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Feasibility of Integrating Solar Desalination with Greenhouse Systems in Semi-Arid Region of North-west India

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Abstract

A two-phase project is underway to develop greenhouse systems suitable for water scarce, semi-arid region of north-west India (Kutch). The first phase aimed at studying the effectiveness of natural ventilation and earth-tube-heat-exchanger for environmental control, in place of fan-pads commonly used. These measures were able to reduce the need for evaporative cooling significantly and offer scope for further improvement. The second phase, just started, aims at finding cost-effective means of desalinating brackish water for plant use. Arrays of simple basin type solar stills have been used in this region in the past to provide drinking water in villages. The area of stills needed to meet the greenhouse crop requirement works out to approximately half the cropping area. It would be cumbersome to integrate these with greenhouse structure. Besides, these were reported to be difficult to maintain. A new option - solar assisted low temperature thermal desalination - is therefore being pursued. An outline of the work in progress is presented.

Key words: greenhouse, semi-arid area, solar desalination

INTRODUCTION

Kutch region of north-west India is a vast semi-arid area, characterized by low rainfall, high ambient temperatures, salt-affected soils and poor quality water. Considerable advances have occurred elsewhere in the world in improving productivity of such areas, but this region continues to have vast un- or underutilized lands for lack of suitable technology. Only one crop is usually possible in open-field, yields are low and fluctuate from year to year driven by low, erratic rains. Greenhouse technology could improve water productivity, stabilize yields, extend cropping season and permit a wider choice of high value produce. But the two major impediments are - lack of cost-effective desalination technology and lack of alternatives to evaporative cooling which consumes large amounts of scarce water. A two-phase program is underway with the aim of developing - Arid Area Greenhouse - a new type of greenhouse specially suited to arid conditions. Alternative to evaporative cooling was developed in the first phase. Conjunctive use of three measures, earth-tube-heat-exchanger coupled to the house in closed-loop, natural ventilation and retractable shading, provide satisfactory environmental control at low energy cost (Sharan and Jethva, 2007) and offer possibility of further improvement. The second phase just starting, aims at finding cost-effective ways to desalinate brackish groundwater for use in irrigation. Groundwater typically is saline with levels exceeding 1 dS/m and can not be used directly.

Initiatives to address this problem have been reported from semi-arid areas elsewhere. Wanwiwat et al. (2007) reported results of recovering water from humid greenhouse air by placing a condenser in its path at the end. Condenser was cooled using chilled water from the sump below the pads, several degrees colder than the dew point of the humid air. They reported that even with relatively inefficient condenser (bypass factor 0.92) a maximum of 26.9% of the water use in plant canopy transpiration could be recovered in the pre-monsoon and a maximum of 15.1% in the monsoon period. A maximum of nearly 100% could be recovered in pre-monsoon and 94.3% in the monsoon period if condensers were made more efficient (bypass factor 0.5). The arid area greenhouse does not employ evaporative cooling and the groundwater is not cold enough to drive a condensation process. Under the conditions that prevail in Kutch region - high levels of radiation and high ambient temperatures- solar thermal processes of desalination are being considered.

One such possibility is described by Chaibi (2003). In this schema, one side of the roof of a double-sloped glass house is made of two layers of glass separated by a gap to permit a sheet of brackish water to flow down slowly. The lower glass is slightly darker, upper one clear. Solar radiation heats the water as it flows down. Vapors rise to the cooler upper glass and condense as in stills. The condensate is collected in a sump. Although a full scale system was not made, Chaibi stated that this concept offers the possibility to produce enough water to meet crop needs, in conditions obtaining in Tunis. He observed further that although the transmittance from the solar absorber part is reduced , sufficient PAR radiation is transmitted. Optical properties of the glass covers are critical. It would be desirable to have some spectral selectivity - transmit high levels of PAR radiation and low levels of IR radiation. Although not for greenhouse use, double-sloped glass covered shallow basin type solar stills have been used in India in the past to produce water for drinking in remote areas including here in Kutch region. Some were large systems in the form of arrays designed to supply up to 5,000 L per day of water. Performance of such stills was studied over several years. Equation (1) gives the input – output correlation (Gomkale, 1988).

$$S_p(t) = 4.63 x 10^{-6} [S_r(t)]^{1.545} \qquad \text{............} \quad (1)$$

Where

Sp (t) distillate output on day t (L/m^2)

S_r (t) solar radiation on day t ($kcal/m^2$)

Sharan and Kumar (1998) examined the possibility of using stand-alone systems made of similar stills to desalinate water for use in irrigation. At the time of that analysis there was shortage of real data. Neither the site specific radiation data nor the actual water consumption of crops was available. The exercise was therefore done via simulation using radiation data of Bhuj (90 km from present greenhouse site), details of which can be seen in the publication referred to. The main conclusion was that the still area needed to meet the crop (tomato) water requirement in open-field will be nearly equal to the cropped area making it infeasible. If the local well water salinity were high, the ratio of stills to crop areas will be even higher. There was no experience of cropping under greenhouse in this area then.

Now onsite radiation and other data are available for Kothara - site of arid area greenhouse facility. Using the daily radiation data in equation (1) quantity of distillate produced during the course of tomato growing season (September to February) was computed (457 mm). The crop water requirement of tomato in the open-field was estimated at 452 mm. The irrigation water given to crop reported by a few farmers who raise tomato, is higher than this value. Thus the required basin area per unit crop area works out to one, similar to the earlier conclusion. Chaibi too observed that stills would not meet the requirement of open-field crop in Tunis area. Several rounds of cropping have been done in arid area greenhouse in the recent years. In the year 2006-07, the two were Okra (July – October) followed by hybrid tomato (November – May). In 2007-08, these were bitter gourds (July – October) followed by hybrid tomato (November – May). The amount of water used in irrigation (via drip) is shown below.

Okra	July 06 - October 06	200 mm
Tomato	November 06 - May 07	260 mm
Bitter gourds	July07 – October 07	150 mm
Tomato	November 07 - May 08	258 mm

Between July and October the distillate output will be 332 mm, against the demand of 200 mm. Between November to May the output will be 591 mm against the demand of 258 mm. Thus, if crops are grown inside greenhouse, still area required per unit crop area reduces to 0.6. Chaibi’s statement that solar desalination apparatus on half of glasshouse may be adequate to supply enough water for the crops appears realistic. But having to use half the roof for desalination will most likely limit the effectiveness of this approach to smaller systems, as also observed by Chaibi.

A relatively new process - low temperature thermal desalination (LTTD)- has been developed by desalination group of Institute of Ocean Technology (NIOT), Chennai, India. A large plant producing 100,000 L per day drinking water by desalination of sea, water based on this process has been working at a remote Indian island since 2005 (www.niot.res.in). Sea water is drawn from the surface and fed to a flash chamber which is partially evacuated to lower the boiling point. The temperature of water entering the flash chamber is usually ~ 30° C. The boiling water draws the heat of vaporization from the rest of raw water in reservoir, cooling it by a few degrees. Vapor is led to a condenser where it is condensed to produce fresh water. Condenser is cooled by sea water drawn from 500 m depth where the temperatures are lower, usually ~ 15° C. Sea water from the surface is referred to as warm stream that from deeper layer as cold stream. The temperature differential between warm and cold streams (Δ T) is the key factor that determines the fraction of raw water converted to fresh water. Equation (2) describes the relationship between condensation and temperature differential (P. Sistla, pers. Commun.).

$$M_f / M_w = (C_p / L_f) * \Delta T \quad .... \quad (2)$$

Where M_f is mass of fresh water produced, M_w mass of raw water , C_p specific heat of water (~ 4186 J / kg-K) and L_f latent heat of evaporation (~ 2448000 J/kg). Using these values, the above relation can be expressed as,

$$(Mf / M_w) * 100 = \Delta T / 5.85 \quad .... \quad (3)$$

Equation (3) shows that approximately 1 % condensation can be achieved for every 5.85 ^{0} C drop in temperature from warm water. The technology is scalable, does not require much space and near the sea, has low running cost due to the fact that pumping heads are low and the temperature differential is available free. The negative features are - large flows required compared to the amount condensed. In addition to the flow needed to flash vapor, it is also needed to cool the condenser. Waste water also needs to be disposed off. The LTTD system is therefore best suited for being located on the sea shore. The sea provides easy source of flows - both warm and cold - and easy sink for disposal. Of course, it needs to be noted that the motivation for developing this technology was to provide drinking water for communities living in remote islands and near sea. The scientists who developed it also indicated that this technology is better suited for large scale desalination.

In the context of need to produce water for greenhouse use, two possibilities are being visualized. One, to build large conventional LTTD plants on the sea shore and distribute the fresh water to greenhouse ranges nearby. Second, adapt the technology to inland locations by using solar energy to create temperature differential - solar assisted LTTD plant. Groundwater which is typically between 30 ^{0}C - 32 ^{0}C in this region could be heated by passage through absorber type solar hot water system to create temperature differential. Evacuated solar tubes are being used in some areas for heating water for domestic use. These are able to create differentials of approximately 30 ^{0}C, which could yield higher (4% to 5%) condensation. But these are expensive and will not be feasible in greenhouse on account of cost. Preliminary investigations were therefore carried out using solar pool heaters that use polypropylene tubes as absorbers. Measurements were made for three consecutive days in each month in 2007. The temperature differential achieved under ambient conditions at Kothara in most months was approximately 15 ^{0}C, similar to that available at sea. A small system is being developed for trial. This is elaborated below.

MATERIAL AND METHODS

An experimental facility has been developed at village Kothara (φ 23° 14 N, λ 68° 45 E, at 21 m a.s.l.). This is in a semi-arid region near the coast of Arabian Sea. It consists of a greenhouse coupled to an earth-tube-heat-exchanger (ETHE). The facility is described in detail elsewhere (Sharan and Jethva, 2007). It is a single span saw-tooth structure - 6 m span, 20 m length and 3.5 m height at the ridge; with floor area of 120 m^2 and enclosed volume 360 m^3. Cladding is 200 micron UV stabilized PE film. For environmental control, it has three closable screened continuous vents, ETHE and array of overhead foggers for occasional use. Total (unscreened) vent area is 25% of the floor area. ETHE provides 40 air changes per hour, moved by a centrifugal blower of 4 KW. The house is furnished with fertigation.

The solar assisted LTTD plant is being developed. It consists of solar hot water unit, flash chamber, condenser unit, supply and return wells. Groundwater will be drawn from supply well and moved through the pool -type solar hot water unit. This unit is in modular form, modules made of 6 m long black surfaced polypropylene tubes arranged in parallel. The tubes act as absorbers. The unit is configured to achieve required flows with minimum head loss, and to achieve temperature rise from 30 ^{0}C – 32 ^{0}C to 45 ^{0}C - 48 ^{0}C. Absorber modules will be installed on slanted wooden racks. Heated water will enter the flash chamber of the LTTD unit. Vapors will be led to the condenser cooled by stream of water from supply well. The units are sized to produce 1000 L per day of fresh water. The desalination system is expected to be installed by December 2008.

SUMMARY

Vast lands in the semi-arid north-west India remain unused for lack of suitable technology. Greenhouse technology has potential. But one major impediment is lack of cost-effective desalination procedure to produce fresh water from the brackish groundwater. Besides being cost-effective, the desalination system needs to be such that does not use up large space, and is easily integrated with the greenhouse facility. Considering these factors, a relatively new process - Low Temperature Thermal Desalination - was selected for trial. These systems have been working successfully in some remote islands in India, to produce drinking water from sea water. The process is being modified for use in inland locations near greenhouse. The modification consists of adding a solar hot water unit , that could raise the temperature of brackish groundwater. Preliminary investigations have shown that pool type solar hot water systems using polypropylene tubes as absorbers can under Kutch conditions , produce temperature differential of about 15 ^{0}C , similar to the differentials that occur naturally between

surface and deep sea level. A small prototype is being developed for trial by the end of 2008.

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Tables

Table 1: Estimated distillate output over the months based on solar Radiation data of Kothara

Month	Distillate output on typical day (L m^{-2})	output over month (L m^{-2})
January	2.1	63
February	2.5	76
March	3.3	98
April	3.7	112
May	4.0	120
June	3.6	107
July	1.7	51
August	2.8	85
September	3.6	109
October	2.9	87
November	2.2	67
December	1.8	55
Annual		1029