International Journal of Engineering and Technical Research (IJETR)
ISSN: 2321-0869 (O) 2454-4698 (P), Volume-7, Issue-2, February 2017

Improving efficiency of flat plate collector integrated with reflectors

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Abstract— **Solar energy is becoming an alternative for the limited fossil fuel resources. One of the simplest and most direct applications of this energy is the conversion of solar radiation into heat, which can be used in water heating systems. A commonly used solar collector is the flat-plate. Actually a lot of research has been conducted in order to analyze the flat -plate operation and improve its efficiency. Solar water heating is a process of tapping energy from the sun for the purpose of raising the temperature of water from local water supply to some desirable higher temperature.**

This paper discusses improving the performance of a liquid flat plate solar energy collector (which is thermosyphon flat plate collector) integrating with external reflectors. The external flat reflectors are mounted on the side of the collector. The external flat reflectors can be tilted to an angle of 15°, 30o and 45°, on the horizontal plane due to the existence of angle adjustment. The effect of four flat plate reflectors which are mounted on (bottom, top, left, and right side reflectors) on the total light radiation on a collector at tilted plane angle of 45o for each reflector is analyzed The effect of these reflectors is more evenly at solar noon since the sun is perpendicular to the collector. Based on this the effect of the reflectors on the collector are analyzed. The flat plate collector integrated with and without reflector for minimum, average and maximum solar radiation intensity of bahir dar has been analyzed, constructed and tested on automotive work shop at bahir dar institute of technology. Experimentations are conducted on flat plate collector with and without reflectors for particular period of various days and data is collected /maintained as per days. For flat plate with reflector the maximum fluid output temperature, and insolation of 98°C, and 1,200 W/m2, respectively, was obtained on a sunny day. Whereas for flat plate without reflector the maximum temperature and solar insolation is 70oc and 1,200 W/m2, respectively, was obtained on a sunny day. The total thermal energy generated by thermal collector with reflectors in optimal position is significantly higher than total thermal energy generated by thermal collector without reflectors. This solar water heating system finds useful application for cooking, pre-heater when temperature of more than 70oC is needed, and for bleaching industrial process in textile factory. The theoretically and experimental results of water outlet temperature are equivalent with the results obtained by using computational fluid dynamics CFD fluid flow (CFX) and there is a good agreement in between them.

Index Terms— **solar energy, flat plate reflector, tilted plane angle, flat plate collector**

I. INTRODUCTION

As we know Solar energy is the energy that sustains life on earth for all plants, animals and people. It provides a compelling solution for society to meet their needs for clean and abundant sources of energy in the future. Solar radiation provides us with enormous amount of energy. Control and make use of the sun's radiant energy as a clean and renewable source of energy has proven to be a challenge over the centuries and in modern times has fallen off in approval of other technologies which are easier to exploit in and take the chance to gain advantage from this resource. [1] Among these Solar collectors are the key component of active solar-heating systems.

They gather the sun's energy, convert its radiation into heat, and then transfer that heat to a fluid for our case water. The solar thermal energy can be used in solar water-heating systems. Solar collectors for hot water domestic applications are flat plate, evacuated tube, or concentrating collectors. Since it is a simple technology, it is simple to adopt for both urban and rural applications. It is basically consists of the flat plate collector, the flow pipe network the water storage tank etc.As the sun heats the collector, the hot water inside rises by natural convection and the colder storage tank water leaving from its bottom flow into the collector by gravity [1].

A natural circulation solar water heater is a passive energy system which operates on the principle of conduction, convection and radiation without assistance of a mechanical device (hunt, 1982). This makes as them generally more reliable, less expensive easier to maintain and possibly longer lasting than active systems. Hence the option of utilizing natural circulation solar water heater for rural application is particularly attractive given that level of deforestation in those areas and the absence of national grip for alterative power supply [1]. They have the advantages of using both beam and diffuse solar radiation not requiring orientation towards the sun and requiring little maintenance. Due to these reasons flat-plate collectors are in wide use for domestic household hot-water heating and for space heating, where the demand temperature is low. It heats the circulating fluid to a temperature considerably less than that of the boiling point of water and is best suited to applications where the demand temperature is 30-70°C. Even it is the most widely used solar collector its temperature is not exceeds 70^{o}c and this type of low temperature uses most probably for bathing.

This work is concerned with improvements of the efficiency of the flat plate solar collector integrating with reflectors. The aim of this work is to increase the efficiency of passive flat plate collector by using solar radiation increase materials like reflectors

The increasing of the efficiency solar plate collector with reflectors will be used for producing hot water having a temperature about 100^{o}c.the production of this hot water is used for cooking, pasteurizing, pre-heater for above 70^{o}c is needed, and bleaching uses in textile industry.

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II. LITERATURE REVIEW

Flat-plate collectors can be designed for applications requiring energy delivery at moderate temperatures, up to perhaps 70^0C above ambient temperature. They have the advantages of using beam and diffuse solar radiation, not requiring orientation towards the Sun, and requiring little maintenance [2]. Moreover, the design and construction of flat-plate collectors are simple and the collectors can be adopted both in urban and rural areas. A pioneering analysis of the enhanced solar energy collection using mirrors-fixed flat plate solar collector combination was presented by Tabor [3]. Kostic and Pavlovic[4]; they were investigated the solar thermal collector with spectral selective absorber without and with flat plate top and bottom reflectors. Their results have shown an average energy gain of about 40% in the summer period for thermal collector with reflectors. The results of the influence of reflectance from flat plate top and bottom reflectors made of aluminum sheet and aluminum foil on energy efficiency of PV/Thermal collector were given by Kosti_c et al.[5]. Kumar et al. considered the general case of a collector with four reflectors. They gave an analytical model for study of the effect of an individual reflector on the collector. Numerical calculations were carried out for the South faced system and collector tilt for May and December in Delhi [6]. S. Farahat et al. [7]: Exergetic optimization is developed for the flat plate solar collector to improve and optimize the performance of the collector. Absorber plate area, dimension of solar collector pipes, diameter, mass flow rate, fluid inlet, outlet temperature, the overall loss coefficient are taken as variables. Exergetic efficiency increases with increase in fluid inlet temperature, decrease with increase in ambient temperature, increase with increase in pipe diameter, decrease with wind speed, increase with increase in optimal efficiency, increase with increase in incident energy. Y. Raja Sekhar et al. [8]: An experiment is performed for to evaluate the top loss coefficient considering the aspects like insolation, emissivity of absorber, ambient temperature, wind loss coefficient, tilt. A theoretical investigation is also done. The following results are obtained from his experiments:

- Efficiency decreases with increase in emissivity of the plate
- Efficiency increases with increase in ambient temperature
- With increase in wind loss coefficient Efficiency decreases
- No significance effect, due to tilt on top loss coefficient

Subhra Das et al. [9]: Study the effect of various parameters on the performance of flat plate solar collector. Alireza Hobbi et al. [10]: An experiment is performed to see the effect of heat enhancement devices on the collector performance. Four types of arrangement were analyzed regular circular tube, regular tube with twisted strip turbolator, regular tube with coil spring wire and regular tube with conical ridges installed in every 152mm. no significant effect on the performance of collector. Naiem Akhtaret et al. [11]: See the effect of absorption of radiation in glass cover on the top loss coefficient for single and double glass cover. Temperature of the glass cover increased by 6ºC in case of single glazing. Temperatures of the glass covers are increased by 14ºC and 11ºC in case of double glazing. There is a difference of 49% in the value of convective heat transfer coefficient, with and without considering the absorption in glass cover in case of double glazing. The correlations are developed for to calculate the absorption effect in the glass cover. Perers and Karlsson [12]. He was developed a model for the calculation of incident solar radiation from flat- and CPC-shaped external reflectors onto the flat plate solar collector arrays. McDaniel's et al [13]; he has been analyzed that the amount of direct light gathered by combination of reflector and flat-plate collector more than 35 years ago.

The calculations were done allowing variable reflector and collector orientation angles, variable latitude and arbitrary sun hour angle away from solar noon. Seitel [14]; similarly (At the same time), Seitel explored the use of diffuse and specular flat reflectors to enhance the performance of flat-plate solar collectors by means of FORTRAN routines, which optimize the size, shape and placement of reflector and collector. Grassie and Sheridan [15]; they were analyzed the mathematical model to simulate the performance of flat-plate collector–reflector systems. The model was used to predict the annual performance of a water heating system with several values of the reflector angle. The problems of energy performance of flat-plate collector–reflector systems were also investigated in works of dang [16] and Arata and Geddes [17].

III. ANALYTICAL MODEL OF FLAT PLATE COLLECTOR WITH REFLECTORS

In this work the model is developed for the South directed flat plate solar collector at tilt angle β which is equal to the latitude location with respect to the horizontal plane. In order to get more solar energy, four aluminum foils made flat plate solar reflectors are mounted on the four edges of flat plate solar collector as shown in the fig below. Two reflectors can attached on left and right side of the collector and the rest are on bottom and top of the collector. Therefore the solar collector consists of left, right, bottom, and top reflectors respectively. Four aluminum foils made flat plate solar reflectors of the same size (left and right and top and bottom) as the collector are mounted on the collector i.e. left and right and top and bottom are the same size but in contrast left and bottom, right and top have different dimensions.

Therefore the total solar radiation $G_{tot\cdot col}$ on the collector surface is;

- The sum of the direct solar radiation on collector surface which is represented by G_{dir-c},
- The reflected solar radiation from bottom reflector which reached the collector surface which is represented by G_{ref-r1} with tilted plane angle a_1.
- The reflected solar radiation from top reflector which reached the collector surface which is represented by G_{ref-r2} with tilted plane angle a_2.
- The reflected solar radiation from the left side reflector which reached the collector surface which is represented by G_{ref-r4} with tilted plane angle σ_2
- The reflected solar radiation from the right side reflector which reached the collector surface which is represented by G_{ref-r3} with tilted plane angle σ_1, and the total diffuse radiation $G_{dif-col}$.

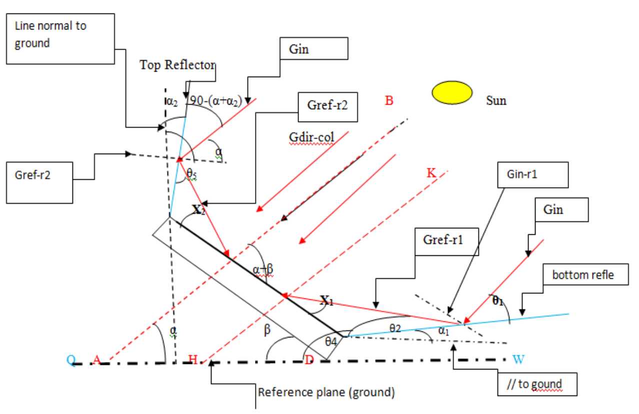


Figure 3.1. General Schematic diagram of the solar collector with top and bottom flat plate reflector

3.1.Analytical modeling of bottom reflector

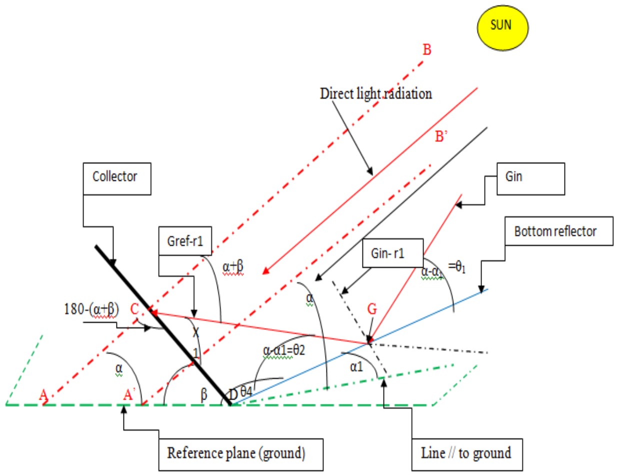


Figure 3.2. Graphical model to calculate the solar radiation reflected from the bottom reflector

The construction line from A-B is solar latitude angle line (direct sun light) which is from the sun to the ground.

Where

The construction line from A'-B' is the line parallel to the solar latitude angle line

The green construction line indicates the reference horizontal plane (ground)

Q-W the horizontal plane (ground)

H-K is the line parallel to the line A-B

The tilted collector explained by reflected beams from the reflector depends on the reflector-collector system geometry and Sun position (α)

α- solar altitude angle (the angle between the horizontal and the line to the sun, that is, the complement of the zenith angle.

a_1- angle of the bottom reflector to the horizontal plane (tilted plane angle)

a_2 -angle of the top reflector to the vertical plane (tilted plane angle)

β -collector's tilt angle

Gin-r1-is incident radiation on the bottom reflector,

Gref-r1- Reflected radiations from the bottom reflector to collector

From fig 3.3 the triangle' ACD'the angle between the collector and the solar latitude line from the ground can determined as follows;

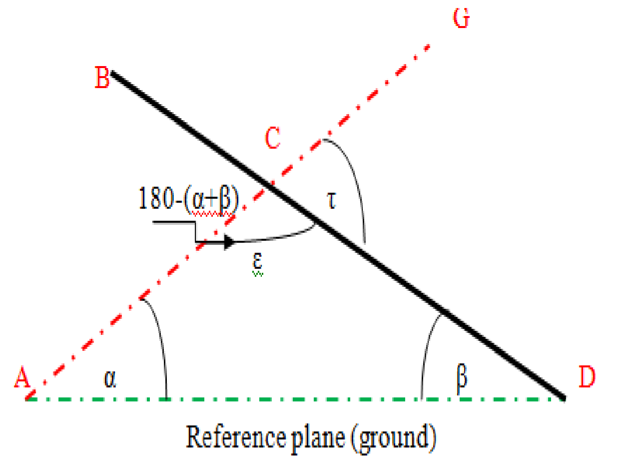


Figure 3.3. Geometric construction of solar altitude line, collector and reference plane

The sum of <ACD is equal to 180°.therefore the only un known angle is ε and can be determined as follows since α and β are known angles

$\alpha + \beta + \varepsilon = 180^o \rightarrow \varepsilon = 180 - (\alpha + \beta) \quad (A)$

Similarly the angle from fig 3.3 the angle GCD which is τ can be separately determined as:

From maths relation the sum of the angles of ε and τ are 180° because they are supplementary angles.

Therefore

$\varepsilon + \tau = 180^o$

$\varepsilon = 180 - (\alpha + \beta) \qquad \textit{from eqn A}$

Hence $\quad \tau = 180^o - \varepsilon \rightarrow 180^o - (180 - (\alpha + \beta))$

$\tau = (\alpha + \beta) \quad (B)$

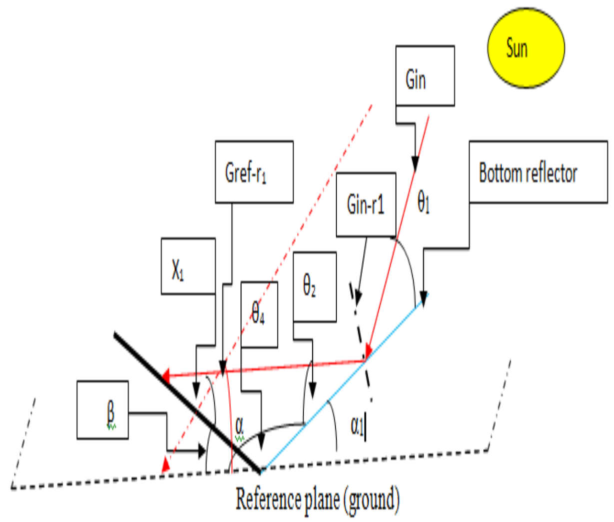


Figure 3.4. Geometrical construction of direct sun light from bottom reflector to collector with reference plane (ground);

Where α -solar altitude angle can be determined as;

$sin(\alpha) = sin(\Phi)sin(\delta) + cos\Phi cos(\delta)cos(\omega) \quad (C)$

θ_1= angle of incidence beam on the bottom reflector

θ_2=angle of reflected beam from the reflector to the collector

$\theta 4 = 180 - (\alpha 1 + \beta)$

The angle at which Reflected radiation from the bottom reflector falls on the collector surface (X_1) can determined as;

$X1 + \theta 4 + \theta 1 = 180$

$X1 = 180 - 180 + \alpha 1 + \beta - \alpha + \alpha 1$

$X1 = 2\alpha 1 + \beta - \alpha \qquad (D)$

In order to describe the relation between reflected and incident rays we need to look at the point where the incident ray meets the reflecting surface.
The behavior of the rays in specular reflection can be described completely by two laws, illustrated in figure 3.6.

- The incident ray, the normal and the reflected ray all lie in the same plane.
- The angle of incidence is equal to the angle of reflection. Based on this concept

$\theta_1=\alpha-\alpha_1$, $\theta_2=\alpha-\alpha_1$ i.e. $\theta_1=\theta_2$ also according to Snell's law that states the angle of incidence beam is equal to angle of reflected beam.

3.2.Analytical modeling of top reflector

Similarly for top reflector the solar angles for the collector also calculated as follows;

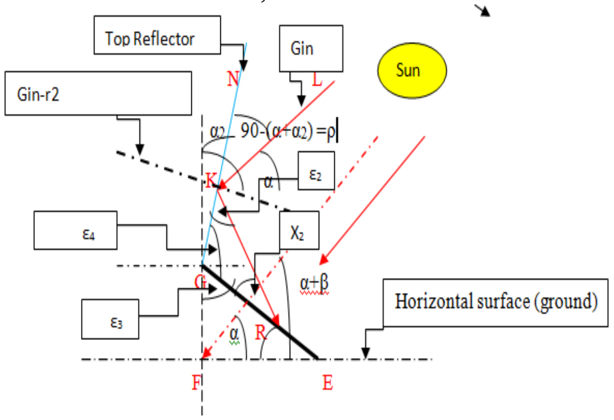


Figure 3.5. Graphical model to calculate the solar radiation reflected from the top reflector

Where

ε_4 -is the angle of the triangle KGR which is constructed between the reflector and collector

ε_3 is the angle between the line perpendicular to the ground and collector i.e. is <FGE

ε_2 is the angle between the reflector and the reflected sun ray from the reflector which reaches the collector i.e.<GKR.

α_2- angle between upper reflector and vertical plane

Hence $\varepsilon_3+\varepsilon_4+\alpha_2=180$

Let's take the triangle EGF

$$\varepsilon 3 + 90 + \beta = 180$$
$$\varepsilon 3 = 180 - (90 + \beta)$$
$$\varepsilon 3 = 90 - \beta$$

Let's take the triangle KGR to determine the angle ε_4 as follows

Now $\varepsilon 4 + \varepsilon 3 + \alpha 2 = 180$

$$\varepsilon 4 = 180 - (90 - \beta + \alpha 2)$$
$$\varepsilon 4 = 90 + \beta - \alpha 2$$

The reflected solar radiation from the top reflector falls on the collector under the angle X_2 can be determined as follows.

The sum of angles for the triangle KGR is 180°.

Now $\varepsilon 4 + \varepsilon 2 + X2 = 180$

Where $\varepsilon 5 = 90 - (\alpha + \alpha 2)$

According to Snell's law that states the angle of incidence beam is equal to angle of reflected beam like.

$\varepsilon_5= 90 - (\alpha+\alpha_2)$

Therefore $\varepsilon 4 + \varepsilon 5 + X2 = 180$

$X_2=180-[(90+\beta-\alpha_2+90-(\alpha+\alpha_2)]$

$X_2=180-90-\beta+\alpha_2-90+\alpha+\alpha_2)$

$X_2=-\beta+\alpha_2+\alpha+\alpha_2$

$X2 = 2\alpha 2 + \alpha - \beta$

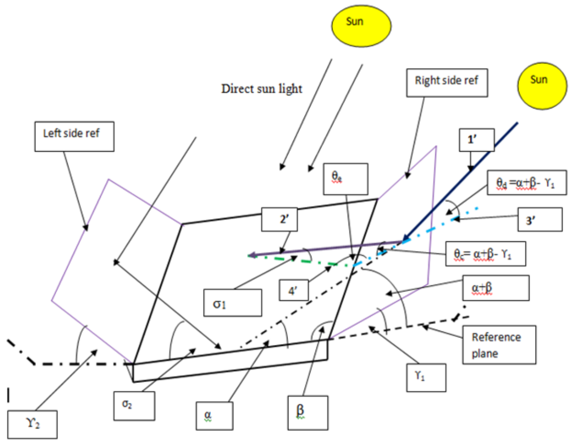


Figure 3.6. Schematic diagram of the collector with left and right side flat plate reflectors (graphical model to calculate the solar radiation reflected from the left and right side reflectors)

Where

1'- indicates the direct sun ray strikes the reflector (Gin-r3)

2'- indicates the reflected sun ray strikes the collector (Gref-r3)

3'-indicates the line // to the reflector

4'-indicates the line // to the collector

α-is the angle between the collector and the sun ray

β- The tilted plane angle of the collector

σ_1- the angle at which the Reflected radiation from the right side reflector falls on collector surface

σ_2- the angle at which the Reflected radiation from the left side reflector falls on collector surface

Υ_1-the tilted plane angle of the right side reflector to the horizontal plane,

Υ_2- the tilted plane angle of the left side reflector to the horizontal plane Ref-reflector

3.3.Analytical model of right side reflector

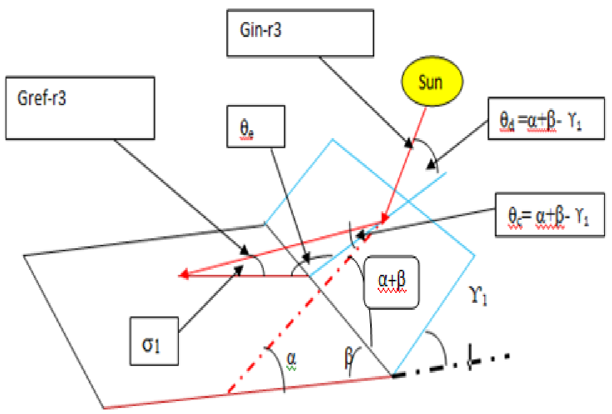


Figure 3.7. Graphical model to calculate the solar radiation reflected from the right side reflector)

Where

θ_d-the angle of incidence for the reflector that is equal to $\alpha+\beta-\Upsilon_1$

$\theta_c=\alpha+\beta-\Upsilon_1$ is the angle between the line 2'and 3' that is between the reflected sun ray and the reflector and equal with the angle of incidence for the reflector i.e. $\theta_d=\alpha+\beta-\Upsilon_1$

The angle of incidence is equal to the angle of reflection. Based on this concept also according to Snell's law that states the angle of incidence beam is equal to angle of reflected beam. Therefore $\theta_d=\theta_c=\alpha+\beta-\Upsilon_1$

θ_e=is the angle between the reflector edge and the collector i.e.
$\theta_e + \Upsilon_1 = 180$
$\theta_e = 180 - \Upsilon_1$ where Υ_1- the tilted plane angle of the right side reflector to the horizontal plane,
Now we can determine the angle at which the Reflected radiation from the left side reflector falls on collector surface (σ_1);
$\sigma_1 + \theta_e + (\alpha + \beta - \Upsilon_1) = 180$
$\sigma_1 = 180 - (\theta_e + \alpha + \beta - \Upsilon_1)$
$\sigma_1 = 180 - (180 - \Upsilon_1 + \alpha + \beta - \Upsilon_1)$
$\sigma 1 = 2\Upsilon_1 - (\alpha + \beta)$

3.4. Analytical model of left side reflector

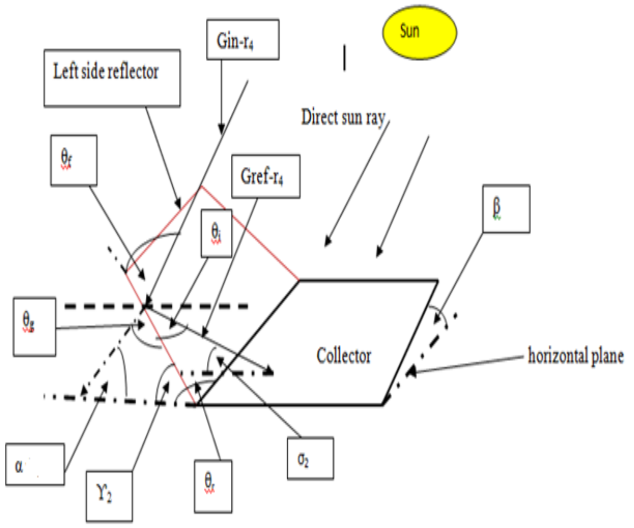


Figure 3.8: Schematic diagram of the collector with left side flat plate reflectors (graphical model to calculate the solar radiation reflected from the left side reflector
Where
$\alpha + \beta$ -the solar altitude angle
θ_r- is the angle between collector and reflector
θ_f-is the angle between sun ray and reflector that is the angle of incidence of the reflector
σ_2- the angle at which the Reflected radiation from the left side reflector falls on collector surface
θ_g-the angle between reflector and direct sun light to the reference plane which is perpendicular to the ground as you can see from the above fig.
For the angle between sun ray and reflector that is the angle of incidence of the reflector (θ_f)
$\theta_f = 180 - (\alpha + \beta) - \Upsilon_2$
For the angle between reflector and direct sun light to the reference plane (θ_g)
$\theta_g = \theta_f = 180 - (\alpha + \beta) - \Upsilon_2$ by means of opposite interior angles
For the angle between collector and reflector (θ_r)
$\theta_r + \Upsilon_2 = 180$
$\theta_r = 180 - \Upsilon_2$
$\theta_f = \theta_i = 180 - (\alpha + \beta) - \Upsilon_2$ by means of the angle of incidence is equal to the angle of reflection from Snell's concept . Finally the angle at which the Reflected radiation from the left side reflector falls on collector surface i.e (σ_2) is obtained as follows;
$\theta_r + \sigma_2 + \theta_i = 180$
$180 - \Upsilon_2 + 180 - (\alpha + \beta) - \Upsilon_2 + \sigma_2 = 180$
$\sigma_2 = 180 - [180 - \Upsilon_2 + 180 - (\alpha + \beta) - \Upsilon_2]$
$\sigma 2 = 2\Upsilon_2 + \alpha + \beta - 180$

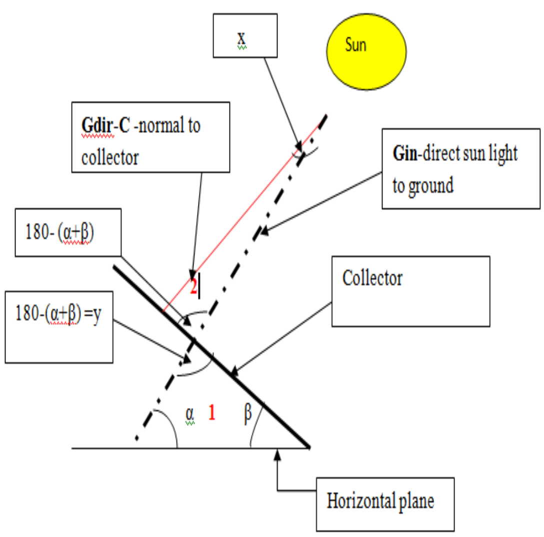
Top and bottom reflectors are about the same size which has the same dimension on the edge of the collector based on our design that are (width of the reflector is equal to the width of the collector i.e. 100 cm and the height of the reflector is i.e.60 cm) or (100 cmx60 cm).
The same is true for the left and right side reflectors are also the same but not equal to the top and bottom length of reflector that is the length of the reflector is equal to the length of collector is 200 cm where as the height is 60 cm i.e. (200x60 cm) .
The collector collects direct solar radiation, the reflected solar radiation from top, bottom, left and right side reflectors and the total diffuse radiation. In collectors with reflectors adjacent to the absorber for increasing efficiency effect.
In order to analyze the flat plate solar collector integrated with reflector simply we can take reasonable assumptions. Hence the analysis is based on the following assumptions:

- The global solar radiation is considered in the present analysis.
- The flat reflector (aluminum foil) is specular with a constant reflectivity (ρ_{Al}=0.88), irrespective of the radiation incidence angle.
- Shading of the reflector on the collector is not taken into consideration (As a result of none fixing the reflector-collector system in position, the reflector may not cast a shadow on the collector surface at certain times.
- The collector does not reflect radiation back to the reflectors;
- There are no mutual reflections between the reflectors;
- Only diffuse component of the solar radiation (the sky-diffuse radiation and the reflected radiation from the reflectors) falls directly on the collector.

Therefore the total solar radiation Gtot-col on the collector surface is;

$$G_{tot-c} = G_{dir-c} + \sum_{i=1}^{4} G_{ref-ri} + G_{diff-c}$$

Direct radiation from the light source on the collector surface is derived as follows;
It depends on the reflector-collector system geometry and Sun position (α)



Graphical model to calculate the direct solar radiation comes from the sun

For triangle

$y + \alpha + \beta = 180$

$y = 180 - (\alpha + \beta)$

By opposite interior angles angle of y=z=180-(α+β)

For triangle (2)

$y + 90 + x = 180$

$x = 180 - (y + 90)$

$x = 180 - (180 - (\alpha + \beta) + 90)$

$x = \alpha + \beta - 90)$

From triangle (2)

$$\cos(x) = \frac{Gdir - c}{Gin}$$

$$\cos(\alpha + \beta - 90) = \frac{Gdir - c}{Gin}$$

$Gdir - c = Gin * \cos(\alpha + \beta - 90) = Gin * \sin(\alpha + \beta)$

From summation rule of trigonometric functions;

$\cos(A - B) = \cos A \cos B + \sin A \sin B$

$\cos(\alpha + \beta - 90) = \cos(\alpha + \beta)\cos 90 + \sin(\alpha + \beta)\sin 90$

$\cos(\alpha + \beta - 90) = 0 + \sin(\alpha + \beta) * 1$

$\cos(\alpha + \beta - 90) = \sin(\alpha + \beta)$

Therefore the direct solar flux strikes the collector can be defined as;

$Gdir - c = Gin * \cos(\alpha + \beta - 90)$ or

$Gdir - c = Gin * \text{sine}(\alpha + \beta)$

The total diffuse radiation on the thermal collector is the sum of the sky-diffuse radiation G_{dif} sky and the reflected radiation

$$G_{diff-c} = G_{diff\ sky} + G_{ref\ g} = Gdif * \frac{1 + \cos\beta}{2} + \rho g * Gh * \frac{1 - \cos\beta}{2}$$

Where;

G_{in-} is incident radiation from the light source

α- the solar altitude angle of radiation from the light source

β-is the tilted plane angle of the collector

ρAl -is Al foil reflectance

G_{dif} - diffuse radiation on horizontal surface

Gh - is global solar radiation on horizontal surface

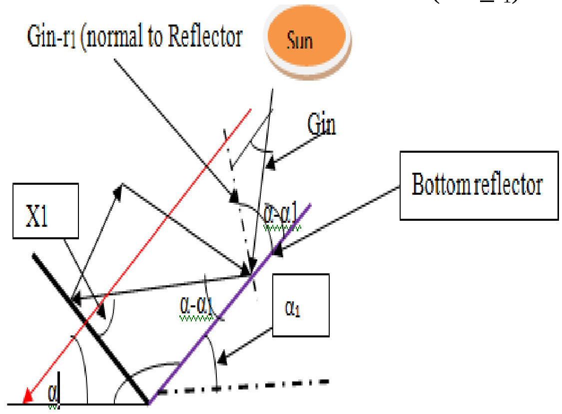
ρ_g is ground reflectance (ground albedo 0.2 without snow, 0.6 with snow).

Due to the existence of reflectors on the edge of the collector the reflected radiation from the ground G_{ref} is neglected and the above eqn becomes;

$$Gdif - col = Gdif - sky = Gdif * \frac{1 + \cos\beta}{2}$$

The incident radiations on the bottom and top reflector can be calculated as follows respectively.

Incident radiation on the bottom reflector (Gin_r_1)



Therefore

$Gin\_r1 - = Gin.\sin(\alpha - \alpha 1)$

Similarly Reflected radiations from the bottom reflector with the tilted plane angle α_1 can formulate as;

$Gref - r1 = \rho Gin.\sin x1.\sin(\alpha - \alpha 1) = \rho Gin - r1.\sin x1$

The reflected solar radiation from the bottom reflector falls on the collector under the angle of X_1 from figure defined as;

$X1 = 2a1 + \beta - \alpha$

Incident radiation on the top reflector (Gin_{r2})

$Gin\_r2 = Gin.\cos(\alpha 2 + \alpha)$

Reflected radiations from the top reflector with the tilted plane angle α_2 are defined as:

$Gref - r2 = \rho Gin.\sin x2.\cos(\alpha 2 + \alpha) = \rho Gin - r2.\sin x2$

The reflected solar radiation from the top reflector falls on the collector under the angle X_2 from fig can be defined as;

$X2 = (2.a2 + a - \beta)$

Where

a_1 and a_2 are angles between the reflectors and their corresponding planes.

X1 and X2 are angles of incidence for bottom and top reflectors.

For the left and right side reflector

The incident radiations on the right and left reflector can be calculated as follows respectively.

Incident radiation on the right side reflector (Gin_r3) from fig expressed as;

$Gin\_r3 = Gin \sin(\theta_d)$ Where $\theta d = \alpha + \beta - \gamma_1$

Incident radiation on the left side reflector (Gin_r4) from fig expressed as, $Gin\_r4 = Gin * \sin(\theta_f)$ Where $\theta_f = 2180 - (\alpha + \beta - \Upsilon 2)$

Similarly, reflected radiation from the left and right side reflector with the tilted plane angle ϒ1 and ϒ2, respectively are defined as:

$Gref - r3 = \rho Al * Gin * \sin\sigma 1 * \sin(\alpha + \beta - \gamma_1) = \rho * Gin - r3 * \sin\sigma_1$ $Gref - r4 = \rho Al * Gin * \sin\sigma 2 * \sin(\theta_f) = \rho * Gin - r4 * \sin\sigma_2$

Where

Gin_r3- is incident radiation on the right side reflector and Gin_r4 -is incident radiation on the left side reflector.

Reflected radiation from the right side reflector falls on the cell's surface at the angle of σ1 from fig expressed as;

$\sigma 1 = 2\gamma 1 - (\alpha + \beta)$

Where σ1 − Incidence angle of right side reflector

Reflected radiation from the left side reflector falls on the collector surface at the angle of σ2 from fig is expressed as;

$\sigma 2 = 2\gamma 2 + (\alpha + \beta) - 180$

Where σ2 − Incidence angle of left side reflector

The angles of reflectors from the collector can adjust to 45, 30, and 15°.For our case the optimal position of the reflectors can fixed at 45° and the reflectors can adjust at 45 degree in order to get maximum solar radiation intensity on the collector.

Hence each reflector can adjusts from the reference plane (vertical plane or ground) on the side of collector. From this point of view the angle of each reflector is equally tilted at 45° from the either reference plane (ground) or collector i.e. $a_1.a_2.\Upsilon_1$ and Υ_2=45°.

IV. MODELING AND SIMULATION

4.1.Modeling of flat plate collector

The 3-D model for the flat plate collector is created using ANSYS R15 workbench Package. It is fluid flow (CFX).

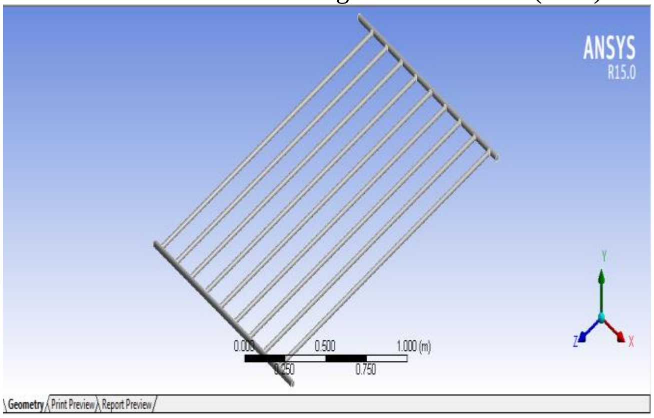
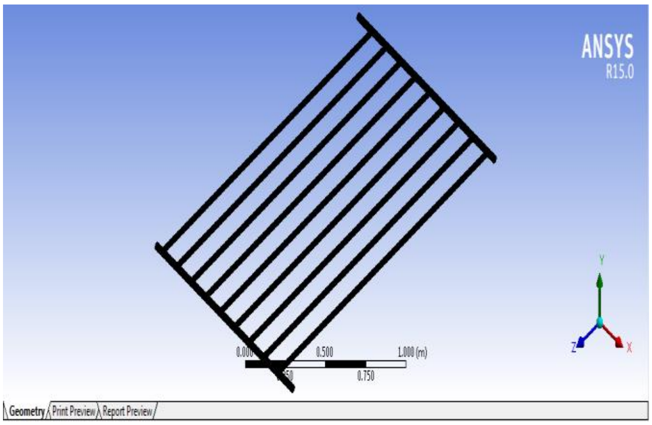


Figure 4.1. 3D Model Meshing

The computational domain is mesh as shown in Figure below. The shape of control volumes should satisfy certain geometry requirements in order to eliminate irregularities in computational results. The mesh is used ANSYS ICEM CFD tetrahedra for collector with the numbers of elements are 1264532 and nodes are 278281.



4.2.Physics of Simulation for CFD Analysis

- Fluid Model

The thermal energy is selected to analyze the heat transfer and contour presentation. Energy model is set to ON position which permits heat transfer analysis and enter a heat flux value.

- Boundary Conditions

Inlet and outlet conditions of the working fluid on each riser are velocity inlet and pressure outlet respectively.

Constant heat flux equivalent to net solar radiation is applied on the top surface of the collector and headers.

- Solver Parameters

The high resolution scheme (from advection scheme) and Auto-time scale (from time scale control) is used for convergence control. The convergence criteria are RMS residual type and residual target 1e-04 is used for mass and momentum which gives the water outlet temperature from flat plate collector configuration after certain (100) number of iterations. The general fluid flow (CFX) simulation model of flat plate collector is shown in below.

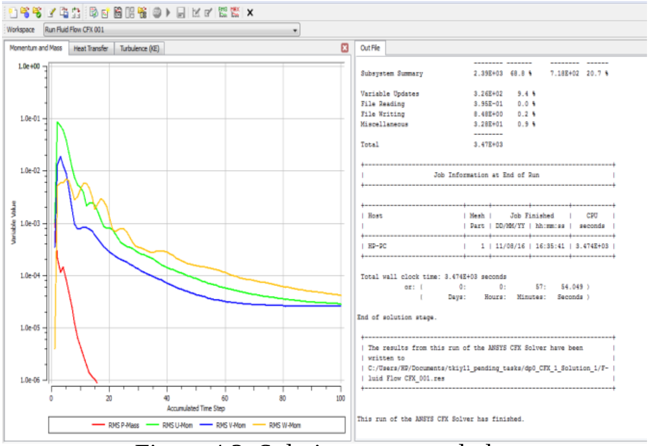


Figure 4.3. Solution converged plot

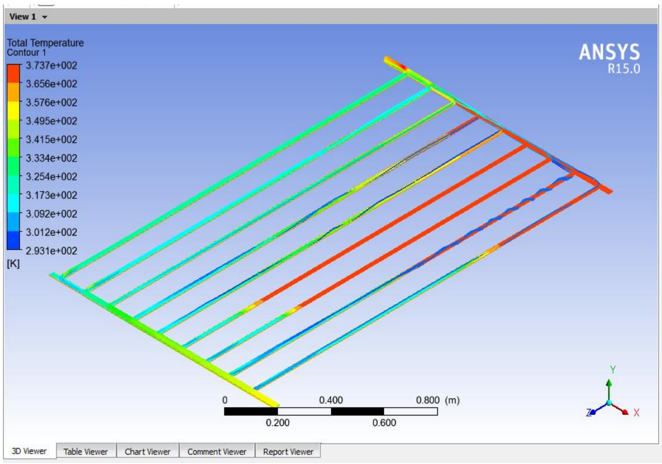


Figure 4.4. Contour plot of total temperature

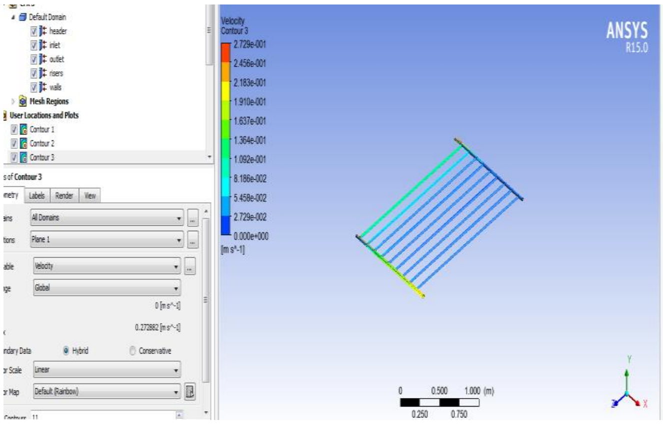


Figure 4.5. Contour plot of flow velocity

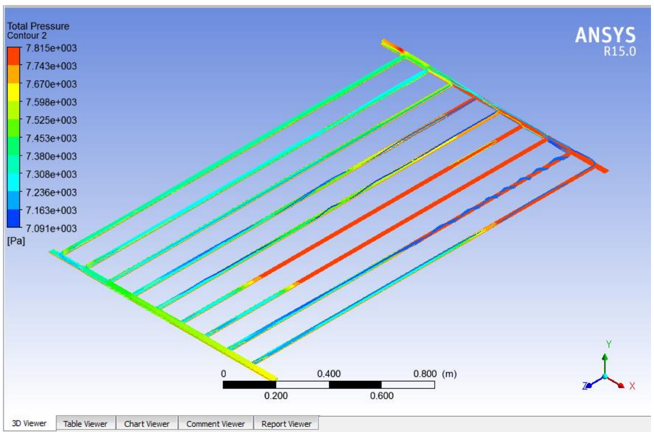


Figure 4.6. Contour plot of dynamic pressure

V. EXPERIMENTAL SETUP

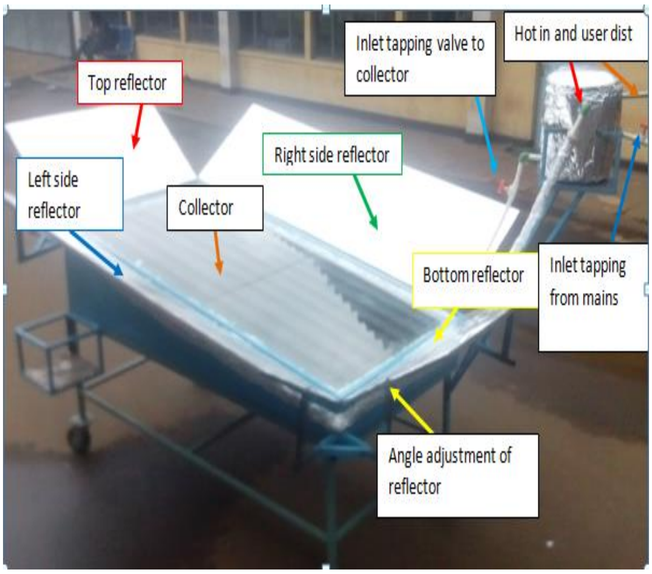


Figure 5.1. Photo graphic of experimental set up of solar water heating with reflector

VI. RESULTS AND DISCUSSION

6.1. Experimental results

The temperature of inlet and outlet water was measured by using mercury thermo meter. The data collected after interval half an hour and fifteen minutes is shown in Appendix D. The data's I collected for nine days consecutively are inlet and outlet temperature and solar flux of flat plate collector integrated with and without reflectors. The first three tables are an interval time of fifteen minutes, the second three tables interval half an hour and the last two tables fifteen minutes interval without reflectors you can see on appendix D.

The solar water heater was tested for a period of eight (8) days. The experiment was carried out in the open where the setup was directly exposed to sunshine which is free from shades of trees and buildings. The experimental work has been done in the Bahirdar institute of technology (BiT). The following data were collected during the experiment.

- Inlet and outlet temperatures were recorded in every 15 and 30 minute with mercury thermometer between the hours of 9:15 and 5:00.

- Radiation intensity using pyranometer was recorded.

Figure 6-1 shows the relationship of the inlet and outlet temperature readings. The inlet temperature increases slightly during the day. The outlet temperature rises significantly until it peaks at 3.00 pm and then starts to reduce due to decline in solar irradiance. A peak outlet hot water temperature of 98^{o}C was registered on the first day experiment. The rest experimental dates maintained average outlet temperature of a hot water was 95^{o}C during the experiments.

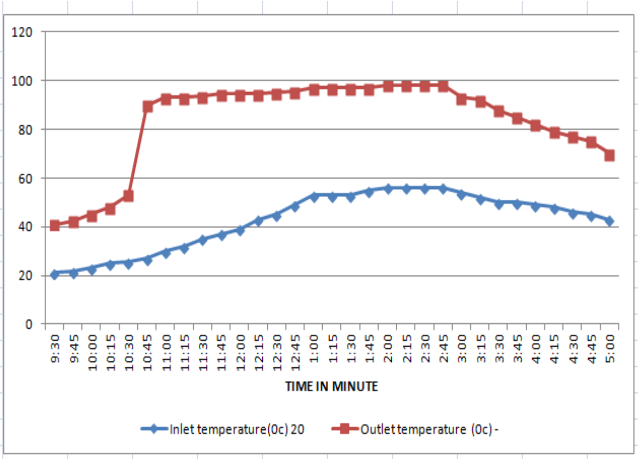


Figure 6-1. Water inlet and outlet temperature versus time on June 02-06-2017

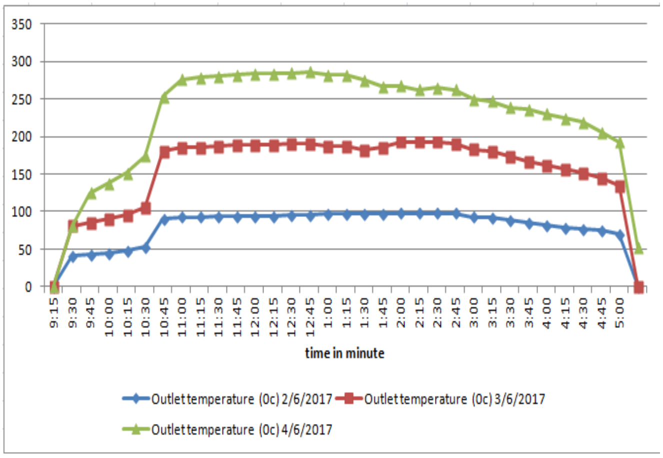


Figure 6-2. Water outlet temperature versus time (on three different dates).

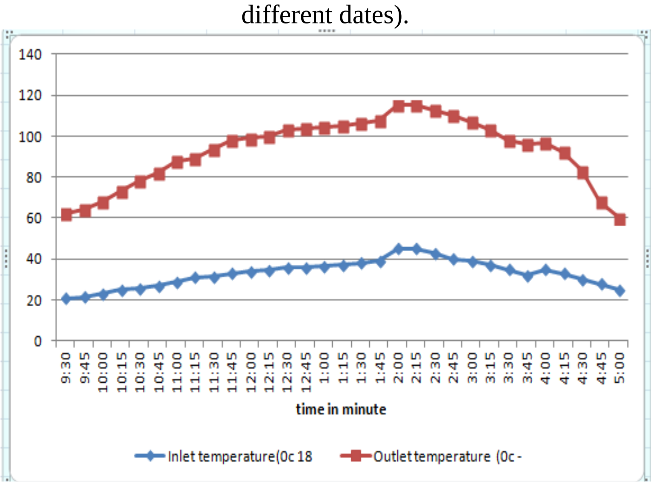


Figure 6-3. Water inlet and outlet temperature versus time on June 09-10-2017 without reflector

6.2. CFD Results

ANSYS 15 software is used to, model and solve the thermal analysis of the collector. The computational fluid dynamics (CFD) which is fluid flow (CFX) is used for simulation of heat transfer on the collector

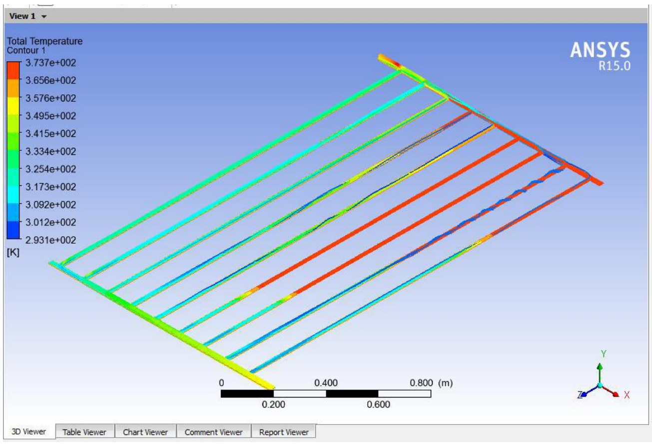


Figure 6.4. Contour plot of total temperature

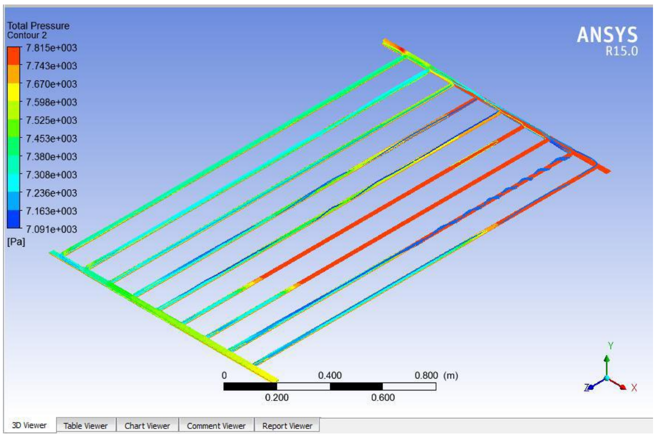


Figure 6.5. Contour plot of dynamic pressure

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