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1- Abstract

The purpose of this paper is to formulate the steam flow that will be generated by the "Linear Fresnel concentrator Steam Generator" according to its dimensions. For mor detail information refer to the article "Desalination of seawater by successive heating of thin layers of water using solar radiations from a Fresnel concentrator"^[1] and the preprint "Detail Design - Linear Fresnel concentrator Steam Generator"^[2]. The steam Flow is the key point out put of this paper. It will allow to figure out the impact of the sea water desalination engine, its cost and its benefits.

2- hydrodynamic problem formulation

The problem dimensions are described in Fig-2. The free salt water surface in the tank has ' h ' as height from the top of the mobile cylinder. The free surface is under atmospheric pressure ' P_a '. the cylinder rotates around the axis Z with an angular speed ' ω '. the cylindrical annular space containing the circulating water has a thickness ' δr '. The rotating cylinder has a radius ' R '. The cylinder is heated by solar radiation from the Linear Fresnel Concentrator.

1.1 Problem Formulation:

We need to calculate for each point of the circulating fluid with cylindrical coordinate (r, θ, z) the pressure P , the component of linear speed " V_z " following " Z " axis, the phase of the fluid at this point. Where " r " is between $(R - \delta r)$ and R , " θ " is the angle from the horizontal axis to the given point inside the cylindrical annular space and " z " the distance from the cylinder basis at the intersection surface with the tank, to the given point.

Fig -2

1.2 Problem Assumptions

1.2.1 Linear Speed Linearity from Viscosity considerations :

This assumption consists of considering that the linear speed of the water and the linear speed of the solid cylindrical extremum of the annular space are the same at the contact surface following Viscosity considerations. For water circulating inside annular space of rotating Cylinder as described in Fig-3, the linear speed profile is linear. This means that the linear speed $V(r)$ is given by the following equation (1) in the steady state :

$$(1) \quad \frac{V(R) - V(R - \delta r)}{\delta r} = \frac{V(R) - V(r)}{R - r}$$

$$\text{Hence : } V(r) = r \times \omega$$

Where :

$$V(R) = R \times \omega$$

$$V(R - \delta r) = (R - \delta r) \times \omega$$

Fig-3

1.2.2 The pressure from centrifugal acceleration is so high that the water stays in liquid state along his motion inside the annular space

This assumption consists of the fact that the pressure from centrifugal acceleration is so high that the water stays in liquid state until the end of its circulation inside the annular space, then the relaxation of the water will occurs at the end of annular space where the sudden relaxation will cause the instant evaporation inside the collector. The centrifugal pressure is given by this equation (2) :

$$(2) \quad P(r) = \frac{\rho \times \omega^2 \times r^2}{2}$$

Where “ ρ ” is the density of water.

Equation (2) is obtained by the integration of the expression of the centrifugal force Fr by the centrifugal acceleration following the static fundamental equation :

$$Fr = \frac{\partial P(r)}{\partial r} = \rho \times \omega^2 \times r$$

So the surface exchange liquid-vapor will be the circular section at the end of the cylinder as described as the red section in Fig-4 , yellow arrow is for Steam generation resulting from sudden water relaxation. We will calculate later in 1.3.1 the minimum value of the angular speed “ ω_{Min} ” to keep this assumption true.

If this assumption is false then the evaporation inside the annular space will cause the increase of salt concentration and the at certain level of concentration the water circulation will be interrupted. So the pressure $P(r)$ will be great enough to keep the water in liquid phase as described in phase diagram of water in Fig-5, $P(r)$ will be kept inside the zone DBCE .

Fig - 4

Fig – 5

1.2.3 The pressure drop is neglected and the water flow is considered laminar

The pressure drop are neglected along the study by the present paper, the turbulence effects as well and the fluid is considered incompressible.

1.3 Hydrodynamic problem resolution

1.3.1 Pressure Equations $P(r)$

The pressure for given point with cylindrical coordinates (r, θ, z) is divided into two (2) parts :

The gravitational part is given by this equation (3):

$$(3) \quad P_g(r, \theta) = P_a + (\rho \times g \times [h + (R - r \times \sin(\theta))])$$

The centrifugal part from centrifugal acceleration is given by this equation (4) :

$$(4) \quad P_c(r) = \frac{\rho \times \omega^2 \times r^2}{2}$$

The centrifugal pressure has two (2) components, vertical and horizontal. So the vertical part which will come in the play with the gravitational part of pressure in equation (3) is the most important, because it's involved for the calculation of linear speed component following "Z" axis. So the vertical component of centrifugal pressure is given by this equation (5) :

$$(5) \quad P_{cv} (r, \Theta) = \frac{\rho \times \omega^2 \times r^2}{2} \times \sin(\Theta)$$

On the other hand, the horizontal component of centrifugal pressure is given by this equation (6) :

$$(6) \quad P_{ch} (r, \Theta) = \frac{\rho \times \omega^2 \times r^2}{2} \times \cos(\Theta)$$

Only equations (3) and (5) will be involved for the linear speed calculation "V_z" following "Z" axis.

The vertical component of the whole pressure , gravitational and centrifugal, is : P_g + P_{cv} which varies from two extremum values. The maximum value is located at the bottom of the cylinder and it's given by this equation (7) :

$$(7) \quad P_{max} = P_a + (\rho \times g \times [h + (R + r)]) + \frac{\rho \times \omega^2 \times r^2}{2}$$

The minimum value is located at the top of the cylinder and it's given by this equation (8) :

$$(8) \quad P_{min} = P_a + (\rho \times g \times [h + (R - r)]) - \frac{\rho \times \omega^2 \times r^2}{2}$$

Hence, to keep the water in liquid state along the annular space in the cylinder, this equation (9) should be satisfied :

$$(9) \quad | P_{min} | > P_a$$

where P_a is atmospheric pression considering the pression generated by the air compressor is near P_a and P_{min} is given by the equation (8)

So, from equation (8), the minimum value of the angular speed to satisfy the stated assumption 1.2.2 is given by this equation (10) :

$$(10) \quad \omega_{Min} = \sqrt{2 \times \frac{(2 \times P_a + \rho \times g \times (h + \delta r))}{\rho \times (R - \delta r)^2}}$$

1.3.2 Equation of Component of linear speed “V_z” following “Z” axis equations :

The speed component following the “Z” axis is given by Bernoulli equation (11) :

$$(11) \quad P_g + P_{cv} = \frac{V_z^2}{2} + P_{exit}$$

Where P_{exit} is the pressure applied by the air compressor at the end of the cylinder which its value is greater than P_a , the atmospheric pressure but its value is enough near P_a

$$\frac{V_z^2}{2} = P_a + (\rho \times g \times [h + (R - r \times \sin(\theta))]) + \left[\frac{\rho \times \omega^2 \times r^2}{2} \times \sin(\theta) \right] - P_{exit}$$

Hence V_z is given by this equation (12)

$$(12) \quad V_z = \sqrt{2 \times [P_a + (\rho \times g \times [h + (R - r \times \sin(\theta))]) + \left[\frac{\rho \times \omega^2 \times r^2}{2} \times \sin(\theta) \right] - P_{exit}}}$$

1.4 Conclusion

The engine should have the angular speed rotation greater than the minimum value calculated in equation (10) to be functional. The steam will be generated continuously and totally at the exit of the cylinder.

The steam flow $FLOW_{steam}$ can be calculated from the speed “V_z” , the component of water speed following “Z” Axis and from the rate of salt in water noted “β” . So it is given by this equation (13):

$$(13) \quad FLOW_{steam} = FLOW_{water} \times (1 - \beta) = \int_{\theta=0}^{\theta=2\pi} V_z(\theta) \times \delta r^2 \times d\theta \times (1 - \beta)$$

Where $(\delta r^2 \times d\theta)$ is the circular section surface element delimited by the angle variation θ and $\theta + d\theta$.

and V_z(θ) obtained from equation (12)

The steam Flow is the key point out put of this paper. It will allow to figure out the impact of the sea water desalination engine, its cost and its benefits.

In the next paper it will be studied the heat flow and boundary dimensions of the cylinder tank and angular speed to have the optimal steam flow.

References :

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