A Solar Water Pumping System

P. Thureau and A.G. Bhave
Laboratoire de Thermique Industrielle
Université Paris Val-de-Marne, Créteil, France

ABSTRACT

A solar (thermal) water pumping system operating on Freon 113 has been developed at the Université Paris Val-de-Marne. The system is characterised by its simplicity and ruggedness.

Experimental tests in the laboratory show that overall efficiencies (including the solar collectors) from about 0.2% to 0.35% at pumping heads from about 6 m to 12 m can be expected.

INTRODUCTION

In developing countries, and especially in remote rural areas without electricity, there is a need for water pumping systems operating on alternative sources of energy.

Though solar photovoltaic based pumping systems have proved to be feasible, they involve sophisticated technology in the form of solar cells and thus are expensive. The ideal system for such applications would be one which is rugged, simple in construction, has low maintenance requirements, and can be completely locally fabricated in developing countries.

With this aim in mind, a water pumping system has been developed at the Université Paris Val-de-Marne.

SYSTEM DESCRIPTION

The pumping system is schematised in Fig. 1.

It consists of four flat-plate solar collectors (total area 8 m^2), a separator, a motor, a condenser, a freon reserve, and a pump.

The motor consists of four bellows of the type used for vehicle suspensions, which serve as pistons. A distributor links bellows 1 and 2 alternately to high pressure freon vapour from the separator. In addition there are two small teflon bellows, for reinjecting condensed freon back into the collectors, which are activated by the movement of bellows 3 and 4 respectively. The motor has, in addition, two funnels with valves for filling the hydraulic circuits with water.

The condenser is cooled by the pumped water.

The pump consists of two chambers and two bellows, 5 and 6, linked by a shaft, and four one-way valves. Bellows 3 and 4 are respectively connected to bellows 5 and 6 by the two hydraulic circuits.

The hydraulic circuits are initially filled with water through the funnels. Bellows 3 and 4 are purged of air by pressing the bellows manually, and the valves below the funnels are closed. Freon 113 is vaporised in the collectors and dry freon vapour from the separator enters the distributor of

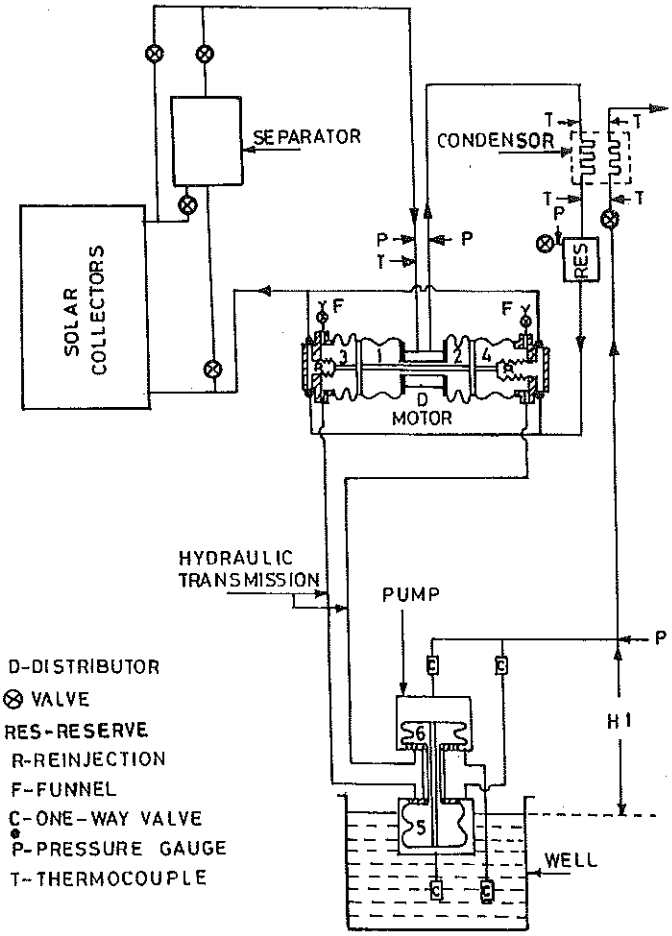

Fig. 1 Solar water pumping system.

the motor. In the figure, bellows 1 is linked to high pressure freon vapour and is in the process of expansion, while bellows 2, which is linked to bellows 1 by a shaft, is in the process of contraction and thus in the process of emptying its contents into the condenser. The movement of bellows 1 causes bellows 3 to contract. The movement of bellows 3 is transmitted to bellows 5 through the hydraulic transmission. Bellows 5 pumps the contents of its chamber towards the condenser, while bellows 6 contracts and aspirates water from the well into its chamber. During this stroke, bellows 3 causes its reinjection pump to pump the condensed freon into the collectors, while bellows 4 causes its reinjection pump to aspirate condensed freon from the freon reserve.

At the end of the stroke the distributor links bellows 2 and bellows 1 to the high pressure of the saturated vapour and low pressure of the condenser, respectively, and the motor reverses its direction.

It should be noted that there are no leakages towards the exterior in this system.

The depth from which water can be pumped by this system depends on the difference between the pressure of freon vapour obtained from the separator and the pressure in the condenser. The maximum pressure difference which can be obtained is limited by the temperature and pressure of

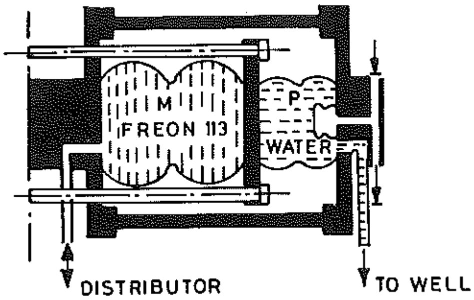

Fig. 2 Multiplication of pressure.

vaporisation in the collectors which is limited to moderately low values due to falling efficiency of the collectors at high temperatures.

To be able to pump from greater depths, and adaptation, as shown in Fig. 2, giving a multiplication of pressure, has to be used. In this arrangement a bellows M is coupled to a bellows P which transmits the motion of the motor to the pump through a hydraulic circuit as before. Multiplication of pressure is obtained in the ratio of cross-sectional area of bellows M to cross-sectional area of bellows P.

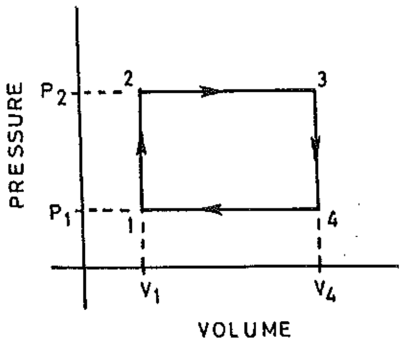

Fig. 3 Indicator diagram for motor bellows.

SYSTEM THERMODYNAMICS

From the description of the operation of the system, the indicator diagram of the motor bellows is as in Fig. 3.

At the end of the stroke, the bellows which was connected to the low pressure of the condenser, P_1, is in position 1, where the volume of the bellows is the clearance volume V_1. At this point the distributor admits the high pressure P_2 and the bellows goes to position 2. The expansion of the bellows under pressure P_2 is the working stroke 2-3. At the end of this stroke the bellows is again linked by the distributor to the condenser pressure P_1, and the new state is 4. The stroke 4-1 is the contraction of the bellows during which it empties its contents into the condenser.

The net work of the cycle is therefore $(P_2-P_1)(V_4-V_1)$. The heat supplied to the freon per cycle is given by $\Delta H(V_4-V_1)/v''$, where ΔH is the difference between the enthalpy of the dry saturated vapour at the pressure P_2 and the enthalpy of liquid freon at the pressure P_1, and v" is the specific

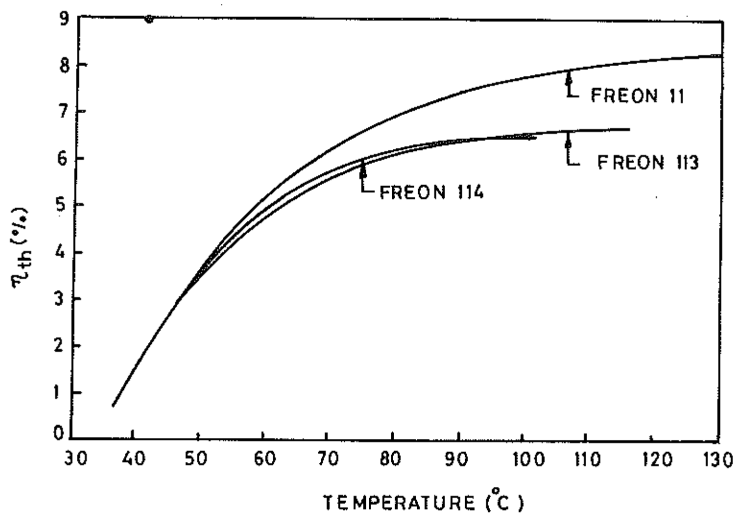

Fig. 4 Variation of thermodynamic efficiency with operating temperature.

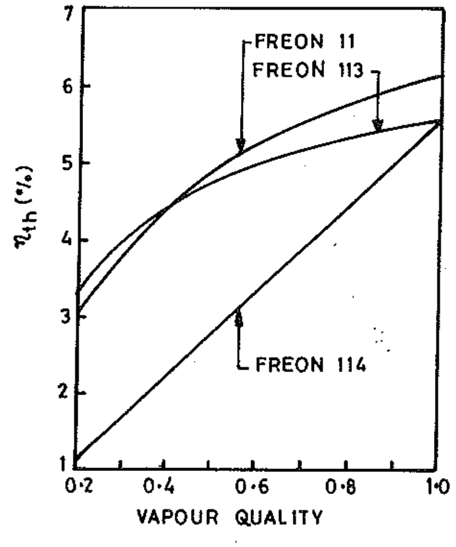

Fig. 5 Variation of thermodynamic efficiency with vapour quality.

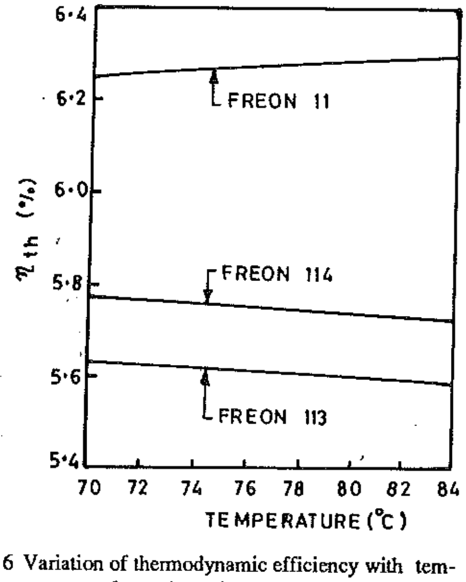

Fig. 6 Variation of thermodynamic efficiency with temperature of superheated vapour.

volume of dry, saturated vapour at pressure P_2. Neglecting the work of reinjection, which is very small, the thermodynamic efficiency of the system is given by $\eta_{th} = (\Delta P)v''/\Delta H$, where $\Delta P = P_2 - P_1$.

Assuming the temperature of condensation to be 35 °C, a plot of η_{th} versus temperature of vaporisation is shown in Fig. 4. We see that the efficiency increases with increase in operating temperature, but it tends to level off at a certain temperature. It is also seen that Freon 11 gives the maximum efficiency at all temperatures.

For wet vapour, considering the enthalpy of wet vapour admitted into the bellows, and the work of reinjection, the variation of thermodynamic efficiency with vapour quality 'x' at a constant temperature (70°C) was worked out and is plotted in Fig. 5. We see that the efficiency increases with increasing vapour quality.

The variation of thermodynamic efficiency for superheated vapour is shown in Fig. 6. We see that the efficiency of the system falls with increasing temperature of superheat for Freon 113 and Freon 114, and that it rises marginally for Freon 11, which does not justify using superheated Freon 11 due to the fall in collector efficiency at higher temperatures.

Thus the system gives optimum thermodynamic efficiency with dry, saturated vapour.

SYSTEM PERFORMANCE

For evaluating the performance of the system in the laboratory, the collectors were heated electrically. The heating power given to the collectors was controlled to obtain the desired temperature of evaporation of Freon 113. The system was instrumented as shown in Fig. 1. The effective puming head was varied by operating the valve in the pumped water circuit just before the condenser. Water flow rate was measured by a burette and a stop-watch. The condenser and the piping carrying hot freon vapour were insulated with glass wool. The pump was located about 5.5 metres below the motor in a water tank.

The power output of the system was calculated from the water flow rate and the effective head developed.

The power absorbed by freon in the collectors was assumed to be equal to the power absorbed by the cooling water in the condenser (which was calculated from the water flow rate and the difference between the outlet and inlet temperatures of the water), ignoring the pumping work, which is comparatively small, and the heat losses from the motor. The system efficiency (excluding the collectors) was found at different pumping heads for two different operating temperatures and pressures. It was found that the efficiency was higher at the higher operating temperature, and at the same temperature and pressure it rose with increasing pumping height up to a certain limit, and then fell. The optimum efficiencies obtained were as in Table 1.

Table 1 Optimum pumping system efficiencies.

Evaporation pressure (bars gauge)	Evaporation temperature (°C)	Effective pumping head (m)	Flow rate (litres/h)	Useful work (watts)	System Efficiency (%)
2.05	84	11.85	553.68	17.88	0.75
1.65	79	9.35	506.88	12.92	0.69

It is thus seen that at each operating pressure and temperature, there is an optimum pumping head which rises with increasing operating pressure.

CONCLUSIONS

The water pumping system described above is simple, rugged and requires little operator attention and maintenance. It is thus eminently suited to meet the water pumping needs of remote rural communities not having access to electricity, but having abundant sunshine.

It can be expected to operate at an overall efficiency (including the collectors) of about 0.2% to 0.35% at heads of about 6 metres to about 12 metres, depending upon the intensity of solar radiation, without multiplication of pressure, and at higher heads with multiplication of pressure.

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