number of the year (1 for January 1, 365 for December 31)

The variation in the equation of time over the year is given in Figure 2.5

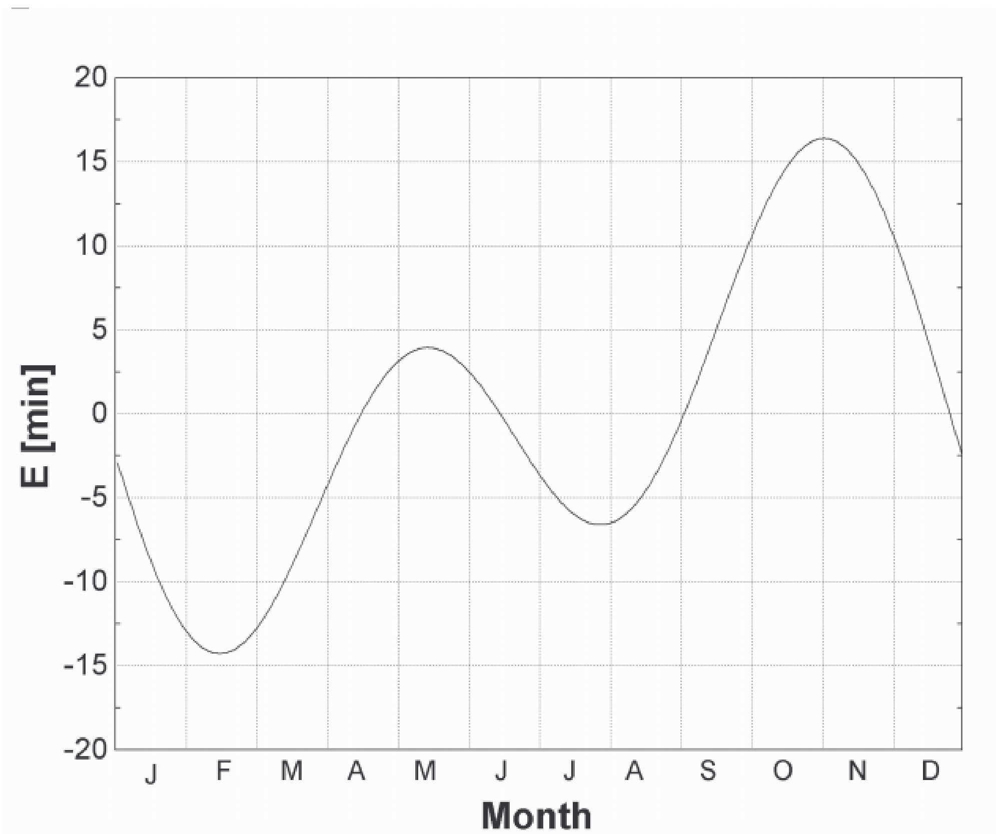

Figure 2.5 Equation of time versus month of the year (from Equation 2.3)

The zenith angle (θz) is the angle between the vertical and the line to the sun. The zenith angle is related to both the declination angle and the hour angle by the following relationship [17].

$$\cos \theta_z = \cos(\delta) \cos(\phi) \cos(\omega) + \sin(\delta) \sin(\phi) \qquad (2.5)$$

δ = declination angle (see Equation 2.1)

ω = hour angle (see Equation 2.6)

ϕ = latitude

The hour angle is the angular displacement of the sun east or west from the local meridian at noon local time. This angle is related to the earth's rate of rotation on its axis of 15° per hour. At solar noon, the hour angle is zero and the sun is in line with the local meridian on earth. The hour angle is negative before solar noon when the sun is east of the local meridian and positive after solar noon when the sun is west of the local meridian [17,18].

$$\omega = (solartime - 12).15^0/_{hr} \qquad (2.6)$$

where ω is the hour angle [deg] and SolarTime is the solar time [hr].

2.3 Solar Radiation

The radiation reaching the earth's surface can be represented in a number of different ways. Global Horizontal Irradiance is the total amount of shortwave radiation which includes both Direct Normal Irradiance (DNI, also called beam normal) and Diffuse Horizontal Irradiance Global Horizontal Irradiance is the radiation received by a surface horizontal to the ground.

Direct Normal Irradiance is the amount of solar radiation that has not been scattered or absorbed by the atmosphere received per unit area by a surface normal to the sun-earth line.

Diffuse Horizontal Irradiance is the amount of radiation received per unit area by the earth that does not arrive in a direct path from the sun, but has been scattered by molecules and particles in the atmosphere and as a first approximation comes equally from all directions.

The incidence angle modifier models the losses that increase with increasing incidence angles. These; losses will occur for many reasons which can include additional reflection and absorption by the glass enclosing the receiver element. The incidence angle modifier corrects for these losses using a mathematical model of the collector. The incidence angle modifier is given as an empirical fit to experimental data for a given collector type. Based on performance tests conducted at Sandia National Laboratories on an LS-2 Collector [19], the incidence angle modifier for the SEGS collector is [17].

$$K = \cos(\theta) + 0.000884(\theta) - 0.00005369(\theta)^2 \quad (2.8)$$

where θ, the incidence angle, is provided in degrees.

Row Shadowing and End Losses; the positions and geometries of the collector troughs and heat collection element (HCE) are important. Relationships between the field and collector parameters and solar radiation data determine the design of the solar collectors. Shading losses occur when one collector shades another [20]. In the early morning, all of the collectors face due east and the first row of collectors receives full sun. While the first row of collectors will receive full sun, this row will shade all subsequent rows to the west, which is termed reciprocative row shading. Shading continues until the sun reaches its critical zenith angle, at which point all rows of collectors receive full sun. Throughout the middle of the day, all collector rows remain unshaded. Reciprocative row shading then re-appears in the late afternoon and continues through the evening. From early to mid-morning Figure 2.6 represents the tracking of solar collectors and the consequent row shading that occurs over this period [21,22].

Figure 2. 6 Collector tracking through morning, showing digression of collector shading as the day progresses. The center figure represents the Critical Zenith Angle for the sun [21,22].

2.4. Previous Modeling and Simulation Studies

Lippke [23] developed a detailed thermodynamic model to study the part-load behavior of a typical 30 MW SEGS plant using EASY simulation software. As part of this analysis, Lippke compared various conditions of receiver tubes, fraction of mirrors lost due to breakage and measured reflectivity based on measurement results of an LS-2 Collector. The objective of this study was to model system behavior during part-load conditions. In this model, real plant conditions for a clear summer day and cloudy winter days were compared [23].

Researchers from The University of Wisconsin, Sandia National Laboratories, Deutsches Zentrum für Luft- und Raumfahrt e.V. modeled the detailed performance of the 30 MW SEGS VI parabolic trough plant using TRNSYS simulation environment. The power cycle and solar parts were modeled and good agreement between the model's predictions and measured plant performance were obtained [16].

Stuetzle developed a thermodynamic solar trough model to develop a control of the HTF mass flow rate. The aim of this study was to develop a linearized control of the HTF mass flow rate through the solar field [22].

Patnode developed a thermodynamic solar trough model using TRNSYS for the solar part of the system and EES for the power cycle part. SEGS VI plant's data were used for modeling. Effects of solar field collector degradation, HTF flow rate control strategies and alternative condenser design's performance are evaluated [16].

Manzolini, Bellarmino, Macchi, and Silva analyze the heat transfer fluid. Synthetic oil and molten salts are used as a heat transfer fluid in solar power plants. Synthetic oil is the most common working fluid but has a temperature limitation of 400 ^{o}C [27]. Molten salts as a HTF has several advantages including it is possible to increase the solar field maximum temperature so the Rankine cycle efficiency increases. The net conversion efficiency of solar energy to electricity is about 10% for conventional synthetic oil plants, but can be 13% for innovative molten salts and direct steam generation [24].

Molim, Fraidenraich, and Tiba developed an analytic model for a solar thermal electric generating systems with parabolic trough collectors. They studied the energy conversion of solar radiataion into thermal power along the absorber tube of the parabolic collector [25].

Jones et al. developed a detailed performance model of the 30 MWe SEGS VI parabolic trough plant which was created in the TRNSYS simulation environment using the Solar Thermal Electric Component (STEC) model library. The power cycle and solar collector performance were modeled but unlike the actual system natural gas- fired hybrid operation was not modeled. Good agreement is obtained when comparing the results of this model with plant measurements. Errors are usually less than 10% [26].

Rivera and Cruz developed a Simulink model for the performance evaluation and simulation of Solar Power Generating or Solar Thermal Power Plants in Puerto Rico with a Compound Parabolic Concentrator. Collector data and other parameters can be set by the user [27].

As part of Middle East Technical University's Fall 2008 graduate Mechanical Engineering class ME 533, the present author worked as part of a group to develop a parabolic trough collector design tool using Visual Basic. A summary of this project is presented in Appendix A.

2.5. Objectives of Current Work

The objectives of the current work are to build on these aforementioned existing works as follows:

- Construct a solar thermal system model of SEGS VI at Kramer Junction, California, within TRNSYS that can be used for seasonal transient simulations.
- Use the common heat transfer fluid Therminol VP-1 in the collector loop.
- Benchmark the model against published performance data for a clear summer day.
- Link the parabolic trough models with a weather data file and perform simulations for Kramer Junction, California, and Antalya, Turkey.
- Perform simulations ranging from multi-day to annual.
- Compare the performance of Antalya and Kramer Junction CSP systems.

CHAPTER 3

MODELS

3.1. The Plant Model

The schematic flow diagram of the parabolic trough collector field is shown Figure 3.1.

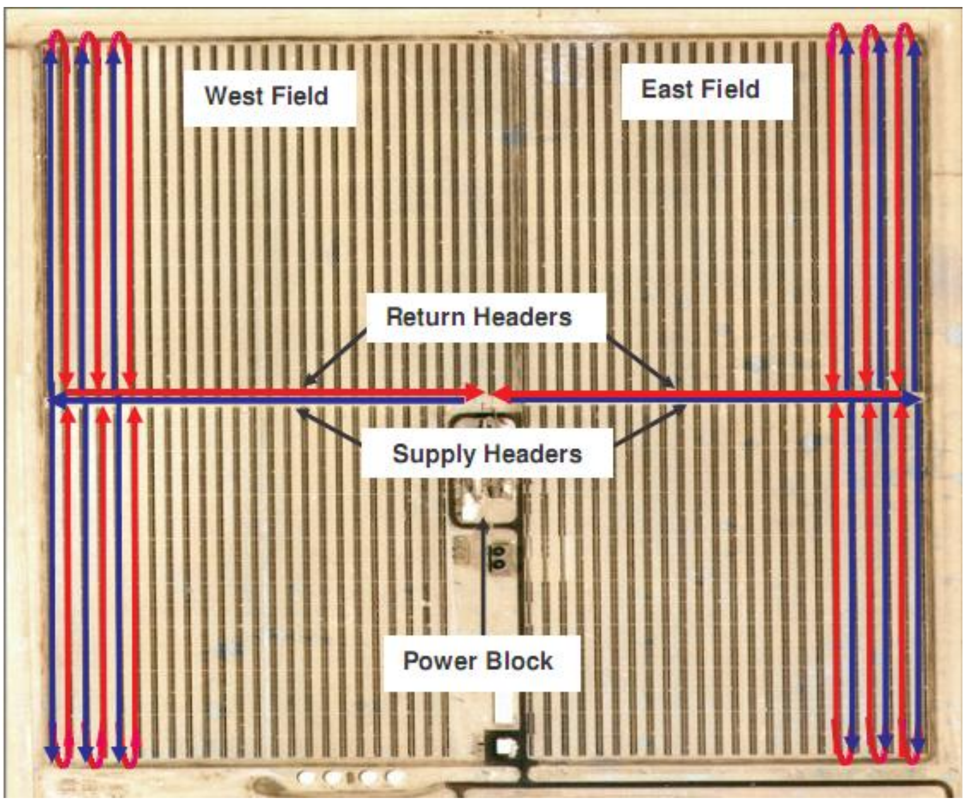

Figure 3.1 Layout of the SEGS VI Solar trough Field KJC Operating Company [16]

The solar field consists of many parallel rows of solar collectors aligned on a north-south horizontal axis. The parabolic shaped mirrors which track the sun from east to west focus the sun's direct beam radiation on a linear receiver tube which is located at the focal point of a trough as shown in Figure 3.2.

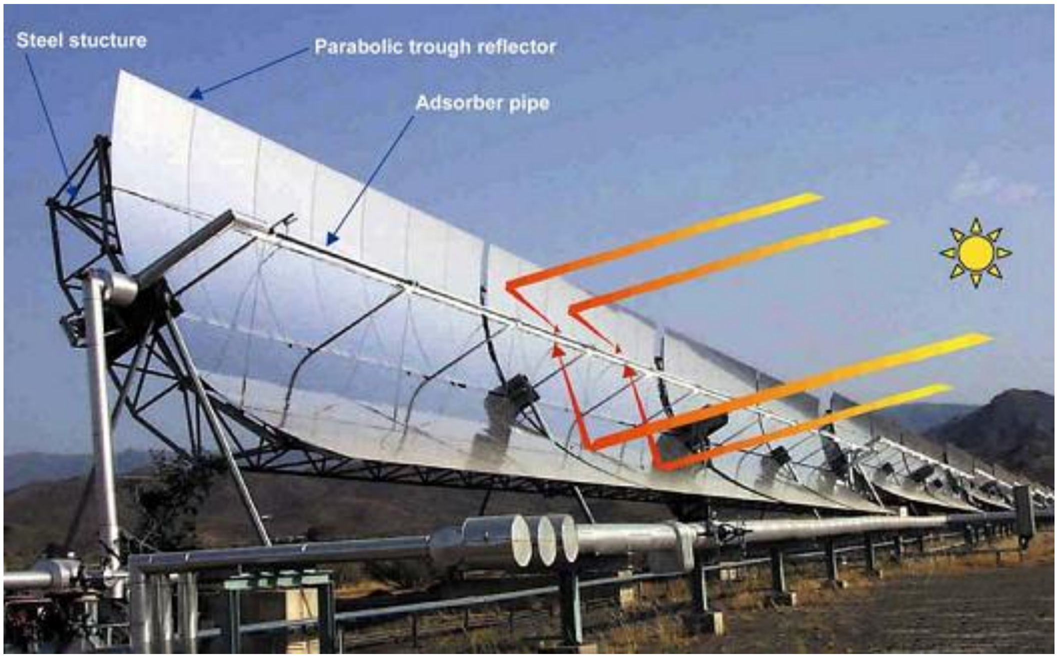

Figure 3.2 Part of the Parabolic Trough Collector [9]

The trough structure for the collector consists of supports for the reflector and receiver tube and a foundation. The structure must be strong enough to withstand wind loading and stiff enough not to suffer torsional bending that would render the structure unable to keep the receiver tube at the focal point along the entire length of the collector. Traditionally a steel truss is used as the frame (LS3-LS2 space frame), although other approaches such as torque tubes (Euro Trough) and lighter metals (Duke Solar space frame) are being explored. The support structure location of drive controls is shown in Figure 3.3.

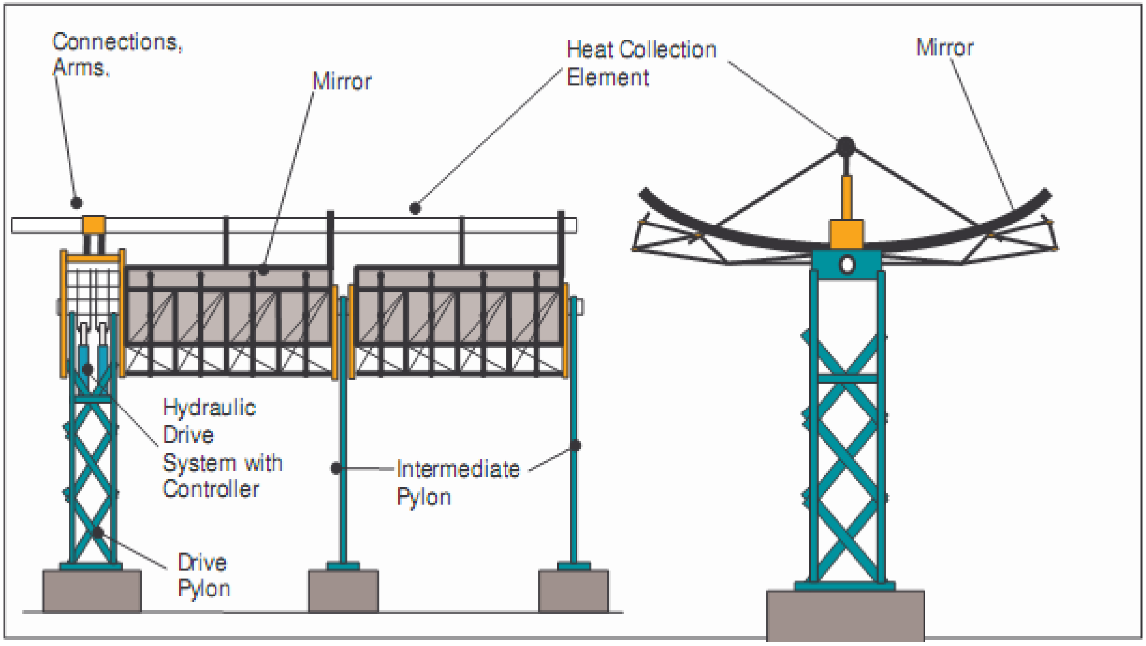

Figure 3.3 Schematic of a Solar Collector Assembly [22]

Luz is the company which constructed the SEGS plant in California and developed a new trough structure design. LS-1 trough structure design is used in SEGS I-II and LS-3 is used in SEGS II-VII. The final through structure design is the Luz LS-3 and is used in the newest SEGS plants [28].

A consortium of European companies and research laboratories known as EuroTrough have developed next-generation trough concentrator. Based on these studies a torque box concentrator concept has been selected. It eliminates many of the problems associated with the LS-2 and LS-3 collectors. EuroTrough has weighs less and suffers less deformations of the collector structure due to dead weight and wind loading than the reference designs [28,29].

Duke Solar, North Carolina, developed an aluminium space frame that resulted in an advanced-generation trough concentrator design. Weight, manufacturing simplicity, corrosion resistance, manufactured cost, and installation ease are unique features of this design [28]. All three models are shown in Figure 3.4.

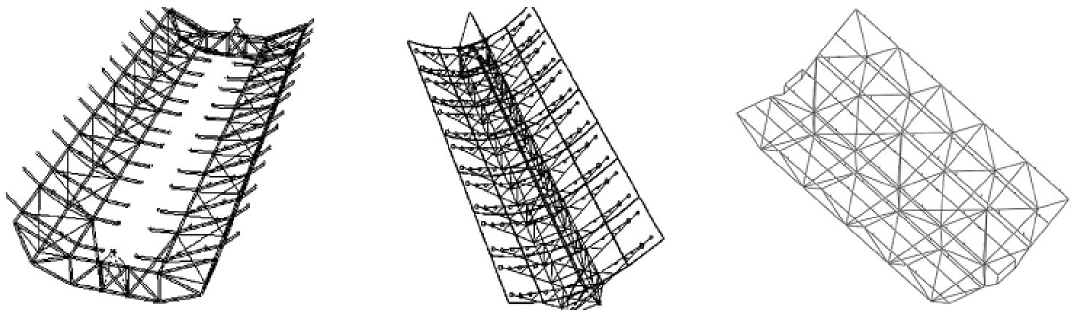

Figure 3.4 LS-3 space frame, EuroTrough torque-box, and Duke Solar Space Frame concentrator designs [28]

A heat transfer fluid (HTF) is circulated through the collector field during the day. It is heated as it circulates through the receiver tubes and returns to heat exchangers in the power block. In the power block the hot HTF is used to generate superheated steam. The superheated steam is then forwarded to steam turbines that drive electricity generators [11].

The HTF circulates in a receiver tube and absorbs concentrated solar radiation. This receiver tube is a vacuum tube designed specifically to maximize the amount of thermal energy adsorbed based on cost constraints. Figure 3.5 shows a diagram of a typical vacuum tube.

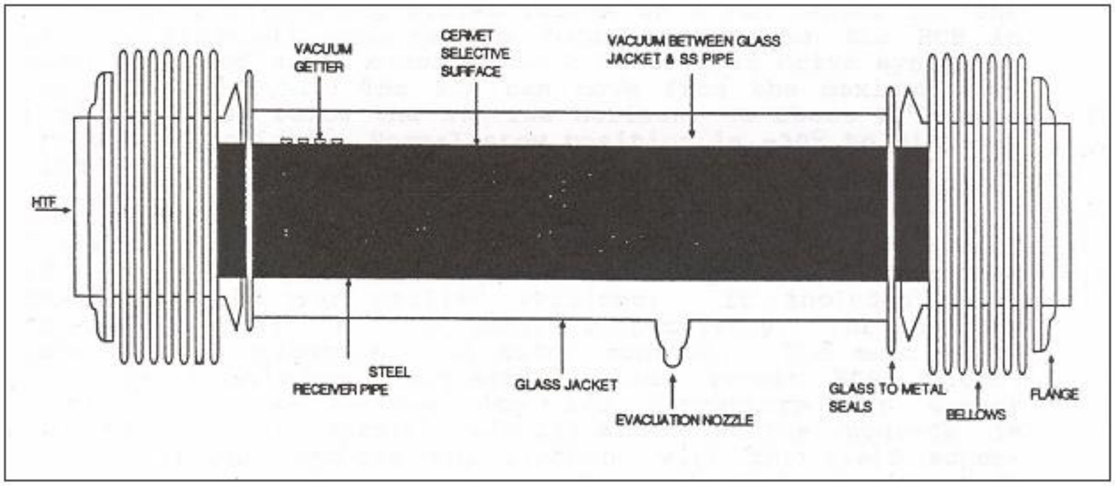

Figure 3.5 Vacuum Tube [16]

Vacuum tubes should be designed using the most suitable material and geometry to absorb the maximum amount of solar energy. Vacuum tubes are usually formed using a cermet coated stainless steel absorber tube surrounded by a glass envelope. The outer glass tube is transparent to shortwave radiation and allows light rays to pass through with minimal reflection. The inner tube is coated with a special selective coating. The coated absorber layer should have high radiative absorbtivity at short wavelengths and low radiative emissivity at long wavelengths. The air between the two tubes is removed making a vacuum. A good vacuum effectively eliminates convective and conductive heat transfer from the absorber tube to the outer tube, thereby minimizing heat transfer losses to the surroundings [28].Figure 3.6 shows a photograph of a Vacuum Tube which is developed by SOLEL Company.

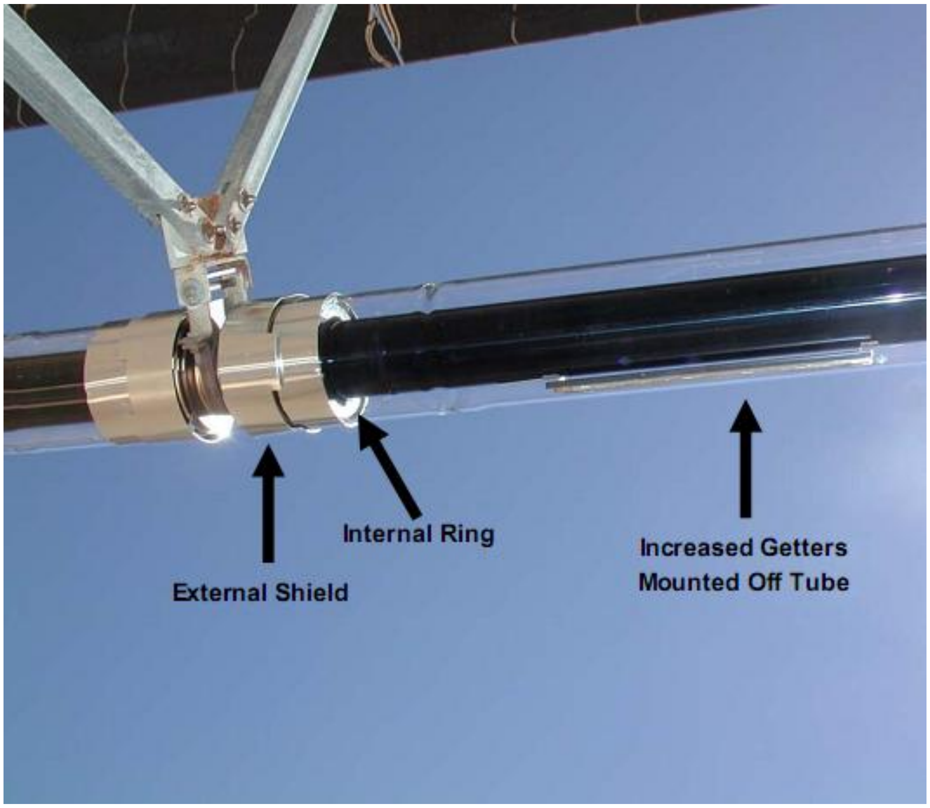

Figure 3.6 A photo of Vacuum Tube Connection [30]

The selection of the type of HTF is also important. Biphenyl-diphenyl-oxide, known by the trade name TherminolVP-1, is used in the latest SEGS plants. It has excellent stability, safety and environmental protection. TherminolVP-1 also has some limitations which are the temperature range, cost, the need for heat exchange equipment to transfer thermal energy to the power cycle and the oil has a high vapour pressure, so it is difficult to store thermal energy [28,31].

Thermal losses, tracking precision, surface properties cleanliness of reflectors, incident solar radiation, HTF flow rate and solar field inlet temperature affect the solar field outlet temperature.

3.2. Power Cycle Model

The objective of the parabolic trough plant is to generate electricity. The larger system consists of a solar collector field linked to a Rankine cycle via a series of heat exchangers. Figure 3.7 shows the flow diagram of the SEGS VI plant. A traditional Rankine cycle is used as the power cycle in these solar electric generating systems. The power cycle is driven by heat transfer from the heat transfer fluid (HTF). The HTF is heated as it circulates through the receiver and returns to the power cycle by an expansion vessel. The average temperature and the total volume of the HTF change significantly throughout the day. The expansion vessel accommodates these effects. The HTF is pumped from the expansion vessel and delivered to two heat exchanger systems. One of the heat exchanger systems consists of a superheater, steam generator and preheater and the other heat exchanger system is the reheater.

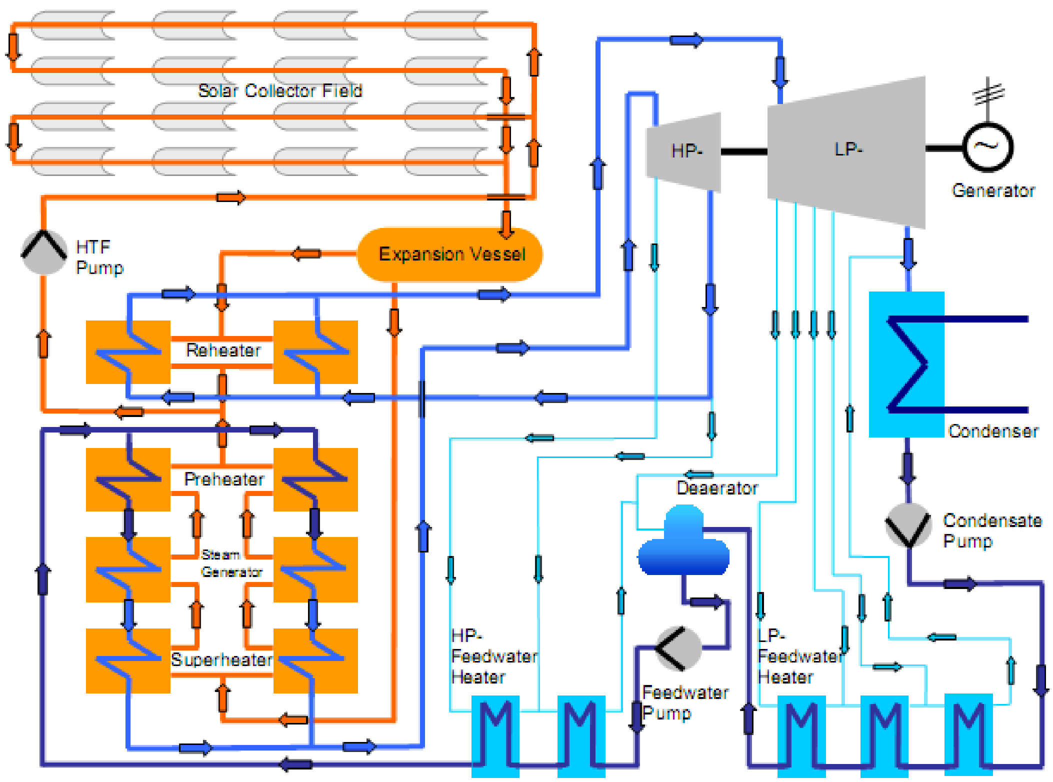

Figure 3.7 Flow Diagram of the SEGSVI Plant [21]

These heat exchanger systems are counterflow with the HTF and water in the Rankine cycle flowing in opposite directions. The HTF enters the superheater at a high temperature before passing to the boiler in which the water in the Rankine cycle changes phases from liquid to steam. The last step for the HTF is to pass through the preheater where it heats the liquid water (termed feedwater) entering the heat exchanger system. The cooled HTF that leaves this heat exchanger system is then recirculated through the solar field. The superheated steam leaving this heat exchanger system is then fed to the high pressure turbine to produce electricity. Both high and low pressure turbines are used with reheat occurring between these turbines stages. The high pressure turbine has two and the low pressure turbine has five steam extractions that flow to the feedwater heaters. This extracted steam is used to heat the feedwater before it enters the pre-heater described above to increase the efficiency of the Rankine cycle. The remaining steam leaving the low pressure turbine is condensed in a standard condenser. Before returning to the preheater to complete the cycle, the liquid feedwater leaving the condenser passes through three low pressure feedwater heaters, a deaerator and two high pressure feedwater heaters.

3.3. Flow and Temperature – Entropy Diagrams

Kearney analyzed a plant with 35 MW gross power and 100% solar operation [16]. Figure 3.8 shows the flow diagram of the power-cycle. A temperature-entropy diagram of the cycle with all corresponding intermediate state points is shown in Figure 3.9.

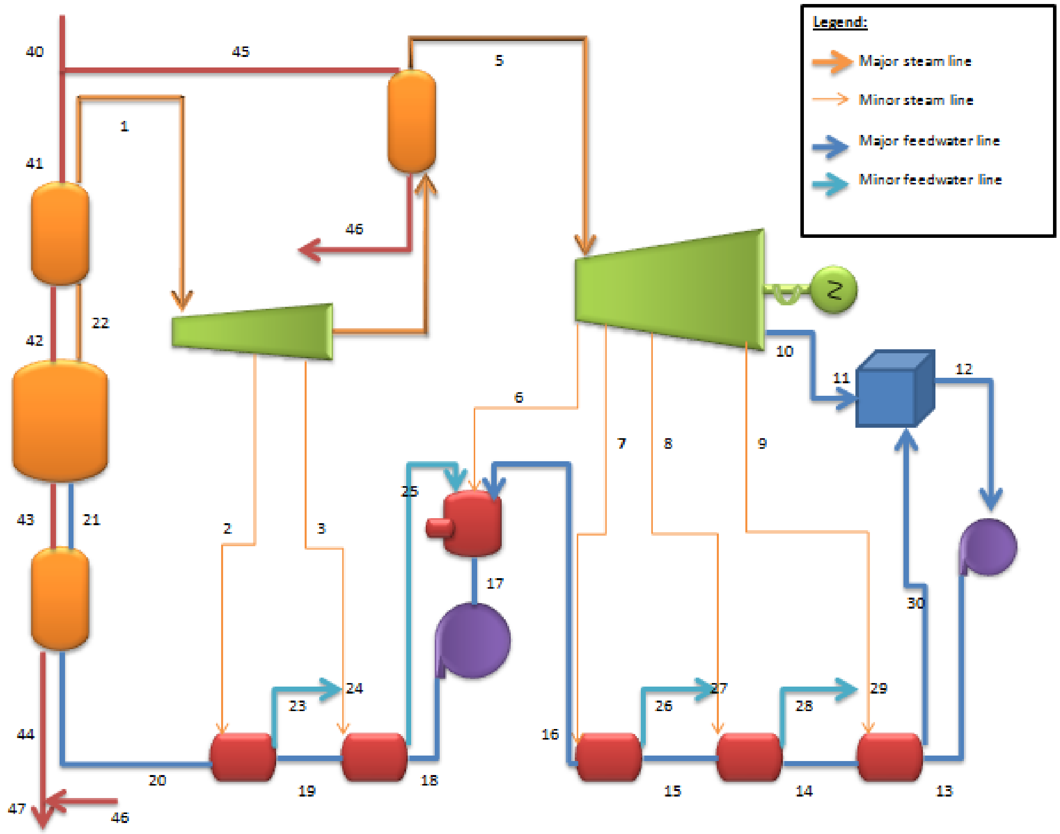

Figure 3.8 Flow Diagram for Power Cycle -state points labeled.

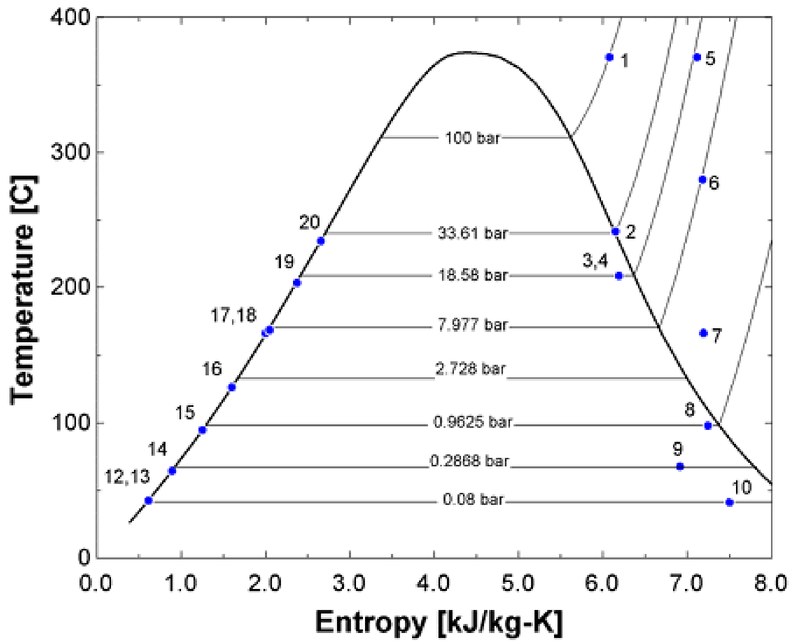

Figure 3.9 Temperature- Entropy Diagram of Power Cycle at Reference State (35 MW,100% solar)[16]

State (9) must be incorrect, as moving from state (8) to state (9) through expansion in a an adiabatic turbine would violate the second law. An isentropic efficiency is assumed 0.88 in the turbine section from (8) – (9). In the present work at state (9) the entropy and enthalpy are recalculated, assuming the pressures provided are correct [16].

3.4. TRNSYS and STEC Library

TRNSYS is software which is developed primarily at The University of Wisconsin and is a complete and extensible simulation environment for the transient simulation of systems. Models of individual components can be created and these individual models are called Types. These models of individual components are then connected within TRNSYS and simulations for the larger system run. Each Type of component is described by a mathematical model in the TRNSYS simulation engine [32].

STEC (Solar Thermal Electric Components) is a TRNSYS library. It is developed by DLR (German Aerospace Centre) and Sandia National Laboratory and consists of models suitable for Rankine and Brayton cycles, concentrating solar thermal systems (central receiver, heliostat field, and parabolic trough models), and storage [33].The software and documentation for TRNSYS [32] and STEC [33] contain numerous examples and tutorials for how to develop energy models of simple energy systems, and interested readers are referred to these software and documentation for introductory information on how to use TRNSYS and STEC.

In this work a model of a solar thermal electric generating system using parabolic trough collector was created using components from the STEC library. Detailed information about these components is given below. A schematic of the model as shown in the TRNSYS simulation studio is shown in Figure 3.10. Both the high pressure (HP) and low pressure (LP) turbines are modeled using several components which are grouped into a single turbine macro. In Figure 3.10, the HP and LP turbine macros are shown as a single icon to aid in understanding the larger system. In Figure 3.10, material and information flows are indicated by connections between two components.

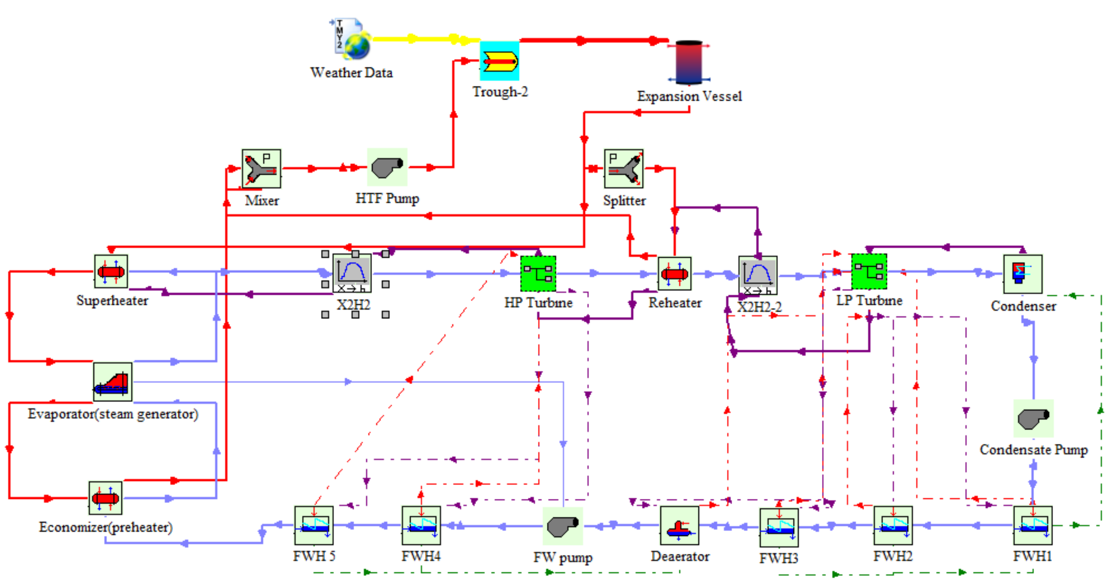

Figure 3.10 The SEGS VI TRNSYS Model

It is important to properly specify the required variables for each component while creating a simulation studio. The user right clicks on the component icon to change the parameters, inputs, derivatives and view the outputs. The parameters, inputs, outputs, and derivatives are all available in separate windows, with the output window being just for informational purposes. A screen shot of the parameter window with tabs for the Input, Output, and Derivative windows is shown in Figure 3.11.

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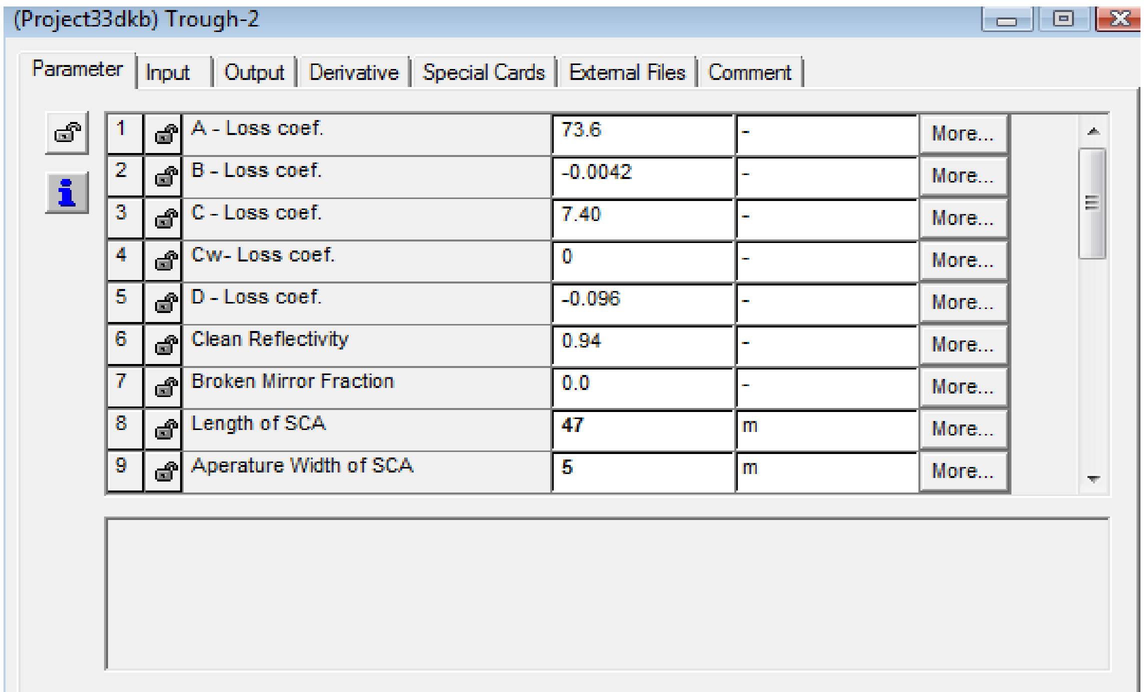

Figure 3.11 Parameters Window

An important step in simulating the operation of a component is specifying the values of transient variables through a link to another component. A link is used between two components so that information flow can occur. To specify the details of the link between two components, the user should use the graphical user interface (GUI) opened by double-clicking on the link. To specify the connection between two components, the user connects the outputs of the first component (left-side) to the required inputs of the second component (right-side). Additionally, users can only connect variables of the same dimension, i.e. 'heat' to 'heat' [32]. Any input that is left unconnected is assumed to be constant at its initial value for all time [32]. Figure 3.12 shows how a sample connection is created.

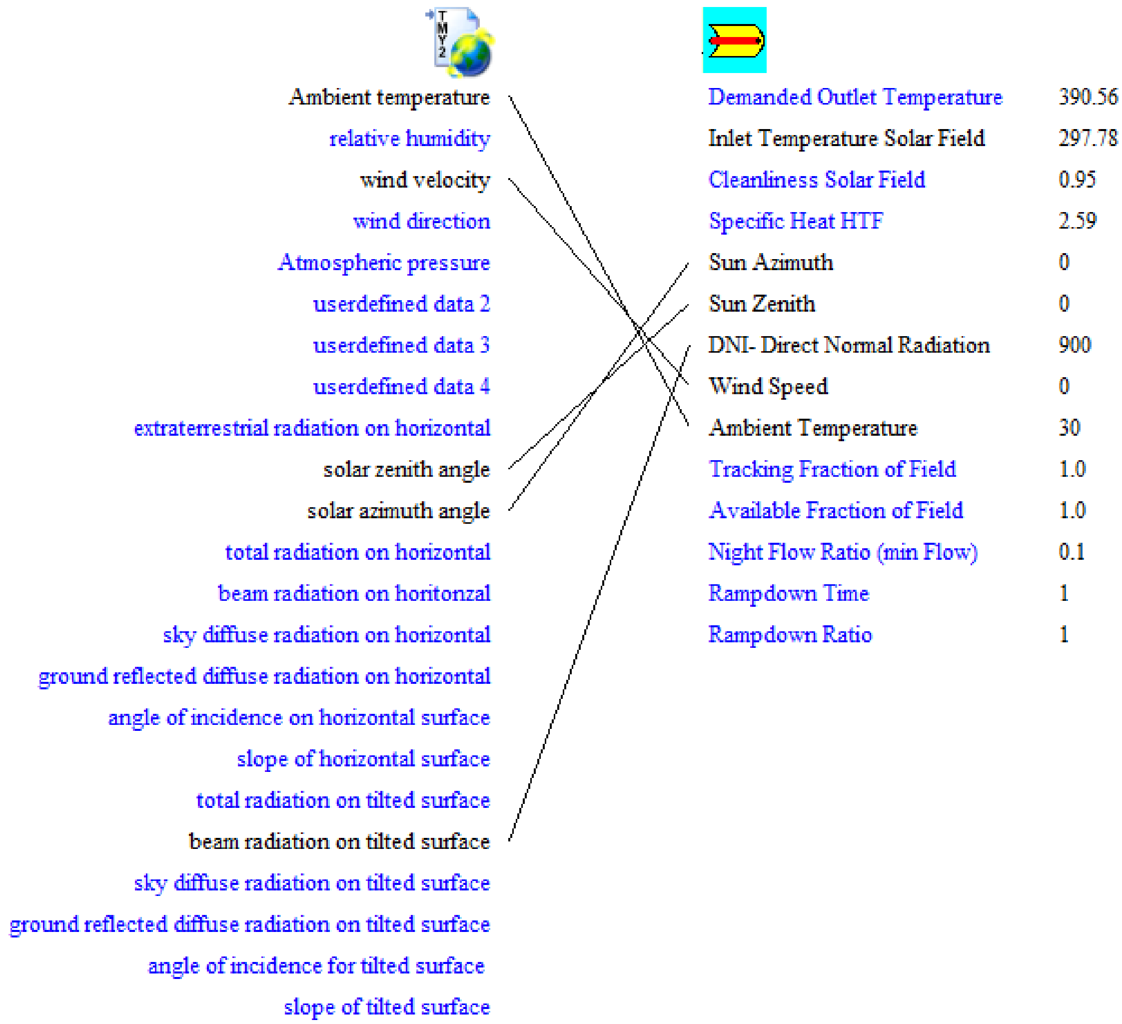

Figure 3.12 Sample Connection Window Showing Connection Between Weather Data (outputs, left column) and Parabolic Trough Collector (inputs, right column)

The same connection information in Figure 3.12 is also presented in Table 3.1. According to table and figure, one can easily see that all connected variables have the same dimension. For conciseness and clarity, all other connections in this TRNSYS model will be communicated through tables such as Table 3.1.

Table 3.1 Description of Connections

Type 109-TMY 2	Trough
Solar azimuth angle	Sun azimuth
Solar zenith angle	Sun zenith
Beam radiation on tilted surface	DNI –Direct Normal Irradiance
Wind velocity	Wind speed
Ambient temperature	Ambient temperature

3.5. Superheater

The superheater used in this system is a tube and shell heat exchanger. The effectiveness of the superheater is related to its thermal performance. The heat exchanger effectiveness (ε) is defined as the actual heat transfer realized between streams ($\dot{Q}$) over the maximum heat transfer possible for the given streams ($\dot{Q}$max) [16]. Figure 3.11 shows the flow diagram for the superheater.

$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{max}} \qquad (3.1)$$

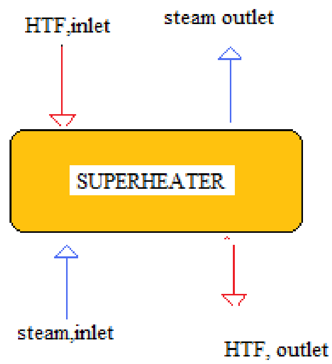

Figure 3.13 Flow diagram of superheater

STEC built-in component Type 315 is used to model the superheater. Values for constant parameters and initial conditions used are given in Table 3.2. For this study the necessary properties are taken from a technical description [23].

Table 3.2 Constant Parameters and Initial Conditions for Superheater

Parameter	Input	Unit
Overall heat transfer coefficient	1015.97	kJ/hr.K
Hot side inlet temperature	390.56	°C
Hot side flow rate	396.4	kg/s
Cold side inlet temperature	313.89	°C
Cold side flow rate	38.969	kg/s
Cold side quality	1	-
Cold side outlet pressure	100	bar
Hot side specific heat	2.59	kJ/kg.K

For all heat exchangers the hot side is the HTF flowing from the collector while the cold side is the water in the Rankine cycle. The transient values for inputs for the superheater are defined by the input connections given in Table 3.3, while the outputs that define transient inputs for other components are given in Table 3.4.

Table 3.3 Input Links for the Superheater

Input	Output
Superheater	Splitter
Hot side flow rate	Outlet flow rate2
Superheater	Boiler
Cold side inlet temperature	Cold side outlet temperature
Cold side flowrate	Cold side outlet flowrate
Cold side quality	Cold side quality
Superheater	X2H
Cold side outlet pressure	Steam pressure

Table 3.4 Output Links for the Superheater

Input	Output
Boiler	Superheater
Hot side inlet temperature	Hot side outlet temperature
Hot side flowrate	Hot side flowrate
Cold side outlet pressure	Cold side inlet pressure
X2H	Superheater
Steam temperature	Cold side outlet temperature
Steam quality	Cold side outlet quality
Steam flow rate	Cold side flow rate

3.6. Boiler (Steam Generator)

The feedwater enters the shell side of the boiler and exits as a saturated vapor. The boiler effectiveness is related to the number of transfer units (NTU). Figure 3.14 shows the flow diagram for the boiler. When the saturated liquid changes phase from saturated liquid feedwater to steam its capacitance infinite [16,34]. The minimum capacitance of the fluid is

$$C_{MIN} = \dot{m}_{HTF}\left(\frac{h_{HTF,in} - h_{HTF,out}}{T_{HTF,in} - T_{HTF,out}}\right) \tag{3.2}$$

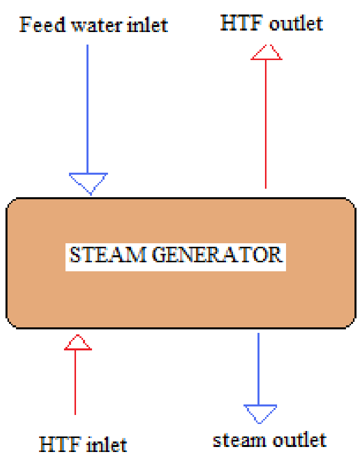

Figure 3.14 Flow diagram of boiler (steam generator)

STEC built-in component Type 316 is used to model a boiler. The parameters that are used to model the boiler STEC Type316 are given in Table 3.5.

Table 3.5 Constant Parameters and Initial Conditions for Boiler

Parameter	Input	Unit
Overall heat transfer coefficient	9717062.142	kJ/hr.K
Hot side inlet temperature	377.22	°C
Hot side flow rate	345.49	kg/s
Cold side inlet temperature	313.89	°C
Cold side flow rate	38.969	kg/s
Cold side inlet quality	0	-
Cold side outlet pressure	103.42	bar
Hot side specific heat	2.54	kJ/kg.K

The transient values for inputs for the boiler are defined by the input connections given in Table 3.6, while the outputs that define transient inputs for other components are given in Table 3.7.

Table3. 6 Input Links for the Boiler

Input	Output
Boiler	Preheater
Cold side inlet temperature	Cold side outlet temperature
Cold side inlet quality	Cold side outlet quality
Boiler	Superheater
Hot side inlet temperature	Hot side outlet temperature
Hot side flowrate	Hot side flowrate
Cold side outlet pressure	Cold side inlet pressure

Table 3.7 Output Links for the Boiler

Input	Output
Preheater	Boiler
Hot side inlet temperature	Hot side outlet temperature
Hot side flowrate	Hot side flowrate
Cold side outlet pressure	Cold side inlet pressure
Superheater	Boiler
Cold side inlet temperature	Cold side outlet temperature
Cold side flowrate	Cold side outlet flowrate
Cold side quality	Cold side outlet quality
Feedwater pump	Boiler
Desired mass flow rate	Cold side flow rate demand

3.7.Preheater

The preheater is also a type of heat exchanger and is used to raise the temperature of the feed water leaving the system of feed water heaters. While modeling the preheater, it is assumed that the feedwater outlet state will be a saturated liquid at the outlet pressure of the preheater [16]. The heat transfer to the feedwater is calculated as

$$\dot{Q} = \dot{m}_{feedwater}(h_{feedwater,out} - h_{feedwater,in}) \quad (3.3)$$

Figure 3.15 shows the flow diagram for the preheater.

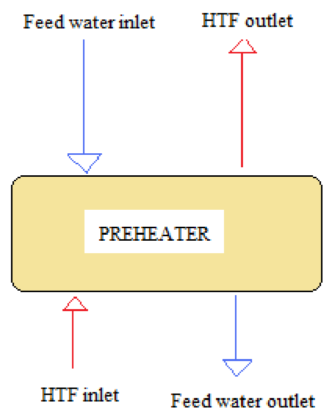

Figure 3.15 Flow diagram of Preheater

STEC built-in component Type 315 is used to model a preheater. The parameters that are used to model the preheater STEC Type315 are given in Table 3.8

Table 3.8 Constant Parameters and Initial Conditions for Preheater

Parameter	Input	Unit
Overall heat transfer coefficient	175710.2297	kJ/hr.K
Hot side inlet temperature	317.78	˚C
Hot side flow rate	345.49	kg/s
Cold side inlet temperature	234.83	˚C
Cold side flow rate	38.969	kg/s
Cold side quality	0	-
Cold side outlet pressure	103.42	bar
Hot side specific heat	2.36	kJ/kg.K

The transient values for inputs for the preheater are defined by the input connections given in Table 3.9. while The outputs that define transient inputs for other components are given in Table 3.10.

Table 3.9 Input Links for the Preheater

Input	Output
Preheater	Boiler
Hot side inlet temperature	Hot side outlet temperature
Hot side flowrate	Hot side outlet flowrate
Cold side outlet pressure	Cold side inlet pressure
Preheater	Feedwaterheater
Cold side inlet temperature	Cold side outlet temperature
Cold side inlet flowrate	Cold side outlet flowrate

Table 3.10 Output Links for the Preheater

Input	Output
Boiler	Preheater
Cold side inlet temperature	Cold side outlet temperature
Cold side inlet quality	Cold side outlet quality
Mixer	Prehater
Inlet flowrate 2	Hot side flowrate

3.8. High Pressure and Low Pressure Turbine

Both high and low pressure turbines are used. Superheated steam leaving the superheater at a high temperature and high pressure enters the high pressure turbine. The expansion of the steam as it moves from a high pressure to a lower pressure converts the steam's enthalpy to shaft work. The shaft work created by the rotating shaft is converted to electrical energy through a generator. Steam is extracted at intermediate points during the expansion process and fed to the feed water heaters. The turbines are modeled as a series of turbine stages connected in series. Each stage consists of a turbine and a splitter. One outlet of the splitter is connected to the next turbine stage (or is the outlet of the larger turbine if the last turbine stage) while the splitter's other outlet is connected to a feedwater heater. Figure 3.16 shows a flow diagram for a turbine stage.

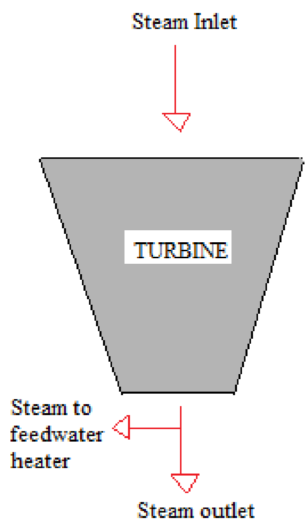

Figure 3.16 Flow diagram of Turbine Stage Consisting of a Turbine and a Splitter.

The high pressure (HP) turbine consists of two stages and the low pressure (LP) turbine consists of five stages. Between the HP and LP turbines steam passes through the reheater to increase the cycle efficiency. The thermodynamic performance of each turbine stage is described by its isentropic efficiency [16,22,34]. The isentropic efficiency of a turbine stage is equal to the change in enthalpy of the fluid to the change in enthalpy of an isentropic (adiabatic and reversible) turbine:

$$\eta = \frac{h_{steam,in} - h_{steam,out}}{h_{steam,in} - h_{steam,out,S}} \quad (3.4)$$

where $h_{steam,out,S}$ is the enthalpy that would have occurred at the outlet of the isentropic turbine. The total power of the turbine is equal to the mass flow rate through each turbine stage multiplied by the mass specific work of that stage. The steam mass flow rate through each stage is equal to turbine inlet mass flow rate minus the total mass flow rates of the steam extracted to flow to the feedwater heaters in the previous stages. The power for each turbine stage is as follows:

$$\dot{W}_{HP1} = \dot{m}_1 \dot{w}_{1-2} \quad (3.5)$$

$$\dot{W}_{HP2} = (\dot{m}_1 - \dot{m}_2)\dot{w}_{2-3} \quad (3.6)$$

$$\dot{W}_{LP1} = \dot{m}_5 \dot{w}_{5-6} \quad (3.7)$$

$$\dot{W}_{LP2} = (\dot{m}_5 - \dot{m}_6)\dot{w}_{6-7} \quad (3.8)$$

$$\dot{W}_{LP3} = (\dot{m}_5 - \dot{m}_6 - \dot{m}_7)\dot{w}_{7-8} \quad (3.9)$$

$$\dot{W}_{LP4} = (\dot{m}_5 - \dot{m}_6 - \dot{m}_7 - \dot{m}_8)\dot{w}_{8-9} \quad (3.10)$$

$$\dot{W}_{LP5} = (\dot{m}_5 - \dot{m}_6 - \dot{m}_7 - \dot{m}_8 - \dot{m}_9)\dot{w}_{9-10} \quad (3.11)$$

The total output equals the sum of the output from each turbine section.

$$\dot{W}_{turbine} = \dot{W}_{HP1} + \dot{W}_{HP2} + \dot{W}_{LP1} + \dot{W}_{LP2} + \dot{W}_{LP3} + \dot{W}_{LP4} + \dot{W}_{LP5} \quad (3.12)$$

For the HP and LP turbines, STEC components Type 318 (turbine) and Type 389 (splitter) are used to model a single turbine stage. The TRNSYS model of the high pressure turbine with two extracts is shown in Figure 3.17

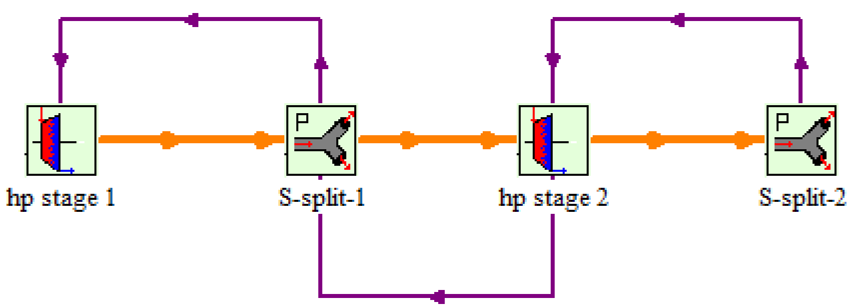

Figure 3.17 STEC Components Turbine and Splitters

The parameters that are used to model the HP turbine's 1st stage are given in Table 3.11 and Table 3.12.

Table 3.11 Constant Parameters and Initial Conditions for HP turbine 1st stage

Parameter	Input	Unit
Design inlet pressure	100	bar
Design outlet pressure	33.61	bar
Design flow rate	38.6415	kg/s
Design inner efficiency	0.8376	-
Turbine outlet pressure	33.61	bar
Turbine inlet flowrate	38.6415	kg/s
Turbine inlet enthalpy	3005	kJ/kg

The controlled splitter has one inlet and two outlets. The mass flow rate for outlet one goes to a feedwater heater, and the remaining flow leaves from outlet two and goes to the next turbine stage. The enthalpies for the splitter's outlets one and two are equal to its inlet enthalpy. In this model the pressure information is transported in a direction opposite to the mass flow, such that the turbine stage's inlet pressure is fixed by the turbine stage's outlet pressure, and the turbine stage's outlet pressure is fixed by the inlet pressure of the next turbine stage.

Table 3.12 Initial Parameters for the HP Turbine 1st stage splitter

Parameter	Input	Unit
Demanded flow out 1	2.9311	kg/s
Inlet flow rate	38.6414	kg/s
Outlet pressure 2	33.61	bar
Inlet enthalpy	3005	kJ/kg

The parameters that are used to model the HP turbine 2nd stage are given in Table 3.13

Table 3.13 Constant Parameters and Initial Conditions for HP Turbine 2nd Stage

Parameter	Input	Unit
Design inlet pressure	33.61	bar
Design outlet pressure	18.58	bar
Design flow rate	35.7326	kg/s
Design inner efficiency	0.8463	-
Turbine outlet pressure	18.58	bar
Turbine inlet flowrate	35.7326	kg/s
Turbine inlet enthalpy	2807	kJ/kg

The link between the HP turbine stage 1 and splitter is shown Table 3.14. A parallel set of links are used for the HP turbine's second stage and all LP turbine stages.

Table 3. 14 Input and Output Links for the Turbine Stage

Input	Output
HP Turbine Stage 1	Splitter
Turbine outlet flowrate	Inlet flowrate
Turbine outlet enthalpy	Inlet enthalpy
Splitter	HP Turbine Stage 1
Inlet Pressure	Turbine outlet pressure

The parameters that are used to model the HP turbine 2nd stage are given in Table 3.15

Table 3.15 Initial Parameters for the HP Turbine 2nd Stage Splitter

Demanded flow out	2.8009	kg/s
inlet flowrate	35.7326	kg/s
Outlet pressure2	18.58	bar
Inlet enthalpy	2807	kJ/kg

3.9. Reheater

The reheater is also a shell and tube heat exchanger. In this cycle after leaving the HP turbine the steam goes to the reheater and the temperature increases so that the system efficiency increases. The reheater model is the same as the superheater model and same equations are used. STEC built-in component Type 315 is used to model the reheater. Values for constant parameters and initial conditions used are given in Table 3.16.

Table 3.16 Constant Parameters and Initial Conditions for the Reheater

Parameter	Input	Unit
Overall heat transfer coefficient	1724.11	kJ/hr.K
Hot side inlet temperature	390.56	˚C
Hot side flow rate	47.87	kg/s
Cold side inlet temperature	208.67	˚C
Cold side flow rate	33.16	kg/s
Cold side quality	1	-
Cold side outlet pressure	17.10	bar
Hot side specific heat	2.59	kJ/kg.K

The transient values for inputs for the reheater are defined by the input connections given in Table 3.17 while the outputs that define transient inputs for other components are given in Table 3.18.

Table 3.17 Input Links for the Reheater

Input	Output
Reheater	HP Turbine
Cold side flowrate	Splitter2 outlet flowrate
Reheater	HTF Splitter
Hot side flowrate	Outler flowrate1
Reheater	X2H2
Cold side outlet Pressure	Steam pressure

Table 3.18 Output Links for the Reheater

Input	Output
HP Turbine	Reheater
Splitter outlet pressure 2	Cold side inlet pressure
Mixer	Reheater
Inlet flowrate 1	Hot side flowrate
X2H2	Reheater
Steam temperature	Cold side outlet temperature
Steam quality	Cold side outlet quality
Steam flowrate	Cold side flowrate

X2H2 is a STEC component which converts steam properties given by T, p, and x used in the superheater and reheater components to h and p used in the turbine stage components [33].

3.10. Low Pressure (LP) Turbine

The LP turbine stages are modeled in a manner parallel to the HP turbine stages. The details on the input and output links and the initial conditions and constants are given in Tables 3.19-3.27 for each LP turbine stage.

For each LP turbine stage, STEC components Type 318 (turbine) and Type 389 (splitter) are used as shown in Figure 3.18.

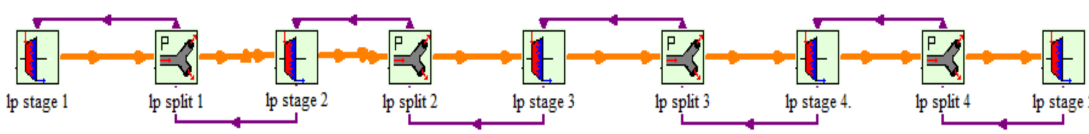

Figure 3.18 STEC Components Turbine and Splitter

Table 3.19 Initial Conditions and Constants for LP turbine 1st stage

Parameter	Input	Unit
Design inlet pressure	17.10	bar
Design outlet pressure	7.98	bar
Design flow rate	32.8068	kg/s
Design inner efficiency	0.8623	-
Turbine outlet pressure	7.98	bar
Turbine inlet flowrate	32.8068	kg/s
Turbine inlet enthalpy	3190	kJ/kg
By pass indicator	1	-

Table 3.20 Initial parameters for LP turbine 1st stage splitter

Demanded flow out	2.03	kg/s
inlet flowrate	32.8068	kg/s
Outlet pressure2	7.97	bar
Inlet enthalpy	3190	kJ/kg

Table 3.21 Initial Conditions and Constants for LP turbine 2nd stage

Parameter	Input	Unit
Design inlet pressure	7.98	bar
Design outlet pressure	2.73	bar
Design flow rate	30.7936	kg/s
Design inner efficiency	0.917	-
Turbine outlet pressure	2.73	bar
Turbine inlet flowrate	30.7936	kg/s
Turbine inlet enthalpy	3016	kJ/kg
By pass indicator	1	-

Table 3.22 Initial Parameters for LP Turbine 2nd Stage Splitter

Demanded flow out	1.76	kg/s
inlet flowrate	30.7936	kg/s
Outlet pressure2	2.72	bar
Inlet enthalpy	3016	kJ/kg

Table 3.23 Initial Conditions and Constants for LP Turbine 3rd Stage

Parameter	Input	Unit
Design inlet pressure	2.73	bar
Design outlet pressure	0.96	bar
Design flow rate	29.0324	kg/s
Design inner efficiency	0.9352	-
Turbine outlet pressure	0.96	bar
Turbine inlet flowrate	29.0324	kg/s
Turbine inlet enthalpy	2798	kJ/kg
By pass indicator	1	-

Table 3.24 Initial Parameters for LP Turbine 3rd Stage Splitter

Demanded flow out	1.62	kg/s
inlet flowrate	29.0324	kg/s
Outlet pressure2	0.96	bar
Inlet enthalpy	2798	kJ/kg

Table 3.25 Initial Conditions and Constants for LP Turbine 4th Stage

Parameter	Input	Unit
Design inlet pressure	0.96	bar
Design outlet pressure	0.29	bar
Design flow rate	27.4158	kg/s
Design inner efficiency	0.88	-
Turbine outlet pressure	0.29	bar
Turbine inlet flowrate	27.4158	kg/s
Turbine inlet enthalpy	2624	kJ/kg
By pass indicator	1	-

Table 3.26 Initial Parameters for LP Turbine 4th Stage Splitter

Demanded flow out	0.79	kg/s
Inlet flowrate	27.4158	kg/s
Outlet pressure2	0.28	bar
Inlet enthalpy	2624	kJ/kg

Table 3.27 Initial Conditions and Constants for LP Turbine 5th Stage

Parameter	Input	Unit
Design inlet pressure	0.29	bar
Design outlet pressure	0.08	bar
Design flow rate	26.6116	kg/s
Design inner efficiency	0.6445	-
Turbine outlet pressure	0.08	bar
Turbine inlet flowrate	26.6116	kg/s
Turbine inlet enthalpy	2325	kJ/kg
By pass indicator	1	-

3.11. Condenser

The condenser is a shell and tube heat exchanger. On the tube side cooling water is flowing and on the shell side the steam from the LP turbine is condensing. The condenser condenses the steam from the LP turbine (steam inlet) to a liquid so that the fluid can be easily pumped back to the boiler (condensed feed water, outlet). Figure 3.19 shows the flow diagram for the condenser.

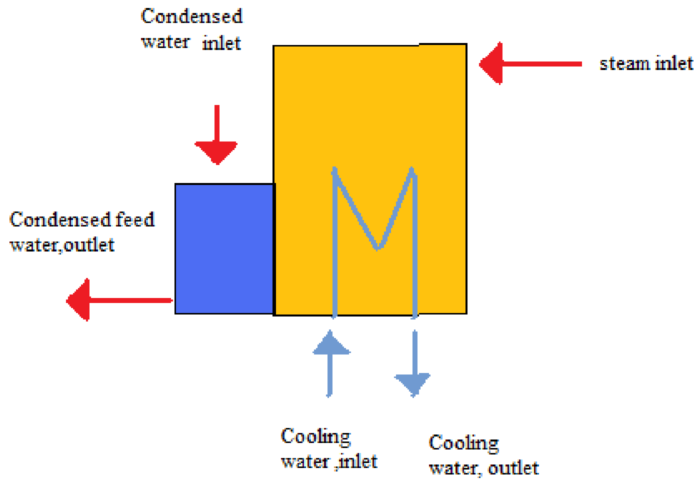

Figure 3. 19 Flow Diagram of Condenser

$$\varepsilon_{condenser} = \frac{Q_{condenser}}{Q_{condenser,max}} \tag{3.13}$$

The condenser effectiveness is the ratio of the heat transfer between cooling water and condensing steam to the maximum heat transfer between these streams [16].

$$\dot{Q}_{condenser} = \dot{m}_{steam}\left(h_{steam,in} - h_{steam,out}\right) \tag{3.14}$$

$$\dot{Q}_{condenser,max} = \dot{m}_{condenser} \cdot \dot{c}_{condenser}\left(T_{steam} - T_{condenser,in}\right) \tag{3.15}$$

The condenser is modeled using STEC component Type 383. The parameters that are used to model the condenser STEC Type383 are given in Table 3.28

Table 3.28 Initial Conditions and Constants for the Condenser

Parameter	Input	Unit
Cooling water inlet temperature	25.5	˚C
Steam enthalpy inlet	2348.1	kJ/kg
Steam mass flow rate	26.4820	kg/s
Condensate inlet flow rate	4.4871	kg/s
Condensate inlet temperature	52.889	˚C
Condensate inlet Quality	0	-

The transient values for inputs for the condenser are defined by the input connections given in Table 3.29 while the outputs that define transient inputs for other components are given in Table 3.30.

Table 3.29 Input Links for the Condenser

Input	Output
Condenser	LP Turbine
Steam enthalpy inlet	Stage 5 Turbine outlet enthalpy
Steam mass flowrate	Stage 5 Turbine outlet flowrate
Condenser	Feed water heater
Condensate inlet flowrate	Hot side outlet flowrate
Condensate inlet quality	Hot side outlet quality

Table 3.30 Output Links for the Condenser

Input	Output
Condensate pump	Condenser
Inlet fluid temperature	Condensing temperature
Inlet mass flowrate	Condensate flowrate
LP Turbine	Condenser
Turbine outlet pressure	Condensing pressure

3.12. Pump

In this solar electric generating system there are three pumping processes. The pumps increase the pressure of the feed water and heat transfer fluid. One pump is a condensate pump and is located at the condenser outlet. The second is a feed pump and is located at the deaerator outlet. The last one is a heat transfer fluid pump and is located before the collector field. Figure 3.20 shows the flow diagram for the pump. The STEC component Type 300 is used to model a pump. Pump performance is characterized by its isentropic efficiency [16,34].The isentropic efficiency of the pump is:

$$\eta_{pump} = \frac{h_{feedwater,in} - h_{feedwater,out,S}}{h_{feedwater,in} - h_{feedwater,out}} \qquad (3.16)$$

where $h_{feedwater,out,S}$ is the enthalpy that would have occurred were the pumping process isentropic. The work performed by the pump per unit mass is the change

$$\dot{w}_{pump} = h_{feedwater,in} - h_{feedwater,out} \qquad (3.17)$$

The parameters that are used to model the condensate pump, feed water pump, and heat transfer fluid pump are given in Table 3.31-Table 3.36.

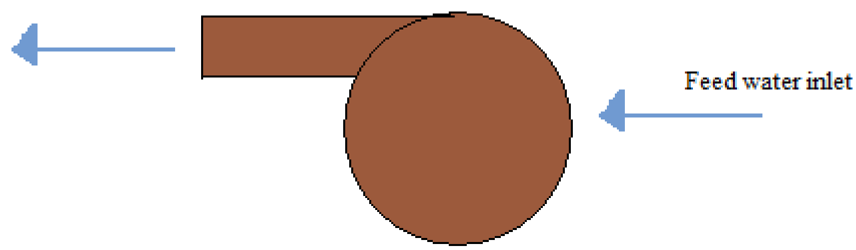

Figure 3.20 Flow Diagram of a Pump

Table 3.31 Initial Conditions and Constants for the Condensate Pump

Parameter	Input	Unit
Inlet fluid temperature	41.439	˚C
Inlet mass flow rate	30.969	kg/s
Desired mass flow rate	30.969	kg/s
Maximum flow rate	30.969	kg/s
Fluid specific heat	4.19	kJ/kg.K
Maximum power	190000	W

Table 3.32 Input and Output Links for the Condensate Pump

Input	Output
Pump	Condenser
Inlet fluid temperature	Condensing temperature
Inlet mass flowrate	Condensate flowrate
Feed water heater1	Pump
Cold side fluid temperature	Outlet fluid temperature
Condensate inlet flowrate	Outlet flowrate

Table 3.33 Initial Conditions and Constants for the Feed Pump

Parameter	Input	Unit
Inlet fluid temperature	169.22	˚C
Inlet mass flow rate	38.969	kg/s
Desired mass flow rate	38.969	kg/s
Maximum flow rate	38.969	kg/s
Fluid specific heat	4.19	kJ/kg.K
Maximum power	8.8×10^5	W

Table 3.34 Output and Input Links for Feedwater Pump

Input	Output
Pump	Condenser
Inlet fluid temperature	Feed water outlet temperature
Inlet mass flow rate	Feed water outlet flow rate
Pump	Boiler
Desired mass flow rate demand	Cold side flow rate demand
Feed water heater1	Pump
Cold side fluid temperature	Outlet fluid temperature
Condensate inlet flow rate	Outlet flow rate

Table 3.35 Initial Conditions and Constants for the HTF Pump

Parameter	Input	Unit
Inlet fluid temperature	297.78	˚C
Inlet mass flow rate	396.4	kg/s
Desired mass flow rate	396.4	kg/s
Maximum flow rate	396.4	kg/s
Fluid specific heat	2.59	kJ/kg.K
Maximum power	1.6×10^7	W

Table 3.36 Output and Input Links for HTF Pump

Input	Output
Pump	Mixer
Inlet mass flow rate	Outlet flowrate 1
Trough	Pump
Inlet temperature solar field	Outlet fluid temperature

3.13.Deaerator

The deaerator preheats the feed water for the steam generator. Steam extracted from the 1st stage of the LP turbine is directly mixed with feed water. At the outlet of the deaerator there is a feed pump which increases the fluid pressure to boiling pressure. The deaerator is a mixing device with three inlets and single outlet stream [16]. Figure 3.21 shows the flow diagram for the deaerator. The three inlets are the drain water from the high pressure feedwater heaters, the extracted steam from the first stage of the low pressure turbine, and the feedwater from the low pressure feed water heaters. The total mass flow rate is the sum of the three inlet.

$$\dot{m}_{steam,extracted} + \dot{m}_{steam,drain} + \dot{m}_{feedwater,in} = \dot{m}_{feedwater,out} \quad (3.18)$$

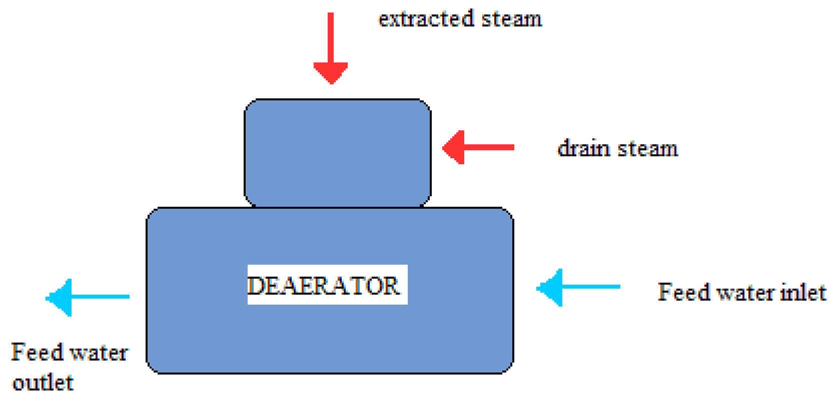

Figure 3.21 Flow Diagram of a Dearator

The parameters that are used to model the deaerator are given in Table 3.37

Table 3.37 Initial Conditions and Constants for the Dearator

Parameter	Input	Unit
Feed water inlet temperature	126.72	˚C
Feed water flow rate	31.034	kg/s
Steam inlet enthalpy	3029.4	kJ/kg
Steam inlet pressure	7.33	bar
Condensate inlet temperature	179.17	˚C
Condensate inlet flowrate	5.73	kg/s
Condensate inlet quality	0	-

The transient values for inputs for the dearator are defined by the input connections given in Table 3.38 while the outputs that define transient inputs for other components are given in Table 3.39.

Table 3. 38 Input Links for Dearator

Input	Output
Dearator	Feed water heater 3
Feedwater inlet temperature	Cold side outlet temperature
Feed water flowrate	Cold side outlet flowrate
Dearotor	LP Turbine Splitter1
Steam inlet enthalpy	Outlet enthalpy
Steam inlet pressure	Outlet pressure

Table 3. 39 Output links for the Dearator

Input	Output
Feed water pump	Dearator
Inlet fluid temperature	Feed water outlet temperature
Inlet mass flowrate	Feed water outlet flowrate
LP Turbine Splitter1	Dearator
Demanded Flow out 1	Required steam flowrate

3.14. Feedwater heaters

A feedwater heater increases the steam temperature and thereby reduces the heat addition from the collector loop and increases the system efficiency.

There are three zones in which the heat transfer occurs in a closed feedwater heater. These zones are the desuperheating zone, condensing zone, subcooling zone. The steam is reduced to a saturated vapor in the desuperheating zone and in the condensing zone steam condenses from a saturated vapor to a saturated liquid. In the subcooling or drain cooling zone the condensed steam is cooled to a temperature below its saturation temperature. The size and conductance determine the feedwater heater's overall heat transfer factor (UA). It is assumed here that the condensing zone of each feedwater heater is sufficiently large in comparison to the desuperheating and subcooling zones that the desuperheating and subcooling zones can be neglected in the model. An overall UA for each feedwater heater is defined assuming steam is condensing throughout the length of the feedwater heater [16].

The preheater model calculates the required steam mass flowrate that keep the water level in this heat exchanger constant. Effective heat transfer factor is described the heat transfer characteristic [29].UA is evaluated as a function of the cold side flow rate by

$$\frac{UA}{UA_{REF}} = \left(\frac{\dot{m}_{feedwater}}{\dot{m}_{feedwater,REF}}\right)^{0.8} \tag{3.19}$$

Figure 3.22 and Figure 3.23 shows the flow diagram for the feed water heater. For feed water heater STEC component Type 317 is used to model a feed water heater. The parameters that are used to model the feed water heater STEC Type317 are given in Table 3.40.

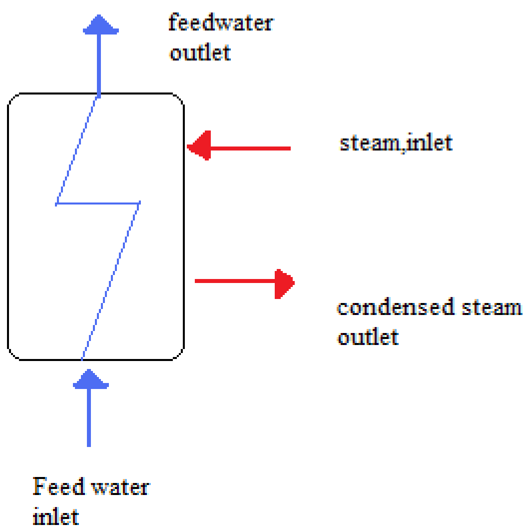

Figure 3.22 Flow Diagram of a Feedwater Heater

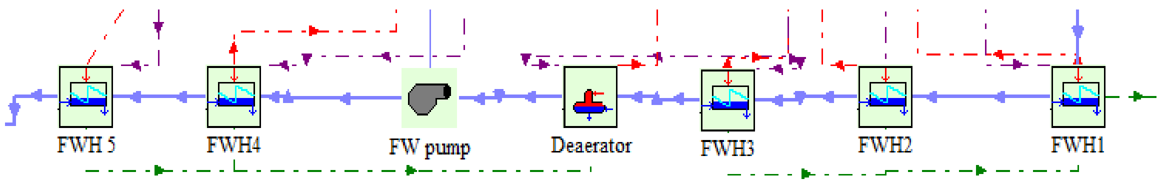

Figure 3.23 STEC Component Feedwater Heater

Table 3.40 Initial Conditions and Constants for the 1st Feedwater Heater (FWH1)

Parameter	Input	Unit
Cold fluid specific heat capacity	4.18	kJ/kg.K
Overall heat transfer factor	456.79	kW/K
Cold side ref flow rate	31.03	kg/s
Power law exp	0.8	-
Hot side inlet enthalpy	2528.1	kJ/kg
Hot side inlet pressure	0.2797	bar
Cold side inlet temperature	41.61	˚C
Cold side inlet flowrate	31.03	kg/s
Condensate inlet temperature	74.722	˚C
Condensate inlet flowrate	3.38	kg/s
Condensate inlet Quality	1	-

The transient values for inputs for the FWH1 are defined by the input connections given in Table 3.41 while the outputs that define transient inputs for other components are given in Table 3.42

Table 3.41Input Links for Feedwater Heater1

Input	Output
Feed water heater1	Condensate pump
Cold side inlet temperature	Outlet fluid temperature
Cold side inlet flowrate	Outlet flowrate
Feed water heater 1	LP Turbine splitter4
Hot side inlet enthalpy	Outlet enthalpy 1
Hot side inlet pressure	Outlet pressure 1
Feed water heater 1	Feed water heater 2
Condensate inlet flowrate	Hot side outlet flowrate
Condensate inlet quality	Hot side outlet quality

Table 3. 42 Output Links for Feedwater Heater1

Input	Output
Condenser	Feed water heater 1
Condensate inlet flowrate	Hot side outlet flowrate
Condensate inlet quality	Hot side outlet quality
LP Turbine splitter4	Feed water heater 1
Demanded flow out 1	Demanded hot inlet flowrate
Hot side inlet pressure	Outlet pressure 1
Feed water heater 2	Feed water heater 1
Cold side inlet temperature	Cold side outlet temperature
Cold side inlet flowrate	Cold side outlet flowrate

A parallel system of connections exists for all other closed feed water heater. Details of these links are not presented herein for brevity.

Table 3.43 Initial Conditions and Constants for the 2nd Feedwater Heater (FWH2)

Parameter	Input	Unit
Cold fluid specific heat capacity	4.18	kJ/kg.K
Overall heat transfer factor	642.317	kW/K
Cold side ref flow rate	31.03	kg/s
Power law exp	0.8	-
Hot side inlet enthalpy	2624.4	kJ/kg
Hot side inlet pressure	0.9625	bar
Cold side inlet temperature	64.722	˚C
Cold side inlet flowrate	31.03	kg/s
Condensate inlet temperature	105.06	˚C
Condensate inlet flowrate	1.7657	kg/s
Condensate inlet Quality	1	-

Table 3.44 Initial Conditions and Constants for 3rd Feedwater Heater (FWH3)

Parameter	Input	Unit
Cold fluid specific heat capacity	4.18	kJ/kg.K
Overall heat transfer factor	191.718	kW/K
Cold side ref flow rate	31.03	kg/s
Power law exp	0.8	-
Hot side inlet enthalpy	2798.2	kJ/kg
Hot side inlet pressure	2.7276	bar
Cold side inlet temperature	95.111	˚C
Cold side inlet flowrate	31.03	kg/s
Condensate inlet temperature	-	˚C
Condensate inlet flowrate	-	kg/s
Condensate inlet Quality	1	-

Table 3.45 Initial Conditions and Constants for 5th Feedwater Heater (FWH5)

Parameter	Input	Unit
Cold fluid specific heat capacity	4.18	kJ/kg.K
Overall heat transfer factor	839.852	kW/K
Cold side ref flow rate	38.969	kg/s
Power law exp	0.8	-
Hot side inlet enthalpy	2709.6	kJ/kg
Hot side inlet pressure	18.581	bar
Cold side inlet temperature	169.22	˚C
Cold side inlet flowrate	38.969	kg/s
Condensate inlet temperature	213.67	˚C
Condensate inlet flowrate	2.9311	kg/s
Condensate inlet Quality	1	-

Table 3. 46 Initial Conditions and Constants for the 6th Feedwater Heater (FWH6)

Parameter	Input	Unit
Cold fluid specific heat capacity	4.18	kJ/kg.K
Overall heat transfer factor	663.115	kW/K
Cold side ref flow rate	38.969	kg/s
Power law exp	0.8	-
Hot side inlet enthalpy	2807	kJ/kg
Hot side inlet pressure	33.612	bar
Cold side inlet temperature	203.61	˚C
Cold side inlet flowrate	38.969	kg/s
Condensate inlet temperature	-	˚C
Condensate inlet flowrate	-	kg/s
Condensate inlet Quality	1	-

3.15. Weather data

This component reads weather data at regular time intervals from a data file. It can easily convert the data to the desired units and make it available to other TRNSYS components. Type 109-TMY2 reads a weather data file in the standard Typical Meteorological Year (TMY2) format. The TMY2 format is used by the National Solar Radiation Data Base (USA) [35].

A TMY is a data file which provides a standard for hourly values of solar radiation and meteorological elements for a 1 year period. The TMY data set is constructed by analyzing a multi-year set of data using statistical methods, and then for each month the year with the "most typical" weather data is selected. Thus a TMY data set may use data from 1982 for January, 1995 for February, 1991 for March, etc. By using actual rather than average weather data for each month, fluctuations between cloudy and sunny days is captured better and these data sets are preferred for simulating the performance of solar energy conversion systems [36]. The initial parameters that are used to model the weather data file Type 109 are given in Table 3.47.

Table 3.47 Initial parameters for weather data file

Parameter	Input	Unit
Ground reflectance	0.2	-
Slope of surface	0	degrees
Azimuth of surface	0	degrees

The transient values for inputs for the weather data are defined by the input connections given in Table 3.48

Table 3.48Input Links for Weather Data File

Input	Output
Weather data	Trough-2
Solar azimuth angle	Sun Azimuth
Solar zenith angle	Sun Zenith
Beam radiation on tilted surfaces	DNI-Direct Normal Irradiance
Wind Velocity	Wind Speed
Ambient temperature	Ambient temperature

In Appendix B detailed information on the TMY2 data and format is presented.

3.16. Expansion vessel

The average temperature of the HTF changes during the day which causes the HTF to undergo significant changes in volume. The expansion vessel accommodates the expansion and contraction of the HTF. The expansion vessel is taken from the TRNSYS library. Figure 3.24 shows the flow diagram for the expansion vessel. The parameters that are used to model the expansion vessel Type 4-a are given in Table 3.49

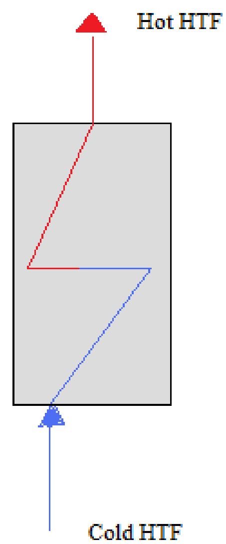

Figure 3.24 Flow diagram of expansion vessel

Table 3.49 Initial parameters for expansion vessel

Parameter	Input	Unit
Tank volume	287	m^3
Fluid specific heat	2.59	kJ/kg.K
Fluid density	704	kg/m^3
Tank loss coefficient	0	$kJ/hr.m^2.K$
Boiling point	257	˚C
Hot side temperature	390.56	˚C
Hot side flowrate	396.4	kg/s
Cold side temperature	297	˚C
Cold side flowrate	0	kg/s
Environment temperature	30	˚C

The transient values for inputs for the expansion vessel are defined by the input connections given in Table 3.50 while the outputs that define transient inputs for other components are given in Table 3.51

Table 3.50 Input Links for the Expansion Vessel

Input	Output
Expansion vessel	Trough-2
Hot side Temperature	Outlet Temperature Solar Field
Hot side Flowrate	Flow rate Solar Field

Table 3. 51 Output Links for the Expansion Vessel

Input	Output
Splitter	Expansion Vessel
Inlet Flowrate	Flow rate to heat source

3.17. Parabolic Trough Field

The parabolic trough collector component is developed using Lippke's model [23].

To account for changing fluid temperature, an integrated efficiency equation is used which calculates the demanded mass flow rate of the heat transfer fluid to achieve a user-defined outlet temperature Tout [26].

Using

$Q_{net} = Q_{abs} - Q_{pipe}$

Q_{net} : net power

Q_{abs} : ratio of absorbed power (%) (3.20)

Q_{pipe} : accounts for losses in the piping.

The thermal efficiency is

$$\boldsymbol{\eta}=\frac{Q_{abs}}{I} = K[A + B(\Delta T)] + C\frac{\Delta T}{I}+D\frac{\Delta T^2}{I} \quad (3.21)$$

In this equation,

A : optical efficiency of the trough and the absorptivity of the selective coating without considering the losses at the end of a collector row.

B, C and D : Describe the heat losses of the heat collecting element (HCE) as a function of operating conditions.

ΔT : Temperature difference between the HTF and the ambient (K).

K:incident angle modifier

I: Direct Normal Insolation (W/m^2)

Q_{abs} : ratio of absorbed power (%)

The model considers electrical parasitic losses during startup, shutdown, pumping and tracking. At high wind speeds the system automatically shutdown [33].

Table 3.52 shows the thermal performance coefficient. Parabolic trough collector model use the third line data which is black chrome and vacuum.

Table 3.52 Thermal performance coefficients [23].

	A	B	C	D
Cermet, vacuum	73.3	-0.007276	-0.496	-0.0691
Cermet, air	73.4	-0.004683	-14.40	-0.0637
Cermet, bare	74.7	-0.042-0.00927 x v_{wind}/K	0.00	-0.000731xI
Black Chrome,vacuum	73.6	-0.004206	7.44	-0.0958
Black Chrome, air	73.8	-0.006460	-12.16	-0.0641

v_{wind} : Wind velocity

STEC component Type 396 is used to model parabolic trough collector model. The parameters that are used to model the parabolic trough collector STEC Type 396 are given in Table 3.53

Table3.53 Initial Conditions and Constants for the Parabolic Trough Collector

Parameter	Input	Unit
A loss coeff.	73.6	-
B loss coeff.	-0.0042	-
C loss coeff.	7.40	-
Cw loss coeff.	0	-
D loss coeff.	-0.096	-
Clean reflectivity	0.94	-
Length of SCA(Solar Collector Area)	47	m
Aperture With of SCA(Solar Collector Area)	5	m
Focal length of SCA(Solar Collector Area)	5	m
Row Spacing	15	m
Total field Area	182000	m^2
Pump Max. Power	1600	kW
Pump Max Flowrate	396.4	kg/s
Demanded Outlet Temperature	390.56	˚C
Inlet Temperature Solar Field	297.78	˚C
Cleanliness Solar Field	0.95	-
Specific Heat HTF	2.59	kJ/kg.K
Ambient temperature	30	˚C
Wind speed Limit for tracking	5	m/s

The transient values for inputs for the Trough are defined by the input connections given in Table 3.54 while the outputs that define transient inputs for other components are given in Table 3.55.

Table 3. 54 Input Links for the Trough

Input	Output
Trough-2	Weather data
Sun Azimuth	Solar azimuth angle
Sun Zenith	Solar zenith angle
DNI-Direct Normal radiation	Beam radiation on tilted surfaces
Wind Speed	Wind Velocity
Ambient temperature	Ambient temperature
Trough-2	HTF Pump
Inlet Temperature Solar Field	Outlet Fluid Temperature

Table 3.55 Output Links for the Trough

Input	Output
Expansion vessel	Trough-2
Hot side Temperature	Outlet Temperature Solar Field
Hot side Flowrate	Flow rate Solar Field

3.18. Model Capabilities and Limitations

The solar field model is computationally efficient. More complex and transient thermodynamics models can be implemented. The solar thermal power community prefers this software because of the availability of the TRNSYS source code [32].

Users easily choose a time period and analyze one or more locations performance and get a Microsoft Excel output. Using the software's online plotter the results can be drawn. The model of the system consists of 34 components and requires a fairly large amount of data. Each component's data may have to be changed if the system is redesigned. In this work the approximate time to run one annual simulation takes 4-5 seconds.

Before running a simulation, TRNSYS converts the model of the energy system developed using the graphical user interface into called a “Deck” file. The Deck file for the present system is presented in Appendix C. This Deck file contains a complete description of the system modeled in TRNSYS.

CHAPTER 4

RESULTS

4.1 Model Validation

The aim of this study is to create a model that correctly predicts SEGS VI plant behavior and apply the same model to Turkey. In order to validate the model its results are compared with measured plant data which is taken from the Kearney et al. technical description and the TRNSYS model predictions [23]. The study by Kearney et al. shows how their model's predictions compare to real operating data for a sunny summer and a cloudy winter day. Figure 4.1 shows the insolation, temperature and wind speed measured during a clear sunny day on July 18, 1991 in California, Daggett.

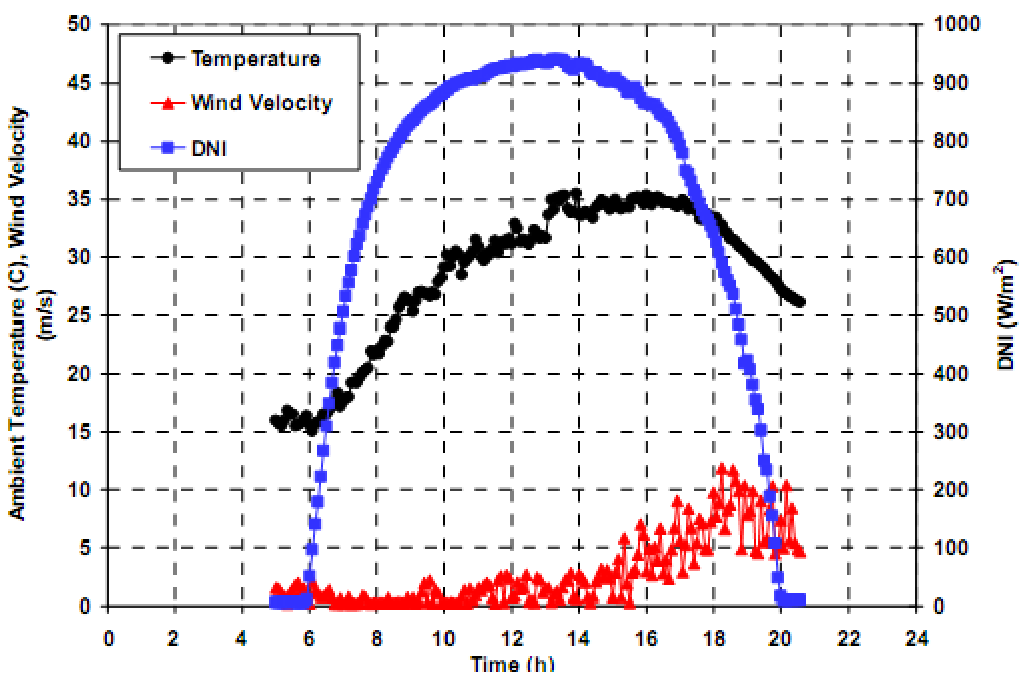

Figure 4.1 Weather Conditions July 18, 1991[26]

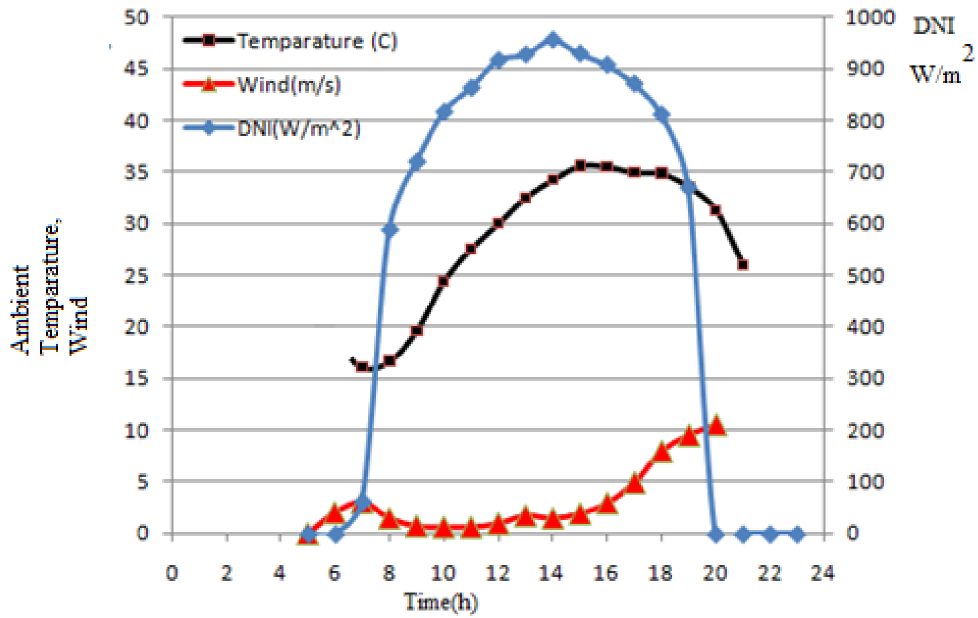

Figure 4.2 Weather Conditions July 18, 1991 TRNSYS results

Figure 4.2 shows results from the TRNSYS modeled developed herein for the same location and data. Comparison of TRNSYS results with predictions reported in the literature shows that the DNI, wind and ambient temperature results are generally close to each other. Atmospheric conditions and large air mass changes throughout the day affect the collector location, orientation and tracking capability. The insolation results from Figures 4.1 and 4.2 are presented in Figure 4.3 and it is easily seen that the DNI results predicted by the current model and that reported in the literature are close to each other.

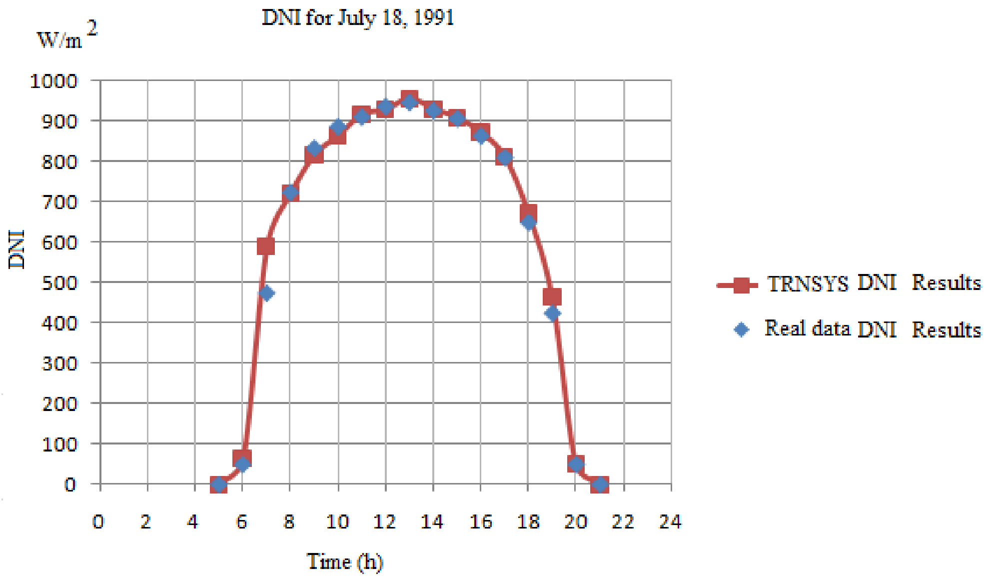

Figure 4.3 Comparison of TRNSYS Results and Real data plant DNI July 18, 1991

Figure 4.4 shows measured and predicted gross power output results on July 18,1991 as reported in [26] and in Figure 4.5 the predictions from the current model are presented. As seen in Figure 4.6 in which the present TRNSYS simulation results are compared to that presented in the literature, the sunny day power predictions match well in the morning, but have error in the afternoon when the ambient temperature is higher. However, within the context of the present study these errors are considered to be acceptable.

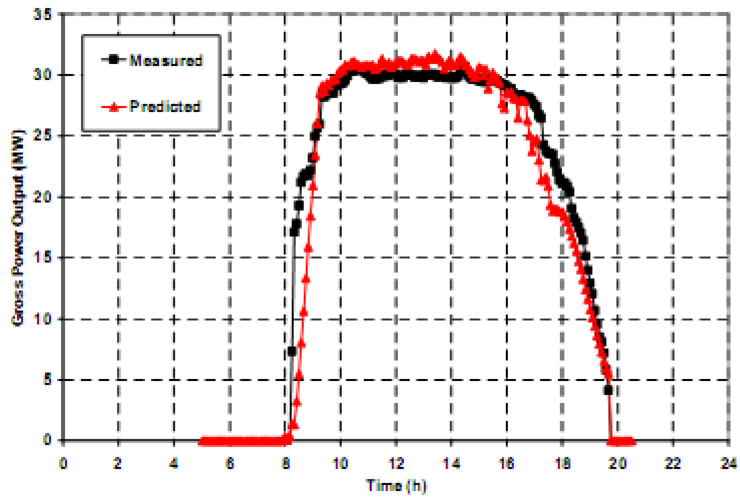

Figure 4.4 Measured and Predicted Gross Power Output on July 18,1991 [26]

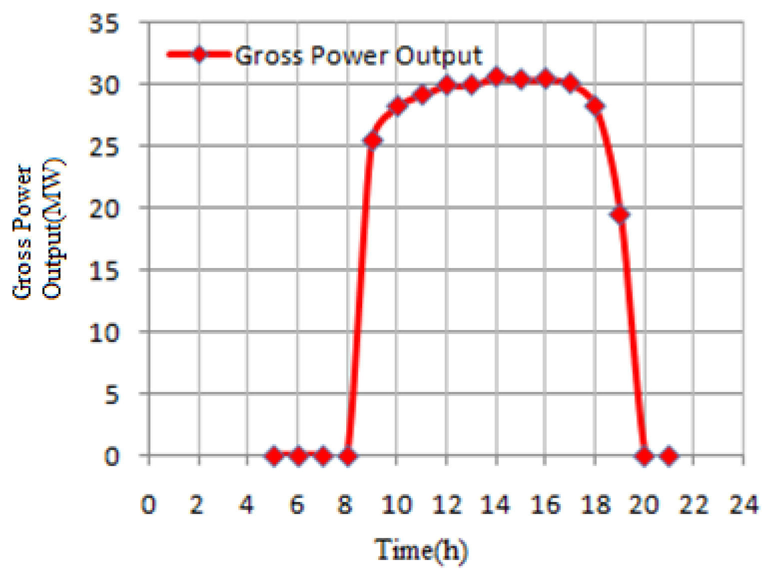

Figure 4.5 Gross Power Output TRNSYS Result July 18, 1991

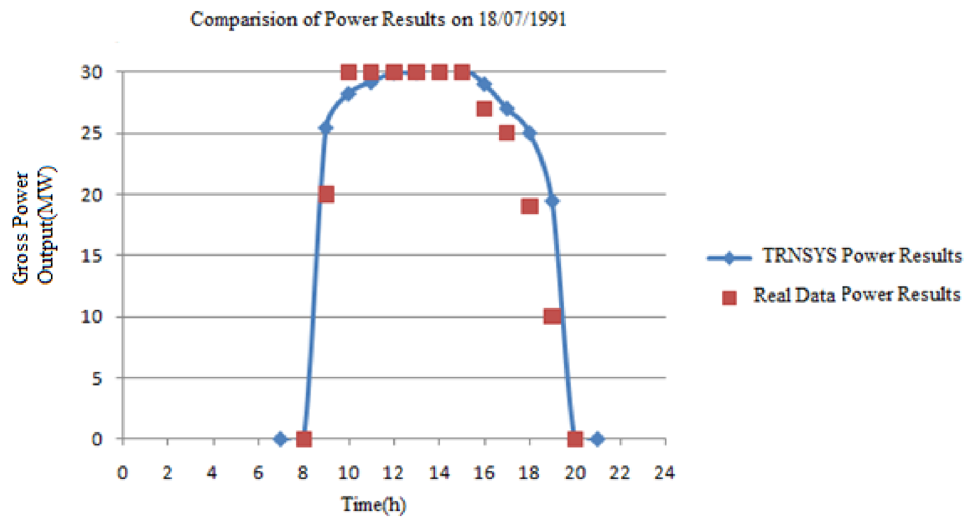

Figure 4.6 Comparision of Power Results on 18/07/1991

4.2 Antalya's Results

The same simulation program is run using weather data for Antalya. Antalya is located on Turkey's Mediterranean coast and has the geographic coordinates of 36 °54' N latitude and 30°42'E longitude. This city has good solar resources and, relative to other regions in Turkey, a more pronounced peak in electrical demand in the summer due to the demand for cooling. This city is also characterized by a large tourism industry and has several top rated resorts, hotels, etc. According to the governor of Antalya, in 2007, the daily electricity production was around 3 million kWh, which is less than the daily peak electricity consumption of Antalya of around 18 million kWh [37]. For these reasons, Antalya needs to produce electricity or reduce its electricity demand. Antalya was specifically chosen for this investigation because of the seasonal coincidence between electricity demand and solar resources. Figure 4.7 shows the DNI, wind, ambient temperature for the representative day August 3, 2005, which can be compared with the representative day from Kramer Junction, California, in Figure 4.1.

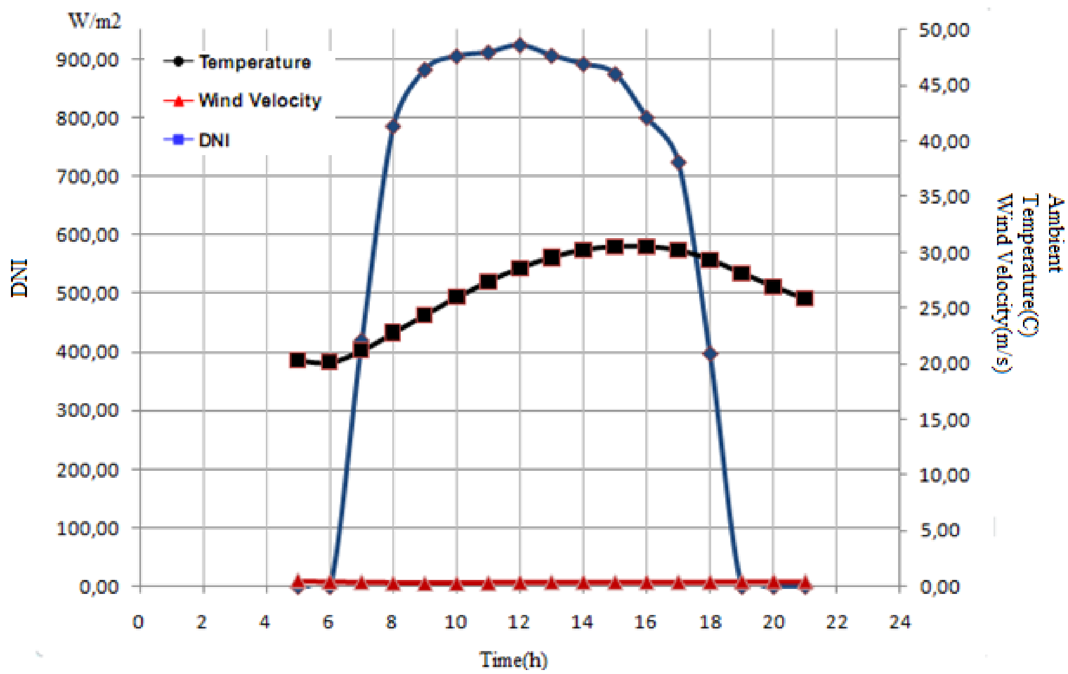

Figure 4.7 Weather Condition of Antalya on August 3, 2005

Figure 4.8 shows the predicted gross power output on August 3, 2005 in Antalya. The results which are conducted on clear summer day reach nearly 30 MW.

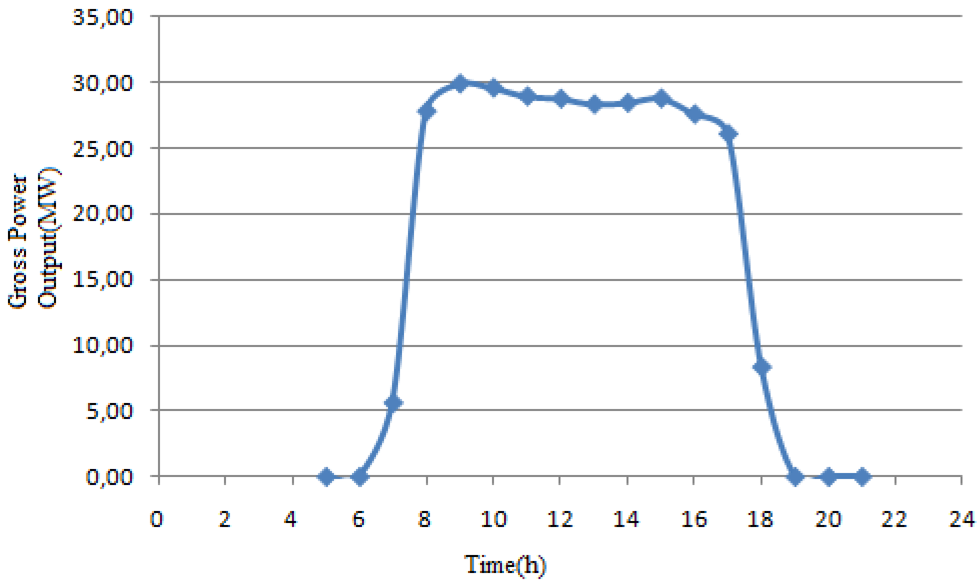

Figure 4.8 Predicted Gross Power Output for Antalya for August 3, 2005.

In this study predictions for three different solar conditions are presented for Antalya. Figure 4.9 shows the typical clear summer week power results. From these predictions it can be seen that the peak daily power which is generated all week nearly reaches 30 MW. But some variation between days does exist due to differences in cloud cover and therefore insolation.

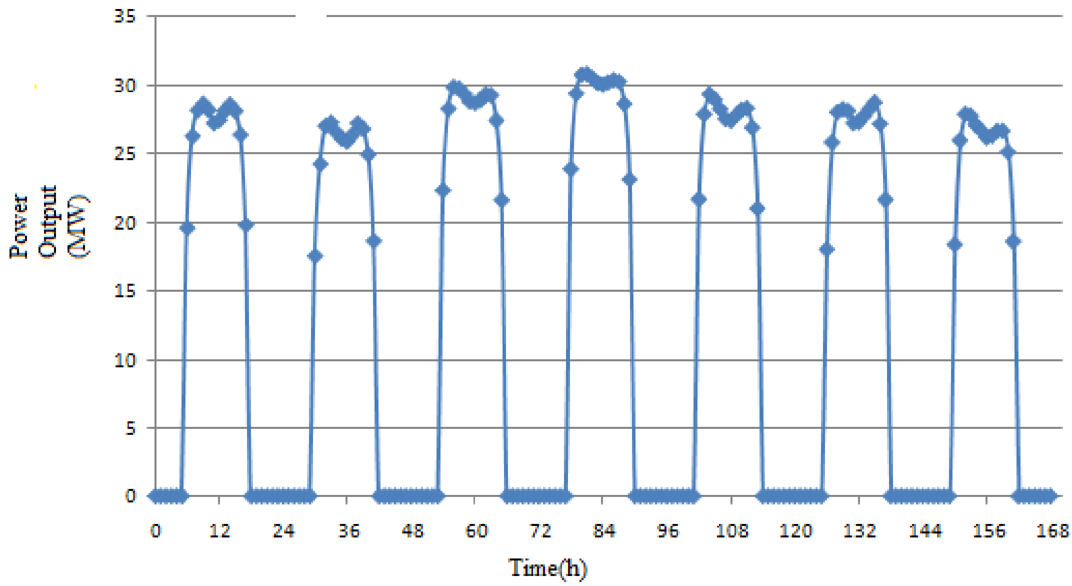

Figure 4.9 Clear Summer Week Power Results(July, 4-10 2005)

Figure 4.10 shows a typical partly cloudy week power output results for the fall. In comparing these predictions to those for the clear summer week in Figure 4.9, one can see significantly larger fluctuations.

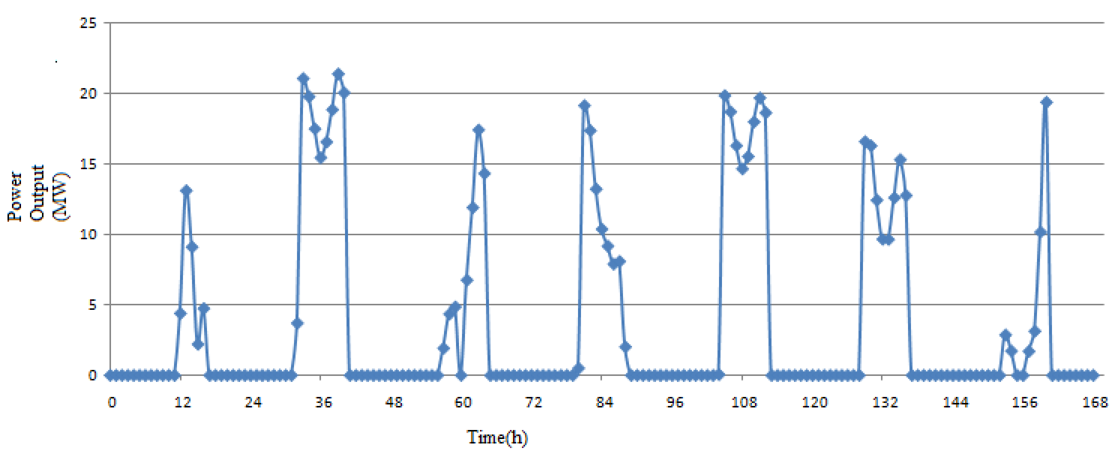

Figure 4.10 Cloudy Week Power Output Results(October,18-24 2005)

Figure 4.11 shows a typical winter week power output results. The insolation is very low and the system's maximum power output is only 15 MW.

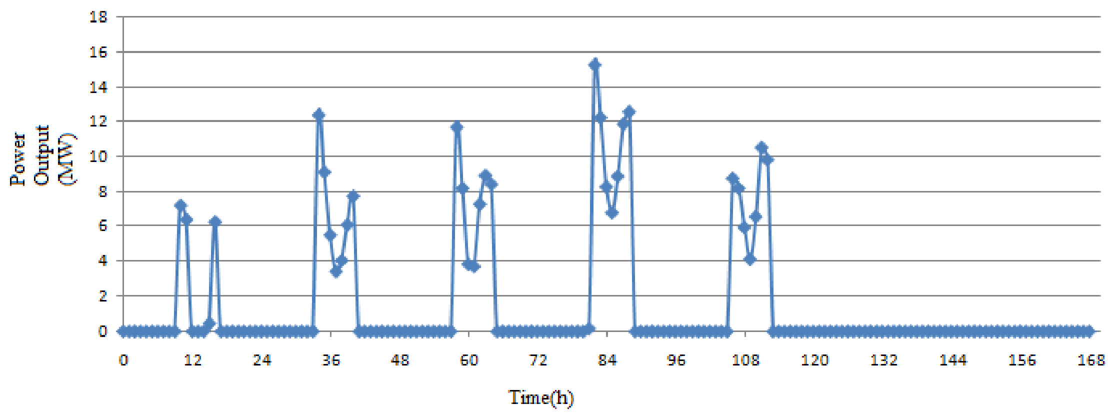

Figure 4.11 Winter Week Power Output Result (January,21-28 2005)

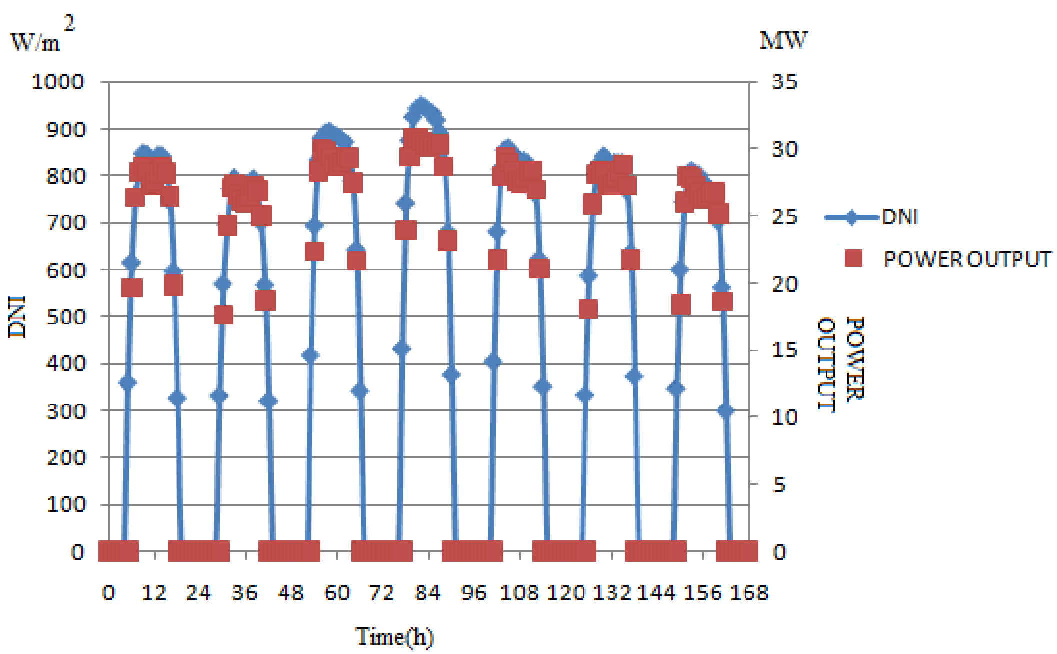

Figure 4.12 Clear Summer Week Power Output and DNI (July, 4-10 2005)

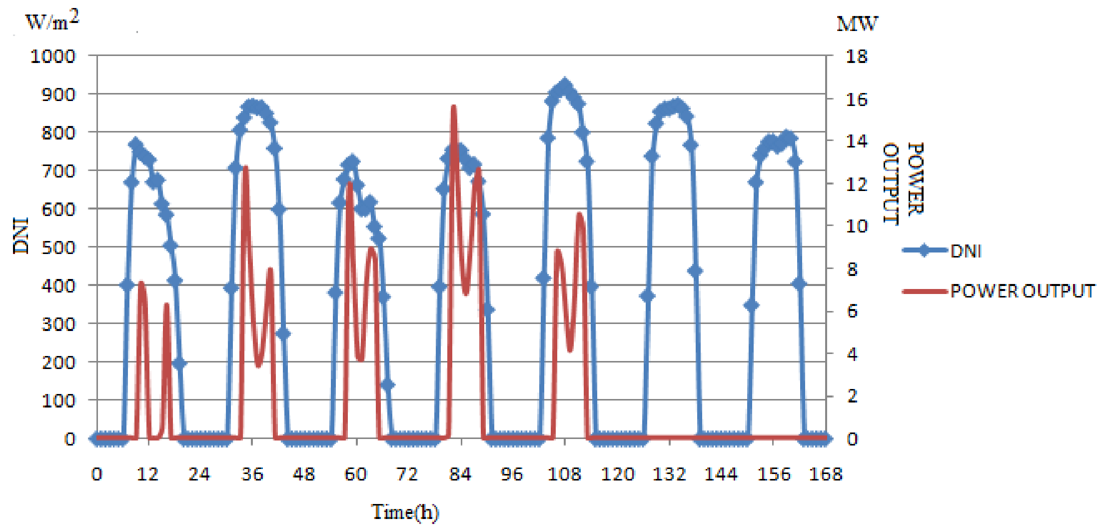

Figure 4.13 Winter Week Power Output and DNI (January,21-28 2005)

In Figures 4.12 and 4.13 the power output and DNI versus time for a summer and winter week are presented. These figures are consistent with the trends for DNI and direct irradiance (DNI x cos(ϕ)) presented in Patnode [16], where the system power output presented in the present work is substituted for the direct irradiance presented by Patnode.

Figure 4.14 shows efficiency over a summer day and the system efficiency is nearly 15%, the collector efficiency is approximately 52 %, and cycle efficiency is approximately 35 %. For winter days efficiency is shown in Figure 4.15. System and cycle efficiencies decrease and system efficiency is approximately 0.5 %, collector efficiency is approximately 52 % and cycle efficiency is approximately 0.8 %.

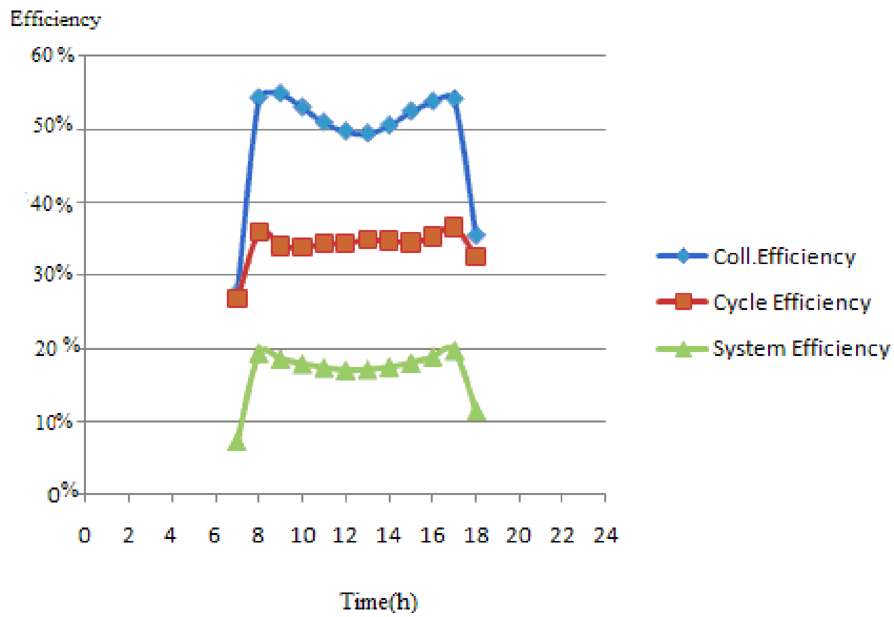

Figure 4.14 System, Cycle and Collector Efficiency versus Time Antalya for August 3, 2005.

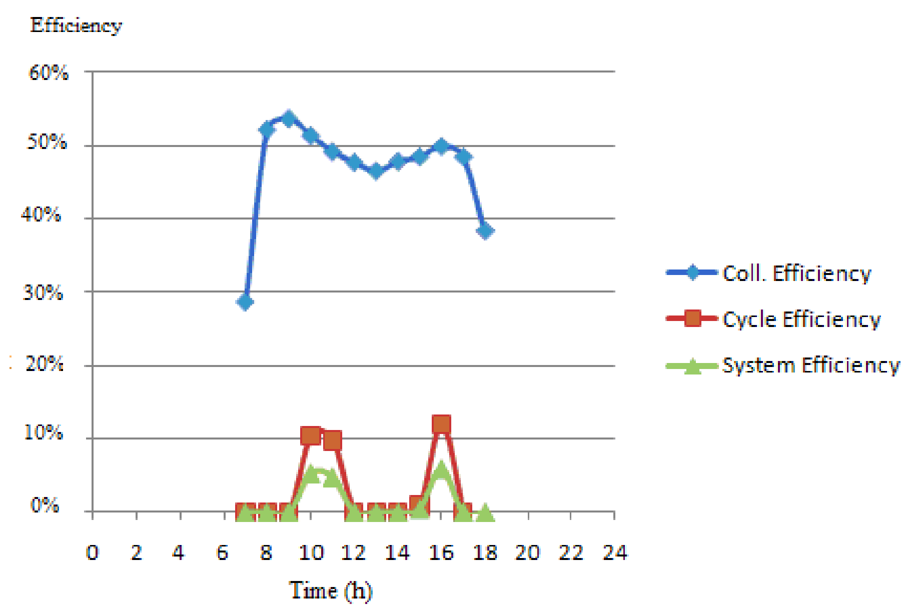

Figure 4.15 System, Cycle, Collector Efficiency versus Time Antalya for January 21, 2005

Figure 4.16 is the last graph and it is a summary of the entire study. Average daily power output of Antalya and Kramer Junction are compared for each month of the year. For Kramer Junction the maximum daily electricity generated is nearly 290 MWh/day and these results are obtained in June. For Antalya the maximum daily electricity generated is 260 MWh/day and these results are obtained in July. According to these results, Antalya is very suitable place to a construct parabolic trough field.

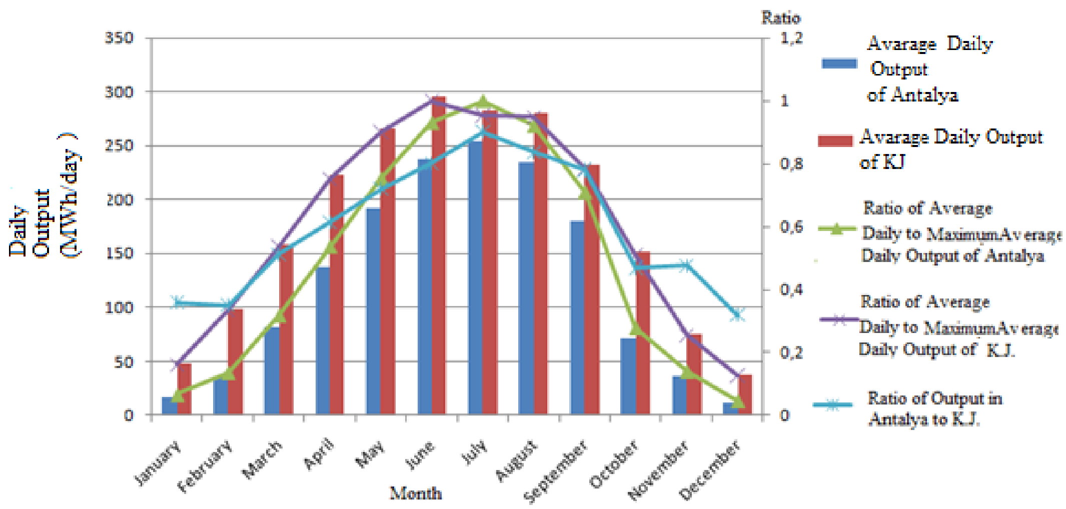

Figure 4.16 Comparison of Monthly Performance of CSP System in Antalya, Turkey, and Kramer Junction, California: Average Daily Output, Ratio of Average Daily to Maximum Average Daily Output, and Ratio of Output in Antalya to Kramer Junction (KJ).

CHAPTER 5

SUMMARY AND CONCLUSIONS

In this study, a model for the solar field and power cycle was created in the TRNSYS simulation environment using the Solar Thermal Electric Component (STEC) model library. A model for a 30 MW CSP system was developed based on published data for an actual system in Kramer Junction, California. The system consists of a collector loop connected to a power block by a series of heat exchangers. The collector loop consists of a field of parabolic trough collectors, expansion vessel, pump and heat exchangers to drive the power block and uses a heat transfer fluid. The series of heat exchangers connecting the collector loop to the power block are a preheater, steam generator, superheater, and reheater. In addition to these heat exchangers, the power block consists of a 2-stage high pressure turbine, 5-stage low pressure turbine, condenser, 5-feed water heaters, 1-dearator, and 2-pumps. The model's predictions were benchmarked against published data for the system in Kramer Junction, California, for a summer day. Good agreement between the model's predictions and published data were found, with errors usually less than 10%. Transient effects such as startup, shutdown, and cloud response were adequately modeled. Previous work in this area focused on modeling the performance of the system for a single day operating at Kramer Junction, California. The present work extends this previous work by presenting and comparing results for annual simulations for both Kramer Junction and for Antalya, Turkey. Results from representative summer, fall and winter weeks for Antalya are presented. Major results are as follows:

- For all months of the year, the system in Antalya produces 10% to 50% less energy than the system in Kramer Junction.
- On an annual basis, the system in Antalya produces 30 % less energy than the system in Kramer Junction.

- In Antalya the system average daily output is maximum in July and minimum in December. The ratio of energy produced in December to July is 0.04.
- In December the system produces less energy because of high angle of incidence angle, small projected area, short days and high air mass.

Therefore, while Antalya is known as having good solar resources for Turkey, the resources are not as good as those in Kramer Junction. Additionally, based on these results much of the capacity of the 30 MW is not used throughout the year if the system only relies on solar power without back-up.

CHAPTER 6

SUGGESTIONS FOR FUTURE INVESTIGATIONS

This presented study forms a foundation and should be considered as a starting point for further studies. It is a basic development for a very promising technology which is the parabolic trough collector system. In the future with required developments and research, these systems can be more commercially viable. Suggestions to improve on this present modeling and simulation work are as follows:

- The current model does not include storage. Storage can be implemented to improve the availability of this system and shift electricity production closer to peak electricity demand.
- The current model only includes Therminol VP-1 as a heat transfer fluid. These models can be improved by implementing water instead of Therminol VP-1 to model a direct steam generation (DSG) system. As a result, some new important aspects, such as collector efficiency can be introduced.
- The model can be extended to model a parabolic trough plant integrated with a gas turbine combined-cycle plant, which is a relatively new and promising concept. This new technology is called an Integrated Solar Combined Cycle System (ISCCS).
- A power tower system can be modeled and its performance compared to that for a parabolic trough system.

- The cooling towers for parabolic trough systems typically consume large quantities of water. The magnitude of this water consumption can be investigated and compared to local water resources. The impact of using alternate cooling technologies such as dry cooling towers, which have higher parasitic energy loses, can be quantified.
- Parabolic trough plants are capital-intensive projects and cost reduction should be investigated and improved.

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APPENDIX A

PARABOLIC TROUGH COLLECTOR DESIGN TOOL USING VISUAL BASIC

A design program was developed by several students from Middle East Technical University [38]. The program is designed to calculate of the amount of heat transmitted from the collector and the transferred heat to the heat transfer fluid. According to the detailed design methodology explained in the Theory section below, an algorithm has been formed.

The program consists of two parts. The first part calculates the energy from the collector field and the second part uses this energy and calculates the efficiency of the vacuum tube, energy loss, and outlet temperature of fluid.

The program consists of a user friendly interface. After starting the program, a menu comes to the screen. In this screen, there are 3 parts: collector geometry, reflective coating of the collector, city and calculation period. In the first part, the important variables that are to be determined by the user are listed as shown in Figures A.1-A3 Some of these are given as a list among which the variable is selected but the others are not.

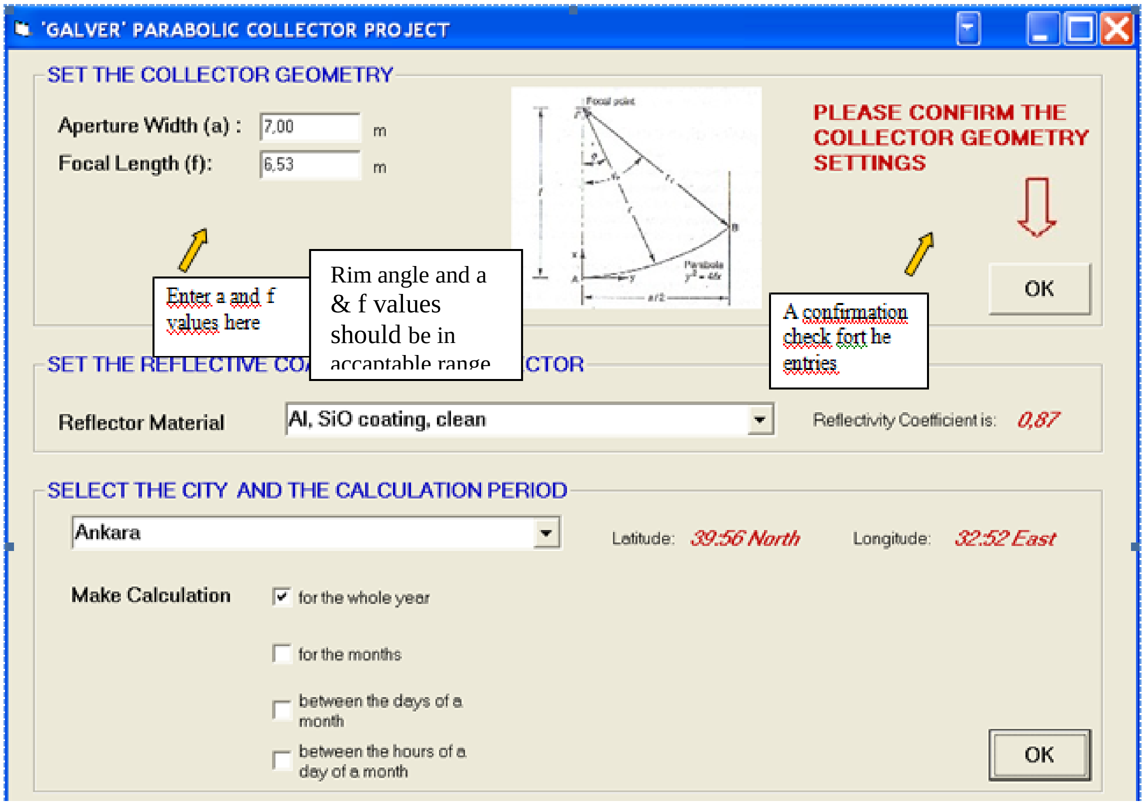

Figure A.1 Design Parameters of Parabolic Trough Collector Field

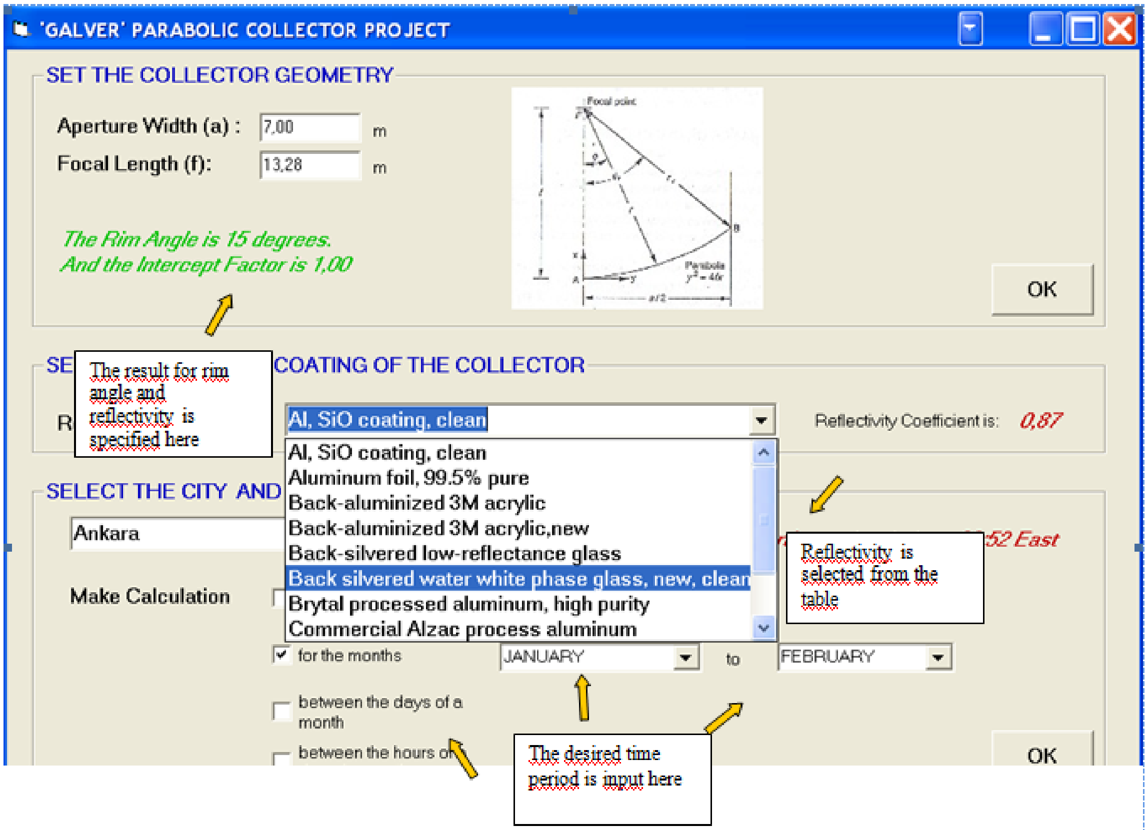

Figure A.2 Selection of City, Months and Coating of the Collector

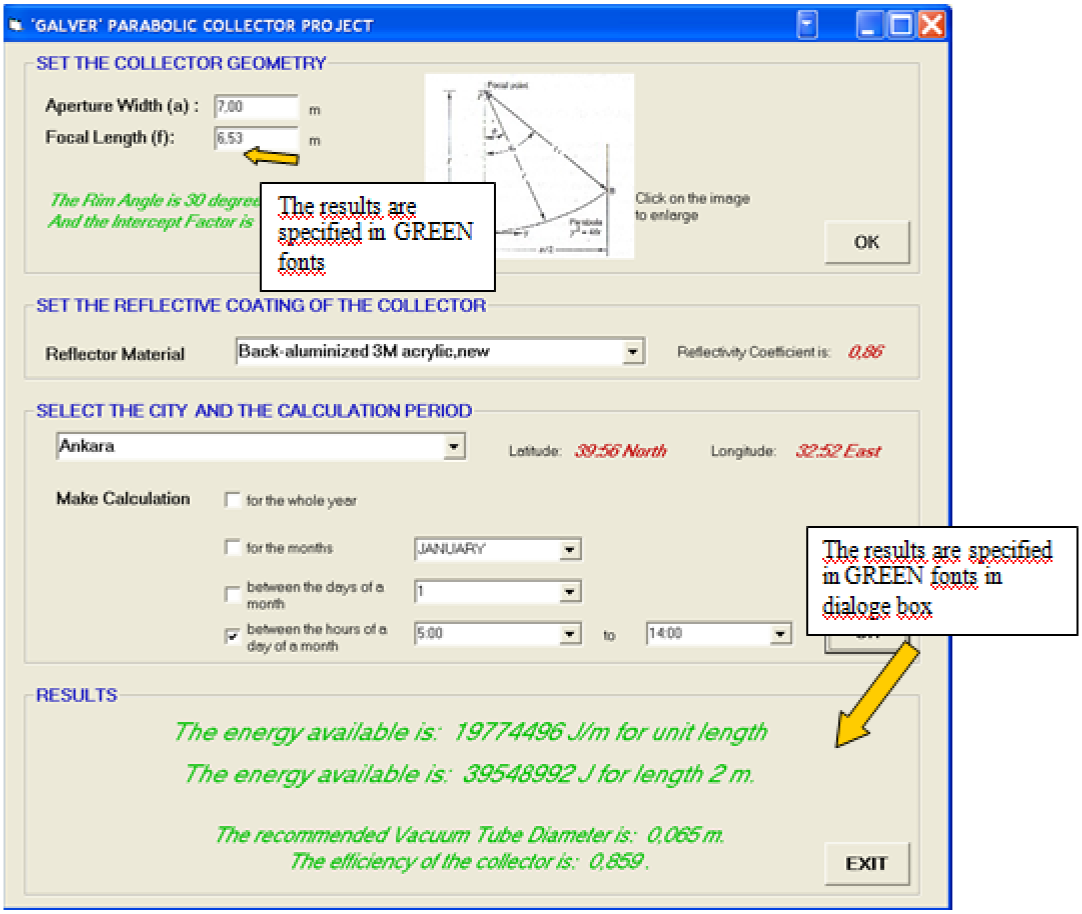

Figure A.3 Result Window

The second part of the program design calculates efficiency, outlet temperature of the fluid, and heat losses of the vacuum tube. The user can change the values assigned in these boxes. In the output section of the program, energy obtained from the tube, energy loss, outlet temperature of the fluid and efficiency of the tube are given.

In addition to all explained features of the program above, there are some safety margins. These margins enable the user to use the program within some definite and reasonable limits. Also possible errors due to unrealistic inputs are avoided. Moreover with the help of the warnings in the program, it is much easier to utilize the program. Firstly, if the users attempts to execute the program without entering one of the parameters in the inputs section, the program warns the user by providing the error message below shown in Figure A.4 (the message changes according to the parameter that is not defined).

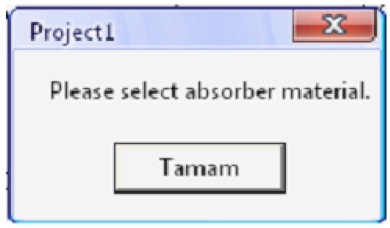

Figure A. 4 Error Message

Secondly, the program is designed to serve a list of fluids. The fluids are assumed to operate in the liquid form. Thus the phase changes and the heat transfer in two phases are excluded. With this respect, if the energy of the system is high enough to change the phase of the given fluid, the program warns the user and asks him for defining new parameters. The error message related to this option is given below in Figure A.5:

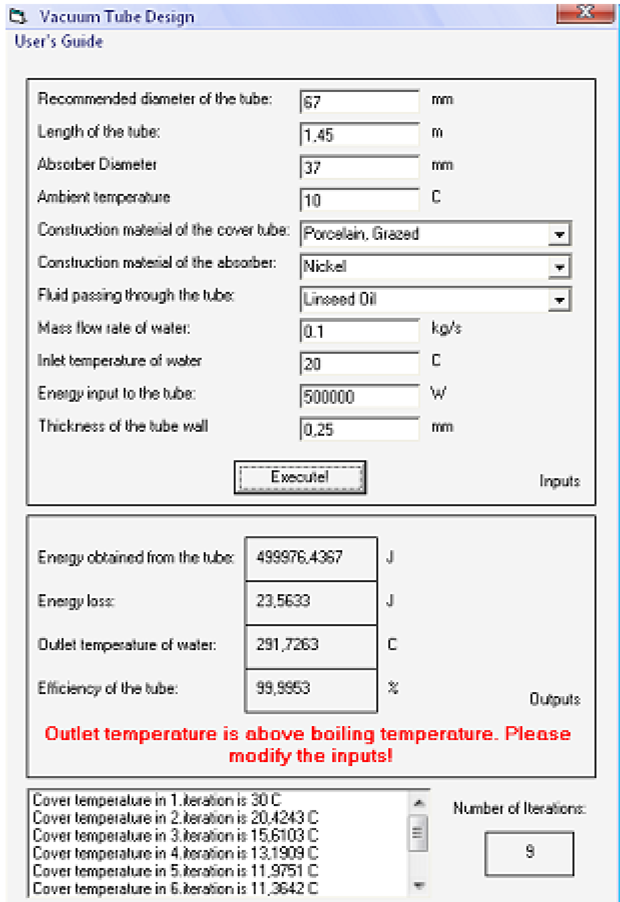

Figure A. 5 Vacuum Tube Datas

Another important limit check is about the diameter of the tube and the absorber diameter. Since it is not geometrically possible that the absorber diameter is greater than the tube diameter, when the user defines wrong values in these boxes, the program warns the user with the following error message shown in Figure A.6:

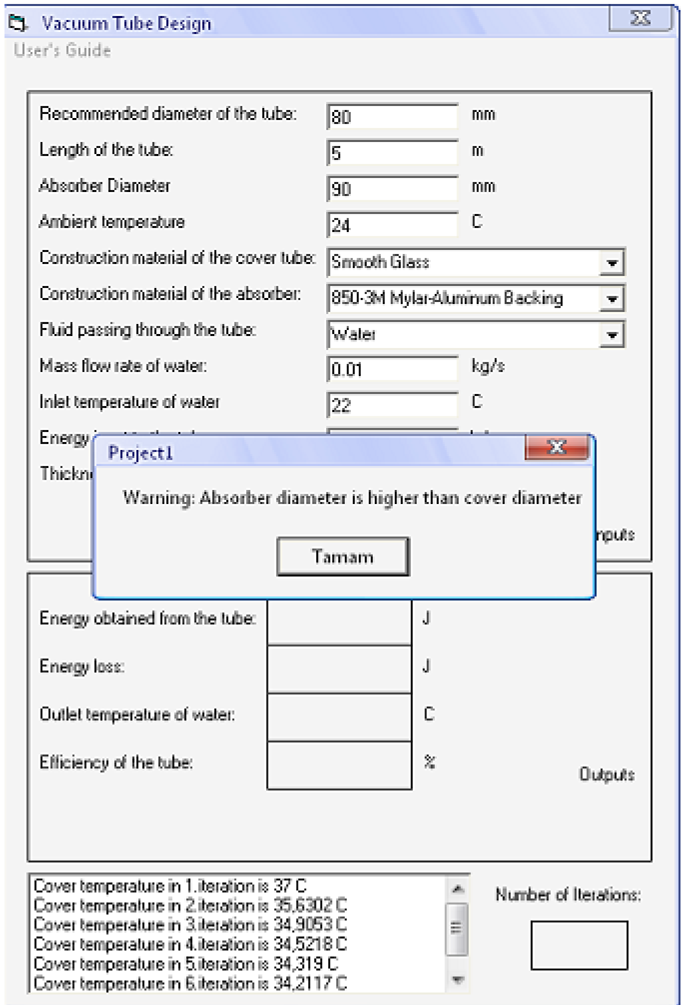

Figure A.6 Chosing Absorber Diameter

The last limit check is about the efficiency of the program. In some circumstances of low energy input, the energy output may be very small. Because of the assumptions used in the calculations, the calculated efficiency may be very small. In these types of circumstances, the program warns the user and prompts him to enter more reasonable values.

APPENDIX B

TMY2 DATA AND FORMAT

For each location, a TMY2 file contains values for one year of hourly solar radiation, illuminance, and meteorological data. The file header contains the, city, state, time zone, latitude, longitude, and elevation. The location and description of these header elements are given in Table 3-1. Each hourly record begins with the year from which the typical month was chosen, followed by the month, day, and hour information in field positions [36].

```
14944 SIOUX_FALLS              SD  -6 N 43 34 W  96 44   435
85010101000000000000?00000?00000?00000?00000?00000?00000?010A710A7-150A7-211A7060A70975A7360A7052A70161A700945A70999099999004E7050F8000A700E7
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85010122000000000000?00000?00000?00000?00000?00000?00000?000A700A7-183A7-239A7062A70977A7220A7021A70241A777777A70999999999003E7050F8000A700E7
85010123000000000000?00000?00000?00000?00000?00000?00000?000A700A7-178A7-239A7059A70977A7220A7015A70241A777777A70999999999003E7050F8000A700E7
85010124000000000000?00000?00000?00000?00000?00000?00000?000A700A7-178A7-239A7059A70977A7240A7010A70241A777777A70999999999003E7050F8000A700E7

                                                                                                   1         1         1         1         1
         1         2         3         4         5         6         7         8         9         0         1         2         3         4
.2345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012
                                        (for field position identification only)
```

Figure B. 1 Sample file header and data in the TMY2 format for January 1[36]

Table B. 1 Header Elements in the TMY2 Format[36]

Field Position	Element	Definition
002 - 006	WBAN Number	Station's Weather Bureau Army Navy number (see Table 2-1)
008 - 029	City	City where the station is located (maximum of 22 characters)
031 - 032	State	State where the station is located (abbreviated to two letters)
034 - 036	Time Zone	Time zone is the number of hours by which the local standard time is ahead of or behind Universal Time. For example, Mountain Standard Time is designated -7 because it is 7 hours behind Universal Time
038 - 044 038 040 - 041 043 - 044	Latitude	Latitude of the station N = North of equator Degrees Minutes
046 - 053 046 048 - 050 052 - 053	Longitude	Longitude of the station W = West, E = East Degrees Minutes
056 - 059	Elevation	Elevation of station in meters above sea level
FORTRAN Sample Format (1X,A5,1X,A22,1X,A2,1X,I3,1X,A1,1X,I2,1X,I2,1X,A1,1X,I3,1X,I2,2X,I4) C Sample Format: (%s %s %s %d %s %d %d %s %d %d %d)		

Table B. 2 Data Elements in the TMY2 Format[36]

Field Position	Element	Values	Definition
002 - 009 002 - 003 004 - 005 006 - 007 008 - 009	Local Standard Time Year Month Day Hour	 61 - 90 1 - 12 1 - 31 1 - 24	 Year, 1961-1990 Month Day of month Hour of day in local standard time
010 - 013	Extraterrestrial Horizontal Radiation	0 - 1415	Amount of solar radiation in Wh/m² received on a horizontal surface at the top of the atmosphere during the60 minutes preceding the hour indicated
014 - 017	Extraterrestrial Direct Normal Radiation	0 - 1415	Amount of solar radiation in Wh/m² received on a surface normal to the sun at the top of the atmosphere during the60 minutes preceding the hour indicated
018 - 023 018 - 021 022 023	Global Horizontal Radiation Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 1200 A - H, ? 0 - 9	Total amount of direct and diffuse solar radiation in Wh/m² received on a horizontal surface during the60 minutes preceding the hour indicated
024 - 029 024 - 027 028 029	Direct Normal Radiation Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 1100 A - H, ? 0 - 9	Amount of solar radiation in Wh/m² received within a 5.7° field of view centered on the sun during the60 minutes preceding the hour indicated

Table B. 3 Data Elements in the TMY2 Format (Continued)

Field Position	Element	Values	Definition
030 - 035 030 - 033 034 035	Diffuse Horizontal Radiation Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 700 A - H, ? 0 - 9	Amount of solar radiation in Wh/m^2 received from the sky (excluding the solar disk) on a horizontal surface during the 60 minutes preceding the hour indicated
036 - 041 036 - 039 040 041	Global Horiz. Illuminance Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 1300 I, ? 0 - 9	Average total amount of direct and diffuse illuminance in hundreds of lux received on a horizontal surface during the 60 minutes preceding the hour indicated. 0 to 1300 = 0 to 130,000 lux
042 - 047 042 - 045 046 047	Direct Normal Illuminance Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 1100 I, ? 0 - 9	Average amount of direct normal illuminance in hundreds of lux received within a 5.7 degree field of view centered on the sun during the 60 minutes preceding the hour indicated. 0 to 1100 = 0 to 110,000 lux
048 - 053 048 - 051 052 053	Diffuse Horiz. Illuminance Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 800 I, ? 0 - 9	Average amount of illuminance in hundreds of lux received from the sky (excluding the solar disk) on a horizontal surface during the 60 minutes preceding the hour indicated. 0 to 800 = 0 to 80,000 lux
054 - 059 054 - 057 058 059	Zenith Luminance Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 7000 I, ? 0 - 9	Average amount of luminance at the sky's zenith in tens of Cd/m^2 during the 60 minutes preceding the hour indicated. 0 to 7000 = 0 to 70,000 Cd/m^2
060 - 063 060 - 061 062 063	Total Sky Cover Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 10 A - F 0 - 9	Amount of sky dome in tenths covered by clouds or obscuring phenomena at the hour indicated
064 - 067 064 - 065 066 067	Opaque Sky Cover Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 10 A - F 0 - 9	Amount of sky dome in tenths covered by clouds or obscuring phenomena that prevent observing the sky or higher cloud layers at the hour indicated
068 - 073 068 - 071 072 073	Dry Bulb Temperature Data Value Flag for Data Source Flag for Data Uncertainty	 -500 to 500 A - F 0 - 9	Dry bulb temperature in tenths of degrees C at the hour indicated. -500 to 500 = -50.0 to 50.0 degrees C
074 - 079 074 - 077 078 079	Dew Point Temperature Data Value Flag for Data Source Flag for Data Uncertainty	 -600 to 300 A - F 0 - 9	Dew point temperature in tenths of degrees C at the hour indicated. -600 to 300 = -60.0 to 30.0 degrees C
080 - 084 080 - 082 083 084	Relative Humidity Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 100 A - F 0 - 9	Relative humidity in percent at the hour indicated

APPENDIX C

SAMPLE TRNSYS INPUT (DECK) FILE

VERSION 16.1

****

****

*** TRNSYS input file (deck) generated by TrnsysStudio

***

*** If you edit this file, use the File/Import TRNSYS Input File function in

*** TrnsysStudio to update the project.

***

*** If you have problems, questions or suggestions please contact your local

*** TRNSYS distributor or mailto:software@cstb.fr

***

****

****

****

****

*** Units

****

****

****

****

```
*** Control cards
***************************************************************************
****
* START, STOP and STEP
CONSTANTS 3
START=4751
STOP=4774
STEP=1
* User defined CONSTANTS

SIMULATION      START      STOP  STEP ! Start time    End time     Time step
TOLERANCES 0.001 0.001               ! Integration   Convergence
LIMITS 30 30 30                      ! Max iterations      Max warnings Trace limit
DFQ 1                              ! TRNSYS numerical integration solver method
WIDTH 80                           ! TRNSYS output file width, number of characters
LIST                               ! NOLIST statement
                                   ! MAP statement
SOLVER 0 1 1                         ! Solver statement    Minimum relaxation factor
        Maximum relaxation factor
NAN_CHECK 0                          ! Nan DEBUG statement
OVERWRITE_CHECK 0                    ! Overwrite DEBUG statement
TIME_REPORT 0                      ! disable time report
EQSOLVER 0                           ! EQUATION SOLVER statement

* Model "Superheater" (Type 315)
*

UNIT 2 TYPE 315    Superheater
*$UNIT_NAME Superheater
*$MODEL .\STEC Library\Rankine\Steamgen\Eco_sh.tmf
*$POSITION 115 247
```

```
*$LAYER Main #
PARAMETERS 6
2                    ! 1 Counter flow mode
1051199.972153                    ! 2 Overall heat transfer coefficient of exchanger
0                    ! 3 Reference press loss cold side
139836.593628                    ! 4 Reference cold side flow
0                    ! 5 power law exp for UA
0                    ! 6 power law exp for DP
INPUTS 7
0,0                  ! [unconnected] Hot side inlet temperature
34,3                 ! Splitter:outlet flow rate 2 ->Hot side flow rate
3,3                  ! Evaporator(steam generator):Cold side outlet temperature ->Cold side inlet
temperature
3,7                  ! Evaporator(steam generator):Cold side outlet flow rate ->Cold side flow rate
3,5                  ! Evaporator(steam generator):Cold side outlet quality ->Cold side quality
33,2                 ! X2H2:steam pressure ->cold side outlet pressure
0,0                  ! [unconnected] hot side spedific heat
*** INITIAL INPUT VALUES
390.56 1427039.978027 313.89 140288.406372 1 100 2.59
*------------------------------------------------------------------------------

* Model "Evaporator(steam generator)" (Type 316)
*

UNIT 3 TYPE 316      Evaporator(steam generator)
*$UNIT_NAME Evaporator(steam generator)
*$MODEL .\STEC Library\Rankine\Steamgen\Evaporator.tmf
*$POSITION 116 345
*$LAYER Main #
PARAMETERS 6
7383599.804401                    ! 1 overall heat transfer factor
0.0                  ! 2 blowdown fraction
```

0 ! 3 reference pressure loss
139836.593628 ! 4 reference flow rate
0 ! 5 power lax exp for UA
0 ! 6 power law exp for dp
INPUTS 6
2,1 ! Superheater:Hot-side outlet temperature ->Hot side inlet temperature
2,2 ! Superheater:Hot-side flow rate ->Hot side flow rate
4,3 ! Economizer(preheater):Cold-side outlet temperature ->Cold side inlet temperature
2,8 ! Superheater:Cold Side Inlet pressure ->Cold side outlet pressure
4,7 ! Economizer(preheater):Cold side Outlet quality ->Cold side inlet quality
0,0 ! [unconnected] Hot side specific heat capacity
*** INITIAL INPUT VALUES
377.22 1243763.964844 313.89 103.42 0.0 2.54
*--

* Model "Economizer(preheater)" (Type 315)
*

UNIT 4 TYPE 315 Economizer(preheater)
*$UNIT_NAME Economizer(preheater)
*$MODEL .\STEC Library\Rankine\Steamgen\Eco_sh.tmf
*$POSITION 110 449
*$LAYER Main #
PARAMETERS 6
2 ! 1 Counter flow mode
175708.795345 ! 2 Overall heat transfer coefficient of exchanger
0 ! 3 Reference press loss cold side
140288.406372 ! 4 Reference cold side flow
0 ! 5 power law exp for UA
0 ! 6 power law exp for DP
INPUTS 7

3,1 ! Evaporator(steam generator):Hot side outlet temperture ->Hot side inlet temperature
3,2 ! Evaporator(steam generator):Hot side outlet flow rate ->Hot side flow rate
28,2 ! FWH 5:Cold side outlet temperture ->Cold side inlet temperature
28,3 ! FWH 5:Cold side outlet flow rate ->Cold side flow rate
0,0 ! [unconnected] Cold side quality
3,4 ! Evaporator(steam generator):Cold side inlet pressure ->cold side outlet pressure
0,0 ! [unconnected] hot side spedific heat
*** INITIAL INPUT VALUES
317.78 1243763.964844 234.83 140288.406372 0.0 103.42 2.36
*---

* Model "hp stage 1" (Type 318)
*

UNIT 5 TYPE 318 hp stage 1
*$UNIT_NAME hp stage 1
*$MODEL .\STEC Library\Rankine\Turbine\Stage.tmf
*$POSITION 174 368
*$LAYER Main #
PARAMETERS 8
100 ! 1 design inlet pressure
33.61 ! 2 design outlet pressure
139109.394836 ! 3 design flow rate
0.8376 ! 4 design inner efficiency
0.95 ! 5 generator efficiency
0.0 ! 6 coef. for inner eff eq
0.0 ! 7 b coeff for inner eff
0.0 ! 8 c coeff for inner eff
INPUTS 4
8,4 ! S-split-1:inlet pressure ->Turbine outlet pressure

```
33,3            ! X2H2:steam flow rate ->Turbine inlet flow rate
33,1            ! X2H2:steam enthalpy ->Turbine inlet enthalpy
0,0             ! [unconnected] Bypass indicator
*** INITIAL INPUT VALUES
33.61 139109.394836 3005 1
*-------------------------------------------------------------------------------

* Model "hp stage 2" (Type 318)
*

UNIT 6 TYPE 318     hp stage 2
*$UNIT_NAME hp stage 2
*$MODEL .\STEC Library\Rankine\Turbine\Stage.tmf
*$POSITION 420 368
*$LAYER Main #
PARAMETERS 8
33.61           ! 1 design inlet pressure
18.58           ! 2 design outlet pressure
128637.364197                   ! 3 design flow rate
0.8463          ! 4 design inner efficiency
0.95            ! 5 generator efficiency
0.0             ! 6 coef. for inner eff eq
0.0             ! 7 b coeff for inner eff
0.0             ! 8 c coeff for inner eff
INPUTS 4
7,4             ! S-split-2:inlet pressure  ->Turbine outlet pressure
8,3             ! S-split-1:outlet flow rate 2 ->Turbine inlet flow rate
8,6             ! S-split-1:outlet enthalpy 2 ->Turbine inlet enthalpy
0,0             ! [unconnected] Bypass indicator
*** INITIAL INPUT VALUES
18.58 128637.364197 2807 1
*-------------------------------------------------------------------------------
```

```
* Model "S-split-2" (Type 389)
*

UNIT 7 TYPE 389     S-split-2
*$UNIT_NAME S-split-2
*$MODEL .\STEC Library\Rankine\Turbine\S-split.tmf
*$POSITION 544 368
*$LAYER Main #
INPUTS 4
27,1            ! FWH4:Demanded hot inlet flow rate ->Demanded Flow Out 1
6,2             ! hp stage 2:turbine outlet flowrate ->inlet flow rate
9,8             ! Reheater:Cold Side Inlet pressure ->outlet pressure 2
6,3             ! hp stage 2:turbine outlet enthalpy ->inlet enthalpy
*** INITIAL INPUT VALUES
10083.239937 128637.364197 18.58 2807
*------------------------------------------------------------------------------

* Model "S-split-1" (Type 389)
*

UNIT 8 TYPE 389     S-split-1
*$UNIT_NAME S-split-1
*$MODEL .\STEC Library\Rankine\Turbine\S-split.tmf
*$POSITION 304 368
*$LAYER Main #
INPUTS 4
28,1            ! FWH 5:Demanded hot inlet flow rate ->Demanded Flow Out 1
5,2             ! hp stage 1:turbine outlet flowrate ->inlet flow rate
6,1             ! hp stage 2:turbine inlet pressure ->outlet pressure 2
5,3             ! hp stage 1:turbine outlet enthalpy ->inlet enthalpy
*** INITIAL INPUT VALUES
```

```
10551.95961 139109.394836 33.61 3005
*------------------------------------------------------------------------------

* Model "Reheater" (Type 315)
*

UNIT 9 TYPE 315      Reheater
*$UNIT_NAME Reheater
*$MODEL .\STEC Library\Rankine\Steamgen\Eco_sh.tmf
*$POSITION 619 249
*$LAYER Main #
PARAMETERS 6
2                    ! 1 Counter flow mode
1720799.954414                    ! 2 Overall heat transfer coefficient of exchanger
0                    ! 3 Reference press loss cold side
118929.597473                    ! 4 Reference cold side flow
0                    ! 5 power law exp for UA
0                    ! 6 power law exp for DP
INPUTS 7
0,0                  ! [unconnected] Hot side inlet temperature
34,1                 ! Splitter:outlet flow rate 1 ->Hot side flow rate
0,0                  ! [unconnected] Cold side inlet temperature
7,3                  ! S-split-2:outlet flow rate 2 ->Cold side flow rate
0,0                  ! [unconnected] Cold side quality
37,2                 ! X2H2-2:steam pressure ->cold side outlet pressure
0,0                  ! [unconnected] hot side spedific heat
*** INITIAL INPUT VALUES
390.56 183254.38385 208.67 118929.597473 1 17.10 2.59
*------------------------------------------------------------------------------

* Model "lp stage 1" (Type 318)
*
```

```
UNIT 10 TYPE 318    lp stage 1
*$UNIT_NAME lp stage 1
*$MODEL .\STEC Library\Rankine\Turbine\Stage.tmf
*$POSITION 36 294
*$LAYER Main #
PARAMETERS 8
17.10           ! 1 design inlet pressure
7.98            ! 2 design outlet pressure
118104.483032           ! 3 design flow rate
0.8623          ! 4 design inner efficiency
0.95            ! 5 generator efficiency
0.0             ! 6 coef. for inner eff eq
0.0             ! 7 b coeff for inner eff
0.0             ! 8 c coeff for inner eff
INPUTS 4
15,4            ! lp split 1:inlet pressure  ->Turbine outlet pressure
37,3            ! X2H2-2:steam flow rate ->Turbine inlet flow rate
37,1            ! X2H2-2:steam enthalpy ->Turbine inlet enthalpy
0,0             ! [unconnected] Bypass indicator
*** INITIAL INPUT VALUES
7.98 118104.483032 3190 1
*------------------------------------------------------------------------------

* Model "lp stage 2" (Type 318)
*

UNIT 11 TYPE 318    lp stage 2
*$UNIT_NAME lp stage 2
*$MODEL .\STEC Library\Rankine\Turbine\Stage.tmf
*$POSITION 249 294
*$LAYER Main #
```

```
PARAMETERS 8
7.98            ! 1 design inlet pressure
2.73            ! 2 design outlet pressure
110856.960297           ! 3 design flow rate
0.917           ! 4 design inner efficiency
0.95            ! 5 generator efficiency
0.0             ! 6 coef. for inner eff eq
0.0             ! 7 b coeff for inner eff
0.0             ! 8 c coeff for inner eff
INPUTS 4
16,4            ! lp split 2:inlet pressure  ->Turbine outlet pressure
15,3            ! lp split 1:outlet flow rate 2 ->Turbine inlet flow rate
15,6            ! lp split 1:outlet enthalpy 2 ->Turbine inlet enthalpy
0,0             ! [unconnected] Bypass indicator
*** INITIAL INPUT VALUES
2.73 110856.960297 3016 1
*------------------------------------------------------------------------------

* Model "lp stage 3" (Type 318)
*

UNIT 12 TYPE 318    lp stage 3
*$UNIT_NAME lp stage 3
*$MODEL .\STEC Library\Rankine\Turbine\Stage.tmf
*$POSITION 452 294
*$LAYER Main #
PARAMETERS 8
2.73            ! 1 design inlet pressure
0.96            ! 2 design outlet pressure
104516.640472           ! 3 design flow rate
0.9352          ! 4 design inner efficiency
0.95            ! 5 generator efficiency
```

0.0 ! 6 coef. for inner eff eq
0.0 ! 7 b coeff for inner eff
0.0 ! 8 c coeff for inner eff
INPUTS 4
17,4 ! lp split 3:inlet pressure ->Turbine outlet pressure
16,3 ! lp split 2:outlet flow rate 2 ->Turbine inlet flow rate
16,6 ! lp split 2:outlet enthalpy 2 ->Turbine inlet enthalpy
0,0 ! [unconnected] Bypass indicator
*** INITIAL INPUT VALUES
0.96 104516.640472 2798 1
*--

* Model "lp stage 4." (Type 318)
*

UNIT 13 TYPE 318 lp stage 4.
*$UNIT_NAME lp stage 4.
*$MODEL .\STEC Library\Rankine\Turbine\Stage.tmf
*$POSITION 677 294
*$LAYER Main #
PARAMETERS 8
0.96 ! 1 design inlet pressure
0.29 ! 2 design outlet pressure
98696.880341 ! 3 design flow rate
0.88 ! 4 design inner efficiency
0.95 ! 5 generator efficiency
0.0 ! 6 coef. for inner eff eq
0.0 ! 7 b coeff for inner eff
0.0 ! 8 c coeff for inner eff
INPUTS 4
18,4 ! lp split 4:inlet pressure ->Turbine outlet pressure
17,3 ! lp split 3:outlet flow rate 2 ->Turbine inlet flow rate

```
17,6		! lp split 3:outlet enthalpy 2 ->Turbine inlet enthalpy
0,0		! [unconnected] Bypass indicator
*** INITIAL INPUT VALUES
0.29 98696.880341 2624 1
*------------------------------------------------------------------------------

* Model "lp stage 5" (Type 318)
*

UNIT 14 TYPE 318	 lp stage 5
*$UNIT_NAME lp stage 5
*$MODEL .\STEC Library\Rankine\Turbine\Stage.tmf
*$POSITION 879 294
*$LAYER Main #
PARAMETERS 8
0.29		! 1 design inlet pressure
0.08		! 2 design outlet pressure
95802.106476		! 3 design flow rate
0.6445		! 4 design inner efficiency
0.95		! 5 generator efficiency
0.0		! 6 coef. for inner eff eq
0.0		! 7 b coeff for inner eff
0.0		! 8 c coeff for inner eff
INPUTS 4
19,2		! Condenser:Condensing pressure ->Turbine outlet pressure
18,3		! lp split 4:outlet flow rate 2 ->Turbine inlet flow rate
18,6		! lp split 4:outlet enthalpy 2 ->Turbine inlet enthalpy
0,0		! [unconnected] Bypass indicator
*** INITIAL INPUT VALUES
0.08 95802.113342 2325 1
*------------------------------------------------------------------------------
```

```
* Model "lp split 1" (Type 389)
*

UNIT 15 TYPE 389    lp split 1
*$UNIT_NAME lp split 1
*$MODEL .\STEC Library\Rankine\Turbine\S-split.tmf
*$POSITION 150 294
*$LAYER Main #
INPUTS 4
22,2          ! Deaerator:required steam flow rate ->Demanded Flow Out 1
10,2          ! lp stage 1:turbine outlet flowrate ->inlet flow rate
11,1          ! lp stage 2:turbine inlet pressure ->outlet pressure 2
10,3          ! lp stage 1:turbine outlet enthalpy ->inlet enthalpy
*** INITIAL INPUT VALUES
7307.999897 118104.483032 7.97 3190
*------------------------------------------------------------------------------

* Model "lp split 2" (Type 389)
*

UNIT 16 TYPE 389    lp split 2
*$UNIT_NAME lp split 2
*$MODEL .\STEC Library\Rankine\Turbine\S-split.tmf
*$POSITION 342 294
*$LAYER Main #
INPUTS 4
26,1          ! FWH3:Demanded hot inlet flow rate ->Demanded Flow Out 1
11,2          ! lp stage 2:turbine outlet flowrate ->inlet flow rate
12,1          ! lp stage 3:turbine inlet pressure ->outlet pressure 2
11,3          ! lp stage 2:turbine outlet enthalpy ->inlet enthalpy
*** INITIAL INPUT VALUES
6335.999966 110856.960297 2.72 3016
```

```
*-------------------------------------------------------------------------------

* Model "lp split 3" (Type 389)
*

UNIT 17 TYPE 389    lp split 3
*$UNIT_NAME lp split 3
*$MODEL .\STEC Library\Rankine\Turbine\S-split.tmf
*$POSITION 566 294
*$LAYER Main #
INPUTS 4
25,1            ! FWH2:Demanded hot inlet flow rate ->Demanded Flow Out 1
12,2            ! lp stage 3:turbine outlet flowrate ->inlet flow rate
13,1            ! lp stage 4.:turbine inlet pressure ->outlet pressure 2
12,3            ! lp stage 3:turbine outlet enthalpy ->inlet enthalpy
*** INITIAL INPUT VALUES
5832.000017 104516.640472 0.96 2798
*-------------------------------------------------------------------------------

* Model "lp split 4" (Type 389)
*

UNIT 18 TYPE 389    lp split 4
*$UNIT_NAME lp split 4
*$MODEL .\STEC Library\Rankine\Turbine\S-split.tmf
*$POSITION 780 294
*$LAYER Main #
INPUTS 4
24,1            ! FWH1:Demanded hot inlet flow rate ->Demanded Flow Out 1
13,2            ! lp stage 4.:turbine outlet flowrate ->inlet flow rate
14,1            ! lp stage 5:turbine inlet pressure ->outlet pressure 2
13,3            ! lp stage 4.:turbine outlet enthalpy ->inlet enthalpy
```

```
*** INITIAL INPUT VALUES
2844.000077 98696.880341 0.28 2624
*---------------------------------------------------------------------------

* Model "Condenser" (Type 383)
*

UNIT 19 TYPE 383    Condenser
*$UNIT_NAME Condenser
*$MODEL .\STEC Library\Rankine\Condenser\Condens.tmf
*$POSITION 930 249
*$LAYER Main #
PARAMETERS 2
5.0              ! 1 dT Cool water out+condensing temp
5.0              ! 2 temp increase in cool. water
INPUTS 6
0,0              ! [unconnected] Cooling water inlet temp
14,3             ! lp stage 5:turbine outlet enthalpy ->steam enthalpy inlet
14,2             ! lp stage 5:turbine outlet flowrate ->steam mass flow rate
24,5             ! FWH1:Hot side outlet flow rate ->Condensate inlet flow rate
0,0              ! [unconnected] Condensate inlet temperture
24,6             ! FWH1:Hot side outlet quality ->Condensate inlet quality
*** INITIAL INPUT VALUES
25.5 2348.1 26.482001 16153.560448 52.889 0
*---------------------------------------------------------------------------

* Model "Condensate Pump" (Type 300)
*

UNIT 20 TYPE 300    Condensate Pump
*$UNIT_NAME Condensate Pump
*$MODEL .\STEC Library\Ste\Utility\Saltpu_1.tmf
```

```
*$POSITION 940 378
*$LAYER Main #
PARAMETERS 5
111488.399506                    ! 1 Maximum flow rate
4.19              ! 2 Fluid specific heat
683999.98188           ! 3 Maximum power
0.0               ! 4 Conversion coefficient
0.5               ! 5 Power coefficient
INPUTS 3
19,1              ! Condenser:Condesing Temperature ->Inlet fluid temperature
19,6              ! Condenser:Condesate flow rate ->Inlet mass flow rate
0,0               ! [unconnected] desired mass flow rate
*** INITIAL INPUT VALUES
41.439 111488.399506 111488.399506
*------------------------------------------------------------------------------

* Model "FW pump" (Type 300)
*

UNIT 21 TYPE 300    FW pump
*$UNIT_NAME FW pump
*$MODEL .\STEC Library\Ste\Utility\Saltpu_1.tmf
*$POSITION 519 474
*$LAYER Main #
PARAMETERS 5
140288.406372                    ! 1 Maximum flow rate
4.19              ! 2 Fluid specific heat
3167999.916077                   ! 3 Maximum power
0.0               ! 4 Conversion coefficient
0.5               ! 5 Power coefficient
INPUTS 3
22,1              ! Deaerator:Feed water out temp ->Inlet fluid temperature
```

```
22,3               ! Deaerator:Feed Water out flow rate ->Inlet mass flow rate
3,6                ! Evaporator(steam generator):Cold side flow rate demand ->desired mass flow
rate
*** INITIAL INPUT VALUES
166.89 140288.406372 140288.406372
*------------------------------------------------------------------------------

* Model "Deaerator" (Type 384)
*

UNIT 22 TYPE 384    Deaerator
*$UNIT_NAME Deaerator
*$MODEL .\STEC Library\Rankine\preheating\Deaerator.tmf
*$POSITION 623 473
*$LAYER Main #
INPUTS 8
26,2               ! FWH3:Cold  side outlet temperture ->Feed Water in tmp
26,3               ! FWH3:Cold side outlet flow rate ->Feed Water flow rate
15,5               ! lp split 1:outlet enthalpy 1 ->steam inlet enthalpy
15,2               ! lp split 1: outlet  pressure 1 ->steam inlet pressure
0,0                ! [unconnected] condesate inlet temperture
27,5               ! FWH4:Hot side outlet flow rate ->Condesate inlet flow rate
27,6               ! FWH4:Hot side outlet quality ->Condensate inlet quality
0,0                ! [unconnected] Dearator on/off
*** INITIAL INPUT VALUES
126.72 111722.401428 3029.4 7.33 179.17 20628.000069 0.0 1.0
*------------------------------------------------------------------------------

* Model "FWH1" (Type 317)
*

UNIT 24 TYPE 317    FWH1
```

```
*$UNIT_NAME FWH1
*$MODEL .\STEC Library\Rankine\preheating\Preheater.tmf
*$POSITION 939 473
*$LAYER Main #
PARAMETERS 4
4.18            ! 1 cold fluid spef. heat capacity
1644332.35644               ! 2 overall heat transfer factor
111708.002472               ! 3 cold sid ref flow rate
0               ! 4 power law exp for UA
INPUTS 8
18,5            ! lp split 4:outlet enthalpy 1 ->Hot side inlet enthalpy
18,2            ! lp split 4: outlet  pressure 1 ->Hot side inlet pressure
20,1            ! Condensate Pump:Outlet fluid temperature ->Cold side inlet temperature
20,2            ! Condensate Pump:Outlet flow rate ->Cold side inlet flow rate
0,0             ! [unconnected] Condensate inlet temperature
25,5            ! FWH2:Hot side outlet flow rate ->Condensate inlet flow rate
25,6            ! FWH2:Hot side outlet quality ->Condensate inlet quality
0,0             ! [unconnected] on/off
*** INITIAL INPUT VALUES
2528.1 0.2797 41.61 111708.002472 74.722 12200.760269 0 1
*------------------------------------------------------------------------------

* Model "FWH2" (Type 317)
*

UNIT 25 TYPE 317    FWH2
*$UNIT_NAME FWH2
*$MODEL .\STEC Library\Rankine\preheating\Preheater.tmf
*$POSITION 814 473
*$LAYER Main #
PARAMETERS 4
4.18            ! 1 cold fluid spef. heat capacity
```

```
2312341.100418                  ! 2 overall heat transfer factor
111708.002472                   ! 3 cold sid ref flow rate
0                ! 4 power law exp for UA
INPUTS 8
17,5             ! lp split 3:outlet enthalpy 1 ->Hot side inlet enthalpy
17,2             ! lp split 3: outlet  pressure 1 ->Hot side inlet pressure
24,2             ! FWH1:Cold  side outlet temperture ->Cold side inlet temperature
24,3             ! FWH1:Cold side outlet flow rate ->Cold side inlet flow rate
0,0              ! [unconnected] Condensate inlet temperature
26,5             ! FWH3:Hot side outlet flow rate ->Condensate inlet flow rate
26,6             ! FWH3:Hot side outlet quality ->Condensate inlet quality
0,0              ! [unconnected] on/off
*** INITIAL INPUT VALUES
2624.4 0.9625 64.722 111708.002472 105.06 6367.320013 0 1
*------------------------------------------------------------------------------

* Model "FWH3" (Type 317)
*

UNIT 26 TYPE 317    FWH3
*$UNIT_NAME FWH3
*$MODEL .\STEC Library\Rankine\preheating\Preheater.tmf
*$POSITION 712 475
*$LAYER Main #
PARAMETERS 4
4.21             ! 1 cold fluid spef. heat capacity
690184.837966                   ! 2 overall heat transfer factor
111708.002472                   ! 3 cold sid ref flow rate
0                ! 4 power law exp for UA
INPUTS 8
16,5             ! lp split 2:outlet enthalpy 1 ->Hot side inlet enthalpy
16,2             ! lp split 2: outlet  pressure 1 ->Hot side inlet pressure
```

```
25,2		! FWH2:Cold  side outlet temperture ->Cold side inlet temperature
25,3		! FWH2:Cold side outlet flow rate ->Cold side inlet flow rate
0,0		! [unconnected] Condensate inlet temperature
0,0		! [unconnected] Condensate inlet flow rate
0,0		! [unconnected] Condensate inlet quality
0,0		! [unconnected] on/off
*** INITIAL INPUT VALUES
2798.2 2.7276 95.111 111708.002472 105.06 0 0 1
*------------------------------------------------------------------------------

* Model "FWH4" (Type 317)
*

UNIT 27 TYPE 317	FWH4
*$UNIT_NAME FWH4
*$MODEL .\STEC Library\Rankine\preheating\Preheater.tmf
*$POSITION 392 473
*$LAYER Main #
PARAMETERS 4
4.38		! 1 cold fluid spef. heat capacity
3023466.894905		! 2 overall heat transfer factor
140288.406372		! 3 cold sid ref flow rate
0		! 4 power law exp for UA
INPUTS 8
7,5		! S-split-2:outlet enthalpy 1 ->Hot side inlet enthalpy
7,4		! S-split-2:inlet pressure  ->Hot side inlet pressure
21,1		! FW pump:Outlet fluid temperature ->Cold side inlet temperature
21,2		! FW pump:Outlet flow rate ->Cold side inlet flow rate
0,0		! [unconnected] Condensate inlet temperature
28,5		! FWH 5:Hot side outlet flow rate ->Condensate inlet flow rate
28,6		! FWH 5:Hot side outlet quality ->Condensate inlet quality
0,0		! [unconnected] on/off
```

```
*** INITIAL INPUT VALUES
2709.6 18.581 169.22 140288.406372 213.67 10551.95961 0 1
*---------------------------------------------------------------------------

* Model "FWH 5" (Type 317)
*

UNIT 28 TYPE 317    FWH 5
*$UNIT_NAME FWH 5
*$MODEL .\STEC Library\Rankine\preheating\Preheater.tmf
*$POSITION 296 473
*$LAYER Main #
PARAMETERS 4
4.51                ! 1 cold fluid spef. heat capacity
2387213.93676                  ! 2 overall heat transfer factor
140288.406372                  ! 3 cold sid ref flow rate
0                   ! 4 power law exp for UA
INPUTS 8
8,5                 ! S-split-1:outlet enthalpy 1 ->Hot side inlet enthalpy
8,2                 ! S-split-1: outlet  pressure 1 ->Hot side inlet pressure
27,2                ! FWH4:Cold  side outlet temperture ->Cold side inlet temperature
27,3                ! FWH4:Cold side outlet flow rate ->Cold side inlet flow rate
0,0                 ! [unconnected] Condensate inlet temperature
0,0                 ! [unconnected] Condensate inlet flow rate
0,0                 ! [unconnected] Condensate inlet quality
0,0                 ! [unconnected] on/off
*** INITIAL INPUT VALUES
2807 33.612 203.61 140288.406372 213.67 0 0 1
*---------------------------------------------------------------------------

* Model "Trough-2" (Type 396)
*
```

```
UNIT 29 TYPE 396    Trough-2
*$UNIT_NAME Trough-2
*$MODEL .\STEC Library\STE\Trough\Trough.tmf
*$POSITION 462 59
*$LAYER Main #
PARAMETERS 22
73.6            ! 1 A - Loss coef.
-0.0042                 ! 2 B - Loss coef.
7.40            ! 3 C - Loss coef.
0               ! 4 Cw- Loss coef.
-0.096          ! 5 D - Loss coef.
0.94            ! 6 Clean Reflectivity
0.0             ! 7 Broken Mirror Fraction
47              ! 8 Length of SCA
5               ! 9 Aperature Width of SCA
5               ! 10 Focal Length of SCA
15              ! 11 Rowspacing
182000                  ! 12 Total Field Area
5759999.847412          ! 13 Pump Max Power
1427039.978027          ! 14 Pump Max Flow Rate
1.308           ! 15 Pump Power Coeff. 1
4.28E-3                 ! 16 Pump Power Coeff. 2
1.99E-5                 ! 17 Pump Power Coeff. 3
0               ! 18 Tank Heat Loss Rate at 275 C
20              ! 19 Piping Heat Loss/Area at 343C
0.86            ! 20 Field Tracking Parasitics/Area
11250           ! 21 Stow Energy for Each m2 Field Area
5               ! 22 Wind Speed Limit for Tracking
INPUTS 14
0,0             ! [unconnected] Demanded Outlet Temperature
36,1            ! HTF Pump:Outlet fluid temperature ->Inlet Temperature Solar Field
```

```
0,0             ! [unconnected] Cleanliness Solar Field
0,0             ! [unconnected] Specific Heat HTF
32,11           ! Weather Data:solar azimuth angle ->Sun Azimuth
32,10           ! Weather Data:solar zenith angle ->Sun Zenith
32,19           ! Weather Data:beam radiation on tilted surface ->DNI- Direct Normal
Radiation
32,3            ! Weather Data:wind velocity ->Wind Speed
32,1            ! Weather Data:Ambient temperature ->Ambient Temperature
0,0             ! [unconnected] Tracking Fraction of Field
0,0             ! [unconnected] Available Fraction of Field
0,0             ! [unconnected] Night Flow Ratio (min Flow)
0,0             ! [unconnected] Rampdown Time
0,0             ! [unconnected] Rampdown Ratio
*** INITIAL INPUT VALUES
390.56 297.78 0.95 2.59 0 0 900 0 30 1.0 1.0 0.1 1 1
*------------------------------------------------------------------------------

* Model "Expansion Vessel" (Type 4)
*

UNIT 30 TYPE 4      Expansion Vessel
*$UNIT_NAME Expansion Vessel
*$MODEL .\Thermal Storage\Stratified Storage Tank\Fixed Inlets\Uniform
Losses\Type4a.tmf
*$POSITION 632 61
*$LAYER Main #
PARAMETERS 20
1               ! 1 Fixed inlet positions
287             ! 2 Tank volume
2.59            ! 3 Fluid specific heat
704             ! 4 Fluid density
0               ! 5 Tank loss coefficient
```

```
0.05            ! 6 Height of node
1               ! 7 Auxiliary heater mode
1               ! 8 Node containing heating element 1
1               ! 9 Node containing thermostat 1
0               ! 10 Set point temperature for element 1
5.0             ! 11 Deadband for heating element 1
16200.0                 ! 12 Maximum heating rate of element 1
1               ! 13 Node containing heating element 2
1               ! 14 Node containing thermostat 2
0               ! 15 Set point temperature for element 2
5.0             ! 16 Deadband for heating element 2
16200           ! 17 Maximum heating rate of element 2
0.0             ! 18 Not used (Flue UA)
20.0            ! 19 Not used (Tflue)
257             ! 20 Boiling point
INPUTS 7
29,2            ! Trough-2:Outlet Temperature Solar Field ->Hot-side temperature
29,1            ! Trough-2:Flow Rate Solar Field ->Hot-side flowrate
0,0             ! [unconnected] Cold-side temperature
0,0             ! [unconnected] Cold-side flowrate
0,0             ! [unconnected] Environment temperature
0,0             ! [unconnected] Control signal for element-1
0,0             ! [unconnected] Control signal for element-2
*** INITIAL INPUT VALUES
390.56 1427039.978027 297 0 30 0.0 0.0
DERIVATIVES 1
0               ! 1 Initial temperature of node
*------------------------------------------------------------------------------

* Model "Weather Data" (Type 109)
*
```

```
UNIT 32 TYPE 109    Weather Data
*$UNIT_NAME Weather Data
*$MODEL .\Weather Data Reading and Processing\Standard Format\TMY2\Type109-TMY2.tmf
*$POSITION 329 40
*$LAYER Main #
PARAMETERS 4
2                   ! 1 Data Reader Mode
32                  ! 2 Logical unit
4                   ! 3 Sky model for diffuse radiation
4                   ! 4 Tracking mode
INPUTS 3
0,0                 ! [unconnected] Ground reflectance
0,0                 ! [unconnected] Slope of surface
0,0                 ! [unconnected] Azimuth of surface
*** INITIAL INPUT VALUES
0.2 0.0 0.0
*** External files
ASSIGN "C:\Users\acer\Desktop\3 değişken+hava.txt" 32
*|? Weather data file |1000
*------------------------------------------------------------------------------

* Model "X2H2" (Type 391)
*

UNIT 33 TYPE 391    X2H2
*$UNIT_NAME X2H2
*$MODEL .\STEC Library\Rankine\Utility\X2H.TMF
*$POSITION 333 249
*$LAYER Main #
INPUTS 4
2,3                 ! Superheater:Cold-side outlet temperature ->Steam temperture
```

```
5,1             ! hp stage 1:turbine inlet pressure ->Steam pressure
2,7             ! Superheater:Cold side Outlet quality ->Steam quality
2,4             ! Superheater:Cold-side flow rate ->Steam flow rate
*** INITIAL INPUT VALUES
371 100 1 140288.406372
*------------------------------------------------------------------------------

* Model "Splitter" (Type 389)
*

UNIT 34 TYPE 389    Splitter
*$UNIT_NAME Splitter
*$MODEL .\STEC Library\Rankine\Turbine\S-split.tmf
*$POSITION 573 155
*$LAYER Main #
INPUTS 4
0,0             ! [unconnected] Demanded Flow Out 1
30,2            ! Expansion Vessel:Flowrate to heat source ->inlet flow rate
0,0             ! [unconnected] outlet pressure 2
0,0             ! [unconnected] inlet enthalpy
*** INITIAL INPUT VALUES
183254.38385 1427039.978027 23.167 0
*------------------------------------------------------------------------------

* Model "Mixer" (Type 330)
*

UNIT 35 TYPE 330    Mixer
*$UNIT_NAME Mixer
*$MODEL .\STEC Library\Rankine\Turbine\S-MIX.tmf
*$POSITION 251 155
*$LAYER Main #
```

```
INPUTS 5
9,2             ! Reheater:Hot-side flow rate ->Inlet Flowrate 1
0,0             ! [unconnected] Inlet Enthalpy 1
4,2             ! Economizer(preheater):Hot-side flow rate ->Inlet Flowrate 2
0,0             ! [unconnected] Inlet Enthalpy 2
0,0             ! [unconnected] Outlet Pressure
*** INITIAL INPUT VALUES
183254.38385 0 1243763.964844 0 21
*------------------------------------------------------------------------------

* Model "HTF Pump" (Type 300)
*

UNIT 36 TYPE 300    HTF Pump
*$UNIT_NAME HTF Pump
*$MODEL .\STEC Library\Ste\Utility\Saltpu_1.tmf
*$POSITION 362 154
*$LAYER Main #
PARAMETERS 5
1427039.978027          ! 1 Maximum flow rate
2.59            ! 2 Fluid specific heat
5759999.847412          ! 3 Maximum power
0.0             ! 4 Conversion coefficient
0.5             ! 5 Power coefficient
INPUTS 3
0,0             ! [unconnected] Inlet fluid temperature
35,1            ! Mixer:Outlet Flowrate 1 ->Inlet mass flow rate
0,0             ! [unconnected] desired mass flow rate
*** INITIAL INPUT VALUES
297.78 1427039.978027 1427039.978027
*------------------------------------------------------------------------------
```

```
* Model "X2H2-2" (Type 391)
*

UNIT 37 TYPE 391    X2H2-2
*$UNIT_NAME X2H2-2
*$MODEL .\STEC Library\Rankine\Utility\X2H.TMF
*$POSITION 694 251
*$LAYER Main #
INPUTS 4
9,3             ! Reheater:Cold-side outlet temperature ->Steam temperture
10,1            ! lp stage 1:turbine inlet pressure ->Steam pressure
9,7             ! Reheater:Cold side Outlet quality ->Steam quality
9,4             ! Reheater:Cold-side flow rate ->Steam flow rate
*** INITIAL INPUT VALUES
371 17.099 1 118929.597473
*------------------------------------------------------------------------------

END
```