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Design of Solar Steam Irrigation Pump

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Abstract— Solar ***irrigation pump is this type of device which uses solar energy for water pumping. Water pumping is an energy intensive activity and consumes a large amount man power, diesel and electricity. Smallholder farmers in low income countries can benefit from affordable irrigation pump systems as they enable cultivation of high value crops during dry season. Currently the majority of small irrigation pumps are manually operated which is time consuming and requires a high level of physical exertion. There is a potential market for a low cost solar thermal pump that produces a high volume of water as well as reducing the labour burden. This will allow more crops to be grown and free up time for other productive tasks. Compared to the existing manual systems, many hours could be saved each day through reduced labour input.***

Keywords— Solar irrigation pump, Non renewable energy device, parabolic collector and Design.

I. Introduction

The Solar collector collects energy coming from sun. Boiler located at focal point of collector absorbs solar energy which heats up water and turns it into steam. Steam conveyed to buffer vessel of steam engine via insulated hose. Pressure in buffer allowed to build up until 1 - 1.5 bar (120 – 130^{o}C). When the desired pressure is reached, operator manually turns the flywheel counter clockwise, opening the inlet valve allowing steam to enter the working chamber. The pump has a reciprocating positive displacement action that lifts water through the relative movements of a piston and a foot valve. The down stroke closes the foot valve and the piston moves through the water displacing a column of water equal to the volume of the stroke; the upstroke displaces the water above the piston while opens the foot valve drawing water into the pump cylinder. The original piston design was a hollow steel cylinder with a diameter fractionally below that of the pump casing cylinder. The idea was that it would be frictionless and resistant to wearing by abrasive soils. However it soon had to be replaced, because the sandy soils would not allow the piston to move freely. There are now two types of pistons installed according to the amount of sand encountered in the initial well development. The pump has a reciprocating positive displacement action that lifts water through the relative movements of a piston and a foot valve. The down stroke closes the foot valve and the piston moves through the water displacing a column of water equal to the volume of the stroke; the upstroke displaces the water above the piston while opens the foot valve drawing water into the pump cylinder. The original piston design was a hollow steel cylinder with a diameter fractionally below that of the pump casing cylinder. The idea was that it would be frictionless and resistant to wearing by abrasive soils. However it soon had to be replaced, because the sandy soils would not allow the piston to move freely. The feeder pump is an important system component with two main purposes (i) return the condensate to the boiler; (ii) allow manual topping up of the boiler. For practical construction and operational reasons it has an oversized capacity and a minimum of 'dead space' so each stroke pumps mainly air. This water pump needs to be designed more carefully to avoid air leaks. The performance of the feeder pump is critical to the effective operation of system. During the monitoring there were frequent problems with the seals and valves, which meant that the boiler sometimes had to be refilled several times in a day. This led to gaps and discontinuities in the data collection.

II. Design

For small level farmer following data are assumed. Discharge,

$$Q = 1000 \text{ lit/hr}$$

Suction head is 15 m so Length of pipe, it may vary as per location

$$L = 15.54 \text{ m}$$

From market survey diameter of discharge pipe is 38.1mm

Area of pipe
$$A_p = \frac{\pi}{4} D^2 = \frac{\pi}{4} 38.1^2 = 1140.09 \text{ mm}^2$$

Velocity of water
$$V_w = \frac{\text{Discharge}}{\text{Area}} = \frac{277777.78}{1140.09} = 243.65 \text{ mm/sec}$$

Suction pressure
$$= 1 \text{ atmosoheric pressure} - \text{suction head}$$
$$= 1 \text{ bar} - \rho_w g L$$
$$= 0.1 - (10^{-6} \times 9.81 \times 10^3 \times \times 15540)$$
$$= -152.35 \frac{N}{mm} . sec^2$$

Note: Here above negative value indicate negative pressure below ground surface. So we have taken positive for actual pumping.

Various Losses in Pipe

Entrance loss $h_i = 0.5\frac{V_w^2}{2g}$

$= \frac{0.5(243.65)^2}{2\times 9.81\times 10^3}$

$= 1.51$ mm

Exit loss $h_e = \frac{V_w^2}{2g}$

$= \frac{(243.65)^2}{2\times 9.81\times 10^3}$

$= 3.03$ mm

Friction loss due to suction head $h_f = \frac{4flV^2}{2gd}$

Reynolds number $R_e = \frac{\rho_w V_w D}{\mu}$

$= \frac{10^{-6}\times 243.65\times 38.1}{10^{-3}}$

$= 9.28$

Co-efficient of friction $f = \frac{0.079}{(Re)^{\frac{1}{4}}}$

$= \frac{0.079}{(9.28)^{\frac{1}{4}}}$

$= \frac{0.079}{1.75}$

$= 0.045$

$h_f = \frac{4flV^2}{2gd}$

$= \frac{4\times 0.045\times 15540\times 243.65^2}{2\times 9.81\times 10^3\times 38.1}$

$= 223.62$ mm

Total loss $= h_i + h_e + h_f$

$= 1.51 + 3.03 + 223.62$

$= 228.16$ mm

Total head H $=$ Suction head $-$ Total losses

$= 15540 - 228.16$

$= 15311.84$

Pressure Vessel

It is a device which is used to receive solar energy from the parabolic collector is used to generate steam from water which is further used to run steam engine. It is generally made from the aluminum and steel. To increase efficiency of this receiver it is painted with prime black colour.

Assumption

To increase quantity of steam and to achieve pressure approximately 1.5 bar the dimension of pressure vessel as given below,

Radius of vessel $r = 150\ mm$

Length of vessel $L_v = 300\ mm$

$Volume\ of\ vessel\ V_v = \pi r^2 h$

$= \pi\times 150^2\times 300$

$= 21205750.41\ mm^3$

Design of Piston for Single Cylinder Double Acting Steam Engine

Assumption

When the steam acts on piston due to the loss in pressure we assume that final pressure on the piston will be,

Steam pressure $P = 0.05\ N/mm^2$

As per working pressure on piston the,

Stroke length $L_s = 50$ mm

Clearance $L_c = 2.5$ mm

Total length $L = 55$ mm

Bore diameter $d = 53$ mm

Speed of piston $N_p = 100$ rpm

Stroke volume $V_s = \frac{\pi}{4}d^2L_s$

$= \frac{\pi}{4}\times 53^2\times 50$

$= 110309.17\ mm^3$

Clearance volume $V_c = \frac{\pi}{4}d^2L_c$

$= \frac{\pi}{4}\times 53^2\times 2.5$

$= 5515.46\ mm^3$

Total clearance volume $V_c' = 2\times V_c$

$= 2\times 5515.46$

$= 11030.92\ mm^3$

Total volume $V_t = V_s + V_c'$

$= 110309.17 + 11030.92$

$= 121340.09\ mm^3$

Compression ratio $r_c = \frac{V_s + V_c'}{V_c'}$

$= \frac{110309.17 + 11030.92}{11030.92}$

$= \frac{121340.09}{11030.92}$

$= 10.99$

Piston Force F_p = Pressure $\times$ Area

$= p\times \frac{\pi}{4}d^2$

$= 0.05\times \frac{\pi}{4}53^2$

$= 110.31\ N.mm/sec^2$

Piston Torque $T_p = F_p\times \frac{d}{2}$ (20)

$= 110.31\times \frac{53}{2}$

$= 2923.19\ N.mm^2/sec^2$

Piston Power $P_p = \frac{2\pi N T_p}{60}$ (21)

$= \frac{2\times\pi\times 100\times 2923.19}{60}$

$= 30611.57\ N.mm^2/sec^3$

Buffer Chamber

Assumption

To give the continuous pressurise steam to piston cylinder assembly dimension of buffer chamber must be less the dimension of pressure vessel

Length of chamber $L_b = 150\ mm$

Height of chamber $H_b = 140\ mm$

Width of chamber $W_b = 80\ mm$

Volume of chamber $V_b = L_b \times H_b \times W_b$ (22)

$= 150 \times 140 \times 80$

$= 168 \times 10^4\ mm^3$

Flywheel

Assumption

To get constant discharge the flow of steam is to be constant, if there is fluctuation in steam generation to give constant energy supply we assume following criteria,

Speed of flywheel $N_f = 60\ RPM$

Density of flywheel

$\rho_f = 7.85 \times 10^{-6} \frac{kg}{mm^3} (For\ ms\ material)$

Mean diameter of flywheel $R = 240\ mm$

Thickness of rim $t = 20\ mm$

Usually $\frac{b}{t} = 2$ is taken.

Area of flywheel $A_f = b \times t$ (23)

$= 40 \times 20$

$= 800\ mm^3$

Volume of flywheel $V_f = 2\pi R \times A_f$

$= 2\pi \times 240 \times 800$

$= 1206371.58\ mm^3$

Mass of flywheel $M = Volume \times \rho_f$

$= 1026371.58 \times 7.85 \times 10^{-6}$

$= 9.47\ kg$

$\cong 10\ kg$

Energy stored in flywheel $= \Delta E$

$= M\omega^2 R^2 C_s$

$= 10 \times (6.28)^2 \times (240)^2 \times 0.04$

$= 908660.74\ kg.mm$

We know that relation between maximum fluctuation of energy and kinetic energy / total energy is given as below,

$\therefore \Delta E = E \times 2C_s$

The value of C_s for pumping is given in appendix.

$\therefore 908660.74 = E \times 2 \times 0.04$

$\therefore E = \frac{908660.74}{2 \times 0.04}$

$= 113582.63\ kg.cm$

III. Conclusion

Research and development into this type of renewable energy technology is particularly important in the present day. Solar energy can easily transmit to kinetic energy by means of solar steam irrigation pump. Solar steam irrigation pump is very useful to small scale farmer and it is feasible to develop with minimum cost. It is beneficial to small scale farmer in following manners

•Improve food security during the dry season

• Reduce labour and fossil fuel inputs

• Adapt better to potential climate change effects

• Create extra income

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