THERMODYNAMIC ANALYSIS AND SIMULATION OF PARABOLIC TROUGH SOLAR COLLECTOR HYBRID STEAM TURBINE POWER PLANT

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THERMODYNAMIC ANALYSIS AND SIMULATION OF PARABOLIC TROUGH SOLAR COLLECTOR HYBRID STEAM TURBINE POWER PLANT

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Approval of the thesis: **Thermodynamic Analysis and Simulation of Parabolic Trough Solar Collector Hybrid Steam Turbine Power Plant**

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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ABSTRACT

THERMODYNAMIC ANALYSIS AND SIMULATION OF PARABOLIC TROUGH SOLAR COLLECTOR HYBRID STEAM TURBINE POWER PLANT

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In this study, thermodynamic analysis of a hybrid solar steam turbine power plant is done considering utilization of solar energy which is produced by parabolic trough collectors. Firstly, simulation of the fuel oil fired simple power plant is carried out and compared with conceptually designed improved solar hybrid version of the plant. During the design procedure, connections of the plant with the solar field via a heat exchanger, preliminary design of this heat exchanger, selection of the solar fluid and sizing and orientation of the solar field are performed.

Different cases using data from one unit of Wassit thermal power plant, Wassit, Iraq including fuel saving and increasing power (power bosting) modes for different times of the year are considered, simulations are carried out with MATLAB SIMULINK and compared with each other in terms of increasing efficiency, saving fuel oil, increasing output electricity, decreasing environmental pollution and use of water. Also, extra energy which can be utilized by the solar collector field is found for all cases and simulation of the solar field is done for different times of the year and compared in terms of useful power output, overall heat loss coefficient, fluid output temperature, glass and absorber temperatures.

One unit of Wassit thermal power plant has output power equal to 330MW, and contains 3 Stages of turbine, a condenser, 4 low pressure closed feedwater heaters, 3 high pressure closed feedwater heaters and an open feedwater heater.

MATLAB simulations performed using the real data from the original power plant for different modes showed that the proposed power plant efficiency is increased in both modes for all schemes. The rate of increasing output power for one case and the fuel saving for the other cases suggested that, integrating parabolic trough collectors with existing thermal power plant is more reliable, less expensive, environmentally friendly and uses less water (in the steam cycle) than getting electric power from only fuel oil powered thermal power plant. The value of efficiency increase, fuel savings and power increase are also compared for different months of the year (summer, spring and winter).

Lastly, simple economic analysis is done and the levelized cost of energy is found to be equal to 13.9 cent/kWh and this price is competitive compared among prices of electricity produced in both conventional and renewable power plants.

Keywords: Solar Energy, Hybrid, Thermal Power Plant, Parabolic Trough Collector, Matlab Simulation, LCOE

ÖZ

PARABOLİK OLUK TİPİ GÜNEŞ KOLLEKTÖRLÜ HİBRİT BUHAR TİRBÜNÜ SANTRALİNİN TERMODİNAMİK ANALİZİ VE SİMÜLASYONU

Anwer Hamed Salih Al-Attwani

Yüksek Lisans, Makine Mühendisliği Anabilim Dalı
Tez Yöneticisi: Yrd. Doç. Dr. Ekin Özgirgin Yapıcı
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Bu çalışmada parabolik oluk tipi güneş kollektörlü hibrit buhar tirbünü santralinin termodinamik analizi yapılmıştır. İlk olarak sıvı yakıtla çalışan basit çevrimli buhar santralının simülasyonu yapılmış, daha sonra da bu simülasyonda bulunan değerler, bu güç santralının solar enerji ile hibritlenmiş olarak tasarlanan, iyileştirilmiş modeli ile kıyaslanmıştır. Tasarım süreci solar kollektörlerde kullanılacak sıvının seçimini, kollektör sahasının ölçüleri ve kullanılacak kollektör sayısının tayinini, kollektör ve buhar santralını bağlayan ısı eşanjörü ve bağlantı parçalarının ön tasarımını içermektedir.

Çalışmada Irak'ın Wassit şehrinde bulunan Wassit Güç Santralı'nın bir kısmının değerleri kullanılarak doğrulanan, yılın farklı zamanları için birbirinden farklı vakalar incelenmiştir. Bu vakalar yakıt tasarrufu modu ve güç artırma modu olmak üzere iki modda incelenmiş ve birbirleri ile verim artışı, yakıt tasarrufu, elektrik üretimi artışı, çevre kirliliği azaltımı ve su kullanımı miktarları olarak kıyaslanmıştır. Ayrıca tüm vakalarda yılın farklı zamanları için güneş kollektörü sahası kullanılarak üretilebilecek ekstra enerji miktarları hesaplanmış ve faydalı enerji, toplam ısı kaybı faktörü, solar akışkan sıcaklıkları, cam ve soğurucu boru sıcaklıkları birbirleri ile kıyaslanmıştır.
Wassit Güç Santralı'nın bir kısmı 330 MW gücünde olup, üç kademe türbin, bir yoğuşturucu, dört adet düşük basınçlı, üç adet yüksek basınçlı kapalı besleme suyu

ısıtıcısı, bir adet açık besleme suyu ısıtıcısından ve bağlantı parçalarıyla gerekli diğer ekipmandan oluşmaktadır.

Farklı modlardaki vakalar için MATLAB simülasyonları gerçek santrala ait orijinal veriler kullanılarak yapılmış ve göstermiştir ki; tüm durumlarda önerilen hibrit santralın verimi artmaktadır. Bir vakada gücün arttığı, diğer vakada da yakıt sarfiyatının azaldığı ispatlanarak, parabolik oluk tipi güneş kollektörlerinin halihazırdaki termik santralla entegrasyonunun pek çok açıdan oldukça akılcı olduğuna dikkat çekilmiştir. Hibrit sistem sıvı yakıtlı buhar santralına göre daha güvenilir, maliyet etkinliği daha yüksek, çevre dostu, ve su kullanımını azaltması bakımından da daha avantajlı olmaktadır. Verim artışı, yakıt tasarrufu ve güç artışı değerleri ayrıca yılın farklı zamanlarında (yaz-kış-bahar) hesaplanarak birbiri ile kıyaslanmıştır.

Son olarak basit ekonomik analiz yapılmış, seviyelendirilmiş enerji maliyeti (LCOE) hesaplanmış, 13.9 cent/kWh olarak bulunan bu değerin yenilenebilir enerjiyi de kapsayan elektrik üretim santralları içinde kıyaslandığında oldukça avantajlı olduğuna dikkat çekilmiştir.

Anahtar Kelimeler: Güneş Enerjisi, Hibrit, Termal Güç Santralı, Parabolik Oluk Tipi Güneş Kollektörü, MATLAB Simülasyonu, LCOE

Dedication

Dedicated to my family, my mother, my wife and to my soul (my daughter Zahraa)

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I would like to express my deepest feelings to my wife. She is always taking care, supporting, and encouraging me.

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CFH	Closed feedwater heater
DS	Daylight saving(min)
D_s	Inside shell diameter (min)
d	Discount rate
ET	Equation of time (min)
G_{Bn}	Direct normal beam radiation (W/m^2)
G_{BT}	Direct normal beam radiation on tilted surface (W/m^2)
H	Enthalpy(KJ)
HTF	Heat transfer fluid
HEX	Heat exchanger
H	Monthly average total radiation on the terrestrial horizontal surface (MJ/ m^2).
Ho	Monthly average total radiation on the extraterrestrial horizontal surface (MJ/ m^2)
HD	Diffuse radiation (W/m^2)
h	specific enthalpy(KJ/kg)
h	hour angle (°)
h	Heat transfer coefficient (W/m^2 K)
I	Initial investment
K	Thermal conductivity(W/mk)
L	Local latitude(°)
LL	Local longitude (°)
LST	Local standard time
LHV	Low heat value (MJ/kg)
LCOE	Levelized cost of energy($/kWh)
$\dot{m}$	mass flow rate (kg/s)
OFH	Open feedwater heater
PTC	Parabolic trough collector

pr	Prandtl number
p	Pressure (N/m^2)
Q	Heat (J)
R_d	System degradation
R_e	Reynold number
R_f	Fouling resistance
SL	Standard longitude
T	Temperature(K)
TR	Tax rate
t	Time (s)
u	Internal energy (kJ/kg)
U	Overall heat transfer coefficient (W/m^2 K)
V	Velocity (m/s)
W	Work(J)
y	the percentage of the bled steam
z	Solar azimuth angle(°)

Greek symbols

θ	Angle of incidence(°)
β	Tilted angle(°)
η	Efficiency
δ	Solar declination angle(°)
α	Solar altitude angle(°)
φ	Solar zenith angle(°)
η_0	Peak optical efficiency
γ	Intercept factor
ρ	Density(kg/m^3)
μ	Dynamic viscosity(Pas)

v	Specific volume(m^3/kg)
v	Kinematic viscosity(m^2/s)

CHAPTER 1

INTRODUCTION AND FUNDAMENTALS

1.1 Introduction

According to the International Energy Outlook (IEO) 2016 report [1], the consumption of energy increasing and will increase further more in following years. As a result, the net electricity generation in the world will be increased by 69% from 21.6 trillion kilowatt-hours in 2012 to 36.5 trillion kilowatt-hours in 2040 with an average annual increase about 1.2 % as shown in the figure (1.1),[1]. Therefore, environmental pollution will also increase especially when huge part of electricity production depends on fossil fuels. The cost of fossil fuel will be more expensive. Hence, (IEO) 2016 report shows that the renewable energy utilization will be growing faster in the same period since the world will be oriented to produce electricity from the sources which are friendly to the environment. Utilization of clean renewable energy can be direct or hybrid with thermal power plant.

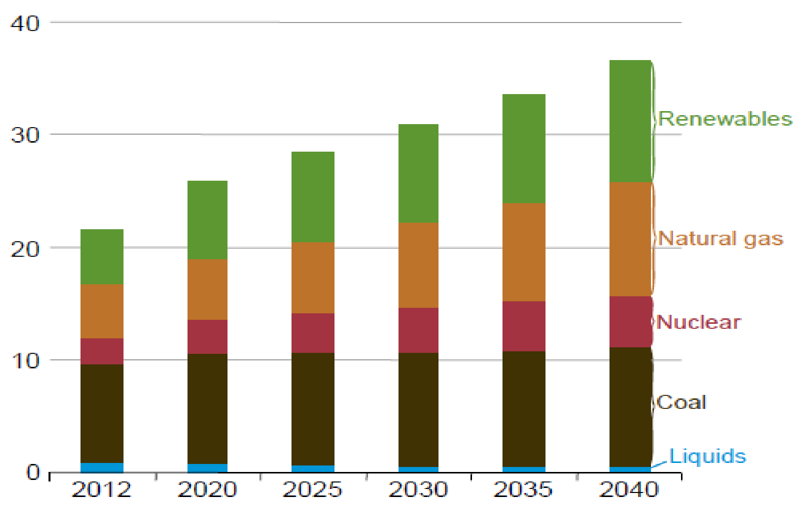


Figure (1.1) Word net electricity generation by energy source, 2012-2040 (trillion kilowatt-hours [1].

1.2 Motivation and Aim of the Study

In the light of above, in this study, utilization of solar energy to be used in a steam power plant in a hybrid manner is investigated. For the power plant, MATLAB simulations and analytical calculations for thermal analysis of a parabolic trough solar collector system with heavy fuel oil hybrid steam turbine power plant is done. The efficiency of this power plant, fuel saving and extra energy which can be utilized by the solar collector field is calculated. As a case study, one unit of Wassit power plant in Iraq which works on heavy fuel oil is studied and fuel consumption and thermal efficiency is determined and compared with measured results. Integrating parabolic trough collectors with existing fossil fuel thermal power plant which works on Rankine cycle. Also, the temperature that is needed to heat feedwater in high pressure preheater is around 300 ^{o}C which can be obtained without using heated fluid tank and that reduces the overall cost. Heat transfer fluid (VP1) is used to transfer heat from solar energy to the working fluid. Also, integrating renewable energy with fossil fuel is benefitable to save money by decreasing the amount of water that is used to produce the electricity. The cost of conservative water (CCW) is equal to 1.16 $/m^3, [43]

In first chapter, some thermodynamic fundamentals will be shown in short detail in addition to explanation of some parts of thermal power plant, and some solar equipment in general.

In second chapter, analytical calculations of original power plant and estimated hybrid power plant are shown.

In third chapter, solar radiation calculation, and optical analysis for parabolic trough collector LS3 are done in addition to the heat transfer analysis for estimated heat gain from solar field.

In forth chapter, heat exchangers conceptual preliminary design is done.

In fifth chapter, MATLAB simulation for original and two schemes of hybrid power plant is shown.

In sixth chapter, all results and discussions for the 2nd to 6th chapters are shown.

In seventh chapter, the conclusion for the study are made.

1.3 Fundamentals

1.3.1 The Efficiency of Power Plant

Efficiency represents the performance of power plant and it is the ratio between the output power to the energy used to generate this power. The first law of thermodynamics states that all kinds of energy is converted from one form to another and the energy is conservative. While the second law of thermodynamics imposes some limitations:

a- The work can be converted entirely to heat.

b- The heat cannot be entirely convert to work.

1.3.2 Unavailable Energy

Unavailable energy is the part of heat which cannot be converted to work, and this energy is rejected to surrounding when the work has been produced. This is called irreversibility. There are many irreversible processes like:

1- Friction;
   a- Mechanical friction; like the heat dissipated by the friction between rotating shaft and journal bearing.
   b- Fluid friction; when a fluid expands in the turbine, internal friction results, which causes energy dissipation as heat. So, the exhaust fluid has high enthalpy and temperature, and hence turbine will produce less work.

2- Heat Transfer; there are three types of heat transfer which are; conduction, convection, and radiation. Heat is transferred from bodies with high temperature to bodies with low temperature. These phenomena cannot be reversed without external work (heat pump). Therefore, heat transfer cause loss of availability. All power plants employ heat transfer from combustion which is primary source to the working fluid. So, it is important to reduce the differences in temperatures between them to reduce the irreversibility of the source that is reducing the efficiency.

3- Throttling; it is expansion processes from high pressure region to low pressure region. In this process, there is no work done and heat transfer is negligible. High kinetic energy will be gotten from this process and this energy will dissipate in fluid to restore the enthalpy. So, it is kind of fluid friction to keep the value of enthalpy constant.

4- Mixing; means that when two or more kinds of fluid are mixed or diffused they cannot be separated without external force. So, this operation causes loss in availability.

1.4 Thermal Power Plant

Thermal power plant works on the principles of Rankine cycle. Figure 1.2, [4] shows the conceptual schematics of a general thermal power plant.

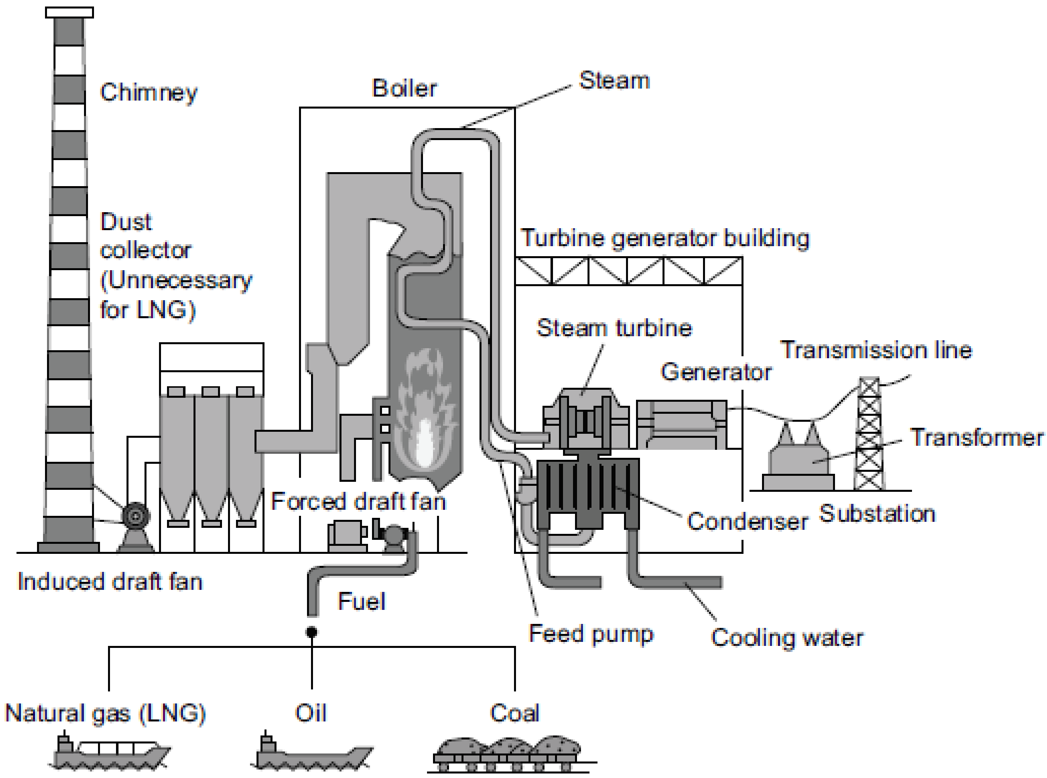


Figure 1.2 General schematic of thermal power plant [4]

1.5 Thermal Power Plant Equipment

1.5.1 The Boiler

The boilers are facilities which are used to produce steam with high pressure and temperature by transferring heat from combustion gases to the water that comes from condenser.

1.5.1.1 Natural Boiler Circulation

Water enters the boiler from high pressure heater. First, enters the economizer and leaves it as a saturated or two-phase mixture state and enters the boiler steam drum. Then water follows through downcomers which is situated outside the furnace to the headers, and flows the riser tubes which construct furnace walls and flows to the headers. After that water enters the boiler steam drum as shown in figure 1.3. The Steam is separated from bubbling water in the steam drum and goes to the primary superheater. Final process is desuperheater process which is mixing the steam with feedwater to reduce the steam temperature and then the steam flows to the second superheater to get specified high temperature and high pressure which is necessary for the inlet of turbine. The water and steam flows in boiler since there is difference in the density which causes natural circulation.

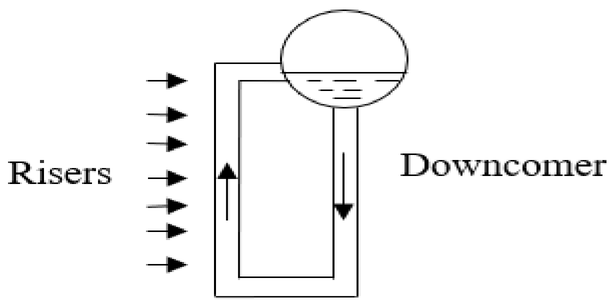


Figure (1.3) Schematic of natural circulating in the boiler

1.5.1.2 Air Circulation

Atmospheric air is forced to flow across air ducts by using forced draft fans. Air is heated with air heaters, and then flows to the wind box and by using air damper to control the quantity of the air which is mixed with fossil oil. The fossil oil comes from oil pumps and then enters the boiler after atomizing it by using atomizing steam in the burners then it burns in the combustion chamber and gets fired with flames and its temperature reaches about 3000 F. Flue gases continue to flow to the economizer and transfer their heat to the feedwater that comes from final feedwater heater. After that flue gases flow to air heater with temperature around 600 F and leave it with temperature around 300 F and flow to atmosphere through stack. Flue gases temperature should be kept above the dew point of water vapor (equal to the saturation temperature of water at partial pressure of the water vapor) to prevent condensation which may cause corrosion of metal component in its path. Also, this range of flue gas temperature has enough buoyancy to rise higher above the stack to suitable atmospheric dispersion.

1.5.1.3 The Steam Drum

The most important feature of the steam drum is separating steam from the boiling water. Also, it is used for chemical water treatment by providing blowdown to reduce solids in the water. The steam drum is equipped with a controller to shut down the boiler if the water reaches the low level or high level. High level causes carryover of water to the superheater. The drum low level cause overheats of steam in superheater which effect the turbine. The steam drum provides mechanical and gravitational separation [2].

1.5.1.4 The Superheater and Reheater

The superheater and reheater in the boiler are used to raise saturated steam temperature which comes from boiler drum to the superheated temperature. The modern reheater and superheater which are operated about 1000 F are usually made from special high specification alloy for both strength and corrosion resistance. Superheaters and reheaters are classified:

1.5.1.4.1 Classification of Superheater and Reheater Based on Heat Transfer Method

a. Convection Superheater

Early design is placed superheater tubes behind or above water tube to protect them from the high temperature and the flue of the combustion gases, thus this kind of superheater are used with low temperature steam generator. The main characteristic for this kind of superheater is response to the load change since when increased load is needed, combustion gases increase. Thus, the convective heat transfers coefficient increases at both outside and inside the tubes. So, the increasing of the overall heat transfer coefficient between flue gases and steam is faster than increases in mass flow rate of the steam.

b. Radiant Superheater

Superheater places nearer high temperature because of need for big heat absorption. The placement of superheater result in significant amount of radiation heat transfer between the flame and hot gases and the boiler tubes. As known radiation heat transfer, proportional to;

$$Q \cong T_f^4 - T_w^4 \quad (1.1)$$

Where; T_f represent fluid temperature and T_w represent wall temperature. Design of reheater is the same of superheater except that the overall temperature and the steam pressure are lower, although the outlet steam temperature is almost the same.

c. Radiant and Convective Superheater

This kind of superheaters is used for getting steam with high temperature.

1.5.1.4.2 Classification of Superheaters and Reheaters Based on Mechanical Construction

There are three types of superheater and reheater based on mechanical construction;

a. Pendant Type

Superheater and reheater are hung from above. There is advantage of structure support and there is disadvantage of flow of condensed steam after cold shutdown. So, the reoperation must be slow to scavenge the water which accumulates in the bottom of the superheater.

b. Inverted Type

Superheaters and reheaters are supported from below. These kinds are provided by suitable drainages of the steam and water, but their structure lack rigidity especially with high flow of gases.

c. Horizontal Type

This kind are supported horizontally in the vertical gas duct which is parallel to main duct. This kind does not view the flame directly so it is mainly convection type, they are suitable for both drainage and good rigidity of its structure.

1.5.1.5 Economizers

It is the heat exchangers which raise the temperature of water coming from highest pressure feedwater heater to the saturation temperature. The economizer is very useful in thermal power plant and cause significant increases in thermal efficiency because if the flue gases do not pass through economizer, it will cause loss of significant part of availability of power plant and that effects directly on loss of economy of operation. Economizer is usually built with extended surface tube to get high rate of heat transfer from the gases.

1.5.1.6 Air Preheaters

The air heater utilizes some of the energy left with the flue gases. It receives 600 to 800 F temperatures of gases. Then the flue gases are cooled to 275 F to avoid condensation of vapor which accompanies it and that is useful to prevent corrosion problem and allow flue gases to disperse in the atmosphere. Reheating the air into the combustion chamber will be useful to save fuel. There are two types of air heaters:

1. Recuperative Air Heater

Heat transfer from the hot gases to the air across the heat exchanger surfaces. They are commonly tubular and like counter flow shell and tube heat exchanger in which air flow outside and flue gases flows inside horizontal or vertical tube. the tubes are provided by baffles to increase the surface of heat exchange. The problem of this kind of air heaters is that, when leakage happens, the air flow goes to flue gas direction since its pressure is higher. Hence circulation of air used in combustion becomes insufficient.

2. Regenerative Air Heaters

Heat is transferred from the flue gases firstly to an intermediate medium which is the air heater, and then heat is transferred to air coming from forced draft fans. This kind of air heater is commonly rotated horizontally or vertically by using motor and reduction gearbox which is used to get air heater rotation around 1-3 rpm, its rotation depending on the size of its diameter.

1.5.1.7 Attemperation (Desuperheater)

Reduction of steam temperature after passing primary superheater is done by one of the two methods;

a. The first method involves using a surface attemperator and this method removes heat from steam in a heat exchanger.
b. The second method is that; the attemperation is done by using spray device that reduces steam temperature by spraying water which has low temperature between primary and secondary superheater. In this method, water which has high velocity mixes with steam. The venture and thermal sleeve protect the main steam pipe from thermal shock which is caused by any water droplet that might otherwise impact the pipe [2]. The attemperation system is provided by regulating control valve which is used to control the amount of water mixing with the steam to maintain a constant temperature for steam that is flown to the turbine.

1.5.2 Forced Draft Fans

Forced draft fans are either used alone to push the atmospheric air to the air heater in pressurize furnaces and put entire system up to the stack entrance under positive gage pressure or they are used with induced fan located in flue gas line near the stack in furnaces that is operated under negative gage pressure. In the furnaces that have positive pressure there are some disadvantages such as:

1. Any leakage in the wall of the furnace will flow out flue gases which are noxious.
2. The design of inspector doors, soot blowers and igniter must be give attention.

1.5.3 The Stacks

The stacks are used nearly in all power plants to assist the forced draft for overcoming the pressure losses and to disperse the flue gas fluently into the atmosphere.

1.5.4 The Steam Turbine

The steam turbine is a work producing device that uses the energy of steam with high temperature and high pressure coming from the boiler and by means of rotation, converts the energy of steam to mechanical energy. The steam turbine contains two kinds of blades. First kind is the stationary blades that are used to accelerate and swirl steam to the second kind of blades; which are moving blades. Hence rotating blades receive impulse and reaction forces from the steam coming from the fixed blades then the rotating blades transmit the torque which is caused by these forces to the rotor and make a rotation of the shaft of the turbine. These two kinds of blades are organized in rows of stages in turbine. The fixed blades are fixed on the turbine casing whereas the moving blades are fixed to the rotating shaft of the turbine. There are two kinds of turbines, classified depending on the kinds of blades such as, [2], [4];

a. The Impulse Turbines**;** the steam with high speed is directed by fixed nozzles to the bucket blades which are fixed on the turbine rotor and caused rotation to the shaft of the turbine. It has an advantage such that, that is no pressure drop in the moving blades except the pressure drop by friction.

b. The Reaction Turbines**;** it is constructed by rows of fixed blades that act as nozzles and rows of moving blades set on the turbine shaft**.** The fixed and moving blades have not symmetrical shapes, but they are curved in opposite direction.

Also, turbines are classified depending on how the steam is supplied and extracted which are shown in the Figure (1.4), [4]:

a. The Condensing Turbine

This kind uses total energy of the inlet steam to produce electricity. In this kind, there is a lot of heat loss because all exhaust steam flows to condenser after passing turbine and meaning a lot of heat is thrown out with condenser cooling water.

b. The Back-Pressure Turbine

This kind of turbine is used for supplying process steam to the facilities, so the expected output efficiency is high. On the other hand, the output energy is low. The back-pressure turbine or extraction back pressure turbine is generally used in refineries, paper-pulp, fiber petrochemical, and food industries when there is a lot of auxiliary equipment work on steam. The back-pressure turbine consists of small exhaust parts, and fewer turbine stages with simple structure.

c. The Extraction Condensing Turbine

It has both features of back pressure turbine and condensing turbine. Since it is able to change the electric power and process steam flue, this kind of turbines have more flexibility in operation compared to back pressure turbine, and the equipment's cost of this kind is higher.
This type of turbine is used in facilities like, the mining industries, cement manufacture and steel mill since they need bigger power compared with steam applied to the facilities.

d. The Mixed Pressure Turbine

In this kind of turbine, the intermediate steam is received from the facilities in addition to main source of steam. Examples are; use of turbine in a paper-mill factory when two kinds of boilers that have difference pressure is provided to recover excessive heat that occurs in manufacture processes of mill or cogeneration plant which provide with this kind of turbine.

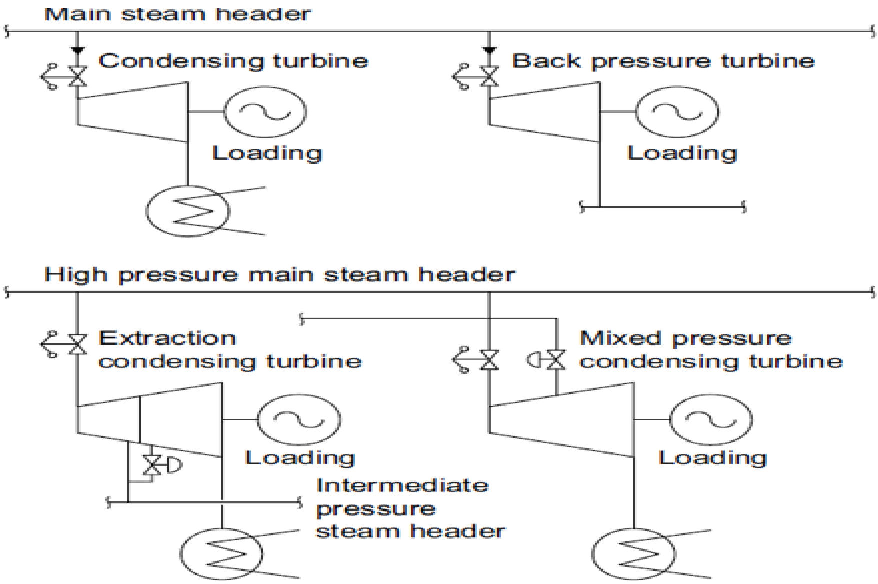


Figure (1.4) Different types of Steam Turbines, [4]

1.5.4.1 Efficiency Enhancement of Steam Turbines

Efficiency of steam turbines is enhanced by increasing their capacity. In high pressure turbines, the blades of first stages is very short and they are less than two inches in height to enhance turbine efficiency. The leakage losses are large in HP turbines. In intermediate turbines, the enhancement of efficiency has been done by designing new kind of sealing and three-dimension designs are developed. For low pressure turbines, providing more efficient last stages which have long blades increases its capacity [4].

1.5.5 The Circulating Water System

Circulating water system is supplying cooling water to the condenser in order to extract heat from the exhaust steam and converts it to saturated water, the heat is rejected to the environment and it represents the maximum heat loss in the power plant.

1.5.5.1 Circulating Water System Classification

a. Once Through System

In this kind of system, condenser water is taken from natural body like rivers, lakes or ocean then is pumped to the condenser after that the circulating water returns to the main source.

b. Closed Loop System;

In this kind of system, condenser water is taken from passed through cooling device and return to the condenser in closed continuous loop.

c. Combination Systems

It combines once through system with a closed loop system.

1.5.6 The Condenser

It is a heat exchanger which operates with the exhaust steam at vacuum pressure. The steam flow in power plants is usually high and that leads to use of condenser with high capacity. There are two kinds of condensers which are;

a. Direct contact condensers

These kinds of condensers are used in special cases such as geothermal power plants. There are two kinds of these condensers; the first one is spray condenser which operates by spraying the water directly into the steam. The second type is barometric and jet condenser which are the early condenser that operate similar to the first one except there is no pump used to flow the water, and the condensers have baffles spraying the water in addition the water flow by effect of vacuum pressure, [2]

b. Surface condensers

In these kinds the steam in shell and circulating water inside the tubes.

1.6 Solar Thermal Power Technology

Solar energy is the most important kind of renewable energy. Solar thermal power technologies are used to convert sun energy to the useful form of energy the first application of solar energy is the invention of solar furnaces used for melting iron in the eighteenth century, [5].

1.7 Solar Energy Collectors

Solar energy collectors are special kind of heat exchangers that are used to transfer solar energy which is coming from sun radiation to the internal energy of the medium that is used to transform this energy to the system.

Basically, there are two types of solar collectors; the first one is non-concentrating and the second one is the concentrating collector as shown in Table (1.1) [5].

Table (1.1) Types of solar energy collectors, [5]

Motion	Collector type	Absorber type	Concentration ratio	Indicative temperature range (˚C)
Stationary	Flat plate collector(FPC)	Flat	1	30-80
	Evacuated tube collector(ETC)	Flat	1	50-200
	Compound parabolic Collector(CPC)	Tubular	1-5	60-240
Single-axis tracking		Tubular	5-15	60-300
	Linear Fresnel reflector(LFR)		10-40	60-250
	Cylindrical trough collector(CTC)	Tubular	15-50	60-300
	Parabolic trough collector (PTC	Tubular	18-85	60-400

1.7.1 Sun Trucking Concentrating Collectors

1.7.1.1 Parabolic Trough Collector

Parabolic trough collector is made from a parabolic trough-shaped mirror that reflects and concentrates direct solar radiation onto a receiver tube that is located in the focal line of the parabola, as seen in the schematics in Figure (1.5), [18]. The feature of concentrating the direct solar radiation reduces the absorber surface area with respect to the aperture area of collector and as a result reduces the overall thermal losses. The energy is absorbed from radiation heats the fluid that flows through the receiver tube.

Parabolic trough collectors have a good efficiency and high performance, and they can achieve temperatures up to 400 ^{o}C.

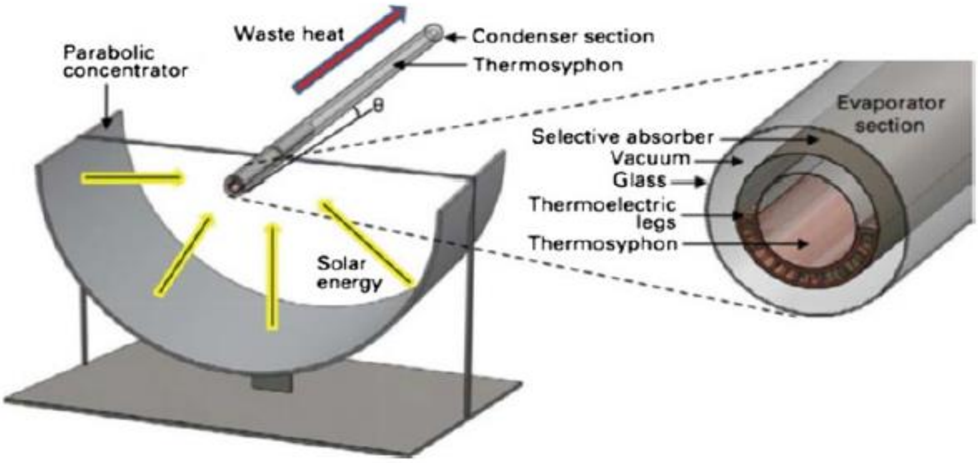


Figure (1.5) The schematic of PTC, [18]

PTCs are dynamic devices since they rotate around an axis which is used to follow the sun at the apparent day time. The rotation around its axis needs a drive unit, and it is provided by a local control unit. One drive unit is enough for several parabolic troughs which are connected in series and driven together. There are two types of local control for the tracking system; the first one includes control units based on sun sensors. These kinds use photocells to detect the position of the sun. The second one uses control units based on astronomical algorithms.

Recently, all commercial designs of PTCs prefer a single-axis sun-tracking system rather than two-axis sun-tracking systems because two-axis sun-tracking PTCs are less cost-effective, the maintenance costs are higher. and the availability is lower because they require a more complex mechanical design.

1.7.1.1.1 Parabola Construction

For construction, high stiffness, low labor cost, and low weight is important for example, Euro Trough collector is designed with a very low weight (almost 14% less than similar collectors) with reduces bending and torsion of the structure.

1.7.1.1.2 The Receiver

Receiver tube is contained of an inner steel pipe covered by a glass tube to reduce convective heat losses. The steel pipe material has a high-absorptivity which is greater than 90%, and low-emissivity which is less than 30%. Also, it is coated by a glass layer to reduce radiation thermal losses. Receiver tubes that have glass vacuum tubes and glass pipes with an anti-reflective coating achieve higher thermal efficiency and better annual performance for a PTC especially for high operation temperature as shown in Figure (1.6), [19]. Receiver tubes without vacuum feature are usually used for working temperatures below 250˚C, since thermal losses are not so critical at these temperatures.

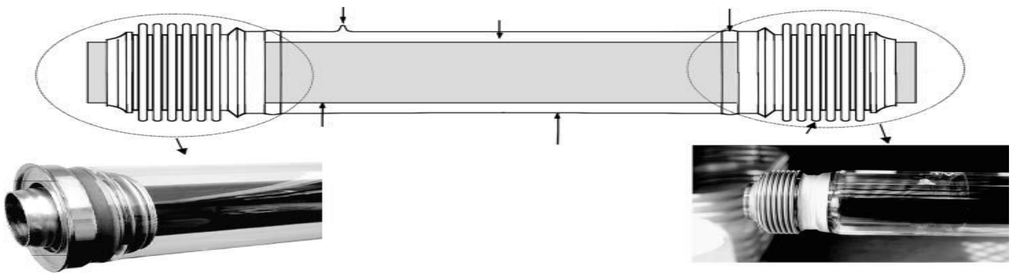


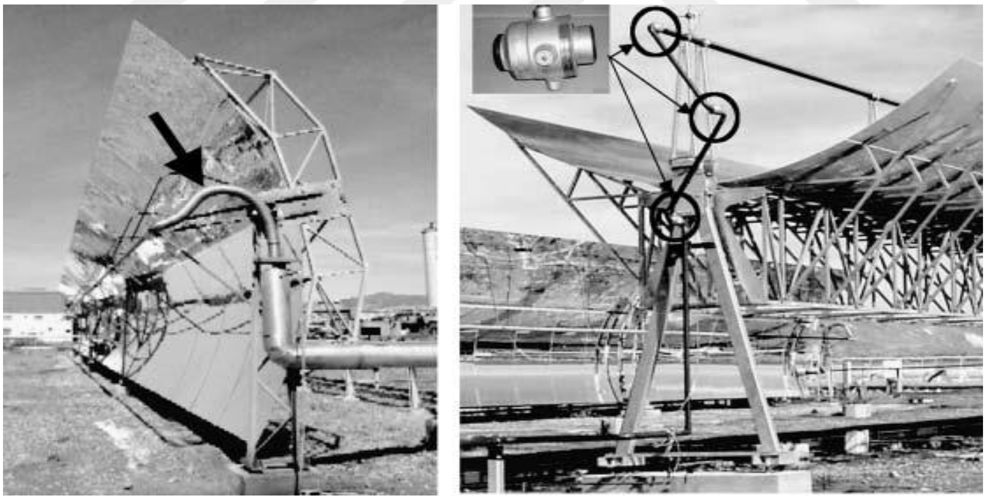
Figure (1.6), a typical receiver tube of a PTC, [19].

1.7.1.1.3 PTC Reflectors

PTC mirrors must have a high specular reflectance (greater than 88%). Solar reflectors usually used in PTC’s are made of back-silvered glass mirrors which have solar specular reflectance about 0.93 and are better than the polished aluminum which has specular reflectance around 0.78.

1.7.1.1.4 PTC Steel Structure

The PTCs are held by a steel support structure which is constructed on pylons that fixes the foundation. There are two particular types of PTCs which are designed for large capacity solar thermal power plants. These are; the LS-3 and Euro Trough (ET-100). They are constructed with total length around 100 m and a width of 5.76 m. as shown in the Figure (1.7), [19]; The steel structure is the main difference between these two kinds of collectors; mechanical rigidity to torsion is assured by a steel torque box of beams and trusses in Euro Trough collectors, whereas the steel structure of LS-3 is based on two "V-trusses" which are held together by end plates. Maximum torsion at the ends of the collector is the most important factor for the mechanical design of a PTC, since the high torsion would cause smaller intercept factor and lower optical efficiency.



LS3 collectors ET-100 Collector

Figure (1.7); LS-3 collector with flexible hose and ET-100 collector with ball–joint connection to allow collector rotation and linear thermal expansion of receiver tubes, [19].

PTCs are usually installed with the rotation axis oriented either north–south or east–west, that depends on some specifications shown in the following details;

a- North- south orientation is used if more energy is demanded in the summer. Also, it is used when energy need is evenly distributed during the year. It provides more energy on a yearly basis.

b- East–west orientation is used if the solar field expected to supply similar thermal power in summer and winter. Influences the sun incidence angle on the aperture.

1.8 Tracking the Sun

There are two methods to track the sun; the first method is the altazimuth method which needs the tracking device to turn in both azimuth and altitude. This method enables to follow the sun exactly. The second method is one axis tracking; collector track the sun in one direction only either from north to south or from east to west. For parabolic trough collectors, usually the second method is used to track the sun. In these kinds of collectors, the light is concentrated in focal zone; therefore, the energy flux is increasing.

1.9 Heat Transfer Fluid

Thermal oils are commonly used in solar applications as working fluid for intermediate temperatures which are above 200 ^{o}C. If water is used at these high operating temperatures, water pressures inside the piping and receiver tubes will be high, which requires stronger joints and piping. For this reason, the price of the collectors and the entire solar field may increase. The main factor to be taken into consideration when choosing thermal oil is the maximum oil bulk temperature for stability. Above this temperature, oil cracking, and rapid degradation occurs. Thermal oil widely used in PTCs for temperatures up to 395˚C is VP-1 that is a eutectic mixture of 73.5% diphenyl oxide and 26.5% diphenyl. The boiling temperature for this oil is 257˚C at 1013 mbar. The main problem with this oil is its solidification temperature which is 12˚C. Because of this, an auxiliary heating system may be required [19].

1.10 Sizing of Solar Fields with PTCs

As shown in Figure (1.8), [19] a typical PTC field is composed of a number of parallel rows each row composed of several collectors connected in series so that the working fluid flows through the absorber pipe when it passes from inlet header to outlet header. To design solar field size, some design parameters are to be determined for thermal performance. These Parameters are;

1. The collector orientation.
2. The date and time of design point (month and day).
3. The direct solar irradiance and ambient air temperature for the selected date and time.
4. The location (latitude and longitude) of the plant site.
5. The total thermal output power needed from solar field.
6. The solar collector soiling factor.
7. The inlet and outlet temperatures of the solar field.
8. The kind of working fluid for the solar collectors.
9. The quantity of fluid flow rate.

If oil is used as a working fluid in the solar field to transfer the energy to an unfired boiler, the difference in the outlet solar field temperature and the steam temperature must be at least +15˚C (working fluid has higher temperature). This difference is important to compensate for thermal losses between the solar field outlet and the steam generator inlet and the boiler pinch point, which is in the order of 5–7˚C.

The used parameters for selection of PTC’s are; peak optical efficiency, incidence angle modifier, heat loss coefficient and aperture area, and lastly; density, heat capacity, and dynamic viscosity of thermal fluid.

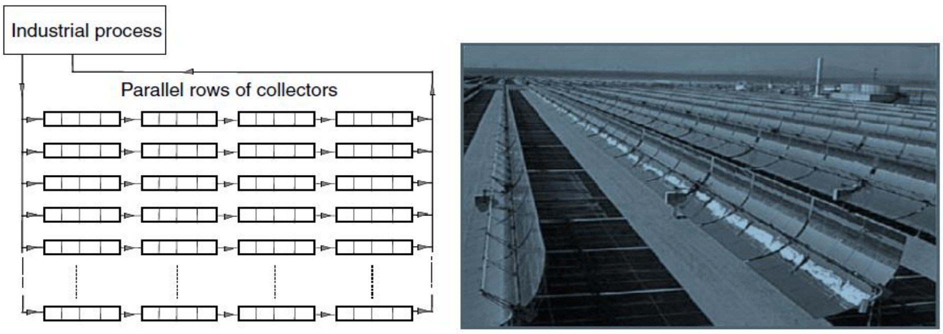


Figure (1.8), a typical solar field with parabolic trough collectors. [19].

1.11 Layout of Solar Fields with PTCs

As shown in Figure (1.9), [19], there are three basic layouts which have been used in solar field with PTCs which are explained below;

1.11.1 The Direct-Return Configuration

This configuration is used in small solar fields since it is the simplest. The main disadvantage is that there is a greater pressure difference between the inlets in parallel rows, so that regulation valves must be used to keep flow rates the same in each row. These valves cause a noticeable pressure drop at the beginning of the array, and thus their contribution to the total system is pressure loss.

1.11.2 The Reverse-Return Configuration

Pipe headers with different diameters are used in this layout to balance the array flow when the fluid enters the collector arrays. Since the large pipe headers are used thermal energy losses and initial investment costs will increase. The balancing valves may still be demanded. Also, the extra length of piping which is used to balance the flow at the solar field inlet causes additional heat loss.

1.11.3 The Center-Feed Configuration

This configuration is widely used for large solar fields. As in the direct return design, pressure loss in the solar field is greater if balancing valves are installed at the row inlets. This layout minimizes the total amount of piping.

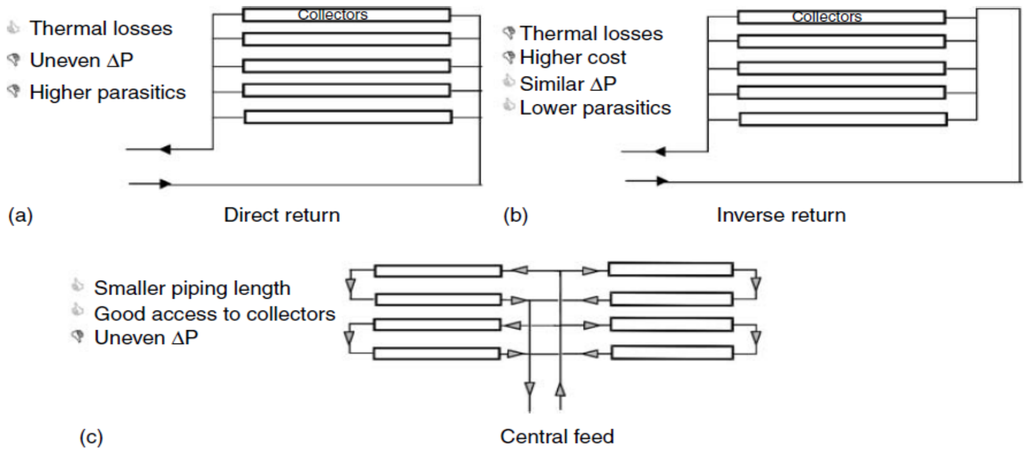


Figure (1.9), layout of solar field with PTCs [19]

1.12 The Existing Data on LCOE (Levelized Cost of Energy)

The LCOE is used to estimate the cost of renewable energy in terms of $/kWh to give a reliable method for comparing with the other kinds of energy production techniques especially for fossil fuel electrical power plants. LCOE is estimated to have values in the range of 0.3 to 0.37$/kWh for parabolic trough solar power plant without thermal storage system while it is in the range of 0.21 to 0.37$/kWh with thermal storage system [42]. The LCOE in the 30MWe SEG parabolic trough solar power plant is equal to 0.17 $/kWh, and for the hybrid power plant with fossil backup around 25%, it is equal to 0.14 $/kWh [26].

1.13 Literature Review

G.C.Bakos, and Ch. Tsechelidou [8] developed a simulation for hybrid solar energy by integrating parabolic trough collector with 300 MW lignite steam power plant by using TRNSYS model of SAPG. Simulation for fluid heated by solar to replace the extraction steam to high pressure preheater in the Ptolemais thermal power plant in Greece is done. The solar heat integrated with high pressure preheater 7 where an additional heat exchanger using thermal oil heater is installed parallel with FWH7. This additional heater is operated when the feedwater temperature after FWH6 becomes less than the temperature of heat transfer fluid. Two modes in this simulation are done the first one is used to save extracted steam and then increase output power and efficiency which is raised from 33.3% to 36.74%. The second mode is used to save fuel oil and remains the output power constant about 275MW. So, the emissions of CO2 with flue gas and lignite consumption are reduced. Simple economic analysis was done and found the cost of boosting power by integrating solar with thermal power plant is 75.25€/MWh while the value of saving fuel is 76.01€/MWh.

S. Gunasekaran, N.D. Mancini, R. El-Khaja, E.J. Sheu, and A. Mitsos. [9] developed four schemes which different from each other for Advanced Zero Emission power cycle with parabolic trough collectors. Aspen Custom Modeler is used to simulate the parabolic trough and Aspen Plus and JACOBIAN is used to simulate the integrated parabolic trough with Advanced Zero Emission plant. The four schemes are; preheating of high pressure water, heating steam directed to low pressure turbine, heating steam directed to intermediate turbine and vaporization of high pressure water. The author makes comparison between the fourth schemes and he found the best one which was the vaporization of high pressure water.

Yawen Zhao, Hui Hong. And Hongguang [10] investigated economical papers for many scales hybrid power plants (200 to 600 MW). All of these power plants are operated on coal and are integrated with parabolic trough collectors without using heat transfer fluid tank since the temperature of heat liquid are needed to heat the feedwater around 300˚C. This study is explored that the major cost of the solar energy comes from the high cost of heat transfer fluid tank and the land parabolic trough furthermore the expensive cost of turbine; condenser, boiler and generator are not considered comparing with parabolic trough directed to steam turbine in solar power plant.

Shuo Peng, Hui Hong, Hongguang Jin, and Zhineng Zhang [11] proposed integrated parabolic trough with (330MW) coal power plant in Changji city in China by driving parabolic trough by partial rotated device. In this study comparison of single axis and rotatable tracking system was done and found the efficiency of solar energy in the second is larger than first around 4% and benefit by reducing the area of the field for parabolic trough collector which is hybrid with fossil fuel power plant.

Jianlan Li, Xiucheng Yu, Jizhou Wang, and Shuhong Huang [12] investigated hybrid solar energy with 600MWcoal, and Zhieng Zhang power plant by using MATLAB simulation. Environment pollution is discussed since the amount of coal consumption in china becomes huge so the demand of solar energy becomes greater. The oil was used to transfer heat from parabolic trough system to the condensate water which is used to heat water in Rankine closed system in condensate water and feedwater eight preheaters. As a result, in saving fuel model was found the integrating solar energy with coal steam turbine power plant will benefits to save fuel consumption. Also, the fluctuating of direct normal irradiance (DNI) affects directly on the output power supply to the grid, and the higher efficiency occurs with high value of DNI. Finally, the benefit of high pressure preheaters is greater than other preheaters was found.

Yawen Zhao, Hui Hong, and Hongguang Jin. [13] proposed hybrid 200MW coal-fired power plant by parabolic trough solar energy. Thermodynamic analysis is done by using equivalent enthalpy drop theory. The parameters are taken from typical summer and winter days after that the results of calculation compared with another previous study and found the error around 5% between two studies. Beside analytical calculation ASPEN PLUS software used to simulate power block. Thermal efficiency is increased as a result of this study.

M. Alguacil, C. Prieto, A. Rodriguez, and J.Lohr [14] work is done on existing direct solar energy power plant which is Abengoa parabolic trough collectors direct solar power plant in Spain that produces 8 MWhr. The power plant works by using thermal oil as an intermediate heat transfer fluid, also the working steam temperature is 450ºC. The power plant is operated at 450ºC for one-year after that with a new coated receiver tubes with new operation conditions at 550ºC is tested for three months. It is found that thermal efficiency for the new design is better than the old design.

Tobias Vogel, Gerd Oeljeklaus, Klaus Görner, Jürgen Dersch and Thomas Polklas [15] deal with different hybridization concepts for parabolic trough power plants which work on natural gas similar to Shams One power plant in United Arab Emirates. The operation of solar part is without thermal heat storage. Initially, the water is evaporated and heated in the solar steam generator to 380°C at 101.5 bars. And then, the steam is superheated further in the natural-gas-fired booster. At 540°C and 100 bars, the steam enters the turbine, and then expanded and flows to the condenser with pressure 0.13 bars and with the help of pumps and other equipment flows to the solar steam generator. The solar steam generator receives the heat transfer fluid with temperature 393°C, and leaves it with temperature 296°C. They used Epsilon Professional program includes a model for EURO Trough ET150 collectors for simulation. In addition to hybridization implemented in Shams One power with parabolic trough solar energy, the integration of Industrial gas turbine was examined. The exhaust gas temperature for industrial turbine is up to 545°C. This range of flue gases temperature are suitable for providing the boosters boiler with heat, hence the results show that, the output power will increase from 2.8 %to 23.3 % for two gas turbines each one produce 12.68 MW in the same power plant.

Shuo Peng, Zhaoguo Wang, Hui Hong, Da Xu, and Hongguang Jin [16] investigated a reheat coal-fired 330MW power plant in Sinkiang, China (before hybridization). The comparison between solar power plant without storage and hybrid solar with existing coal power plant is done. ASPEN PLUS program is used for the simulation. The result of this study suggests that the exergy destruction of the solar-hybrid coal-fired power plant is lower, furthermore, the economic performance is better since it needs less collection area and that reduces the solar field cost. Beside it does not need many instruments since the power block already exists. The cost of electricity generation could be reduced about 20–30% lower compared with only solar power plant.

Y. Aldali and K. Morad [17] have done numerical simulation of the integrated solar with North Benghazi combined Power plant. In this power plant two gas turbines work on the natural gas with output electricity around 128.13MW, they combined with steam turbine of output electricity of 147MW. Hybrid power plant is examined numerically for two modes. the first one is boosting power mode. The results, the annual increase of electrical Energy approximately 93.33 GW h. The second mode is fuel saving mode which results the annual saving of natural gas consumption around 3001.56 tons. CO2 emission are approximately 7972.25 tons compared with the original combined cycle power plant.

CHAPTER 2

THERMAL POWER BLOCK-ANALYTICAL CALCULATIONS

2.1 The Analytical Calculations of Thermal Power Plant

As shown in figure (2.1) thermal power plant has three stages of turbines which are the high-pressure turbine, the intermediate-pressure turbine and the low-pressure turbine in addition to seven closed feedwater heaters, open feedwater heater and other general equipment like the boiler, generator, condenser, circulating water pump and auxiliary equipment. In this chapter, the analytical calculation in terms of thermal efficiency and fuel consumption will be shown depending on the first law of thermodynamics and regeneration Rankine-cycle concept by using real data for one unit from Wassit this power plant. These calculations also represent the calculation of estimated thermal power plant at night when there is no sunlight.

2.1.1 The Assumptions Made for Calculations

a- Every component in this cycle is considered as a control volume.
b- Adiabatic operation of turbines and pumps are considered.
c- Saturated liquid exits from the condenser.
d- Kinetic and potential energy differences are neglected among control volumes.
e- The differential pressures of the fluid in the preheaters and boiler are neglected.
f- Expansion in traps is considered as constant enthalpy process(Hi=Ho).
g- Condensate water exiting closed feedwater heaters and open feedwater heater is considered as a saturated liquid at each specified pressure.

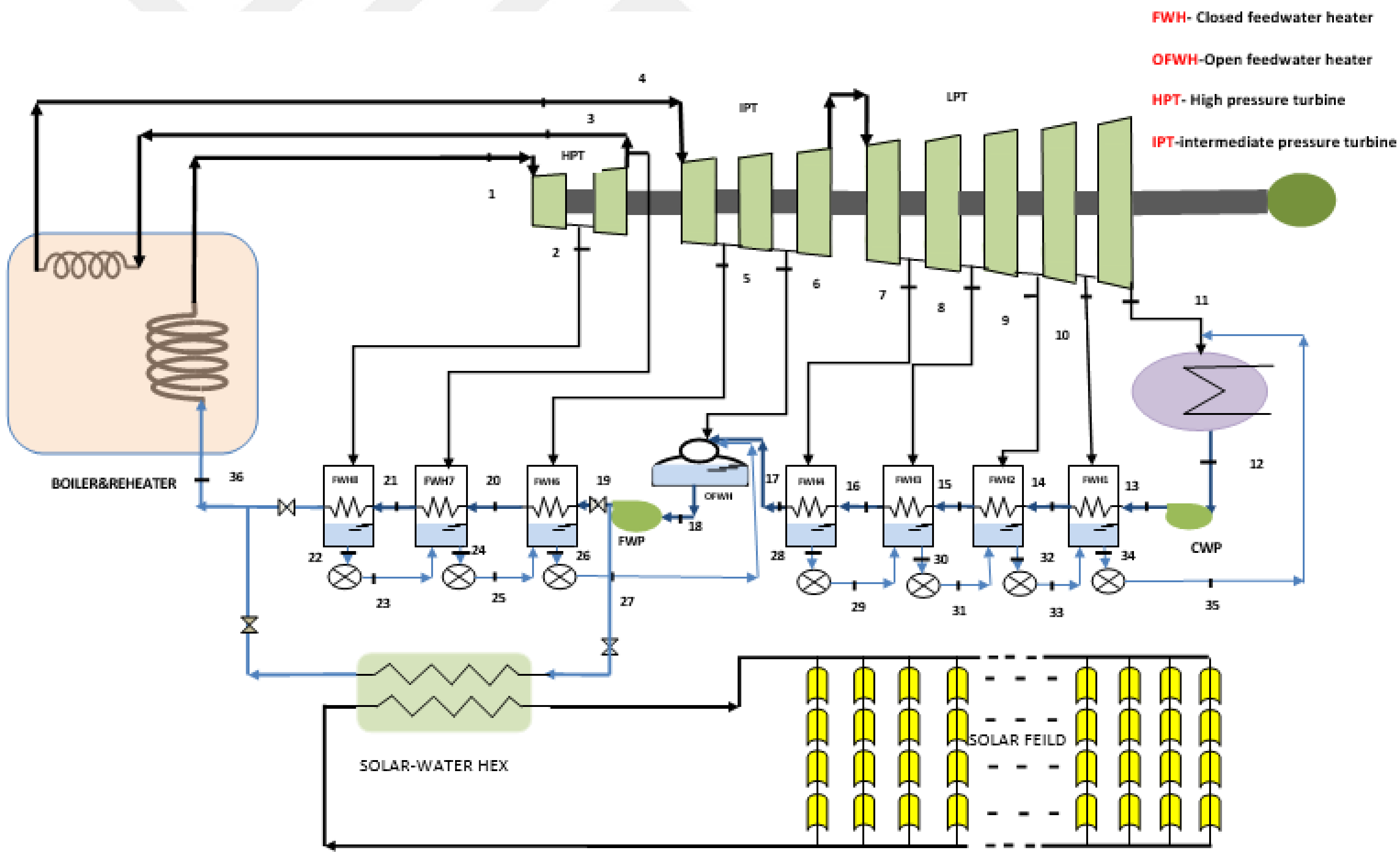


Figure (2.1) Thermal power plant schematic.

2.1.2 Evaluating the Fluid Properties in the Cycle

According to T-s diagram of the regeneration Rankine cycle of Wassit power plant which is shown in the Figure (2.2), properties of the working fluid (steam) are found considering the real data for the power plant by using XSteam tables with MATLAB to ensure that the values from the simulation are same as the values of analytical calculations.

The properties of the subcooled water after closed feedwater heaters for states (14,15,16,17,20,21) are calculated by adopting the formula shown below [20];

$h_0 = h_f + v_f\,(p - psat)$ 2.1

where;

h_0 and p are enthalpy and pressure for subcooled water exiting from preheater, respectively.

psat, h_f and v_f are the saturated pressure, enthalpy and specific volume at specified temperature of the subcooled water exiting the preheater, respectively.

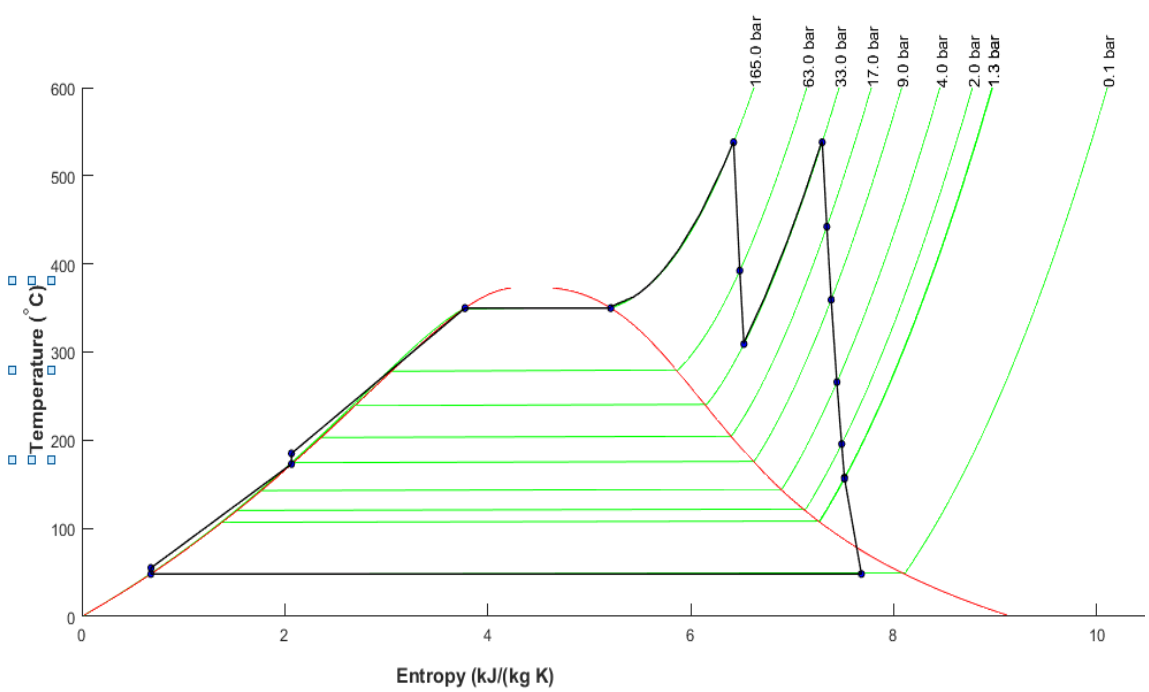


Figure (2.2) T-S diagram of thermal powerplant

2.1.3 The Steady-State Energy Balance for Control Volume

The rate of change in energy in the control volume at time (t) is equal to net rate of energy transfer in at time(t) by heat transfer - net rate of energy transfer out of control volume by work at time(t)+ net rate of energy transfer into control volume accompanying mass flow.

$$\frac{dE_{cv}}{dt} = \dot{Q}-\dot{W}+\dot{m}_i\left(u_i+\frac{V_i^2}{2}+gz_i\right)-\dot{m}_e(u_e+\frac{V_e^2}{2}+gz_e) \qquad 2.2$$

Where

The ($\dot{W}$) represents the rate of energy transfer by work for all portion of the boundaries of the control volume. It contains two forms of work; first form is the work associated with fluid pressure, and the second form includes all other effects of work like; the work associated with rotating shaft, electrical resistances…etc., and it is denoted by ($\dot{W}_{cv}$).

$$\dot{W} = \dot{W}_{cv}+V_e(p_eA_e)-V_i(p_iA_i) \qquad 2.3$$

Where;

Substituting equation 2.3 in equation 2.2, and replacing the specific enthalpy $h = u + pv$ and $VA = \dot{m}v$; for steady state the final formula becomes;

$$\dot{Q}-\dot{W}_{cv}+\dot{m}_i\left(h_i+\frac{V_i^2}{2}+gz_i\right)-\dot{m}_e\left(h_e+\frac{V_e^2}{2}+gz_e\right) = 0 \qquad 2.4$$

2.1.4 Energy Balance Equations for Preheaters

Equation 2.4 is applied to find the fraction of the steam supplied to the preheaters by considering every preheater as a separate control volume.

2 .1.4.1 Closed Feedwater Preheater (8)

$$h_{21}+y_1h_2-h_{36}-y1h_{22}=0 \qquad 2.5$$

$$y_1=\frac{h_{36}-h_{21}}{h_2-h_{22}} \qquad 2.6$$

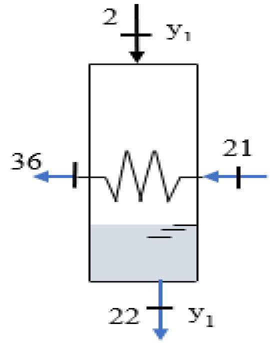


Figure (2.3) Closed feedwater heater 8

2 .1.4.2 Closed Feedwater Preheater (7)

Energy balance for closed feedwater heater 7 which is shown in the figure (2.4) is given below;

$$y_2h_3+h_{20}+y_1h_{23}-(y_1+y_2)h_{24}-h_{21}=0 \qquad 2.7$$

$$y_2=\frac{-y_1h_{23}+y_1h_{24}+h_{21}-h_{20}}{h_3-h_{24}} \qquad 2.8$$

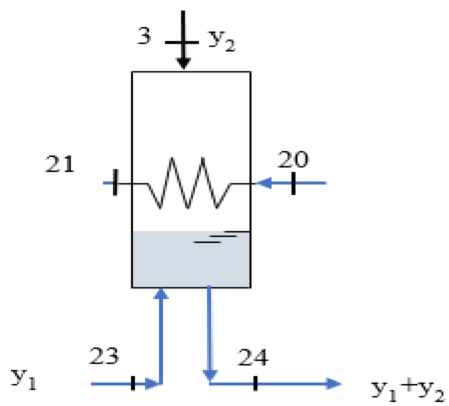


Figure (2.4) Closed feed water heater 7

2.1 .4.3 Closed Feedwater Preheater (6)

Energy balance for closed feedwater heater 6 which is shown in the figure (2.5);

$$y_3h_5-(y_1+y_2+y_3)h_{26}+(y_1+y_2)h_{25}+h_{19}-h_{20}=0 \qquad 2.9$$

$$y3=\frac{y_1h_{26}+y_2h_{26}-y_1h_{25}-y_2h_{25}-h_{19}+h_{20}}{h_5-h_{26}} \quad 2.10$$

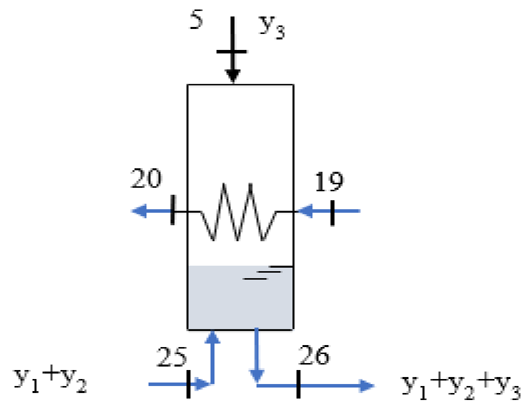


Figure (2.5) closed feed water heater 6

2.1.4.4 Open Feedwater Preheater

Energy balance for open feedwater heater which is shown in the figure (2.7) is given with following equations;

$$y_4h_6+(y_1+y_2+y_3)h_{27}+(1-(y_1+y_2+y_3+y_4))h_{17}-h_{18}=0 \quad 2.11$$

$$y_4=\frac{-(1-(y_1+y_2+y_3))h_{17}-(y_1+y_2+y_3)h_{27}+h_{18}}{h_6-h_{17}} \quad 2.12$$

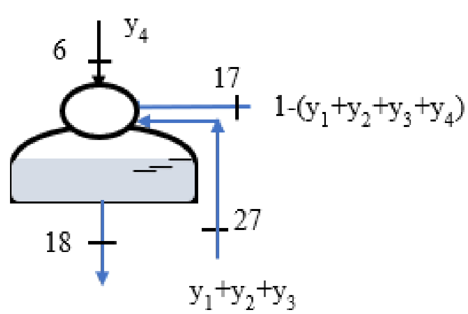


Figure (2.6) Open feedwater heater

2.1.4.5 Closed Feedwater Preheater (4)

Energy balance for closed feedwater heater 4 which is shown in the figure (2.7) is given below;

$$y_5(h_7-h_{28})+\left(1-(y_1+y_2+y_3+y_4)\right)h_{16}-\left(1-(y_1+y_2+y_3+y_4)\right)h_{17}=0 \quad 2.13$$

$$y_5=\frac{(1-(y_1+y_2+y_3+y_4)h_{17}-(1-(y_1+y_2+y_3+y_4))h_{16}}{h_7-h_{28}} \quad 2.14$$

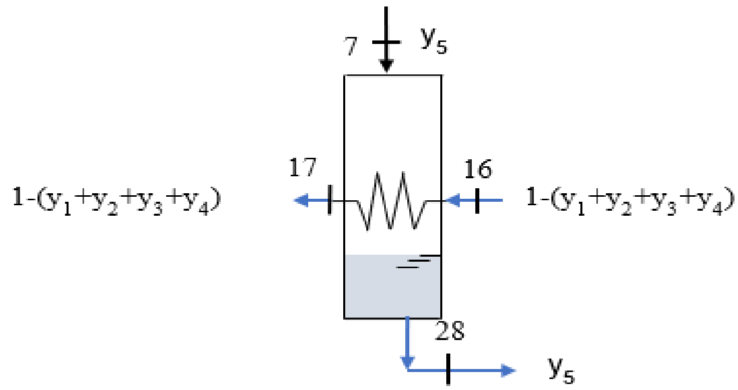


Figure (2.7) Closed feedwater heater (4)

2.1.4.6 Closed Feedwater Preheater (3)

Energy balance for closed feedwater heater 3 which is shown in the figure (2.8) is given below;

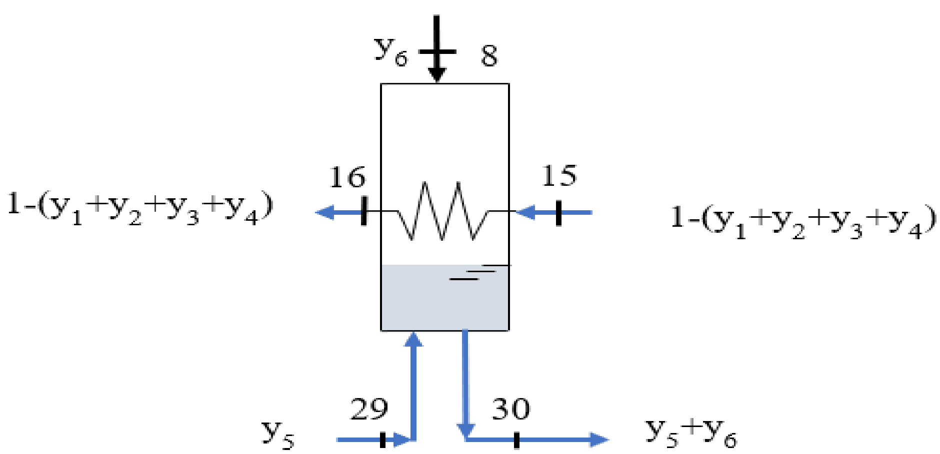


Figure (2.8) Closed feedwater heater 3

$$y_6h_8+y_5h_{29}+\left(1-(y_1+y_2+y_3+y_4)\right)h_{15}-\left(1-(y_1+y_2+y_3+y_4)\right)h_{16}-(y_5+y_6)h_{30}=0 \qquad 2.15$$

$$y_6=\frac{\left(1-(y_1+y_2+y_3+y_4)\right)h_{16}-\left(1-(y_1+y_2+y_3+y_4)\right)h_{15}-y_5(h_{29}-h_{30})}{h_8-h_{30}} \qquad 2.16$$

2.1.4.7 Closed Feedwater Preheater (2)

Energy balance for closed feedwater heater 2 shown in the figure (2.9) is given below:

$$y_7h_9+(1-(y_1+y_2+y_3+y_4)h_{14}-(1-(y_1+y_2+y_3+y_4)h_{15}+(y_5+y_6)h_{31}-(y_5+y_6+y_7)h_{32}=0 \qquad 2.17$$

$$y_7=\frac{(1-(y_1+y_2+y_3+y_4)h_{15}-(1-(y_1+y_2+y_3+y_4)h_{14}+(y_5+y_6)(h_{32}-h_{31})}{h_9-h_{32}} \qquad 2.18$$

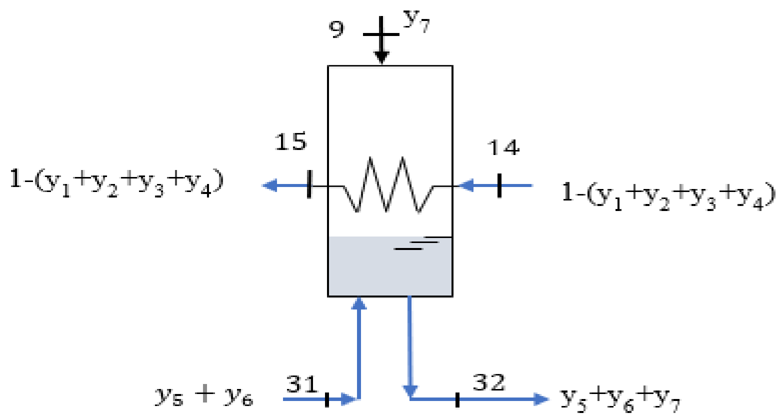


Figure (2.9) Closed feedwater heater 2

2.1.4.8 Closed Feedwater Preheater (1)

Energy balance for closed feedwater heater 1 shown in the figure (2.10) is given below;

$$y_8h_{10}+(1-(y_1+y_2+y_3+y_4)h_{13}-(1-(y_1+y_2+y_3+y_4)h_{14}+(y_5+y_6+y_7)h_{33}-(y_5+y_6+y_7+y_8)h_{34}=0$$

2.19

$$y_8=\frac{(1-(y_1+y_2+y_3+y_4)h_{14}-(1-(y_1+y_2+y_3+y_4)h_{13}+(y_5+y_6+y_7)(h_{34}-h_{33})}{h_{10}-h_{34}} \qquad 2.20$$

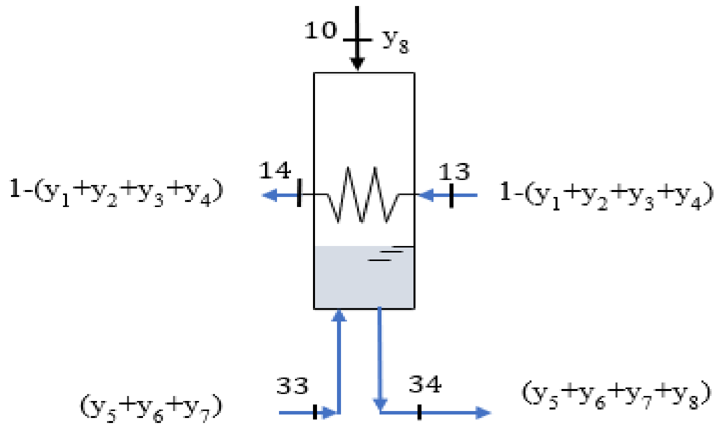


Figure (2.10) Closed feedwater heater 1

2.1.5 Turbine Energy Balance Equation

2.1.5.1 High Pressure-Turbine

The energy balance of high pressure turbine which is shown in the figure (2.11) is as follows;

$$\frac{w_{HPT}}{\dot{m}}=(h_1-h_2)+(1-y_1)(h_2-h_3) \quad 2.21$$

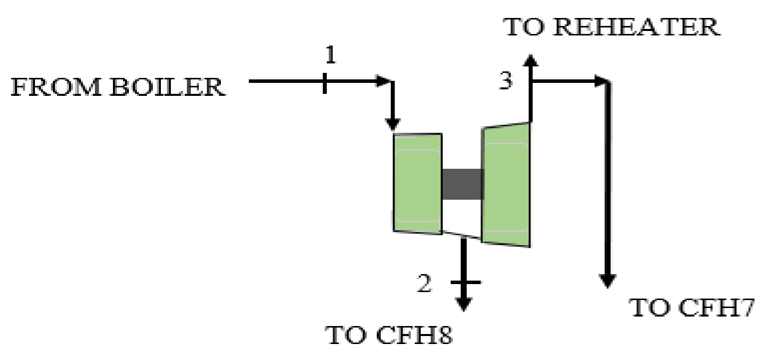


Figure (2.11) High pressure turbine

2.1.5.2 Intermediate Pressure Turbine

The energy balance of intermediate pressure turbine which is shown in the figure (2.12) as follows:

$$\frac{w_{IPT}}{\dot{m}}=\left(1-y_1-y_2\right)(h_4-h_5)+\left(1-y_1-y_2-y_3\right)(h_5-h_6) \qquad 2.22$$

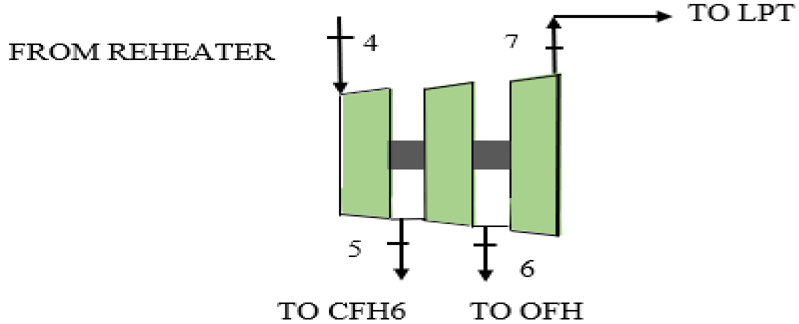


Figure (2.12) Intermediate pressure turbine

2.1.5.3 Low Pressure Turbine

The energy balance of low pressure turbine which is shown in the figure 2.13 is as shown below;

$$\frac{w_{LPT}}{\dot{m}}=\left(1-(y_1+y_2+y_3+y_4)\right)(h_6-h_7)+\left(1-(y_1+y_2+y_3+y_4+y_5)\right)(h_7-h_8)+\left(1-(y_1+y_2+y_3+y_4+y_5+y_6)\right)(h_8-h_9)+\left(1-(y_1+y_2+y_3+y_4+y_5+y_6+y_7)\right)(h_9-h_{10})+\left(1-(y_1+y_2+y_3+y_4+y_5+y_6+y_7+y_8)\right)(h_{10}-h_{11}) \qquad 2.23$$

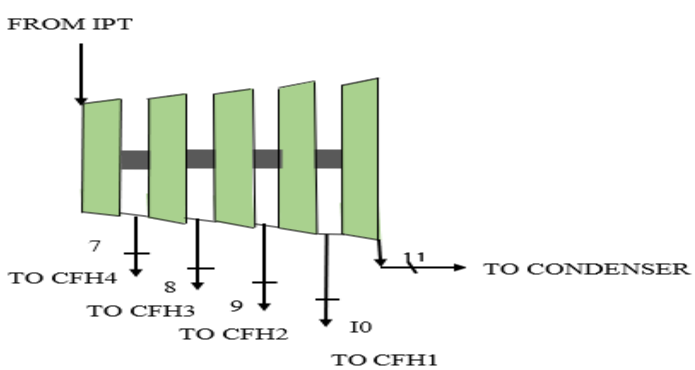


Figure (2.13) Low-pressure turbine

2.1.6 Condensate Water Pump Energy Balance Equations

The energy balance of condensate water pump which is shown in the figure 2.14 as follows:

$$\frac{w_{cp}}{\dot{m}}=(1-(y_1+y_2+y_3+y_4))(h_{13}-h_{12}) \quad 2.24$$

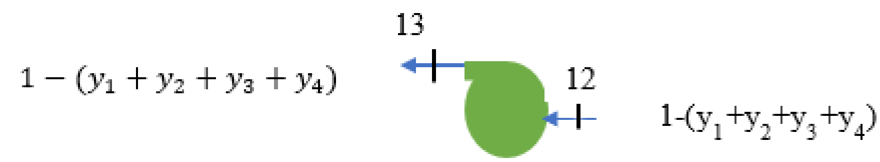


Figure (2.14) Condensate water pump

2.1.7 Feed Water Pump Energy Balance Equations

The energy balance of feedwater pump which is shown in the figure (2.15) is as follows;

$$\frac{w_{fwp}}{\dot{m}}=(h_{19}-h_{18}) \quad 2.25$$

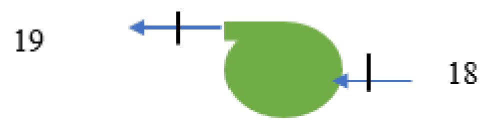


Figure (2.15) Feedwater pump

2.1.8 Energy Balance Equations for the Boiler and Reheater

As shown in figure (2.16), the total heat added is equal to heat gain by water coming from high pressure close feedwater preheater and heat gain by the steam coming from the final stage of HPT.

$\frac{Q}{\dot{m}}$= $(h_1-h_{36})+(1-y_1-y_2)(h_4-h_3)$ 2.26

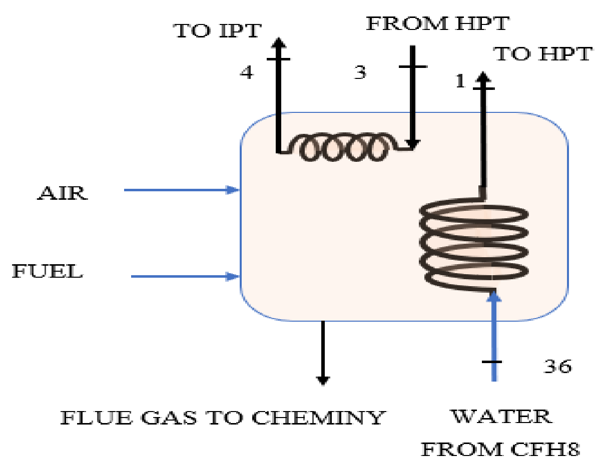


Figure (2.16) Boiler and Reheater

Heat added by combustion of fuel is given as;

$Q_{fuel}=\dot{m}_{fuel}$ LHV 2.27

Where;

LHV for heavy fuel oil =42.7 MJ/kg

According to the power plant data; one unit of Wassit thermal power plant consumes 70000 kg of heavy fuel oil to produce 330 MW.

2.1.9 Fluid Mass Flow Rate for the Overall Thermal Power plant

Mass flow rate of steam for the overall plant is given by:

$$\dot{m} = \frac{overall\ output\ elictricity \frac{MW}{hr} * \frac{3600hr}{s} * 1000}{\text{overall turbine work}\left(\frac{kJ}{kg}\right) * 1000 - \text{pumps work}\left(\frac{kJ}{kg}\right)}$$ 2.28

2.1.10 Boiler Efficiency

The boiler efficiency is the ratio between the heat added by the working fluid to the heat added by combustion of fuel as shown in the equation below;

$$\eta_b = \frac{Q}{Q_{fuel}} \qquad 2.29$$

2.1.11 Thermal Power Plant Efficiency

2.1.11.1 Thermal Efficiency in Terms of Regenerative Rankine Cycle Work Relations;

The efficiency is given as:

$$\eta_{th} = \frac{\text{net work}}{\frac{heat\ added}{\eta_b}} \qquad 2.30$$

Where;

$$\text{network} = \frac{w_{HPT}}{\dot{m}} + \frac{w_{IPT}}{\dot{m}} + \frac{w_{LPT}}{\dot{m}} - \frac{w_{cp}}{\dot{m}} - \frac{w_{fwp}}{\dot{m}} \qquad 2.31$$

$$heat\ added = \frac{\dot{Q}}{\dot{m}} \qquad 2.32$$

2.1.11.2 Thermal Efficiency in Terms of Fuel Consumption

The efficiency in terms of output power and fuel consumption is given as:

$$\eta_{th} = \frac{\text{output power}}{Q_{fuel}} \qquad 2.33$$

2.1.12 Condenser Heat Balance Equations

Heat rejected in condenser is given by following formula;

$$Q_{rejected} = \dot{m}[(1- y_1 - y_2 - y_3 - y_4 - y_5 - y_6 - y_7 - y_8)\, h_{11} + (y_5 - y_6 - y_7 - y_8)\, h_{34} - (1- y_1 - y_2 - y_3 - y_4) h_{12}] \qquad 2.34$$

2.2 Analytical Calculations of Hybrid Power Plant at Solar Time

The effect of solar field is felt during the day since there is no solar radiation in the night. So, the calculations of section (2.1) which is for the original power plant will be exactly the same calculations of the estimated hybrid power plant at night.

The heat exchanger is estimated to transfer heat from heat transfer fluid (therminol VP1) to the water coming from the feedwater pump instead of using extraction steam in high pressure closed feedwater heaters by two schemes. The first scheme is using solar energy to transfer heat from solar field to heat transfer fluid VP1 and then to the water coming from feedwater pump instead of using high pressure preheaters (6,7,8) which is used for March, April, May, June, July, August, September, and October. On the other hand, the second scheme is formed by using solar energy to transfer heat from solar field to heat transfer fluid and then to the water coming from closed feedwater heater 7, instead of using high pressure preheater (8) which is used for January, February, November and December. Figure (2.17) shows the hybrid solar power plant schematic.

2.2.1 Estimating the Amount of Solar Energy

The amount of solar energy required for the hybrid power plant for the first scheme is estimated by multiplying the difference between enthalpy values of water at the exit of feedwater pump and water at the exit of CFH8 by the mass flow rate of water. While the amount of solar energy required for the hybrid power plant for second scheme is estimated by multiplying the difference between enthalpy values of water at the exit of CFH7 and water at the exit of CFH8 by the mass flow rate of water. The enthalpy value of water incoming to boiler is assumed to be same as the value in the original power plant. Therefore,

$$Q_{solar,1}=\dot{m}(h_{36}-h_{19}) \quad 2.35$$

$$Q_{solar,2}=\dot{m}(h_{36}-h_{21}) \quad 2.36$$

2.2.2 Analytical Calculations for Hybrid Power Plant at Solar Time for the First Scheme

Using all data for the original power plant to find the turbine work, condensate water pump, feed water pumps and high and low-pressure preheaters for the calculation of first scheme by setting each value of fraction steam (y_1,y_2, y_3) equal to zero.

2.2.2.1 Open Feed Water Heater (First Scheme)

The energy balance of open FWH becomes:

$$(1\text{-}y_4)h_{17}+y_4h_6\text{-}h_{18}=0 \quad 2.37$$

$$y_4=\frac{h_{18}\text{-}h_{17}}{h_6\ \text{-}h_{17}} \quad 2.38$$

2.2.2.2 Closed Feedwater Heater 4 (First Scheme)

The energy balance of closed FWH4 becomes:

$$(1\text{-}y_4)h_{16}\text{-}(1\text{-}y_4)h_{17}+y_5h_7\text{-}y_5h_{28}=0 \quad 2.39$$

$$y_5=\frac{(1\text{-}y_4)(h_{17}\text{-}h_{16})}{h_7\ \text{-}h_{28}} \quad 2.40$$

2.2.2.3 Closed Feedwater Heater 3 (First Scheme)

The energy balance of closed FWH3 becomes:

$$(1\text{-}y_4)h_{15}+y_5h_{29}+y_6h_8\text{-}(1\text{-}y_4)h_{16}\text{-}(y_5+y_6)h_{30}=0 \quad 2.41$$

$$y_6=\frac{(1\text{-}y_4)(h_{16}\text{-}h_{15})+y_5(h_{30}\text{-}h_{29})}{h_8\ \text{-}h_{30}} \quad 2.42$$

2.2.2.4 Closed Feedwater Heater 2 (First Scheme)

The energy balance of closed FWH2 becomes;

$$(1\text{-}y_4)h_{14}+y_5h_{29}+y_7h_9-(1\text{-}y_4)h_{15}+(y_5+y_6)h_{31}-(y_5+y_6+y_7)h_{32}=0 \quad 2.43$$

$$y_7=\frac{(1\text{-}y_4)(h_{15}-h_{14})+(y_5+y_6)(h_{32}-h_{31})}{h_9-h_{32}} \quad 2.44$$

2.2.2.5 Closed Feedwater Heater 1 (First Scheme)

The energy balance of closed FWH1 becomes;

$$(1\text{-}y_4)(h_{13}+h_{14})+y_8h_{10}+(y_5+y_6+y_7)h_{33}-(y_5+y_6+y_7+y_8)h_{34}=0 \quad 2.45$$

$$y_8=\frac{(1\text{-}y_4)(h_{14}-h_{13})+(y_5+y_6+y_7)(h_{34}-h_{33})}{h_{10}-h_{34}} \quad 2.46$$

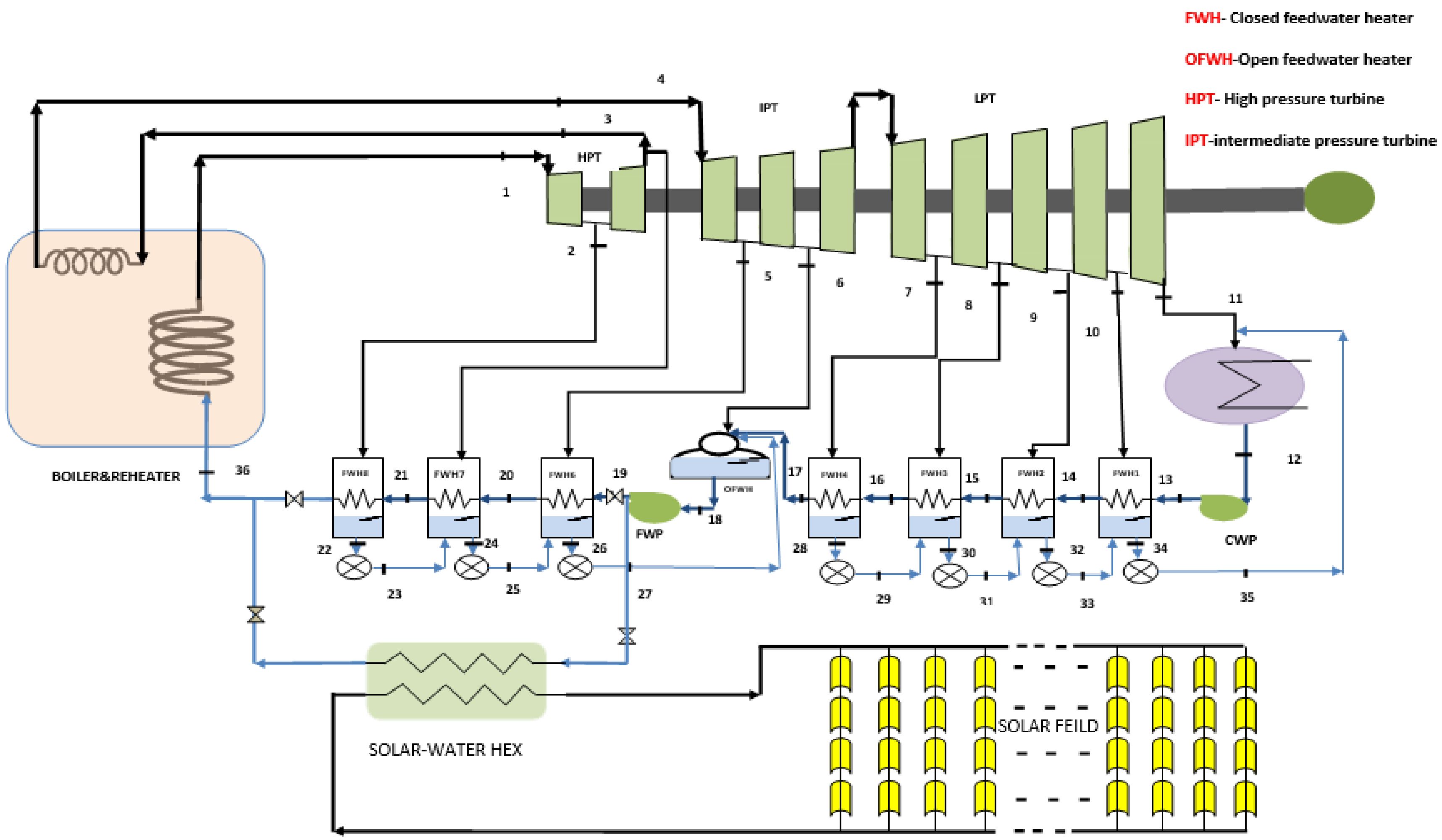


Figure (2.17) Hybrid power plant schematic

2.2.2.6 Hybrid Power Plant Turbine Work at Solar Time (First Scheme)

High-Pressure specific turbine work is given as;

$$\frac{w}{\dot{m}}=h_1-h_3 \qquad 2.47$$

Intermediate and Low-Pressure Turbine Work

$$\frac{w_{t2}}{\dot{m}}=h_4-h_6+(1-y_4)(h_6-h_7)+(1-y_4-y_5)(h_7-h_8)+(1-y_4-y_5-y_6)(h_8-h_9)+(1-y_4-y_5-y_6-y_7)(h_9-h_{10})+(1-y_4-y_5-y_6-y_7-y_8)(h_{10}-h_{11}) \qquad 2.48$$

2.2.2.7 Hybrid Power Plant Feedwater Pump Work (First Scheme)

The energy balance of feedwater pump becomes;

$$\frac{w_p}{\dot{m}}=h_{19}-h_{18} \qquad 2.49$$

2.2.2.8 Hybrid Power Plant Condensate Water Pump Work (First Scheme)

The energy balance of condensate water pump becomes;

$$\frac{W_c}{\dot{m}}=(1-y_4)(h_{13}-h_{12}) \qquad 2.50$$

2.2.3 Analytical Calculations for Hybrid Power Plant at Solar Time for the Second Scheme

Calculation are done using all data for the original power plant to find the work of turbine, condensate water pump, feed water pumps and high and low-pressure preheaters for the calculation of second scheme by setting the value of fraction steam (y_1) equal to zero.

2.2.3.1 Closed Feedwater Heater 7 (Second Scheme)

The energy balance of CFH7 becomes;

$$y_2h_3+h_{20}-y_2h_{24}-h_{21}=0 \qquad 2.51$$

$$y_2=\frac{h_{21}-h_{20}}{h_3-h_{24}} \quad (2.52)$$

2.2.3.2 Closed Feedwater Heater 6 (Second Scheme)

The energy balance of CFH6 becomes;

$$y_3h_5-(y_2+y_3)h_{26}+y_2h_{25}+h_{19}-h_{20}=0 \quad (2.53)$$

$$y3=\frac{y_2h_{26}-y_2h_{25}-h_{19}+h_{20}}{h_5-h_{26}} \quad (2.54)$$

2.2.3.3 Open Feedwater Heater (Second Scheme)

The energy balance of OFH becomes;

$$y_4h_6+(y_2+y_3)h_{27}+(1-(y_2+y_3+y_4))h_{17}-h_{18}=0 \quad (2.55)$$

$$y_4=\frac{-(1-(y_2+y_3))h_{17}-(y_2+y_3)h_{27}+h_{18}}{h_6-h_{17}} \quad (2.56)$$

2.2.3.4 Closed Feedwater Heater 4 (Second Scheme)

The energy balance of CFH4 is given as;

$$y_5(h_7-h_{28})+(1-(y_2+y_3+y_4))h_{16}-(1-(y_2+y_3+y_4))h_{17}=0 \quad (2.57)$$

$$y_5=\frac{(1-(y_2+y_3+y_4))h_{17}-(1-(y_2+y_3+y_4))h_{16}}{h_7-h_{28}} \quad (2.58)$$

2.2.3.5 Closed Feedwater Heater 3 (Second Scheme)

The energy balance of CFH3 is shown below;

$$y_6h_8+y_5h_{29}+(1-(y_2+y_3+y_4))h_{15}-(1-(y_2+y_3+y_4))h_{16}-(y_5+y_6)h_{30}=0 \quad (2.59)$$

$$y_6=\frac{(1-(y_2+y_3+y_4))h_{16}-(1-(y_2+y_3+y_4))h_{15}-y_5(h_{29}-h_{30})}{h_8-h_{30}} \quad (2.60)$$

2.2.3.6 Closed Feedwater Heater 2 (Second Scheme)

The energy balance of CFH2 is as follows;

$$y_7h_9+(1-(y_2+y_3+y_4)h_{14}-(1-(y_2+y_3+y_4)h_{15}+\left(y_5+y_6\right)h_{31}-(y_5+y_6+y_7)h_{32}=0 \quad 2.61$$

$$y_7=\frac{(1-(y_2+y_3+y_4)h_{15}-(1-(y_2+y_3+y_4)h_{14}+(y_5+y_6)(h_{32}-h_{31})}{h_9-h_{32}} \quad 2.62$$

2.2.3.7 Closed Feedwater Heater1 (Second Scheme)

The energy balance of CFH1 becomes;

$$y_8h_{10}+\left(1-(y_2+y_3+y_4\right)h_{13}-\left(1-(y_2+y_3+y_4\right)h_{14}+\left(y_5+y_6+y_7\right)h_{33}-\left(y_5+y_6+y_7+y_8\right)h_{34}=0 \quad 2.63$$

$$y_8=\frac{\left(1-(y_2+y_3+y_4\right)h_{14}-\left(1-(y_2+y_3+y_4\right)h_{13}+\left(y_5+y_6+y_7\right)(h_{34}-h_{33})}{h_{10}-h_{34}} \quad 2.64$$

2.2.3.8 Hybrid Power Plant Turbine Work at Solar Time (Second Scheme)

High-pressure specific turbine work is calculated as follows;

$$\frac{w}{\dot{m}}=h_1-h_3 \quad 2.65$$

Intermediate -pressure specific turbine work is calculated as follows;

$$\frac{w_{IPT}}{\dot{m}}=\left(1-y_2\right)(h_4-h_5)+\left(1-y_2-y_3\right)(h_5-h_6) \quad 2.66$$

Low -pressure specific turbine work is calculated as below;

$$\frac{w_{LPT}}{\dot{m}}=\left(1-\left(y_2+y_3+y_4\right)\right)(h_6-h_7)+\left(1-\left(y_2+y_3+y_4+y_5\right)\right)(h_7-h_8)+\left(1-\left(y_2+y_3+y_4+y_5+y_6\right)\right)(h_8-h_9)+\left(1-\left(y_2+y_3+y_4+y_5+y_6+y_7\right)\right)(h_9-h_{10})+\left(1-\left(y_2+y_3+y_4+y_5+y_6+y_7+y_8\right)\right)(h_{10}-h_{11}) \quad 2.67$$

2.2.3.9 Hybrid Power Plant Feed Water Pump Work (Second Scheme)

The energy balance of the feed water pump becomes;

$$\frac{w_p}{\dot{m}}=h_{19}-h_{18} \quad 2.68$$

2.2.3.10 Hybrid Power Plant Condensate Water Pump Work (Second Scheme)

The energy balance of the condensate water pump becomes;

$$\frac{W_c}{\dot{m}}=(1-y_2-y_3-y_4)(h_{13}-h_{12}) \quad 2.69$$

2.2.4 Calculation of Working Fluid Mass Flow Rate and Energy Production in Boosting Power Mode

In boosting power mode, which is for producing more power from the original power plant, the amount of fuel consumption is considered constant as 70 ton/h for 330 MW energy production as the original power plant consumes. The equation below which is formulated upon the equations 2.27, 2.29, and 2.32 are used to find the amount of mass flow rate of working fluid (water).

$$\dot{m} = \frac{0.88*LHV*1000*\dot{m}_{fuel}*1000}{h_{add}*1000*3600} \quad 2.70$$

Where;

$\dot{m}_{fuel}$ is mass flow rate of heavy fuel oil.

The equation used to find energy production is;

$$E = \dot{m}(w_t - w_{fwp} - w_{cwp}) \quad 2.71$$

Where;

E; is energy production

2.2.5 Calculation of Mass Flow Rate of Heavy Fuel Oil in Fuel Saving Mode

In fuel saving mode, the amount of mass flow rate of working fluid (water) is considered constant; and is equal to the amount that is used to produce the output electricity in original power plant which is 330 MW. The equation below is formulated to compute the amount of fuel consumption upon the equations 2.27, 2.29, and 2.32;

$$\dot{m}_{fuel} = \frac{\dot{m}*heat\ added*3600}{\eta_b*LHV*1000} \quad 2.72$$

CHAPTER 3

SOLAR ENERGY CALCULATIONS

3.1 Equation of Time (ET)

Equation of time (ET) it is the variation in apparent solar time which is caused by rotation of the earth in elliptical orbit around the sun. The value of (ET) is obtained by the equation below [5];

$$ET = 9.87\sin(2B) - 7.35\cos(B) - 1.5\sin(B) \quad [min] \qquad 3.1$$

$$B = (N - 81)360/364 \qquad 3.2$$

Where;

N: number of day in the year

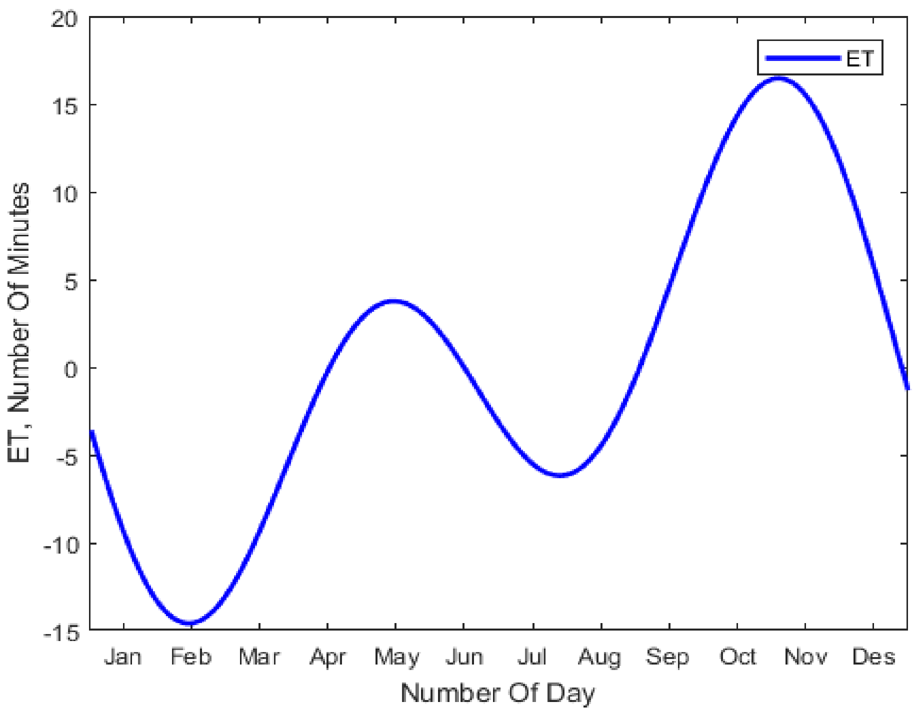


Figure (3.1) Equation of time

3.2 Longitude Correction

The standard time is considered at the center of the meridian in the Greenwich (longitude is equal to ˚0). The sun needs 4 minutes to pass ˚1 of longitude. So,

longitude correction= $\mp 4(SL\text{-}LL)$ 3.3

where; SL is standard longitude, and LL is local longitude.

3.3 Apparent Solar Time (AST)

Apparent Solar Time is found by using the formula below;

AST=LST+ET$\mp$4(SL-LL)-DS 3.4

Where; LST = Local standard time, DS; Daylight saving.

The daylight-saving time in Iraq equal to zero, and the sign of longitude correction is minus since, Iraq's location is in the east of Greenwich.

3.4 Solar Angles

According to the daily rotation of earth around itself and yearly rotation of earth around the sun in elliptical orbit, the seasonal variations happen. The distance between the earth and sun varies throughout the year. The maximum distance in the summer is equal to $152.1\text{x}10^6$ km while the minimum distance in the winter is equal to $147.1\ \text{x}10^6$ km. The angle between the axis of rotation of the earth around itself and the elliptic orbit is equal to 23.45˚. This angle is the capital variation of the amount of available solar radiation in different seasons at any region on the earth. Figure (3.2) [5] shows the solar angles (latitude, hour angle, and solar declination).

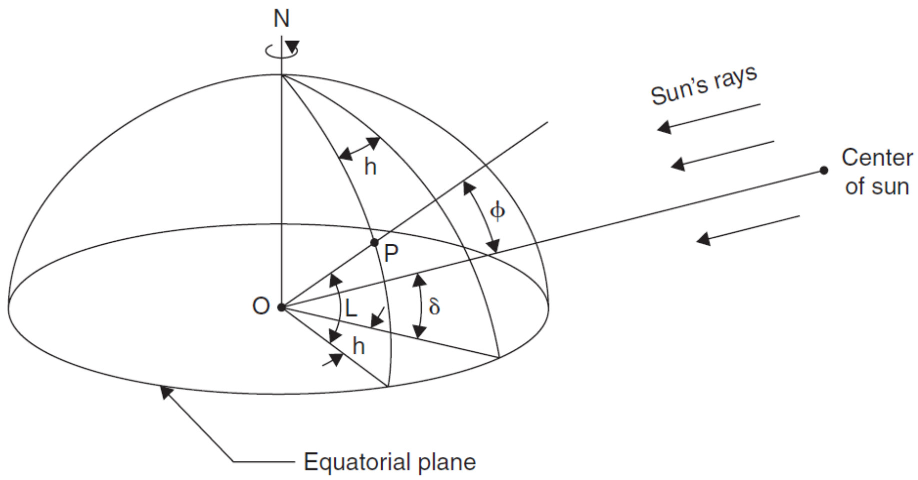


Figure (3.2) schematic showing the solar angles (latitude, hour angle, and solar declination), [5].

3.4.1 Solar Declination

Solar declination **(**δ) is the angle between the imaginary line between the center of the earth and the center of the sun with its projection on the equator plane. Figure (3.3) shows the annual variation of the solar declination. Solar declination is approximately calculated by [ASHRAE, 2007];

$$\delta=23.45\left(\frac{360}{365}(284+N)\right) \quad 3.5$$

Where (N) represents the number of days of the year.

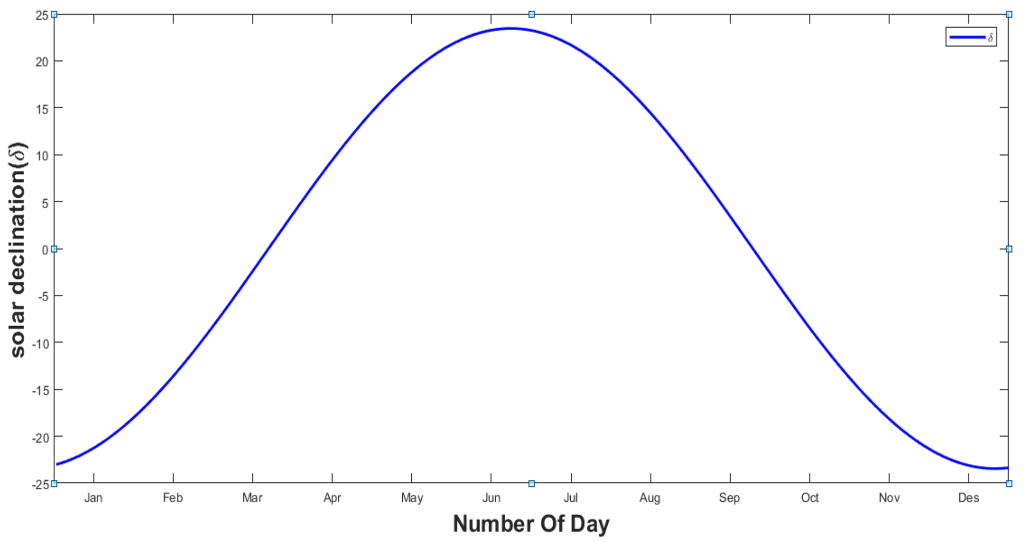


Figure (3.3) The annual variation of the solar declination

3.4.2 Hour Angle

Hour Angle (h) is the angle that is needed to turn any location of the earth to the meridian. The figure (3.2), [5] shows the angle between the projection of the imaginary line (OP) and the projection of the sun-earth imaginary line on the equator plane. The hour angle is found by using either the equation;

$$h = \mp 0.25(\text{No. of minutes}) \quad 3.6$$

where;

number of minutes represents the number of minutes from solar noon which are positive in the afternoon hours and negative before noon hours.

Or by using the equation;

$$h = (AST-12)15 \quad 3.7$$

3.4.3 Solar Altitude and Solar Zenith Angle

As shown in figure (3.4), solar altitude angle **(**α)is the angle between the sun rays and its projection on the equator plane the while zenith angle **(**ϕ) is the angle between the sun-ray and the vertical. The equations for altitude and zenith angles are;

$$\sin(\alpha) = \cos(\phi) = \sin(L)\sin(\delta) + \cos(L)\cos(\delta)\cos(h) \quad 3.8$$

and from definition;

$$\phi + \alpha = 90 \quad 3.9$$

where;

L=Local latitude

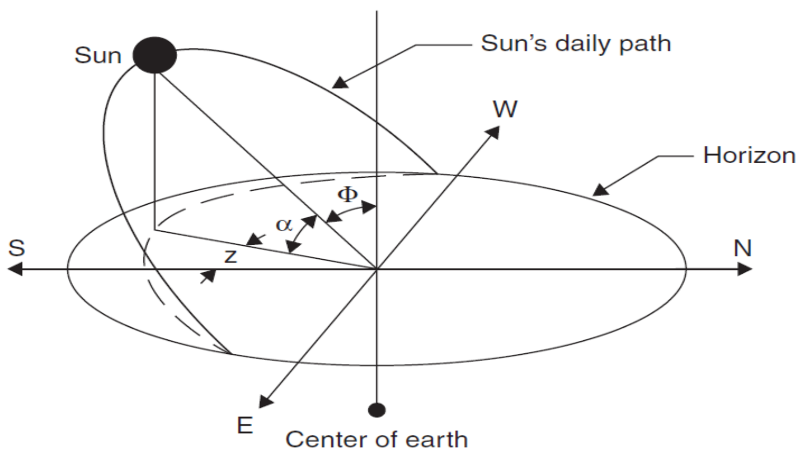


Figure (3.4), the daily sun path from sun rise to sun set, [5].

3.4.4 Solar Azimuth Angle

Solar Azimuth Angle (z) is the angle between the projection of the sun rays on the equator plane and the line between north-south in the same plane. It is positive in the western and negative in the eastern side. The mathematical equation for the solar azimuth angle is;

$$\sin(z)=\frac{\cos(\delta)\sin(h)}{\cos(\alpha)} \quad 3.10$$

at solar noon, the solar azimuth angle is equal to zero.

3.4.5 Sun Rise and Sun Set

When the sun rises or sets the solar altitude angle becomes zero. So, the equation (3.7) will become;

$$\sin(\alpha)=\sin(0)=0=\sin(L)\sin(\delta)+\cos(L)\cos(\delta)\cos(h_{ss}) \quad 3.11$$

and

$$\cos(h_{ss})=\frac{-\sin(L)\sin(\delta)}{\cos(L)\cos(\delta)}=-\tan(L)\tan(\delta) \quad 3.12$$

Where;

h_{ss} is the hour angle at sun-set. It is taken as a positive sign at sun set. The hour angle needs 4 minutes to pass 1° from longitude that means, it needs one hour to pass 15° of longitude.

$$H_{ss}=\frac{1}{15}\cos^{-1}(\tan(L)\tan(\delta)) \quad 3.13$$

Where;

H_{ss}&H_{sr} are the sun-set and sun rise time from local solar noon (hour).

$$\text{day length}=\frac{2}{15}\cos^{-1}(\tan(L)\tan(\delta)) \quad 3.14$$

3.4.6 Incidence Angle

Incidence angle **(θ)** is the angle between sun rays and the normal of the surfaces as shown in the figure (3.6), [5]. The equation for incidence angle is given as [Kreith and Kreider,1978; Duffie and Beckman,1991];

$$\cos(\theta) = \sin(L)\sin(\delta)\cos(\beta) - \cos(L)\sin(\delta)\sin(\beta)\cos(Z_s) + \cos(L)\cos(\delta)\cos(h)\cos(\beta) + \sin(L)\cos(\delta)\cos(h)\sin(\beta)\cos(Z_s) + \cos(\delta)\sin(h)\sin(\beta)\sin(Z_s) \qquad 3.15$$

3.5 Horizontal North-South Axis with East- West Tracking

Using the tracking system with parabolic trough collectors for utilizing solar energy decreases the incidence angle which increases the incidence beam radiation, [7]. Iraq country consumes a big amount of electricity in the summer compared to the requirement in the winter. Since single axis tracking (N-S horizontal with E-W tracking) collects high-power electricity in the summer and less in the winter it is suitable for this operation, which is shown in figure (3.6). The mathematical equation for incidence angle for this type of single-axis tracking [Kreith and Kreider,1978; Duffie and Beckman],1991] is given as;

$$\cos(\theta) = \sqrt{\sin^2(\alpha) + \cos^2(\delta)\sin^2(h)} \qquad 3.16$$

and the equation for collector slope (β) shown in the figure (3.5) is;

$$\tan(\beta) = \tan(\phi)\,|\cos(Z_s - z)| \qquad 3.17$$

where; Z_s is either equal to (90) or (-90) that is depended on solar azimuth angle (z);

If (z)>0° degree, Z_s=90° ; If (z)<0° degree, Z_s= - 90°

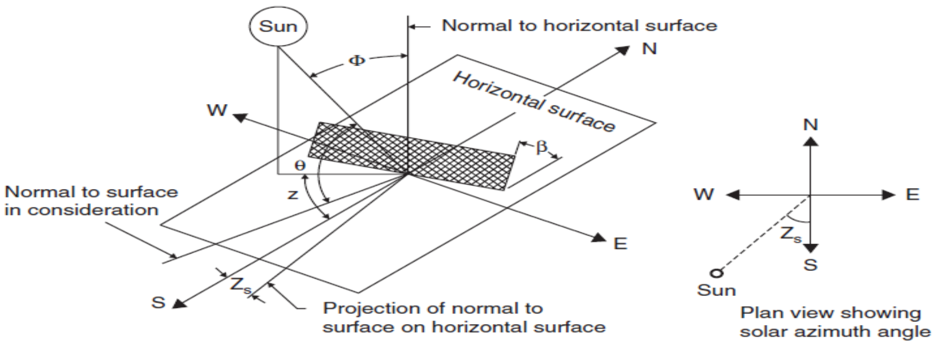


Figure (3.5) Solar Angels ($\theta, \mathcal{B}, z, \phi, Z_s$), [5].

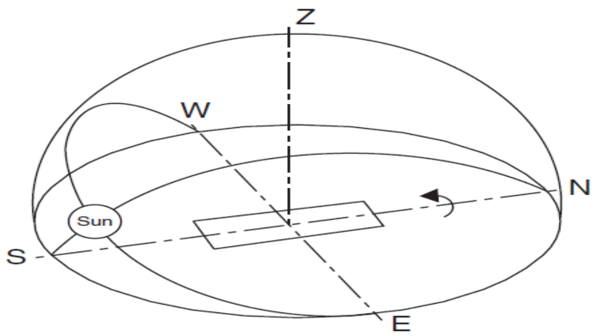


Figure (3.6) N- W horizontal and E-W tracking, [5].

3.6 Hourly Beam Radiation

Wassit power plant which is the case studies are conducted is located in Iraq in Wassit City where Longitude=44.8˚N and Latitude=33.01˚E. Table (3.1) shows the data of monthly average daily radiation for July, wind velocity, and air temperature [24], and monthly average daily total insolation on extraterrestrial horizontal surface, [5];

Table (3.1) Geographical and weather properties for the site of power plant

No.	Geographical and physical properties	The value	Note
1	Longitude	44.84˚E	
2	Latitude	33.01˚N	
3	Wind velocity (m/s)	2.68	
4	Ambient temperature (˚C)	44.2	
5	Monthly average daily radiation on a terrestrial horizontal surface for July (MJ/m^{2}-day)	26.86	The data for 17^{th} July
6	Monthly average daily total insolation on extraterrestrial horizontal surface for July (MJ/m^{2}-day)	40.5	
7	Number of days for 17 July	17+181=198	

Since there is no hourly radiation data the method follows is used to calculate hourly beam radiation, [5];

Monthly average index clearance (K_T) is;

$$K_T=\frac{H}{H_0} \qquad 3.18$$

where;

H ; Monthly average total radiation on the terrestrial horizontal surface, (MJ/m^2-day).

H_0 ; Monthly average daily total radiation on the extraterrestrial horizontal surface, (MJ/m^2).

The following empirical equation is used to find the average diffuse radiation;

$$\frac{H}{H_D}=1.39-4.027K_T+5.531K_T^2-3.108K_T^3 \qquad 3.19$$

According to (Lui and Jordan (1977)) correlation of the ratio of hourly diffuse radiation to daily diffuse radiation is (r_d);

$$r_d=\frac{\text{average hourly diffuse radiation}}{H_D}=\left(\frac{\pi}{24}\right)\frac{\cos(h)-\cos(h_{ss})}{\sin(h_{ss})-\left(\frac{2\pi h_{ss}}{360}\right)\cos(h_{ss})} \qquad 3.20$$

According to (Collares-Pereira and Rabl 1977) correlation of the ratio of hourly total radiation to daily total radiation is (r);

$$r=\frac{\text{average hourly total radiation}}{H}=\left(\frac{\pi}{24}\right)[\alpha+\beta\cos(h_{ss})]\left(\frac{\cos(h)-\cos(h_{ss})}{\sin(h_{ss})-\left(\frac{2\pi h_{ss}}{360}\right)\cos(h_{ss})}\right) \qquad 3.21$$

$$\alpha=0.409+0.5016\sin(h_{ss}-60) \qquad 3.22$$

$$\beta=0.6609-0.4767\sin(h_{ss}-60) \qquad 3.23$$

$$H=H_D+G_{Bn} \qquad 3.24$$

Where;

G_{Bn} ; Direct beam radiation.

$$G_{BT}=G_{Bn}\cos(\theta) \qquad 3.25$$

where;

G_{BT}; average hourly beam radiation on the tilted surface (W/m^2).

3.7 Characteristics for Parabolic Trough Collectors and Receiver

LS-3 parabolic trough collectors which are manufactured by Luz. company and SCHOTT PTR70 receivers which are manufactured by German company are estimated to be used in the construction of the solar field in Wassit thermal power plant. The characteristics of LS-3 collectors, [19] and SCHOTT PTR70 receivers, [25], [29] are shown in the table (3.2).

Table (3.2) characteristics of LS-3 collectors, [19] and SCHOTT PTR70 receivers, [25], [29].

No.	characteristics	value
1	Maximum wind velocity(km/h)	56
2	Steel structure based on	Space frame
3	Absorptivity/transmissivity (%)	96/95
4	Emissivity (%)	18/350˚C
5	Focal distance of the concentrator	1.71
6	Aperture angle (°)	80
7	Reflectivity (%)	94
8	Trough aperture (m)	5.76
9	Absorber steel pipe outer diameters (m)	0.07
10	Geometric concentration ratio	26
11	Mirror surface per collectors (m^2)	545
12	Maximum working temperature	390 ˚C
13	Distance between parallel rows (m)	17
14	Intercept factor (%)	93
15	Overall length (m)	99
Receiver characteristics		
1	Tube thermal conductivity (W/m.K)	15
2	Outer diameter (Glass) (m)	0.125
3	The inner diameter (Glass m)	0.119 m
4	Outer diameter of receiver (m)	0.07
5	Absorber steel pipe inner diameters(m)	0.055
6	Solar absorbance (%)	96
7	Thermal emittance (%)	9.5
8	Glass envelope solar emittance (%)	0.97
9	Receiver length (m)	4.06

3.8 Optical Analysis for Parabolic Trough Collectors

Figure (3.7), [5] shows a cross-section of parabolic trough collector,

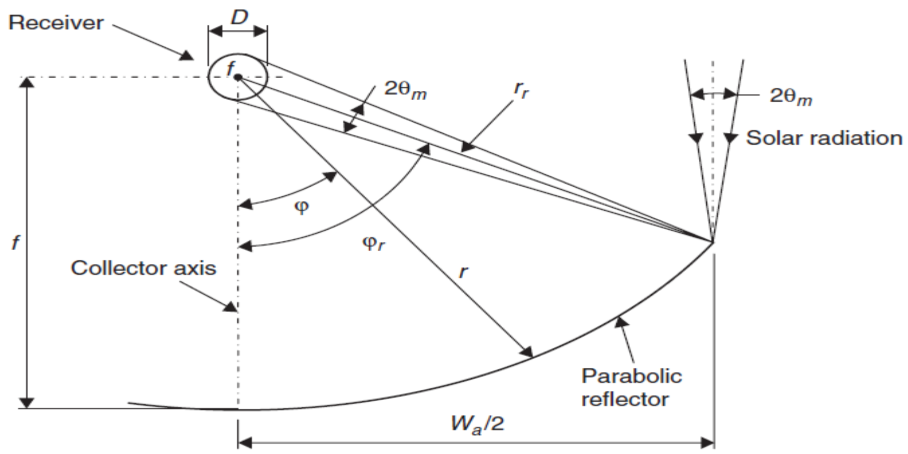


Figure (3.7) cross section of parabolic trough collector [5]

The equation of parabola is;

$$y=\sqrt{4f\,x} \quad 3.26$$

where;

f is parabola focal distance, (m)

$$D=2\,r_r\,\sin(\theta_m) \quad 3.27$$

r_r ; maximum radius of the mirror.

θ_m; the half acceptance angle.

$$r=\frac{2f}{1+\cos(\varphi)} \quad 3.28$$

$$r_r=\frac{2f}{1+\cos(\psi_r)} \quad 3.29$$

Where;

ψ_r is the angle between r_r and f which is called rim angle.

ψ is angle between the collector axis and reflected beam radiation at the focus.

The aperture distance (W_a) is shown below;

$$W_a=4f\tan(\frac{\psi_r}{2}) \quad 3.30$$

The concentrating ratio (C) is shown below;

$$C=\frac{W_a}{\pi D} \quad 3.31$$

Geometric factor (A_f) calculation is as follows;

$$h_p=f=\frac{W_a}{4\tan(\frac{\psi_r}{2})} \quad 3.32$$

$$A_l=\frac{2}{3}W_a\,h_p+f\,W_a(1+\frac{W_a^2}{48f^2}) \quad 3.33$$

$$A_f=\frac{A_l}{A_a} \quad 3.34$$

Where;

A_l is the total loss in aperture area

h_p is the parabola height

and

$$A_a = W_a L \quad 3.35$$

Optical efficiency is equal to the ratio of energy absorbed by receiver to energy incidence on the collector, and the mathematical expression (Sodha et al (1984)) is given as;

$$\eta_0 = \rho\, \tau\, \alpha\, \gamma\, (1 - A_f \tan(\theta) \cos(\theta)) \quad 3.36$$

Where;

ρ; The reflectance of the mirror

γ ; The intercept factor (for LS-3=0.93)

τ; The transmittance of the glass cover

α ; The absorbance of the receiver

The peak optical efficiency is found at zero value of the incidence angle.

3.9 Thermal Analysis of Parabolic Trough Collectors

Energy collected by the beam radiation for one collector is calculated at the time of 11:00- 12:00 from 17 July by considering this date and time as a design point. The mass flow rate for one collector is estimated equal to 5 kg/s, [26]. Figure (3.8) shows the schematic of a section of parabolic trough collector [28]. The glass cover is used in SCHOTT receiver to reduce thermal losses by making vacuum space between the absorber tube and the glass cover. Also, the glass cover is coated by anti-reflective to decrease reflective losses. The absorber tube is coated by high absorbance material with low emittance to increase energy absorbed and decrease the energy losses by emittance. The length of SCHOTT receiver is 4.06 m. So, LS3 receiver is needed around 24.3 segments. The analytical calculations are done on one segment. [5], [7], [30],

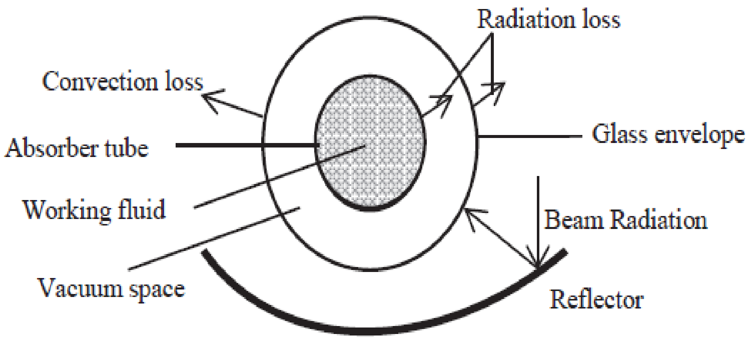


Figure (3.8) schematic of a section of parabolic trough collector [28]

3.9.1 Heat Transfer Coefficient (h_i) for Therminol Heat Transfer Fluid VP1.

The average temperature and velocity of heat transfer fluid VP1 is calculated as;

$$T_{fm}=\frac{T_i+T_0}{2} \quad 3.37$$

$$U_f=\frac{\dot{m}_f}{\rho\, A_i} \quad 3.38$$

where;

$\dot{m}_f$; The mass flow rate of heat transfer fluid.

A_i; The inside area of the receiver.

ρ; The density of heat transfer fluid at T_{fm}

Reynold number and Prandtl number are calculated respectively as;

$$R_{eD}=\frac{U_f\, D_i}{\mu} \quad 3.39$$

. Prandtl number is calculated as;

$$p_r=\frac{\mu\, Cp}{k} \quad 3.40$$

Where;

μ ; The viscosity of heat transfer fluid at T_{fm}.;

C_p, k ; The thermal conductivity and heat capacity of heat transfer fluid at T_{fm}

By assuming the flow is fully developed turbulent flow.

$R_{eD} > 10^4$, $0.6 < p_r < 160$, and$\frac{L}{D} > 10$,The Dittus-Boelter correlation for the flow inside the pipe with heating processes can be applied to find Nusselt number and heat transfer coefficient, [21];

$$N_{UD}=0.023\ (R_{eD}^{\frac{4}{5}})(p_r^{0.4}) \quad 3.41$$

$$h_i = \frac{N_{UD} D_i}{k} \quad 3.42$$

3.9.2 Overall Heat Loss Coefficient (U_L)

Axial conduction is neglected since the temperature gradients along the receiver is small, and the receiver temperature is assumed to be constant. So, the overall heat transfer coefficient is calculated by the following procedure;

The first step is assuming the glass temperature which is close to ambient temperature rather than absorber temperature since the ambient temperature is around 44˚C, the first guess is 65˚C, and the final guess is 51˚C.

The properties of air (ρ_w,μ_w,k_w) are found by using the mean temperature between the temperature of glass envelope and the ambient temperature.

$$R_{ew} = \frac{\rho_w U_w}{\mu_w} \quad 3.43$$

According to McAdams (1954) correlations to find Nusselt number for air passing a single tube in the outdoor environment are, [7];

$$Nu = 0.4 + 0.54 {R_{ew}}^{0.52} \qquad \text{For } 0.1 < Re < 1000 \quad 3.44$$

or

$$Nu = 0.3 {R_{ew}}^{0.6} \qquad \text{For } 1000 < Re < 50000 \quad 3.45$$

and

$$h_w = \frac{Nu\ k_w}{D_{g0}} \quad 3.46$$

Where

D_{g0} ; The outer diameter of glass cover. So;

$$U_L = \left(\frac{A_r}{(h_w + h_{r,g\text{-}a}) A_g} + \frac{1}{h_{r,r\text{-}g}} \right)^{-1} \quad 3.47$$

Where;

U_L ; loss coefficient based on receiver area(A_r).

$h_{r,g\text{-}a}$; Linearized radiation coefficient from glass cover to ambient.

$h_{r,r\text{-}g}$; Linearized radiation coefficient from absorber to glass cover.

A_g ; The outside area the glass cover.

$$h_{r,g\text{-}a} = \varepsilon_g \sigma (T_g + T_a)(T_g^2 + T_a^2) \quad 3.48$$

Radiation coefficient are calculated as follows;

$$h_{r,r\text{-}g}=\frac{\sigma(T_r+T_g)(T_r^2+T_g^2)}{\frac{1}{\varepsilon_r}+\frac{A_r}{A_g}\left[\frac{1}{\varepsilon_g}-1\right]} \quad 3.49$$

Where;

ε_g ; The emissivity of the glass cover.

ε_g ; The emissivity of the absorbance.

T_r ; absorbance temperature (assumed constant along receiver).

T_g ; The glass cover temperature.

The energy balance for the piping is;

$$A_g\left(h_{r,g\text{-}a}+h_w\right)\left(T_g-T_a\right)=A_r h_{r,r\text{-}g}(T_r-T_c) \quad 3.50$$

$$T_g=\frac{A_r h_{r,r\text{-}g} T_r+A_c(h_{r,g\text{-}a}+h_w)T_a}{A_r h_{r,r\text{-}g}+A_c(h_{r,g\text{-}a}+h_w)} \quad 3.51$$

$$U_0=\left(\frac{1}{U_L}+\frac{D_O}{h_{fi}D_i}+\frac{D_0\ \ln\left({}^{D_0}/_{D_i}\right)}{2k}\right)^{-1} \quad 3.52$$

where;

U_0 ; Overall heat transfer coefficient inside the pipe;

The collector efficiency factor($\bar{F}$) is calculated as;

$$\bar{F}=\frac{U_0}{U_L}=\frac{{}^{1}/_{U_L}}{\frac{1}{U_L}+\frac{D_0}{h_{fi}D_i}+\left(\frac{D_0}{2k}\ln\frac{D_0}{D_i}\right)} \quad 3.53$$

Finally, the useful energy collected by the collector (Q_U) is found as;

$$Q_U=F_R[SA_a-A_rU_L(T_i-T_a)] \quad 3.54$$

where;

F_R The heat removal factor given below.

$$F_R=\frac{\dot{m}Cp}{A_rU_L}\left[1\text{-exp}\left[-\frac{A_rU_L\bar{F}}{\dot{m}Cp}\right]\right] \quad 3.55$$

and

$$S=G_b\eta_0 \quad 3.56$$

Also, Useful energy is equal to:

$$Q_U=\dot{m}Cp\ (T_0-T_{i0}) \quad 3.57$$

then;

$$T_0=200+\frac{Q_U}{\dot{m}Cp} \quad 3.58$$

3.10 Sizing of Solar Fields

As already explained in the introduction chapter; a typical PTC field is composed of a number of parallel rows each row composed of several collectors connected in series so that the working fluid flows through the absorber pipe when it passes from inlet header to outlet header, Figure (1.9), [19].

3.10.1 Number of Collectors in One Row

The following formula is used to find the number of collectors in one row**;**

$$N = \frac{\Delta T}{\Delta Tc} \qquad 3.59$$

Where;

N; it is the number of collectors to be connected in series in a row.

ΔT ; It is the difference between the outlet and inlet temperature of the solar field.

ΔTc ; It is the difference between the single collector nominal inlet and outlet temperature for heat transfer fluid.

3.10.2 Number of Rows in Solar Field

Number of rows is the ratio between the thermal power needed by the industrial process and the thermal power delivered by a single row of collectors at design point.

3.10.3 The Layout of Solar Fields with PTCs

As shown in section (1.11.3), the best layout for a large solar field is the center-feed configuration that is used to decrease the length of the piping in the construction of the solar field.

3.10.4 The Solar Multiple

Solar multiple is the ratio between the energy output from solar field at design point to the energy demand at the same design point. For the solar power plant without heat storage, it is in the range of 1.14 to 1.3, [26].

3.10.5 Overall Energy Gain from the Solar Field

The energy gain from the solar field is obtained by using the following formula;

$$Q_{u,all} = (q_{u1} + q_{u2} + q_{u3} + q_{u4})N_{rows} \quad 3.60$$

where;

$q_{u1} + q_{u2} + q_{u3} + q_{u4}$ are the energy gain from collector 1 to 4 respectively.

N_{rows} ; number of rows.

3.10.6 Heat Transfer Fluid VP1 Mass Flow Rate

The amount of mass flow rate of heat transfer fluid is obtained by using the following formula;

$$\dot{m}_{VP1} = \dot{m}_{VP1,row} * N_{rows} \quad 3.61$$

Where;

$\dot{m}_{VP1}$; Overall mass flow rate of VP1.

$\dot{m}_{VP1,row}$; mass flow rate of VP1 for one row and it is equal to 5 kg/s.

3.11 Economic Analysis

Economic analysis is done by using levelized cost of energy method (LCOE). This method is used to evaluate the cost of the energy of the project with respect to energy production for life cycle. Also, it is beneficial to compare the cost of alternative energy (hybrid power plant in this case) with the cost of the energy that is generated from fossil fuel oil. The formula that is used to evaluate (LCOE) is, [22];

$$LCOE = \frac{I + \sum_{n=1}^{N}\left[\frac{Cost_{annual,n}}{(1+d)^n}\right] * (1 - T_R)}{\sum_{n=1}^{N} \dot{E}_{annual}(1 - R_d)^n / (1+d)^n} \quad 3.62$$

where;

I; is initial investment cost

$Cost_{annual,n}$ is annual fuel, operation and maintenance (O&M) cost.

d; is the discount rate.

T_R ; is the tax rate.

R_d ; is the system degradation rate.

$\dot{E}_{annual}$; is the net output power annually in kWh.

N; is the project life.

The estimated cost that is used to find the LCOE is adapted from the studies, [22], [37], [38] which depend on SOLAR ADVISOR MODEL (SAM) model as shown in the table (3.3).

Table (3.3) The estimated cost that are used to calculate LCOE, [22], [37], [38]

Direct Cost (DC)	Value	Unit
Site Improvements	25	$/m^2
Solar Field	295	$/m^2
HTF System	90	$/m^2
Fossil Backup	0	$/kW
Contingency	10	% of DC
Indirect Cost Category		
Engineer, Procure, Construct	15	% of DC
Project, Land, Management	3.5	% of DC
Sales Tax	7.75	%
HEX COST*	12990x8	$
O&M Cost		
Fixed Annual Cost	0	$/yr
Fixed Cost by Capacity	70	$/kW-yr
Fuel Cost	0	$/MMBTU
Other		
Project Life	30	years
Annual Degradation Rate	0.5	%
Inflation Rate	2.5	%
Variable Cost per Generation	3	$/MWh

*Necessary parameters for calculating heat exchangers cost is obtained from Chapter 4.

3.11.1 Initial Investment Cost

Initial investment cost is total of direct and indirect costs. Direct cost is found from the formulations below**;**

$$DC = [(SI + SF + HTF_{system})A_{sf} + HEXcost + C_{storage} + C_{FB} + C_{PB}](1 + F_{contingency}) \quad 3.63$$

where;

DC; is the direct cost,

SI is the site improvement cost,

SF is the solar field cost,

HTF_{system} is the cost of heat transfer fluid,

A_{sf}, is the area of solar field,

HEXcost, is the heat exchangers cost, [40].

$C_{storage}$; is the cost of the storage tank of HTF.

C_{FB} is the cost of fossil fuel back-up?

C_{PB} ; is the cost of the power block.

$F_{contingency}$, is the contingency factor.

Indirect costs are found as below;

$$IC = DC(EPC + PLM + ST) \quad 3.64$$

where;

IC; is the indirect cost. EPC , are the engineering, procurement and construction costs. ST , is the sale tax. PLM ; is the project, land, management cost.

3.11.2 The Discount Rate

There are two different analyses which can be used to evaluate the discount rate, the first one is evaluating nominal discount rate which is includes inflationary effects, and the second is for evaluating real discount rate which is excludes inflationary effects. By using the following formulas, the discount rate can be converted from nominal to real and vice versa [39]:

$$d_n = (1 + d_r)(1 + e) - 1 \quad 3.65$$

$$d_r = \left[\frac{1+d_r}{1+e}\right] - 1 \quad 3.66$$

Where;

d_n , is the nominal discount rate.

d_r , is the real discount rate.

e, inflation rate.

3.11.3 Tax rate

Tax rate will be estimated equal to 15%, [42].

3.11.4 Annual Cost

Using the following formula to find annual cost for the project;

$$Cost_{annual,n} = FC + (FCC)P_{nom} + (VCG)\dot{E}_{annual}(MWh) + Cfuel \qquad 3.67$$

Where;

FC , is the fixed annual cost. FCC is the fixed cost by capacity. VCG is the variable cost per generation. $Cfuel$ is the fuel cost.

CHAPER 4

HEAT EXCHANGER PRELIMINARY DESIGN

4.1 Solar Heat Exchanger Preliminary Design

The process of the solar heat exchanger (HEX) in the hybrid power plant is considered high duty process since the water flows at a pressure of 165 bar. So, one pass- E Type [TEMA standard] shell and tube heat exchanger is chosen for using in hybrid power plant as shown in the figure (4.1) [32]. The limit of temperature difference in the inlets of heat exchanger must not exceed 50˚C from a thermal expansion consideration, [31]. Also, this kind of heat exchanger is a counter flow heat exchanger and it is more efficient than other kinds of heat exchangers, [21]. This heat exchanger is constructed parallel to high pressure closed feed water heaters. The water coming from feed water pump enters the pipe side of heat exchanger whereas the heat transfer fluid passes throughout the shell of the heat exchanger. The heat transfer from HTF to the water raises the water temperature to about 280˚C.

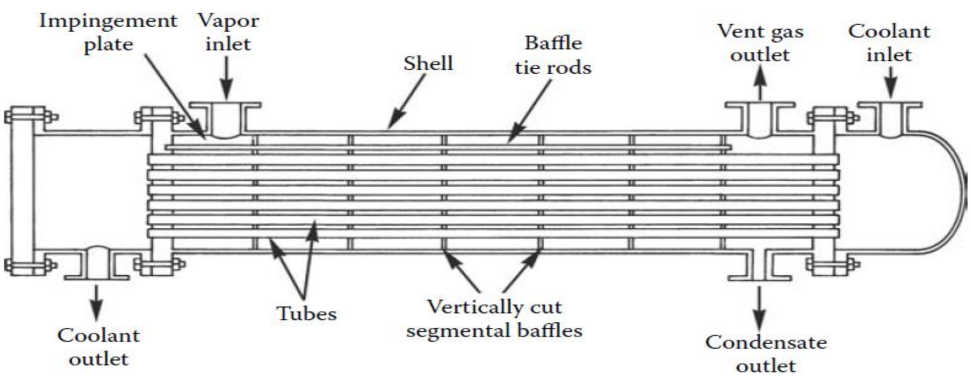


Figure (4.1) One pass E-Type shell and tube heat exchanger, [32]

4.1.1 The Heat Exchanger Pipes

The heat exchanger processes will be at 165 bars inside the tubes with operating fluid temperature in the range of 170-280 ˚C. So, the pipe will be chosen according to ASME standards, [35] by considering the hydraulic pressure inside the pipe equal to 1.5 multiplied by operating pressure and the operating temperature is considered with some additional safety value which is 426˚C.

Following equation is used to find the thickness of the tubes of the heat exchangers;

$$t = \frac{P*D}{2(SE+PY)} \qquad 4.1$$

Where;

t is pressure design thickness.

P is design pressure (250 bar).

D is pipe outside diameter (is assumed equal to 26.7mm).

S is allowable stress

E is longitudinal joint quality factor.

Y is wall thickness correction factor.

Nominal thickness (t_{nom}) and minimum required thickness(t_m) are calculated as

$$t_m = t + CA \qquad 4.2$$

$$t_{nom} = \frac{t_m}{0.875} \qquad 4.3$$

Where;

CA; corrosion allowance (estimated equal to 2 mm).

Alloy steel A691 1Cr is chosen for pipe material, and the nominal pipe is 3/4 inches (schedule 160) with outside diameter equal to 26.7 mm and the inner diameter equal to 15.68 mm.

4.1.2 Tube Layout

The layout with angle 30˚ is used when a large amount of heat transfer is needed, [34], [33] so this kind will be used in the preliminary design of heat the exchanger in this study. figure (4.2), shows triangular layout.

The tube pitch (p) is the distance between the center of two tubes and it must be computed with range of pitch ratio ($\frac{p}{d}$) equal to (1.25-1.5).

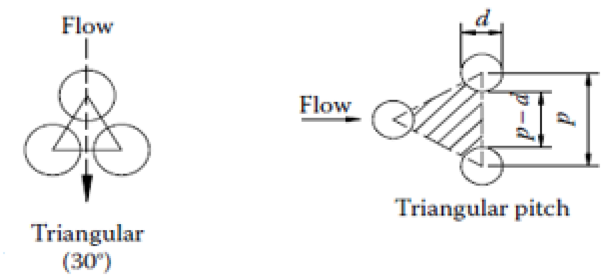


Figure (4.2) Triangular tube layout (30˚)

4.1.3 The Baffles

The baffles are the most important concern in the heat exchanger design since is it beneficial making the flow a turbulent flow which resist the vibration produced by the flow inside the tubes and inside the shell. There are many kinds of baffles but the most common are single segmental and double segmental [34]. The distance between two baffles is around (0.4-0.6) times shell diameter. The baffle cut is commonly used between 25% to 35% of the outer diameter to decrease the pressure drop generated in the shell. [32].

4.1.4 Assumptions used in HEX preliminary Design

The design calculations of solar-water heat exchanger will be done with some assumptions which are, [22];

1- The outer surface of the heat exchanger is adiabatic.
2- The pressure drops for both water and heat transfer fluid in heat exchanger are negligible;
3- The heat exchanger operates in steady state.
4- There is no heat generation in the heat transfer fluid.

As the heat transfer fluid, therminol VP1 will be used with the pressure up to the vapor pressure [15] to avoid evaporation risk. The vapor pressure of heat transfer fluid at the maximum temperature which is 310˚C for operation is around 2.87 bar. So, the heat transfer fluid pressure is chosen equal to 15 bars to cope with the difference of pressure produced in the solar field and heat exchanger in addition to the evaporation caused by low pressure.

4.1.5 Solar-Water Heat Exchanger Energy Balance

As shown in the figure (4.3) the water with pressure equal to 165 bar and temperature equal to 170˚C enters the heat exchanger from the tube side and exits with temperature equal to 280˚C. The heat transfer fluid with temperature equal to 310˚C enters the shell and exits the heat exchanger at temperature equal to 200˚C.

The total heat transfer needed from heat exchangers is;

$$Q_{solar}=\dot{m}(h_{36}-h_{19}) \qquad 4.4$$

$$\dot{m}(h_{36}-h_{19})=\dot{m}_f\, cp\, (T_i-T_0) \qquad 4.5$$

$$T_0 = T_i - \frac{\dot{m}(h_{36}-h_{19})}{\dot{m}_f cp} \qquad 4.6$$

The values of T_i&T_0 are the inlet and outlet heat transfer fluid temperature.

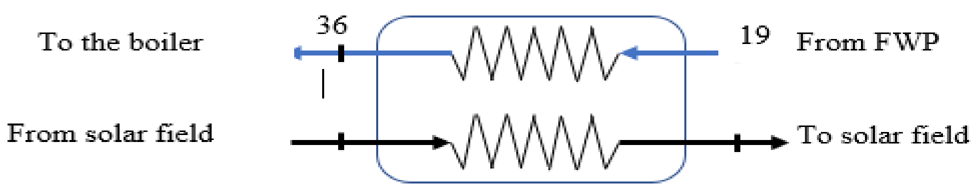


Figure (4.3), General heat exchanger simple schematic

4.1.6 Sizing of the Heat exchanger

Since there is a need of very high amount of energy from the solar field, sizing was determined after many trails. Eight heat exchangers are designed to transfer the energy from solar radiation to the water comes from feed-water pump by using heat transfer fluid VP1. These heat exchangers are constructed in series, so the maximum required from one heat exchanger is equa1 to;

$$Q_{hex}=\frac{Q_{solar}}{8} \qquad 4.7$$

4.1.7 Estimation of Unit Size

The size of heat exchanger can be found from the equation;

$$A_0=\frac{Q_{hex}}{U_0\Delta T_{lm,cf}} \qquad 4.8$$

Where;

A_0 ; It is the overall outside heat transfer area.

U_0 ; the overall heat transfer coefficient which is based on the outside area of the tube. It is calculated by considering the wall conduction resistance, convection (internal and external) resistance (eq 4.6), and for the later case, with fouling resistance (eq 4.7).

$$U_{0c}=\left[\frac{1}{h_0}+\frac{d_0}{d_i}\frac{1}{h_i}+\frac{d_0}{2}\frac{\ln\left(\frac{d_0}{d_i}\right)}{k}\right]^{-1} \qquad 4.9$$

$$U_{0f}=\left[\frac{1}{h_0}+\frac{d_0}{d_i}\frac{1}{h_i}+R_f+\frac{d_0}{2}\frac{\ln\left(\frac{d_0}{d_i}\right)}{k}\right]^{-1} \qquad 4.10$$

Where;

U_{0c} ; Overall heat transfer coefficient.

U_{0f} ; Overall heat transfer coefficient considering fouling.

h_0; heat transfer fluid VP1 heat transfer coefficient which is estimated equal to 1700W/m^{2}K, [32].

h_i; water heat transfer coefficient which is estimated equal to 10000W/m^{2}K, [32].

R_f ; Fouling resistance which is estimated equal to 0.000352, [32].

d_i ; The inside diameter of the pipe (15.58 mm).

d_0 ; The outside diameter of the pipe (25.67 mm).

$$\Delta T_{lm}=\frac{(T_i-T_{36})-(T_o-T_{19})}{\ln\frac{(T_i-T_{36})}{(T_0-T_{19})}}=\frac{\Delta T_1-\Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \qquad 4.11$$

Where;

ΔT_{lm} is [LMTD]log mean temperature difference

ΔT_1 is the temperature difference between two fluids (water leaving and heat transfer fluid entering the heat exchanger).

ΔT_2 ; is the temperature difference between two fluids (water entering and heat transfer fluid leaving the heat exchanger)

In the case of $\Delta T_1=\Delta T_2$,

$$[\Delta T_{lm}=\Delta T_1=\Delta T_2=(T_i-T_{36})=(T_o-T_{19})] \qquad 4.12$$

$\Delta T_{lm,cf} = \Delta T_{lm} F$ 4.13

where;

F; is equal to 1 for one pass E-shell and tube heat exchanger.

$A_0 = \pi d_0 N_t L$ 4.14

$N_t = (CTP)\frac{\pi D_s^2}{4A_1}$ 4.15

Where;

N_t ; The total number of tubes.

L; the tube length(m).

A_1 ; single tube area.

CTP; The tube count constant for the shell area not covered by the tube due to the clearance which is caused by tube layout, and it is equal to 0.93 for one tube pass, 0.9 for two tube passes, 0.85 for three tube passes.

$A_1 = [CL]P_T^2$ 4.16

Where;

CL; is the tube layout constant, and it is equal to 1 for 45˚& 90˚ layout, and equal to 0.87 for 30˚&60˚ layout.

The shell inside diameter (D_s) is calculated as;

$D_s = 0.637\sqrt{\frac{CL}{CTP}} \left(\frac{A_{0f}(PR)^2 d_0}{L}\right)^{0.5}$ 4.17

$N_t = 0.785\left(\frac{CTP}{CL}\right)\frac{D_s^2}{PR^2 d_0^2}$ 4.18

Where;

A_{0f} is the total heat transfer area by using U_{0f} .

4.1.8 Verification of the Preliminary Design

Verification of the preliminary Design of the heat exchanger by using suitable correlation for pressure drop in shell side and tube side is done in this part. Also, rerating shell side is done by using Kern method as shown in the next sections**.**

4.1.9 Heat Transfer Coefficient in Shell Side

Every heat exchanger has many baffles. The distance between two baffles is estimated as equal to 1 m. Using baffles in the heat exchanger make fluctuations in the flow causing turbulence and that assists to increase the heat transfer coefficient in the shell side.

By using McAdams correlation, the heat transfer coefficient in the shell side is found which is;

$$\frac{h_0 D_e}{k}=0.36\left(\frac{D_e G_s}{\mu}\right)^{0.55}\left(\frac{c_p \mu}{k}\right)^{\frac{1}{3}}\left(\frac{\mu}{\mu_w}\right)^{0.14} \quad 4.19$$

The correlation (4.16) is valid for;

$$2000\leq R_{es}=\frac{D_e G_s}{\mu}<1\times10^6 \quad 4.20$$

$$G_s=\frac{\dot{m}}{A_s} \quad 4.21$$

where;

G_s is the mass velocity of the shell side.

D_e the equivalent diameter which is;

$$D_e=\frac{4\times\text{flow area}}{\text{wetted peremeter}} \quad 4.22$$

$$D_e=\frac{4\times(\frac{p_T{}^2*\sqrt{3}}{4}-\pi d_0^2/8)}{\frac{\pi\, d_0}{2}} \quad 4.23$$

$$A_s=\frac{D_s C B}{P_T} \quad 4.24$$

Where;

C is the clearance between two tubes.

B is the space between two baffles.

D_s; is the inside diameter of the shell.

$$R_{es}=\frac{G_s D_e}{\mu} \quad 4.25$$

μ_w is found at T_w where;

$$T_w=0.5[0.5(T_{c1}+T_{c2})+0.5(T_{h1}+T_{h2})] \quad 4.26$$

Where;

$(T_{c1},T_{c2}),(T_{h1},T_{h2})$ represent the inlet and outlet temperature of water, and the inlet and outlet temperature of HTF respectively.

4.1.10 Heat Transfer Coefficient in Tube Side

The heat transfer coefficient inside the tube is found by using Gnielinkis' correlation as shown below;

$$N_b = \frac{\left(\frac{f}{2}\right)(R_e - 1000)pr}{1 + 12.7\left(f/_2\right)^2\left(pr^{\frac{2}{3}} - 1\right)} \qquad 4.27$$

$$A_{tp} = \frac{\pi\, d_i^2}{4}\frac{N_t}{n} \qquad 4.28$$

$$u_m = \frac{\dot{m}}{\rho A_{tp}} \qquad 4.29$$

$$R_e = \frac{\rho u_m d_i}{\mu} \qquad 4.30$$

Where;

A_{tp} ; is the inside tube area.

n; is the number of tube pass.

$$f = (1.58 \ln(R_e) - 3.28)^{-2} \qquad 4.31$$

$$h_i = \frac{N_{ub} k}{d_i} \qquad 4.32$$

4.1.11 Pressure Drop in Shell Side

The pressure drop in the shell side depends on the space between the baffles and the clearance among the tubes. The expression bellow is used to find the pressure drop in the shell side;

$$\Delta p_s = \frac{f G_s^2 (N_b + 1) D_s}{2 \rho D_e \emptyset_s} \qquad 4.33$$

Where;

$$\emptyset_s = \left[\frac{\mu}{\mu_w}\right]^{0.14} \qquad 4.34$$

$$N_b = \frac{L}{B} - 1 \qquad 4.35$$

$$f = EXP(0.576 - 0.19 \ln(R_{es})) \qquad 4.36$$

where this formula of friction factor is valid for,

$$400 < R_{es} = \frac{D_e G_s}{\mu} \leq 1 \times 10^6 \qquad 4.37$$

4.1.12 The Pressure Drop in the Tubes Side

The pressure drop in the tube side is calculated by using the below correlation;

$$\Delta p_t = 4f\frac{LN_p}{d_i}\rho u_m^2 \quad 4.38$$

Another kind of pressure drop in the tube side is caused by the change of the direction

$$\Delta p_r = 4N_p\frac{\rho u_m^2}{2} \quad 4.39$$

Finally, the total pressure drop of the tube side is;

$$\Delta p_{total} = \left(4f\frac{LN_p}{d_i} + 4N_p\right)\frac{\rho u_m^2}{2} \quad 4.40$$

CHAPTER 5

MATLAB SIMULATION

5.1 MATLAB Simulation of Original Power Plant

All thermodynamics equations in Chapter 2 are used in MATLAB simulation to analyze the original power plant. This simulation is used to find all values of enthalpy, entropy, fractions of extraction steam in all stages in the thermal power plant as well as specific work input and outputs to the system etc. with the help of SIMULINK module as shown in figure (5.1), and figures (D.1 to D.12).

5.1.1 The Fraction of Steam Extraction

The calculation of fractions of steam are done by using the heat balance formulation as shown in the section (2.1.4). The MATLAB simulation for the values ($y_1, y_2, y_3, y_4, y_5, y_6, y_7$, and y_8) of extraction steam for preheaters CFH8, CFH7, CFH6, OFH, CFH4, CFH3, CFH2, and CFH1, respectively are shown in the figures (D.1), (D.2), (D.3), (D.4), (D.5), and (D.6) respectively.

5.1.2 Pumps Work

As shown in the figure (D.7) the specific condensate water pump work and specific feed-water pump work (kJ/kg) are simulated by using energy balance formulation shown in the sections (2.1.6) and (2.1.7).

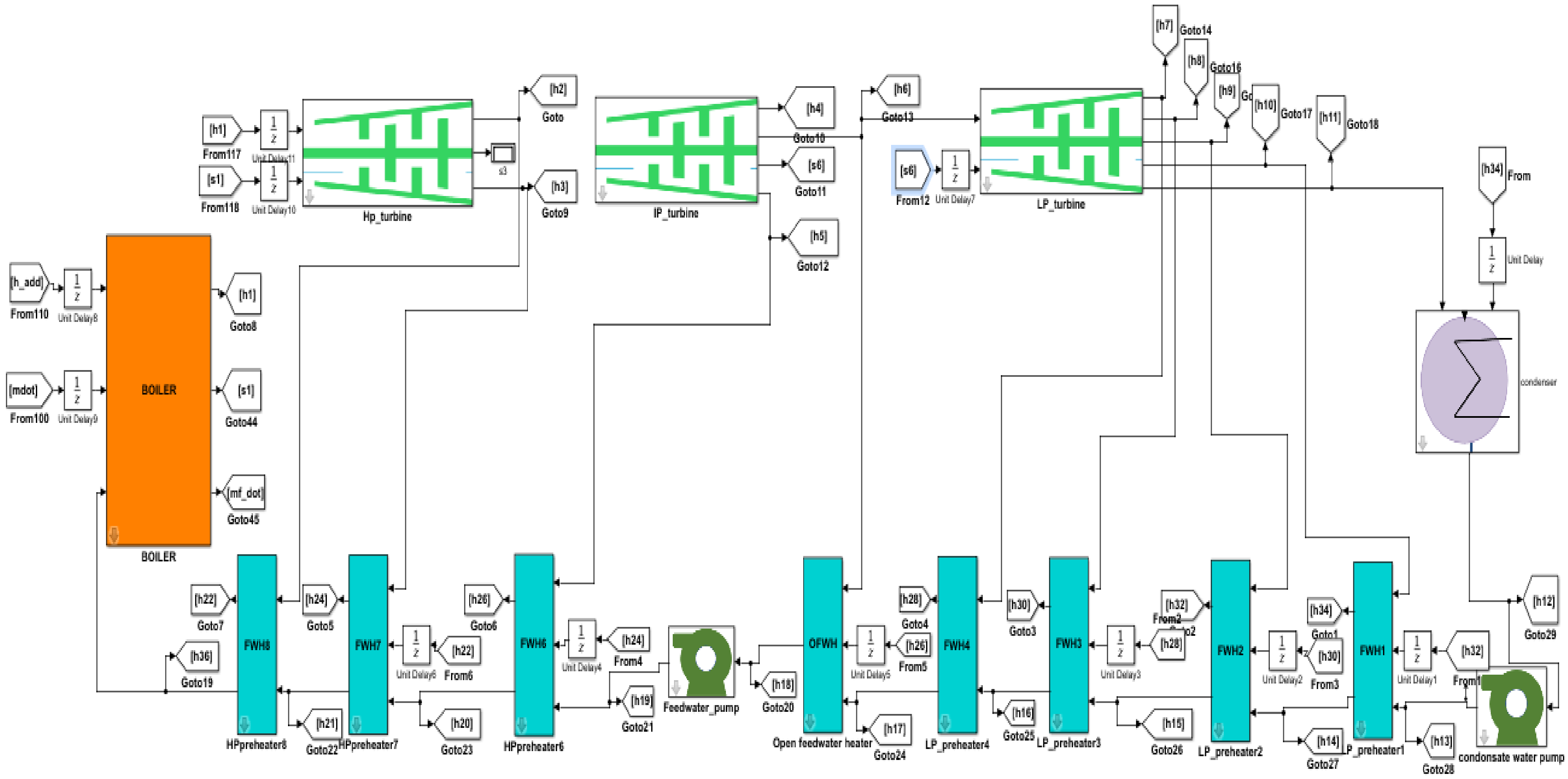


Figure (5.1) Thermal Power Plant MATLAB Simulation

5.1.3 Turbine Work

As shown in the figure (D.8), the total specific turbine work simulation in (kJ/kg) is done by using the energy balance equations for high-pressure, intermediate-pressure, and low-pressure turbines which were mentioned in section (2.1.5).

5.1.4 Heat Added in Boiler and Reheater

As shown in the figure (D.9), heat added in the boiler and reheater is simulated by using the formulations of heat balance which is mentioned in section (2.1.8).

5.1.5 Power Plant Efficiency Simulation

The equations mentioned in the section (2.1.11) are used to simulate power plant efficiency as shown in the SIMULINK module in figure (D.10).

5.1.6 Working Fluid Mass Flow Rate Simulation

The equation (2.28) is used to simulate working fluid mass flow rate at constant output energy which is 330 MW as shown in the figure (D.11).

5.1.7 Simulation of Heat Extracted in Condenser

The formulations were shown in the section (2.1.12) are used to simulate energy extracted from the condenser as shown in the figure (D.12).

5.2 Hybrid Power Plant Simulation

In this part, the figures of the simulation of extraction steam to the preheaters, specific turbine work, feed water pump work, heat extracted from condenser are not repeated since they are same as before as used in the original power plant simulations which are mentioned in the previous section. Only there are some manipulations like equating the fractions of steam (y_1, y_2, y_3) to zero for first scheme and (y_1) equal to zero for second scheme.

5.2.1 Solar Simulation

5.2.1.1 Solar Radiation Simulation

The simulation of the direct solar beam radiation is done by modeling the equations which are shown in sections 3.1 to 3.6.

5.2.1.2 Solar Field Simulation

Figure (5.2) shows a part of the simulation of first five segment from the first and second collectors respectively. Every segment is simulated depending on the procedure that was shown in chapter 3 to find the energy gain, the glass temperature, receiver temperature, heat loss coefficient and the output temperature of the heat transfer fluid for each segment. The original simulation represents one row from solar field which is made of 4 collectors, each collector is constructed from 24 segments and each segment has a length equal to 4.125 m, and connected to next one in series.
Solar hybrid power plant simulations are done for three representing days;
17^{th} July represent the average of summer months (June, July, August, and September).
15^{th} April represent the average of spring and fall months (March, April, October, and November).
17^{th} January represent the average of winter months (January, February, September, and December).

5.2.1.3 Overall Energy Gain from Solar Field and the Mass Flow Rate of VP1 Simulation

The simulation of the overall energy gain from the solar field and the amount of heat transfer fluid VP1 mass flow rate is shown in the figure (D.13). This simulation is done by using the equation (3.60)

5.2.2 The First Scheme Simulation

In the first scheme the solar heat exchanger is used instead of the high pressure closed feed water heaters 8,7, and 6 as shown in the figure (5.3).

5.2.3 The Second Scheme Simulation

In the second scheme the solar heat exchanger is used instead of the high pressure closed feed water heater 8 as shown in the figure (5.4).

5.2.4 Boosting Power Mode for Hybrid simulation

The simulation is used to find mass flow rate of working fluid and electricity generation in boosting power mode and is done by using the equations in section 2.2.4 as shown in the figure (D14).

5.2.5 Saving Fuel Mode for Hybrid simulation

The simulation is used to find mass flow rate of heavy fuel oil consumption in saving fuel mode and is done by using the equations in section 2.2.5 as shown in the figure (D.15).

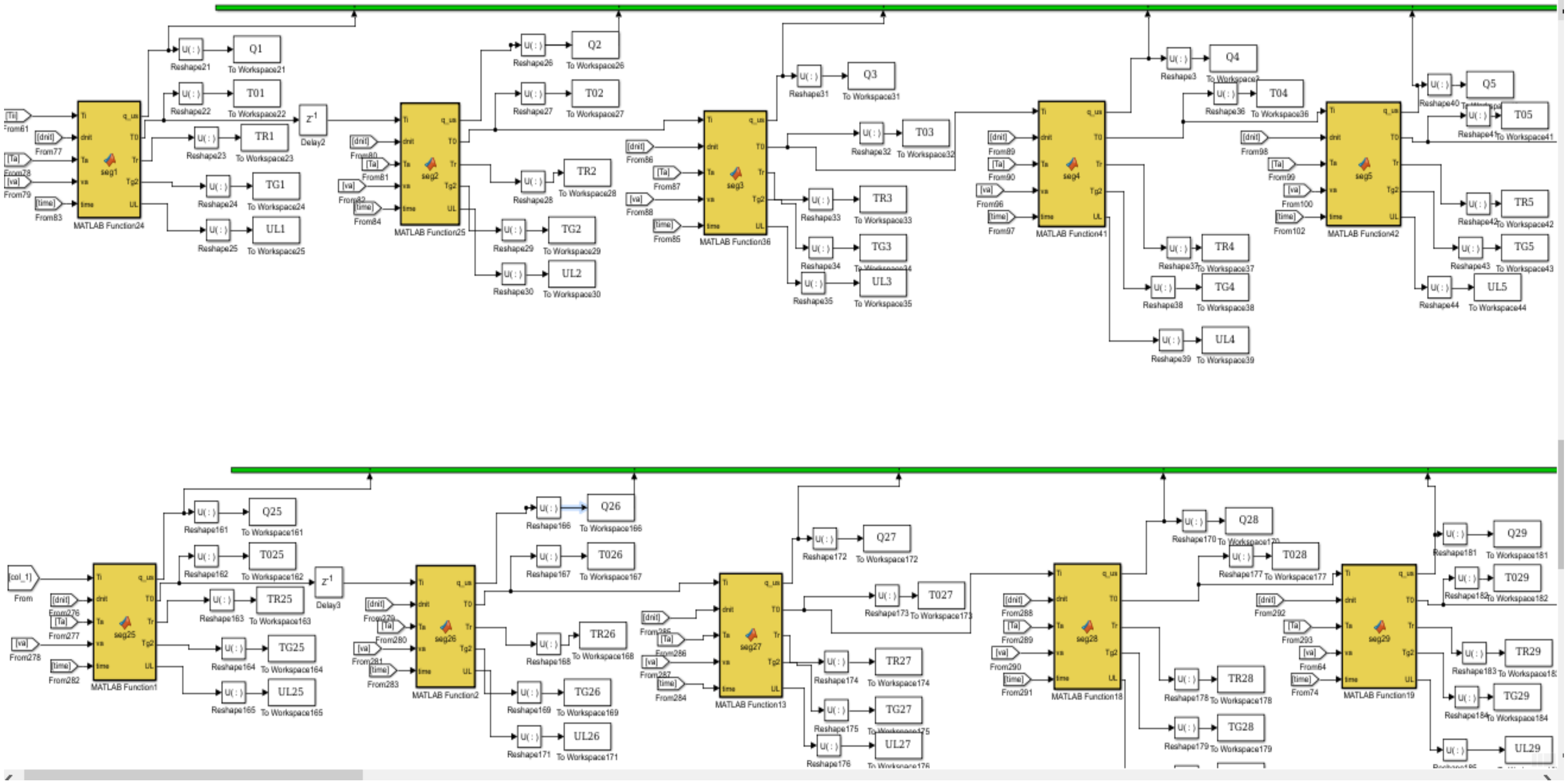


Figure (5.2) The first 5 segments for first and second collector simulation

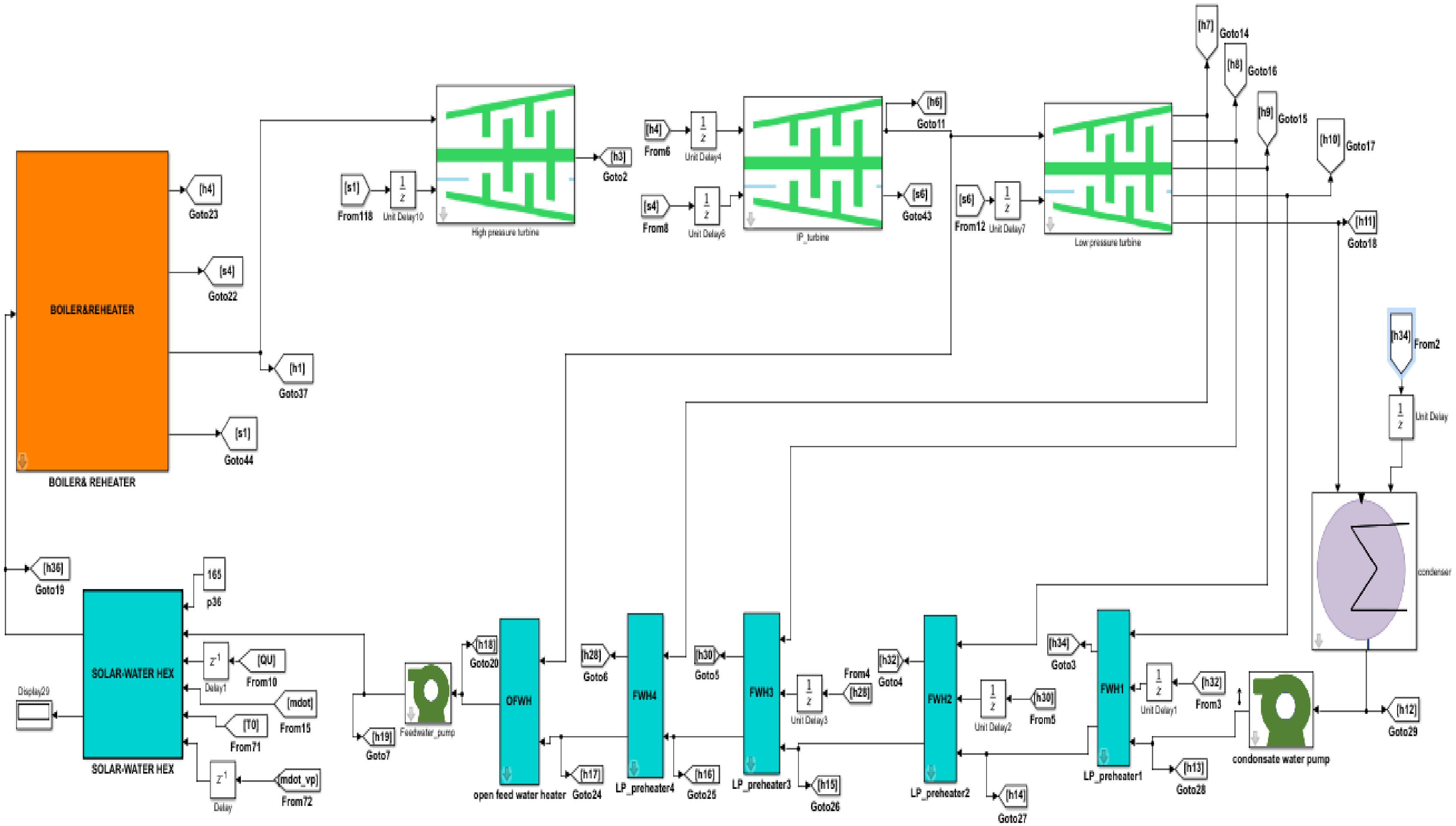


Figure (5.3) Hybrid power plant (the first scheme)

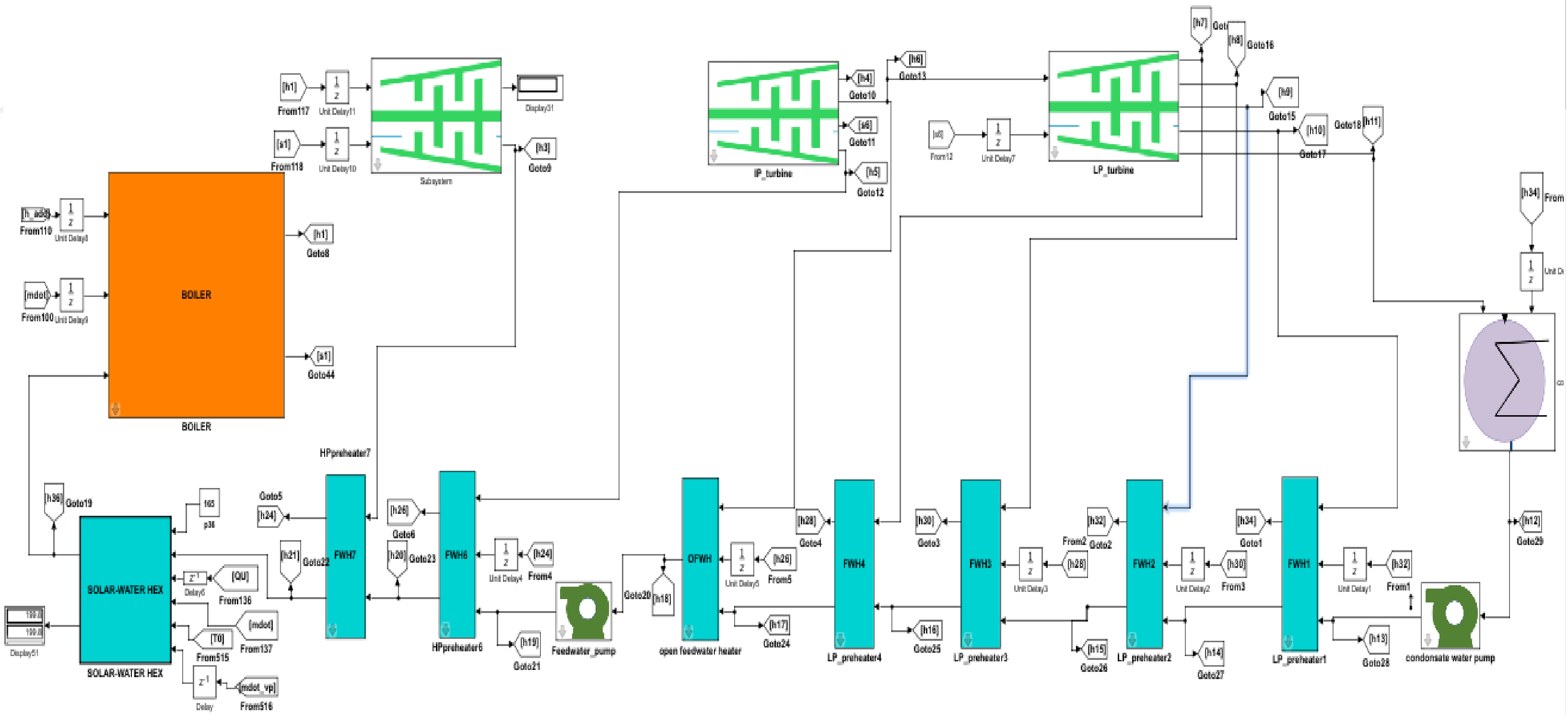


Figure (5.4) Hybrid power plant (the second scheme)

CHAPTER 6

THE RESULTS AND DISCUSSION

6.1 Results of Calculation of Working Fluid Properties for Simple Cycle Power Plant

The results of working fluid properties for all stages of original power plant are shown in the table (E.1) in Appendix E.

6.2 Results of Calculation of Working Fluid Properties in Hybrid Power Plant

The results of enthalpy of working fluid for all stages of hybrid power plant for first scheme (spring and summer) and second scheme (winter) are shown in the table (E.2) in Appendix E.

6.3 The Result of Calculation of fraction Steam for Different Schemes

The result of analytical calculations for fractions of steam for original power plant and two schemes (in January and July) for hybrid thermal power plant are shown in the table (E.3) in Appendix E.

6.4 The Results of Solar Radiation Calculation

The amount of average hourly beam radiation on the tilted surface(G_{BT}) in W/m^2 for 17th of July found by analytical calculation are shown in the table (6.1), while the MATLAB simulation result for the amount of (G_{BT})for the days 17/1/2016, 15/4/2016, and 17/7/2016 are shown in the figure (6.1).

Table (6.1) The results of solar calculations at noon (11:00-12:00)

1	Monthly average clearance index(KT)	0.66287	
2	Solar declination(degree)	21.18	
3	Sunset hour angle(degree)	104.579	
4	Hour angle(degree)	-7.5	Taken half an hour before solar noon
5	Average hourly total radiation(kJ/m^2)	3.214	
6	Average hourly diffuse radiation(kJ/m^2)	0.7524	
7	Average hourly beam radiation(w/m^2)	713.6333	
8	Average hourly beam radiation on tilted surface (w/m^2)	699.11	
9	Tilted angle(degree)	11.66	

Since the amount of G_{BT} is low for the first and last two hours of an average day for July and April, the number of hours that are used in simulation is equal to 10 hours starting from 7:30 till 16:30, while the number of hours that is considered for January is equal to 8 starting from 8:30 till 15:30 for the same reason. As shown in the figure, the amount of beam radiation in January is less than that in April and much less than in July since the extraterrestrial radiation is less and the incidence angle which is shown in the figure (6.2) is much high in January and less in April and July.

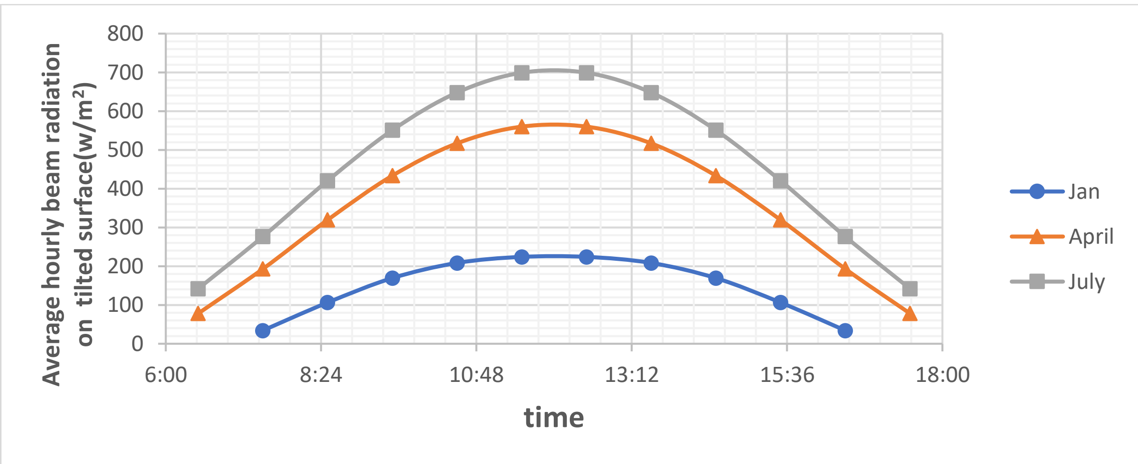


Figure (6.1), The average hourly beam radiation on tilted surface(G_{BT})in (w/m^2).

6.5 The Results of the Incidence Angle

As shown in the figure 6.2, the incidence angles for 17th of July is higher than in the 15th of April and 17th of Jan, respectively. The increasing amount of the incidence angles results on decreasing of the amount of the beam radiation.

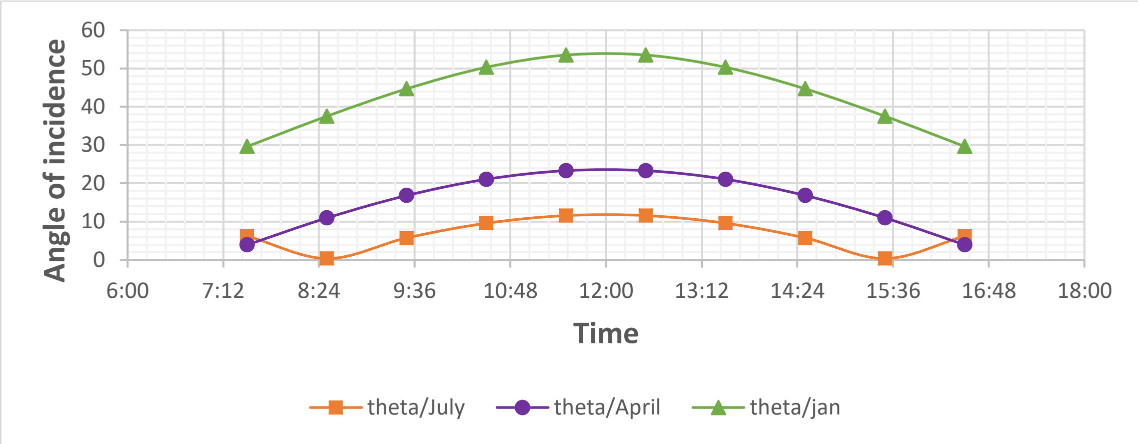


Figure (6.2) The angles of incidence for 17th July, 15th April and 17th Jan

6.6 Results of Optical Calculation

The results of the optical calculation which are shown in the section (3.8) can be seen in table (6.2);

Table (6.2) Results of optical analysis

NO.	The characteristics		Values
1	The rim angle (degree)	ψ_r	80
2	Concentration ratio (%)	C	26.19
3	Rim radius (m)	r_r	2.914
4	The parabola lactus rectum (m)	H_p	6.84
5	The length of parabola (m)	S	6.3553
6	The total loss in aperture area (m^2)	A_l	18.74425
7	The geometry factor	A_f	0.03287
8	The peek value of the optical efficiency (%)	η_0	79.7

6.7 Result of the Solar Field Calculation

The result of analytical calculation of solar field is shown in the table (6.3)

Table (6.3) Results of solar field calculations

No.	The properties	Value
1	Number of collectors in a row	4
2	Number of rows	154
3	Estimated solar multiple	1.3
4	Total aperture area (m^2)	351267.8
5	Total area of the solar field (m^2)	1387995

6.8 The Simulation Results of Thermal Performance of Parabolic Trough Collector

The detailed results including heat loss coefficient, useful energy gain, the output temperature of VP1, receiver temperature and glass cover temperature for each segment in a row of parabolic trough collectors found by the thermal performance simulations are shown in appendix A, B, and C.

6.8.1 Useful Energy Collected from Segments

The figures (6.3), (6.4), and (6.5) show the energy gain from each segment for one row (one row has 4 collectors each with 24 segments) of the solar field from morning hours till 11:30 for the days; 17th July,15th April and 17th January respectively. As seen in these figures the energy gain in July is higher than the energy gain in April and much higher than energy gain in January since the beam radiation is higher for the reasons mentioned in section (6.5). Also, the energy gain in the first segment is higher than in the second in the same hour because the receiver temperature is higher which cause the radiation losses to increase with the same amount of beam radiation.

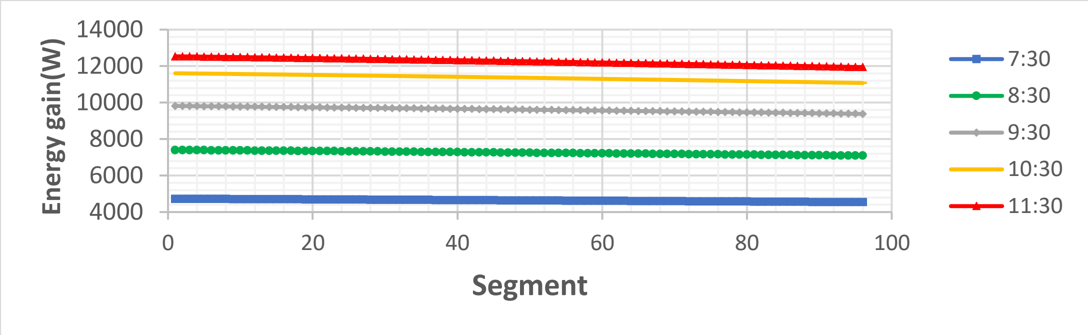


Figure (6.3) Energy collected from every segment for 17th of July

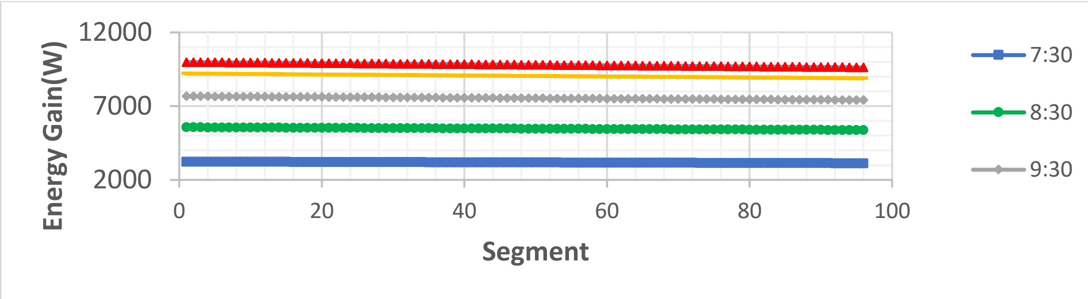


Figure (6.4) Energy collected from every segment for 15th of April

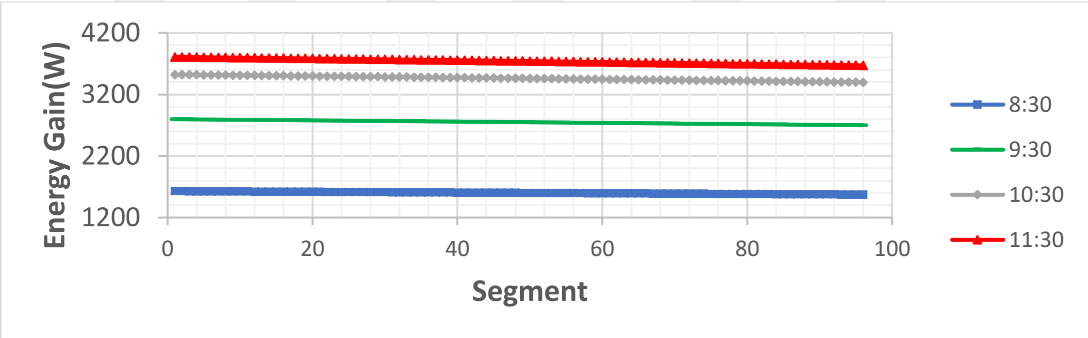


Figure (6.5) Energy collected from every segment for 17th of January

6.8.2 Output Temperature of VP1 from Every Segment

The figures (6.6), (6.7), and (6.8) show the output temperature of each segment for one row of the solar collector field for morning hours till 11:30 on the days; 17th July, 15th April and 17th January respectively. As shown in these figures, the temperature increases gradually from every segment to next one because the energy transferred to the heat transfer fluid increase with increasing the area that is used to collect energy. Also, the output temperature of VP1 in the July is higher than in April and much higher than the output temperature in January for the same reason mentioned in previous sections.

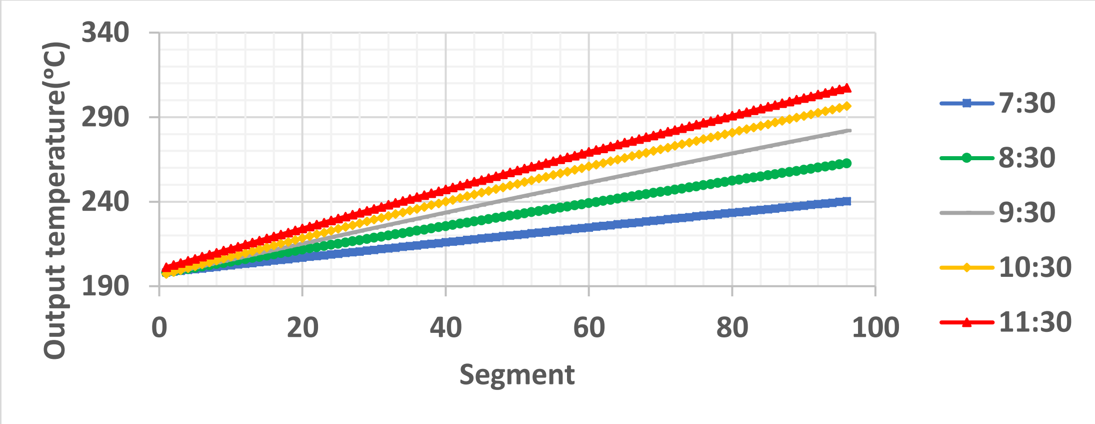


Figure (6.6) VP1 output temperature of every segment for 17th of July

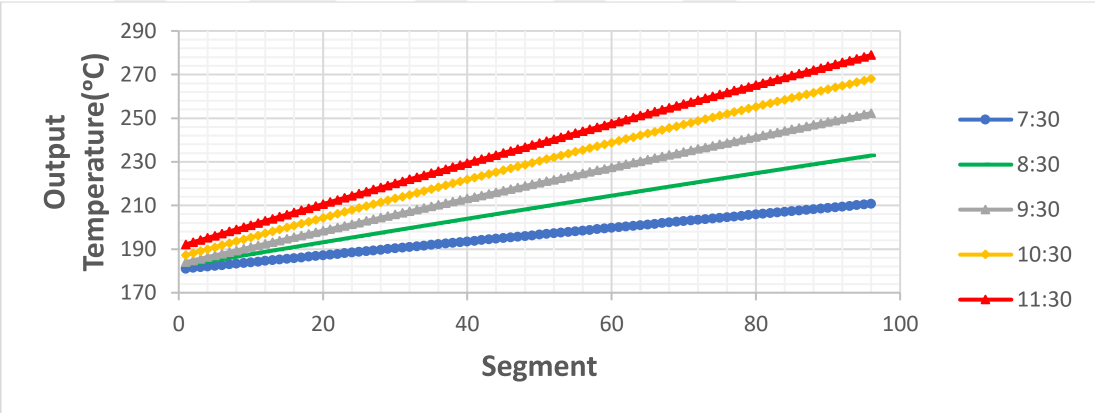


Figure (6.7) VP1 output temperature of every segment for 15th April

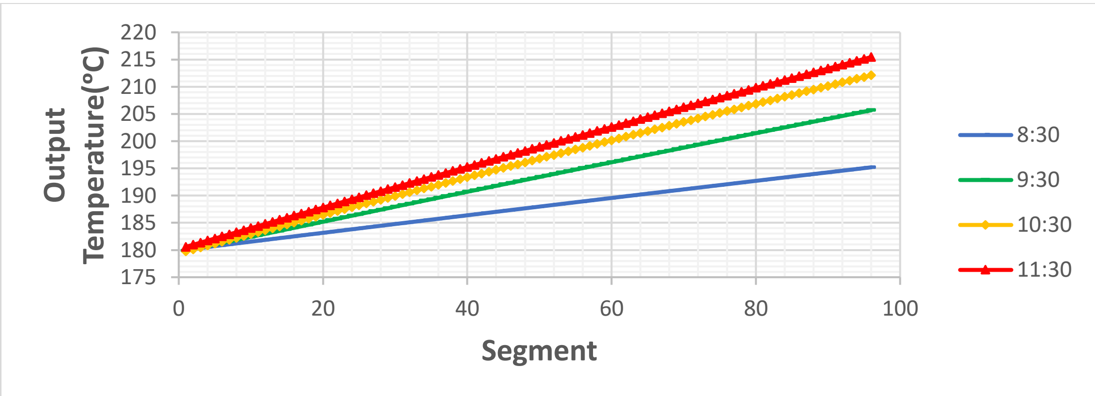


Figure (6.8) VP1 output temperature of every segment for 17th January

6.8.3 Receiver pipe (Absorber) Temperature for Every Segment

The figures (6.9), (6.10), and (6.11) show the receiver temperature for every segment for one row of the solar field for morning hours till 11:30 on the days; 17th July, 15th April and 17th January respectively. As shown in these figures, the absorber temperature in July is higher than in April and much higher than in January since it depends on the amount of beam radiation and the enthalpy of HTF which are higher in July. Receiver temperature is always higher than output temperature of VP1 for each segment.

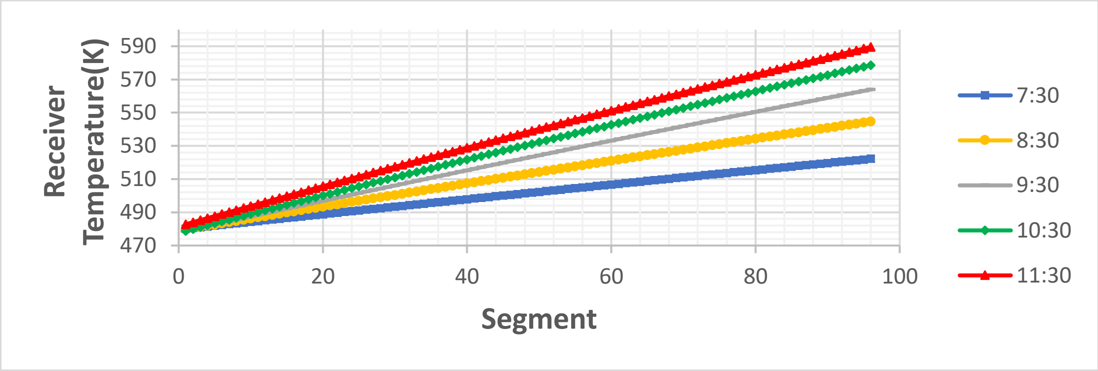


Figure (6.9) Receiver temperature from every segment for 17th July

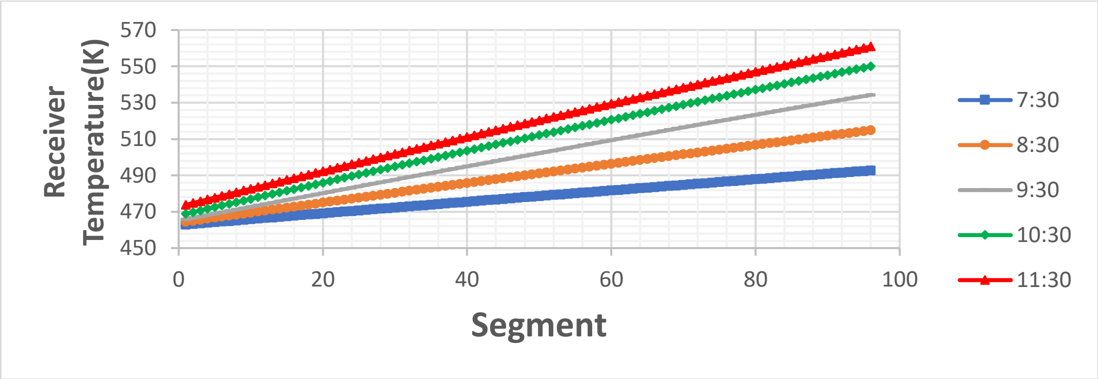


Figure (6.10) Receiver temperature from every segment for 15th April

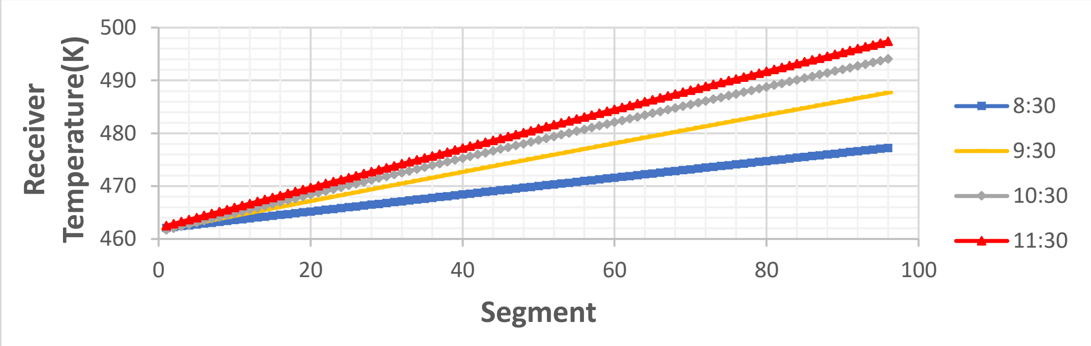


Figure (6.11) Receiver temperature from every segment for 17thJanuary

6.8.4 Glass Cover Temperature for Every Segment

The figures (6.12), (6.13), and (6.14) show the glass cover temperature for every segment for one row of the solar field for morning hours till 11:30 on the days; 17th July, 15th April and 17th January respectively. As seen in these figures, the glass cover temperature increases gradually from one segment to next one according to the equation (3.51), also the glass cover temperature in July is higher than in April and January respectively. The glass cover temperature is close to ambient temperature.

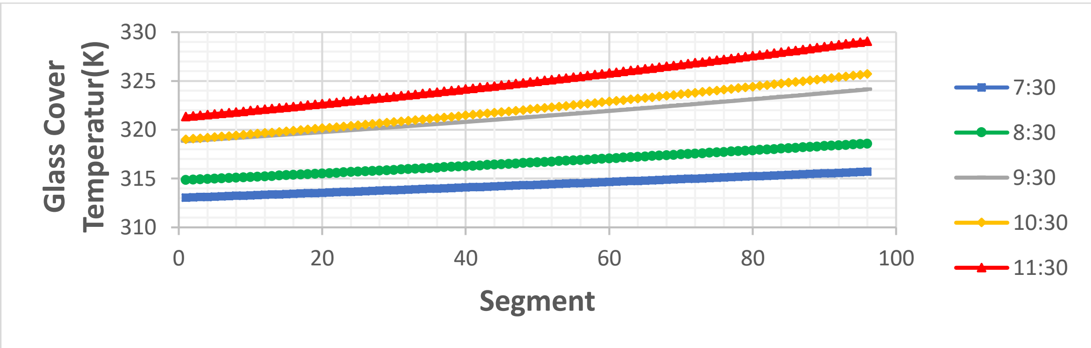


Figure (6.12) Glass cover temperature from every segment for 17th July

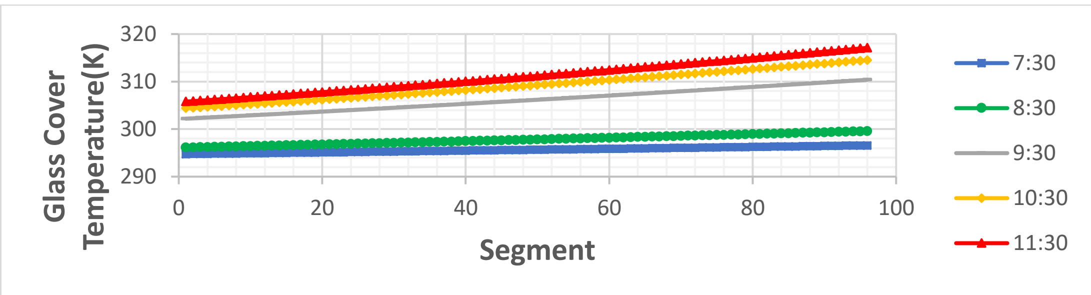


Figure (6.13) Glass cover temperature from every segment for 15th April

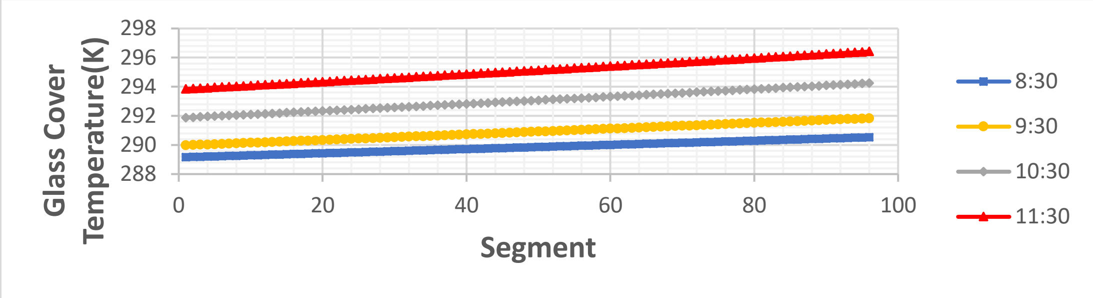


Figure (6.14) Glass cover temperature from every segment for 17th July

6.8.5 Heat Loss Coefficient for Every Segment

Figures (6.15), (6.16), and (6.17) show the heat loss coefficient UL in units of W/m^2K for every segment for one row of the solar field for morning hours till 11:30 on the days; 17thJuly, 15th April and 17th January respectively.

Heat loss coefficient depends on many parameters. The first parameter is the wind coefficient which depends on wind velocity, ambient temperature and glass cover temperature according to the equation (3.46). Second parameter is the heat radiation coefficient between the glass cover and the sky. It depends on the emissivity of the glass cover, the temperature of glass cover and the ambient temperature according to the equation (3.48). Final parameter is the heat radiation coefficient between the absorber and glass cover which depends on the absorber emissivity, absorber temperature, and glass cover temperature according to the equation (3.49). For the reasons mentioned above, heat loss coefficient is higher in July and low in April and January respectively.

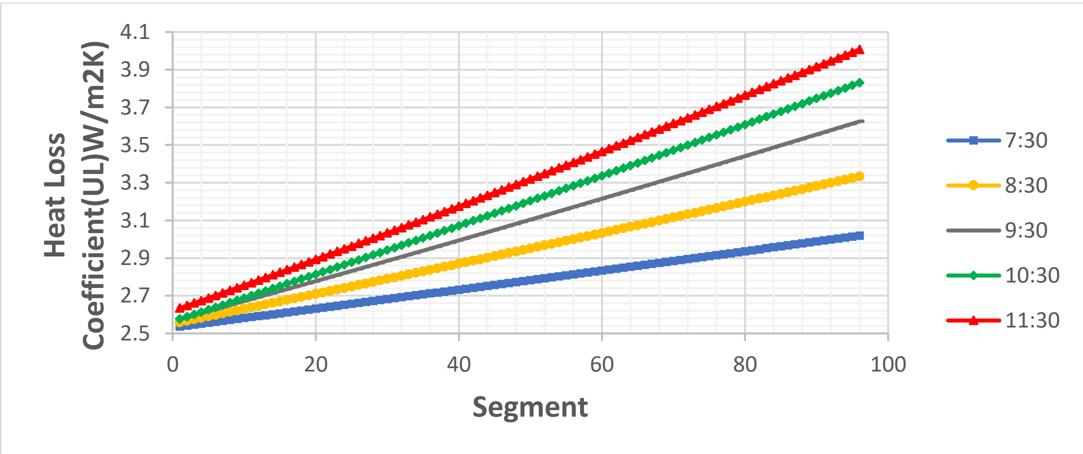


Figure (6.15) Heat Loss coefficient UL for every segment for 17th July

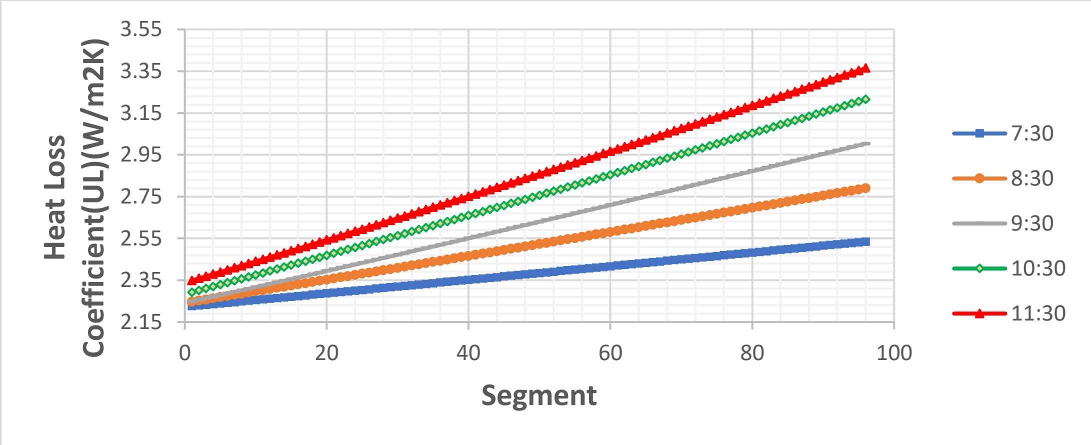


Figure (6.16) Heat Loss coefficient UL for every segment for 15th April

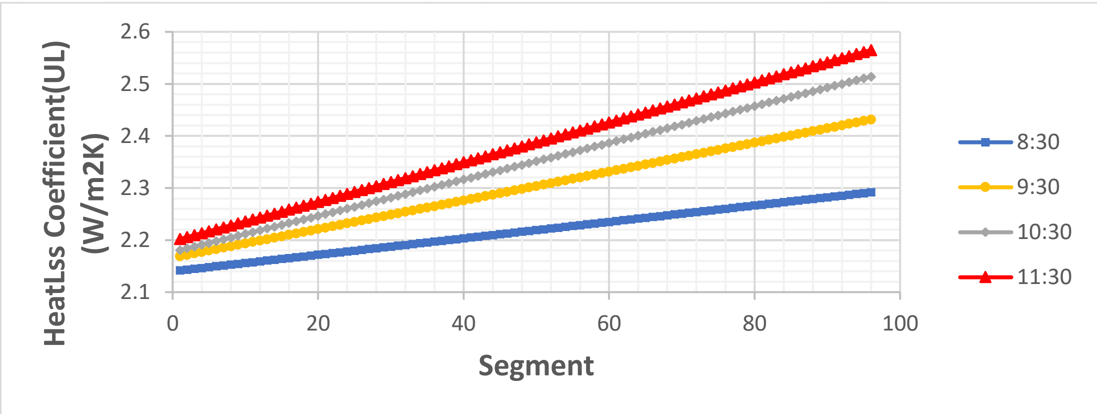


Figure (6.17) Heat loss coefficient UL for every segment for 17th January

6.8.6 Overall Energy from Solar Field

The overall energy gain from the solar field for the days; 17th July, 15th April and 17th January respectively are shown in the figure (6.18). As seen in the figure, the maximum output power is obtained in July and less power is obtained in April and January, respectively. Also, the output power in midday hours in July and April are approximately the same because the energy utilized from solar field is nearly same with different number of rows of solar field with noticing that the amount of beam radiation is higher in July as mentioned in the previous section.

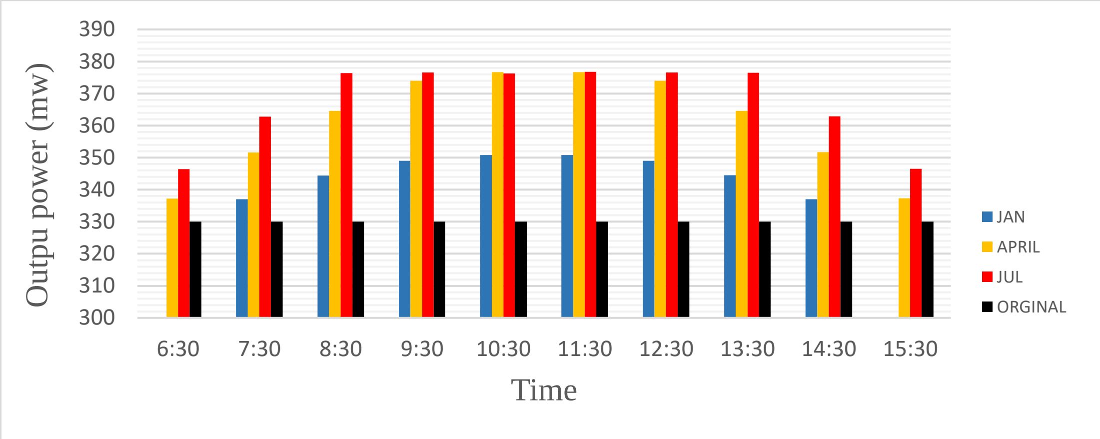


Figure (6.18) Overall energy gain from solar field

6.8.7 Total Fuel Consumption

Total fuel consumption in the hybrid power plant in saving fuel mode for the days; 17th July, 15th April and 17th January respectively are shown in the figure (6.19).

As shown in this figure, the amount of fuel consumption in the hours of midday is nearly same for April and July for the same reason mentioned in section (6.8.7) in this chapter. Also, the amount of fuel consumption for the first and last hours of all days are higher since the amount of energy collected in the solar field is low and the boiler will have to compensate for the deficit of energy by extra amount of heavy fuel oil combustion.

The amount of fuel consumption of hybrid power plant for boosting power mode is the same as the amount of fuel consumption of original thermal power plant.

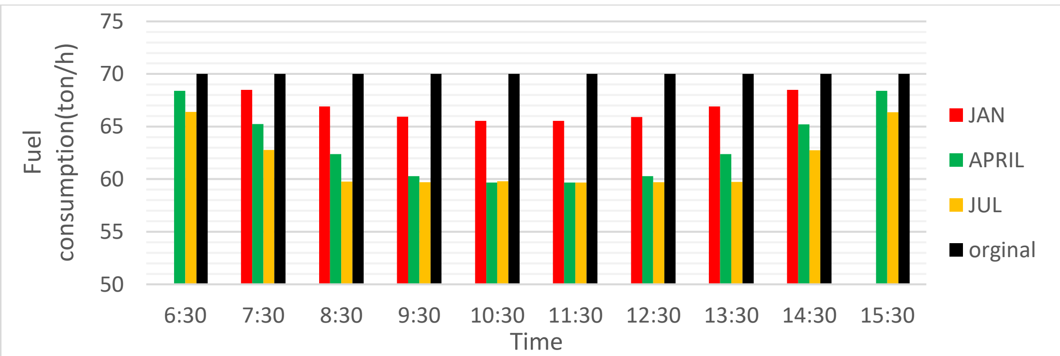


Figure (6.19) Comparison of total fuel consumption in power plant (fuel saving mode)

6.8.8 Efficiency of Hybrid Power Plant

Comparison between the efficiencies of the original power plant and the hybrid power plant in saving fuel mode for the days; 17th July, 15th April and 17th January respectively are shown in the figure 6.20, while, the comparison between the efficiencies of the original power plant and the hybrid power plant in boosting power mode for the same days is shown in the figure (6.21). As can be seen in both figures, efficiency increases in both modes. For the saving fuel mode, the amount of energy added to the water in the boiler is lower than in the original power plant with higher specific work and lower mass flow rate of water. For the boosting power mode, the efficiency of power plant is increased with consumption of same amount of fuel oil compared with the original power plant with higher specific work.

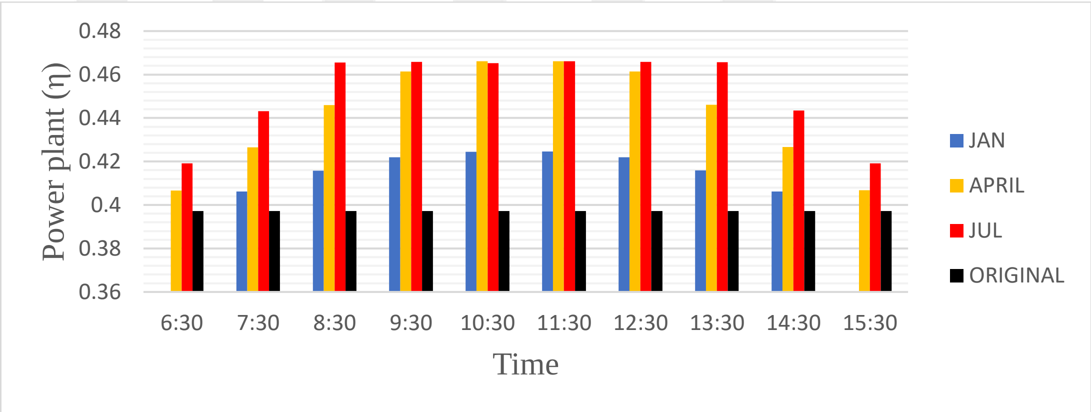


Figure (6.20) Comparison between original thermal power plant efficiency and hybrid power plant efficiency in saving fuel mode.

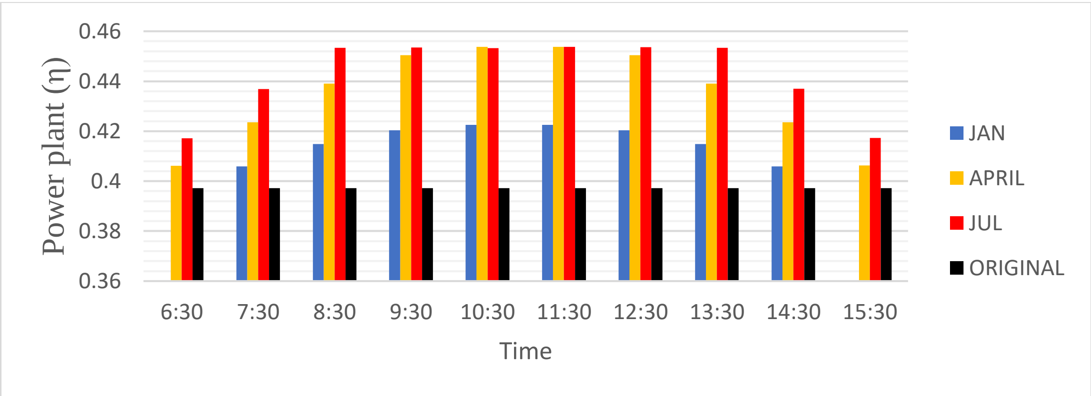


Figure (6.21) Comparison between original thermal power plant efficiency and hybrid power plant efficiency in boosting power mode.

6.8.9 Heat Extracted from the Condenser

Comparison between the amount of the overall heat extracted from the condenser in the original power plant with same values in the hybrid power plant in boosting power mode for the same days is shown in the figure (6.22). Comparison between the amount of overall heat extracted from the condenser in the original power plant with same values in the hybrid power plant in saving fuel mode for the days; 17thJuly, 15th of April, and 17thJanuary respectively is shown in the figure (6.23).

The amount of heat extracted in condenser depends on two main factors which are the amount of the mass flow rate of saturated steam flowing to the condenser, and its specific enthalpy value. Figure (6.22) show that the amount of energy extracted in boosting power mode in 17th January, 15th April and 17th July is higher than that of the original power plant.

Figure (6.23) shows the amount of energy extracted in the condenser in saving fuel mode. Amount of energy extracted in the condenser is higher in 17th July and 15th April and lower in 17th January and that of the original power plant, respectively since the fraction of steam flows to condenser is higher in July and April and lower in January, and without solar field, in the original power plant.

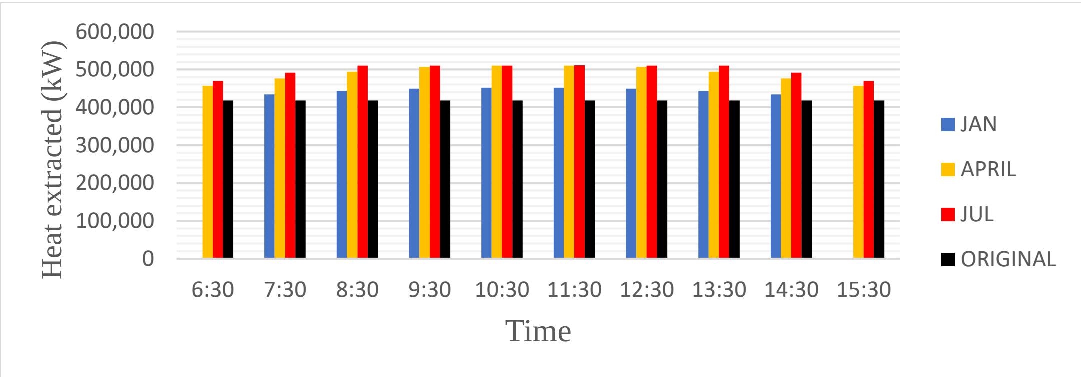


Figure (6.22) Comparison between heat extraction from condenser in original thermal power plant and hybrid power plant in boosting power mode.

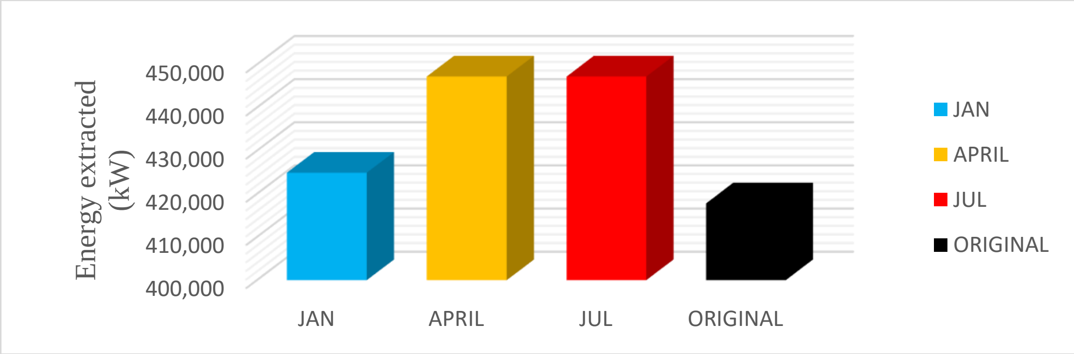


Figure (6.23) Comparison between heat extraction from condenser in original thermal power plant and hybrid power plant in saving fuel mode.

6.8.10 Heat added in the Boiler

Comparison between the amount of overall heat added in the boiler of the original power plant with its values in the hybrid power plant in saving fuel mode for the days; 17th July,15th April, and 17th January respectively are shown in the figure (6.24). The amount of heat added in the boiler is lower in 17th July and higher in 15th April, 17th Jan, and original power plant respectively since the energy collects from solar field is higher in 17th July and lower in the 15th April and 17th January respectively.

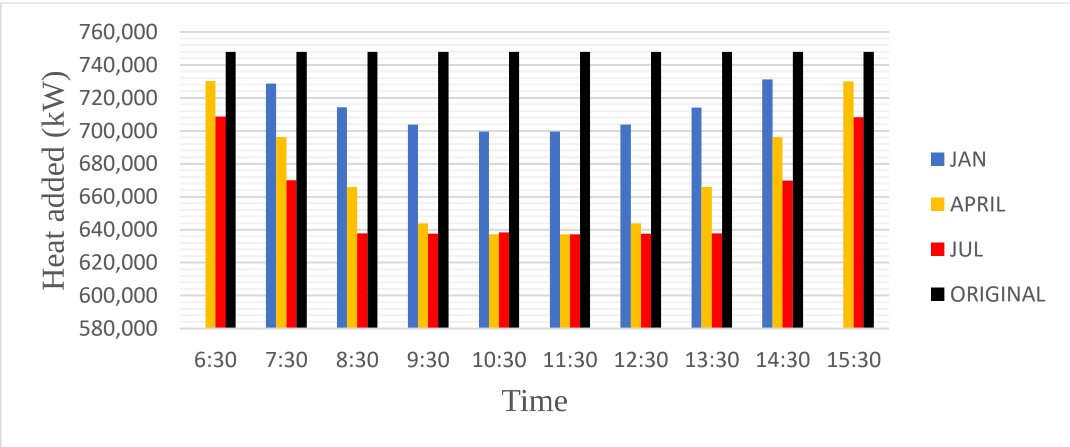


Figure (6.24), Comparison between the amount of overall heat added in saving fuel mode.

6.9 The Results of Heat Exchanger Design

The method shown in chapter 4 is used to preliminary design the solar-water heat exchanger according to ASME B31.3 standards and TEMA standards and the results are shown in table (6.7);

Table (6.4) Results of heat exchangers design

No.	The characteristic	The value	Notes
1	The kind of heat exchanger	E shell and tube heat exchanger	
2	Number of heat exchangers	8	
3	The pipe material	ASTM A691 1Cr	At T=800°F
4	Output diameter of the pipe	26.7 mm	
5	Input diameter of the pipe	15.58 mm	
6	The pipe schedule	¾ schedule 160	
7	The length of the pipe	6 m	
8	Inside shell diameter	1.52 m	
9	Number of tubes in the heat exchanger	1515	
10	Tube layout	30°	
11	Number of baffles	5	
12	Amount of pressure drop in shell side at design point	0.9 bar	
13	Amount of pressure drop in tube side at design point	0.41 bar	
14	VP1 heat transfer coefficient (h_0)	1673 W/ m^2K	
15	Water heat transfer coefficient (h_i)	17382 W/ m^2K	
16	Overall heat transfer coefficient (fouling)	821.9 W/ m^2K	
17	Overall heat transfer coefficient (clean)	1156.6 W/ m^2K	

6.10 The Results of Economic Analysis

Results of economic analysis are shown in table (6.5). The cost of kWh of electricity of hybrid power plant is found equal to 13.9 cents and this price is competitive comparing with the electricity prices that are mentioned in section (1.11).

Table (6.5) The result for economic calculations

No	Investment	The cost	Notes
1	Heat exchangers	8x2,300,940 $	Adding to the equation of LCOE
2	Initial investment cost	200,143,272 $	
3	Cost annual	108350 $/Yr.	
4	Real discount rate	0.054	
5	Levelized cost of energy LCOE	13.9 cents/kWh	

CHAPTER 7

CONCLUSION

7.1 Conclusion

In this study, A simple power plant thermal analysis is done and is compared with the improved solar hybrid version of the plant with parabolic trough collectors in terms of; increasing efficiency, saving fuel oil, increasing output electricity, decreasing environmental pollution and use of water using MATLAB SIMULINK.

The efficiency of the estimated hybrid power plant is increased in the saving fuel mode with average value during day time in 17th July, 15th April and 17th January are 5.47%, 4.4 % and 2% respectively, while in boosting power mode the efficiency is 4.57%, 3.74%, and 1.87% respectively.

The amount of heavy fuel oil saved during one year in saving fuel mode is 21,6 tons which is a very big amount considering the bad effects of the combustion of fuel oil on the environment. The amount of electricity produced in boosting power mode is equal to 98,4 MWh annually. This amount can be used to help overcome some part of the deficiency of electricity in Iraq.

Extra benefit for hybrid thermal power plant which is mentioned in chapter one is that, the cost of conserved water will decrease. The average amount of decreasing water flow rate for saving fuel mode for the day hours in 17th July, 15th April, and 17th Jan are 42.7 kg/s, 42.7 kg/s, and 17.4 kg/s respectively while in boosting power mode these 14.57 kg/s, 19.75 kg/s, and 4.8 kg/s respectively.

Heat exchanger preliminary design is one of the most important aspects of this study, since it is connecting the simple power plant with the solar power block. Preliminary design is done using Kern’s Method [31], [32], [33] and, 8 E shell and tube type heat exchangers are found to be used in series parallel to the high pressure closed feed water heater, with an overall heat transfer capacity of 140,080 Kw.

Simple economic analysis is done in this study and found that levelized cost of energy is equal to 13.9 cent/kWh and this price is competitive comparing with electricity produced from renewable power plants.

The outcome of the thesis studies can be a guide for clever utilization of renewable energy in Iraq since there is a deficit of electricity. Hybrid power plant enables the electricity prices to decrease and since there are no hybrid power plants in Iraq, this study can be a road map for a future implementation of such a hybrid energy production facility.

7.2. Suggestions for Future Investigations

This study can be considered as a starting point for the further studies including solar hybrid thermal power plants. Suggestions to improve the present MATLAB modeling and simulation work are as follows:

a. Heat transfer fluid storage tanks are not included in the current model. Storage tanks can be implemented to improve the efficiency and production of electricity with small variations during the day for operation.

b. Water can be used as the heat transfer fluid instead of therminol VP-1 with taking care of the effect of two phase mode flow on the receiver pipe.

c. The MATLAB model can be extended with integration of Combined Power Cycle System with parabolic trough collector.

d. The current model can be modified to simulate power plants with other kinds of concentrating collector, like Parabolic Dish Reflectors (PDRs) and Heliostat Field Collectors (HFCs).

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APPENDIX A

Table (A1) receiver temperature at every segment for one row in 17th July (K)

segment	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30
1	480.1489	479.7796	478.7983	478.7865	482.8325	482.8324	478.7869	478.7987	479.7802	480.1497
2	480.6128	480.5055	479.7629	479.9273	484.0584	484.0583	479.9284	479.7641	480.5073	480.6151
3	481.0763	481.2304	480.7259	481.066	485.2819	485.2818	481.0678	480.7279	481.2334	481.08
4	481.5393	481.9543	481.6873	482.2026	486.5031	486.5028	482.2051	481.6901	481.9586	481.5445
5	482.0019	482.6773	482.6472	483.337	487.7218	487.7215	483.3402	482.6508	482.6828	482.0085
6	482.464	483.3993	483.6055	484.4694	488.9381	488.9378	484.4733	483.6098	483.4061	482.4721
7	482.9256	484.1204	484.5622	485.5996	490.1521	490.1516	485.6043	484.5674	484.1283	482.9352
8	483.3868	484.8405	485.5174	486.7278	491.3637	491.3632	486.7332	485.5233	484.8497	483.3979
9	483.8475	485.5596	486.471	487.8539	492.5729	492.5723	487.86	486.4778	485.5701	483.8601
10	484.3078	486.2779	487.4231	488.9779	493.7798	493.7791	488.9847	487.4306	486.2895	484.3218
11	484.7677	486.9951	488.3736	490.0999	494.9843	494.9836	490.1073	488.382	487.008	484.7831
12	485.2271	487.7114	489.3226	491.2198	496.1865	496.1857	491.2279	489.3317	487.7255	485.2439
13	485.686	488.4268	490.2701	492.3376	497.3864	497.3855	492.3465	490.28	488.4421	485.7043
14	486.1445	489.1413	491.2161	493.4534	498.584	498.583	493.463	491.2267	489.1578	486.1643
15	486.6025	489.8548	492.1605	494.5672	499.7792	499.7782	494.5774	492.1719	489.8725	486.6237
16	487.0601	490.5673	493.1034	495.6789	500.9722	500.9711	495.6899	493.1156	490.5862	487.0828
17	487.5172	491.279	494.0448	496.7886	502.1629	502.1617	496.8003	494.0578	491.2991	487.5413
18	487.9739	491.9897	494.9847	497.8963	503.3512	503.35	497.9086	494.9984	492.011	487.9995
19	488.4301	492.6994	495.9231	499.002	504.5374	504.536	499.015	495.9376	492.7219	488.4571
20	488.8859	493.4083	496.86	500.1057	505.7212	505.7197	500.1194	496.8752	493.4319	488.9143
21	489.3412	494.1162	497.7953	501.2074	506.9028	506.9012	501.2218	497.8114	494.141	489.3711
22	489.7961	494.8232	498.7292	502.307	508.0821	508.0805	502.3221	498.746	494.8492	489.8274
23	490.2506	495.5292	499.6616	503.4048	509.2592	509.2575	503.4205	499.6792	495.5565	490.2833
24	490.7046	496.2344	500.5925	504.5005	510.434	510.4323	504.517	500.6109	496.2628	490.7387
25	491.1581	496.9386	501.522	505.5942	511.6067	511.6048	505.6114	501.5411	496.9682	491.1937
26	491.6112	497.6419	502.4499	506.686	512.7771	512.7751	506.7039	502.4698	497.6727	491.6482
27	492.0639	498.3443	503.3764	507.7759	513.9453	513.9432	507.7944	503.397	498.3762	492.1023
28	492.5161	499.0457	504.3014	508.8638	515.1112	515.1091	508.883	504.3228	499.0788	492.556
29	492.9679	499.7463	505.2249	509.9497	516.275	516.2728	509.9696	505.247	499.7806	493.0092
30	493.4192	500.4459	506.147	511.0337	517.4366	517.4343	511.0543	506.1699	500.4814	493.4619
31	493.8701	501.1447	507.0676	512.1158	518.596	518.5937	512.137	507.0912	501.1813	493.9142
32	494.3205	501.8425	507.9868	513.1959	519.7533	519.7508	513.2178	508.0112	501.8803	494.366
33	494.7705	502.5394	508.9045	514.2741	520.9083	520.9058	514.2967	508.9296	502.5783	494.8175
34	495.2201	503.2354	509.8208	515.3504	522.0612	522.0586	515.3737	509.8466	503.2755	495.2684
35	495.6692	503.9305	510.7356	516.4248	523.212	523.2092	516.4488	510.7622	503.9717	495.719

Continued table (A1)

36	496.1179	504.6247	511.649	517.4973	524.3606	524.3578	517.5219	511.6763	504.6671	496.169
37	496.5662	505.318	512.5609	518.5679	525.507	525.5041	518.5932	512.589	505.3616	496.6187
38	497.014	506.0104	513.4714	519.6366	526.6514	526.6483	519.6625	513.5002	506.0551	497.0679
39	497.4613	506.7019	514.3805	520.7034	527.7935	527.7904	520.73	514.41	506.7478	497.5166
40	497.9083	507.3925	515.2882	521.7683	528.9336	528.9304	521.7956	515.3184	507.4395	497.9649
41	498.3548	508.0822	516.1944	522.8313	530.0715	530.0682	522.8593	516.2254	508.1304	498.4128
42	498.8008	508.7711	517.0992	523.8925	531.2074	531.204	523.9211	517.1309	508.8203	498.8603
43	499.2464	509.459	518.0026	524.9518	532.3411	532.3376	524.9811	518.0351	509.5094	499.3073
44	499.6916	510.146	518.9046	526.0092	533.4727	533.4691	526.0392	518.9378	510.1976	499.7538
45	500.1363	510.8322	519.8052	527.0648	534.6023	534.5986	527.0955	519.8391	510.8849	500.1999
46	500.5806	511.5174	520.7043	528.1186	535.7297	535.7259	528.1498	520.739	511.5713	500.6456
47	501.0245	512.2018	521.6021	529.1704	536.8551	536.8512	529.2024	521.6374	512.2568	501.0909
48	501.468	512.8853	522.4985	530.2205	537.9784	537.9744	530.2531	522.5345	512.9414	501.5357
49	501.911	513.5679	523.3934	531.2687	539.0996	539.0955	531.3019	523.4302	513.6251	501.98
50	502.3535	514.2497	524.287	532.315	540.2187	540.2145	532.349	524.3245	514.308	502.424
51	502.7957	514.9305	525.1792	533.3596	541.3358	541.3315	533.3942	525.2174	514.99	502.8675
52	503.2374	515.6105	526.07	534.4023	542.4508	542.4464	534.4375	526.1089	515.6711	503.3105
53	503.6786	516.2896	526.9594	535.4432	543.5638	543.5593	535.4791	526.999	516.3513	503.7532
54	504.1195	516.9678	527.8474	536.4823	544.6748	544.6701	536.5188	527.8878	517.0306	504.1954
55	504.5599	517.6452	528.734	537.5195	545.7837	545.7789	537.5568	528.7751	517.7091	504.6371
56	504.9999	518.3217	529.6193	538.555	546.8906	546.8857	538.5929	529.6611	518.3867	505.0784
57	505.4394	518.9973	530.5032	539.5887	547.9954	547.9904	539.6272	530.5457	519.0634	505.5193
58	505.8785	519.672	531.3857	540.6205	549.0982	549.0931	540.6597	531.4289	519.7393	505.9598
59	506.3172	520.3459	532.2669	541.6506	550.199	550.1938	541.6904	532.3108	520.4142	506.3998
60	506.7555	521.0189	533.1467	542.6789	551.2978	551.2925	542.7194	533.1913	521.0884	506.8394
61	507.1933	521.6911	534.0251	543.7054	552.3946	552.3892	543.7465	534.0704	521.7616	507.2786
62	507.6307	522.3623	534.9022	544.7301	553.4893	553.4838	544.7719	534.9482	522.434	507.7173
63	508.0676	523.0328	535.7779	545.7531	554.5821	554.5765	545.7955	535.8246	523.1055	508.1556
64	508.5042	523.7023	536.6523	546.7742	555.6729	555.6671	546.8173	536.6997	523.7761	508.5935
65	508.9403	524.371	537.5253	547.7936	556.7617	556.7558	547.8374	537.5734	524.4459	509.031
66	509.376	525.0388	538.397	548.8113	557.8485	557.8425	548.8557	538.4458	525.1148	509.468
67	509.8112	525.7058	539.2673	549.8272	558.9333	558.9272	549.8722	539.3168	525.7829	509.9046
68	510.2461	526.3719	540.1363	550.8413	560.0161	560.0099	550.887	540.1864	526.4501	510.3407
69	510.6805	527.0372	541.0039	551.8537	561.097	561.0906	551.9	541.0548	527.1165	510.7764
70	511.1145	527.7016	541.8702	552.8643	562.1759	562.1694	552.9112	541.9218	527.782	511.2117
71	511.548	528.3652	542.7352	553.8732	563.2528	563.2462	553.9208	542.7874	528.4466	511.6466
72	511.9812	529.0279	543.5988	554.8803	564.3278	564.3211	554.9285	543.6517	529.1104	512.0811
73	512.4139	529.6898	544.4611	555.8857	565.4008	565.394	555.9346	544.5147	529.7734	512.5151
74	512.8461	530.3508	545.3221	556.8894	566.4718	566.4649	556.9389	545.3764	530.4354	512.9487

Continued table (A1)

75	**513.278**	**531.011**	**546.1817**	**557.8913**	**567.5409**	**567.5339**	**557.9414**	**546.2367**	**531.0967**	**513.3819**
76	**513.7094**	**531.6703**	**547.0401**	**558.8915**	**568.6081**	**568.6009**	**558.9423**	**547.0957**	**531.7571**	**513.8146**
77	**514.1405**	**532.3288**	**547.8971**	**559.89**	**569.6733**	**569.666**	**559.9414**	**547.9534**	**532.4166**	**514.2469**
78	**514.5711**	**532.9864**	**548.7528**	**560.8867**	**570.7366**	**570.7291**	**560.9388**	**548.8098**	**533.0753**	**514.6788**
79	**515.0012**	**533.6432**	**549.6071**	**561.8818**	**571.7979**	**571.7903**	**561.9345**	**549.6648**	**533.7332**	**515.1103**
80	**515.431**	**534.2992**	**550.4602**	**562.8751**	**572.8573**	**572.8496**	**562.9284**	**550.5186**	**534.3902**	**515.5413**
81	**515.8603**	**534.9543**	**551.3119**	**563.8667**	**573.9148**	**573.907**	**563.9207**	**551.371**	**535.0464**	**515.972**
82	**516.2892**	**535.6085**	**552.1624**	**564.8566**	**574.9704**	**574.9624**	**564.9112**	**552.2221**	**535.7017**	**516.4022**
83	**516.7177**	**536.262**	**553.0115**	**565.8448**	**576.024**	**576.0159**	**565.9**	**553.0719**	**536.3562**	**516.832**
84	**517.1458**	**536.9146**	**553.8593**	**566.8313**	**577.0757**	**577.0675**	**566.8872**	**553.9204**	**537.0099**	**517.2613**
85	**517.5734**	**537.5664**	**554.7059**	**567.8161**	**578.1255**	**578.1171**	**567.8726**	**554.7676**	**537.6627**	**517.6903**
86	**518.0007**	**538.2173**	**555.5511**	**568.7992**	**579.1734**	**579.1649**	**568.8563**	**555.6135**	**538.3147**	**518.1188**
87	**518.4275**	**538.8674**	**556.395**	**569.7806**	**580.2194**	**580.2107**	**569.8384**	**556.4581**	**538.9658**	**518.5469**
88	**518.8539**	**539.5166**	**557.2376**	**570.7603**	**581.2635**	**581.2547**	**570.8187**	**557.3014**	**539.6161**	**518.9745**
89	**519.2798**	**540.1651**	**558.079**	**571.7384**	**582.3056**	**582.2967**	**571.7974**	**558.1434**	**540.2656**	**519.4018**
90	**519.7054**	**540.8127**	**558.919**	**572.7147**	**583.3459**	**583.3368**	**572.7743**	**558.9841**	**540.9142**	**519.8286**
91	**520.1305**	**541.4595**	**559.7578**	**573.6894**	**584.3843**	**584.3751**	**573.7496**	**559.8235**	**541.5621**	**520.255**
92	**520.5553**	**542.1054**	**560.5952**	**574.6623**	**585.4207**	**585.4114**	**574.7232**	**560.6616**	**542.209**	**520.681**
93	**520.9796**	**542.7505**	**561.4314**	**575.6337**	**586.4553**	**586.4459**	**575.6952**	**561.4984**	**542.8552**	**521.1066**
94	**521.4035**	**543.3948**	**562.2663**	**576.6033**	**587.488**	**587.4784**	**576.6654**	**562.334**	**543.5005**	**521.5318**
95	**521.8269**	**544.0383**	**563.0999**	**577.5712**	**588.5188**	**588.5091**	**577.634**	**563.1683**	**544.145**	**521.9565**
96	**522.25**	**544.681**	**563.9323**	**578.5375**	**589.5478**	**589.5379**	**578.6009**	**564.0012**	**544.7887**	**522.3808**

Table (A2) energy gain from every segment for one row in 17thJuly (W)

segment	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30
1	4729.295	7395.514	9814.959	11607.93	12539.47	12538.77	11615.23	9823.109	7408.104	4744.379
2	4727.475	7392.651	9811.161	11603.42	12534.5	12533.79	11610.72	9819.312	7405.238	4742.552
3	4725.652	7389.779	9807.346	11598.89	12529.5	12528.78	11606.2	9815.497	7402.364	4740.722
4	4723.826	7386.897	9803.515	11594.34	12524.47	12523.74	11601.65	9811.667	7399.48	4738.888
5	4721.996	7384.007	9799.667	11589.76	12519.41	12518.68	11597.08	9807.819	7396.586	4737.051
6	4720.162	7381.107	9795.803	11585.15	12514.33	12513.59	11592.48	9803.955	7393.684	4735.21
7	4718.326	7378.198	9791.921	11580.53	12509.22	12508.47	11587.86	9800.074	7390.773	4733.365
8	4716.485	7375.28	9788.024	11575.88	12504.08	12503.32	11583.22	9796.177	7387.852	4731.518
9	4714.642	7372.353	9784.11	11571.21	12498.91	12498.14	11578.55	9792.263	7384.922	4729.666
10	4712.795	7369.417	9780.179	11566.51	12493.71	12492.94	11573.86	9788.333	7381.984	4727.812
11	4710.944	7366.471	9776.232	11561.79	12488.49	12487.7	11569.15	9784.386	7379.036	4725.953
12	4709.09	7363.517	9772.268	11557.05	12483.24	12482.44	11564.41	9780.422	7376.079	4724.092
13	4707.233	7360.553	9768.287	11552.28	12477.96	12477.16	11559.65	9776.442	7373.112	4722.227
14	4705.372	7357.581	9764.29	11547.49	12472.66	12471.84	11554.86	9772.445	7370.137	4720.358
15	4703.507	7354.599	9760.277	11542.67	12467.32	12466.5	11550.06	9768.432	7367.153	4718.486
16	4701.64	7351.609	9756.247	11537.83	12461.96	12461.13	11545.22	9764.402	7364.159	4716.611
17	4699.769	7348.609	9752.2	11532.97	12456.57	12455.73	11540.37	9760.355	7361.157	4714.732
18	4697.894	7345.6	9748.137	11528.09	12451.15	12450.3	11535.49	9756.292	7358.145	4712.849
19	4696.016	7342.582	9744.057	11523.18	12445.71	12444.85	11530.59	9752.213	7355.124	4710.964
20	4694.135	7339.555	9739.961	11518.24	12440.24	12439.36	11525.66	9748.117	7352.095	4709.074
21	4692.25	7336.519	9735.848	11513.29	12434.74	12433.85	11520.71	9744.004	7349.056	4707.182
22	4690.362	7333.474	9731.719	11508.31	12429.21	12428.31	11515.74	9739.875	7346.008	4705.286
23	4688.471	7330.42	9727.573	11503.31	12423.65	12422.75	11510.74	9735.729	7342.951	4703.386
24	4686.576	7327.357	9723.411	11498.28	12418.07	12417.15	11505.72	9731.567	7339.885	4701.483
25	4684.678	7324.285	9719.232	11493.23	12412.46	12411.53	11500.68	9727.389	7336.81	4699.577
26	4682.776	7321.204	9715.037	11488.16	12406.82	12405.88	11495.61	9723.193	7333.726	4697.667
27	4680.871	7318.115	9710.825	11483.06	12401.15	12400.21	11490.52	9718.982	7330.633	4695.754
28	4678.963	7315.016	9706.597	11477.94	12395.45	12394.5	11485.41	9714.754	7327.531	4693.838
29	4677.051	7311.908	9702.353	11472.79	12389.73	12388.77	11480.27	9710.509	7324.42	4691.918
30	4675.136	7308.791	9698.092	11467.63	12383.98	12383.01	11475.11	9706.248	7321.3	4689.995
31	4673.217	7305.665	9693.814	11462.43	12378.21	12377.22	11469.92	9701.971	7318.171	4688.068
32	4671.296	7302.53	9689.521	11457.22	12372.4	12371.4	11464.72	9697.677	7315.033	4686.138
33	4669.37	7299.386	9685.211	11451.98	12366.57	12365.56	11459.48	9693.367	7311.886	4684.204
34	4667.442	7296.234	9680.884	11446.72	12360.71	12359.69	11454.23	9689.04	7308.73	4682.268
35	4665.51	7293.072	9676.541	11441.44	12354.82	12353.79	11448.95	9684.697	7305.565	4680.327
36	4663.575	7289.902	9672.182	11436.13	12348.9	12347.86	11443.65	9680.338	7302.391	4678.384

Continued table (A2)

37	4661.636	7286.722	9667.806	11430.8	12342.96	12341.91	11438.33	9675.962	7299.208	4676.437
38	4659.695	7283.534	9663.414	11425.44	12336.99	12335.93	11432.98	9671.57	7296.016	4674.487
39	4657.749	7280.337	9659.006	11420.06	12330.99	12329.92	11427.61	9667.162	7292.816	4672.533
40	4655.801	7277.13	9654.581	11414.66	12324.97	12323.88	11422.21	9662.737	7289.606	4670.576
41	4653.849	7273.915	9650.14	11409.24	12318.92	12317.82	11416.79	9658.296	7286.388	4668.616
42	4651.894	7270.692	9645.683	11403.79	12312.83	12311.73	11411.35	9653.838	7283.16	4666.652
43	4649.936	7267.459	9641.21	11398.32	12306.73	12305.61	11405.89	9649.365	7279.924	4664.685
44	4647.974	7264.217	9636.72	11392.82	12300.59	12299.46	11400.4	9644.875	7276.679	4662.715
45	4646.009	7260.967	9632.214	11387.3	12294.43	12293.29	11394.89	9640.368	7273.425	4660.741
46	4644.041	7257.708	9627.692	11381.76	12288.24	12287.09	11389.36	9635.846	7270.162	4658.764
47	4642.069	7254.44	9623.153	11376.2	12282.02	12280.86	11383.8	9631.307	7266.89	4656.784
48	4640.094	7251.163	9618.599	11370.61	12275.78	12274.6	11378.22	9626.752	7263.61	4654.8
49	4638.116	7247.877	9614.028	11365	12269.51	12268.32	11372.61	9622.181	7260.32	4652.813
50	4636.135	7244.583	9609.441	11359.37	12263.21	12262.01	11366.99	9617.594	7257.022	4650.823
51	4634.15	7241.279	9604.838	11353.71	12256.88	12255.67	11361.34	9612.991	7253.715	4648.83
52	4632.162	7237.967	9600.219	11348.03	12250.53	12249.31	11355.67	9608.371	7250.399	4646.833
53	4630.171	7234.647	9595.583	11342.33	12244.15	12242.92	11349.97	9603.735	7247.075	4644.833
54	4628.176	7231.317	9590.932	11336.6	12237.74	12236.5	11344.25	9599.083	7243.741	4642.829
55	4626.179	7227.979	9586.264	11330.85	12231.31	12230.05	11338.51	9594.415	7240.399	4640.823
56	4624.178	7224.632	9581.581	11325.08	12224.85	12223.58	11332.74	9589.731	7237.048	4638.813
57	4622.173	7221.276	9576.881	11319.28	12218.36	12217.08	11326.96	9585.031	7233.689	4636.8
58	4620.166	7217.911	9572.165	11313.47	12211.84	12210.55	11321.15	9580.315	7230.32	4634.783
59	4618.155	7214.538	9567.434	11307.63	12205.3	12203.99	11315.31	9575.583	7226.943	4632.763
60	4616.141	7211.156	9562.686	11301.76	12198.73	12197.41	11309.46	9570.834	7223.557	4630.74
61	4614.124	7207.766	9557.922	11295.88	12192.14	12190.8	11303.58	9566.07	7220.163	4628.714
62	4612.104	7204.367	9553.142	11289.97	12185.52	12184.17	11297.67	9561.29	7216.759	4626.684
63	4610.08	7200.959	9548.347	11284.03	12178.87	12177.51	11291.75	9556.494	7213.347	4624.652
64	4608.053	7197.542	9543.535	11278.08	12172.19	12170.82	11285.8	9551.681	7209.927	4622.616
65	4606.023	7194.117	9538.708	11272.1	12165.49	12164.1	11279.83	9546.853	7206.497	4620.576
66	4603.99	7190.683	9533.864	11266.1	12158.76	12157.36	11273.84	9542.01	7203.059	4618.534
67	4601.954	7187.241	9529.005	11260.08	12152	12150.59	11267.82	9537.15	7199.613	4616.488
68	4599.914	7183.79	9524.13	11254.03	12145.22	12143.79	11261.78	9532.274	7196.157	4614.439
69	4597.871	7180.33	9519.239	11247.96	12138.41	12136.97	11255.72	9527.382	7192.693	4612.387
70	4595.825	7176.862	9514.333	11241.87	12131.57	12130.12	11249.64	9522.475	7189.221	4610.332
71	4593.776	7173.385	9509.41	11235.76	12124.71	12123.25	11243.53	9517.552	7185.74	4608.273
72	4591.724	7169.9	9504.472	11229.62	12117.82	12116.35	11237.41	9512.613	7182.25	4606.211
73	4589.668	7166.406	9499.518	11223.46	12110.91	12109.42	11231.26	9507.658	7178.752	4604.146

Continued table (A2)

74	4587.609	7162.904	9494.549	11217.28	12103.97	12102.46	11225.08	9502.688	7175.245	4602.078
75	4585.547	7159.393	9489.563	11211.08	12097	12095.48	11218.89	9497.702	7171.73	4600.007
76	4583.482	7155.873	9484.562	11204.85	12090.01	12088.48	11212.67	9492.7	7168.206	4597.932
77	4581.414	7152.345	9479.546	11198.61	12082.99	12081.44	11206.43	9487.683	7164.673	4595.854
78	4579.343	7148.809	9474.514	11192.34	12075.94	12074.38	11200.17	9482.65	7161.132	4593.773
79	4577.268	7145.264	9469.466	11186.04	12068.87	12067.3	11193.88	9477.601	7157.583	4591.689
80	4575.191	7141.711	9464.402	11179.73	12061.77	12060.19	11187.57	9472.537	7154.025	4589.602
81	4573.11	7138.149	9459.323	11173.39	12054.65	12053.05	11181.25	9467.457	7150.458	4587.511
82	4571.026	7134.579	9454.229	11167.03	12047.5	12045.89	11174.89	9462.362	7146.883	4585.418
83	4568.939	7131	9449.119	11160.65	12040.33	12038.7	11168.52	9457.251	7143.3	4583.321
84	4566.849	7127.413	9443.993	11154.25	12033.13	12031.48	11162.13	9452.124	7139.708	4581.221
85	4564.756	7123.817	9438.853	11147.82	12025.9	12024.24	11155.71	9446.982	7136.108	4579.118
86	4562.66	7120.214	9433.696	11141.38	12018.65	12016.97	11149.27	9441.825	7132.499	4577.012
87	4560.56	7116.601	9428.525	11134.91	12011.37	12009.68	11142.81	9436.652	7128.882	4574.903
88	4558.458	7112.981	9423.338	11128.42	12004.07	12002.36	11136.33	9431.464	7125.257	4572.79
89	4556.352	7109.352	9418.135	11121.9	11996.74	11995.02	11129.82	9426.261	7121.623	4570.675
90	4554.243	7105.714	9412.917	11115.37	11989.38	11987.65	11123.29	9421.042	7117.981	4568.556
91	4552.132	7102.069	9407.684	11108.81	11982	11980.26	11116.75	9415.808	7114.33	4566.434
92	4550.017	7098.415	9402.436	11102.24	11974.6	11972.84	11110.18	9410.559	7110.671	4564.309
93	4547.899	7094.753	9397.173	11095.64	11967.17	11965.39	11103.58	9405.294	7107.004	4562.182
94	4545.778	7091.082	9391.894	11089.01	11959.71	11957.92	11096.97	9400.014	7103.329	4560.05
95	4543.654	7087.403	9386.6	11082.37	11952.23	11950.43	11090.34	9394.719	7099.645	4557.916
96	4541.527	7083.716	9381.291	11075.71	11944.73	11942.9	11083.68	9389.409	7095.953	4555.779

Table (A3) VP1 output temperature from every segment for one row in 17thJuly (°C)

Segment	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30
1	198.2638	198.0258	197.1647	197.2411	201.3259	201.3258	197.2418	197.1655	198.027	198.2653
2	198.7271	198.7505	198.1277	198.3799	202.5493	202.5491	198.3813	198.1293	198.753	198.73
3	199.1899	199.4743	199.0891	199.5165	203.7701	203.7699	199.5186	199.0915	199.478	199.1943
4	199.6522	200.197	200.0488	200.6509	204.9885	204.9882	200.6538	200.052	200.202	199.6582
5	200.1141	200.9188	201.0069	201.7831	206.2043	206.204	201.7867	201.0109	200.925	200.1215
6	200.5755	201.6396	201.9634	202.9131	207.4176	207.4172	202.9174	201.9681	201.647	200.5844
7	201.0365	202.3594	202.9182	204.0409	208.6285	208.628	204.0459	202.9238	202.368	201.0468
8	201.497	203.0782	203.8715	205.1666	209.8369	209.8363	205.1723	203.8778	203.088	201.5087
9	201.957	203.796	204.8231	206.29	211.0428	211.0422	206.2964	204.8302	203.807	201.9702
10	202.4165	204.5128	205.7731	207.4114	212.2463	212.2456	207.4184	205.781	204.525	202.4312
11	202.8756	205.2286	206.7215	208.5305	213.4473	213.4465	208.5383	206.7302	205.2421	202.8917
12	203.3342	205.9435	207.6683	209.6475	214.6459	214.645	209.656	207.6778	205.9581	203.3518
13	203.7923	206.6574	208.6135	210.7624	215.8421	215.8411	210.7716	208.6238	206.6732	203.8114
14	204.25	207.3703	209.5571	211.8751	217.0358	217.0348	211.885	209.5682	207.3873	204.2705
15	204.7072	208.0822	210.4992	212.9858	218.2272	218.2261	212.9963	210.511	208.1004	204.7291
16	205.1639	208.7931	211.4396	214.0942	219.4161	219.415	214.1055	211.4522	208.8126	205.1873
17	205.6202	209.5031	212.3785	215.2006	220.6027	220.6014	215.2126	212.3918	209.5238	205.645
18	206.076	210.2121	213.3158	216.3049	221.7869	221.7855	216.3176	213.3299	210.234	206.1023
19	206.5314	210.9202	214.2515	217.4071	222.9687	222.9673	217.4205	214.2664	210.9432	206.5591
20	206.9862	211.6273	215.1857	218.5072	224.1481	224.1466	218.5213	215.2014	211.6515	207.0154
21	207.4407	212.3334	216.1183	219.6053	225.3252	225.3237	219.62	216.1347	212.3588	207.4712
22	207.8946	213.0385	217.0494	220.7012	226.5	226.4983	220.7166	217.0665	213.0651	207.9266
23	208.3481	213.7427	217.9789	221.7951	227.6724	227.6707	221.8112	217.9968	213.7705	208.3815
24	208.8012	214.446	218.9069	222.8869	228.8425	228.8407	222.9037	218.9255	214.4749	208.836
25	209.2537	215.1482	219.8333	223.9767	230.0103	230.0084	223.9942	219.8527	215.1784	209.29
26	209.7059	215.8496	220.7582	225.0644	231.1758	231.1738	225.0826	220.7784	215.8809	209.7435
27	210.1575	216.55	221.6815	226.1501	232.3389	232.3369	226.1689	221.7025	216.5824	210.1966
28	210.6087	217.2494	222.6034	227.2338	233.4998	233.4977	227.2533	222.625	217.283	210.6492
29	211.0595	217.9479	223.5237	228.3154	234.6584	234.6562	228.3356	223.5461	217.9826	211.1014
30	211.5098	218.6454	224.4424	229.3951	235.8147	235.8124	229.4159	224.4656	218.6813	211.5531
31	211.9596	219.342	225.3597	230.4727	236.9688	236.9664	230.4942	225.3836	219.3791	212.0043
32	212.409	220.0376	226.2755	231.5483	238.1206	238.1181	231.5705	226.3001	220.0759	212.4551
33	212.8579	220.7323	227.1897	232.6219	239.2701	239.2675	232.6448	227.2151	220.7718	212.9054
34	213.3063	221.4261	228.1025	233.6935	240.4175	240.4148	233.7171	228.1286	221.4667	213.3553
35	213.7543	222.1189	229.0137	234.7632	241.5625	241.5598	234.7874	229.0406	222.1607	213.8047
36	214.2019	222.8108	229.9235	235.8309	242.7054	242.7025	235.8557	229.9511	222.8537	214.2536
37	214.649	223.5018	230.8317	236.8966	243.846	243.8431	236.9221	230.86	223.5458	214.7021

Continued table (A3)

38	**215.0956**	**224.1918**	**231.7385**	**237.9603**	**244.9845**	**244.9814**	**237.9865**	**231.7676**	**224.237**	**215.1501**
39	**215.5418**	**224.8809**	**232.6438**	**239.0221**	**246.1207**	**246.1175**	**239.0489**	**232.6736**	**224.9272**	**215.5977**
40	**215.9876**	**225.5691**	**233.5476**	**240.0819**	**247.2547**	**247.2515**	**240.1094**	**233.5781**	**225.6165**	**216.0448**
41	**216.4329**	**226.2564**	**234.4499**	**241.1398**	**248.3866**	**248.3832**	**241.168**	**234.4812**	**226.3049**	**216.4915**
42	**216.8777**	**226.9427**	**235.3508**	**242.1958**	**249.5162**	**249.5128**	**242.2246**	**235.3828**	**226.9924**	**216.9377**
43	**217.3221**	**227.6281**	**236.2502**	**243.2498**	**250.6438**	**250.6402**	**243.2793**	**236.2829**	**227.6789**	**217.3835**
44	**217.766**	**228.3126**	**237.1481**	**244.3019**	**251.7691**	**251.7655**	**244.332**	**237.1816**	**228.3645**	**217.8288**
45	**218.2095**	**228.9961**	**238.0446**	**245.3521**	**252.8923**	**252.8886**	**245.3829**	**238.0788**	**229.0492**	**218.2736**
46	**218.6525**	**229.6788**	**238.9396**	**246.4003**	**254.0133**	**254.0095**	**246.4318**	**238.9745**	**229.733**	**218.718**
47	**219.0951**	**230.3605**	**239.8332**	**247.4467**	**255.1322**	**255.1283**	**247.4788**	**239.8688**	**230.4158**	**219.162**
48	**219.5373**	**231.0413**	**240.7254**	**248.4911**	**256.249**	**256.245**	**248.5239**	**240.7616**	**231.0978**	**219.6055**
49	**219.979**	**231.7212**	**241.616**	**249.5337**	**257.3637**	**257.3595**	**249.5672**	**241.653**	**231.7788**	**220.0486**
50	**220.4202**	**232.4002**	**242.5053**	**250.5744**	**258.4762**	**258.4719**	**250.6085**	**242.543**	**232.4589**	**220.4912**
51	**220.861**	**233.0783**	**243.3931**	**251.6132**	**259.5866**	**259.5823**	**251.648**	**243.4315**	**233.1381**	**220.9333**
52	**221.3014**	**233.7555**	**244.2795**	**252.6501**	**260.6949**	**260.6905**	**252.6855**	**244.3186**	**233.8164**	**221.375**
53	**221.7413**	**234.4318**	**245.1644**	**253.6852**	**261.8012**	**261.7966**	**253.7212**	**245.2043**	**234.4938**	**221.8163**
54	**222.1807**	**235.1071**	**246.048**	**254.7184**	**262.9053**	**262.9006**	**254.7551**	**246.0885**	**235.1703**	**222.2571**
55	**222.6197**	**235.7816**	**246.9301**	**255.7497**	**264.0074**	**264.0026**	**255.7871**	**246.9713**	**235.8458**	**222.6975**
56	**223.0583**	**236.4552**	**247.8108**	**256.7792**	**265.1073**	**265.1025**	**256.8172**	**247.8527**	**236.5205**	**223.1374**
57	**223.4964**	**237.1279**	**248.69**	**257.8068**	**266.2053**	**266.2003**	**257.8455**	**248.7327**	**237.1943**	**223.5768**
58	**223.9341**	**237.7996**	**249.5679**	**258.8326**	**267.3011**	**267.296**	**258.8719**	**249.6112**	**237.8672**	**224.0159**
59	**224.3714**	**238.4705**	**250.4444**	**259.8566**	**268.3949**	**268.3897**	**259.8965**	**250.4884**	**238.5391**	**224.4544**
60	**224.8082**	**239.1405**	**251.3194**	**260.8787**	**269.4867**	**269.4814**	**260.9193**	**251.3642**	**239.2102**	**224.8926**
61	**225.2445**	**239.8096**	**252.1931**	**261.899**	**270.5764**	**270.571**	**261.9403**	**252.2385**	**239.8804**	**225.3303**
62	**225.6805**	**240.4778**	**253.0653**	**262.9175**	**271.6641**	**271.6586**	**262.9594**	**253.1115**	**240.5497**	**225.7675**
63	**226.1159**	**241.1451**	**253.9362**	**263.9342**	**272.7498**	**272.7441**	**263.9767**	**253.9831**	**241.2181**	**226.2043**
64	**226.551**	**241.8116**	**254.8057**	**264.9491**	**273.8335**	**273.8277**	**264.9923**	**254.8532**	**241.8856**	**226.6407**
65	**226.9856**	**242.4771**	**255.6738**	**265.9622**	**274.9151**	**274.9092**	**266.006**	**255.722**	**242.5523**	**227.0766**
66	**227.4197**	**243.1418**	**256.5405**	**266.9735**	**275.9947**	**275.9887**	**267.0179**	**256.5894**	**243.218**	**227.5121**
67	**227.8534**	**243.8056**	**257.4059**	**267.983**	**277.0724**	**277.0663**	**268.028**	**257.4555**	**243.8829**	**227.9471**
68	**228.2867**	**244.4685**	**258.2699**	**268.9907**	**278.148**	**278.1418**	**269.0364**	**258.3201**	**244.5469**	**228.3817**
69	**228.7196**	**245.1305**	**259.1325**	**269.9966**	**279.2217**	**279.2153**	**270.043**	**259.1834**	**245.2099**	**228.8159**
70	**229.152**	**245.7916**	**259.9937**	**271.0008**	**280.2934**	**280.2869**	**271.0478**	**260.0453**	**245.8722**	**229.2496**
71	**229.5839**	**246.4519**	**260.8536**	**272.0032**	**281.3631**	**281.3565**	**272.0508**	**260.9059**	**246.5335**	**229.6829**
72	**230.0154**	**247.1113**	**261.7121**	**273.0038**	**282.4308**	**282.4241**	**273.0521**	**261.7651**	**247.194**	**230.1157**
73	**230.4465**	**247.7698**	**262.5693**	**274.0027**	**283.4966**	**283.4898**	**274.0516**	**262.6229**	**247.8536**	**230.5481**
74	**230.8772**	**248.4275**	**263.4251**	**274.9998**	**284.5605**	**284.5535**	**275.0494**	**263.4794**	**248.5123**	**230.9801**
75	**231.3074**	**249.0843**	**264.2795**	**275.9952**	**285.6224**	**285.6153**	**276.0454**	**264.3346**	**249.1701**	**231.4116**

Continued table (A3)

76	231.7372	249.7402	265.1326	276.9888	286.6823	286.6751	277.0396	265.1883	249.8271	231.8427
77	232.1666	250.3953	265.9844	277.9807	287.7404	287.733	278.0322	266.0408	250.4832	232.2733
78	232.5955	251.0494	266.8348	278.9709	288.7965	288.789	279.023	266.8919	251.1385	232.7035
79	233.024	251.7028	267.6839	279.9594	289.8506	289.843	280.0121	267.7416	251.7929	233.1333
80	233.452	252.3552	268.5317	280.9461	290.9029	290.8952	280.9994	268.5901	252.4464	233.5627
81	233.8797	253.0068	269.3781	281.9311	291.9532	291.9454	281.9851	269.4372	253.099	233.9916
82	234.3068	253.6576	270.2232	282.9144	293.0017	292.9937	282.969	270.2829	253.7508	234.42
83	234.7336	254.3075	271.067	283.896	294.0482	294.0401	283.9512	271.1274	254.4018	234.8481
84	235.1599	254.9565	271.9095	284.8759	295.0929	295.0846	284.9317	271.9705	255.0519	235.2757
85	235.5858	255.6047	272.7506	285.8541	296.1357	296.1273	285.9106	272.8123	255.7011	235.7029
86	236.0113	256.252	273.5904	286.8306	297.1766	297.1681	286.8877	273.6528	256.3495	236.1296
87	236.4363	256.8985	274.429	287.8054	298.2156	298.2069	287.8632	274.492	256.997	236.5559
88	236.8609	257.5442	275.2662	288.7786	299.2528	299.244	288.8369	275.3299	257.6436	236.9818
89	237.2851	258.1889	276.1021	289.7501	300.2881	300.2791	289.809	276.1664	258.2895	237.4072
90	237.7089	258.8329	276.9367	290.7199	301.3215	301.3124	290.7795	277.0017	258.9344	237.8323
91	238.1322	259.476	277.77	291.688	302.3531	302.3439	291.7482	277.8356	259.5786	238.2569
92	238.5551	260.1182	278.602	292.6545	303.3828	303.3735	292.7153	278.6683	260.2218	238.681
93	238.9776	260.7596	279.4327	293.6193	304.4107	304.4013	293.6808	279.4997	260.8643	239.1047
94	239.3996	261.4002	280.2622	294.5825	305.4368	305.4272	294.6445	280.3298	261.5059	239.528
95	239.8212	262.0399	281.0903	295.544	306.4611	306.4513	295.6067	281.1586	262.1466	239.9509
96	240.2424	262.6788	281.9172	296.5039	307.4835	307.4736	296.5672	281.9861	262.7865	240.3734

Table (A4) Glass cover temperature from each segment for one row in 17th July (K)

segment	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30
1	313.0379	314.8312	318.8296	319.0081	321.3538	320.7992	325.0084	325.4618	325.0913	325.1068
2	313.0639	314.8659	318.8766	319.0657	321.4193	320.858	325.0673	325.5064	325.1219	325.1265
3	313.0899	314.9006	318.9237	319.1236	321.4852	320.9171	325.1265	325.5511	325.1527	325.1462
4	313.116	314.9355	318.971	319.1817	321.5514	320.9765	325.186	325.5961	325.1836	325.1659
5	313.1421	314.9705	319.0185	319.2401	321.618	321.0363	325.2458	325.6412	325.2145	325.1857
6	313.1682	315.0056	319.0662	319.2988	321.6849	321.0963	325.3059	325.6866	325.2456	325.2055
7	313.1944	315.0408	319.1141	319.3578	321.7521	321.1567	325.3662	325.7321	325.2767	325.2253
8	313.2207	315.0761	319.1622	319.4171	321.8197	321.2174	325.4269	325.7778	325.3079	325.2452
9	313.247	315.1115	319.2105	319.4767	321.8876	321.2784	325.4878	325.8236	325.3392	325.2651
10	313.2733	315.147	319.259	319.5365	321.9559	321.3397	325.5491	325.8697	325.3707	325.2851
11	313.2997	315.1826	319.3077	319.5966	322.0245	321.4013	325.6106	325.916	325.4022	325.305
12	313.3261	315.2183	319.3565	319.657	322.0935	321.4632	325.6724	325.9624	325.4338	325.3251
13	313.3525	315.2542	319.4056	319.7177	322.1628	321.5254	325.7346	326.009	325.4655	325.3451
14	313.3791	315.2901	319.4549	319.7787	322.2325	321.588	325.797	326.0558	325.4973	325.3652
15	313.4056	315.3261	319.5043	319.8399	322.3025	321.6508	325.8597	326.1028	325.5291	325.3853
16	313.4322	315.3622	319.5539	319.9015	322.3728	321.714	325.9227	326.15	325.5611	325.4055
17	313.4589	315.3984	319.6037	319.9633	322.4435	321.7775	325.9859	326.1974	325.5932	325.4257
18	313.4855	315.4347	319.6538	320.0254	322.5145	321.8412	326.0495	326.2449	325.6254	325.4459
19	313.5123	315.4712	319.704	320.0878	322.5859	321.9053	326.1134	326.2927	325.6576	325.4661
20	313.539	315.5077	319.7544	320.1504	322.6576	321.9697	326.1775	326.3406	325.69	325.4864
21	313.5659	315.5443	319.8049	320.2133	322.7296	322.0344	326.242	326.3887	325.7224	325.5068
22	313.5927	315.5811	319.8557	320.2766	322.802	322.0994	326.3067	326.4369	325.7549	325.5271
23	313.6196	315.6179	319.9067	320.3401	322.8748	322.1648	326.3717	326.4854	325.7875	325.5475
24	313.6466	315.6548	319.9578	320.4038	322.9478	322.2304	326.437	326.5341	325.8203	325.568
25	313.6736	315.6918	320.0092	320.4679	323.0212	322.2963	326.5026	326.5829	325.8531	325.5884
26	313.7006	315.729	320.0607	320.5322	323.095	322.3626	326.5685	326.6319	325.886	325.609
27	313.7277	315.7662	320.1125	320.5969	323.1691	322.4291	326.6347	326.6811	325.9189	325.6295
28	313.7548	315.8035	320.1644	320.6618	323.2435	322.496	326.7012	326.7305	325.952	325.6501
29	313.782	315.841	320.2165	320.7269	323.3183	322.5631	326.7679	326.7801	325.9852	325.6707
30	313.8092	315.8785	320.2688	320.7924	323.3934	322.6306	326.8349	326.8298	326.0185	325.6913
31	313.8365	315.9162	320.3213	320.8581	323.4688	322.6984	326.9023	326.8797	326.0518	325.712
32	313.8638	315.9539	320.3739	320.9241	323.5446	322.7665	326.9699	326.9298	326.0853	325.7327
33	313.8911	315.9917	320.4268	320.9904	323.6207	322.8348	327.0378	326.9801	326.1188	325.7535
34	313.9185	316.0297	320.4798	321.057	323.6972	322.9035	327.106	327.0306	326.1524	325.7742
35	313.946	316.0677	320.5331	321.1238	323.774	322.9725	327.1744	327.0813	326.1861	325.7951
36	313.9734	316.1058	320.5865	321.1909	323.8511	323.0418	327.2432	327.1321	326.2199	325.8159
37	314.0009	316.1441	320.6401	321.2583	323.9286	323.1114	327.3122	327.1831	326.2538	325.8368

Continued table (A4)

38	314.0285	316.1824	320.6939	321.326	324.0064	323.1813	327.3816	327.2343	326.2878	325.8577
39	314.0561	316.2208	320.7479	321.3939	324.0845	323.2515	327.4512	327.2857	326.3219	325.8787
40	314.0838	316.2594	320.8021	321.4622	324.163	323.3221	327.5211	327.3373	326.3561	325.8996
41	314.1114	316.298	320.8564	321.5307	324.2418	323.3929	327.5913	327.389	326.3903	325.9207
42	314.1392	316.3367	320.911	321.5994	324.321	323.464	327.6617	327.4409	326.4247	325.9417
43	314.167	316.3756	320.9657	321.6685	324.4004	323.5354	327.7325	327.493	326.4591	325.9628
44	314.1948	316.4145	321.0206	321.7378	324.4803	323.6071	327.8035	327.5453	326.4937	325.9839
45	314.2226	316.4535	321.0757	321.8074	324.5604	323.6791	327.8748	327.5978	326.5283	326.0051
46	314.2505	316.4926	321.131	321.8773	324.6409	323.7515	327.9464	327.6504	326.563	326.0263
47	314.2785	316.5319	321.1865	321.9474	324.7217	323.8241	328.0183	327.7032	326.5978	326.0475
48	314.3065	316.5712	321.2421	322.0178	324.8028	323.897	328.0905	327.7562	326.6327	326.0687
49	314.3345	316.6106	321.298	322.0885	324.8843	323.9702	328.1629	327.8094	326.6677	326.09
50	314.3626	316.6501	321.354	322.1594	324.9661	324.0437	328.2356	327.8627	326.7027	326.1114
51	314.3907	316.6897	321.4102	322.2307	325.0482	324.1175	328.3086	327.9163	326.7379	326.1327
52	314.4188	316.7295	321.4666	322.3022	325.1306	324.1916	328.3819	327.97	326.7731	326.1541
53	314.447	316.7693	321.5232	322.3739	325.2134	324.2661	328.4555	328.0239	326.8085	326.1755
54	314.4753	316.8092	321.58	322.446	325.2965	324.3408	328.5293	328.0779	326.8439	326.197
55	314.5036	316.8492	321.6369	322.5183	325.3799	324.4158	328.6034	328.1322	326.8794	326.2185
56	314.5319	316.8893	321.6941	322.5909	325.4637	324.4911	328.6778	328.1866	326.915	326.24
57	314.5602	316.9295	321.7514	322.6637	325.5478	324.5666	328.7525	328.2412	326.9507	326.2616
58	314.5887	316.9698	321.8089	322.7368	325.6322	324.6425	328.8274	328.2959	326.9864	326.2832
59	314.6171	317.0102	321.8665	322.8102	325.7169	324.7187	328.9027	328.3509	327.0223	326.3048
60	314.6456	317.0507	321.9244	322.8839	325.802	324.7952	328.9782	328.406	327.0583	326.3264
61	314.6741	317.0913	321.9824	322.9578	325.8874	324.8719	329.0539	328.4613	327.0943	326.3481
62	314.7027	317.1319	322.0407	323.032	325.9731	324.949	329.13	328.5168	327.1304	326.3698
63	314.7313	317.1727	322.0991	323.1064	326.0591	325.0264	329.2063	328.5724	327.1666	326.3916
64	314.76	317.2136	322.1576	323.1811	326.1455	325.104	329.2829	328.6282	327.2029	326.4134
65	314.7887	317.2546	322.2164	323.2561	326.2321	325.1819	329.3598	328.6842	327.2393	326.4352
66	314.8174	317.2956	322.2754	323.3314	326.3191	325.2601	329.437	328.7404	327.2758	326.4571
67	314.8462	317.3368	322.3345	323.4069	326.4064	325.3387	329.5144	328.7967	327.3124	326.4789
68	314.875	317.378	322.3938	323.4826	326.4941	325.4175	329.5921	328.8533	327.349	326.5009
69	314.9039	317.4194	322.4533	323.5587	326.582	325.4965	329.67	328.9099	327.3857	326.5228
70	314.9328	317.4608	322.5129	323.635	326.6703	325.5759	329.7483	328.9668	327.4226	326.5448
71	314.9617	317.5024	322.5728	323.7115	326.7588	325.6556	329.8268	329.0238	327.4595	326.5668
72	314.9907	317.544	322.6328	323.7884	326.8477	325.7355	329.9056	329.081	327.4965	326.5889
73	315.0197	317.5857	322.693	323.8654	326.9369	325.8158	329.9846	329.1384	327.5335	326.6109
74	315.0488	317.6275	322.7533	323.9428	327.0265	325.8963	330.0639	329.196	327.5707	326.6331
75	315.0779	317.6695	322.8139	324.0204	327.1163	325.9771	330.1435	329.2537	327.608	326.6552

Continued table (A4)

76	**315.107**	**317.7115**	**322.8746**	**324.0983**	**327.2065**	**326.0582**	**330.2234**	**329.3116**	**327.6453**	**326.6774**
77	**315.1362**	**317.7536**	**322.9355**	**324.1764**	**327.2969**	**326.1395**	**330.3035**	**329.3696**	**327.6827**	**326.6996**
78	**315.1654**	**317.7958**	**322.9966**	**324.2548**	**327.3877**	**326.2212**	**330.3839**	**329.4279**	**327.7202**	**326.7218**
79	**315.1947**	**317.8381**	**323.0578**	**324.3334**	**327.4788**	**326.3031**	**330.4645**	**329.4863**	**327.7578**	**326.7441**
80	**315.224**	**317.8804**	**323.1193**	**324.4123**	**327.5702**	**326.3853**	**330.5454**	**329.5448**	**327.7955**	**326.7664**
81	**315.2533**	**317.9229**	**323.1809**	**324.4914**	**327.6619**	**326.4678**	**330.6266**	**329.6036**	**327.8333**	**326.7887**
82	**315.2827**	**317.9655**	**323.2427**	**324.5708**	**327.7539**	**326.5506**	**330.7081**	**329.6625**	**327.8711**	**326.8111**
83	**315.3122**	**318.0082**	**323.3046**	**324.6505**	**327.8462**	**326.6337**	**330.7898**	**329.7216**	**327.909**	**326.8335**
84	**315.3416**	**318.0509**	**323.3667**	**324.7304**	**327.9388**	**326.717**	**330.8718**	**329.7808**	**327.9471**	**326.8559**
85	**315.3711**	**318.0938**	**323.429**	**324.8106**	**328.0318**	**326.8006**	**330.954**	**329.8402**	**327.9852**	**326.8784**
86	**315.4007**	**318.1367**	**323.4915**	**324.891**	**328.125**	**326.8845**	**331.0365**	**329.8998**	**328.0233**	**326.9009**
87	**315.4303**	**318.1797**	**323.5541**	**324.9717**	**328.2185**	**326.9687**	**331.1192**	**329.9595**	**328.0616**	**326.9234**
88	**315.4599**	**318.2228**	**323.617**	**325.0526**	**328.3124**	**327.0531**	**331.2023**	**330.0195**	**328.1**	**326.946**
89	**315.4895**	**318.2661**	**323.68**	**325.1338**	**328.4065**	**327.1378**	**331.2855**	**330.0795**	**328.1384**	**326.9686**
90	**315.5192**	**318.3094**	**323.7431**	**325.2152**	**328.501**	**327.2228**	**331.3691**	**330.1398**	**328.1769**	**326.9912**
91	**315.549**	**318.3528**	**323.8064**	**325.2969**	**328.5957**	**327.308**	**331.4529**	**330.2002**	**328.2155**	**327.0138**
92	**315.5788**	**318.3963**	**323.8699**	**325.3788**	**328.6907**	**327.3936**	**331.5369**	**330.2608**	**328.2542**	**327.0365**
93	**315.6086**	**318.4398**	**323.9336**	**325.461**	**328.7861**	**327.4794**	**331.6212**	**330.3215**	**328.293**	**327.0592**
94	**315.6384**	**318.4835**	**323.9975**	**325.5434**	**328.8817**	**327.5654**	**331.7058**	**330.3824**	**328.3318**	**327.082**
95	**315.6683**	**318.5273**	**324.0615**	**325.6261**	**328.9777**	**327.6518**	**331.7906**	**330.4435**	**328.3708**	**327.1048**
96	**315.6983**	**318.5711**	**324.1257**	**325.709**	**329.0739**	**327.7384**	**331.8757**	**330.5047**	**328.4098**	**327.1276**

Table (A5) heat loss coefficient from every segment for one row in 17th July (W/m^2K)

segment	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30
1	2.536163	2.558441	2.577491	2.575948	2.633757	2.638223	2.621133	2.633791	2.648185	2.652222
2	2.541134	2.566258	2.587896	2.588249	2.647172	2.651664	2.633524	2.644302	2.656135	2.657315
3	2.546107	2.574083	2.598316	2.600572	2.660614	2.665131	2.645936	2.654827	2.664094	2.662411
4	2.551082	2.581916	2.608751	2.612917	2.67408	2.678624	2.65837	2.665367	2.67206	2.667509
5	2.55606	2.589756	2.619201	2.625284	2.687572	2.692142	2.670826	2.675923	2.680034	2.672609
6	2.561041	2.597604	2.629666	2.637672	2.701089	2.705685	2.683304	2.686493	2.688016	2.677712
7	2.566024	2.60546	2.640146	2.650082	2.714632	2.719254	2.695803	2.697078	2.696005	2.682818
8	2.571009	2.613324	2.65064	2.662513	2.7282	2.732848	2.708323	2.707678	2.704003	2.687925
9	2.575997	2.621195	2.661149	2.674966	2.741792	2.746467	2.720864	2.718292	2.712007	2.693036
10	2.580988	2.629074	2.671673	2.68744	2.75541	2.760111	2.733427	2.728921	2.72002	2.698149
11	2.58598	2.636961	2.682211	2.699935	2.769052	2.77378	2.746011	2.739565	2.72804	2.703264
12	2.590976	2.644855	2.692764	2.712451	2.782719	2.787474	2.758616	2.750223	2.736067	2.708381
13	2.595973	2.652756	2.703332	2.724988	2.79641	2.801193	2.771242	2.760896	2.744102	2.713501
14	2.600973	2.660666	2.713914	2.737546	2.810126	2.814936	2.783888	2.771583	2.752144	2.718624
15	2.605975	2.668582	2.72451	2.750126	2.823867	2.828703	2.796556	2.782284	2.760194	2.723748
16	2.61098	2.676506	2.735121	2.762725	2.837632	2.842495	2.809244	2.793	2.768252	2.728875
17	2.615987	2.684438	2.745745	2.775346	2.85142	2.856312	2.821953	2.80373	2.776316	2.734005
18	2.620996	2.692377	2.756384	2.787987	2.865233	2.870152	2.834682	2.814474	2.784388	2.739136
19	2.626008	2.700323	2.767038	2.800649	2.87907	2.884017	2.847432	2.825232	2.792468	2.74427
20	2.631022	2.708276	2.777705	2.813331	2.892931	2.897905	2.860202	2.836004	2.800554	2.749407
21	2.636038	2.716237	2.788386	2.826034	2.906816	2.911818	2.872992	2.846791	2.808648	2.754546
22	2.641057	2.724205	2.799082	2.838757	2.920724	2.925754	2.885803	2.857591	2.81675	2.759687
23	2.646078	2.732181	2.809791	2.8515	2.934656	2.939714	2.898633	2.868405	2.824858	2.76483
24	2.651101	2.740163	2.820514	2.864263	2.948611	2.953697	2.911484	2.879233	2.832974	2.769975
25	2.656127	2.748153	2.831251	2.877046	2.96259	2.967704	2.924355	2.890075	2.841097	2.775123
26	2.661154	2.75615	2.842002	2.889849	2.976592	2.981734	2.937245	2.90093	2.849227	2.780273
27	2.666184	2.764154	2.852766	2.902672	2.990617	2.995788	2.950156	2.911799	2.857364	2.785426
28	2.671216	2.772165	2.863544	2.915515	3.004665	3.009865	2.963085	2.922682	2.865508	2.79058
29	2.676251	2.780183	2.874336	2.928378	3.018736	3.023964	2.976035	2.933578	2.873659	2.795737
30	2.681288	2.788208	2.885141	2.94126	3.03283	3.038087	2.989004	2.944488	2.881817	2.800896
31	2.686326	2.79624	2.89596	2.954161	3.046946	3.052233	3.001992	2.955411	2.889982	2.806057
32	2.691367	2.804279	2.906792	2.967082	3.061085	3.066401	3.015	2.966348	2.898154	2.81122
33	2.696411	2.812325	2.917637	2.980023	3.075247	3.080592	3.028027	2.977298	2.906333	2.816386
34	2.701456	2.820378	2.928496	2.992982	3.089431	3.094805	3.041073	2.988261	2.914519	2.821554
35	2.706504	2.828438	2.939368	3.005961	3.103637	3.109041	3.054139	2.999238	2.922712	2.826724
36	2.711553	2.836505	2.950253	3.018959	3.117866	3.123299	3.067223	3.010227	2.930912	2.831896
37	2.716605	2.844579	2.961151	3.031975	3.132117	3.137579	3.080326	3.02123	2.939118	2.83707

Continued table (A5)

38	2.721659	2.852659	2.972062	3.045011	3.146389	3.151882	3.093448	3.032246	2.947331	2.842246
39	2.726715	2.860746	2.982986	3.058066	3.160683	3.166206	3.106588	3.043274	2.955551	2.847424
40	2.731774	2.86884	2.993924	3.071139	3.175	3.180552	3.119748	3.054316	2.963778	2.852605
41	2.736834	2.876941	3.004874	3.084231	3.189337	3.19492	3.132925	3.06537	2.972011	2.857788
42	2.741896	2.885048	3.015837	3.097341	3.203697	3.209309	3.146121	3.076437	2.980251	2.862972
43	2.746961	2.893162	3.026812	3.11047	3.218077	3.22372	3.159336	3.087517	2.988497	2.868159
44	2.752027	2.901282	3.037801	3.123617	3.232479	3.238153	3.172569	3.09861	2.996751	2.873348
45	2.757096	2.909409	3.048802	3.136782	3.246903	3.252607	3.18582	3.109715	3.00501	2.878539
46	2.762167	2.917543	3.059815	3.149966	3.261347	3.267082	3.199089	3.120833	3.013277	2.883732
47	2.767239	2.925683	3.070841	3.163168	3.275812	3.281578	3.212376	3.131963	3.021549	2.888926
48	2.772314	2.93383	3.08188	3.176387	3.290298	3.296095	3.225681	3.143106	3.029829	2.894123
49	2.777391	2.941983	3.092931	3.189625	3.304805	3.310633	3.239003	3.154261	3.038114	2.899322
50	2.78247	2.950142	3.103994	3.20288	3.319332	3.325191	3.252344	3.165428	3.046406	2.904523
51	2.78755	2.958308	3.11507	3.216153	3.33388	3.33977	3.265702	3.176608	3.054705	2.909726
52	2.792633	2.966481	3.126158	3.229444	3.348448	3.35437	3.279077	3.1878	3.06301	2.914931
53	2.797718	2.974659	3.137258	3.242752	3.363037	3.36899	3.29247	3.199004	3.071321	2.920138
54	2.802804	2.982844	3.14837	3.256078	3.377645	3.38363	3.305881	3.21022	3.079638	2.925347
55	2.807893	2.991036	3.159494	3.269421	3.392274	3.398291	3.319308	3.221448	3.087962	2.930558
56	2.812983	2.999233	3.17063	3.282781	3.406923	3.412971	3.332753	3.232688	3.096292	2.93577
57	2.818076	3.007437	3.181778	3.296158	3.421591	3.427672	3.346215	3.24394	3.104628	2.940985
58	2.82317	3.015647	3.192938	3.309553	3.436279	3.442392	3.359694	3.255203	3.11297	2.946201
59	2.828267	3.023863	3.20411	3.322964	3.450987	3.457132	3.373189	3.266479	3.121318	2.95142
60	2.833365	3.032085	3.215293	3.336392	3.465714	3.471891	3.386702	3.277766	3.129673	2.95664
61	2.838465	3.040313	3.226488	3.349837	3.48046	3.48667	3.400231	3.289065	3.138033	2.961862
62	2.843567	3.048548	3.237695	3.363299	3.495226	3.501468	3.413776	3.300375	3.1464	2.967086
63	2.848671	3.056788	3.248913	3.376777	3.51001	3.516286	3.427338	3.311697	3.154772	2.972312
64	2.853776	3.065034	3.260143	3.390272	3.524814	3.531122	3.440917	3.32303	3.163151	2.97754
65	2.858884	3.073287	3.271384	3.403783	3.539636	3.545978	3.454511	3.334375	3.171536	2.98277
66	2.863993	3.081545	3.282637	3.41731	3.554477	3.560852	3.468122	3.345731	3.179926	2.988001
67	2.869104	3.089809	3.2939	3.430854	3.569337	3.575745	3.481749	3.357098	3.188322	2.993234
68	2.874217	3.098079	3.305175	3.444414	3.584215	3.590657	3.495392	3.368477	3.196724	2.998469
69	2.879332	3.106355	3.316462	3.457989	3.599112	3.605587	3.509051	3.379866	3.205132	3.003706
70	2.884448	3.114637	3.327759	3.471581	3.614027	3.620535	3.522726	3.391267	3.213546	3.008945
71	2.889567	3.122924	3.339067	3.485188	3.628959	3.635501	3.536416	3.402679	3.221966	3.014185
72	2.894687	3.131218	3.350387	3.498811	3.64391	3.650486	3.550122	3.414101	3.230391	3.019427
73	2.899809	3.139517	3.361717	3.51245	3.658879	3.665489	3.563844	3.425535	3.238822	3.024671
74	2.904932	3.147821	3.373058	3.526104	3.673865	3.680509	3.577581	3.436979	3.247259	3.029917
75	2.910058	3.156132	3.38441	3.539773	3.688869	3.695547	3.591333	3.448434	3.255701	3.035164

Continued table (A5)

76	2.915185	3.164448	3.395772	3.553458	3.70389	3.710603	3.6051	3.4599	3.264149	3.040413
77	2.920314	3.172769	3.407146	3.567158	3.718929	3.725676	3.618882	3.471377	3.272602	3.045664
78	2.925444	3.181097	3.418529	3.580873	3.733985	3.740767	3.63268	3.482864	3.281061	3.050916
79	2.930576	3.189429	3.429924	3.594603	3.749058	3.755874	3.646492	3.494361	3.289526	3.056171
80	2.93571	3.197767	3.441329	3.608348	3.764148	3.770999	3.660319	3.505869	3.297996	3.061426
81	2.940846	3.206111	3.452744	3.622108	3.779254	3.786141	3.674161	3.517387	3.306471	3.066684
82	2.945983	3.21446	3.464169	3.635882	3.794378	3.801299	3.688017	3.528916	3.314952	3.071943
83	2.951122	3.222815	3.475605	3.649671	3.809517	3.816474	3.701888	3.540455	3.323438	3.077204
84	2.956262	3.231175	3.487051	3.663474	3.824674	3.831666	3.715773	3.552004	3.33193	3.082466
85	2.961404	3.23954	3.498508	3.677292	3.839846	3.846874	3.729672	3.563563	3.340426	3.08773
86	2.966548	3.24791	3.509974	3.691124	3.855035	3.862098	3.743586	3.575132	3.348929	3.092996
87	2.971693	3.256286	3.52145	3.70497	3.87024	3.877339	3.757513	3.586711	3.357436	3.098263
88	2.97684	3.264667	3.532936	3.71883	3.88546	3.892595	3.771455	3.5983	3.365949	3.103532
89	2.981989	3.273053	3.544432	3.732704	3.900696	3.907868	3.78541	3.609899	3.374466	3.108802
90	2.987139	3.281445	3.555938	3.746592	3.915948	3.923156	3.799379	3.621507	3.382989	3.114074
91	2.992291	3.289842	3.567454	3.760494	3.931216	3.938459	3.813362	3.633125	3.391517	3.119348
92	2.997444	3.298243	3.578979	3.774409	3.946498	3.953778	3.827358	3.644753	3.400051	3.124623
93	3.002599	3.30665	3.590514	3.788338	3.961796	3.969113	3.841367	3.656391	3.408589	3.129899
94	3.007755	3.315062	3.602058	3.80228	3.977109	3.984462	3.85539	3.668038	3.417132	3.135177
95	3.012913	3.323479	3.613612	3.816235	3.992437	3.999827	3.869426	3.679694	3.42568	3.140457
96	3.018072	3.331901	3.625175	3.830204	4.007779	4.015206	3.883475	3.69136	3.434234	3.145738

APPENDIX B

Table (B1) energy gain from every segment for one row in 15th April (W)

segment	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30
1	3234.618	5566.35	7676.025	9208.134	9987.301	9990.427	9210.144	7680.288	5576.229	3245.341
2	3233.476	5564.361	7673.285	9204.786	9983.573	9986.722	9206.797	7677.544	5574.253	3244.208
3	3232.334	5562.367	7670.535	9201.423	9979.828	9983	9203.436	7674.791	5572.272	3243.074
4	3231.189	5560.369	7667.775	9198.046	9976.066	9979.262	9200.061	7672.027	5570.286	3241.938
5	3230.044	5558.365	7665.006	9194.655	9972.288	9975.506	9196.671	7669.254	5568.295	3240.801
6	3228.901	5556.374	7662.261	9191.3	9968.551	9971.793	9193.317	7666.506	5566.316	3239.668
7	3227.758	5554.378	7659.506	9187.93	9964.798	9968.063	9189.949	7663.747	5564.333	3238.533
8	3226.614	5552.382	7656.752	9184.56	9961.045	9964.332	9186.581	7660.989	5562.349	3237.398
9	3225.471	5550.386	7653.997	9181.191	9957.291	9960.602	9183.213	7658.231	5560.365	3236.263
10	3224.327	5548.39	7651.242	9177.821	9953.538	9956.872	9179.845	7655.472	5558.382	3235.127
11	3223.184	5546.394	7648.487	9174.451	9949.785	9953.142	9176.476	7652.714	5556.398	3233.992
12	3222.04	5544.398	7645.733	9171.081	9946.031	9949.412	9173.108	7649.956	5554.415	3232.857
13	3220.897	5542.402	7642.978	9167.712	9942.278	9945.681	9169.74	7647.197	5552.431	3231.722
14	3219.753	5540.406	7640.223	9164.342	9938.525	9941.951	9166.372	7644.439	5550.448	3230.587
15	3218.61	5538.409	7637.468	9160.972	9934.771	9938.221	9163.003	7641.681	5548.464	3229.452
16	3217.466	5536.413	7634.714	9157.602	9931.018	9934.491	9159.635	7638.922	5546.48	3228.317
17	3216.322	5534.417	7631.959	9154.233	9927.265	9930.761	9156.267	7636.164	5544.497	3227.182
18	3215.179	5532.421	7629.204	9150.863	9923.511	9927.03	9152.899	7633.405	5542.513	3226.047
19	3214.035	5530.425	7626.45	9147.493	9919.758	9923.3	9149.531	7630.647	5540.53	3224.912
20	3212.892	5528.429	7623.695	9144.123	9916.005	9919.57	9146.162	7627.889	5538.546	3223.777
21	3211.748	5526.433	7620.94	9140.754	9912.251	9915.84	9142.794	7625.13	5536.563	3222.642
22	3210.605	5524.437	7618.185	9137.384	9908.498	9912.11	9139.426	7622.372	5534.579	3221.507
23	3209.461	5522.441	7615.431	9134.014	9904.745	9908.379	9136.058	7619.614	5532.595	3220.372
24	3208.318	5520.445	7612.676	9130.644	9900.991	9904.649	9132.689	7616.855	5530.612	3219.237
25	3207.174	5518.449	7609.921	9127.275	9897.238	9900.919	9129.321	7614.097	5528.628	3218.102
26	3206.03	5516.453	7607.167	9123.905	9893.485	9897.189	9125.953	7611.339	5526.645	3216.967
27	3204.887	5514.457	7604.412	9120.535	9889.731	9893.459	9122.585	7608.58	5524.661	3215.832
28	3203.743	5512.461	7601.657	9117.165	9885.978	9889.728	9119.217	7605.822	5522.678	3214.697
29	3202.6	5510.464	7598.902	9113.796	9882.225	9885.998	9115.848	7603.063	5520.694	3213.562
30	3201.456	5508.468	7596.148	9110.426	9878.471	9882.268	9112.48	7600.305	5518.71	3212.427
31	3200.313	5506.472	7593.393	9107.056	9874.718	9878.538	9109.112	7597.547	5516.727	3211.292
32	3199.169	5504.476	7590.638	9103.686	9870.965	9874.807	9105.744	7594.788	5514.743	3210.157
33	3198.026	5502.48	7587.884	9100.317	9867.211	9871.077	9102.375	7592.03	5512.76	3209.022
34	3196.882	5500.484	7585.129	9096.947	9863.458	9867.347	9099.007	7589.272	5510.776	3207.887

Continued table (B1)

35	**3195.739**	**5498.488**	**7582.374**	**9093.577**	**9859.705**	**9863.617**	**9095.639**	**7586.513**	**5508.793**	**3206.752**
36	**3194.595**	**5496.492**	**7579.619**	**9090.207**	**9855.951**	**9859.887**	**9092.271**	**7583.755**	**5506.809**	**3205.617**
37	**3193.451**	**5494.496**	**7576.865**	**9086.838**	**9852.198**	**9856.156**	**9088.903**	**7580.997**	**5504.825**	**3204.482**
38	**3192.308**	**5492.5**	**7574.11**	**9083.468**	**9848.445**	**9852.426**	**9085.534**	**7578.238**	**5502.842**	**3203.347**
39	**3191.164**	**5490.504**	**7571.355**	**9080.098**	**9844.692**	**9848.696**	**9082.166**	**7575.48**	**5500.858**	**3202.212**
40	**3190.021**	**5488.508**	**7568.601**	**9076.728**	**9840.938**	**9844.966**	**9078.798**	**7572.721**	**5498.875**	**3201.077**
41	**3188.877**	**5486.512**	**7565.846**	**9073.359**	**9837.185**	**9841.236**	**9075.43**	**7569.963**	**5496.891**	**3199.942**
42	**3187.734**	**5484.515**	**7563.091**	**9069.989**	**9833.432**	**9837.505**	**9072.061**	**7567.205**	**5494.908**	**3198.807**
43	**3186.59**	**5482.519**	**7560.336**	**9066.619**	**9829.678**	**9833.775**	**9068.693**	**7564.446**	**5492.924**	**3197.672**
44	**3185.447**	**5480.523**	**7557.582**	**9063.249**	**9825.925**	**9830.045**	**9065.325**	**7561.688**	**5490.94**	**3196.537**
45	**3184.303**	**5478.527**	**7554.827**	**9059.88**	**9822.172**	**9826.315**	**9061.957**	**7558.93**	**5488.957**	**3195.402**
46	**3183.16**	**5476.531**	**7552.072**	**9056.51**	**9818.418**	**9822.585**	**9058.589**	**7556.171**	**5486.973**	**3194.267**
47	**3182.016**	**5474.535**	**7549.317**	**9053.14**	**9814.665**	**9818.854**	**9055.22**	**7553.413**	**5484.99**	**3193.132**
48	**3180.872**	**5472.539**	**7546.563**	**9049.77**	**9810.912**	**9815.124**	**9051.852**	**7550.655**	**5483.006**	**3191.997**
49	**3179.729**	**5470.543**	**7543.808**	**9046.401**	**9807.158**	**9811.394**	**9048.484**	**7547.896**	**5481.023**	**3190.862**
50	**3178.585**	**5468.547**	**7541.053**	**9043.031**	**9803.405**	**9807.664**	**9045.116**	**7545.138**	**5479.039**	**3189.727**
51	**3177.442**	**5466.551**	**7538.299**	**9039.661**	**9799.652**	**9803.934**	**9041.748**	**7542.379**	**5477.055**	**3188.591**
52	**3176.298**	**5464.555**	**7535.544**	**9036.291**	**9795.898**	**9800.203**	**9038.379**	**7539.621**	**5475.072**	**3187.456**
53	**3175.155**	**5462.559**	**7532.789**	**9032.922**	**9792.145**	**9796.473**	**9035.011**	**7536.863**	**5473.088**	**3186.321**
54	**3174.011**	**5460.563**	**7530.034**	**9029.552**	**9788.392**	**9792.743**	**9031.643**	**7534.104**	**5471.105**	**3185.186**
55	**3172.868**	**5458.567**	**7527.28**	**9026.182**	**9784.638**	**9789.013**	**9028.275**	**7531.346**	**5469.121**	**3184.051**
56	**3171.724**	**5456.57**	**7524.525**	**9022.812**	**9780.885**	**9785.282**	**9024.906**	**7528.588**	**5467.138**	**3182.916**
57	**3170.58**	**5454.574**	**7521.77**	**9019.443**	**9777.132**	**9781.552**	**9021.538**	**7525.829**	**5465.154**	**3181.781**
58	**3169.437**	**5452.578**	**7519.016**	**9016.073**	**9773.378**	**9777.822**	**9018.17**	**7523.071**	**5463.17**	**3180.646**
59	**3168.293**	**5450.582**	**7516.261**	**9012.703**	**9769.625**	**9774.092**	**9014.802**	**7520.313**	**5461.187**	**3179.511**
60	**3167.15**	**5448.586**	**7513.506**	**9009.333**	**9765.872**	**9770.362**	**9011.434**	**7517.554**	**5459.203**	**3178.376**
61	**3166.006**	**5446.59**	**7510.751**	**9005.964**	**9762.118**	**9766.631**	**9008.065**	**7514.796**	**5457.22**	**3177.241**
62	**3164.863**	**5444.594**	**7507.997**	**9002.594**	**9758.365**	**9762.901**	**9004.697**	**7512.037**	**5455.236**	**3176.106**
63	**3163.719**	**5442.598**	**7505.242**	**8999.224**	**9754.612**	**9759.171**	**9001.329**	**7509.279**	**5453.253**	**3174.971**
64	**3162.576**	**5440.602**	**7502.487**	**8995.854**	**9750.858**	**9755.441**	**8997.961**	**7506.521**	**5451.269**	**3173.836**
65	**3161.432**	**5438.606**	**7499.733**	**8992.485**	**9747.105**	**9751.711**	**8994.592**	**7503.762**	**5449.285**	**3172.701**
66	**3160.289**	**5436.61**	**7496.978**	**8989.115**	**9743.352**	**9747.98**	**8991.224**	**7501.004**	**5447.302**	**3171.566**
67	**3159.145**	**5434.614**	**7494.223**	**8985.745**	**9739.598**	**9744.25**	**8987.856**	**7498.246**	**5445.318**	**3170.431**
68	**3158.001**	**5432.618**	**7491.468**	**8982.375**	**9735.845**	**9740.52**	**8984.488**	**7495.487**	**5443.335**	**3169.296**
69	**3156.858**	**5430.622**	**7488.714**	**8979.006**	**9732.092**	**9736.79**	**8981.12**	**7492.729**	**5441.351**	**3168.161**
70	**3155.714**	**5428.625**	**7485.959**	**8975.636**	**9728.339**	**9733.06**	**8977.751**	**7489.971**	**5439.368**	**3167.026**
71	**3154.571**	**5426.629**	**7483.204**	**8972.266**	**9724.585**	**9729.329**	**8974.383**	**7487.212**	**5437.384**	**3165.891**
72	**3153.427**	**5424.633**	**7480.45**	**8968.896**	**9720.832**	**9725.599**	**8971.015**	**7484.454**	**5435.4**	**3164.756**

Continued table (B1)

73	3152.284	5422.637	7477.695	8965.527	9717.079	9721.869	8967.647	7481.695	5433.417	3163.621
74	3151.14	5420.641	7474.94	8962.157	9713.325	9718.139	8964.278	7478.937	5431.433	3162.486
75	3149.997	5418.645	7472.185	8958.787	9709.572	9714.409	8960.91	7476.179	5429.45	3161.351
76	3148.853	5416.649	7469.431	8955.417	9705.819	9710.678	8957.542	7473.42	5427.466	3160.216
77	3147.709	5414.653	7466.676	8952.048	9702.065	9706.948	8954.174	7470.662	5425.483	3159.081
78	3146.566	5412.657	7463.921	8948.678	9698.312	9703.218	8950.806	7467.904	5423.499	3157.946
79	3145.422	5410.661	7461.166	8945.308	9694.559	9699.488	8947.437	7465.145	5421.515	3156.811
80	3144.279	5408.665	7458.412	8941.939	9690.805	9695.757	8944.069	7462.387	5419.532	3155.676
81	3143.135	5406.669	7455.657	8938.569	9687.052	9692.027	8940.701	7459.629	5417.548	3154.541
82	3141.992	5404.673	7452.902	8935.199	9683.299	9688.297	8937.333	7456.87	5415.565	3153.406
83	3140.848	5402.677	7450.148	8931.829	9679.545	9684.567	8933.964	7454.112	5413.581	3152.271
84	3139.705	5400.68	7447.393	8928.46	9675.792	9680.837	8930.596	7451.353	5411.598	3151.136
85	3138.561	5398.684	7444.638	8925.09	9672.039	9677.106	8927.228	7448.595	5409.614	3150.001
86	3137.418	5396.688	7441.883	8921.72	9668.285	9673.376	8923.86	7445.837	5407.63	3148.866
87	3136.274	5394.692	7439.129	8918.35	9664.532	9669.646	8920.492	7443.078	5405.647	3147.731
88	3135.13	5392.696	7436.374	8914.981	9660.779	9665.916	8917.123	7440.32	5403.663	3146.596
89	3133.987	5390.7	7433.619	8911.611	9657.025	9662.186	8913.755	7437.562	5401.68	3145.461
90	3132.843	5388.704	7430.865	8908.241	9653.272	9658.455	8910.387	7434.803	5399.696	3144.326
91	3131.7	5386.708	7428.11	8904.871	9649.519	9654.725	8907.019	7432.045	5397.713	3143.191
92	3130.556	5384.712	7425.355	8901.502	9645.765	9650.995	8903.651	7429.287	5395.729	3142.055
93	3129.413	5382.716	7422.6	8898.132	9642.012	9647.265	8900.282	7426.528	5393.745	3140.92
94	3128.269	5380.72	7419.846	8894.762	9638.259	9643.535	8896.914	7423.77	5391.762	3139.785
95	3127.126	5378.724	7417.091	8891.392	9634.505	9639.804	8893.546	7421.011	5389.778	3138.65
96	3125.982	5376.728	7414.336	8888.023	9630.752	9636.074	8890.178	7418.253	5387.795	3137.515

Table (B2) VP1 output temperature from every segment for one row in 15th April (℃)

segment	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30
1	181.0248	182.6579	184.068	187.2175	192.1884	192.1887	187.2177	184.0684	182.6588	181.0259
2	181.3493	183.2151	184.8349	188.1335	193.1751	193.1757	188.1339	184.8358	183.217	181.3515
3	181.6736	183.7717	185.6008	189.0479	194.16	194.1609	189.0485	185.602	183.7746	181.6768
4	181.9975	184.3276	186.3655	189.9609	195.1433	195.1445	189.9617	186.3672	184.3316	182.0019
5	182.3213	184.8829	187.1291	190.8724	196.1248	196.1264	190.8734	187.1312	184.8879	182.3267
6	182.6448	185.4376	187.8917	191.7824	197.1047	197.1066	191.7836	187.8942	185.4436	182.6512
7	182.968	185.9917	188.6532	192.6909	198.0828	198.085	192.6923	188.6561	185.9986	182.9755
8	183.2909	186.5451	189.4136	193.598	199.0593	199.0618	193.5996	189.4169	186.553	183.2995
9	183.6136	187.0979	190.1729	194.5036	200.0341	200.037	194.5054	190.1767	187.1068	183.6233
10	183.936	187.6501	190.9311	195.4077	201.0073	201.0104	195.4097	190.9353	187.66	183.9468
11	184.2582	188.2017	191.6883	196.3103	201.9787	201.9822	196.3125	191.6929	188.2125	184.27
12	184.5801	188.7526	192.4444	197.2115	202.9485	202.9523	197.2139	192.4494	188.7645	184.593
13	184.9017	189.3029	193.1994	198.1113	203.9167	203.9208	198.1138	193.2048	189.3158	184.9158
14	185.2231	189.8526	193.9533	199.0095	204.8831	204.8876	199.0123	193.9592	189.8664	185.2382
15	185.5443	190.4016	194.7062	199.9064	205.848	205.8528	199.9093	194.7125	190.4165	185.5604
16	185.8651	190.9501	195.4581	200.8018	206.8112	206.8163	200.8049	195.4647	190.9659	185.8824
17	186.1857	191.4979	196.2088	201.6957	207.7727	207.7782	201.6991	196.2159	191.5147	186.204
18	186.5061	192.0451	196.9585	202.5882	208.7326	208.7384	202.5918	196.966	192.0629	186.5255
19	186.8262	192.5917	197.7072	203.4793	209.6909	209.6971	203.483	197.7151	192.6105	186.8466
20	187.146	193.1377	198.4548	204.3689	210.6476	210.6541	204.3729	198.4631	193.1574	187.1675
21	187.4656	193.683	199.2013	205.2572	211.6026	211.6094	205.2613	199.21	193.7038	187.4882
22	187.7849	194.2278	199.9468	206.144	212.5561	212.5632	206.1483	199.9559	194.2495	187.8086
23	188.1039	194.7719	200.6913	207.0293	213.5079	213.5154	207.0339	200.7008	194.7946	188.1287
24	188.4227	195.3154	201.4347	207.9133	214.4581	214.4659	207.918	201.4446	195.3391	188.4486
25	188.7413	195.8583	202.1771	208.7959	215.4067	215.4149	208.8008	202.1874	195.883	188.7682
26	189.0596	196.4006	202.9184	209.677	216.3537	216.3622	209.6821	202.9291	196.4263	189.0876
27	189.3776	196.9422	203.6587	210.5568	217.2991	217.308	210.5621	203.6698	196.9689	189.4067
28	189.6954	197.4833	204.398	211.4351	218.243	218.2522	211.4406	204.4094	197.511	189.7255
29	190.0129	198.0238	205.1362	212.3121	219.1852	219.1948	212.3177	205.1481	198.0524	190.0441
30	190.3301	198.5636	205.8734	213.1876	220.1259	220.1358	213.1935	205.8856	198.5932	190.3624
31	190.6471	199.1029	206.6096	214.0618	221.065	221.0753	214.0679	206.6222	199.1335	190.6805
32	190.9639	199.6415	207.3447	214.9346	222.0025	222.0132	214.9409	207.3577	199.6731	190.9983
33	191.2804	200.1795	208.0788	215.806	222.9385	222.9495	215.8125	208.0922	200.2121	191.3159
34	191.5966	200.7169	208.8119	216.6761	223.8729	223.8843	216.6827	208.8257	200.7505	191.6332
35	191.9126	201.2538	209.544	217.5447	224.8057	224.8175	217.5516	209.5582	201.2883	191.9502
36	192.2283	201.79	210.275	218.412	225.737	225.7491	218.419	210.2896	201.8255	192.267
37	192.5437	202.3256	211.0051	219.278	226.6668	226.6793	219.2852	211.02	202.3621	192.5836

Continued table (B2)

38	192.8589	202.8606	211.7341	220.1425	227.595	227.6078	220.1499	211.7494	202.8981	192.8999
39	193.1739	203.395	212.4621	221.0058	228.5217	228.5349	221.0133	212.4778	203.4335	193.2159
40	193.4886	203.9288	213.1891	221.8676	229.4468	229.4604	221.8754	213.2052	203.9683	193.5317
41	193.803	204.462	213.9151	222.7281	230.3704	230.3844	222.7361	213.9316	204.5025	193.8472
42	194.1172	204.9947	214.6401	223.5873	231.2925	231.3068	223.5954	214.657	205.0361	194.1624
43	194.4312	205.5267	215.3641	224.4451	232.2131	232.2278	224.4534	215.3814	205.5691	194.4774
44	194.7448	206.0581	216.0871	225.3016	233.1321	233.1472	225.3101	216.1047	206.1015	194.7922
45	195.0583	206.5889	216.8091	226.1567	234.0497	234.0651	226.1654	216.8271	206.6333	195.1067
46	195.3714	207.1192	217.5301	227.0105	234.9657	234.9816	227.0194	217.5485	207.1645	195.4209
47	195.6844	207.6488	218.2501	227.863	235.8802	235.8965	227.872	218.2689	207.6951	195.7349
48	195.997	208.1778	218.9692	228.7141	236.7933	236.8099	228.7233	218.9882	208.2252	196.0487
49	196.3094	208.7063	219.6872	229.5639	237.7048	237.7218	229.5734	219.7066	208.7546	196.3622
50	196.6216	209.2342	220.4042	230.4124	238.6148	238.6322	230.422	220.424	209.2835	196.6754
51	196.9335	209.7614	221.1203	231.2596	239.5234	239.5412	231.2694	221.1405	209.8117	196.9884
52	197.2451	210.2881	221.8353	232.1055	240.4305	240.4486	232.1154	221.8559	210.3394	197.3011
53	197.5565	210.8142	222.5494	232.95	241.3361	241.3546	232.9602	222.5703	210.8665	197.6136
54	197.8677	211.3397	223.2625	233.7933	242.2402	242.2591	233.8036	223.2838	211.3929	197.9258
55	198.1786	211.8646	223.9746	234.6352	243.1428	243.1622	234.6457	223.9963	211.9188	198.2378
56	198.4892	212.389	224.6858	235.4758	244.044	244.0638	235.4866	224.7078	212.4442	198.5495
57	198.7996	212.9127	225.396	236.3152	244.9437	244.9639	236.3261	225.4183	212.9689	198.861
58	199.1098	213.4359	226.1052	237.1532	245.842	245.8625	237.1643	226.1279	213.493	199.1722
59	199.4197	213.9584	226.8134	237.99	246.7388	246.7598	238.0013	226.8365	214.0166	199.4831
60	199.7293	214.4804	227.5207	238.8255	247.6341	247.6555	238.8369	227.5441	214.5396	199.7939
61	200.0387	215.0019	228.227	239.6597	248.528	248.5498	239.6713	228.2508	215.062	200.1043
62	200.3478	215.5227	228.9323	240.4926	249.4205	249.4427	240.5044	228.9565	215.5838	200.4145
63	200.6567	216.0429	229.6367	241.3242	250.3115	250.3341	241.3362	229.6612	216.105	200.7245
64	200.9653	216.5626	230.3401	242.1545	251.2011	251.2241	242.1667	230.3649	216.6257	201.0342
65	201.2737	217.0817	231.0426	242.9836	252.0892	252.1127	242.996	231.0677	217.1458	201.3437
66	201.5819	217.6002	231.7441	243.8114	252.976	252.9999	243.824	231.7696	217.6653	201.6529
67	201.8898	218.1181	232.4446	244.638	253.8613	253.8856	244.6507	232.4705	218.1842	201.9618
68	202.1974	218.6355	233.1442	245.4632	254.7452	254.7699	245.4762	233.1704	218.7025	202.2705
69	202.5048	219.1523	233.8428	246.2873	255.6276	255.6528	246.3004	233.8694	219.2203	202.579
70	202.8119	219.6685	234.5405	247.11	256.5087	256.5343	247.1233	234.5674	219.7375	202.8872
71	203.1188	220.1841	235.2373	247.9315	257.3883	257.4143	247.945	235.2645	220.2541	203.1952
72	203.4254	220.6992	235.9331	248.7518	258.2665	258.293	248.7654	235.9607	220.7701	203.5029
73	203.7318	221.2137	236.6279	249.5708	259.1434	259.1703	249.5846	236.6559	221.2856	203.8103
74	204.038	221.7276	237.3218	250.3886	260.0188	260.0462	250.4026	237.3501	221.8005	204.1176
75	204.3439	222.2409	238.0148	251.2051	260.8929	260.9206	251.2193	238.0434	222.3148	204.4245

Continued table (B2)

76	204.6495	222.7537	238.7068	252.0204	261.7655	261.7937	252.0348	238.7358	222.8286	204.7312
77	204.9549	223.2659	239.3979	252.8344	262.6368	262.6654	252.849	239.4272	223.3418	205.0377
78	205.26	223.7776	240.0881	253.6473	263.5067	263.5358	253.662	240.1178	223.8544	205.3439
79	205.5649	224.2886	240.7773	254.4589	264.3752	264.4047	254.4738	240.8073	224.3665	205.6499
80	205.8696	224.7991	241.4656	255.2692	265.2423	265.2723	255.2843	241.496	224.8779	205.9556
81	206.174	225.309	242.153	256.0784	266.108	266.1385	256.0936	242.1837	225.3889	206.2611
82	206.4782	225.8184	242.8395	256.8863	266.9724	267.0033	256.9017	242.8704	225.8992	206.5664
83	206.7821	226.3272	243.525	257.693	267.8354	267.8668	257.7086	243.5563	226.409	206.8713
84	207.0857	226.8354	244.2096	258.4984	268.6971	268.7289	258.5142	244.2412	226.9182	207.1761
85	207.3892	227.3431	244.8933	259.3027	269.5574	269.5897	259.3187	244.9252	227.4269	207.4806
86	207.6923	227.8502	245.576	260.1058	270.4163	270.4491	260.1219	245.6083	227.935	207.7848
87	207.9953	228.3568	246.2579	260.9076	271.2739	271.3071	260.924	246.2905	228.4425	208.0888
88	208.2979	228.8628	246.9388	261.7083	272.1301	272.1638	261.7248	246.9717	228.9495	208.3926
89	208.6004	229.3682	247.6188	262.5077	272.985	273.0192	262.5244	247.6521	229.4559	208.6961
90	208.9026	229.8731	248.2979	263.306	273.8385	273.8732	263.3228	248.3315	229.9617	208.9993
91	209.2045	230.3774	248.9761	264.103	274.6907	274.7259	264.1201	249.01	230.467	209.3024
92	209.5062	230.8811	249.6534	264.8989	275.5416	275.5772	264.9161	249.6876	230.9718	209.6051
93	209.8076	231.3843	250.3297	265.6936	276.3912	276.4272	265.7109	250.3643	231.4759	209.9077
94	210.1088	231.8869	251.0052	266.487	277.2394	277.2759	266.5046	251.0401	231.9796	210.2099
95	210.4098	232.389	251.6798	267.2793	278.0862	278.1233	267.2971	251.7149	232.4826	210.512
96	210.7105	232.8905	252.3534	268.0704	278.9318	278.9693	268.0884	252.3889	232.9851	210.8138

Table (B3) Receiver temperature from every segment for one row in 15th April (K)

segment	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30
1	462.9761	464.4921	465.7968	468.8712	473.8075	473.8076	468.8713	465.797	464.4926	462.9766
2	463.3006	465.0494	466.5641	469.7879	474.7954	474.7959	469.7882	466.5647	465.0509	463.3022
3	463.6249	465.6062	467.3304	470.7032	475.7817	475.7824	470.7037	467.3314	465.6087	463.6276
4	463.9489	466.1623	468.0956	471.6171	476.7663	476.7674	471.6178	468.0971	466.1658	463.9526
5	464.2726	466.7179	468.8597	472.5296	477.7493	477.7507	472.5305	468.8616	466.7223	464.2775
6	464.5961	467.2728	469.6229	473.4406	478.7307	478.7324	473.4417	469.6252	467.2782	464.602
7	464.9194	467.8271	470.3849	474.3502	479.7104	479.7125	474.3515	470.3877	467.8336	464.9264
8	465.2424	468.3808	471.146	475.2584	480.6886	480.6909	475.2599	471.1491	468.3883	465.2504
9	465.5651	468.9339	471.906	476.1651	481.6651	481.6678	476.1668	471.9095	468.9424	465.5742
10	465.8876	469.4865	472.6649	477.0705	482.64	482.643	477.0724	472.6689	469.4959	465.8978
11	466.2098	470.0384	473.4228	477.9744	483.6133	483.6166	477.9765	473.4273	470.0487	466.2211
12	466.5318	470.5897	474.1797	478.877	484.585	484.5887	478.8793	474.1846	470.601	466.5442
13	466.8535	471.1404	474.9356	479.7781	485.5552	485.5591	479.7806	474.9409	471.1527	466.867
14	467.175	471.6904	475.6904	480.6779	486.5237	486.528	480.6805	475.6961	471.7038	467.1895
15	467.4962	472.2399	476.4443	481.5762	487.4907	487.4953	481.5791	476.4503	472.2543	467.5118
16	467.8172	472.7888	477.1971	482.4732	488.456	488.461	482.4763	477.2035	472.8042	467.8339
17	468.1379	473.3371	477.9488	483.3688	489.4198	489.4251	483.3721	477.9557	473.3535	468.1557
18	468.4583	473.8848	478.6996	484.263	490.3821	490.3877	484.2665	478.7069	473.9021	468.4772
19	468.7786	474.4319	479.4493	485.1558	491.3427	491.3487	485.1595	479.457	474.4502	468.7985
20	469.0985	474.9784	480.1981	486.0473	492.3019	492.3082	486.0511	480.2061	474.9977	469.1195
21	469.4182	475.5244	480.9458	486.9374	493.2594	493.2661	486.9414	480.9543	475.5446	469.4403
22	469.7377	476.0697	481.6925	487.8261	494.2154	494.2224	487.8303	481.7014	476.0909	469.7609
23	470.0569	476.6144	482.4382	488.7135	495.1699	495.1772	488.7179	482.4475	476.6366	470.0811
24	470.3759	477.1585	483.1829	489.5995	496.1228	496.1305	489.6041	483.1926	477.1818	470.4012
25	470.6946	477.7021	483.9266	490.4841	497.0742	497.0822	490.489	483.9367	477.7263	470.721
26	471.013	478.245	484.6693	491.3674	498.024	498.0324	491.3725	484.6798	478.2702	471.0405
27	471.3312	478.7874	485.411	492.2494	498.9723	498.981	492.2546	485.4218	478.8136	471.3598
28	471.6492	479.3292	486.1517	493.13	499.9191	499.9282	493.1354	486.1629	479.3563	471.6788
29	471.9669	479.8703	486.8914	494.0093	500.8644	500.8738	494.0149	486.903	479.8985	471.9976
30	472.2843	480.4109	487.6301	494.8872	501.8081	501.8179	494.893	487.6422	480.4401	472.3161
31	472.6015	480.9509	488.3678	495.7638	502.7504	502.7605	495.7698	488.3803	480.9811	472.6344
32	472.9185	481.4904	489.1045	496.6391	503.6911	503.7016	496.6452	489.1174	481.5215	472.9524
33	473.2352	482.0292	489.8403	497.513	504.6303	504.6412	497.5194	489.8535	482.0613	473.2702
34	473.5517	482.5675	490.5751	498.3857	505.5681	505.5793	498.3922	490.5887	482.6006	473.5878
35	473.8679	483.1051	491.3088	499.257	506.5043	506.5159	499.2637	491.3229	483.1392	473.905
36	474.1838	483.6422	492.0417	500.1269	507.439	507.451	500.1339	492.0561	483.6773	474.2221
37	474.4996	484.1787	492.7735	500.9956	508.3723	508.3846	501.0027	492.7883	484.2148	474.5389

Continued table (B3)

38	474.815	484.7147	493.5043	501.863	509.304	509.3167	501.8703	493.5195	484.7517	474.8554
39	475.1302	485.25	494.2342	502.729	510.2343	510.2474	502.7365	494.2498	485.288	475.1717
40	475.4452	485.7848	494.9631	503.5938	511.1631	511.1766	503.6015	494.9791	485.8238	475.4878
41	475.7599	486.319	495.6911	504.4572	512.0905	512.1043	504.4651	495.7074	486.359	475.8036
42	476.0744	486.8526	496.4181	505.3194	513.0163	513.0305	505.3274	496.4348	486.8936	476.1191
43	476.3886	487.3856	497.1441	506.1802	513.9407	513.9553	506.1885	497.1611	487.4276	476.4344
44	476.7026	487.9181	497.8691	507.0398	514.8636	514.8786	507.0482	497.8866	487.961	476.7495
45	477.0164	488.45	498.5932	507.8981	515.7851	515.8004	507.9067	498.611	488.4939	477.0643
46	477.3298	488.9813	499.3163	508.7551	516.7051	516.7208	508.7639	499.3345	489.0262	477.3788
47	477.6431	489.512	500.0385	509.6108	517.6237	517.6398	509.6198	500.0571	489.5579	477.6932
48	477.9561	490.0422	500.7597	510.4652	518.5408	518.5573	510.4744	500.7786	490.0891	478.0072
49	478.2688	490.5718	501.4799	511.3184	519.4565	519.4734	511.3277	501.4993	490.6197	478.3211
50	478.5813	491.1008	502.1992	512.1702	520.3707	520.388	512.1798	502.2189	491.1497	478.6346
51	478.8936	491.6292	502.9176	513.0209	521.2835	521.3012	513.0306	502.9377	491.6791	478.948
52	479.2056	492.1571	503.635	513.8702	522.1949	522.2129	513.8801	503.6554	492.208	479.2611
53	479.5174	492.6844	504.3515	514.7183	523.1048	523.1233	514.7284	504.3722	492.7363	479.5739
54	479.8289	493.2112	505.067	515.5651	524.0133	524.0322	515.5754	505.0881	493.264	479.8865
55	480.1402	493.7373	505.7815	516.4106	524.9204	524.9397	516.4211	505.8031	493.7912	480.1989
56	480.4512	494.263	506.4952	517.2549	525.8261	525.8457	517.2656	506.517	494.3178	480.511
57	480.762	494.788	507.2078	518.098	526.7303	526.7504	518.1088	507.2301	494.8438	480.8228
58	481.0725	495.3125	507.9196	518.9398	527.6331	527.6536	518.9508	507.9422	495.3693	481.1344
59	481.3828	495.8364	508.6304	519.7803	528.5345	528.5554	519.7915	508.6534	495.8942	481.4458
60	481.6929	496.3597	509.3403	520.6196	529.4345	529.4558	520.631	509.3636	496.4185	481.7569
61	482.0027	496.8825	510.0492	521.4577	530.3331	530.3548	521.4693	510.0729	496.9423	482.0678
62	482.3122	497.4047	510.7572	522.2945	531.2303	531.2524	522.3062	510.7813	497.4655	482.3785
63	482.6216	497.9264	511.4643	523.13	532.1261	532.1487	523.142	511.4887	497.9881	482.6889
64	482.9306	498.4475	512.1705	523.9644	533.0205	533.0435	523.9765	512.1952	498.5102	482.999
65	483.2395	498.968	512.8757	524.7975	533.9135	533.9369	524.8098	512.9008	499.0318	483.3089
66	483.5481	499.488	513.58	525.6294	534.8051	534.8289	525.6419	513.6055	499.5527	483.6186
67	483.8564	500.0075	514.2834	526.46	535.6954	535.7196	526.4727	514.3092	500.0731	483.928
68	484.1645	500.5263	514.9858	527.2894	536.5842	536.6088	527.3023	515.012	500.593	484.2372
69	484.4724	501.0446	515.6874	528.1176	537.4717	537.4967	528.1307	515.7139	501.1123	484.5461
70	484.78	501.5624	516.388	528.9446	538.3577	538.3832	528.9578	516.4148	501.631	484.8548
71	485.0874	502.0796	517.0877	529.7704	539.2424	539.2684	529.7838	517.1149	502.1492	485.1633
72	485.3945	502.5962	517.7865	530.5949	540.1258	540.1521	530.6085	517.814	502.6668	485.4715
73	485.7014	503.1123	518.4844	531.4182	541.0077	541.0345	531.432	518.5122	503.1839	485.7795
74	486.008	503.6278	519.1813	532.2403	541.8883	541.9156	532.2543	519.2095	503.7004	486.0872
75	486.3144	504.1428	519.8774	533.0613	542.7675	542.7952	533.0754	519.9059	504.2164	486.3947

Continued table (B3)

76	486.6206	504.6572	520.5725	533.881	543.6454	543.6735	533.8953	520.6014	504.7318	486.7019
77	486.9265	505.1711	521.2667	534.6995	544.5219	544.5505	534.714	521.296	505.2467	487.0089
78	487.2322	505.6844	521.9601	535.5167	545.397	545.4261	535.5314	521.9897	505.761	487.3157
79	487.5377	506.1972	522.6525	536.3328	546.2708	546.3003	536.3477	522.6824	506.2748	487.6222
80	487.8429	506.7094	523.344	537.1477	547.1433	547.1732	537.1628	523.3743	506.788	487.9285
81	488.1478	507.2211	524.0346	537.9614	548.0143	548.0447	537.9767	524.0652	507.3006	488.2345
82	488.4525	507.7322	524.7244	538.7739	548.8841	548.9149	538.7894	524.7553	507.8127	488.5403
83	488.757	508.2428	525.4132	539.5853	549.7525	549.7838	539.6009	525.4444	508.3243	488.8459
84	489.0613	508.7528	526.1011	540.3954	550.6195	550.6513	540.4112	526.1327	508.8353	489.1512
85	489.3653	509.2623	526.7881	541.2043	551.4852	551.5175	541.2203	526.8201	509.3458	489.4563
86	489.669	509.7712	527.4743	542.0121	552.3496	552.3823	542.0282	527.5065	509.8557	489.7611
87	489.9725	510.2796	528.1595	542.8187	553.2126	553.2458	542.835	528.1921	510.3651	490.0657
88	490.2758	510.7875	528.8438	543.6241	554.0743	554.108	543.6406	528.8768	510.8739	490.3701
89	490.5789	511.2948	529.5273	544.4283	554.9347	554.9688	544.445	529.5605	511.3822	490.6742
90	490.8817	511.8015	530.2099	545.2313	555.7937	555.8283	545.2482	530.2434	511.89	490.9781
91	491.1842	512.3077	530.8915	546.0332	556.6514	556.6865	546.0502	530.9254	512.3972	491.2817
92	491.4865	512.8134	531.5723	546.8339	557.5078	557.5434	546.8511	531.6066	512.9039	491.5851
93	491.7886	513.3185	532.2523	547.6334	558.3629	558.3989	547.6508	532.2868	513.41	491.8883
94	492.0905	513.8231	532.9313	548.4317	559.2166	559.2531	548.4493	532.9661	513.9156	492.1912
95	492.3921	514.3272	533.6094	549.2289	560.069	560.106	549.2467	533.6446	514.4206	492.4939
96	492.6935	514.8307	534.2867	550.0249	560.9201	560.9576	550.0429	534.3222	514.9251	492.7963

Table (B4) Glass cover temperature from every segment for one row in 15th April (K)

segment	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30
1	294.7277	296.0828	302.1945	304.3648	305.7944	308.6319	306.2299	306.1241	305.7321	305.2923
2	294.7459	296.1159	302.2703	304.4564	305.8956	308.7502	306.3209	306.1932	305.7752	305.3193
3	294.7641	296.149	302.3462	304.5482	305.9972	308.8689	306.4122	306.2626	305.8184	305.3463
4	294.7823	296.1822	302.4224	304.6405	306.0992	308.9881	306.5039	306.3321	305.8617	305.3733
5	294.8006	296.2155	302.4988	304.733	306.2015	309.1078	306.5959	306.4019	305.905	305.4003
6	294.8188	296.2489	302.5754	304.8259	306.3043	309.2279	306.6882	306.4719	305.9485	305.4274
7	294.8371	296.2823	302.6523	304.9191	306.4075	309.3485	306.7809	306.5421	305.9921	305.4545
8	294.8554	296.3158	302.7294	305.0127	306.511	309.4695	306.8739	306.6125	306.0357	305.4817
9	294.8737	296.3494	302.8067	305.1066	306.615	309.591	306.9673	306.6832	306.0795	305.5088
10	294.8921	296.383	302.8843	305.2008	306.7194	309.7129	307.0609	306.754	306.1234	305.5361
11	294.9104	296.4168	302.962	305.2954	306.8241	309.8353	307.155	306.825	306.1673	305.5633
12	294.9288	296.4506	303.04	305.3903	306.9293	309.9581	307.2493	306.8963	306.2113	305.5905
13	294.9472	296.4844	303.1183	305.4855	307.0348	310.0814	307.344	306.9678	306.2555	305.6178
14	294.9656	296.5184	303.1967	305.5811	307.1407	310.2052	307.439	307.0395	306.2997	305.6452
15	294.9841	296.5524	303.2754	305.677	307.2471	310.3294	307.5344	307.1114	306.344	305.6725
16	295.0026	296.5865	303.3544	305.7733	307.3538	310.454	307.63	307.1835	306.3884	305.6999
17	295.021	296.6206	303.4335	305.8698	307.4609	310.5791	307.726	307.2558	306.4329	305.7273
18	295.0395	296.6549	303.5129	305.9667	307.5684	310.7046	307.8224	307.3284	306.4775	305.7547
19	295.0581	296.6892	303.5925	306.0639	307.6763	310.8306	307.9191	307.4011	306.5222	305.7822
20	295.0766	296.7235	303.6723	306.1615	307.7846	310.9571	308.0161	307.4741	306.567	305.8097
21	295.0952	296.758	303.7524	306.2594	307.8933	311.084	308.1134	307.5472	306.6119	305.8373
22	295.1138	296.7925	303.8326	306.3576	308.0023	311.2113	308.2111	307.6206	306.6569	305.8648
23	295.1324	296.8271	303.9131	306.4562	308.1118	311.3391	308.309	307.6942	306.7019	305.8924
24	295.151	296.8618	303.9939	306.555	308.2216	311.4673	308.4074	307.768	306.7471	305.92
25	295.1697	296.8965	304.0748	306.6542	308.3319	311.596	308.506	307.842	306.7923	305.9477
26	295.1883	296.9313	304.156	306.7538	308.4425	311.7251	308.605	307.9162	306.8377	305.9754
27	295.207	296.9662	304.2374	306.8536	308.5535	311.8547	308.7043	307.9906	306.8831	306.0031
28	295.2257	297.0011	304.319	306.9538	308.6649	311.9847	308.8039	308.0653	306.9286	306.0308
29	295.2444	297.0361	304.4009	307.0543	308.7767	312.1151	308.9039	308.1401	306.9743	306.0586
30	295.2632	297.0712	304.4829	307.1552	308.8888	312.246	309.0041	308.2151	307.02	306.0864
31	295.282	297.1064	304.5652	307.2563	309.0014	312.3773	309.1047	308.2904	307.0658	306.1142
32	295.3007	297.1416	304.6477	307.3578	309.1143	312.5091	309.2057	308.3659	307.1117	306.1421
33	295.3196	297.1769	304.7305	307.4597	309.2276	312.6413	309.3069	308.4415	307.1576	306.1699
34	295.3384	297.2122	304.8134	307.5618	309.3413	312.7739	309.4085	308.5174	307.2037	306.1979
35	295.3572	297.2477	304.8966	307.6643	309.4554	312.907	309.5104	308.5935	307.2499	306.2258
36	295.3761	297.2832	304.98	307.767	309.5698	313.0405	309.6126	308.6698	307.2961	306.2538
37	295.395	297.3188	305.0636	307.8702	309.6847	313.1745	309.7151	308.7462	307.3425	306.2818

Continued table (B4)

38	295.4139	297.3544	305.1475	307.9736	309.7999	313.3089	309.818	308.8229	307.3889	306.3098
39	295.4328	297.3901	305.2315	308.0773	309.9155	313.4437	309.9212	308.8998	307.4355	306.3379
40	295.4518	297.4259	305.3158	308.1814	310.0315	313.5789	310.0247	308.9769	307.4821	306.366
41	295.4707	297.4618	305.4003	308.2858	310.1478	313.7146	310.1285	309.0543	307.5288	306.3941
42	295.4897	297.4977	305.485	308.3905	310.2646	313.8507	310.2327	309.1318	307.5756	306.4222
43	295.5087	297.5337	305.57	308.4956	310.3817	313.9873	310.3371	309.2095	307.6225	306.4504
44	295.5278	297.5698	305.6551	308.6009	310.4992	314.1242	310.4419	309.2874	307.6695	306.4786
45	295.5468	297.6059	305.7405	308.7066	310.617	314.2616	310.547	309.3655	307.7165	306.5068
46	295.5659	297.6421	305.8261	308.8126	310.7353	314.3995	310.6524	309.4438	307.7637	306.5351
47	295.585	297.6784	305.9119	308.9189	310.8539	314.5377	310.7582	309.5224	307.811	306.5634
48	295.6041	297.7147	305.9979	309.0255	310.9729	314.6764	310.8642	309.6011	307.8583	306.5917
49	295.6232	297.7512	306.0841	309.1324	311.0922	314.8155	310.9706	309.68	307.9057	306.6201
50	295.6423	297.7876	306.1706	309.2397	311.212	314.955	311.0773	309.7592	307.9532	306.6484
51	295.6615	297.8242	306.2573	309.3473	311.3321	315.095	311.1843	309.8385	308.0008	306.6768
52	295.6807	297.8608	306.3442	309.4552	311.4525	315.2354	311.2916	309.918	308.0485	306.7053
53	295.6999	297.8975	306.4313	309.5634	311.5734	315.3762	311.3992	309.9978	308.0963	306.7337
54	295.7191	297.9343	306.5186	309.6719	311.6946	315.5174	311.5071	310.0777	308.1442	306.7622
55	295.7383	297.9711	306.6061	309.7807	311.8161	315.659	311.6154	310.1579	308.1922	306.7907
56	295.7576	298.008	306.6939	309.8898	311.9381	315.8011	311.7239	310.2382	308.2402	306.8193
57	295.7769	298.0449	306.7818	309.9993	312.0604	315.9436	311.8328	310.3187	308.2884	306.8479
58	295.7962	298.082	306.87	310.1091	312.1831	316.0865	311.942	310.3995	308.3366	306.8765
59	295.8155	298.1191	306.9584	310.2191	312.3061	316.2298	312.0515	310.4804	308.3849	306.9051
60	295.8348	298.1562	307.047	310.3295	312.4295	316.3735	312.1613	310.5615	308.4333	306.9337
61	295.8542	298.1935	307.1358	310.4402	312.5533	316.5176	312.2714	310.6428	308.4818	306.9624
62	295.8735	298.2308	307.2248	310.5512	312.6774	316.6622	312.3818	310.7244	308.5304	306.9911
63	295.8929	298.2681	307.314	310.6625	312.8019	316.8071	312.4925	310.8061	308.579	307.0199
64	295.9124	298.3056	307.4035	310.7741	312.9268	316.9525	312.6036	310.888	308.6278	307.0487
65	295.9318	298.3431	307.4931	310.886	313.052	317.0983	312.7149	310.9701	308.6766	307.0774
66	295.9512	298.3806	307.583	310.9983	313.1776	317.2445	312.8266	311.0524	308.7256	307.1063
67	295.9707	298.4183	307.6731	311.1108	313.3035	317.3911	312.9385	311.1349	308.7746	307.1351
68	295.9902	298.456	307.7633	311.2236	313.4298	317.5381	313.0508	311.2177	308.8237	307.164
69	296.0097	298.4938	307.8538	311.3368	313.5565	317.6855	313.1633	311.3005	308.8729	307.1929
70	296.0292	298.5316	307.9445	311.4502	313.6835	317.8333	313.2762	311.3836	308.9221	307.2218
71	296.0488	298.5695	308.0354	311.564	313.8108	317.9815	313.3893	311.4669	308.9715	307.2508
72	296.0683	298.6075	308.1265	311.678	313.9385	318.1302	313.5028	311.5504	309.0209	307.2798
73	296.0879	298.6455	308.2179	311.7924	314.0666	318.2792	313.6166	311.6341	309.0705	307.3088
74	296.1075	298.6836	308.3094	311.907	314.195	318.4286	313.7306	311.7179	309.1201	307.3379
75	296.1271	298.7218	308.4011	312.022	314.3238	318.5784	313.845	311.802	309.1698	307.3669

Continued table (B4)

76	**296.1468**	**298.76**	**308.4931**	**312.1372**	**314.4529**	**318.7287**	**313.9597**	**311.8863**	**309.2196**	**307.396**
77	**296.1664**	**298.7983**	**308.5852**	**312.2528**	**314.5824**	**318.8793**	**314.0746**	**311.9707**	**309.2694**	**307.4251**
78	**296.1861**	**298.8367**	**308.6775**	**312.3686**	**314.7122**	**319.0303**	**314.1899**	**312.0553**	**309.3194**	**307.4543**
79	**296.2058**	**298.8751**	**308.7701**	**312.4848**	**314.8424**	**319.1817**	**314.3055**	**312.1402**	**309.3694**	**307.4835**
80	**296.2255**	**298.9136**	**308.8629**	**312.6012**	**314.9729**	**319.3335**	**314.4213**	**312.2252**	**309.4196**	**307.5127**
81	**296.2452**	**298.9522**	**308.9558**	**312.7179**	**315.1038**	**319.4857**	**314.5375**	**312.3104**	**309.4698**	**307.5419**
82	**296.265**	**298.9908**	**309.049**	**312.835**	**315.235**	**319.6383**	**314.6539**	**312.3958**	**309.5201**	**307.5712**
83	**296.2848**	**299.0295**	**309.1424**	**312.9523**	**315.3666**	**319.7913**	**314.7706**	**312.4814**	**309.5705**	**307.6005**
84	**296.3045**	**299.0683**	**309.2359**	**313.0699**	**315.4985**	**319.9447**	**314.8877**	**312.5672**	**309.6209**	**307.6298**
85	**296.3243**	**299.1071**	**309.3297**	**313.1878**	**315.6307**	**320.0984**	**315.005**	**312.6531**	**309.6715**	**307.6591**
86	**296.3442**	**299.146**	**309.4237**	**313.306**	**315.7633**	**320.2526**	**315.1226**	**312.7393**	**309.7221**	**307.6885**
87	**296.364**	**299.185**	**309.5178**	**313.4245**	**315.8962**	**320.4071**	**315.2405**	**312.8256**	**309.7728**	**307.7179**
88	**296.3839**	**299.224**	**309.6122**	**313.5433**	**316.0295**	**320.562**	**315.3587**	**312.9121**	**309.8236**	**307.7473**
89	**296.4037**	**299.2631**	**309.7068**	**313.6624**	**316.1631**	**320.7173**	**315.4772**	**312.9989**	**309.8745**	**307.7767**
90	**296.4236**	**299.3023**	**309.8016**	**313.7817**	**316.297**	**320.873**	**315.596**	**313.0858**	**309.9255**	**307.8062**
91	**296.4435**	**299.3415**	**309.8965**	**313.9014**	**316.4313**	**321.029**	**315.715**	**313.1728**	**309.9765**	**307.8357**
92	**296.4635**	**299.3808**	**309.9917**	**314.0213**	**316.5659**	**321.1855**	**315.8344**	**313.2601**	**310.0277**	**307.8652**
93	**296.4834**	**299.4201**	**310.0871**	**314.1416**	**316.7009**	**321.3423**	**315.954**	**313.3476**	**310.0789**	**307.8948**
94	**296.5034**	**299.4595**	**310.1826**	**314.2621**	**316.8361**	**321.4995**	**316.0739**	**313.4352**	**310.1302**	**307.9244**
95	**296.5234**	**299.499**	**310.2784**	**314.3829**	**316.9718**	**321.6571**	**316.1941**	**313.5231**	**310.1816**	**307.954**
96	**296.5434**	**299.5385**	**310.3744**	**314.504**	**317.1077**	**321.815**	**316.3146**	**313.6111**	**310.233**	**307.9836**

Table (B5) Heat loss coefficient from every segment for one row in 15^{th} April (W/m^2K)

segment	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30
1	2.225863	2.246132	2.248227	2.292143	2.348681	2.342556	2.305652	2.286858	2.289074	2.262893
2	2.229072	2.251675	2.255811	2.30132	2.358743	2.352562	2.314852	2.294512	2.294646	2.266114
3	2.232282	2.257224	2.263405	2.31051	2.36882	2.362584	2.324065	2.302175	2.300223	2.269335
4	2.235493	2.262776	2.271007	2.319713	2.378913	2.37262	2.333291	2.309847	2.305804	2.272558
5	2.238704	2.268333	2.278618	2.328929	2.389021	2.382672	2.34253	2.317527	2.311389	2.275781
6	2.241917	2.273894	2.286237	2.338158	2.399144	2.392739	2.351782	2.325216	2.316977	2.279006
7	2.245131	2.279459	2.293865	2.347399	2.409282	2.40282	2.361047	2.332913	2.32257	2.282231
8	2.248346	2.285028	2.301501	2.356654	2.419435	2.412917	2.370324	2.34062	2.328168	2.285457
9	2.251561	2.290601	2.309146	2.365921	2.429604	2.423028	2.379614	2.348334	2.333769	2.288685
10	2.254778	2.296179	2.3168	2.375201	2.439787	2.433153	2.388917	2.356058	2.339374	2.291913
11	2.257995	2.30176	2.324462	2.384493	2.449985	2.443294	2.398233	2.363789	2.344983	2.295142
12	2.261214	2.307346	2.332132	2.393798	2.460198	2.453449	2.407561	2.37153	2.350596	2.298372
13	2.264433	2.312936	2.339811	2.403116	2.470426	2.463619	2.416901	2.379278	2.356214	2.301603
14	2.267654	2.31853	2.347498	2.412446	2.480669	2.473803	2.426254	2.387035	2.361835	2.304834
15	2.270875	2.324128	2.355194	2.421789	2.490926	2.484001	2.43562	2.394801	2.36746	2.308067
16	2.274097	2.32973	2.362898	2.431144	2.501198	2.494214	2.444998	2.402574	2.373089	2.311301
17	2.27732	2.335336	2.37061	2.440511	2.511484	2.504442	2.454388	2.410357	2.378722	2.314535
18	2.280544	2.340946	2.37833	2.44989	2.521785	2.514683	2.46379	2.418147	2.384359	2.31777
19	2.283769	2.34656	2.386058	2.459282	2.532101	2.524939	2.473205	2.425946	2.39	2.321006
20	2.286995	2.352178	2.393795	2.468686	2.54243	2.535209	2.482632	2.433752	2.395645	2.324243
21	2.290222	2.3578	2.40154	2.478102	2.552774	2.545492	2.492071	2.441567	2.401294	2.327481
22	2.293449	2.363426	2.409293	2.487531	2.563133	2.55579	2.501522	2.449391	2.406946	2.33072
23	2.296678	2.369056	2.417054	2.496971	2.573505	2.566102	2.510986	2.457222	2.412603	2.33396
24	2.299907	2.374689	2.424823	2.506423	2.583892	2.576428	2.520461	2.465061	2.418263	2.3372
25	2.303137	2.380327	2.4326	2.515888	2.594292	2.586767	2.529948	2.472909	2.423927	2.340441
26	2.306368	2.385969	2.440385	2.525364	2.604707	2.597121	2.539447	2.480764	2.429595	2.343684
27	2.3096	2.391614	2.448178	2.534852	2.615136	2.607488	2.548958	2.488628	2.435267	2.346927
28	2.312833	2.397264	2.455979	2.544352	2.625578	2.617869	2.558481	2.496499	2.440942	2.35017
29	2.316067	2.402917	2.463788	2.553863	2.636035	2.628263	2.568015	2.504378	2.446621	2.353415
30	2.319301	2.408574	2.471605	2.563387	2.646505	2.638671	2.577561	2.512266	2.452304	2.35666
31	2.322537	2.414235	2.479429	2.572922	2.656989	2.649092	2.587119	2.520161	2.457991	2.359907
32	2.325773	2.419899	2.487261	2.582468	2.667486	2.659527	2.596688	2.528064	2.463681	2.363154
33	2.32901	2.425568	2.495102	2.592026	2.677997	2.669975	2.606269	2.535974	2.469376	2.366402
34	2.332248	2.43124	2.502949	2.601596	2.688522	2.680436	2.615862	2.543893	2.475073	2.36965
35	2.335487	2.436916	2.510805	2.611177	2.69906	2.690911	2.625466	2.551819	2.480775	2.3729
36	2.338727	2.442596	2.518668	2.62077	2.709611	2.701398	2.635081	2.559753	2.48648	2.37615
37	2.341967	2.448279	2.526539	2.630374	2.720176	2.711899	2.644708	2.567695	2.492189	2.379401

Continued table (B5)

38	2.345208	2.453966	2.534417	2.639989	2.730754	2.722413	2.654345	2.575644	2.497901	2.382653
39	2.348451	2.459657	2.542303	2.649615	2.741345	2.73294	2.663995	2.583601	2.503617	2.385906
40	2.351693	2.465352	2.550197	2.659253	2.75195	2.74348	2.673655	2.591565	2.509337	2.38916
41	2.354937	2.47105	2.558098	2.668902	2.762567	2.754033	2.683327	2.599537	2.51506	2.392414
42	2.358182	2.476752	2.566006	2.678562	2.773198	2.764598	2.693009	2.607517	2.520787	2.395669
43	2.361427	2.482457	2.573922	2.688233	2.783842	2.775177	2.702703	2.615504	2.526517	2.398925
44	2.364673	2.488167	2.581845	2.697915	2.794498	2.785767	2.712408	2.623498	2.532251	2.402181
45	2.36792	2.493879	2.589776	2.707608	2.805167	2.796371	2.722123	2.6315	2.537988	2.405438
46	2.371168	2.499596	2.597714	2.717312	2.81585	2.806987	2.73185	2.63951	2.543729	2.408697
47	2.374416	2.505316	2.60566	2.727026	2.826544	2.817616	2.741588	2.647526	2.549473	2.411955
48	2.377665	2.511039	2.613612	2.736752	2.837252	2.828257	2.751336	2.65555	2.555221	2.415215
49	2.380915	2.516766	2.621572	2.746488	2.847972	2.83891	2.761095	2.663581	2.560972	2.418475
50	2.384166	2.522497	2.629539	2.756235	2.858705	2.849576	2.770864	2.67162	2.566727	2.421736
51	2.387418	2.528231	2.637513	2.765993	2.86945	2.860254	2.780645	2.679666	2.572485	2.424998
52	2.39067	2.533969	2.645495	2.775761	2.880207	2.870944	2.790436	2.687719	2.578247	2.428261
53	2.393923	2.53971	2.653483	2.78554	2.890977	2.881647	2.800237	2.695779	2.584012	2.431524
54	2.397177	2.545454	2.661479	2.795329	2.901759	2.892361	2.810049	2.703846	2.58978	2.434788
55	2.400432	2.551202	2.669482	2.805129	2.912554	2.903088	2.819872	2.71192	2.595552	2.438053
56	2.403687	2.556954	2.677492	2.814939	2.92336	2.913826	2.829705	2.720002	2.601327	2.441318
57	2.406943	2.562709	2.685508	2.82476	2.934179	2.924576	2.839548	2.72809	2.607105	2.444584
58	2.4102	2.568467	2.693532	2.834591	2.94501	2.935339	2.849401	2.736186	2.612887	2.447851
59	2.413458	2.574229	2.701563	2.844432	2.955852	2.946112	2.859265	2.744288	2.618672	2.451118
60	2.416716	2.579994	2.7096	2.854283	2.966707	2.956898	2.869139	2.752397	2.62446	2.454387
61	2.419975	2.585762	2.717645	2.864145	2.977573	2.967695	2.879023	2.760513	2.630252	2.457656
62	2.423235	2.591534	2.725696	2.874017	2.988452	2.978504	2.888917	2.768637	2.636047	2.460925
63	2.426495	2.597309	2.733754	2.883898	2.999341	2.989324	2.898821	2.776766	2.641845	2.464195
64	2.429756	2.603088	2.741818	2.89379	3.010243	3.000156	2.908736	2.784903	2.647646	2.467466
65	2.433018	2.60887	2.74989	2.903691	3.021156	3.010999	2.91866	2.793047	2.653451	2.470738
66	2.436281	2.614655	2.757968	2.913603	3.032081	3.021853	2.928594	2.801197	2.659259	2.47401
67	2.439544	2.620443	2.766053	2.923524	3.043017	3.032719	2.938538	2.809354	2.66507	2.477283
68	2.442808	2.626235	2.774144	2.933455	3.053964	3.043596	2.948491	2.817518	2.670884	2.480557
69	2.446072	2.63203	2.782243	2.943396	3.064923	3.054484	2.958455	2.825688	2.676701	2.483831
70	2.449338	2.637828	2.790347	2.953347	3.075893	3.065383	2.968428	2.833865	2.682522	2.487106
71	2.452604	2.643629	2.798458	2.963307	3.086874	3.076293	2.97841	2.842048	2.688345	2.490382
72	2.45587	2.649434	2.806576	2.973276	3.097867	3.087214	2.988403	2.850238	2.694172	2.493658
73	2.459138	2.655242	2.8147	2.983256	3.10887	3.098146	2.998405	2.858435	2.700002	2.496935
74	2.462406	2.661053	2.822831	2.993244	3.119885	3.109088	3.008416	2.866638	2.705834	2.500212
75	2.465674	2.666867	2.830968	3.003243	3.13091	3.120042	3.018436	2.874847	2.71167	2.50349

Continued table (B5)

76	2.468944	2.672684	2.839111	3.01325	3.141946	3.131006	3.028466	2.883063	2.717509	2.506769
77	2.472214	2.678504	2.847261	3.023267	3.152993	3.141981	3.038506	2.891285	2.723351	2.510048
78	2.475484	2.684328	2.855417	3.033293	3.164051	3.152966	3.048554	2.899514	2.729196	2.513328
79	2.478756	2.690154	2.863579	3.043328	3.17512	3.163961	3.058612	2.907749	2.735044	2.516609
80	2.482028	2.695984	2.871748	3.053373	3.186199	3.174968	3.068679	2.91599	2.740895	2.51989
81	2.4853	2.701817	2.879922	3.063426	3.197288	3.185984	3.078755	2.924237	2.746749	2.523172
82	2.488573	2.707652	2.888103	3.073489	3.208388	3.197011	3.08884	2.932491	2.752606	2.526454
83	2.491847	2.713491	2.89629	3.083561	3.219499	3.208048	3.098934	2.940751	2.758466	2.529737
84	2.495122	2.719333	2.904483	3.093641	3.230619	3.219095	3.109037	2.949017	2.764329	2.533021
85	2.498397	2.725178	2.912683	3.103731	3.24175	3.230152	3.119149	2.957289	2.770195	2.536305
86	2.501672	2.731026	2.920888	3.113829	3.252892	3.241219	3.12927	2.965567	2.776064	2.53959
87	2.504949	2.736876	2.929099	3.123936	3.264043	3.252297	3.139399	2.973851	2.781935	2.542875
88	2.508225	2.74273	2.937316	3.134052	3.275204	3.263384	3.149538	2.982141	2.78781	2.546161
89	2.511503	2.748587	2.945539	3.144176	3.286376	3.274481	3.159685	2.990437	2.793687	2.549448
90	2.514781	2.754447	2.953768	3.154309	3.297557	3.285587	3.16984	2.998739	2.799567	2.552735
91	2.51806	2.760309	2.962003	3.164451	3.308748	3.296704	3.180004	3.007047	2.80545	2.556023
92	2.521339	2.766174	2.970244	3.174601	3.319949	3.30783	3.190177	3.015361	2.811336	2.559311
93	2.524619	2.772043	2.978491	3.18476	3.33116	3.318965	3.200358	3.023681	2.817224	2.5626
94	2.527899	2.777914	2.986743	3.194927	3.34238	3.33011	3.210547	3.032007	2.823115	2.565889
95	2.53118	2.783788	2.995001	3.205102	3.35361	3.341265	3.220745	3.040338	2.829009	2.569179
96	2.534462	2.789665	3.003265	3.215286	3.36485	3.352429	3.230951	3.048675	2.834906	2.572469

APPENDIX C

Table (C1) Heat loss coefficient from every segment for one row in 17th Jan (W/m^2K)

segment	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30
1	2.141855	2.169003	2.180679	2.202016	2.217747	2.213196	2.218145	2.222419
2	2.143436	2.171743	2.184137	2.205772	2.221518	2.216685	2.220919	2.22404
3	2.145017	2.174483	2.187597	2.209529	2.225291	2.220175	2.223693	2.225661
4	2.146598	2.177225	2.191057	2.213288	2.229065	2.223666	2.226468	2.227282
5	2.148179	2.179966	2.194519	2.217049	2.232841	2.227158	2.229243	2.228902
6	2.149761	2.182709	2.197983	2.220811	2.236619	2.230652	2.232019	2.230523
7	2.151342	2.185452	2.201447	2.224575	2.240398	2.234147	2.234795	2.232144
8	2.152923	2.188196	2.204913	2.22834	2.244179	2.237643	2.237572	2.233764
9	2.154504	2.19094	2.20838	2.232107	2.247961	2.241141	2.24035	2.235385
10	2.156085	2.193685	2.211848	2.235875	2.251745	2.24464	2.243128	2.237005
11	2.157666	2.19643	2.215317	2.239645	2.25553	2.24814	2.245907	2.238626
12	2.159246	2.199176	2.218788	2.243417	2.259317	2.251641	2.248686	2.240246
13	2.160827	2.201923	2.22226	2.247189	2.263105	2.255144	2.251466	2.241866
14	2.162408	2.20467	2.225733	2.250964	2.266895	2.258647	2.254247	2.243487
15	2.163989	2.207417	2.229207	2.25474	2.270687	2.262152	2.257028	2.245107
16	2.16557	2.210166	2.232683	2.258517	2.274479	2.265658	2.25981	2.246727
17	2.16715	2.212914	2.236159	2.262296	2.278274	2.269166	2.262592	2.248348
18	2.168731	2.215664	2.239637	2.266077	2.28207	2.272674	2.265375	2.249968
19	2.170312	2.218414	2.243116	2.269859	2.285867	2.276184	2.268158	2.251588
20	2.171892	2.221164	2.246597	2.273642	2.289666	2.279695	2.270942	2.253208
21	2.173473	2.223915	2.250078	2.277427	2.293466	2.283207	2.273726	2.254828
22	2.175053	2.226667	2.253561	2.281214	2.297268	2.286721	2.276511	2.256448
23	2.176634	2.229419	2.257045	2.285001	2.301071	2.290235	2.279297	2.258068
24	2.178214	2.232172	2.26053	2.288791	2.304876	2.293751	2.282083	2.259688
25	2.179795	2.234925	2.264016	2.292582	2.308682	2.297268	2.28487	2.261308
26	2.181375	2.237679	2.267503	2.296374	2.31249	2.300786	2.287657	2.262928
27	2.182955	2.240433	2.270992	2.300167	2.316299	2.304305	2.290445	2.264548
28	2.184535	2.243188	2.274481	2.303962	2.32011	2.307825	2.293233	2.266167
29	2.186116	2.245944	2.277972	2.307759	2.323921	2.311347	2.296022	2.267787
30	2.187696	2.2487	2.281464	2.311557	2.327735	2.314869	2.298811	2.269407
31	2.189276	2.251456	2.284957	2.315356	2.33155	2.318393	2.301601	2.271026
32	2.190856	2.254213	2.288451	2.319157	2.335366	2.321918	2.304391	2.272646

Continued table (C1)

33	2.192436	2.25697	2.291946	2.322959	2.339183	2.325444	2.307182	2.274265
34	2.194016	2.259728	2.295443	2.326762	2.343002	2.328971	2.309973	2.275885
35	2.195596	2.262487	2.29894	2.330567	2.346823	2.332499	2.312765	2.277504
36	2.197175	2.265246	2.302439	2.334373	2.350644	2.336028	2.315557	2.279123
37	2.198755	2.268006	2.305938	2.338181	2.354467	2.339559	2.31835	2.280742
38	2.200335	2.270766	2.309439	2.34199	2.358292	2.34309	2.321143	2.282362
39	2.201915	2.273526	2.312941	2.3458	2.362118	2.346623	2.323937	2.283981
40	2.203494	2.276287	2.316444	2.349612	2.365945	2.350157	2.326732	2.2856
41	2.205074	2.279049	2.319948	2.353425	2.369773	2.353692	2.329526	2.287219
42	2.206653	2.281811	2.323453	2.357239	2.373603	2.357227	2.332322	2.288838
43	2.208232	2.284573	2.326959	2.361055	2.377434	2.360764	2.335117	2.290456
44	2.209812	2.287336	2.330466	2.364872	2.381267	2.364302	2.337914	2.292075
45	2.211391	2.2901	2.333975	2.368691	2.385101	2.367841	2.34071	2.293694
46	2.21297	2.292863	2.337484	2.37251	2.388936	2.371382	2.343508	2.295313
47	2.214549	2.295628	2.340994	2.376331	2.392772	2.374923	2.346305	2.296931
48	2.216129	2.298393	2.344506	2.380153	2.39661	2.378465	2.349103	2.29855
49	2.217708	2.301158	2.348018	2.383977	2.400449	2.382008	2.351902	2.300168
50	2.219286	2.303924	2.351532	2.387802	2.40429	2.385553	2.354701	2.301786
51	2.220865	2.30669	2.355046	2.391628	2.408131	2.389098	2.357501	2.303405
52	2.222444	2.309457	2.358562	2.395455	2.411974	2.392644	2.360301	2.305023
53	2.224023	2.312224	2.362078	2.399284	2.415818	2.396192	2.363101	2.306641
54	2.225602	2.314992	2.365596	2.403114	2.419664	2.39974	2.365902	2.308259
55	2.22718	2.31776	2.369114	2.406945	2.423511	2.40329	2.368703	2.309877
56	2.228759	2.320528	2.372634	2.410778	2.427358	2.40684	2.371505	2.311495
57	2.230337	2.323297	2.376154	2.414612	2.431208	2.410391	2.374307	2.313113
58	2.231915	2.326067	2.379676	2.418447	2.435058	2.413944	2.37711	2.314731
59	2.233494	2.328836	2.383198	2.422283	2.43891	2.417497	2.379913	2.316348
60	2.235072	2.331607	2.386722	2.42612	2.442763	2.421052	2.382716	2.317966
61	2.23665	2.334377	2.390246	2.429959	2.446617	2.424607	2.38552	2.319583
62	2.238228	2.337148	2.393772	2.433799	2.450472	2.428163	2.388325	2.321201
63	2.239806	2.33992	2.397298	2.43764	2.454329	2.43172	2.391129	2.322818
64	2.241384	2.342692	2.400826	2.441482	2.458187	2.435279	2.393935	2.324435
65	2.242962	2.345464	2.404354	2.445325	2.462046	2.438838	2.39674	2.326053
66	2.244539	2.348237	2.407883	2.44917	2.465906	2.442398	2.399546	2.32767
67	2.246117	2.35101	2.411413	2.453016	2.469767	2.445959	2.402353	2.329287
68	2.247695	2.353784	2.414945	2.456863	2.47363	2.449521	2.405159	2.330904
69	2.249272	2.356558	2.418477	2.460711	2.477494	2.453084	2.407967	2.33252

Continued table (C1)

70	2.25085	2.359333	2.42201	2.46456	2.481359	2.456648	2.410774	2.334137
71	2.252427	2.362107	2.425543	2.468411	2.485225	2.460213	2.413582	2.335754
72	2.254004	2.364883	2.429078	2.472263	2.489092	2.463779	2.416391	2.33737
73	2.255581	2.367658	2.432614	2.476115	2.49296	2.467345	2.419199	2.338987
74	2.257158	2.370434	2.436151	2.479969	2.49683	2.470913	2.422008	2.340603
75	2.258735	2.373211	2.439688	2.483824	2.5007	2.474482	2.424818	2.34222
76	2.260312	2.375987	2.443227	2.487681	2.504572	2.478051	2.427628	2.343836
77	2.261889	2.378765	2.446766	2.491538	2.508445	2.481621	2.430438	2.345452
78	2.263465	2.381542	2.450306	2.495396	2.512319	2.485192	2.433249	2.347068
79	2.265042	2.38432	2.453847	2.499256	2.516194	2.488764	2.43606	2.348684
80	2.266619	2.387098	2.457389	2.503117	2.52007	2.492337	2.438871	2.350299
81	2.268195	2.389877	2.460932	2.506978	2.523948	2.495911	2.441683	2.351915
82	2.269771	2.392656	2.464476	2.510841	2.527826	2.499486	2.444495	2.353531
83	2.271347	2.395435	2.46802	2.514705	2.531705	2.503061	2.447308	2.355146
84	2.272924	2.398215	2.471566	2.51857	2.535586	2.506638	2.450121	2.356762
85	2.2745	2.400995	2.475112	2.522436	2.539468	2.510215	2.452934	2.358377
86	2.276075	2.403776	2.478659	2.526303	2.54335	2.513793	2.455747	2.359992
87	2.277651	2.406556	2.482207	2.530171	2.547234	2.517372	2.458561	2.361607
88	2.279227	2.409338	2.485756	2.534041	2.551119	2.520952	2.461376	2.363222
89	2.280803	2.412119	2.489305	2.537911	2.555005	2.524532	2.46419	2.364837
90	2.282378	2.414901	2.492856	2.541782	2.558892	2.528114	2.467005	2.366452
91	2.283953	2.417683	2.496407	2.545655	2.56278	2.531696	2.46982	2.368066
92	2.285529	2.420466	2.499959	2.549528	2.566669	2.535279	2.472636	2.369681
93	2.287104	2.423248	2.503512	2.553402	2.570559	2.538863	2.475452	2.371295
94	2.288679	2.426032	2.507065	2.557278	2.57445	2.542448	2.478268	2.37291
95	2.290254	2.428815	2.51062	2.561154	2.578342	2.546033	2.481084	2.374524
96	2.291829	2.431599	2.514175	2.565032	2.582235	2.549619	2.483901	2.376138

Table (C2) energy gain from every segment for one row in 17th Jan (W)

Segment	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30
1	1629.325	2797.557	3522.605	3809.958	3811.536	3525.558	2803.907	1636.679
2	1628.758	2796.578	3521.371	3808.618	3810.195	3524.321	2802.926	1636.107
3	1628.19	2795.597	3520.136	3807.275	3808.852	3523.083	2801.944	1635.534
4	1627.623	2794.616	3518.899	3805.931	3807.506	3521.842	2800.961	1634.962
5	1627.055	2793.634	3517.659	3804.585	3806.158	3520.6	2799.978	1634.389
6	1626.487	2792.65	3516.419	3803.236	3804.808	3519.356	2798.993	1633.816
7	1625.918	2791.665	3515.176	3801.885	3803.456	3518.111	2798.006	1633.242
8	1625.35	2790.68	3513.932	3800.532	3802.102	3516.863	2797.019	1632.669
9	1624.781	2789.693	3512.685	3799.177	3800.745	3515.614	2796.031	1632.095
10	1624.211	2788.705	3511.437	3797.82	3799.387	3514.363	2795.042	1631.521
11	1623.642	2787.716	3510.187	3796.46	3798.026	3513.11	2794.052	1630.946
12	1623.072	2786.726	3508.936	3795.099	3796.663	3511.855	2793.06	1630.371
13	1622.502	2785.735	3507.682	3793.735	3795.298	3510.598	2792.068	1629.796
14	1621.932	2784.743	3506.427	3792.369	3793.931	3509.34	2791.074	1629.221
15	1621.361	2783.75	3505.17	3791.001	3792.562	3508.079	2790.079	1628.645
16	1620.79	2782.755	3503.911	3789.631	3791.191	3506.817	2789.084	1628.069
17	1620.219	2781.76	3502.65	3788.259	3789.817	3505.554	2788.087	1627.493
18	1619.648	2780.764	3501.388	3786.885	3788.441	3504.288	2787.089	1626.917
19	1619.076	2779.766	3500.124	3785.508	3787.064	3503.021	2786.09	1626.34
20	1618.504	2778.768	3498.858	3784.13	3785.684	3501.751	2785.09	1625.763
21	1617.932	2777.768	3497.59	3782.749	3784.302	3500.48	2784.089	1625.186
22	1617.359	2776.768	3496.32	3781.366	3782.917	3499.208	2783.087	1624.608
23	1616.787	2775.766	3495.049	3779.981	3781.531	3497.933	2782.084	1624.03
24	1616.213	2774.763	3493.776	3778.594	3780.143	3496.657	2781.08	1623.452
25	1615.64	2773.76	3492.501	3777.205	3778.752	3495.379	2780.075	1622.874
26	1615.067	2772.755	3491.224	3775.813	3777.359	3494.099	2779.069	1622.295
27	1614.493	2771.749	3489.946	3774.42	3775.965	3492.817	2778.061	1621.716
28	1613.919	2770.742	3488.666	3773.025	3774.568	3491.534	2777.053	1621.137
29	1613.344	2769.734	3487.384	3771.627	3773.169	3490.248	2776.044	1620.558
30	1612.77	2768.726	3486.1	3770.227	3771.767	3488.961	2775.033	1619.978
31	1612.195	2767.716	3484.814	3768.825	3770.364	3487.673	2774.022	1619.398
32	1611.619	2766.705	3483.527	3767.421	3768.959	3486.382	2773.009	1618.818
33	1611.044	2765.693	3482.238	3766.015	3767.552	3485.09	2771.996	1618.237
34	1610.468	2764.68	3480.947	3764.607	3766.142	3483.796	2770.981	1617.656
35	1609.892	2763.665	3479.655	3763.197	3764.73	3482.5	2769.966	1617.075

Continued table (C2)

36	1609.316	2762.65	3478.36	3761.785	3763.317	3481.202	2768.949	1616.494
37	1608.74	2761.634	3477.064	3760.37	3761.901	3479.903	2767.931	1615.912
38	1608.163	2760.617	3475.767	3758.954	3760.483	3478.602	2766.912	1615.33
39	1607.586	2759.599	3474.467	3757.535	3759.063	3477.299	2765.893	1614.748
40	1607.008	2758.58	3473.166	3756.115	3757.641	3475.994	2764.872	1614.166
41	1606.431	2757.559	3471.863	3754.692	3756.217	3474.688	2763.85	1613.583
42	1605.853	2756.538	3470.558	3753.267	3754.791	3473.38	2762.827	1613
43	1605.275	2755.516	3469.251	3751.84	3753.362	3472.07	2761.803	1612.417
44	1604.697	2754.492	3467.943	3750.411	3751.932	3470.758	2760.778	1611.833
45	1604.118	2753.468	3466.633	3748.98	3750.5	3469.445	2759.753	1611.249
46	1603.539	2752.443	3465.322	3747.547	3749.065	3468.13	2758.726	1610.665
47	1602.96	2751.416	3464.008	3746.112	3747.629	3466.813	2757.698	1610.081
48	1602.381	2750.389	3462.693	3744.675	3746.19	3465.494	2756.669	1609.497
49	1601.801	2749.361	3461.376	3743.236	3744.749	3464.174	2755.639	1608.912
50	1601.221	2748.331	3460.058	3741.795	3743.307	3462.852	2754.608	1608.327
51	1600.641	2747.301	3458.737	3740.351	3741.862	3461.528	2753.576	1607.741
52	1600.061	2746.269	3457.415	3738.906	3740.415	3460.203	2752.543	1607.156
53	1599.48	2745.237	3456.091	3737.458	3738.966	3458.876	2751.508	1606.57
54	1598.899	2744.203	3454.766	3736.009	3737.515	3457.547	2750.473	1605.984
55	1598.318	2743.169	3453.439	3734.557	3736.062	3456.216	2749.437	1605.397
56	1597.737	2742.134	3452.11	3733.104	3734.607	3454.884	2748.4	1604.811
57	1597.155	2741.097	3450.779	3731.648	3733.15	3453.55	2747.362	1604.224
58	1596.573	2740.06	3449.447	3730.191	3731.691	3452.214	2746.323	1603.637
59	1595.991	2739.021	3448.113	3728.731	3730.23	3450.876	2745.283	1603.049
60	1595.408	2737.982	3446.777	3727.269	3728.767	3449.537	2744.242	1602.462
61	1594.826	2736.941	3445.44	3725.806	3727.301	3448.196	2743.2	1601.874
62	1594.243	2735.9	3444.101	3724.34	3725.834	3446.854	2742.157	1601.286
63	1593.66	2734.858	3442.76	3722.872	3724.365	3445.509	2741.113	1600.697
64	1593.076	2733.814	3441.418	3721.402	3722.894	3444.163	2740.067	1600.109
65	1592.493	2732.77	3440.073	3719.931	3721.42	3442.816	2739.021	1599.52
66	1591.909	2731.724	3438.728	3718.457	3719.945	3441.466	2737.974	1598.931
67	1591.325	2730.678	3437.38	3716.981	3718.468	3440.115	2736.926	1598.341
68	1590.74	2729.631	3436.031	3715.503	3716.988	3438.762	2735.877	1597.751
69	1590.155	2728.582	3434.68	3714.024	3715.507	3437.408	2734.827	1597.161
70	1589.571	2727.533	3433.327	3712.542	3714.024	3436.052	2733.776	1596.571
71	1588.985	2726.483	3431.973	3711.058	3712.538	3434.694	2732.724	1595.981
72	1588.4	2725.431	3430.617	3709.572	3711.051	3433.335	2731.671	1595.39

Continued table (C2)

73	1587.814	2724.379	3429.26	3708.084	3709.562	3431.973	2730.617	1594.799
74	1587.229	2723.326	3427.9	3706.595	3708.07	3430.61	2729.562	1594.208
75	1586.642	2722.272	3426.539	3705.103	3706.577	3429.246	2728.506	1593.617
76	1586.056	2721.217	3425.177	3703.609	3705.082	3427.88	2727.449	1593.025
77	1585.469	2720.16	3423.813	3702.113	3703.584	3426.512	2726.391	1592.433
78	1584.883	2719.103	3422.447	3700.616	3702.085	3425.142	2725.332	1591.841
79	1584.295	2718.045	3421.079	3699.116	3700.584	3423.771	2724.273	1591.248
80	1583.708	2716.986	3419.71	3697.614	3699.081	3422.398	2723.212	1590.656
81	1583.121	2715.926	3418.339	3696.111	3697.575	3421.024	2722.15	1590.063
82	1582.533	2714.865	3416.967	3694.605	3696.068	3419.648	2721.087	1589.47
83	1581.945	2713.803	3415.592	3693.097	3694.559	3418.27	2720.023	1588.876
84	1581.356	2712.74	3414.217	3691.588	3693.048	3416.89	2718.959	1588.283
85	1580.768	2711.676	3412.839	3690.076	3691.535	3415.509	2717.893	1587.689
86	1580.179	2710.612	3411.46	3688.563	3690.02	3414.126	2716.826	1587.095
87	1579.59	2709.546	3410.079	3687.048	3688.503	3412.742	2715.759	1586.5
88	1579.001	2708.479	3408.697	3685.53	3686.984	3411.356	2714.69	1585.906
89	1578.411	2707.411	3407.313	3684.011	3685.463	3409.968	2713.621	1585.311
90	1577.822	2706.343	3405.927	3682.49	3683.94	3408.579	2712.55	1584.716
91	1577.232	2705.273	3404.54	3680.966	3682.415	3407.188	2711.479	1584.12
92	1576.641	2704.203	3403.151	3679.441	3680.889	3405.795	2710.407	1583.525
93	1576.051	2703.131	3401.761	3677.914	3679.36	3404.401	2709.333	1582.929
94	1575.46	2702.059	3400.369	3676.385	3677.829	3403.005	2708.259	1582.333
95	1574.869	2700.985	3398.975	3674.854	3676.297	3401.608	2707.184	1581.737
96	1574.278	2699.911	3397.58	3673.321	3674.762	3400.208	2706.108	1581.14

Table (C3) Vp1 output temperature from every segment for one row in 17th Jan (°C)

segment	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30
1	180.0638	179.8813	179.7543	180.5828	180.583	179.7546	179.882	180.0645
2	180.2274	180.1624	180.1084	180.9653	180.9656	180.109	180.1637	180.2289
3	180.391	180.4433	180.4621	181.3475	181.3479	180.463	180.4453	180.3932
4	180.5544	180.724	180.8156	181.7293	181.7299	180.8168	180.7266	180.5574
5	180.7178	181.0045	181.1687	182.1107	182.1115	181.1702	181.0077	180.7215
6	180.8811	181.2848	181.5216	182.4919	182.4928	181.5234	181.2886	180.8855
7	181.0443	181.5649	181.8741	182.8727	182.8738	181.8762	181.5693	181.0494
8	181.2074	181.8447	182.2264	183.2531	183.2544	182.2287	181.8498	181.2133
9	181.3704	182.1244	182.5783	183.6332	183.6346	182.581	182.1301	181.377
10	181.5333	182.4038	182.93	184.013	184.0146	182.9329	182.4102	181.5406
11	181.6961	182.683	183.2813	184.3924	184.3942	183.2846	182.69	181.7042
12	181.8588	182.9621	183.6324	184.7716	184.7734	183.6359	182.9697	181.8676
13	182.0214	183.2409	183.9832	185.1503	185.1524	183.987	183.2491	182.031
14	182.1839	183.5195	184.3336	185.5288	185.531	184.3377	183.5284	182.1942
15	182.3463	183.7979	184.6838	185.9069	185.9092	184.6882	183.8074	182.3574
16	182.5087	184.0761	185.0337	186.2846	186.2871	185.0383	184.0862	182.5204
17	182.6709	184.3541	185.3832	186.662	186.6647	185.3882	184.3649	182.6834
18	182.8331	184.6318	185.7325	187.0391	187.0419	185.7378	184.6433	182.8463
19	182.9951	184.9094	186.0815	187.4159	187.4189	186.087	184.9215	183.0091
20	183.1571	185.1868	186.4302	187.7923	187.7954	186.436	185.1995	183.1717
21	183.3189	185.4639	186.7786	188.1684	188.1717	186.7847	185.4772	183.3343
22	183.4807	185.7409	187.1267	188.5442	188.5476	187.1331	185.7548	183.4968
23	183.6424	186.0176	187.4745	188.9196	188.9232	187.4812	186.0322	183.6592
24	183.804	186.2942	187.822	189.2947	189.2984	187.829	186.3093	183.8215
25	183.9655	186.5705	188.1692	189.6694	189.6733	188.1765	186.5863	183.9837
26	184.1269	186.8466	188.5161	190.0438	190.0479	188.5237	186.8631	184.1459
27	184.2882	187.1225	188.8627	190.4179	190.4221	188.8706	187.1396	184.3079
28	184.4494	187.3983	189.2091	190.7917	190.796	189.2172	187.4159	184.4698
29	184.6105	187.6738	189.5551	191.1651	191.1696	189.5635	187.6921	184.6316
30	184.7715	187.9491	189.9008	191.5382	191.5429	189.9095	187.968	184.7934
31	184.9324	188.2242	190.2463	191.911	191.9158	190.2552	188.2437	184.955
32	185.0933	188.499	190.5915	192.2834	192.2884	190.6007	188.5192	185.1166
33	185.254	188.7737	190.9363	192.6555	192.6606	190.9458	188.7945	185.278
34	185.4147	189.0482	191.2809	193.0273	193.0325	191.2907	189.0696	185.4394
35	185.5752	189.3225	191.6252	193.3987	193.4041	191.6352	189.3445	185.6007

Continued table (C3)

36	185.7357	189.5966	191.9692	193.7699	193.7754	191.9795	189.6192	185.7618
37	185.8961	189.8704	192.3129	194.1406	194.1463	192.3235	189.8937	185.9229
38	186.0563	190.1441	192.6563	194.5111	194.5169	192.6672	190.1679	186.0839
39	186.2165	190.4175	192.9994	194.8812	194.8872	193.0106	190.442	186.2448
40	186.3766	190.6908	193.3422	195.251	195.2572	193.3537	190.7159	186.4056
41	186.5366	190.9638	193.6848	195.6205	195.6268	193.6965	190.9895	186.5663
42	186.6965	191.2367	194.027	195.9897	195.9961	194.039	191.263	186.7269
43	186.8563	191.5093	194.369	196.3585	196.365	194.3812	191.5363	186.8874
44	187.016	191.7817	194.7106	196.727	196.7337	194.7231	191.8093	187.0478
45	187.1756	192.054	195.052	197.0951	197.102	195.0648	192.0821	187.2082
46	187.3352	192.326	195.3931	197.463	197.47	195.4062	192.3548	187.3684
47	187.4946	192.5978	195.7339	197.8305	197.8376	195.7472	192.6272	187.5285
48	187.6539	192.8694	196.0744	198.1977	198.205	196.088	192.8994	187.6886
49	187.8132	193.1409	196.4146	198.5645	198.572	196.4285	193.1715	187.8485
50	187.9723	193.4121	196.7545	198.9311	198.9386	196.7687	193.4433	188.0084
51	188.1314	193.6831	197.0942	199.2973	199.305	197.1086	193.7149	188.1681
52	188.2904	193.9539	197.4335	199.6631	199.671	197.4482	193.9863	188.3278
53	188.4493	194.2245	197.7726	200.0287	200.0367	197.7876	194.2575	188.4874
54	188.608	194.4949	198.1114	200.3939	200.4021	198.1266	194.5285	188.6469
55	188.7667	194.7651	198.4499	200.7589	200.7672	198.4654	194.7994	188.8063
56	188.9253	195.0351	198.7881	201.1234	201.1319	198.8038	195.07	188.9656
57	189.0838	195.3049	199.126	201.4877	201.4963	199.142	195.3404	189.1248
58	189.2423	195.5745	199.4636	201.8517	201.8604	199.4799	195.6106	189.2839
59	189.4006	195.8439	199.801	202.2153	202.2241	199.8175	195.8805	189.4429
60	189.5588	196.1131	200.138	202.5786	202.5876	200.1548	196.1503	189.6018
61	189.7169	196.382	200.4748	202.9415	202.9507	200.4919	196.4199	189.7606
62	189.875	196.6508	200.8113	203.3042	203.3135	200.8286	196.6893	189.9194
63	190.0329	196.9194	201.1475	203.6665	203.676	201.1651	196.9585	190.078
64	190.1908	197.1878	201.4834	204.0285	204.0381	201.5013	197.2275	190.2366
65	190.3486	197.456	201.8191	204.3902	204.3999	201.8372	197.4963	190.395
66	190.5062	197.724	202.1544	204.7516	204.7615	202.1728	197.7648	190.5534
67	190.6638	197.9917	202.4895	205.1126	205.1226	202.5081	198.0332	190.7116
68	190.8213	198.2593	202.8242	205.4734	205.4835	202.8431	198.3014	190.8698
69	190.9787	198.5267	203.1587	205.8338	205.8441	203.1779	198.5694	191.0279
70	191.136	198.7939	203.4929	206.1939	206.2043	203.5123	198.8371	191.1859
71	191.2932	199.0608	203.8269	206.5536	206.5642	203.8465	199.1047	191.3438
72	191.4504	199.3276	204.1605	206.9131	206.9238	204.1804	199.3721	191.5016

Continued table (C3)

73	191.6074	199.5942	204.4939	207.2722	207.283	204.5141	199.6393	191.6593
74	191.7643	199.8606	204.827	207.631	207.642	204.8474	199.9062	191.8169
75	191.9212	200.1267	205.1598	207.9895	208.0006	205.1804	200.173	191.9744
76	192.0779	200.3927	205.4923	208.3477	208.3589	205.5132	200.4396	192.1319
77	192.2346	200.6585	205.8245	208.7055	208.7169	205.8457	200.7059	192.2892
78	192.3912	200.9241	206.1564	209.0631	209.0746	206.1779	200.9721	192.4465
79	192.5476	201.1894	206.4881	209.4203	209.432	206.5098	201.2381	192.6036
80	192.704	201.4546	206.8195	209.7772	209.789	206.8414	201.5038	192.7607
81	192.8603	201.7196	207.1506	210.1338	210.1457	207.1728	201.7694	192.9177
82	193.0165	201.9844	207.4814	210.4901	210.5021	207.5039	202.0348	193.0745
83	193.1726	202.249	207.812	210.846	210.8582	207.8347	202.2999	193.2313
84	193.3286	202.5133	208.1422	211.2017	211.214	208.1652	202.5649	193.388
85	193.4846	202.7775	208.4722	211.557	211.5695	208.4954	202.8297	193.5446
86	193.6404	203.0415	208.8019	211.912	211.9246	208.8254	203.0942	193.7011
87	193.7962	203.3053	209.1313	212.2667	212.2794	209.155	203.3586	193.8575
88	193.9518	203.5689	209.4605	212.6211	212.634	209.4844	203.6228	194.0139
89	194.1074	203.8323	209.7893	212.9752	212.9882	209.8135	203.8868	194.1701
90	194.2628	204.0954	210.1179	213.3289	213.342	210.1423	204.1505	194.3262
91	194.4182	204.3584	210.4462	213.6823	213.6956	210.4709	204.4141	194.4823
92	194.5735	204.6212	210.7743	214.0355	214.0489	210.7992	204.6775	194.6382
93	194.7287	204.8838	211.102	214.3883	214.4018	211.1272	204.9407	194.7941
94	194.8838	205.1462	211.4295	214.7408	214.7545	211.4549	205.2036	194.9498
95	195.0388	205.4084	211.7567	215.093	215.1068	211.7823	205.4664	195.1055
96	195.1937	205.6704	212.0836	215.4448	215.4588	212.1094	205.729	195.2611

Table (C4) Receiver temperature from every segment for one row in 17th Jan (K)

segment	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30
1	462.096	461.8549	461.6915	462.5053	462.5054	461.6916	461.8552	462.0963
2	462.2596	462.1359	462.0455	462.8878	462.888	462.0459	462.1369	462.2607
3	462.4231	462.4168	462.3992	463.27	463.2704	462.4	462.4184	462.425
4	462.5866	462.6975	462.7526	463.6518	463.6523	462.7537	462.6997	462.5892
5	462.7499	462.978	463.1058	464.0333	464.034	463.1071	462.9808	462.7532
6	462.9132	463.2582	463.4587	464.4145	464.4153	463.4603	463.2617	462.9172
7	463.0763	463.5383	463.8112	464.7953	464.7963	463.8131	463.5424	463.0811
8	463.2394	463.8181	464.1635	465.1758	465.177	464.1657	463.8229	463.2449
9	463.4024	464.0978	464.5155	465.556	465.5573	464.518	464.1032	463.4086
10	463.5653	464.3773	464.8672	465.9359	465.9374	464.87	464.3833	463.5723
11	463.7281	464.6565	465.2186	466.3154	466.3171	465.2217	464.6632	463.7358
12	463.8908	464.9355	465.5697	466.6946	466.6964	465.5731	464.9429	463.8992
13	464.0534	465.2144	465.9205	467.0735	467.0755	465.9242	465.2223	464.0626
14	464.2159	465.493	466.2711	467.4521	467.4542	466.275	465.5016	464.2258
15	464.3783	465.7715	466.6213	467.8303	467.8326	466.6256	465.7807	464.389
16	464.5406	466.0497	466.9713	468.2082	468.2106	466.9758	466.0596	464.552
17	464.7029	466.3277	467.321	468.5858	468.5883	467.3258	466.3382	464.715
18	464.865	466.6056	467.6704	468.963	468.9658	467.6755	466.6167	464.8779
19	465.0271	466.8832	468.0195	469.34	469.3428	468.0249	466.8949	465.0406
20	465.189	467.1606	468.3683	469.7166	469.7196	468.374	467.173	465.2033
21	465.3509	467.4379	468.7168	470.0928	470.096	468.7228	467.4509	465.3659
22	465.5127	467.7149	469.0651	470.4688	470.4721	469.0713	467.7285	465.5284
23	465.6744	467.9917	469.413	470.8444	470.8479	469.4196	468.006	465.6908
24	465.836	468.2683	469.7607	471.2197	471.2234	469.7675	468.2832	465.8532
25	465.9975	468.5448	470.1081	471.5947	471.5985	470.1152	468.5603	466.0154
26	466.1589	468.821	470.4552	471.9694	471.9734	470.4626	468.8371	466.1775
27	466.3202	469.097	470.802	472.3437	472.3479	470.8097	469.1138	466.3395
28	466.4814	469.3728	471.1485	472.7178	472.722	471.1565	469.3902	466.5015
29	466.6426	469.6485	471.4948	473.0915	473.0959	471.503	469.6664	466.6633
30	466.8036	469.9239	471.8407	473.4649	473.4694	471.8492	469.9425	466.8251
31	466.9646	470.1991	472.1864	473.8379	473.8426	472.1952	470.2183	466.9868
32	467.1254	470.4741	472.5318	474.2106	474.2155	472.5409	470.494	467.1484
33	467.2862	470.7489	472.8769	474.5831	474.5881	472.8863	470.7694	467.3098
34	467.4469	471.0236	473.2217	474.9552	474.9603	473.2314	471.0447	467.4712
35	467.6074	471.298	473.5662	475.3269	475.3323	473.5762	471.3197	467.6325

Continued table (C4)

36	467.7679	471.5722	473.9105	475.6984	475.7039	473.9207	471.5945	467.7937
37	467.9283	471.8462	474.2545	476.0695	476.0752	474.265	471.8692	467.9548
38	468.0886	472.1201	474.5982	476.4404	476.4461	474.6089	472.1436	468.1159
39	468.2489	472.3937	474.9416	476.8109	476.8168	474.9526	472.4179	468.2768
40	468.409	472.6671	475.2847	477.181	477.1871	475.296	472.6919	468.4376
41	468.569	472.9403	475.6275	477.5509	477.5571	475.6391	472.9657	468.5984
42	468.729	473.2134	475.9701	477.9205	477.9268	475.982	473.2394	468.759
43	468.8888	473.4862	476.3124	478.2897	478.2962	476.3245	473.5128	468.9196
44	469.0486	473.7588	476.6544	478.6586	478.6652	476.6668	473.7861	469.0801
45	469.2083	474.0312	476.9961	479.0272	479.034	477.0088	474.0591	469.2404
46	469.3678	474.3035	477.3375	479.3955	479.4024	477.3505	474.332	469.4007
47	469.5273	474.5755	477.6787	479.7634	479.7705	477.6919	474.6046	469.5609
48	469.6867	474.8473	478.0196	480.1311	480.1383	478.0331	474.877	469.721
49	469.846	475.119	478.3602	480.4984	480.5058	478.3739	475.1493	469.881
50	470.0052	475.3904	478.7005	480.8654	480.8729	478.7145	475.4213	470.0409
51	470.1644	475.6617	479.0405	481.2321	481.2398	479.0548	475.6932	470.2008
52	470.3234	475.9327	479.3803	481.5985	481.6063	479.3948	475.9648	470.3605
53	470.4823	476.2036	479.7197	481.9646	481.9725	479.7346	476.2363	470.5201
54	470.6412	476.4742	480.0589	482.3303	482.3384	480.074	476.5076	470.6797
55	470.7999	476.7447	480.3979	482.6958	482.704	480.4132	476.7786	470.8391
56	470.9586	477.0149	480.7365	483.0609	483.0693	480.7521	477.0495	470.9985
57	471.1172	477.285	481.0749	483.4257	483.4342	481.0908	477.3201	471.1578
58	471.2757	477.5548	481.4129	483.7902	483.7989	481.4291	477.5906	471.317
59	471.4341	477.8245	481.7507	484.1544	484.1632	481.7672	477.8609	471.476
60	471.5924	478.094	482.0883	484.5183	484.5272	482.105	478.131	471.635
61	471.7506	478.3632	482.4255	484.8818	484.8909	482.4425	478.4008	471.7939
62	471.9087	478.6323	482.7625	485.2451	485.2543	482.7797	478.6705	471.9528
63	472.0668	478.9012	483.0992	485.608	485.6174	483.1167	478.94	472.1115
64	472.2247	479.1699	483.4356	485.9706	485.9801	483.4533	479.2093	472.2701
65	472.3826	479.4383	483.7717	486.3329	486.3426	483.7897	479.4784	472.4287
66	472.5403	479.7066	484.1076	486.6949	486.7047	484.1259	479.7473	472.5871
67	472.698	479.9747	484.4432	487.0566	487.0666	484.4617	480.0159	472.7455
68	472.8556	480.2426	484.7785	487.418	487.4281	484.7973	480.2844	472.9037
69	473.0131	480.5103	485.1135	487.7791	487.7893	485.1326	480.5527	473.0619
70	473.1705	480.7778	485.4483	488.1398	488.1502	485.4676	480.8209	473.22
71	473.3278	481.0451	485.7828	488.5003	488.5108	485.8023	481.0888	473.378
72	473.485	481.3123	486.117	488.8604	488.8711	486.1368	481.3565	473.5359

Continued table (C4)

73	473.6421	481.5792	486.4509	489.2202	489.231	486.471	481.624	473.6937
74	473.7991	481.8459	486.7846	489.5798	489.5907	486.8049	481.8913	473.8514
75	473.9561	482.1124	487.1179	489.939	489.95	487.1385	482.1584	474.0091
76	474.113	482.3788	487.4511	490.2979	490.3091	487.4719	482.4254	474.1666
77	474.2697	482.6449	487.7839	490.6565	490.6678	487.805	482.6921	474.324
78	474.4264	482.9109	488.1164	491.0147	491.0262	488.1378	482.9587	474.4814
79	474.583	483.1766	488.4487	491.3727	491.3843	488.4703	483.225	474.6387
80	474.7395	483.4422	488.7807	491.7304	491.7421	488.8026	483.4911	474.7958
81	474.8959	483.7075	489.1125	492.0877	492.0996	489.1346	483.7571	474.9529
82	475.0522	483.9727	489.4439	492.4448	492.4568	489.4663	484.0229	475.1099
83	475.2084	484.2377	489.7751	492.8015	492.8137	489.7977	484.2884	475.2668
84	475.3646	484.5025	490.1061	493.158	493.1703	490.1289	484.5538	475.4236
85	475.5206	484.7671	490.4367	493.5141	493.5265	490.4598	484.819	475.5803
86	475.6766	485.0314	490.7671	493.8699	493.8825	490.7904	485.084	475.737
87	475.8324	485.2956	491.0972	494.2255	494.2381	491.1208	485.3488	475.8935
88	475.9882	485.5597	491.427	494.5807	494.5935	491.4509	485.6134	476.05
89	476.1439	485.8235	491.7566	494.9356	494.9485	491.7807	485.8778	476.2063
90	476.2995	486.0871	492.0859	495.2902	495.3033	492.1102	486.142	476.3626
91	476.455	486.3505	492.4149	495.6445	495.6577	492.4395	486.406	476.5188
92	476.6104	486.6137	492.7436	495.9985	496.0118	492.7684	486.6698	476.6749
93	476.7658	486.8768	493.0721	496.3522	496.3657	493.0972	486.9334	476.8308
94	476.921	487.1396	493.4003	496.7055	496.7192	493.4256	487.1969	476.9868
95	477.0762	487.4023	493.7282	497.0586	497.0724	493.7538	487.4601	477.1426
96	477.2312	487.6648	494.0559	497.4114	497.4253	494.0817	487.7231	477.2983

Table (C5) Glass cover temperature from every segment for one row in 17th Jan (K)

segment	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30
1	289.1581	289.9706	291.8772	293.8486	295.3517	294.6562	296.273	295.9419
2	289.1722	289.9894	291.9007	293.874	295.3755	294.6758	296.2904	295.9515
3	289.1864	290.0082	291.9243	293.8995	295.3993	294.6956	296.3078	295.9611
4	289.2006	290.0271	291.9479	293.925	295.4232	294.7153	296.3252	295.9707
5	289.2147	290.0459	291.9715	293.9505	295.447	294.7351	296.3426	295.9803
6	289.2289	290.0648	291.9952	293.9761	295.4709	294.7549	296.3601	295.9899
7	289.2431	290.0837	292.0189	294.0017	295.4949	294.7747	296.3775	295.9996
8	289.2573	290.1026	292.0426	294.0273	295.5189	294.7945	296.395	296.0092
9	289.2715	290.1215	292.0664	294.053	295.5429	294.8144	296.4125	296.0188
10	289.2857	290.1405	292.0901	294.0787	295.5669	294.8343	296.43	296.0284
11	289.2999	290.1594	292.114	294.1044	295.591	294.8542	296.4476	296.0381
12	289.3141	290.1784	292.1378	294.1302	295.6151	294.8742	296.4651	296.0477
13	289.3283	290.1974	292.1617	294.156	295.6392	294.8942	296.4827	296.0574
14	289.3425	290.2164	292.1856	294.1819	295.6634	294.9142	296.5003	296.067
15	289.3568	290.2355	292.2095	294.2077	295.6876	294.9342	296.5179	296.0767
16	289.371	290.2545	292.2335	294.2337	295.7118	294.9542	296.5355	296.0863
17	289.3852	290.2736	292.2574	294.2596	295.7361	294.9743	296.5531	296.096
18	289.3995	290.2927	292.2815	294.2856	295.7604	294.9944	296.5707	296.1057
19	289.4137	290.3118	292.3055	294.3116	295.7848	295.0145	296.5884	296.1153
20	289.428	290.3309	292.3296	294.3377	295.8091	295.0347	296.6061	296.125
21	289.4422	290.35	292.3537	294.3638	295.8335	295.0548	296.6238	296.1347
22	289.4565	290.3692	292.3778	294.3899	295.858	295.075	296.6415	296.1444
23	289.4708	290.3883	292.402	294.4161	295.8824	295.0953	296.6592	296.154
24	289.485	290.4075	292.4262	294.4422	295.9069	295.1155	296.677	296.1637
25	289.4993	290.4267	292.4504	294.4685	295.9315	295.1358	296.6947	296.1734
26	289.5136	290.4459	292.4746	294.4947	295.956	295.1561	296.7125	296.1831
27	289.5279	290.4652	292.4989	294.521	295.9806	295.1764	296.7303	296.1928
28	289.5422	290.4844	292.5232	294.5474	296.0053	295.1967	296.7481	296.2025
29	289.5565	290.5037	292.5475	294.5737	296.0299	295.2171	296.7659	296.2122
30	289.5708	290.523	292.5719	294.6001	296.0546	295.2375	296.7837	296.2219
31	289.5851	290.5423	292.5963	294.6266	296.0794	295.2579	296.8016	296.2317
32	289.5994	290.5616	292.6207	294.653	296.1041	295.2784	296.8195	296.2414
33	289.6137	290.5809	292.6452	294.6796	296.1289	295.2988	296.8374	296.2511
34	289.628	290.6003	292.6696	294.7061	296.1537	295.3193	296.8553	296.2608
35	289.6424	290.6197	292.6942	294.7327	296.1786	295.3398	296.8732	296.2706

Continued table (C5)

36	289.6567	290.639	292.7187	294.7593	296.2035	295.3604	296.8911	296.2803
37	289.671	290.6584	292.7432	294.7859	296.2284	295.381	296.9091	296.29
38	289.6854	290.6779	292.7678	294.8126	296.2534	295.4015	296.927	296.2998
39	289.6997	290.6973	292.7925	294.8393	296.2783	295.4222	296.945	296.3095
40	289.7141	290.7167	292.8171	294.866	296.3034	295.4428	296.963	296.3193
41	289.7285	290.7362	292.8418	294.8928	296.3284	295.4635	296.981	296.329
42	289.7428	290.7557	292.8665	294.9196	296.3535	295.4841	296.999	296.3388
43	289.7572	290.7752	292.8912	294.9465	296.3786	295.5049	297.0171	296.3485
44	289.7716	290.7947	292.916	294.9733	296.4037	295.5256	297.0351	296.3583
45	289.7859	290.8142	292.9408	295.0002	296.4289	295.5463	297.0532	296.368
46	289.8003	290.8338	292.9656	295.0272	296.4541	295.5671	297.0713	296.3778
47	289.8147	290.8534	292.9904	295.0542	296.4794	295.5879	297.0894	296.3876
48	289.8291	290.8729	293.0153	295.0812	296.5046	295.6088	297.1075	296.3974
49	289.8435	290.8925	293.0402	295.1082	296.5299	295.6296	297.1256	296.4071
50	289.8579	290.9122	293.0651	295.1353	296.5553	295.6505	297.1438	296.4169
51	289.8723	290.9318	293.0901	295.1624	296.5806	295.6714	297.162	296.4267
52	289.8867	290.9514	293.1151	295.1895	296.606	295.6923	297.1801	296.4365
53	289.9011	290.9711	293.1401	295.2167	296.6314	295.7133	297.1983	296.4463
54	289.9155	290.9908	293.1651	295.2439	296.6569	295.7342	297.2165	296.4561
55	289.93	291.0105	293.1902	295.2712	296.6824	295.7552	297.2348	296.4659
56	289.9444	291.0302	293.2153	295.2984	296.7079	295.7763	297.253	296.4757
57	289.9588	291.0499	293.2404	295.3257	296.7335	295.7973	297.2713	296.4855
58	289.9733	291.0697	293.2655	295.3531	296.759	295.8184	297.2895	296.4953
59	289.9877	291.0894	293.2907	295.3804	296.7847	295.8395	297.3078	296.5051
60	290.0022	291.1092	293.3159	295.4078	296.8103	295.8606	297.3261	296.515
61	290.0166	291.129	293.3412	295.4353	296.836	295.8817	297.3444	296.5248
62	290.0311	291.1488	293.3664	295.4628	296.8617	295.9029	297.3628	296.5346
63	290.0456	291.1686	293.3917	295.4903	296.8874	295.9241	297.3811	296.5444
64	290.06	291.1885	293.417	295.5178	296.9132	295.9453	297.3995	296.5543
65	290.0745	291.2083	293.4423	295.5454	296.939	295.9665	297.4179	296.5641
66	290.089	291.2282	293.4677	295.573	296.9648	295.9877	297.4363	296.5739
67	290.1035	291.2481	293.4931	295.6006	296.9907	296.009	297.4547	296.5838
68	290.1179	291.268	293.5185	295.6282	297.0165	296.0303	297.4731	296.5936
69	290.1324	291.2879	293.544	295.6559	297.0425	296.0516	297.4915	296.6035
70	290.1469	291.3078	293.5695	295.6837	297.0684	296.073	297.51	296.6133
71	290.1614	291.3278	293.595	295.7114	297.0944	296.0944	297.5284	296.6232
72	290.1759	291.3477	293.6205	295.7392	297.1204	296.1158	297.5469	296.633

Continued table (C5)

73	290.1904	291.3677	293.646	295.767	297.1464	296.1372	297.5654	296.6429
74	290.205	291.3877	293.6716	295.7949	297.1725	296.1586	297.5839	296.6528
75	290.2195	291.4077	293.6972	295.8228	297.1986	296.1801	297.6024	296.6626
76	290.234	291.4277	293.7229	295.8507	297.2247	296.2016	297.621	296.6725
77	290.2485	291.4478	293.7485	295.8787	297.2509	296.2231	297.6395	296.6824
78	290.2631	291.4678	293.7742	295.9066	297.2771	296.2446	297.6581	296.6923
79	290.2776	291.4879	293.7999	295.9347	297.3033	296.2661	297.6767	296.7022
80	290.2921	291.508	293.8257	295.9627	297.3296	296.2877	297.6953	296.712
81	290.3067	291.5281	293.8514	295.9908	297.3558	296.3093	297.7139	296.7219
82	290.3212	291.5482	293.8772	296.0189	297.3822	296.3309	297.7325	296.7318
83	290.3358	291.5683	293.903	296.047	297.4085	296.3526	297.7512	296.7417
84	290.3503	291.5885	293.9289	296.0752	297.4349	296.3742	297.7698	296.7516
85	290.3649	291.6086	293.9548	296.1034	297.4613	296.3959	297.7885	296.7615
86	290.3795	291.6288	293.9807	296.1316	297.4877	296.4176	297.8072	296.7714
87	290.394	291.649	294.0066	296.1599	297.5141	296.4394	297.8259	296.7813
88	290.4086	291.6692	294.0325	296.1882	297.5406	296.4611	297.8446	296.7913
89	290.4232	291.6895	294.0585	296.2165	297.5671	296.4829	297.8633	296.8012
90	290.4378	291.7097	294.0845	296.2449	297.5937	296.5047	297.882	296.8111
91	290.4524	291.7299	294.1105	296.2733	297.6203	296.5265	297.9008	296.821
92	290.467	291.7502	294.1366	296.3017	297.6469	296.5484	297.9196	296.8309
93	290.4816	291.7705	294.1627	296.3301	297.6735	296.5702	297.9384	296.8409
94	290.4962	291.7908	294.1888	296.3586	297.7002	296.5921	297.9572	296.8508
95	290.5108	291.8111	294.2149	296.3871	297.7268	296.614	297.976	296.8607

APPENDIX D

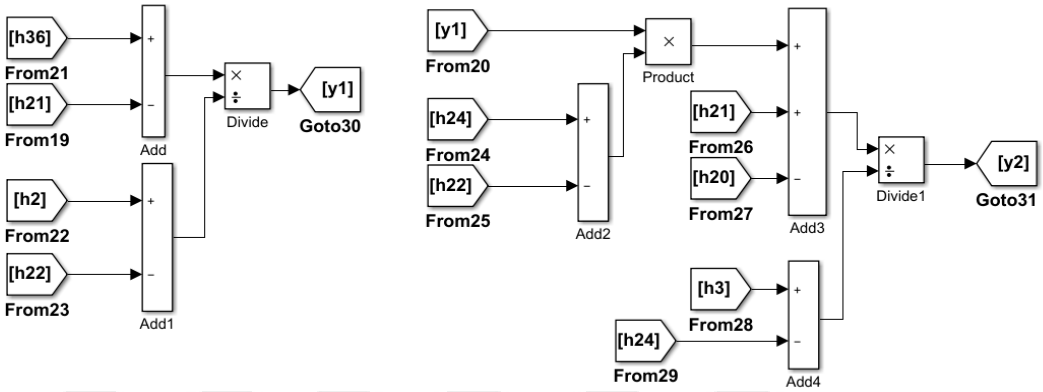

Figure (D.1) The fractions of extraction steam to HPH8 and HPH7

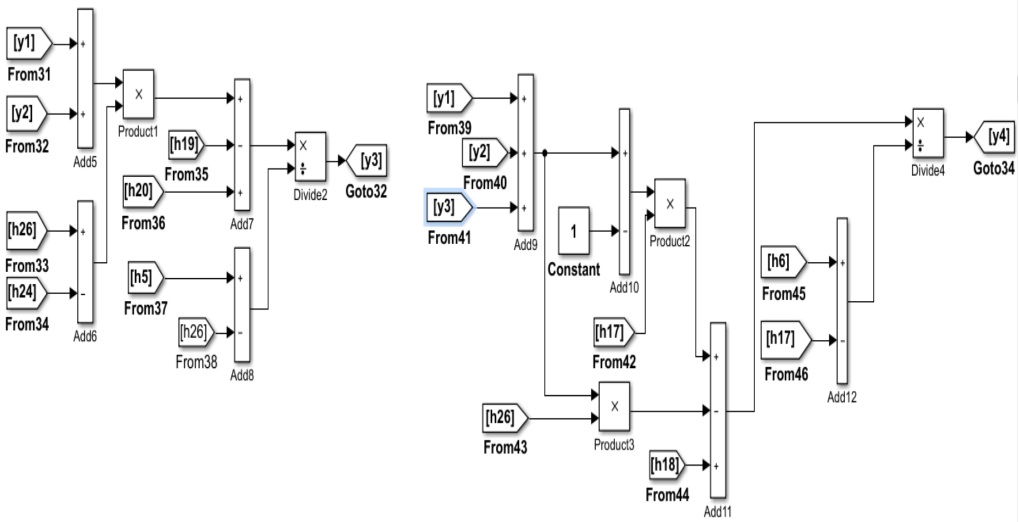

Figure (D.2) The fractions of extraction steam to HPH6 and OFH

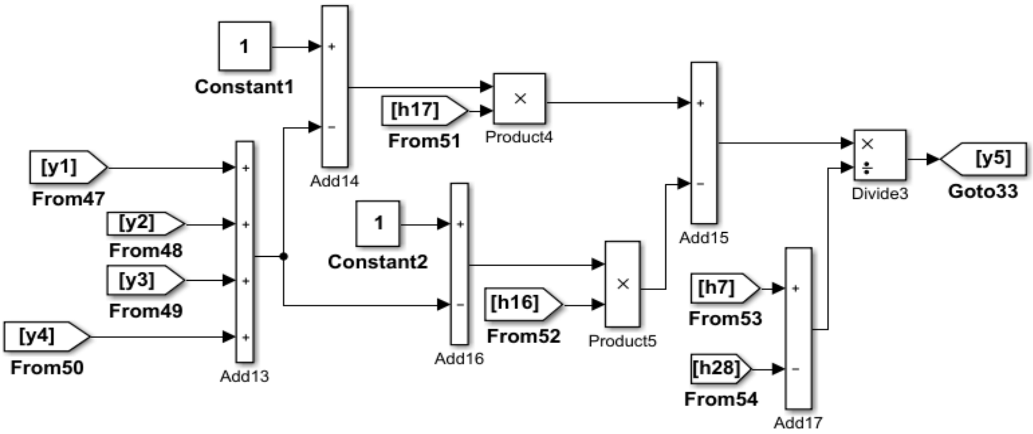

Figure (D.3) The fractions of extraction steam to LPH4

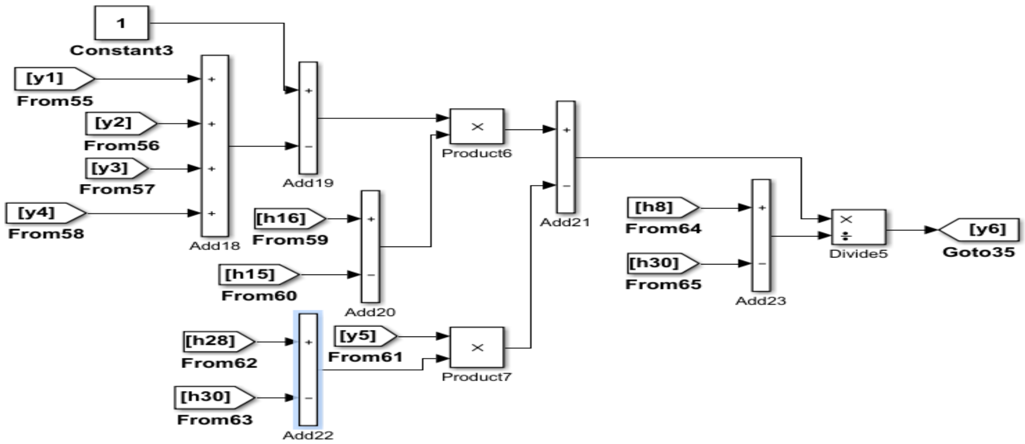

Figure (D.4) The fractions of extraction steam to LPH3

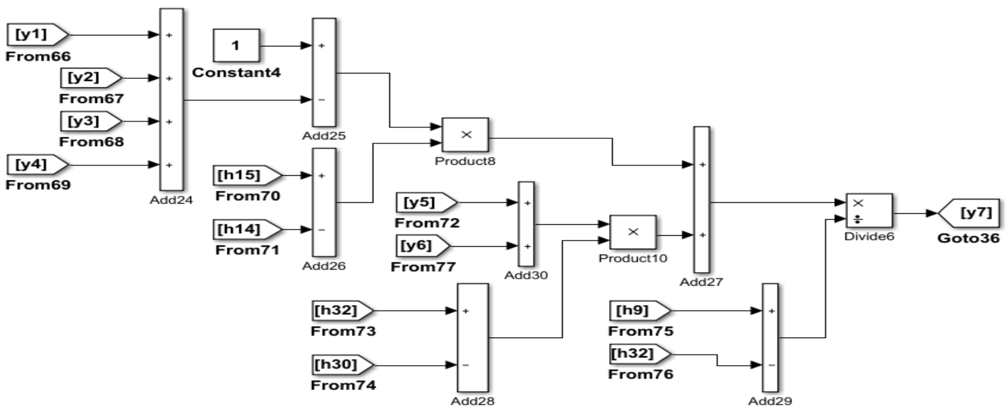

Figure (D.5) The fractions of extraction steam to LPH2

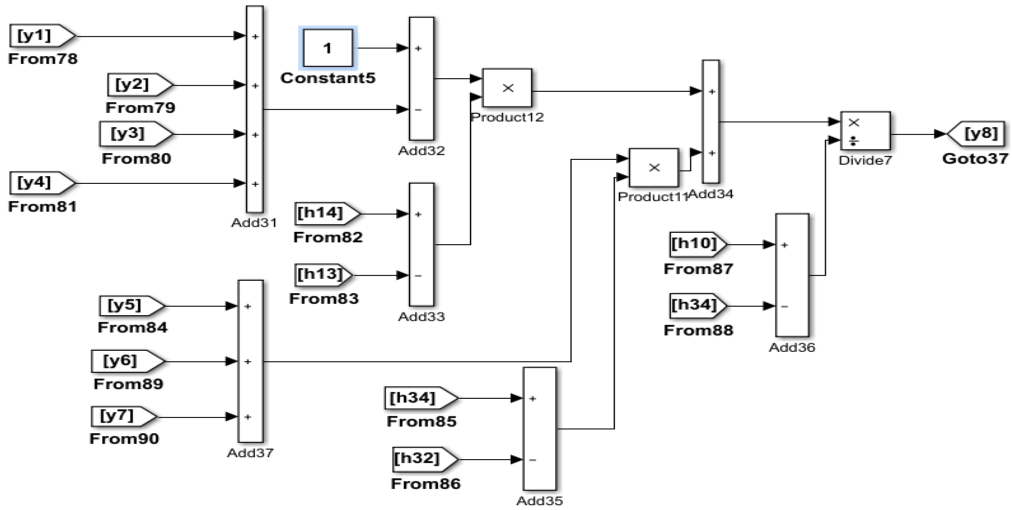

Figure (D.6) The fractions of extraction steam to LPH1

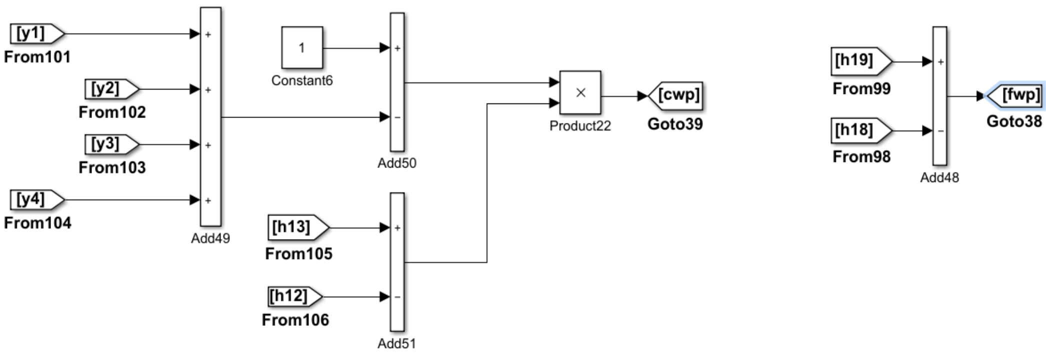

Figure (D.7) MATLAB simulation for condensate water pump work and feed water pump work.

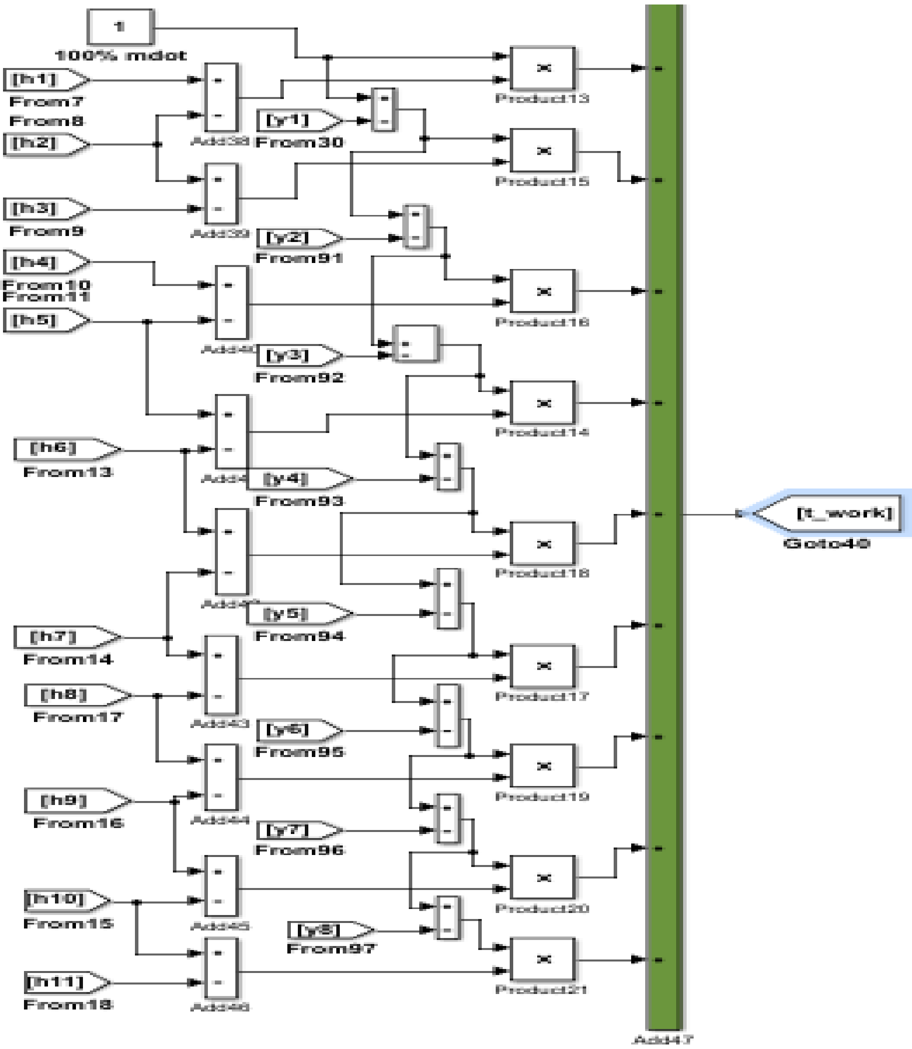

Figure (D.8) turbine work simulation

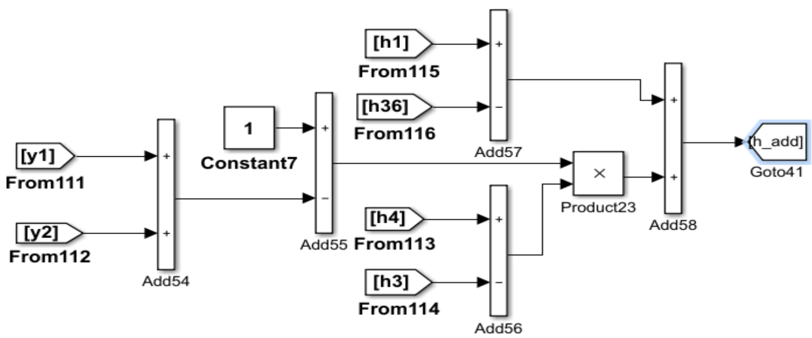

Figure (D.9) simulation of heat added

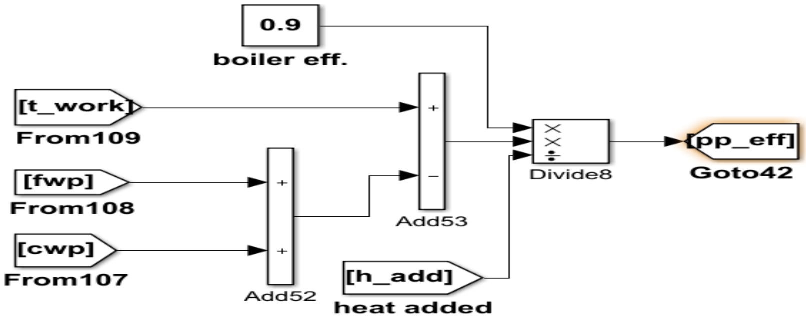

Figure (D.10) power plant efficiency simulation

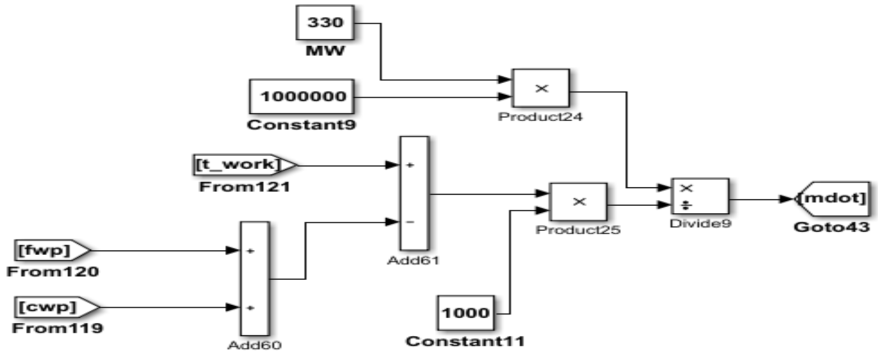

Figure (D.11) working fluid mass flow rate simulation

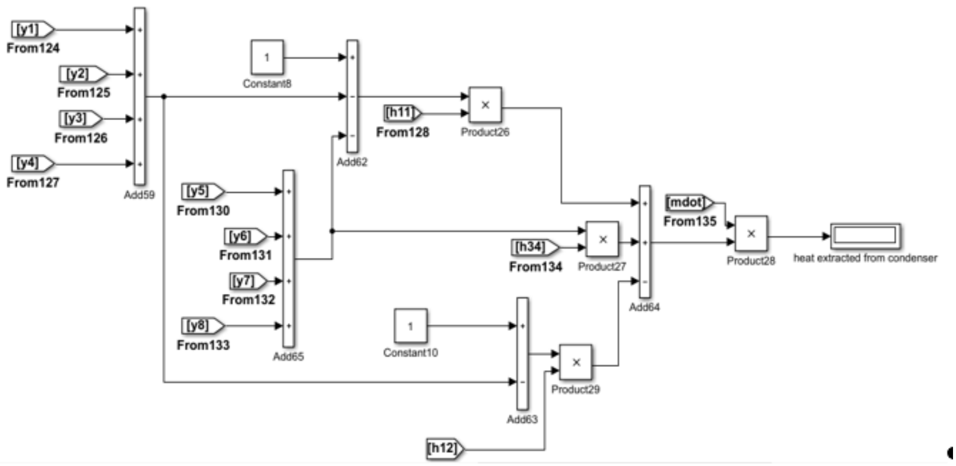

Figure (D.12) heat extracted in condenser simulation

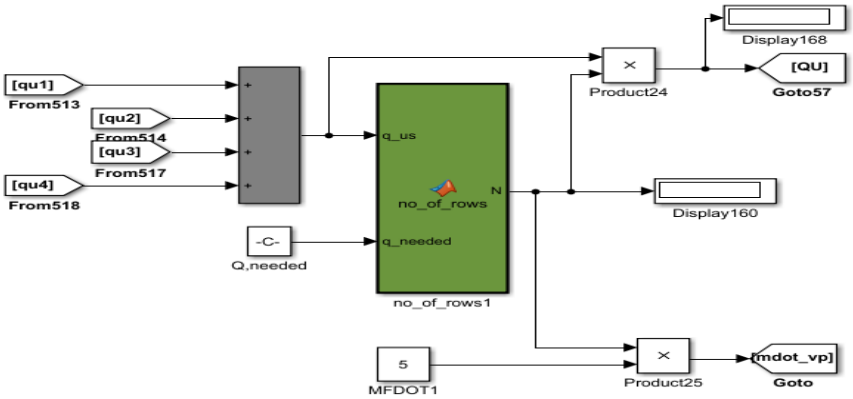

Figure (D.13) the simulation of Overall energy gain from the solar field and mass flow rate of VP1

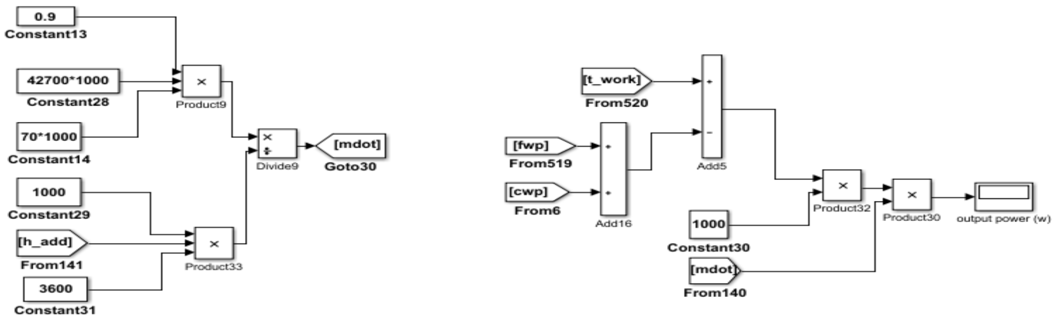

Figure (D.14). the simulation for finding the mass flow rate of working fluid and electricity generation.

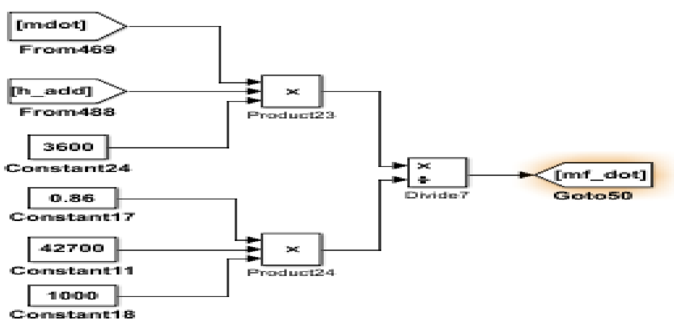

Figure (D15) the simulation for finding the mass flow rate of heavy fuel oil

APPENDIX E

Table (E.1) The properties of water and steam in all stages of thermal power plant

No.	P(bar)	T(˚C)	State	Enthalpy h (kJ/kg)	Entropy s (KJ/kg.)	Notes
1	165	538	Superheated steam	3401	6.423	Turbine Eff=0.86
2	63		Superheated steam	3153	6.484	
3	33	332	Superheated steam	3008	6.525	
4	33	538	Superheated steam	3540	7.297	
5	17	447	Superheated steam	3345	7.342	
6	9.006	440	Superheated steam	3183	7.385	
7	4.006	262.8	Superheated steam	2997	7.441	
8	2.006	184	Superheated steam	2865	7.488	
9	1.326		Superheated steam	2712	7.516	
10	1.306	262	Superheated steam	2690	7.517	
11	0.113		Saturated steam	2374	7.686	
12	0.113		Saturated liquid	201.9		Cwp. Eff=0.813
13	9.006		Saturated liquid	203		
14	9.006	65	Saturated liquid	273		
15	9.006	87.5	Saturated liquid	367.3		
16	9.006	107	Saturated liquid	449.4		
17	9.006	141	Saturated liquid	594.1		
18	9.006		Saturated liquid	742.8		
19	165		Saturated liquid	764.3		Fwp.Eff=0.817
20	165	208	Saturated liquid	905.8		
21	165	243	Saturated liquid	1092		
22/23	63		Saturated liquid	1230		
24/25	33		Saturated liquid	1034		
26/27	17		Saturated liquid	871.9		
28/29	4.006		Saturated liquid	605		
30/31	2.006		Saturated liquid	505.1		
32/33	1.326		Saturated liquid	451.6		
34/35	1.306		Saturated liquid	449.7		
36	165	280	Saturated liquid	1250		

Table (E.2) fluid properties of working fluid for all stages in two schemes for hybrid power plant

No.	P(bar)	T(˚C)	State	First scheme	Second scheme
				Enthalpy-h(kJ/kg)	Enthalpy-h(kJ/kg)
1	165	538	Superheated steam	3401	3401
4	33	538	Superheated steam	3540	3540
5	17		Superheated steam	-------	3345
6	9.006	440	Superheated steam	3183	3180
7	4.006	262.8	Superheated steam	3000	2979
8	2.006	184	Superheated steam	2865	2862
9	1.326		Superheated steam	2712	2712
10	1.306	262	Superheated steam	2690	2690
11	0.113		Saturated steam	2374	2374
12	0.113		Saturated liquid	201.9	201.9
13	9.006		Saturated liquid	203	203
14	9.006	65	Saturated liquid	273	273
15	9.006	87.5	Saturated liquid	367.3	367.3
16	9.006	107	Saturated liquid	449.5	449.5
17	9.006	141	Saturated liquid	594.1	594.1
18	9.006		Saturated liquid	742.8	742.8
19	165		Saturated liquid	764.3	764.3
20	165	208	Saturated liquid		905.8
21	165	243	Saturated liquid		1092
24/25	33		Saturated liquid		1034
26/27	17		Saturated liquid		871.9
28/29	4.006		Saturated liquid	561.5	605
30/31	2.006		Saturated liquid	505.1	505.1
32/33	1.306		Saturated liquid	451.6	451.6
34/35	1.306		Saturated liquid	449.7	449.7

Table (E.3) overall results of analytical calculations for steam fractions for original and hybrid thermal power plant and two schemes of hybrid power plant

NO.	Name	symbol	Original Power Plant Values	Hybrid Power Plant First Scheme Values (July-April)	Hybrid Power Plant Second Scheme Values (January)
1	The extraction steam percentage to CFH8	y_1	0.08213	0	0
2	The extraction steam percentage to CFH7	y_2	0.08626	0	0.09421
3	The extraction steam percentage to CFH6	y_3	0.0426	0	0.05106
4	The extraction steam percentage to OFH	y_4	0.03449	0.05746	0.04193
5	The extraction steam percentage to CFH4	y_5	0.04539	0.0569	0.04193
6	The extraction steam percentage to CFH3	y_6	0.02425	0.03041	0.02625
7	The extraction steam percentage to CFH2	y_7	0.02871	0.036	0.03108
8	The extraction steam percentage to CFH1	y_8	0.0224	0.02809	0.02425