A review on water cooling techniques for solar panels

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Abstract: Renewable energy sources are the most useful way to generate clean energy and guide the transition toward green power generation and a low-carbon economy. Among Renewables, the best alternative to electricity generation from fossil fuels is solar energy because it is the most abundant and does not release pollutants during conversion processes. Despite the photovoltaic (PV) module ability to produce electricity in an eco-friendly way, PV cells are extremely sensitive to temperature increments. This can result in efficiency drop of 0.25%/°C to 0.5%/°C. To overcome this issue, manufacturers and researchers are devoted to the improvement of PV cell efficiency by decreasing operating temperature. This paper highlights different water cooling techniques to reduce the operating temperature of the PV cells. This review paper focuses on the improvement of the performance of the small domestic use PV systems by keeping the temperature of the cells as low as possible and uniform.

***Index Terms* - Efficiency, PV module, Temperature, Water Cooling .**

I. INTRODUCTION

The renewable energy use becomes more popular during the increase of human population and the environmental issues. Among the 13,511.2 Mtoe (Millions of tonnes of oil equivalent) consumed around the world, about 85% came from fossil fuels. Thus, the world's primary energy consumption is still covered by non-renewable sources. Clearly, this is a slightly Lower value compared to 2005, when it stood at 92%, but is still very high because, In 2017, oil, coal, and natural gas contributed for 34.2%, 27.6%, and 23.4%, respectively, of the world's primary energy consumption [1]. Regarding other sources, nuclear energy stood at 4.4%, while renewable energy sources (RES) reached 10.4%: 6.8% from hydro-electricity and 3.6% from other Renewables, where wind and solar represented only 0.6% and 1.9%, respectively [1] .The solar energy is one of the important type of the renewable energy sources that has attracted many researchers around the world to work on.

There are two types of energy that can be produced from the solar energy: electrical energy and thermal energy. One of the most widespread technologies of renewable energy generation is the use of photovoltaic (PV) systems which convert sunlight to into usable electrical energy. This type of renewable energy technology which is pollutant free during operation, diminishes global warming issues, lowers operational cost, and offers minimal maintenance and highest power density compared to the other renewable energy technologies, highlights the advantages of solar photovoltaic (PV) energy. Apart from the several advantages displayed by the PV technology, this conversion system does have some general problems, such as hail, dust and surface operating temperature which can negatively affect the efficiency of the conversion system . PV cell performance is very much sensitive to cell surface temperature. This temperature is influenced by weather parameters like ambient temperature, wind velocity, humidity, solar irradiance, cell structure and material [2].

II. CLASSIFICATION

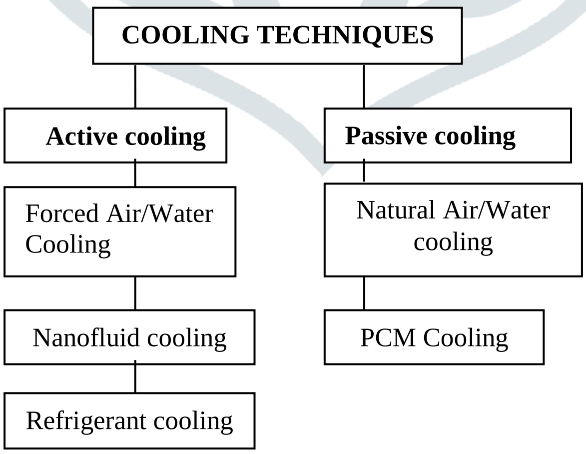

Fig. 1:- Classification of cooling techniques.

Various technologies can be used to achieve cooling of PV systems such as liquid based, Air-based, heat pipe based, PCM-based (Phase change Materials). However, the cooling technique is dependent on several factors such as, type of photovoltaic technology used, types of photovoltaic geometries and weather conditions (place) at which the system is installed [3]. In cooling systems, the cooling techniques have been classified as-

(1) Active cooling system.
(2) Passive cooling system.

Passive cooling system refers to technologies which reduces the temperature of PV module by absorbing heat from it without additional power consumption. On the other hand, active cooling systems include of heat extraction utilizing devices such as fans to force air or pump water to the panels to extract away the heat .These systems are powered using energy to affect some kind of heat transfer usually by convection and conduction. Active cooling methods are generally more effective and also more costly. For both passive and active cooling systems the commonly used cooling mediums are air and water. Air cooling is not well suited to the extraction of thermal energy from the PV absorber at hot regions. Water cooling on the other hand, permits operation at much higher temperature levels and allows waste heat recovery to be employed more efficiently [4]. Hence, Water cooling is more favourable option in many cases.

2.1 Active Water Cooling Techniques

Several studies have investigated experimentally the performance of the PV cells with active cooling water. In the present work, the authors present a set of experimental measurements devoted to selecting the PV cooling arrangement that guarantees the best compromise of water-film uniformity, module temperature reduction, water-consumption minimization, and module power production maximization. Alberto Benato and Anna Stoppato[1] have experimented that a cooling system equipped with 3 nozzles characterized by a spraying angle of 90°. Working with an inlet pressure of 1.5 bar, and which remains active for 30 s and is switched off for 120 s, can reduce module temperature by 28 °C and improve the module efficiency from 12.2% to 13.9%.To simulate the solar radiation, two halogen lamps characterized by a design power of 1000W, a lumen output of 33,000 lumen, and a colour temperature of 3350 K, are installed over the PV module at a distance of 1 m each. They performed experimental measurements on different days of the year under Padova's climate conditions, and solar irradiance showed that adopting two lamps guarantees a realistic simulation of outdoor conditions in the laboratory test facility. .In addition, cost per single module of the cooling system was only 15 € [1].Their hydraulic water circuit is shown in fig. 2.

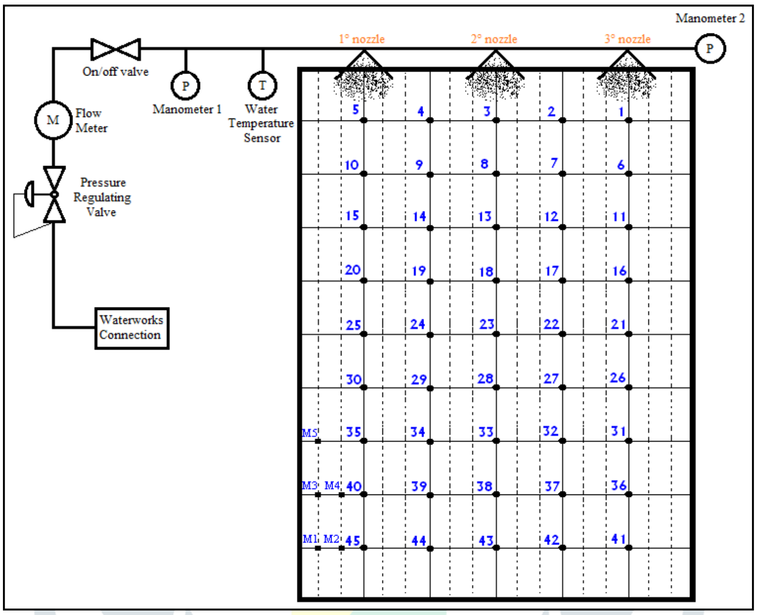

Fig. 2 **:-** Hydraulic water circuit and thermocouples position on the PV module.[1]

Numbers refer to thermocouple name and position on the PV module. This type of cooling system can be easily applied to floating PV installations because, in that case, the water consumption is not an issue since PV modules are located on lake, sea, or river surface. The cooling water is sucked from, e.g., the lake and, after it cools the module, it returns to the lake. No water is wasted**.** K. A. Moharram et al. [5] developed a heating rate and cooling rate models to predict the commencement of cooling of solar module by water cooling and the duration for which the water was sprayed in order to enhance the performance of the PV module and also to reduce the amount of cooling water and electrical energy needed to provide cooling. The heating model determines the maximum allowable temperature (MAT) at which the water to be sprayed to cool the solar PV module. They found from the mathematical model that the heating rate of the solar cells was 6 °C/h and the cooling rate of the solar cells was 2 °C/min for the water flow of 29 l/min. The experimental setup used six mono- crystalline module of power output 185W each and 120 water nozzles to spray water over the front surface of the module and found that the cooling rate were 2.05 °C/min. They also observed that without cooling the temperature was increased from 35 °C to 45 °C and the efficiency dropped from 12% to 10.5%. The cooling process was repeated each 15 min, approximately, where the cooling period of the photovoltaic cells was 5 min each time. The proposed cooling system reduced the operating temperature by 10 °C in 5 min and increased the solar module efficiency by 12.5%. The PV panels yields the highest output energy if cooling of the panels starts when the temperature of the PV panels reaches the maximum allowable temperature (MAT), i.e., 45 °C. The MAT is a compromise temperature between the output energy from the PV panels and the energy needed for cooling. The experimental setup is shown in fig. 3. It is expected that as the MAT value increases, the rate of water evaporation during the cooling operation will increase, and thus, more water consumption will be needed.

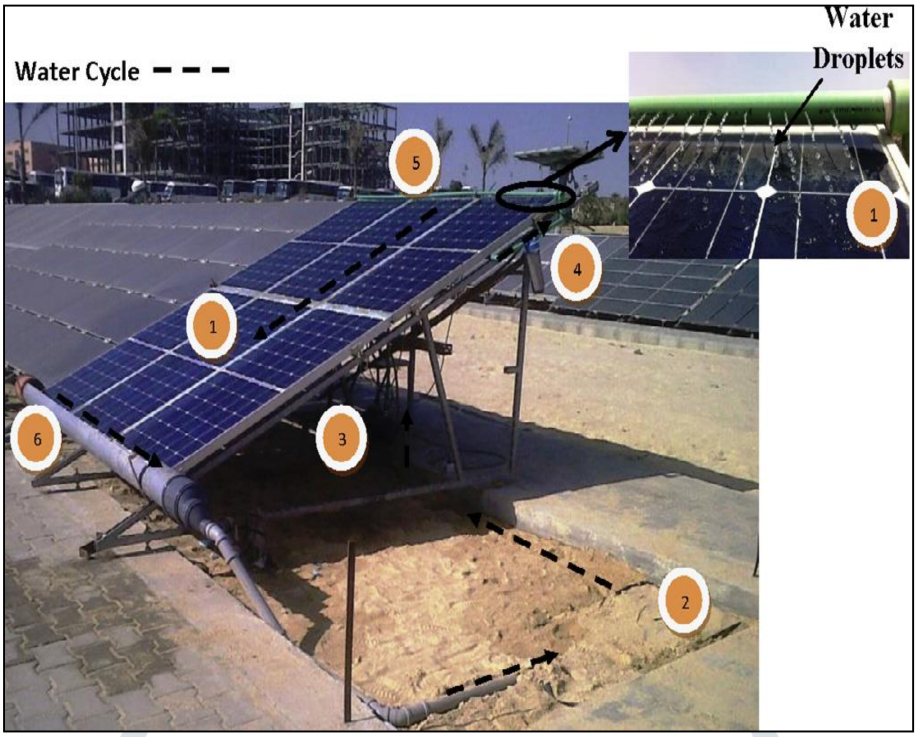

Fig. 3:- Experimental setup 1 – PV module, 2 – tank, 3 – pump,4 – filter, 5 – nozzle and 6 – drain pipe.[5]

In Fig. 4, the net output energy as the function of maximum allowable pressure is shown. A cooling model has been developed to determine how long it takes to cool down the PV panels to its normal operating temperature, i.e., 35 °C, based on the proposed cooling system. Both models, the heating rate model and the cooling rate model, are validated experimentally. It is concluded that the optimum MAT is 45 °C, which yields the highest output energy.

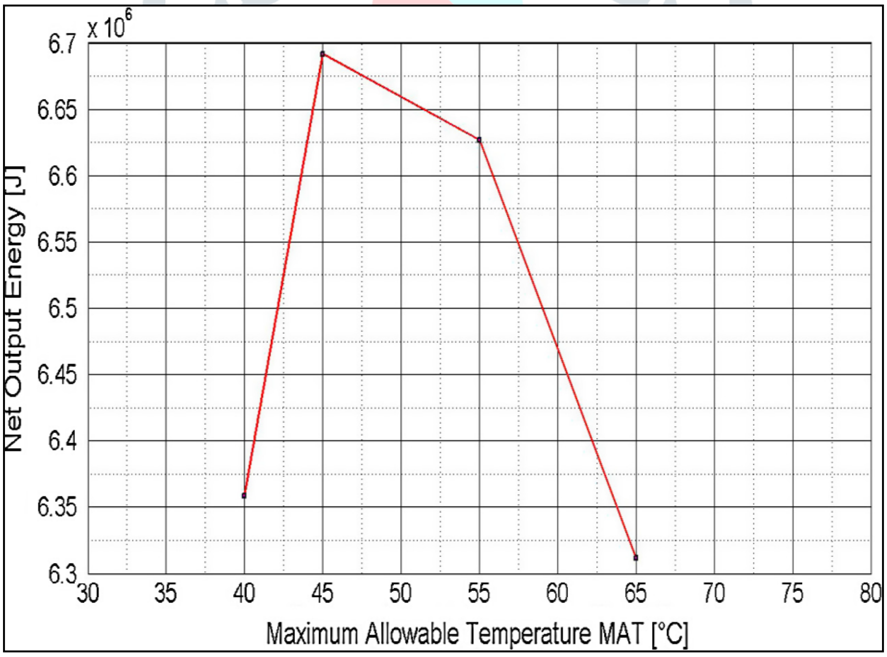

Fig. 4 :-The net output energy of the PV panel as a function of the maximum allowable temperature (MAT) [5].

It can be concluded that this system is suitable for photovoltaic stations installed in deserts. Calebe A. Matias et. al.[6] developed system which enables the application of reuse water flow, at ambient temperature, over the front surface of photovoltaic (PV) panel and is composed of an inclined plane support, a perforated aluminium profile and a water gutter. A luminaire was specially developed to simulate the solar radiation over the module under test in a closed room, free from the influence of external climatic conditions, to carry out the repetition of the experiment in controlled situations.

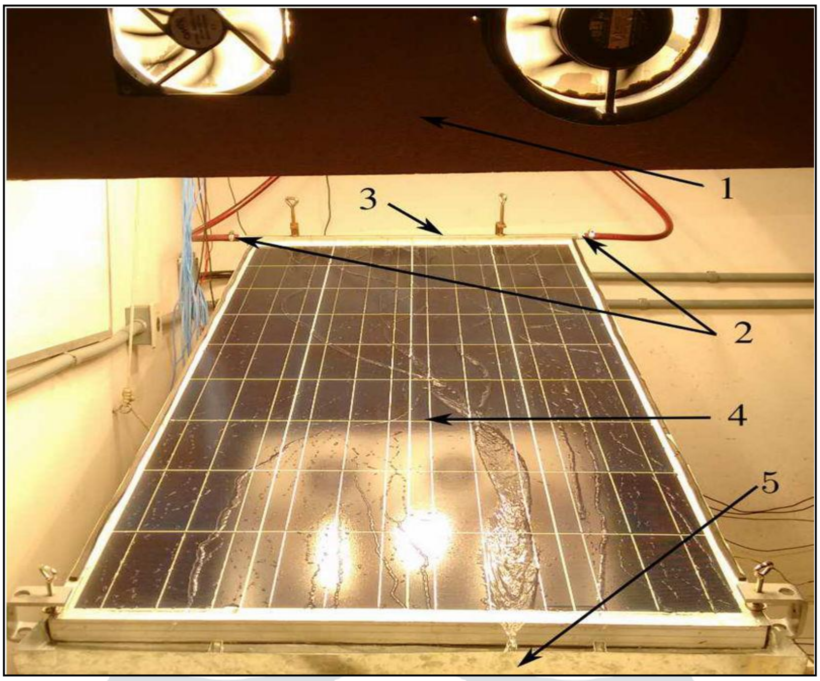

Fig. 5:- It shows the apparatus developed, where: 1 is the built luminaries capable of simulating solar radiation, 2 is the water inlet, 3 is the perforated metal profile for distribution of water over the module, 4 is the PV module and 5 is the water outlet gutter [6].

The best ratio was flow of 0.6 L/min and net energy of 77.41Wh. Gain of 22.69% compared to the panel without the cooling system [3].The results show that the water distribution system, under the PV panel can be improved to optimize the efficiency of the water flow used. Another specific experimental setup was elaborated in detail and the developed cooling system for the PV panel was tested by S. Nizˇetic´ et. al. [7].

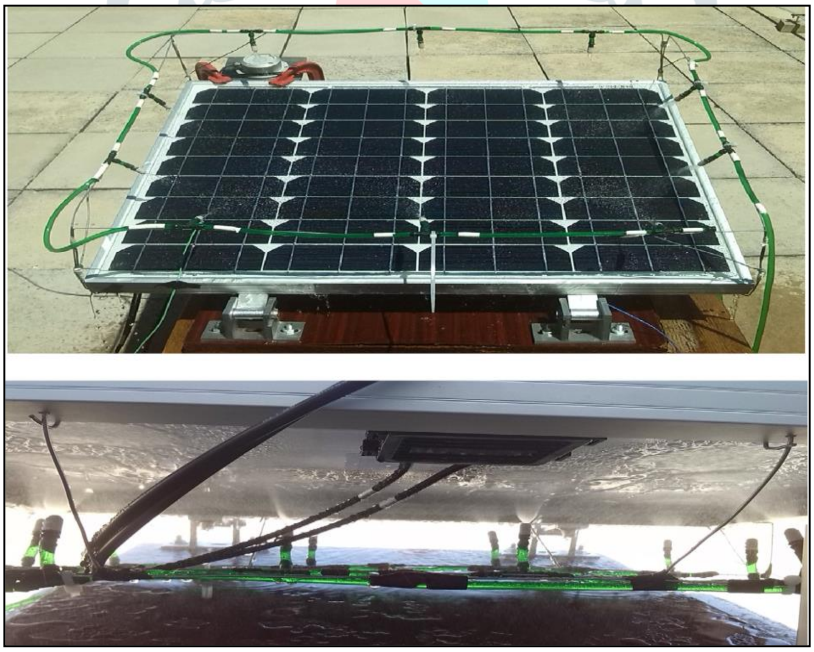

Fig. 6:- The front and backside of the PV panel with the specific water nozzle system.[7]

The setup of front and back cooling of PV panel by water nozzle is shown in fig. 6. They have used small diameter pipes and water nozzle. The experimental result shows that it is possible to achieve a maximal total increase of 16.3% (effective 7.7%) in electric power output and a total increase of 14.1% (effective 5.9%) in PV panel electrical efficiency. it was also possible to decrease panel temperature from an average 54 °C (non-cooled PV panel) to 24 °C in the case of simultaneous front and backside PV panel cooling. Fabio Schiro et. al. [8] developed Steady state model and PV dynamic model of water cooling on front side. The Schematic diagram of PV panel energy balance is shown in fig. 7. The water film cooling and the spray cooling methods have been considered and implemented.

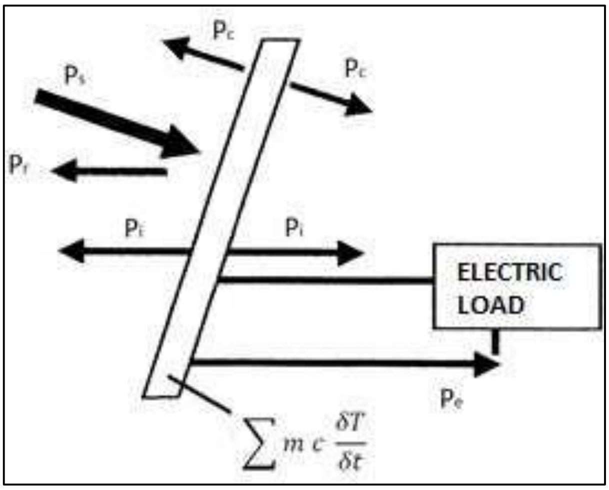

Fig. 7:- Schematic of the PV panel energy balance [8].

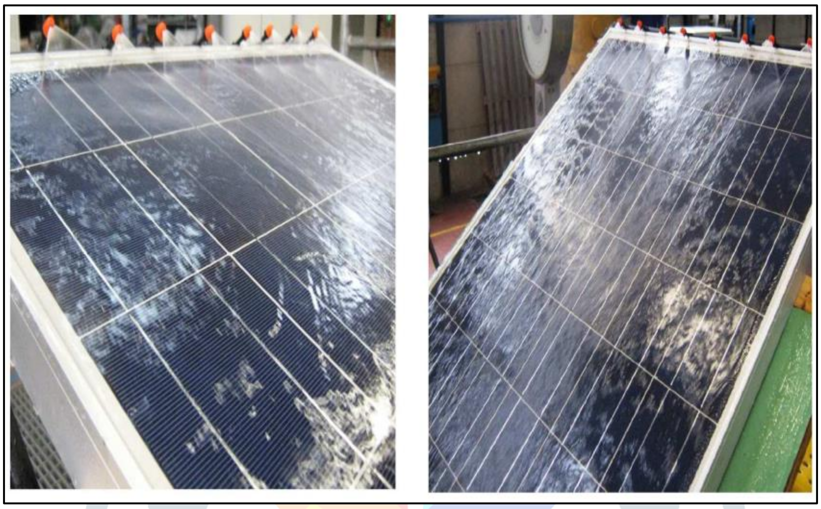

Fig. 8:- Best result obtained in terms of water film uniformity. Total water flow rate 0.09 l/(s m^2) [8].

A test rig has been set up to verify the mathematical models results which are shown in fig. 8. An economic analysis has been performed to evaluate the PV cooling feasibility. The Comparison of cell temperatures of conventional PV panel and PV Panel with water flow is shown in fig. 9. The Authors struggled against a strong non-uniformity of water flow over the surface when approaching the experimental tests. This is the reason why the validation of numerical results is not yet complete, and in this paper only the actions taken to improve uniformity are described. Stefan Krauter [9] investigated experimentally the impact of water between glass (n_{glass}=1.5) and air (n_{air}=1.0)in PV Panel. In addition to help keeping the surface clean, water reduces reflection by 2–3.6%, decreases cell temperatures up to 22˚C. The Comparison of cell temperatures of a conventional PV module vs. a PV module with water flow and comparison of photovoltaic conversion efficiencies is shown in fig. 9 and fig. 10.

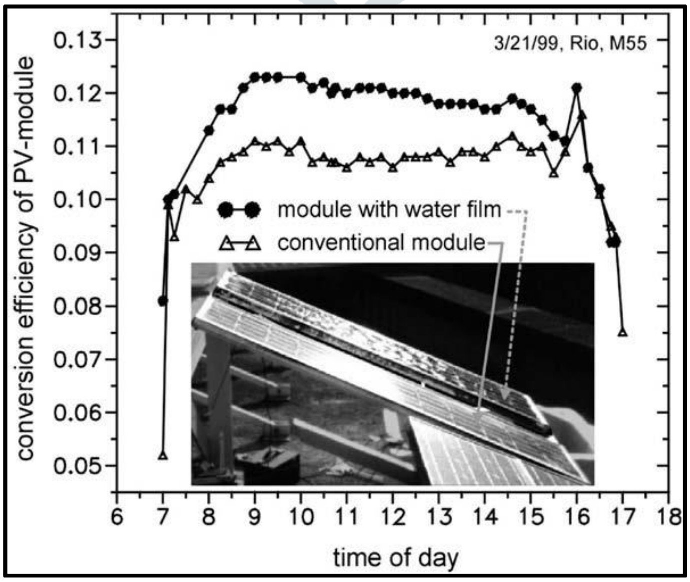

Fig. 9:- Comparison of cell temperatures of a conventional PV module vs. a PV module with water flow. [9]

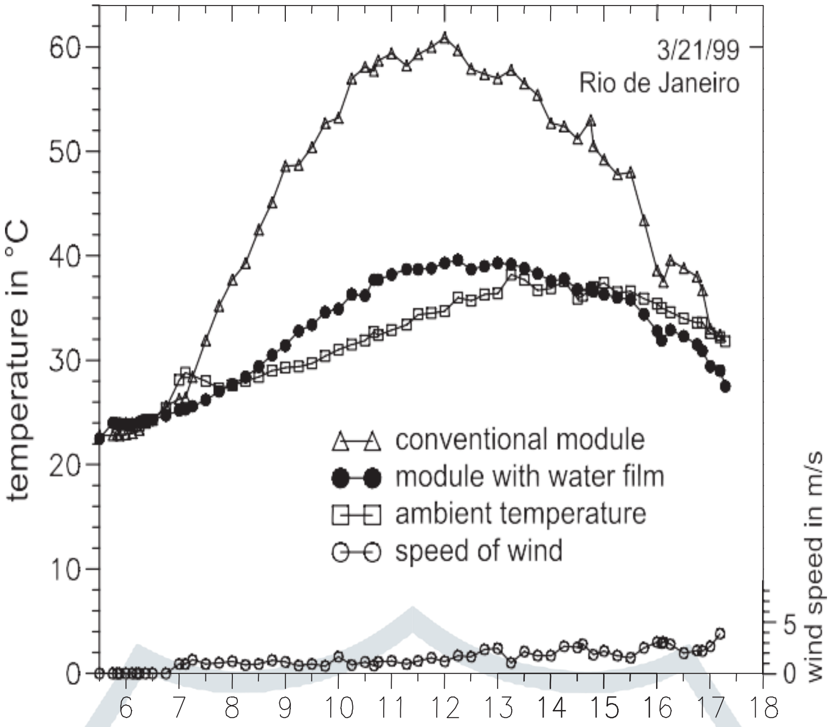

Fig. 10:- Comparison of photovoltaic conversion efficiencies of the PV-modules.[9]

The electrical yield can return a surplus of 10.3%; a net-gain of 8–9% can be achieved even when accounting for power needed to run the pump. Y.M.Irwan et. al. [10] investigated indoor experiment of water cooling. The experimental setup is shown in fig. 11.

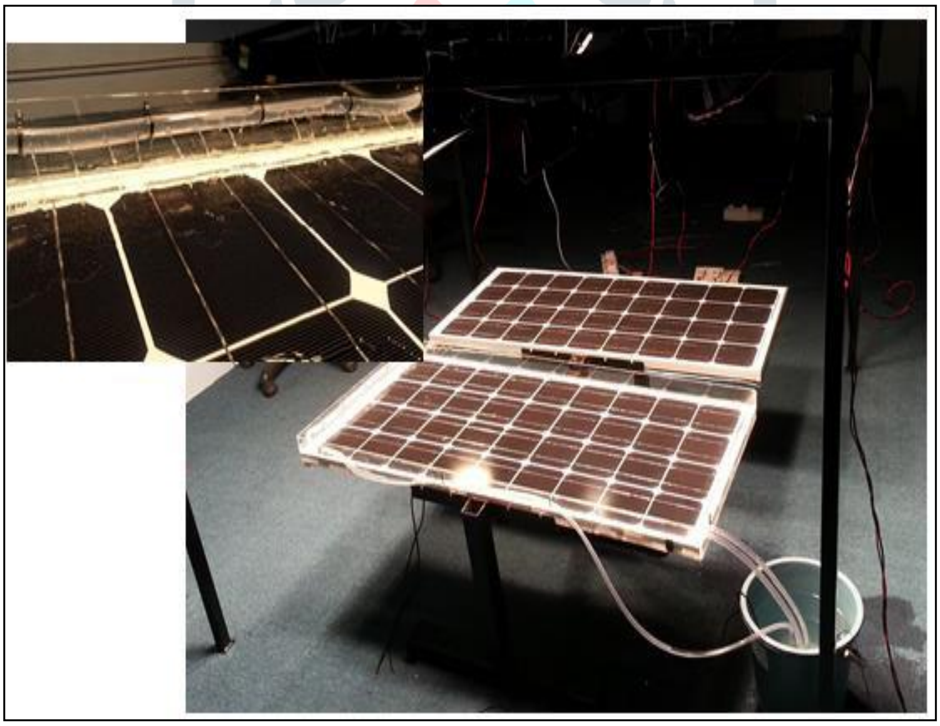

Fig. 11:- PV panel with and without water cooling mechanism by using solar simulator.[10]

The solar simulator was set upon a steel frame used to lift all the halogen lamp bulbs. The halogen lamp bulbs act as a natural sunlight. Four sets of average solar radiation at the test surface of the solar simulator measured as 413, 620, 821 and 1016 W/m².A DC water pump used to overcome the problem of low efficiency of PV panel with water flow over the front surface of PV panel. The experimental results mentioned that the decrement of operating temperature is around 5 - 23 ˚C increase the power output of the PV panel with a water cooling mechanism by 9 - 22 % as shown in fig. 12.

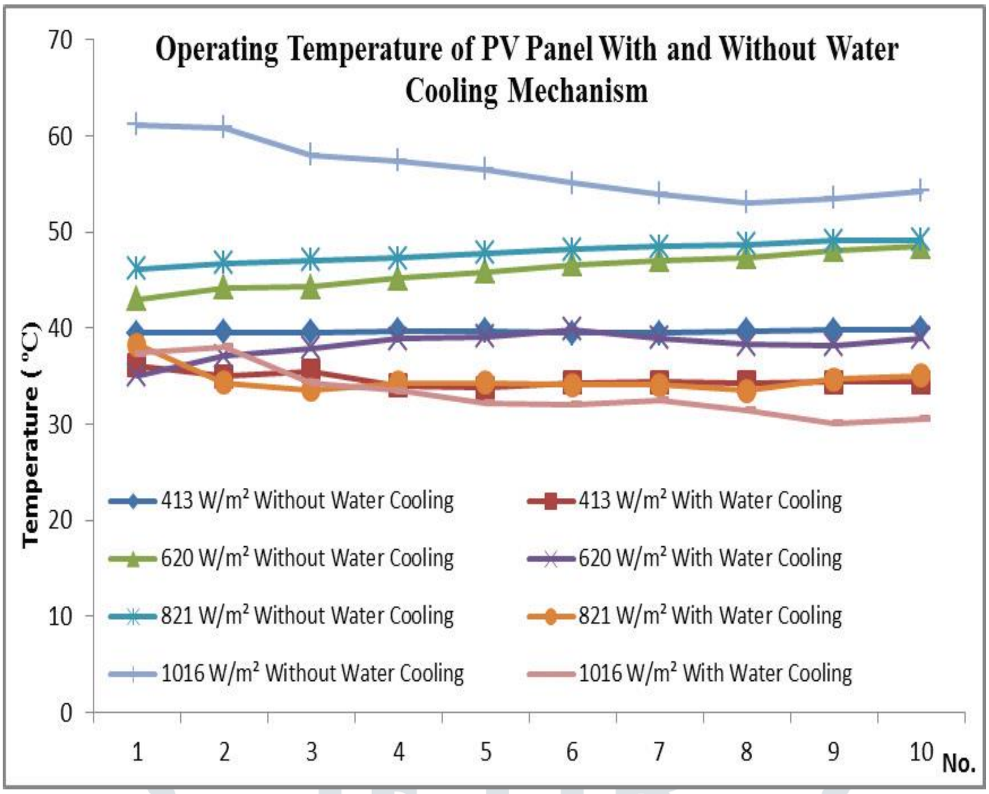

Fig.12:- Operating temperature of PV panel with and without water cooling mechanism.[10]

On other hand, Zeyad A. Haidar et al.[14] developed the theoretical model based on the heat and mass transfer occurring in the Vicinity of the bottom side of a solar PV panel . A schematic diagram for the PV panel with evaporative cooling is shown in fig.13. The model incorporates the heat and mass exchange occurring between a layer of water and ambient air as well as the heat transfer with the PV panel.

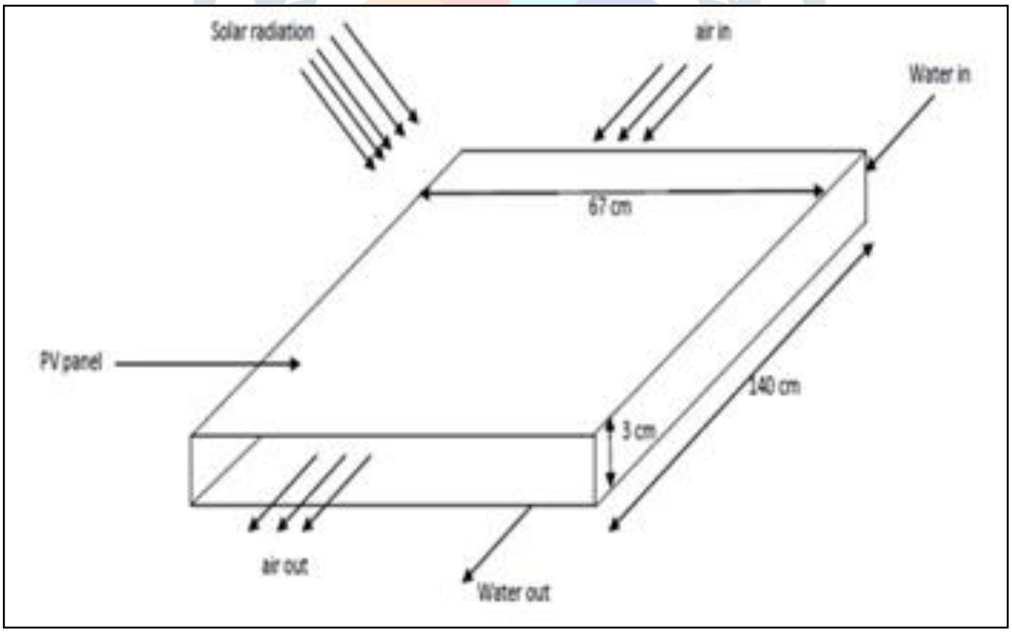

Fig. 13:- A schematic diagram for the PV panel with evaporative cooling.[14]

Air is blown inside the duct via a fan in same direction of water flow (co-current configuration). The model based on mass and energy balances was used to investigate the effect of solar radiation intensity, inlet water and air temperatures on the PV panel temperature. Change in water temperature is very small. Inlet air temperature has an important influence on the temperature of the PV panel. The obtained results show the effect of some geometrical parameters as well as the air flow rate, temperature and humidity on the cooling process. It was found in particular that when the air inlet temperature decreases, the temperature of the PV panel decreases significantly. A reduction in PV panel temperature of about 6 °C has been obtained when cooling is used.

2.2 Passive Water Cooling Techniques:-

The study on enhancing the efficiency of solar panel is very necessary. Free flow front water cooling of PV panels can improve the efficiency and reliability of photovoltaic energy conversion**.** Nair Milind et al. [11] have rectified the free flow front water cooling system. Their setup is shown in fig. 14.

Fig. 14:- With free front flow cooling [12].

The cooling system consist of a ¾ inch polyvinylchloride (PVC) pipe of length 27 inches, ball valve of ¾ inch, hose nipple for connecting the garden hose to the ball valve, for collecting water a 4-inch pipe of length 27 inch and its stopper is used. The flow of the water was controlled by using the ball valve. Holes were drilled in the ¾ inch pipe so as to accommodate the flow of water uniformly over the surface of the panel. The readings of voltage and current where taken, during the same time period (11:00am to 2:00pm) for five days and average of those readings were taken. There is an average increase in power of about 14.15%. Another passive cooling system was designed and fabricated by Malagouda Patil et al.[12].The system setup is shown in fig. 15. The experiment was investigated according to the meteorological conditions of Belgaum (latitude of 15.8497° N; longitude of 74.4977ºE) in India from 09.00 a.m. in the morning to 5.00 p.m. in the evening. Water is used as a coolant in the investigation, voltage (Voc), current (Isc), solar radiation (G) and power output of solar PV system were measured every one hour for both normal solar PV and water cooled solar PV systems. The passive water-cooled solar PV system was fabricated using 110W monocrystalline silicon and amorphous (Thin) silicon solar panel. The area of the panel was 0.8905m^2. The maximum output voltage and current are respectively 17 V, 6.5A and with a maximum power output of 110W. One of the panels is used to set up water cooling system. The cooling water was supplied uniformly on the back surface of PV panel for homogeneous cooling of the panel as shown in Fig.15. Without a cooling system, the average cell temperature reaches to 60°C, and the solar panel efficiency reduced to 8 to 16%.

Fig. 15:- Experimental Setup.

However, when the panel was operated under the passive water system, the temperature of the PV cell was reduced to 47°C, resulting in a 10% - 21% improve in the solar PV cell efficiency. Both systems, without cooling and with cooling systems are validated experimentally. Water immersion cooling technique was used by Saurabh Mehrotra et al. [17]. The Water immersion cooling setup is shown in fig. 16. Solar cell immersed in water was monitored under real climatic conditions; cell surface temperature can be controlled from 31°C-39°C.

Fig 16:- Panel immersed in water[17].

Electrical performance of cell increases up to great extent. Results show that, panel efficiency has increased about 17.8% at water depth 1cm.Another experiment with water immersion cooling investigated by Sayran A. Abdulgafar et al.[25]. Experiment was done for polycrystalline silicon panel. A sizeable increase of electric power output is found for shallow distillate water.

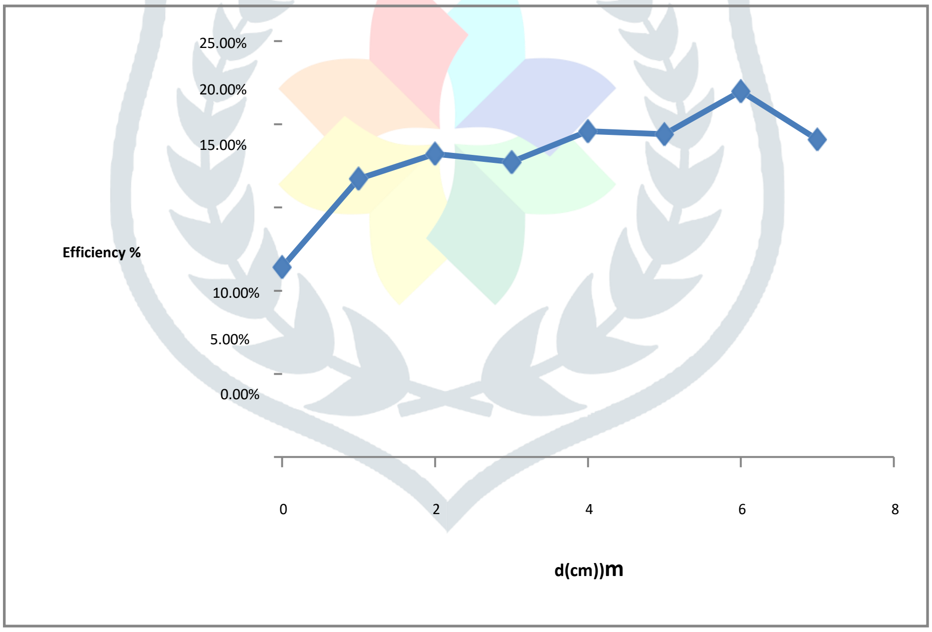

Fig. 17: The Relative Efficiency of PV panel as a function of water depth [25].

It was found that when the depth of water is more than 6 cm, the efficiency for the PV panel started to decrease. The repeal of thermal drift increases the solar panel efficiency by about 11% at water depth 6 cm. A passive thermal regulation technique with fins in conjunction with cotton wicks is developed in the present work for controlling the temperature of PV module during its operation[10]. Experiments were conducted by M. Chandrasekar et al.[13] with the developed technique in the location of Tiruchirappalli (78.6°E and 10.8°N), Tamil Nadu, India with flat 25 WP PV module and its viability was confirmed. Their setup is shown in fig. 18.

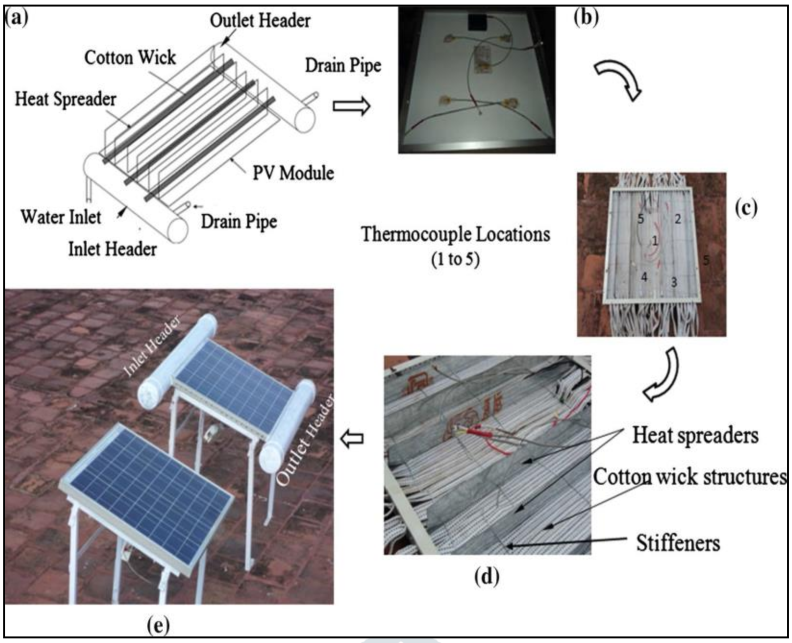

Fig.18:- Photographic view of the experimental PV module with stages of fabrication. **a)** Desired rear side of PV module **b)** location of thermocouples **c)** fins in conjunction with wick structures **d)** details of the stiffeners and **e** final fabricated experimental setup with headers.[13]

Three aluminum fins (630 × 100 × 60 mm) of 2 mm thick were fabricated in-house and screwed to the photovoltaic modules. A commercial grade thermal interface material was used to avoid air gap between the panel surface and fins. Flat cotton wicks of 12 mm width and 2 mm thick that are commonly used for lamps and lanterns were positioned to the base of the fins with their free ends dipped in water that is stored in the headers. The cotton wick are about 0.355 ± 0.0029 mm with a porosity of 0.8 and water permeability of 42.03 % used in experiment. PVC pipes (100 mm diameter) were used as headers in which a rectangular slot (57 × 35 mm) was cut on the surface on the longitudinal direction for the insertion of the ends of the PV panel and the wicks. The average of the best results observed on consecutive 3 days is reported in their paper. The PV module temperature got reduced by 12 % while the electrical yield is increased by 14 % with the help of the developed cooling system. Another work of Zeyad A. Haidar et al.[14] presented the results of an experimental study on the effect of cooling of solar photovoltaic (PV) panels by evaporative cooling. Figure 19 shows the back side of the cooled panel. A piece of cloth was attached directly to the back surface of the cooled PV panel and water from a tank was allowed to flow and wet this cloth using rubber pipes attached to the panel back surface. The back surface of a PV panel was wetted and exposed to surrounding. Aluminium bars were used to support and fix the pipes on the cloth. Water was supplied to the back of the PV panel from a tank by gravity.

Fig. 19:- The configuration of cloth and pipes on the back of the cooled PV panel.[14]

A series of experiments were conducted and analyzed. More than 20 °C reduction in PV panel temperature and around 14% increment in electrical power generation efficiency were achieved compared with a referent PV panel. One of the major disadvantages of the evaporative cooling method is related to the water consumption.

III. CONCLUSION:-

Active Cooling methods:-

- While reviewing the cooling techniques water based cooling system was found to be the most efficient. The operating temperature plays a most important role in the photovoltaic conversion process. Various methods can be used to achieve cooling for PV systems.
- PV module with water flow show lower module temperature than that without water flow leading to higher electrical efficiency. Loss of efficiency due to a raised temperature of PV panel can be reduced by heat removal from the front surface into the water spray across the cells which absorb the heat generated by the cells during the day.
- Different cooling techniques have been examined and compared. It was shown that active cooling techniques, as expected, have higher efficiency than passive ones. In several cases, however, passive cooling can replace active cooling, in order to save the installation costs. Also, when pumping costs are taken into account, especially for back side cooling, passive techniques can sometimes yield more power gain than active ones.
- Here is the comparison of temperature drops achieved by different researchers who used active water front flow method for cooling of panel in figure 20.
- Different back cooling methods also used by researchers. The comparison of temperature Drops shown in figure 21.

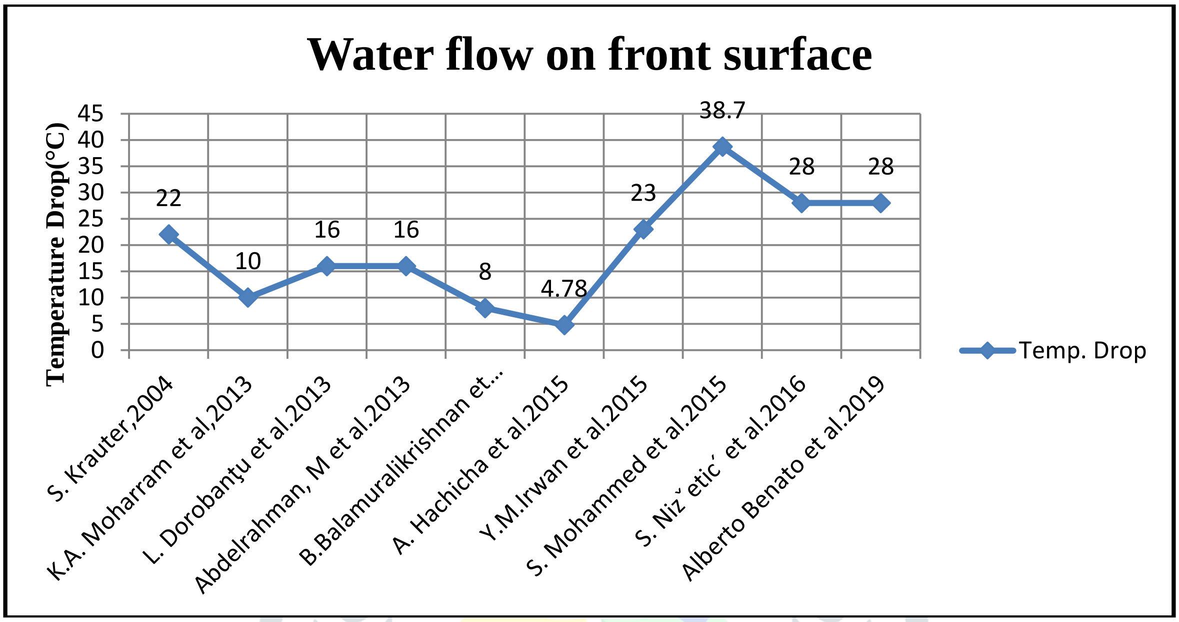

Fig. 20:- Temp. Drops achieved in different researches (Front water flow)

- By these comparisons we can say that Front water cooling is more effective than back cooling.
- The Highest Temp. Drop achieved is 38.7°C by front cooling while for back cooling is 22.3°C.

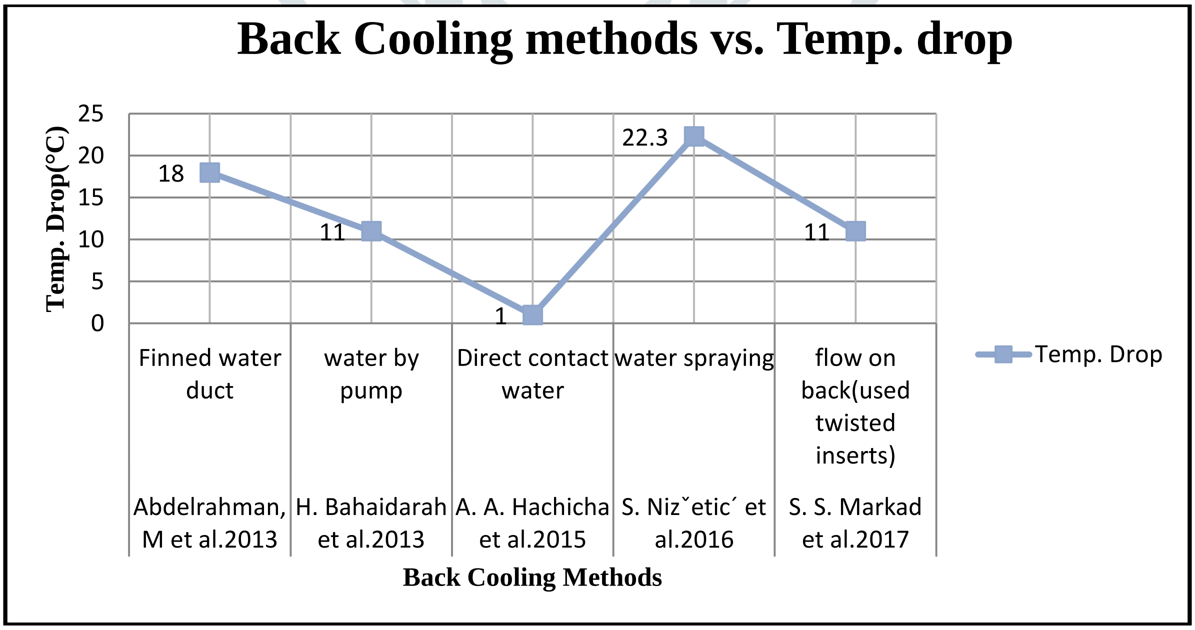

Fig. 21:- Temp. Drops achieved by different back water cooling methods in different research works.

- The increased efficiencies achieved by different researchers using front water flow are shown in fig. 22.
- The maximum percentage increase in efficiency is 14% achieved.

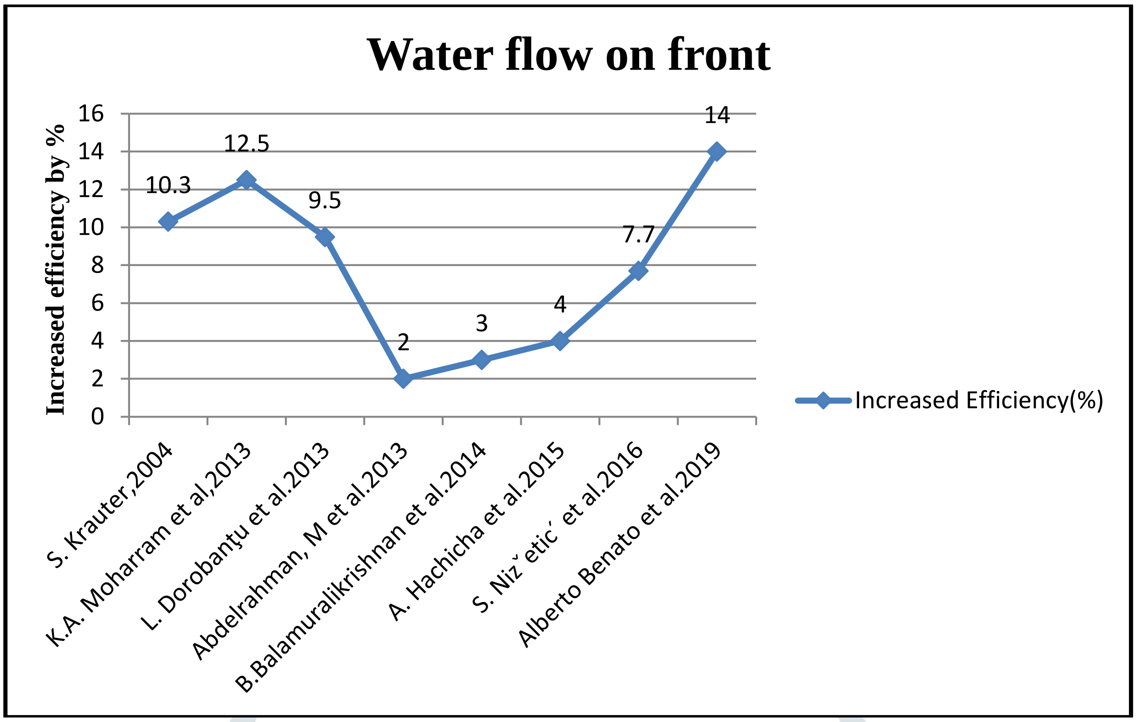

Fig. 22:- Efficiency increased by front water flow in different researches.

Passive water Cooling:-

- Passive cooling method is found more favourable in some situations because there is no external power or source is used.
- As you can see in figure 23, Effective Temperature Drops can be achieved by flowing water freely without using any pumps.

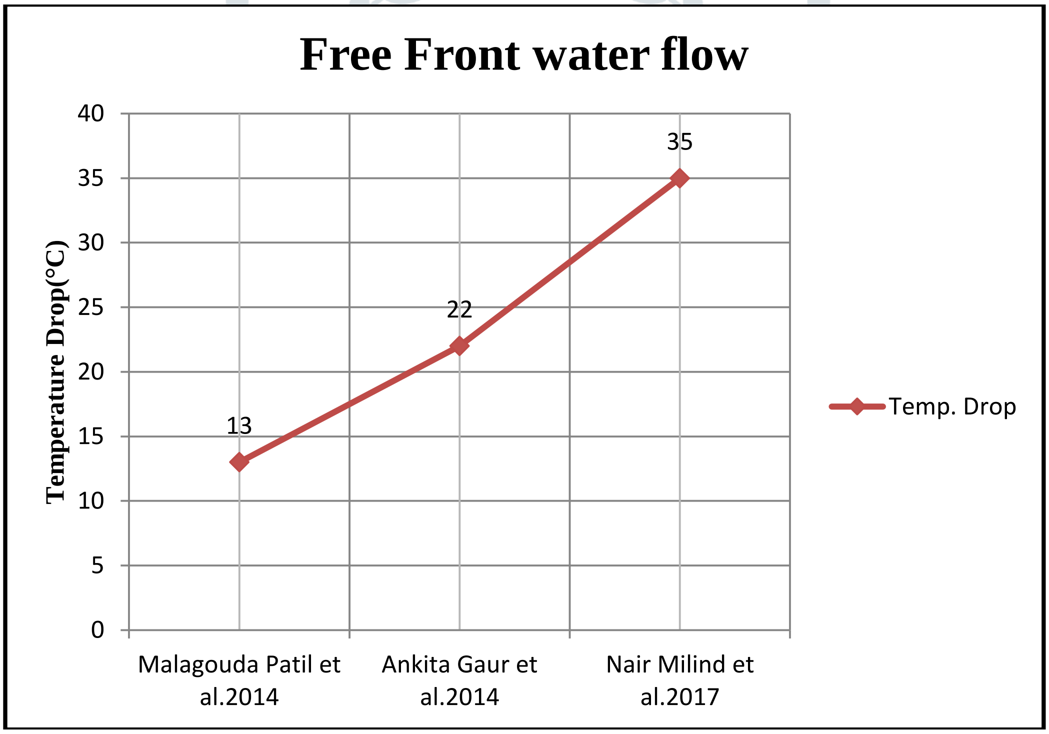

Fig. 23:- Free Front water flow (Temp. Drop °C).

- From Comparison we can see that highest Temp. Drop achieved is 35°C by free front water flow.
- Even Water immersion method found to be one of the most useful passive methods for increasing the efficiency.
- The efficiency increased using this method by researchers is shown in fig. 24.
- The maximum percentage increase of 17.8% is achieved, which is even higher than using active cooling techniques. So it is the most effective passive method for cooling.

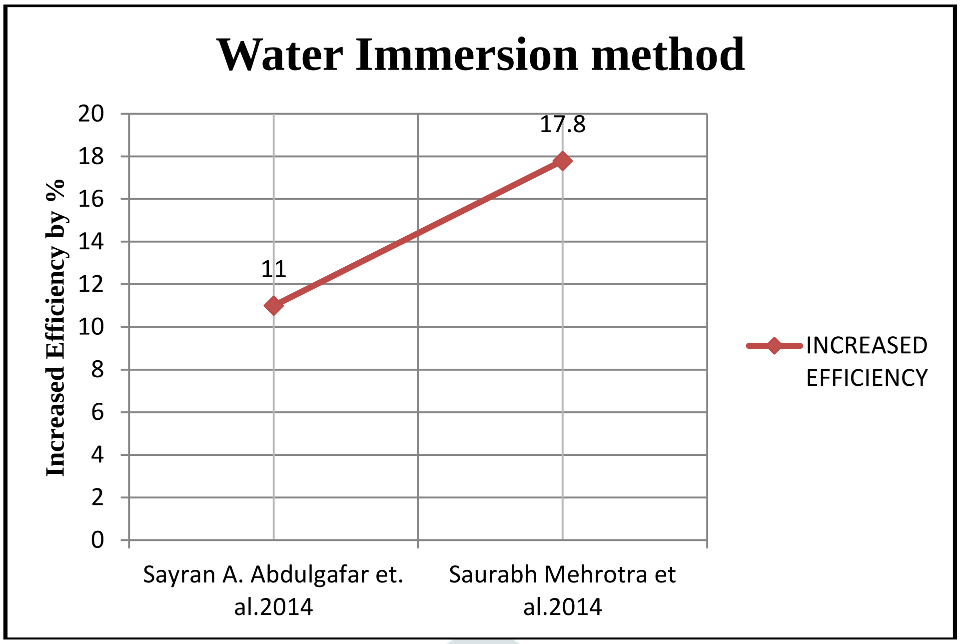

Fig. 24:- Efficiency increased by water immersion method in different researches.

IV. Acknowledgment

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