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DESIGN, INSTALLATION AND EVALUATION OF SOLAR DRIP IRRIGATION SYSTEM AT MINI DAM COMMAND AREA

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For Agricultural development and strong economy of the country, three important factors Land, Energy and Water play an important role. It is necessary to replace the traditional sources of energy with solar power and conventional methods of irrigation with High Efficiency Irrigation Systems (HEIS) to achieve the challenges of agriculture in future. A study was conducted with the objective to install and evaluate the solar operated drip irrigation system in arid zone of Punjab, Pakistan. The performance, efficiency and distribution uniformity of the system was evaluated. An economic analysis was also made to compare the solar operated with the diesel engine operated drip irrigation system. The range of average discharge values of drip was between 0.0083-0.00856m^3/hr (8.3-8.56lph) at different pressures. For 0.0083m^3/hr discharge, the emission uniformity was between 85-90%, application uniformity was 98-99% and distribution uniformity was 99% at different pressures (kPa). It was found that solar power unit was more efficient, energy saving and economical. The operational cost of the unit was also very low as compared to diesel system while the initial installation cost of solar operational system was high.

Keywords: Solar system, drip irrigation system, application uniformity, water distribution efficiency

INTRODUCTION

Water is one of the important lives saving element on the earth. Every living thing needs water for its survival. The increased allocations of surface and groundwater for domestic, industrial and agricultural sectors are leading to pressure on water resources and also on the environment. The increasing demands of water brought stress on fresh water resources and profligate use, as well as on the growing pollution worldwide (Anonymous, 2010).

Pakistan has one of the world best irrigation system, but there is still water shortage in every part of the country. Average annual rainfall is less than the total crop water requirement, so surface water is not enough to fulfill the requirements in agriculture sector. To overcome water shortage more than one million tubewells have been installed in the country, out of which 83% are diesel operated and remaining by electricity (Qureshi *et al.,* 2011). In Pakistan, water shortage is a big challenge along with water wastage through inefficient irrigation system, which ultimately leads less crop water productivity (Kim and Evans, 2009).

The pressurized irrigation system (drip irrigation system) is one of the options to get the high water use efficiency and to get more crops per drop. Drip irrigation, is a remarkable water technology, established about two decades ago (Shyamaa *et al.* 2009; Kang *et al.* 2000). In drip irrigation system, soil moisture is maintained around the plants in growing period, which results in an increase in production and growth because the plants are not under wet or dry stress as in other irrigation methods. With the help of this technology, serious problem related to water has been resolved, and additionally it improved the farm output by increasing income and reducing cost (Bisconer, 2008; Dursun and Ozden, 2012).

The increasing prices of petroleum and current breakdown of electricity is the main dispute to adopt efficient irrigation system in Pakistan. The shortfall of electricity in the Pakistan, in May-2011 was near about 7000mega-watt (MW) reported by the Pakistan Electric Power Company. Pakistan is an agriculture based country and its rural areas are in severe electricity shortfall. The main use of electricity is to pump water for the agriculture use and there is unscheduled load shedding in the rural areas, which has totally turned down its agriculture system. The excessive load shedding in rural areas has also dropped down the yield of the crops per year. Power experts suggested that there might be more energy crises in the country in next two years (Faheem and Mir, 2009).

Drip irrigation users need an alternate to traditional energy possibility, which may be solar, wind, bio-mass, hydral and geothermal sources. Solar energy (photovoltaic) is one of the major focuses as a renewable energy source in the world. Photovoltaic (PV) is a technique in which sun energy is directly converted to the electric power with the PV cells. A set of cells in form of PV Panels are reliable energy source with about 20-25 years life span in all weather conditions. It was estimated that Pakistan received about 16-17mega-joule per square meter (MJ/m^2) of solar radiation in a year, which was the best solution of the era to overcome the electric shortfall (Anonymous, 2008).

In last two decades, PV water pumping has become a widely adopted solar energy technology. PV water pumping system has been measured as attractive resource of providing water in distant locations since the majority of global rural population lives in sunny tropical or sub-tropical regions. PV systems were particularly useful in areas, which were not approached to extend electricity grid. Even in locations where connection could be made to a grid, practicalities have found it more feasible to use PV pumps than to extend and maintain the electric grid (Firatoglu and Yesilata, 2004; Phuangpornpitak and Kumar, 2007). The PV pumping system is naturally matched with solar radiations as usually water requirements increased during summer when solar radiation is in its peak (Awady *et al.,* 2002).

A lot of work has been done on solar operated drip irrigation system in many countries, which are facing problems of energy crisis and water shortage. In designing of solar operated drip irrigation system, it is very important to have exact number of solar panels according to energy consumption, from the drip installation point of view number of emitters and spacing between the lateral lines are essential parameters for efficient use of water (Purohit and Michaelowa, 2008). In Pakistan, there is lack of such experimental work so, it is very essential to test, design and evaluate the drip irrigation system to achieve the maximum efficiency of irrigation with low cost. Therefore, a well-designed drip irrigation system practically leaves no water for runoff, evaporation and deep percolation and hence, it is very essential need to test, design and evaluate the solar drip irrigation system to achieve the maximum efficiency of irrigation with low cost.

MATERIALS AND METHODS

***Study Area*:** The research was carried out at Mini Dam, Fateh Jang, District Attock, Punjab province of Pakistan. The system was located between Latitude 33°32'05" to 33°33'05" N and Longitude 72°40'50" to 72°42'50" E, as shown in Figure 1. It was situated almost 40km Southwest of Islamabad, along Rawalpindi-Mianwali road.

Climate of the study area varied from very hot to very cold. In summer, the maximum temperature is 45°C, while in winter it may goes below the freezing point. Summer season stretches from April to October and winter starts from November and ends in March. Whereas, rainfall is the major source of irrigation for crops at Fateh Jang and average annual rainfall varies from 800-825 mm. Soil and water samples of the study area were investigated during the field research. Six Samples were collected from the field at different locations from 30cm depth and tested in laboratories of Water Resources Research Institute (WRRI),

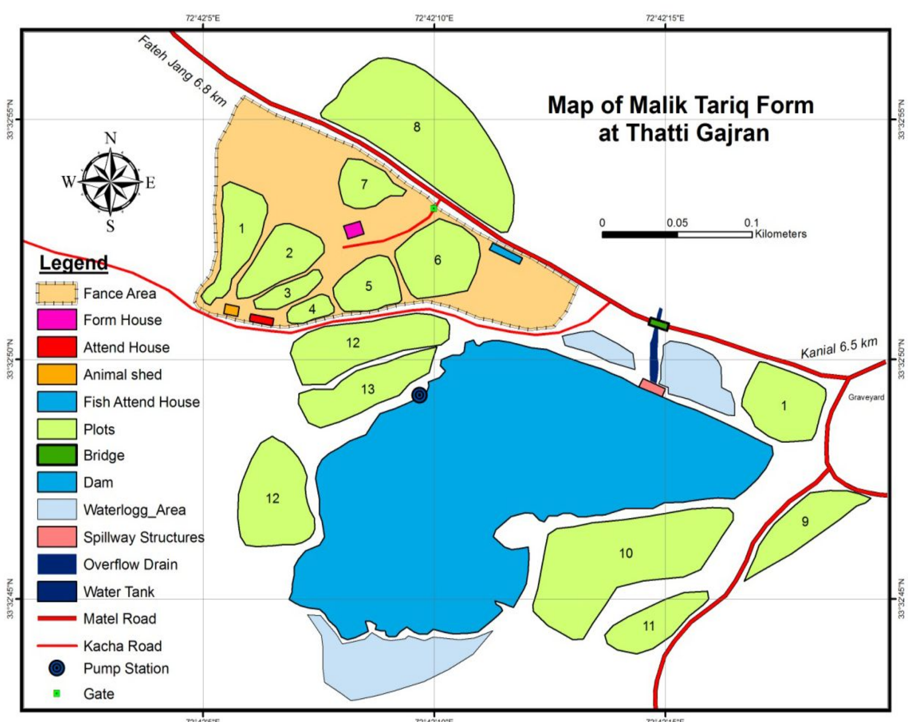

Figure 1. Geographical location of the study area

Table 1. Physical and chemical properties of the soil

Sr. No.	ECe (dS/m)	Organic matter (%)	pH	P (ppm)	K (ppm)	FC (%)	WP (%)	TAW (%)	HC (mm/hr)	n (%)
1	1.08	0.62	8.1	2.16	39.37	22	8	11	25	45
2	1.09	0.61	8.09	2.19	40.36	21	9	12	24	43
3	1.1	0.59	8.11	2.2	41.55	20	10	10	23	42
4	1.07	0.6	8.08	2.17	42.44	19	9	11	24	41
5	1.06	0.63	8.07	2.18	39.11	23	10	12	23	40
6	1.09	0.6	8.12	2.15	38.22	18	11	11	25	44

P=Phosphorous, K= Potassium, FC= Field capacity, WP=Wilting point, TAW= Total available water, HC= Hydraulic conductivity and n= Porosity

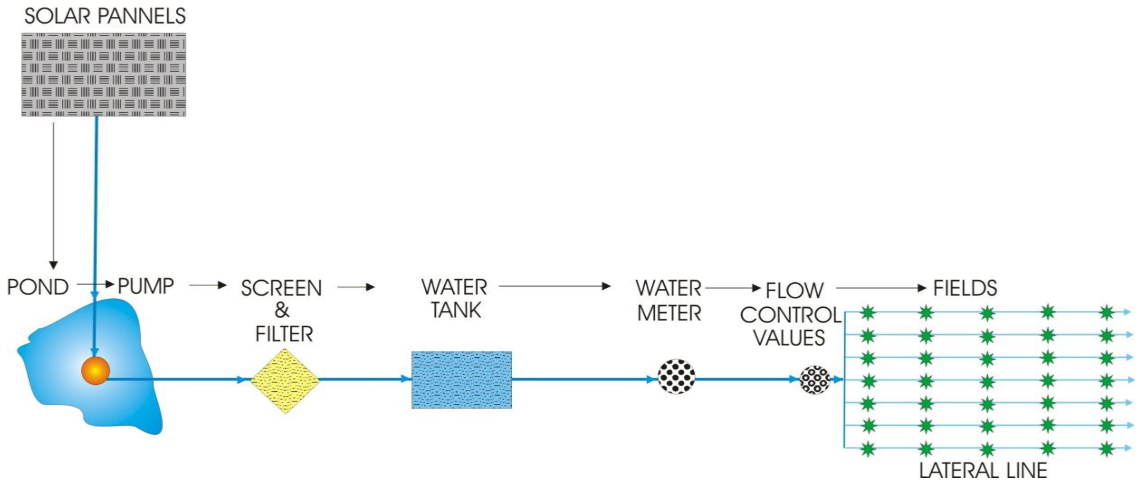

Figure 2. Flow chart diagram of solar drip irrigation system

National Agriculture Research Centre (NARC), Islamabad. Physical analysis of soil showed that the soil of the study area was silty clay loam.

The physical properties of the soil are shown in Table 1. The soil provide good environment for germination. The irrigation on the experimental site was provided from tubewell and pond water. The chemical analysis indicated that water from both sources was fit for irrigation.

Designing of solar drip irrigation system: The flow chart diagram of the Solar Drip Irrigation System is shown in Figure 2. The design of the power unit was prepared on the basis of size of irrigated area, type of crops grown, type of soil at the farm and climate of the area, which helped to determining design daily irrigation requirement (DDIR). The total area was 0.404ha, which was divided into 4 zones. The design daily irrigation requirement for power unit was taken 7.49mm/day, which was maximum value of daily crop water requirement in the study area, calculated using reference evapotranspiration (7.88mm/day) and crop coefficient (0.95). The reservoir was approximately 2.9m×2.9m×2.3m (L × W × H) size with water storage capacity of 20.98m^3. Reservoir has a drain to ground level for periodic cleaning. The line spacing between the drip lines was 1, 2 and 3m with dripper outlet size of 300mm. The solar pump system was managed on volume basis with respect to time because there was fluctuation in solar intensity. The following formulae were used in the designing procedure of the drip system after Sharma and Sharma (2008).

Area irrigated: Area to be irrigated (P_f) was measured using equation 1.

$$P_f = L_L \times L \times N_L/K \times A_f \quad (1)$$

Where,

L_L (Spacing between laterals) = 3m
L (Length of lateral) = 18.3m
N_L (Number of laterals) = 7
K (Constant) = 435.6
A_f (Total outright) = 0.404ha
P_f = 10 × 60 × 7/435.6 × 1 = 9.6%

Time of operation: Operational time was calculated with the help of equation 2.

$$H = 0.24 \times P_f \times D/DDIR \quad (2)$$

Where,

D (Desired depth of irrigation) = 25.4mm
DDIR (Design daily irrigation requirement) = 7.49mm/day
H (Time of operation) = 0.24 × 9.6 × 25.4/ 7.49 = 5hrs.
Decided hours for the system were 5-6 hours.

Depth to be applied**:** Depth of irrigation was measured by using equation 3.

$$Da = H \times DDIR / 0.24 \times P_f \quad (3)$$

Where, Da (Depth to be applied) = 243.84mm

Friction Loss in Pipelines: For calculating the head loss in pipe lines William and Hazen (1933) formula was used as giving in equation 4.

$$H_f = 0.2083\ (L/\ C)^{1.852}\ (Q^{1.852}/\ d^{4.866}) \times F \quad (4)$$

Where,

L = Length of the Pipe (feet)

C = Design coefficient determined for the type of pip

Q = Discharge (gpm)

D = Diameter of Pipe (inches)

F = Christiansen friction factor

Head losses calculated in main line were 0.103, 0.0036, 0.1036 and 0.0067m for zones 1, 2, 3 and 4, respectively. Head losses calculated in sub-main line were 0.0144, 0.0112, 0.6025 and 0.032m for zones 1, 2, 3 and 4, respectively. Head losses calculated in laterals were 0.06, 0.163, 0.288 and 0.1539m for zones 1, 2, 3 and 4, respectively.

Photo voltaic (PV) solar pumping system**:** The mono-crystalline type of photovoltaic system was selected having 16 number of panel. Each panel contained of 180 watts capacity of DC-DC current converter.

Pump specifications**:** The submersible pump of 2.2hp was selected for pond of 4.57m depth. The Total Dynamic Head was 24.39m with design and actual discharge of 13 and 20.16m^3/hr, respectively. The electric motor used in this system is operated by DC current and electric controller is used to fix DC-DC type. The output generated by PV array and input provided to motor in a well was monitored by electronic controller.

RESULTS AND DISCUSSION

The performance, uniformity and the relationships between irradiance, discharge and temperature of the solar drip irrigation system was calculated, as described below:

Effect of temperature on discharge**:** The effect of temperature on discharge is shown in Figure3. It was found that in January, the mean monthly average temperature was 14°C and the monthly average discharge of the system was 20.16m^3/hr. In February, discharge was 20.53m^3/hr against a temperature of 17°C. In the same way, in the month of March, the mean monthly average temperature was 22.5°C and the average discharge was 20.53m^3/hr. It was found that discharge of the system increased with increase in temperature up to a limit e.g. 27°C to 30°C and after that it was remain same. It was observed that due to increase in temperature above described limit, the rate of voltage was increased and amount of current decreased as the result of open voltage condition produced and maximum power flow become zero.

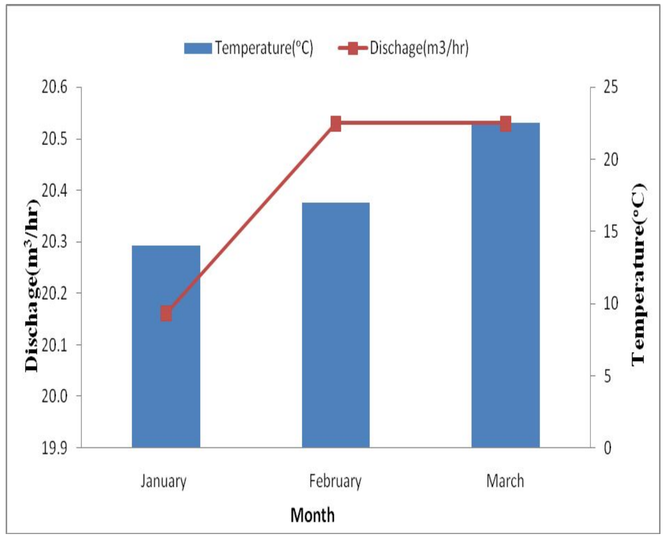

Figure 3. Relationship between discharge and temperature in different months

Due to it, the rated supply of DC current not reaching to the pump and the system produces less discharge. Photovoltaic module was designed for specific temperature range of 25-30°C, as described by the manufacturer. The performance of the modules remains effective under standard described conditions but in field there was no ideal condition. The meteorological parameters do not remain constant all day long, but change considerably. It is necessary to determine the effect of variation of these parameters on the performances of the pumping system.

Relationship between the solar irradiance & discharge on monthly basis**:** The relationship between solar irradiance and discharge in month of January, February and March are shown in Figures 4, 5 and 6, respectively. It was noticed that discharge was zero up to 7:00hr in Jan and Feb, and for March up to 6:00hr. After that, discharge gradually increased with time with the increase in solar irradiance.

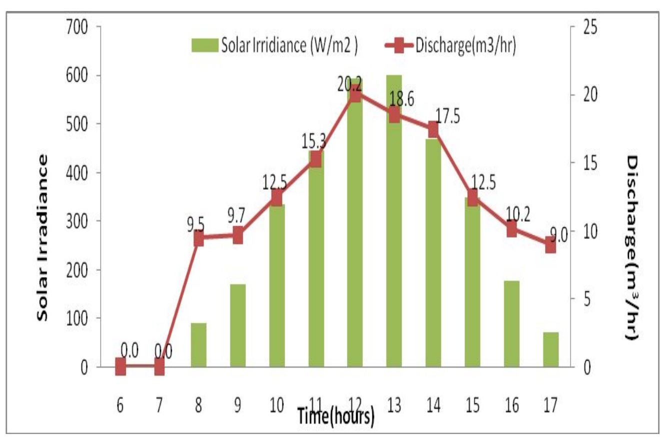

Figure 4. Relationship between discharge and solar irradiance in month of January

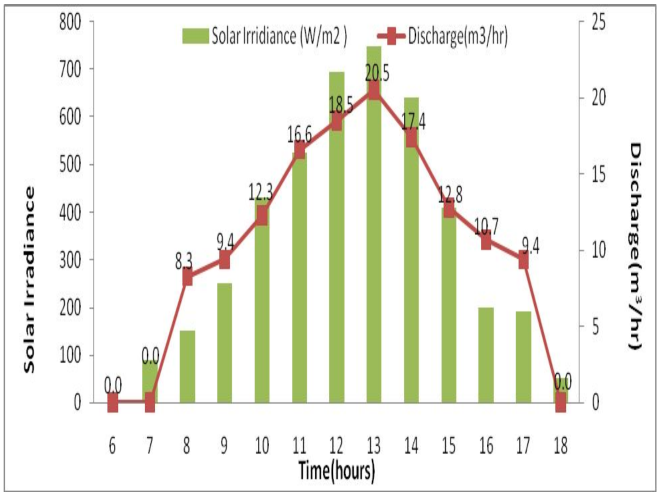

Figure 5. Relationship between discharge and solar irradiance in month of February

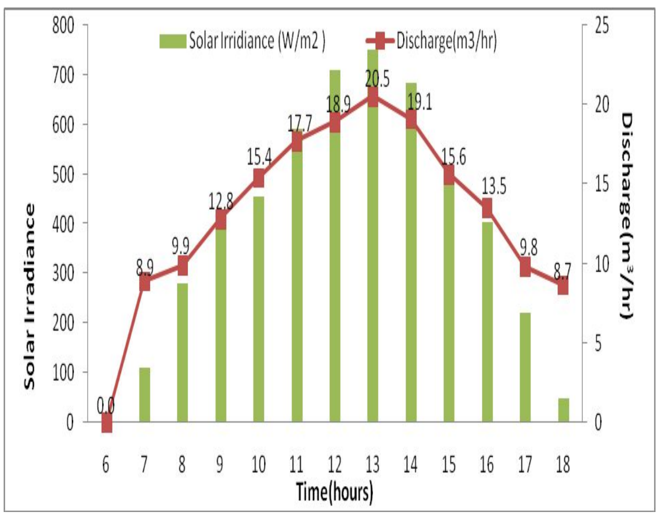

Figure 6. Relationship between discharge and solar irradiance in month of March

The maximum solar irradiance achieved was 595, 750 and 750 W/m^2 in the month of January, February and March, respectively at 12:00 and 13:00hr for January and at 13:00hr for February and March. The maximum discharge against the maximum solar irradiance was 20.2, 20.5 and 20.5m^3/hr in Jan, Feb and March, respectively. After that it was found that the discharge decreased with respect to the solar irradiance and time in all three months. The solar irradiance and discharge was low in January, because of peck winter season. It was observed that maximum solar irradiance and discharge was same for February and March. It was also found that the peak discharge of these three months was from 11:00-14:00hours and the trend of discharge of these three months was almost same in magnitude. This graph also showed that maximum solar irradiance occurred at the time of 11:00 to 14:00hours because of the peak time of sun shines. It was also noticed that in the month of January there was less irradiance as compared to February and March. The main reason of less irradiance was the presence of moisture in the environment and less extraterrestrial radiation outside the atmosphere and vice versa.

Uniformity of Solar Drip Irrigation System:

***Coefficient of variation*:** The coefficient of variation for drip tape used at experimental site was found 0.02 to 0.03 and the values were in acceptable limits (< 0.05, excellent) as recommended by Joseph (1985). The results indicated that the variation in the data of discharge at different pressures collected from the field were very low.

The pressure was applied between 21 and 103kPa according to manufacturer's manual and their relevant average discharge was 0.0083 and 0.00856m^3/ha, respectively. The relationship between flow rate and pressure is shown in Figure 7, which shows that discharge is increasing with pressure. The regression analysis between pressure and emitter discharge showed a linear relationship with 93.92% coefficient of determination (R^2).

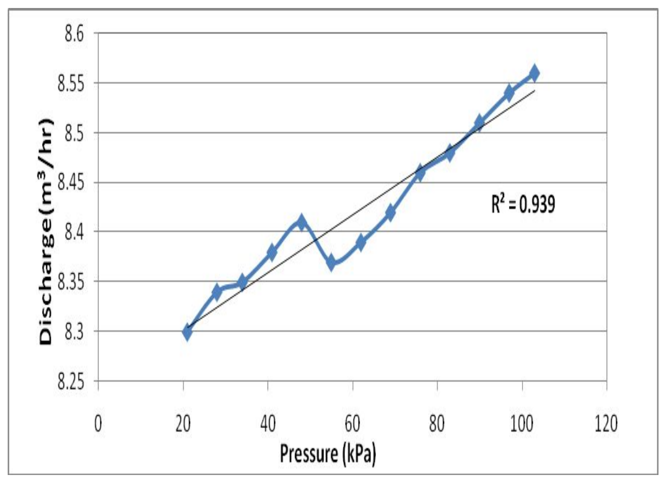

Figure 7. Relationship between pressure and discharge

***Emission uniformity (E_u)*:** The relationship between pressure (kPa) and emission uniformity is given in Figure 8. The emission uniformity (E_u) for the drip irrigation system at experimental site was found 85 and 89.75% for 21 and 103kPa, respectively. The acceptable range of E_u was 85-90% as recommended by Joseph (1985). The maximum E_u was obtained at higher pressure. The regression analysis between Pressure (kPa) and Emission Uniformity (E_u) showed an exponential relationship with 74.4% coefficient of determination (R^2).

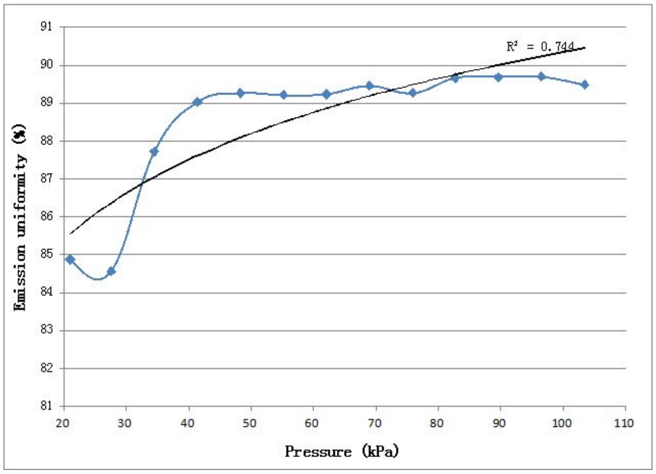

Figure 8. Relationship between pressure and emission uniformity (E_u)

***Application uniformity (C_u)*:** The relationship between pressure (kPa) and application Uniformity is given in Figure 9. The application uniformity for the drip irrigation system was found 98 to 99% in 8 lph emitter at different pressures (kPa). The acceptable range for C_u was 90 to 95% recommended by Joseph (1985). The application uniformity of drip system was also in confirmation with results of Baqui and Honorato (1994).

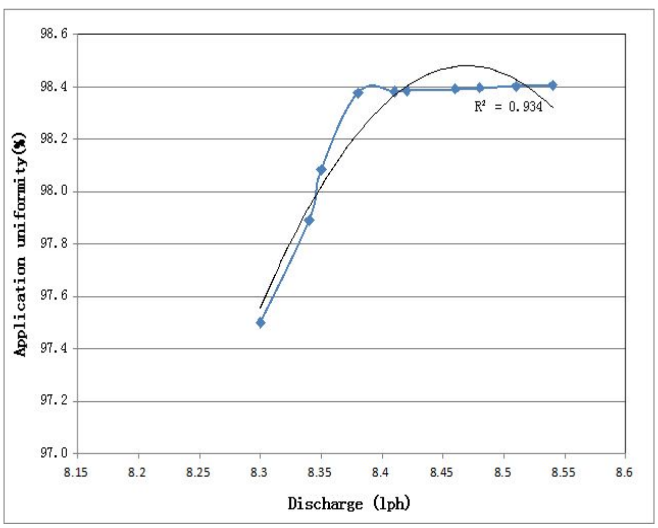

Figure 9. Relationship between application uniformity and discharge

***Distribution uniformity (D_u)*:** The relationship between pressure (kPa) and Distribution Uniformity is given in Figure10. The 99% distribution uniformity for drip tape was recorded at research site for 8.2lph at different pressures (kPa). The acceptable range for D_u was 90 to 95% as recommended by Joseph (1985). The application uniformity of drip system was also in confirmation with results of Baqui and Honorato (1994). All the values of efficiencies were very high and in accordance with the standards, which was due the enough electric current produced in the solar panels to run the pump to lift the water at required capacity. Moreover, pressure produced by solar was so good that water reached in the entire study area equally with required pressure of the emitters.

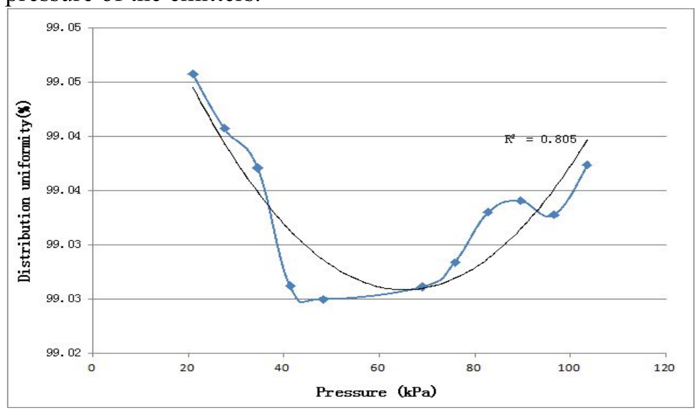

Figure 10. Relationship between pressure and distribution uniformity

***Economical analysis*:** The economic analysis of the solar drip irrigation system was compared with the diesel engine operated drip irrigation system in Pakistani rupees (1US$ = 103 rupees). The cost of the solar system was Rs.1.10 million with an installation cost of drip irrigation system of Rs.0.125 million. In this way, total fixed cost, which was concerned for the installation of complete solar operated drip irrigation system was Rs.1.2 million. The operational cost for one year was Rs.0.092 million, which included the labor cost of Rs.0.031 and repair and maintenance cost of Rs.0.061 million. Hence, total cost of solar operated drip system was Rs.1.29 million, as shown in Figure 11.

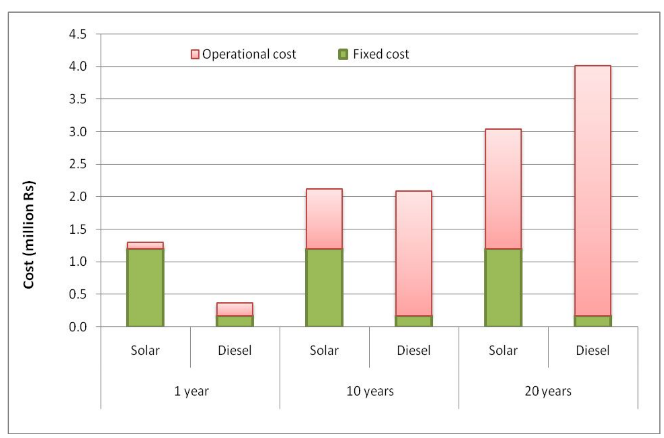

Figure 11. Economic comparison of diesel and solar operated drip system

A diesel engine of 16hp was used in the field to operate drip irrigation system. Initial cost of purchasing diesel engine was Rs.0.045 million and cost involved for installation of drip irrigation system was Rs.0.125 million. So the total fixed cost of diesel operated system was 0.170 million. The one year operational cost of diesel engine was Rs.0.191 million rupees (Fuel: 0.089, labor: 0.093 and repairing: 0.009 million). So the total cost of diesel operated drip irrigation system was Rs.0.361 million rupees.

It was found that in first year total cost of solar drip irrigation system (SDIS) was very high than the diesel drip irrigation system (DDIS), that was due to the high rates of the solar panels. On the other side, the first year operational cost in DDIS was higher than the SDIS due to the consumption of expensive fuels. The comparison was extended to 10 and 20 years. After 10 years, the total cost became equal and the operational cost was significantly high in DDIS. After 20 years, the total cost was become higher in DDIS, due the consumption of plenty of diesel to operate engine. The life of diesel engine was not included during the comparison, which is almost 10 years, otherwise the difference would be much higher. Hence, it was cleared from the results that diesel system had double operational cost as compared to solar operated drip irrigation system.

***Conclusions*:** The overall impact of the solar drip irrigation system was found more efficient, energy saving, economical and environmentally safe as compared to diesel operated drip irrigation system, even though the initial installation cost is very high. The operational cost of SDIS was very low as compared to diesel operated drip irrigation system. The range of average discharge values was between 0.0083-0.00856m^3/hr (8.3-8.56lph) at different pressures, while the emission uniformity values were between 85-90% at 8.3 lph discharge. Application uniformity was 98-99% and distribution uniformity was 99% at 8.3 lph discharge for different pressures (kPa). The system was found satisfactory regarding uniformity with low cost and easy handling. The system was found best suitable in arid zone of Fateh Jang. It was found that the solar system is more economical in terms of operation therefore, it is recommended to install solar panels for pumping units. The government should give subsidy to the local farmers in order to publicize these units as these are the best replacement to conserve our natural resources. The government should encourage our local industry to make these solar panels available at its lowest prices.

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