

The solar energy collectors engineering essay



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Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The major component of any solar system is the solar collector. Solar collectors transform solar radiation into heat and transfer that heat to a medium (water, solar fluid, or air). Solar collectors capture incident solar radiation energy and either convert it to heat (thermal energy) or directly to electricity (photovoltaic cells). The solar energy thus collected is carried from the circulating fluid either directly to the hot water or space conditioning equipment or to a thermal energy storage tank from which can be drawn for use at night and/or cloudy days.

TYPES:

There are two types of solar collectors.

Non-Concentrating

Concentrating

A non concentrating collector has the same area for intercepting and for absorbing solar radiation, whereas a sun tracking concentrating solar collector usually has concave reflecting surfaces to intercept and focus the sun's beam radiation to a smaller receiving area, thereby increasing the radiation flux.

NON-CONCENTRATING:

Solar energy collectors are basically distinguished by their motion, i. e. stationary, single axis tracking and two axes tracking, and the operating

temperature. Initially, the stationary solar collectors are examined. These collectors are permanently fixed in position and do not track the sun. Three types of collectors fall in this category:

Flat plate collectors (FPC).

Stationary compound parabolic collectors (CPC).

Evacuated tube collectors (ETC). [Ref 1]

FLAT PLATE COLLECTORS:

A typical flat-plate collector consists of an absorber, transparent cover sheets and an insulated box. The absorber is usually a sheet of high-thermal conductivity metal with tubes or ducts either integral or attached. Its surface is painted or coated to maximize radiant energy absorption and in some cases to minimize radiant emission. The insulated box provides structure and sealing and reduces heat loss from the back or sides of the collector [2].

When solar radiation passes through a transparent cover and impinges on the blackened absorber surface of high absorptivity, a large portion of this energy is absorbed by the plate and then transferred to the transport medium in the fluid tubes to be carried away for storage or use. The underside of the absorber plate and the side of casing are well insulated to reduce conduction losses. The liquid tubes can be welded to the absorbing plate, or they can be an integral part of the plate. The liquid tubes are connected at both ends by large diameter header tubes. The transparent cover is used to reduce convection losses from the absorber plate through the restraint of the stagnant air layer between the absorber plate and the

glass. It also reduces radiation losses from the collector as the glass is transparent to the short wave radiation received by the sun but it is nearly opaque to long-wave thermal radiation emitted by the absorber plate (greenhouse effect). FPC are usually permanently fixed in position and require no tracking of the sun. The collectors should be oriented directly towards the equator, facing south in the northern hemisphere and north in the southern. The optimum tilt angle of the collector is equal to the latitude of the location with angle variations of 10-15° more or less depending on application.

REF: http://visual.merriam-webster.com/images/energy/solar-energy/flat-plate-solar-collector_2.jpg

Flat Plate collectors can be divided into two types:

LIQUID FLAT PLATE COLLECTORS:

Liquid flat plate collectors heat liquid as it flows through tubes in or adjacent to the absorber plate. The simplest liquid systems use potable household water, which is heated as it passes directly through the collector and then flows to the house. Solar pool heating also uses liquid flat-plate collector technology, but the collectors are typically unglazed.

AIR FLAT PLATE COLLECTORS:

Air flat-plate collectors are used primarily for solar space heating. The absorber plates in air collectors can be metal sheets, layers of screen, or non-metallic materials. The air flows past the absorber by using natural convection or a fan. Because air conducts heat much less readily than liquid

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does, less heat is transferred from an air collector's absorber than from a liquid collector's absorber, and air collectors are typically less efficient than liquid collectors [7].

STATIONARY COMPOUND PARABOLIC COLLECTORS:

CPC are non-imaging concentrators. These have the capability of reflecting to the absorber all of the incident radiation within wide limits. The necessity of moving the concentrator to accommodate the changing solar orientation can be reduced by using a trough with two sections of a parabola facing each other. Compound parabolic concentrators can accept incoming radiation over a relatively wide range of angles. By using multiple internal reflections, any radiation that is entering the aperture, within the collector acceptance angle, finds its way to the absorber surface located at the bottom of the collector. The absorber can take a variety of configurations. It can be cylindrical as shown in or flat. In the cylindrical

CPC shown in the lower portion of the reflector is circular, while the upper portions are parabolic. As the upper part of a CPC contribute little to the radiation reaching the absorber, they are usually truncated thus forming a shorter version of the CPC, which is also cheaper. CPCs are usually covered with glass to avoid dust and other materials from entering the collector and thus reducing the reflectivity of its walls [12].

These collectors are more useful as linear or trough-type concentrators. A CPC concentrator can be orientated with its long axis along either the north-south or the east-west direction and its aperture is tilted directly towards the equator at an angle equal to the local latitude. When orientated along the

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north-south direction the collector must track the sun by turning its axis so as to face the sun continuously. As the acceptance angle of the concentrator along its long axis is wide, seasonal tilt adjustment is not necessary. It can also be stationary but radiation will only be received the hours when the sun is within the collector acceptance angle. When the concentrator is orientated with its long axis along the east-west direction, with a little seasonal adjustment in tilt angle the collector is able to catch the sun's rays effectively through its wide acceptance angle along its long axis [13].

Ref: http://constructionmanuals.tpub.com/14259/img/14259_322_1.jpg

EVACUATED TUBE COLLECTORS:

In this type of vacuum collector, the absorber strip is located in an evacuated and pressure proof glass tube. The heat transfer fluid flows through the absorber directly in a U-tube or in countercurrent in a tube-in-tube system. Several single tubes, serially interconnected, or tubes connected to each other via manifold, make up the solar collector. The collectors are usually made of parallel rows of transparent glass tubes. Each tube contains a glass outer tube and metal absorber tube attached to a fin. The fin is covered with a coating that absorbs solar energy well, but which inhibits radiative heat loss. Air is removed, or evacuated, from the space between the two glass tubes to form a vacuum, which eliminates conductive and convective heat loss. ETC has demonstrated that the combination of a selective surface and an effective convection suppressor can result in good performance at high temperatures [14].

The vacuum envelope reduces convection and conduction losses, so the collectors can operate at higher temperatures than FPC. Like FPC, they collect both direct and diffuse radiation. However, their efficiency is higher at low incidence angles. This effect tends to give ETC an advantage over FPC in day-long performance. ETC use liquid-vapor phase change materials to transfer heat at high efficiency. These collectors feature a heat pipe (a highly efficient thermal conductor) placed inside a vacuum-sealed tube. The pipe, which is a sealed copper pipe, is then attached to a black copper fin that fills the tube (absorber plate). Protruding from the top of each tube is a metal tip attached to the sealed pipe (condenser). The heat pipe contains a small amount of fluid (e. g. methanol) that undergoes an evaporating-condensing cycle. In this cycle, solar heat evaporates the liquid, and the vapor travels to the heat sink region where it condenses and releases its latent heat. The condensed fluid return back to the solar collector and the process is repeated. When these tubes are mounted, the metal tips up, into a heat exchanger (manifold). Water, or glycol, flows through the manifold and picks up the heat from the tubes. The heated liquid circulates through another heat exchanger and gives off its heat to a process or to water that is stored in a solar storage tank. Because no evaporation or condensation above the phase-change temperature is possible, the heat pipe offers inherent protection from freezing and overheating. This self limiting temperature control is a unique feature of the evacuated heat pipe collector [15].

Ref: http://greenterrafirma.com/images/evacuated_tube_schematic.jpg

CONCENTRATING:

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Energy delivery temperatures can be increased by decreasing the area from which the heat losses occur.

Temperatures far above those attainable by FPC can be reached if a large amount of solar radiation is concentrated on a relatively small collection area. This is done by interposing an optical device between the source of radiation and the energy absorbing surface. Concentrating collectors exhibit certain advantages as compared with the conventional flat-plate type. These collectors are not permanently fixed and they can easily track the sun [16].

The collectors falling in this category are:

Linear Fresnel Reflector.

Stirling dish.

Central receiver.

Parabolic Trough Collector.

LINEAR FRESNAL COLLECTOR:

LFR technology relies on an array of linear mirror strips which concentrate light on to a fixed receiver mounted on a linear tower. The LFR field can be imagined as a broken-up parabolic trough reflector, but unlike parabolic troughs, it does not have to be of parabolic shape, large absorbers can be constructed and the absorber does not have to move [1]. The greatest advantage of this type of system is that it uses flat or elastically curved reflectors which are cheaper compared to parabolic glass reflectors [17]. Additionally, these are mounted close to the ground, thus minimizing

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structural requirements. The first to apply this principle was the great solar pioneer Giorgio Francia who developed both linear and two-axis tracking Fresnel reflector systems at Genoa, Italy in the 60s. These systems showed that elevated temperatures could be reached using such systems but he moved on to two-axis tracking, possibly because advanced selective coatings and secondary optics were not available [18]. One difficulty with the LFR technology is that avoidance of shading and blocking between adjacent reflectors leads to increased spacing between reflectors. Blocking can be reduced by increasing the height of the absorber towers, but this increases cost. Compact linear Fresnel reflector (CLFR) technology has been recently developed at Sydney University in Australia. This is in effect a second type of solution for the Fresnel reflector field problem which has been overlooked until recently. In this design adjacent linear elements can be interleaved to avoid shading. The classical LFR system has only one receiver, and there is no choice about the direction and orientation of a given reflector. However, if it is assumed that the size of the field will be large, as it must be in technology supplying electricity in the MW class, it is reasonable to assume that there will be many towers in the system. If they are close enough then individual reflectors have the option of directing reflected solar radiation to at least two towers. This additional variable in the reflector orientation provides the means for much more densely packed arrays, because patterns of alternating reflector orientation can be such that closely packed reflectors can be positioned without shading and blocking [19].

Ref: http://www.eere.energy.gov/basics/renewable_energy/images/linear_frisnel.gif

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STIRLING DISH:

The Stirling dish system consists of a parabolic dish shaped concentrator (like a satellite dish) that reflects direct solar irradiation onto a receiver at the focal point of the dish. The receiver may be a Stirling engine (dish/engine systems) or a micro-turbine. Stirling dish systems require the sun to be tracked in two axes, but the high energy concentration onto a single point can yield very high temperatures. Stirling dish systems are yet to be deployed at any scale. Most research is currently focused on using a Stirling engine in combination with a generator unit, located at the focal point of the dish, to transform the thermal power to electricity. There are currently two types of Stirling engines: Kinematic and free piston. Kinematic engines work with hydrogen as a working fluid and have higher efficiencies than free piston engines. Free piston engines work with helium and do not produce friction during operation, which enables a reduction in required maintenance [3]. A parabolic dish reflector, shown schematically in is a point-focus collector that tracks the sun in two axes, concentrating solar energy onto a receiver located at the focal point of the dish. The dish structure must track fully the sun to reflect the beam into the thermal receiver. For this purpose tracking mechanisms are employed in double so as the collector is tracked in two axes. The receiver absorbs the radiant solar energy, converting it into thermal energy in a circulating fluid. The thermal energy can then either be converted into electricity using an engine-generator coupled directly to the receiver, or it can be transported through pipes to a central power-conversion system. Parabolic-dish systems can achieve temperatures in excess of 1500 oC. Because the receivers are distributed throughout a

collector field, like parabolic troughs, parabolic dishes are often called distributed-receiver systems.

The main use of this type of concentrator is for parabolic dish engines. A parabolic dish-engine system is an electric generator that uses sunlight instead of crude oil or coal to produce electricity. The major parts of a system are the solar dish concentrator and the power conversion unit. Parabolic-dish systems that generate electricity from a central power converter collect the absorbed sunlight from individual receivers and deliver it via a heat-transfer fluid to the power-conversion systems. The need to circulate heat transfer fluid throughout the collector field raises design issues such as piping layout, pumping requirements, and thermal losses. Systems that employ small generators at the focal point of each dish provide energy in the form of electricity rather than as heated fluid. The power conversion unit includes the thermal receiver and the heat engine. The thermal receiver absorbs the concentrated beam of solar energy, converts it to heat, and transfers the heat to the heat engine. A thermal receiver can be a bank of tubes with a cooling fluid circulating through it. The heat transfer medium usually employed as the working fluid for an engine is hydrogen or helium. Alternate thermal receivers are heat pipes wherein the boiling and condensing of an intermediate fluid is used to transfer the heat to the engine. The heat engine system takes the heat from the thermal receiver and uses it to produce electricity [31].

Ref: <http://www.solarthermalpowerplant.com/images/avanzado12b.jpg>

CENTRAL RECEIVER:

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Central receiver (or power tower) systems use a field of distributed mirrors - heliostats - that individually track the sun and focus the sunlight on the top of a tower. By concentrating the sunlight 600-1000 times, they achieve temperatures from 800°C to well over 1000°C. The solar energy is absorbed by a working fluid and then used to generate steam to power a conventional turbine [4]. The operation of this kind of plants is based in the concentration of incoming solar energy using a heliostat field that reflects the incident solar radiation onto a receiver . As the sun position changes during the day, each heliostat of the field has to change its position in real time according to the selected aiming point on the receiver, as different aiming points can be selected in order to achieve a uniform temperature distribution on the receiver [5]. For extremely high inputs of radiant energy, a multiplicity of flat mirrors, or heliostats, using altazimuth mounts, can be used to reflect their incident direct solar radiation onto a common target By using slightly concave mirror segments on the heliostats, large amounts of thermal energy can be directed into the cavity of a steam generator to produce steam at high temperature and pressure. The concentrated heat energy absorbed by the receiver is transferred to a circulating fluid that can be stored and later used to produce power [32].

Ref: <http://ars.els-cdn.com/content/image/1-s2.0-S1364032111006058-gr6.jpg>

PARABOLIC TROUGH:

DESCRIPTION:

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An effective approach to sustainable energy is the utilization of solar energy. The parabolic trough collector with central receiver is one of the most suitable systems for solar power generation. A type of concentrating solar collector that uses U-shaped troughs to concentrate sunlight onto a receiver tube, containing a working fluid such as water or oil, which is positioned along the focal line of the trough. Sometimes a transparent glass tube envelops the receiver tube to reduce heat loss. Parabolic troughs often use single-axis or dual-axis tracking. Temperatures at the receiver can reach 400°C. The heated working fluid may be used for medium temperature space or process heat, or to operate a steam turbine for power or electricity generation [10]. In order to deliver high temperatures with good efficiency a high performance solar collector is required. Systems with light structures and low cost technology for process heat applications up to 400 8C could be obtained with parabolic through collectors (PTCs). Parabolic-trough collectors use curved mirrors to focus sunlight on a dark-surfaced tube running the length of the trough. A parabolic trough is simply a linear translation of a two-dimensional parabolic reflector where, as a result of the linear translation, the focal point becomes a line. These are often called line-focus concentrators. A parabolic dish (paraboloid), on the other hand, is formed by rotating the parabola about its axis; the focus remains a point and is often called point-focus concentrators. The parabola is an intriguing geometric shape with important practical uses-including concentrating sunlight. The curve of a parabola is such that light travelling parallel to the axis of a parabolic mirror will reflect to a single focal point from any place along the curve. Because the sun is so far away, all light coming directly (excludes diffuse) from it is essentially parallel, so if the parabola is facing the sun, the

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sunlight is concentrated at the focal point. A parabolic trough extends the parabolic shape to three dimensions along a single direction, creating a focal line along which the absorber tube is run [8]. When the parabola is pointed towards the sun, parallel rays incident on the reflector are reflected onto the receiver tube. It is sufficient to use a single axis tracking of the sun and thus long collector modules are produced. The collector can be orientated in an east-west direction, tracking the sun from north to south, or orientated in a north-south direction and tracking the sun from east to west. The advantages of the former tracking mode is that very little collector adjustment is required during the day and the full aperture always faces the sun at noon time but the collector performance during the early and late hours of the day is greatly reduced due to large incidence angles (cosine loss). North-south orientated troughs have their highest cosine loss at noon and the lowest in the mornings and evenings when the sun is due east or due west. Over the period of one year, a horizontal north-south trough field usually collects slightly more energy than a horizontal east-west one. However, the north-south field collects a lot of energy in summer and much less in winter. The east-west field collects more energy in the winter than a north-south field and less in summer, providing a more constant annual output. Therefore, the choice of orientation usually depends on the application and whether more energy is needed during summer or during winter [20].

Parabolic trough technology is the most advanced of the solar thermal technologies because of considerable experience with the systems and the development of a small commercial industry to produce and market these

systems. PTCs are built in modules that are supported from the ground by simple pedestals at either end. The receiver of a parabolic trough is linear. Usually, a tube is placed along the focal line to form an external surface receiver (Fig. 7). The size of the tube, and therefore the concentration ratio, is determined by the size of the reflected sun image and the manufacturing tolerances of the trough. The surface of the receiver is typically plated with selective coating that has a high absorptance for solar radiation, but a low emittance for thermal radiation loss. A glass cover tube is usually placed around the receiver tube to reduce the convective heat loss from the receiver, thereby further reducing the heat loss coefficient. A disadvantage of the glass cover tube is that the reflected light from the concentrator must pass through the glass to reach the absorber, adding a transmittance loss of about 0.9, when the glass is clean. The glass envelope usually has an antireflective coating to improve transmissivity. One way to further reduce convective heat loss from the receiver tube and thereby increase the performance of the collector, particularly for high temperature applications, is to evacuate the space between the glass cover tube and the receiver. In order to achieve cost effectiveness in mass production, not only the collector structure must feature a high stiffness to weight ratio so as to keep the material content to a minimum, but also the collector structure must be amenable to low labor manufacturing processes. A number of structural concepts have been proposed such as steel framework structures with central torque tubes or double V-trusses, or fiberglass [21].

Ref: www.newenergyportal.files.wordpress.com

WORKING:

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A mixture of water and fluids that transfer heat is pumped through the tube. The fluids absorb solar heat and reach temperatures up to 299 °C (570 °F). The hot water is sent to a thermal storage tank, or the steam is directed through a turbine to generate electricity. Parabolic-trough collectors provide hot water and/or electricity for industrial and commercial buildings. Parabolic trough collectors use only direct radiation, and even though they use tracking systems to keep them facing the sun, they are most effective where there are good solar resources. Parabolic-trough collectors are more efficient for large facilities that require hot water around the clock. They also require large areas for installation, yet they offset the need for conventional energy and provide energy savings and environmental benefits [6].

TERMS USED IN PARABOLIC TROUGHS:

THE PARABOLA:

A parabola is the locus of a point that moves so that its distances from a fixed line and a fixed point are equal. This is shown on Figure, where the fixed line is called the directrix and the fixed point F , the focus. Note that the length FR equals the length RD . The line perpendicular to the directrix and passing through the focus F is called the axis of the parabola. The parabola intersects its axis at a point V called the vertex, which is exactly midway between the focus and the directrix.

If the origin is taken at the vertex V and the x -axis along the axis of the parabola, the equation of the parabola is

(m2)

PARABOLIC RADIUS:

Parabolic radius p , is the distance from the focus F to the curve.

(m)

HEIGHT OF PARABOLA:

It may be defined as the maximum distance from the vertex to a line drawn across the aperture of the parabola. In terms of focal length and aperture diameter, the height of the parabola is

RIM ANGLE:

Rim angle (θ) is the ratio of the focal length to aperture diameter f/d .

ARC LENGTH:

Another property of the parabola that may be of use in understanding solar concentrator design is the arc length s . This may be found for a particular parabola from Equation by integrating a differential segment of this curve and applying the limits $x = h$ and $y = d/2$. The result is

OPTICAL ANALYSIS:

The concentration ratio (C) is defined as the ratio of the aperture area to the receiver/absorber area, i. e.

$$C = A_a / A_r$$

For FPC with no reflectors, $C = 1$: For concentrators C is always greater than 1. For a single axis tracking collector the maximum possible concentration is given by

$$C_{\max} = 1/\sin(\epsilon_{\mu})$$

and for two-axes tracking collector

$$C_{\max} = 1/\sin^2(\epsilon_{\mu})$$

where ϵ_{μ} is the half acceptance angle. The half acceptance angle denotes coverage of one-half of the angular zone within which radiation is accepted by the concentrator's receiver. Radiation is accepted over an angle of $2 \epsilon_{\mu}$ because radiation incident within this angle reaches the receiver after passing through the aperture. This angle describes the angular field within which radiation can be collected by the receiver without having to track the concentrator.

For a stationary CPC the angle ϵ_{μ} depends on the motion of the sun in the sky. For example, for a CPC having its axis in a N-S direction and tilted from the horizontal such that the plane of the sun's motion is normal to the aperture, the acceptance angle is related to the range of hours over which sunshine collection is required, e. g. for 6 h of useful sunshine collection $2 \epsilon_{\mu} = 90^\circ$ (sun travels $15^\circ/\text{h}$). In this case

$$C_{\max} = 1/\sin^2 45^\circ = 1.41$$

For a tracking collector ϵ_{μ} is limited by the size of the sun's disk, small scale errors and irregularities of the reflector surface and tracking errors. For

The geometry of the collector dictates the geometric factor A_f ; which is a measure of the effective reduction of the aperture area due to abnormal incidence effects. For a PTC, its value can be obtained by the following relation:

$$A_f = \frac{2}{3} \frac{W_a h_p + f W_a [1 + \frac{W_a^2}{48 f^2}]}{W_a} \quad [26]$$

The most complex parameter involved in determining the optical efficiency of a PTC is the intercept factor. This is defined as the ratio of the energy intercepted by the receiver to the energy reflected by the focusing device, i. e. parabola. Its value depends on the size of the receiver, the surface angle errors of the parabolic mirror, and solar beam spread. The errors associated with the parabolic surface are of two types, random and non-random [101]. Random errors are defined as those errors which are truly random in nature and, therefore, can be represented by normal probability distributions. Random errors are identified as apparent changes in the sun's width, scattering effects caused by random slope errors (i. e. distortion of the parabola due to wind loading) and scattering effects associated with the reflective surface. Non-random errors arise in manufacture/assembly and/or in the operation of the collector. These can be identified as reflector profile imperfections, misalignment errors and receiver location errors [27]. Random errors are modeled statistically, by determining the standard deviation of the total reflected energy distribution, at normal incidence and are given by:

$$\sigma = \sqrt{\sigma_{\text{sun}}^2 + 4 \sigma_{\text{slope}}^2 + \sigma_{\text{mirror}}^2}$$

Non-random errors are determined from knowledge of the misalignment angle error β (i. e. the angle between the reflected ray from the centre of sun and the normal to the reflector's aperture plane) and the displacement of the receiver from the focus of the parabola (dr). As reflector profile errors and receiver mislocation along the Y axis essentially have the same effect a single parameter is used to account for both [28]. Another parameter that needs to be determined is the radiation concentration distribution on the receiver of the collector, called local concentration ratio (LCR). The shape of the curves depends on the same type or errors mentioned above and on the angle of incidence [29].

THERMAL ANALYSIS:

It is necessary to derive appropriate expressions for the collector efficiency factor F' ; the loss coefficient U_L and the collector heat removal factor F_R : For the loss coefficient standard heat transfer relations for glazed tubes can be used. The instantaneous efficiency of a concentrating collector may be calculated from an energy balance of its receiver.

$$q_u = G b n o A_a - A_r U_L (T_r - T_a)$$

The useful energy gain per unit of collector length can be expressed in terms of the local receiver temperature T_r as:

$$q'_u = (q_u/L) = (A_a n o G b/L) - (A_r U_L/L) (T_r - T_a)$$

In terms of the energy transfer to the fluid at local fluid temperature T_f :

$$q'_u = [(A_r/L) (T_r - T_f)] / (D_o / h_{fi} D_i) + (D_o / 2k) \ln (D_o / D_i)$$

If T_r is eliminated, we have:

$$q'u = F'(Aa/L) [(noGb) - (UL/C)(Tf-Ta)]$$

Where F' is the collector efficiency factor given by:

$$F' = (1/UL) / (1/UL) + (Do/hfiDi) + (Do/2k) \ln(Do/Di)$$

The heat removal factor can be given as:

$$q_u = FR [GbnoAa - ArUL(Ti-Ta)]$$

And the collector efficiency can be obtained by dividing q_u by $(GbAa)$.

Therefore

$$\eta = FR [no - (UL)(Ti-Ta/GbC)]$$

Where C is the concentration ratio $C = Aa/Ar$.

Another analysis usually performed for PTCs is by applying a piecewise two-dimensional model of the receiver by considering the circumferential variation of solar flux. Such an analysis can be performed by dividing the receiver into longitudinal and isoth