ISSN Print: 2394-7500
ISSN Online: 2394-5869
Impact Factor: 5.2
IJAR 2015; 1(11): 182-191
www.allresearchjournal.com
Received: 17-08-2015
Accepted: 20-09-2015

Usman Iqbal
Water Resources Engineer, Centre of Excellence in Water Resources Engineering, University of Engineering and Technology, Lahore, Pakistan.

Correspondence
Usman Iqbal
Water Resources Engineer, Centre of Excellence in Water Resources Engineering, University of Engineering and Technology, Lahore, Pakistan.

The Desalination: Solar distillation of Water Using Heat Recovery Technique – New Methodology for Faisalabad, Pakistan

Usman Iqbal

Abstract

Water is the most essential ingredient of the atmosphere and it is necessary for life on earth. Pakistan is facing serious problem of energy crisis and the gap between demand and supply of electricity is getting higher day by day. The objectives of current study are design and development of solar desalination system using heat recovery method, performance evaluation and cost estimation of solar desalination system for Faisalabad, Pakistan. The basic concepts of thermodynamics was utilized in-order to introduce new valued instrumentation regarding desalination less expensive with more economical. The experimental parameters Time, Tilt angle, Mass flow rate, Solar radiations, Ambient temperature, Solar irradiation, Collector inlet and outlet temperatures, Evaporation and Condensation Chambers Temperature, per minute distillate, Water quality tests, Overall efficiency was highly sensitive and estimate carefully in-order to avoid any chances of error. The daily fresh water productivity can be reached up to 2.7 l/m^2 in months of summer season. The fresh water exhibits excellent results having EC = 0.18 dS/cm, pH = 6.1, TDS = 127 ppm, Na^+, Ca^{2+} and Mg^{2+} are 0.53, 0.78 and 0.61 respectively. Finally, the cost per liter of distilled water is estimated about PKR 2.81/m^2 (\$ 0.03 per m^2/£ 0.02 per m^2).The results dictates that the solar desalination system is more cost effective as compared with other conventional systems. The water quality parameters (TDS, EC, pH, Ca^{2+}, Mg^{2+} and Na^+) were reduced to a level of safe limits as defined by World Health Organization (WHO) for drinking water quality standards. It is highly recommended that the similar studies conduct in future in behalf of Pakistan specially, in-order to produce the fresh/drinking/desalinated water at low potential costs and search the feasible alternatives of RO, EC. To produce such technologies for drinking as well as irrigation at low potential costs, to reduce health hazards.

Keywords: Solar Desalination; SOLIDWORKS; Flat Plate Solar Collector; RO.

Introduction

Energy demand is constantly growing due to ruthless global industrialization, fossil fuel remains the major source of energy for most of the world; however, reserves are diminishing and consumption is harming the environment. Desalination is an expensive way to produce fresh water because it requires high energy and initial costs, which demonstrate the importance of discovery alternative energy resources. Only 3% of fresh water exists in ground water, glaciers, lakes and rivers that fulfill the needs of humans and animals and oceans, which are major source of water, contain salty water (Service, 2006) [11]. A serious situation prevails in Asia, where 42% people in Asia Pacific and 19% people in South Asia have no access to safe drinking water. As a whole, 1.1 to 1.5 billion people in the world still do not have access to safe drinking water (Attia, 2012) [1]. Desalination is a process that uses huge amount of energy to separate saline water into two parts; pure water and brine concentrate. Salt water is fed as input into the process, and the output of the process is a stream of fresh water and another portion with a high salt concentration. It has been assessed that to produce desalinated 1000 m^3 per day of fresh water involves 10,000 to television and telephones. Several industries are associated with information technology, such as computer hardware, software, electronics, semiconductors, internet, telecom equipment, e-commerce and computer services. Personal computers and notebooks have evolved in the market; the conventional personal computers will remain the main computing device for providing basic services in an academic environment. According to Battin (1984), early efforts to apply computer technology to library activities took place between 1960 and early 1980s as the per year (Kalogirou, 2005) [3]. Among desalination options, reverse osmosis (RO) is rapidly surpassing solar desalination of water in terms of market shares. Fouling and scaling of the RO membranes can be potentially reduced by pretreatment and thus reducing energy consumption and overall costs (Fritzmann*et al*., 2007) [2]. While deciding about the water quality and its usage, parameters like Alkalinity, pH, total dissolved solids, electrical conductivity, DO, heavy metals and physical properties like taste, colour and odor should be monitored **(**Nafey., 2007) [7]. According to World Health Organization (WHO), allowable range of total dissolved solids for drinking water is 500-1000 ppm whereas most of the water present on earth has the total dissolved solids up to 10,000 ppm and sea water generally has total dissolved solids in the range of 35,000–45,000 ppm (Dessouky and Ettouney, 2002) [5]. Long term use of water having a greater EC causes the soil to be salt affected (Garcia, 2002) [6]. Problems related to use of fossil fuels may be fixed by utilization of renewable resources like wind, geo-thermal, biomass and solar energy (Khayet, 2012) [4]. The principle of solar energy is thermo nuclear process, which is the cause of producing the instantaneous energy in the sun, about 650,000,000 tons of hydrogen is converted to helium in every second. The sun transmits its energy through electromagnetic radiation (contain ultra-violet, visible and infra-red radiation) which are produced during thermonuclear process and spread out in entire space in all possible directions. (Rabl, 1976) [9]. In Pakistan mean global irradiation ranges between 200-250W/m^2/day. It is equal to 1,500-3,000 sunshine hours. Pakistan is receiving on an average 5.3 kWh m^{-2} per day. Daily global radiation up to 6 KWh/m^2 /day is accessible in this area. It means it is the ideal location to use photovoltaic and other solar thermal applications (Khalil *et al*., 2008) [10]. The current system included 1m^2 flat plate solar collector, an evaporation chamber and condensation chamber with enclosed copper heat exchanger was developed at small scale in-order to evaluate the performance of solar system. This is basically a new innovative technique which was developed (at small scale) with some expertise on trial basics, for future to create some high profile technologies may be some alternatives of RO. The system was based on the generation heat from flat plate collector which is then transferred to water flowing in copper tubes in a closed cycle loop and then it enters the chamber where the heat of hot water is utilized for the generation of vapor from saline water which is present in evaporation chamber and finally the condensation of water vapor is done by recovering the from the vapors and in return heating of the feed water present in condensation chamber. The key objectives of the current study are to design a solar desalination system coupled with a solar flat plate collector and to improve the productivity and efficiency of the system. The solar desalination system was designed to increase the rate of evaporation at low temperature by using copper heat exchanger. By using the heat recovery method, the feed water for evaporation chamber pre heated in the condensation chamber by using the latent heat of vaporization of hot water vapors. Intel temperature of feed water for evaporation chamber is raised to 20-25 ºC more than ambient temperature. System has much higher daily productivity than other desalination techniques. Solar desalination system using evaporation condensation/heat recovery works effectively during daytime. The primary objective of the study was to make use of solar energy as foremost source of heat supply. Keeping in view the above stated problems of water scarcity, energy crisis and the opportunity of utilizing solar energy potential in Pakistan, this research was focused on design, development and performance evaluation of the system to meet the following objectives. (a) Design and development of solar desalination system using heat recovery/evaporation condensation method, (b) Performance evaluation and cost estimation of solar desalination system. Scheffler (2011) [12] estimated that nearly half of the power of the solar radiations which is collected by the reflector becomes finally available in the cooking vessel. He claimed that water could be brought to boiling point within 10 minutes with 2.7 m² reflector and 9.7 m² could bring 4.5 liters of water. The author also claimed that 12.6 m² and 16m² reflectors were used to produce steam, either for cooking or industrial processes.

Material and Method

Present research involves the design and development of solar water desalination system based on evaporation condensation/heat recovery method. The objective of this research was to design a desalination system that utilizes solar energy to desalinate water and give good quality water at a low cost. For this purpose a solar desalination system was designed and developed with locally available low cost material. The solar desalination system was comprised of flat plate solar collector, closed loop heating fluid circulation, pump, evaporation unit, heat recovery unit, fresh water drum and control panel. Water quality analysis of fresh water was performed and compared with standards defined by World Health Organization (WHO) to check performance of the desalination system under local climatic conditions.

Climatic Conditions and Materials

The research was conducted on small scale in Faisalabad, Pakistan. The extreme climate of the city can be observed in a summer maximum temperature 50 °C and winter minimum temperature of -2 °C. The mean maximum temperature in summer and winter are 39 °C and 17 °C respectively. Average annual direct solar radiation of Faisalabad is about 4.5 to 5.0 kWh m^{-2} per day. The average annual direct solar radiation of Pakistan and Google Earth Map (2015) is shown in Figure 1.

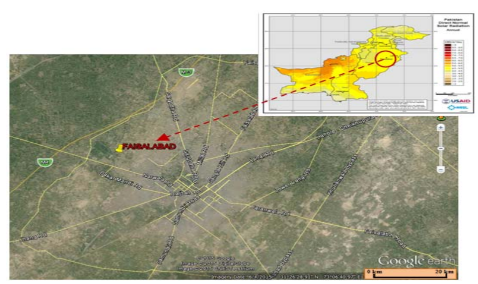

Fig 1: The average annual direct solar radiations- Pakistan and Google Earth Location Map (Faisalabad).

Materials

Iron Sheet

Iron's intrinsic properties have contributed to its popularity and varied uses; Iron is best known as the metal that gave us weapons and tools, and whose ability by means of alloys and heat treatment to suit itself to every application makes it the primary metal of technology. Iron is good a conductor of heat and electricity (k=73 Watts m^{-1} ºk^{-1}; where k represents thermal conductivity). Iron is recyclable with little deterioration in quality. Physical properties are usually those that can be observed using our senses such as color, luster, freezing point, boiling point, melting point, density, hardness and odor. The Physical Properties of Iron is shown in Table 1.

Table 1: Physical Properties of Iron

Parameter	Physical Properties of Iron
Color	Silver-gray metal
Malleability	Capable of being shaped or bent
Ductility	Easily pulled or stretched into a thin wire
Luster	Has a shine or glow
Conductivity	Good transmission of heat or electricity
Tensile	It can be stretched without breaking

Chemical properties are only observable during a chemical reaction. Reactions to substances may be brought about by burning, rusting, heating, exploding, tarnishing etc. The Chemical Properties of Iron is shown in Table 2.

Table 2: Chemical Properties of Iron

Parameter	Chemical Properties of Iron
Chemical Formula	Fe
Toxicity	Non Toxic
Reactivity with water	Reacts with very hot water and steam to produce hydrogen gas
Oxidation	Readily combines with oxygen in moist air which produces iron oxide also known as rust
Solubility	Dissolves in acids

A GI: 18 iron sheet of thickness 0.052 inch (1.25mm) and 2.156 lb/ft^2 specific weights was used in this study as a base material for evaporation and condensation chamber. A view of galvanized iron sheet is shown in Figure 2.

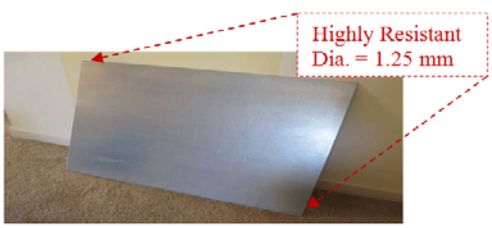

Fig 2: Iron sheet used as base material(1.25 mm)

Copper

Copper is a ductile, malleable, reddish-brown metallic element that is an excellent conductor of heat and electricity and is widely used for electrical wiring, water piping, and corrosion-resistant parts. The atomic number of this element is 29 and atomic weight is 58.The Physical Properties of Copper is shown in Table 3 and Chemical Properties of Copper is shown in Table 4.

Table 3: Physical Properties of Copper

Parameter	Physical Properties of Copper
Color	Reddish-Brown metal
Malleability	Capable of being shaped or bent
Ductility	Easily pulled or stretched into a thin wire
Conductivity	Excellent transmission of heat or electricity

Table 4: Chemical Properties of Copper

Parameter	Chemical Properties of Copper
Chemical Formula	Cu
Toxicity	Poisonous in large amounts
Reactivity with water	It does not react with water
Oxidation	Readily combines with water and carbon dioxide
Corrosion	Corrodes when exposed to air

Copper tubes are used to circulate hot water in the system. Copper is an excellent electrical conductor. Most of its uses are based on this property or the fact that it is also a good thermal conductor (k=385Watts m^{-1} ^{o}k^{-1}; where k represents thermal conductivity). However, many of its applications also rely on one or more of its other properties like recyclable and non-magnetic etc. A copper tube of 5 mm and 25 mm external diameter with 4 mm and 24 mm internal diameter respectively having 0.5 mm wall thickness was used in the development of the heat exchangers for evaporation and condensation chamber respectively as shown in Figure 3.

Fig 3: A view of 5 mm (external diameter) copper tube

Thermocol insulation sheet (Expanded Polystyrene)A 1 inch (25 mm) thick thermocol sheet was used to insulate the chamber to avoid heat losses from the system as shown in Figure 4.Thermocol isnon-hydroscopic, odorless, rigid, closed cell expanded polystyrene. It contains 98% by its volume still air entrapped in its cell and is the major reason for its excellent insulation properties. Because of its closed cell structure, it offers a remarkable resistance to unwanted heat, chill and moisture to penetrate through it and also gives a rigid, structurally strong product to withstand various kinds of loads and vibrations. It does not decay or age with the time and gives permanent lifelong insulation without regular maintenance. It is Suitable for its various applications like residential air-conditioning, air-conditioning in industrial houses, cold storages, mushroom plants, sound proofing etc. The typical Properties of thermocol are shown in Table 5.

Table 5: Typical Properties of Thermocol

Parameter	Typical Range
Density Range	15-30 Kg/m
Thermal conductivity	0.0035 to 0.0043 W m^{-1} K$^{-1.}$
Compressive Strength	0.8-1.6 Kg/cm
Cross breaking Strength	1.4-2.0 Kg/cm
Tensile Strength	3-6 kg/cm
Application Range	-200 to +80^{o}C
Melting Range	100 - 200^{o}C
Self-ignition point	300^{o}C

It is fully resistant to all concentrated acid expect (HNO_3 and H_2SO_4) but it is non-resistant to aliphatic, hydrocarbons, Ketones and chlorinated hydrocarbons and is affected by ultraviolet rays. It turns yellow and ultimate become brittle if left permanently exposed to sun. It can be cut easily with simple tools like knife or a saw. It can be painted with Plastic Emulsion paints or water bound distemper.

Fig 4: A view of 25 mm thermocol insulation sheet

Connecting pipe

A 4 inch (102 mm) internal diameter PVC pipe was used in the system and the pipe connects the evaporation and condensation chamber for the efficient transfer of water and water vapors from evaporation chamber to condensation chamber. The selection of pipe is made on the basis of different properties of material which is shown in Table 6.

Table 6: Typical Properties of PVC pipes

Parameter	Typical Properties
Durability	PVC is highly resistant to oxidative reactions, and maintains its performance for a long time.
Oil/Chemical resistance	PVC is resistant to acid, alkali and almost all inorganic chemicals.
Odor & Flavor	Owing to low bacterial growth in PVC, pipes are generally very good for water.
Mechanical stability	PVC is a chemically stable material, and also exhibits little change in its mechanical strength.
Lightweight	PVC pipes are light and easy to handle,

As a result of the combination of the above characteristics, PVC is generally the most efficient, quick installing and cost-effective of all the solutions for piping.

Thermocouples

K-Type thermocouples usually work in most applications as they are nickel based and exhibit good corrosion resistance. It is the most common sensor calibration type providing the widest operating temperature range. Due to its reliability and accuracy the K-Type thermocouple is used extensively at temperatures up to 2300°F (1260 °C). This type of thermocouple should be protected with a suitable metal or ceramic protection tube. In oxidizing atmospheres, such as electric furnaces, tube protection is not always necessary when other conditions are suitable; however, it is recommended for cleanliness and general mechanical protection. K-Type generally outlast than J-Type because the JP wire rapidly oxidizes, especially at higher temperatures. Two K-Type thermocouples with calibrated temperature meter were used to read the upper and lower side temperature of absorber sheet. The K-type in data collection is shown in Figure 5.

Fig 5: K-Type thermocouple and calibrated temperature meter

Storage tank

Polyethylene storage tank of capacity 20 liters was used for the storage of hot water as it is commonly and locally available as shown in Figure 6. Polyethylene is the most common plastic. Its primary use is in packaging (plastic bag, plastic films, geo- membranes, containers including bottles, etc.). Polyethylene is a thermoplastic polymer consisting of long hydrocarbon chains. For common commercial grades of medium and high-density polyethylene the melting point is typically in the range 120 to 180 °C (248 to 356 °F). The melting point for average, commercial, low-density polyethylene is typically 105 to 115 °C (221 to 239 °F).

Fig 6: Polyethylene/polythene storage Tank

Flat plate collector

A flat-plate solar collector is most commonly used solar collectors for water heating. Flat plate solar collector is used as primary heat source having $1m^2$ surface area as shown in Figure 7. This flat plate collector was developed and fabricated by Engr. Usman Iqbal in Faisalabad. Flat plate solar collecting system was used as a primary heat source and was coupled with solar desalination system. This was a great innovation of marriage/coupling of Flat plate solar collector with desalination unit. The insulation was made of glass wool. The specifications of collector are given above in Table 7.

Table 7: Major Specification of Flat Plate Collector

Component	Material Used	Thermal Conductivity Watts $m^{-1}\,{}^{o}k^{-1}$	Thickness(cm)	Dimensions L * W (cm^2)
Absorber Plate	Aluminum	204	0.05	100 * 100
Coil	Copper	385	0.05	---
Insulation	Glass wool	<0.007	2.5	100 * 100

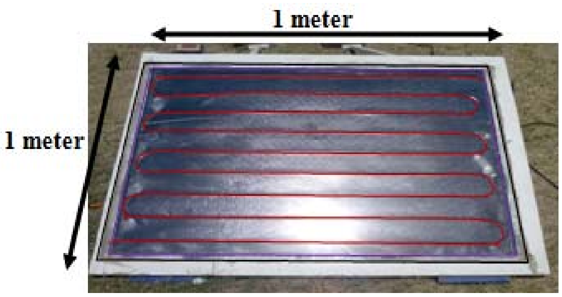

Fig 7: A view of flat-plate solar collector (1 m^2 area)

Water pump

A small water pump as shown in Figure 8was used for the circulation of water through the copper tubes in collector and evaporation chamber in a closed loop. The pump was operated with 12V battery. The battery was charged using 60 W_p

Fig. 8: A view of pump used for continuous circulation of fluid (water)

Solar PV panel. The pump forced the water into the collector from where water gets heated. After heating, the water flows out of the collector and enters into the evaporation unit. The flow of water in the loop was controlled by changing the speed of motor by using a regulator attached to the control panel.

Pyranometer

Pyranometer is the device used to measure the solar radiation. The used pyranometer was calibrated with standard pyranometer. The calibrated value is 1 m ampere is equals to 1W m^{-2}. A view of pyranometer is shown in Figure 9.

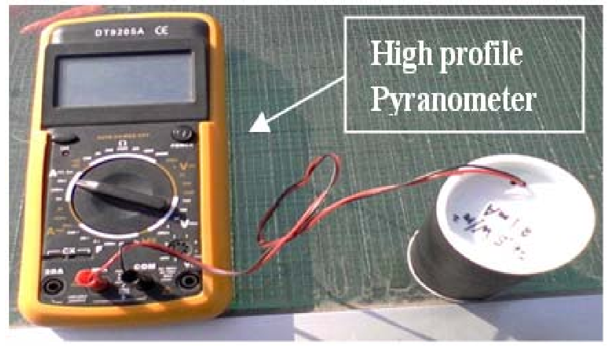

Fig 9: A view of calibrated pyranometer

Thermometer

Mercury filled glass thermometer is used for recording the temperature during the operation of the system. Mercury is a chemical element with symbol Hg and atomic number 80. Its melting point is -38.83 °C and boiling point is 356.7 °C. Mercury filled glass thermometer are one of the most common types of temperature instruments and are available in a variety of styles, sizes, and versions. The major specifications of the thermometer are given in the Table 8. A view of mercury thermometer is shown in Figure 10.

Table 8: Specifications of the mercury thermometer

Type	Material Filled	Range	Division	Accuracy	Length (mm)	Immersion (mm)
General purpose Lab Thermometer	Mercury	-10 to 110 °C	1 °C	0.5 °C	305mm (12")	50mm (2")

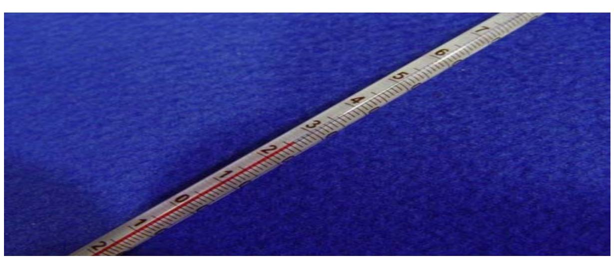

Fig 10: A view of mercury thermometer

Paints

Paints of two different colors were used to paint the evaporation and condensation chamber;

Aerosol black matte paint: For coating galvanized iron sheet of the evaporation chamber dull black aerosol black matte paint is used. Its dying time is about 10 - 15 minutes and it can withstand up to required temperature 40 to 105 °C. Due to its dull color and matting property it can absorb more radiation then enamel black paint.

Enamel paint: Blue enamel paint is painted over the condensation chamber of the desalination unit because of two reasons; firstly as the blue color is cooler than other colors, secondly enamel paint is also used galvanized iron sheet to make it resistant to the other elements via the waterproofing and rust proofing properties of enamel. Generally, treated surfaces last much longer and are much more resistant to wear than untreated surfaces.

Methodology

The research process was accomplished in three different segments, as follows;

Segment I: Design and development of solar desalination system using evaporation condensation/heat recovery method with locally available low cost materials.

Segment II: Performance evaluation of solar desalination system under local climatic conditions.

Segment III: Cost estimation and analysis of solar desalination system in comparison with conventional desalination system.

All the necessary materials and equipment required in development process, which were not available by us, and are purchased from local market before the development of the solar desalination system.

Segment I: - In the first step the focus was on the basic design parameters of the research such as selection of system components like flat plate collector, evaporation and condensation chamber surface area, water storage capacity, flow rate of water through tubes, number and diameter of tubes, size of water pump for water circulation, thickness of tube walls and chamber sheet etc. along with material for connecting the two chambers and insulation. The size of the sheet selected for the base of evaporation and condensation chamber was 76×76 cm^2 or 0.76×0.76 m^2. The depth of the evaporation chamber was 22 cm or 0.22 m and the size of sheet for the walls of evaporation chamber was 4(22×76) cm^2or 4(0.22×0.76) m^2. The depth of the condensation chamber was 18 cm or 0.18 m and the size of sheet for the walls of condensation chamber was 4(18×76) cm^2or 4(0.18×0.76) m^2. The top cover of both chambers was gable shape with height of gable 18 cm or 0.18 m. For having minimum thermal losses through the system, thermocol insulation of thickness 25 mm was selected. This thickness is also available locally in the 40 in^2 (100 cm^2) dimensions. It offers a remarkable resistance to unwanted heat, chill and moisture to penetrate through it and also gives a rigid, structurally strong product to withstand various kinds of loads. It does not decay with the time and gives permanent lifelong insulation without regular maintenance. Length of tubes of heat exchanger and water flow rate was decided with reference to each other by the equation. We must have to decide one thing i.e. flow rate or length of tube. The flow rate can be changed by adjusting motor speed but length of pipe once if selected it cannot be changed. Therefore the number of tubes was decided to be 8 in the evaporation chamber having 4 inch (100 mm) distance from each other with total length of tube was 6.25 mor 6250 mm. The number of tubes was decided to be 4 in the heat recovery chamber having 4 inch (100 mm) distance from each other with total length of tube was 3.30 mor 3300 mm. After that flow rate was decided by the following Equation 1.

$$Q = \frac{m c_p \Delta T}{L} \text{-----------------} 1$$ Where; Q is available total

radiation in Watt per unit length of tube, m is mass flow rate in kg sec^{-1}, ΔT is change in temperature in °K, C_p is specific heat of water in J kg^{-1} K^{-1}, L is length of tube in m.

The maximum mass flow rate "m" through collector was calculated to be 0.02 kg sec^{-1} by taking into account the average radiation as 500 W m^{-2}, length of pipe as 10.3 m, change in temperature as 60 °K and the specific heat of water as 4187 J kg^{-1} K^{-1}(Nauman, 2014) [8].

In the second step all the materials and equipment were selected on the basis of their required properties and finally the material were purchased from the local market. The instruments and all the selected materials that were used in the development of solar desalination system were used for the introduction of new innovation. The specifications of the materials are described in the material section above.

During the third step, the drawings of the proposed system were prepared in SOLIDWORKS software the development processes were performed according to the prepared layout plan and sketches in the SOLIDWORKS were drawn according to the prescribed material units. The SOLIDWORKS drawing (Figure 11).

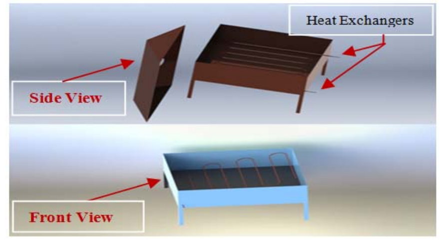

Fig 11: Solid works sketches for solar desalination system in Faisalabad

Preparation of sketch

Efficient operation of a system or machine largely depends upon feasibility and precision of the designing. Design plays a vital role in the required performance of the system. For efficiency point of view, it is of intense importance to take care of all the design parameters separately and precisely. For this purpose, rough sketch of the system was drawn on plain paper. The solid works drawings were prepared keeping in view the sketches. The piping layout was also drawn by hand on the plain paper and according to this layout the copper pipes were bended into required shape which was then fitted to the evaporation and condensation chamber as a heat exchanger. In this layout the gap between two pipes was kept 100 mm and radius of bending kept at 50 mm. A view of layout sketch for tube fitting is shown in Figure 12.

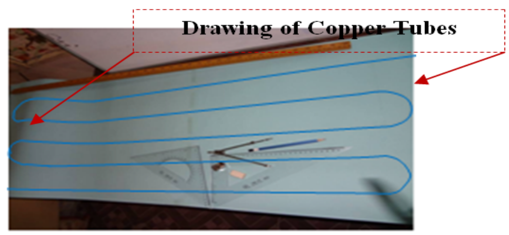

Fig 12: Layout sketch of tube fitting on drawing paper

Preparation of sketch in SOLIDWORKS

The drawings of the proposed system were prepared in SOLIDWORKS software as shown in Figure 13.

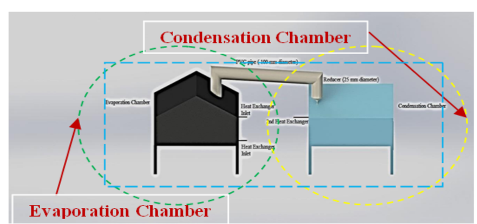

Fig 13: SOLIDWORKS drawings of the desalination system

Cutting and preparation of Iron sheet

After the preparation of layout sketch on the drawing paper this layout is shifted to the iron sheet. After shifting the sketch on iron sheet, the extra sheet was cut according to that layout to get the iron sheets of the size of 760 × 760 mm. The size of the evaporation chamber was 220 mm and the size of sheet for the walls of evaporation chamber was 4(220×760) mm^2. The depth of the condensation chamber was 180 mm and the size of sheet for the walls of condensation chamber was 4(180×760) mm^2. A view of sketch on the sheet is shown in Figure 14.

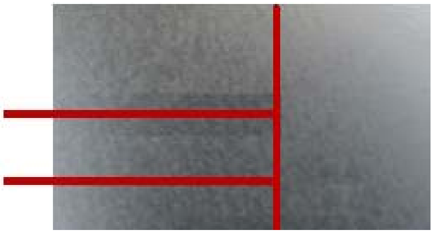

Fig 14: Galvanized iron sheet layout sketch

Welding of Iron sheet

After cutting the sheet into required dimensions, sheet was welded to required shape, in order to form two rectangular chambers according to the dimensions of sketches drawn in SOLIDWORKS software. Each dimension is precisely measured to ensure a leak proof chamber that does not allow water to leave the chamber. The major specifications of the evaporation and condensation units are shown above in the section Phase I. The bend was made in the sheet to form gable type top cover of rectangular chambers with hydraulic press machine from the local market.

Bending of copper tubes

Copper tube was then bended by keeping distance between two tubes 100 mm and radius of bend 50 mm with the help of spring bender and a wooden mold specially designed for this particular task. A 5 mm and 25 mm external diameter copper tube was used in the evaporation chamber and condensation chamber of the system. The Length of copper tube is selected as 6.25 m for evaporation chamber and 3.30 m for condensation chamber.

Fitting of copper tubes in chambers

After the bend process of copper tubes, firstly the tubes were fitted with the silver square tube via thin copper wires partially so that tubes were remain attached with the square tube during the fitting within the evaporation and condensation chamber before final fitting. Before the fixing of copper tubes, the holes were made in the side wall by the drill machine for the passage of inlet and outlet of the tube from the chamber. Then the both ends copper is fitted through the holes within the wall of chamber. The holes are made leak proof by the application of silicon sealant, to make sure that the chamber is water and air tight. The top view of evaporation and condensation chamber is shown of Figure 15.

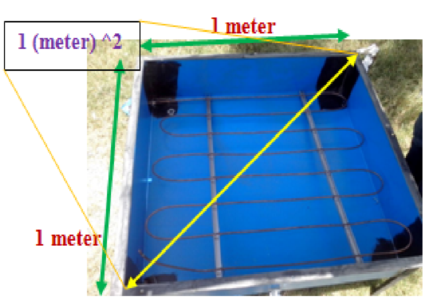

Fig 15: The A top view of evaporation and condensation chamber

Preparation, fixing of iron stand with the chamber, Painting the system and Insulation

The strong mild steel angle iron was used to prepare the stand for the evaporation and condensation chambers. Angle iron was cut in small length of 9 inch each to make the legs of the chambers. The legs were welded with the chamber so that to avoid chamber's direct contact with the ground surface. After fixing the legs it was painted to avoid deteriorates with rust. The evaporation and condensation chamber was then enameled by black and blue enamel paint to it protect from damage, deterioration, corrosion, rust and seasonal weather effects. Before painting, the joints were filled with silicon sealant to avoid any leakage and sand paper was used to remove any kind of dust and rust on the material to have better, smooth and sealed surface. After the enameling and matting of both chambers, a thermocol insulation of 25 mm thickness was attached on the base of evaporation chamber with silicon sealant. The sides of the evaporation chamber were also insulated with thermocol using silicon sealant.

Fixing of PVC Pipes

A 4 inch (10.2 cm) internal diameter PVC pipe was used in the system. The pipe connects the evaporation and condensation chamber from the top for the transfer of water vapors from evaporation to condensation chamber. For fixing of PVC pipe, a hole of 4 inch (10.2 cm) diameter was made in the center of evaporation chamber top cover. This connection uses two elbows that change the direction of pipe outlet at 180°. A small hole of 25 mm is drilled in the top cover of condensation unit through which the copper tube having 25 mm diameter comes out. The pipe connection uses a reducer as well which reduces the diameter from 4 inch (102 mm) to 25 mm. Finally, with the help of the reducer, PVC pipe was connected to copper tube (Figure 16). After the PVC pipe is connected, rubber gas kit is installed between the base and roof of the chamber to make it air tight and water tight. The top cover was placed on the both chamber and screws were tightened to make sure that system works without leakage. Silicon sealant was also used to make the system free from leakage.

Finally coupling with Flat Plate Solar Collector and other accessories

Figure 16 dictates the solar desalination system is coupled with flat plate solar collector using heat resistant pipes.

Fig 16: Solar desalination system with 1 m^2 flat plate solar collector

Segment II: - Energy production and collector losses

Power of the flat plate collector can be explained in terms of energy produced from the collector when the intensity of solar radiation incident on the aperture plane of the flat plate collector, then the amount of solar radiation received by the collector, which is the incoming energy toward the collector was calculated by the following Equation 2.

$$Q_{in} = I_t \times A_c \qquad \text{......} 2$$

Where;

Q_{in} is total incoming energy W, I_t is total radiation Wm^{-2}, and A_c is area of collector m^2.

The energy produced by the collector is represented in term of energy used; it is also known as the rate of extraction of heat from the collector may be measured by means of the amount of heat carried away by the fluid that passed through it. So the energy which was converted by the collector is forced water circulation is calculated by the Equation 3.

$$Q = \frac{\mathrm{m}c_p\Delta\mathrm{T}}{\mathrm{t}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

Where;
Q_u is energy used by the collector in W, m is mass of fluid taking energy in kg, ΔT is change in temperature in °K, C_p is specific heat of water in J kg^{-1} K^{-1}, and t is time span in seconds.
The optical losses from glass cover are the product of the rate of transmission of the cover and the absorption rate of the absorber glass and it was calculated by the following Equation 4.

$$Q_o = I \times (\tau \times \alpha) \times A_c \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

Where;
Q_o is optical losses W, I is total radiation Wm^{-2}, A_c is area of collector m^2, τ is transmittance of cover glass and α is absorbance of cover glass. As the collector absorbs heat its temperature is higher than that of the surrounding atmosphere and heat is lost to the atmosphere by convection and radiation. The rate of heat loss (Q_t) depends on the collector overall heat transfer coefficient (U_L) and the collector temperature. The overall heat loss was determined by the following Equation 5.

$$Q_t = U_L \times A_c \times (T_p - T_a) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

Where;
Q_t is overall thermal loss W, U_L is overall heat loss coefficient $Wm^{-2}K^{-1}$, A_c is area of collector m^2, T_p is temperature of absorber plate °K and T_a ambient temperature °K. The overall heat transfer coefficient (UL) was determined by the following Equation 6.

$$U_L = q\Delta T \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Where;
q is incident solar radiation in W m^{-2} and ΔT is absorber plate and surrounding fluid.

Collector efficiency
Collector efficiency (η) defined as the ratio of the useful energy gain (Q_u) to the incident solar energy (Q_i) over a particular time period (Struckmann, 2008). The efficiency of the collector was measured by following Equation 3.7.

$$\eta = \frac{Q_u}{Q_i} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7$$

Where;
η is the efficiency of the flat plate collector, Q_u is useful energy in W or J sec^{-1} and Q_i is incident energy W or J sec^{-1}.

Segment III: - In this segment performance evaluation of conventional desalination system (RO membrane) were executed and the results were compared with the solar water desalination system. After that cost analysis was performed between conventional desalination systems and solar energy based desalination system. The comparisons of initial investments of different water desalination systems were made in this segment.

Results and Discussions

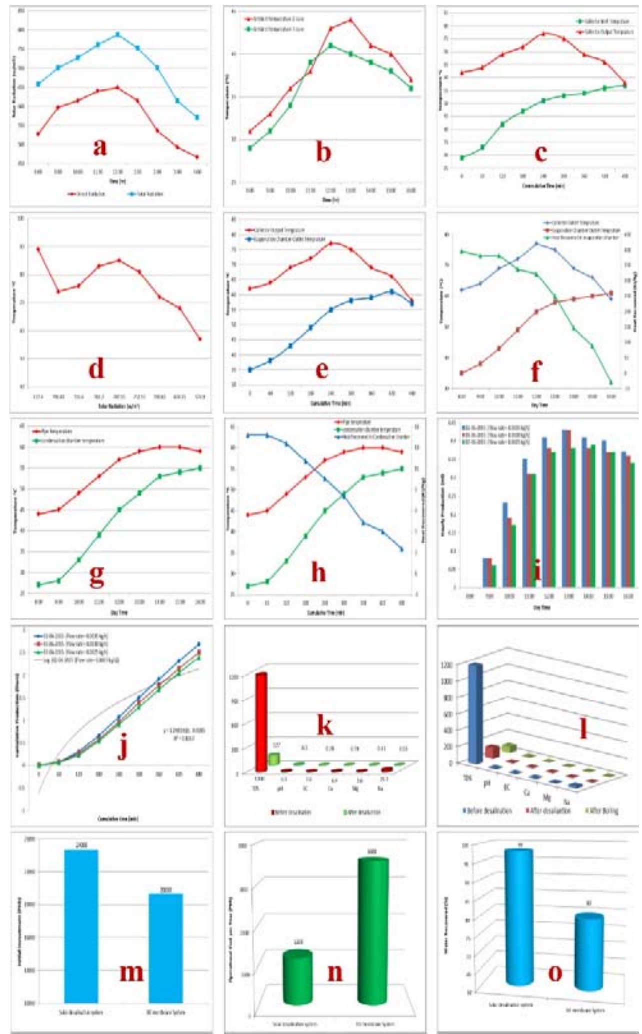

Fig 17: Graph "a" dictates difference between two consecutive times was 60 minutes and the total radiation and direct radiation increases with time, the curve indicates that the solar radiation increased with the day time in peak hours up to 12:00 pm and then decreased gradually. The gap between the direct radiation (red line) and total radiation (blue line) is low at the start of the day but as the cumulative time increases the gap between them also increases due to due scattering of direct radiation by the suspended particle or dust present in air. Graph "b" shows the typical ambient temperature and solar radiation on June 2, 2015 and June 7, 2015 has been measured with an interval of 60min. The experiment was conducted in peak hours (11:00am-4:00pm) and the mean ambient temperature on June 2 and June 7, 2015 is recorded 38 °C and 36 °C. Graph "c" indicates typical FPC inlet and outlet temperature on June 2, 2015 has been measured with an interval of 60min. The rate of increase in inlet temperature up to 300min from the start of experiment is observed very high because large temperature difference exists between FPC inlet, outlet and ambient

temperature. The rate of increase of inlet temperature becomes constant after 360min. This is due to the fact that when the inlet temperature increases from ambient temperature the losses from the system became significant due to the reverse heat flow from the system to the environment. Graph "d" represents relationship between solar radiation and absorber plate temperature. Before the flow of the liquid started through the collector and evaporation chamber, absorber plate temperature varies directly with solar radiation until it got its maximum temperature. After the flow of water started the sudden fall in the absorber plate temperature was noted due to very low temperature of inlet water as it can gain more energy because of high temperature difference, after that the increase in plate temperature showed direct relation of the water outlet temperature and solar radiation with the absorber plate temperature. Graph "e" indicates relationship between collector outlet/evaporation chamber inlet temperature and evaporation chamber outlet temperature at a specific point of time. This graph shows how much the heat energy of water from collector is being utilized by the water in the evaporation chamber. The difference between two consecutive cumulative times was 60 minutes. The collector outlet temperature (red line) showed direct relationship with time up to mid-day, and then it decreases gradually. Graph "f" shows The typical FPC and EC outlet temperature and heat energy utilized by water in EC on June 2, 2015 has been measured with an interval of 60min It is depicted from the Figure that FPC outlet temperature has direct relationship with time. The maximum rate of increase in FPC outlet temperature is recorded from 10:00am to 12:00pm as compared to 08:00am to 10:00am. After 12:00pm the outlet temperature decreases at a high pace due to decrease in solar radiation in the evening. The EC outlet temperature also shows a direct relationship with time. The rate of increase in EC outlet is recorded low from 08:00am to 10:00 am as compared to 10:00am to 12:00pm. Graph "g" gives a relationship between connecting pipe outlet/condensation chamber inlet temperature and condensation chamber outlet temperature/storage temperature with day time. This graph shows how much the heat energy water vapors from evaporation chamber is being utilized by the water in the condensation chamber. The difference between two consecutive cumulative times was 60 minutes. The evaporation chamber outlet from pipe (red line) showed direct relationship with time up to mid-day, and then it decreases gradually. The condensation chamber outlet temperature (green line) also showed direct relationship with time but amount of heat recovered has an inverse relation. Graph "h" The typical pipe temperature and CC temperature and heat energy of vapors utilized by water in CC on June 2, 2015 has been measured with an interval of 60 min It is depicted from the Figure that the pipe temperature has a direct relation with cumulative time. The maximum rate of increase is observed from 60min to 300min from start of experiment. Afterwards the rate of increase in the temperature is become constant and it gradually decreases after 420min. The Figure also depicts that CC temperature has direct relationship with time. The maximum rate of increase in CC temperature is observed from 120min to 240min from the start of experiment. Graph "i" The typical freshwater hourly productivity at different mass flow rates on June 2, June 5 and June 7, 2015 has been measured with an interval of 60min It is depicted from the Figure freshwater productivity has a direct relation with mass flow rates, cumulative time and solar radiation. The maximum productivity at high flow rates (0.0035 Kg/s and 0.0030 kg/s) is observed at 01:00pm while the maximum productivity at low flow rate (0.0025 Kg/s) is observed at 02:00pm with the mean distillate production at different mass flow rates as 0.386 l/hr, 0.359l/hr and 0.341 l/hr respectively. This variation is due to the fact that at low flow rates, the losses from the collector are high as all the thermal energy is not carried away by the heat transfer medium (water). Graph "j" The typical cumulative productivity at different mass flow rates on June 2, June 5 and June 7, 2015 has been measured with an interval of 60 min. It is depicted from the Figure freshwater productivity has a direct relation with mass flow rates and cumulative time. The maximum productivity at flow rates 0.0035 Kg/s, 0.0030 kg/s and 0.0025 Kg/s is observed as 2.70 l/m^2, 2.51 l/m^2 and 2.39 l/m^2 respectively. The curve for cumulative distillate is steeper during the mid-day than in the morning and evening. From 0 to 60min from start of experiment the productivity of the system the is almost negligible. Graph "k" shows the test for color and turbidity of water were also conducted and their results showed that the values were in the range of safe limit of drinking water as defined by international agencies for water quality standards. Results of every single parameter is compared with its standard value and lastly, it was concluded that the water sample fulfill the criteria of drinking water (portable water range = 6.5-8.5). Graph "l" The variation in the concentration of different water quality parameters with time (after 1 week and 15 days) and boiling of water is graphically represents in curve "l". From the graph, a comparison on the concentration of different water quality parameters at different point of time can be made to assess any change in water quality. Graph "m" shows the comparisons of initial investments of two different water desalination systems. The initial cost of RO membrane system is approx. PKR 20000 from the local market. As from the figure it is clear that solar desalination of water with DC pump forced circulation of have about 20% higher initial cost than other desalination system available in the local market i.e. RO membrane system. Graph "n" The life of the filters in RO system is 3 months which cost PKR 900 from the local market. The filters must be replaced 4 times in a year for the efficient operation of the system and this result to an increased operational cost of the RO system. The total operational cost of the solar desalination system and RO system (Curve "n"). Graph "o" indicated the comparison between the efficiencies of different desalination system in terms of water losses from the system. The losses from the solar desalination system were negligible because the system works on evaporation and condensation theory and all the vapors produced in the evaporation system remains in the system. The complete system is closed and do not allow any vapors to move out of the system. On the other hand, water losses from RO plant are noticeable with water cleaning efficiency of the system is about 70-80%, which means for every 1 liter of water input, 0.2 ml water is the water losses from membranes. The results demonstrate that the designed solar desalination system using heat recovery method has good performance in solar energy collection, saline water evaporation and heat recovery. The result shows the daily fresh water productivity can be reached up to 2.7 l/m^2 in months of summer season. The fresh water exhibits excellent results having EC 0.18 dScm^{-1}, pH 6.1, TDS 127 ppm, Na^+, Ca^{2+} and Mg^{2+} 0.53, 0.78 and 0.61 respectively. Lastly, the cost per liter of distilled water is estimated about PKR 2.81.The results showed that the solar desalination system is more cost effective as compared with other conventional systems.

Conclusions and Recommendations

The mass flow rate, inlet water temperature has a significant effect on efficiency and productivity of the desalination system. The increase in mass flow rate increases the productivity of the system at the same tilt angle of the collector. The productivity of the system depends upon all climatic factors, but solar radiation has greatest effect on fresh water productivity of the system. The water quality parameters (TDS, EC, pH, Ca^{2+}, Mg^{2+} and Na^+ etc.) were reduced to a level of safe limits as defined by World Health Organization (WHO) for drinking water quality standards. The daily productivity can reached up to 2.7 l/m^2 of solar collector area. It was also concluded that system is more cost effective as compared to other conventional desalination systems. The cost per liter of distilled water is PKR 2.81/m^2 (\$ 0.03/m^2 or £ 0.02/m^2). It is highly recommended that the similar studies conduct in future in behalf of Pakistan specially, in-order to produce the fresh/drinking/desalinated water at low potential costs and search the feasible alternatives of RO, EC.

Acknowledgements

This study was conducted in the favor of Pakistan for the estimation of desalination capacity per m^2 with cost. Faisalabad city is acknowledged for permission to carry out this study.

References

1. Attia AAA. Thermal analysis for system uses solar energy as a pressure source for reverse osmosis (RO) water desalination. Energy 2012; 86:2486-93.
2. Fritzmann C, Loewenberg J, Wintgens T, Melin T. State-of-the-art of reverse osmosis desalination. Desalination 2007; 216:1-76.
3. Kalogirou SA. Seawater desalination using renewable energy sources. Progress in Energy and Combustion Science 2005; 31:242-281.
4. Khayet M. Solar desalination by membrane distillation dispersion in energy consumption analysis and water production costs (a review).Desalination, 2012; 308(2):89-101.
5. El-Dessouky HT, Ettouney HM. Fundamentals of salt water desalination. Science 2002; 31:177-185
6. Garcia RL. Seawater desalination driven by renewable energies: a review. Desalination 2002; 143:103-13.
7. Nafey AS, Mohamad MA, El-Helaby SO, Sharaf MA. Theoretical and experimental study of a small unit for solar desalination using flashing process. Energy 2007; 48:528-53.
8. Nauman M. Development of locally fabricated flat plate collector (FPC) for energy production. A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Agricultural Engineering, Department of Farm Machinery and Power, University of Agriculture Faisalabad, Pakistan, 2014, 1-80.
9. Rabl A. Comparison of solar concentrators. Journal of Solar Energy 1976; 18:93-111.
10. Khalil MS, Khan NA, Mirza IA. Renewable energy in Pakistan: Status and trends. University of Engineering and Technology, Taxila, Pakistan, 2008.
11. Service RF. Desalination freshens up. Science 2006; 313:1088-90.
12. Scheffler W. Introduction to the revolutionary design of Scheffler reflectors, International Solar Cooker Conference, Granada, Spain, 2011.

Statement: I hereby confirm that this research paper is my own original work and I have cited all sources that were used. I again corroborate that the contents of this research "**The Desalination: Solar distillation of Water Using Heat Recovery Technique – New Methodology for Faisalabad, Pakistan"** are product of my own study in Faisalabad and no part has been copied from any published source (except the references, standard mathematical/genetic models/equations/formulae/protocols).

Biography of Author

Usman Iqbal is a Water Resources Engineer from Center of Excellence in Water Resources Engineering, University of Engineering & Technology Lahore, Pakistan. He received Master of Science in Water Resources Engineering (WRE) degree in 2013 from University of Engineering & Technology Lahore, Pakistan. He is an active member of Pakistan Engineering Council (PEC). His areas of expertise are Dam and Reservoir Engineering, Design of Hydraulic Structures, Solar Desalination of Ground Water using latest Desalination Technologies and he is always in search of innovative techniques regarding Solar Distillation in behalf of Pakistan. Now a day's Mr. Usman Iqbal is in try/ search of any Solar Technology which will alternative of Reverse Osmosis (RO) and similar processes in future. The Heat Recovery Technology was introduced on small scale by corresponding author in PKR 2.81/m^2 (with 2.71/m^2 capacity). If we increase the unit size upto 20-25 m^2 then we shall enhance the daily productivity using Heat Recovery Technique upto 54.2-67.75 capacity per 20-25 m^2. If Government of Pakistan or any other countries provide me funds in future then I shall provide more economical solutions in behalf of Pakistan and entire world may be solution of Brackish Ground Water, and problems concerning Dam's and Barrages etc.