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# OPTIMUM RADIUS OF CYLINDERICAL ENVELOPE OF SOLAR ENERGY RECEIVER

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ABSTRACT:

This paper presents an analytical procedure for estimation of the optimum radius of the cylinderical envelope of solar energy receiver. The cylinderical solar absorber and the envelope of the solar receiver are located horizontally and their axes are coincided.

The study is based on the fact of the variation of the convective heat loss from the solar receiver to the surrounding air by varying the envelope radius for a given absorber radius and given boundary conditions. For the case of an unevacuated air layer in the cylinderical space in between the solar absorber and the envelope it is found that the optimum radius of the envelope equals to 1.348 times the absorber radius.

NOMENCLATURE:

| | | |
|---|---|---|
| A , | parameter given by Eqn. (11), | $w/m^2.k^{1.25}$ ; |
| B , | parameter given by Eqn. (13), | ---------- ; |
| g , | acceleration of gravity, | $m/sec^2$ ; |
| Gr, | Grashof number, $(gd^3/\nu^2)(\beta.\Delta T)$, | ---------- ; |
| h , | convective heat transfer coefficient, | $w/m^2.k$ ; |
| k , | thermal conductivity, | w/m.k ; |
| l , | length, | m ; |
| Pr, | Prandtl number, $(\nu/\alpha)$, | ---------- ; |
| Q , | convective heat loss rate, | w ; |
| R , | radius, | m ; |

$T$ , temperature, k ;

$\alpha$ , thermal diffusivity, $m^2/sec$ ;

$\beta$ , coefficient of volume thermal expansion, 1/k ;

$\varepsilon$ , thermal condutivity correction factor, --------- ;

$\nu$ , kinematic viscosity, $m^2/sec$ ;

Subscripts:

1 , absorber;

2 , envelope;

d , diameter;

eq, equivalent;

f , ambient air;

m , air layer at mean temperature;

s , surface temperature;

un, uncovered absorber;

$\delta$ , thickness of air layer in between surfaces.

INTRODUCTION:

It is well known that in the solar energy technology [1,2] glass envelopes are used for covering the solar absorbers to minimize the heat losses from the absorbers to the surroundings. The heat losses from a cylinderical solar absorber are not influenced only by the absorber properties and the surrounding conditions but also by the envelope (cover) material and size.

The present work is devoted to estimate the optimum radius (diameter) of the cylinderical envelope of cylinderical solar energy absorber. The optimum envelpoe radius is the radius at which the heat losses from the absorber to the surroundings will be minimum. An analytical procedure is proposed.

ANALYSIS:

The theoretical analysis of the heat losses from the solar absorber to the surroundings is based on the assumption that the envelope material does not absorb and does not emit thermal radiation.

Figure (1) shows schemtically a solar energy receiver which consists of a cylinderical absorber of radius $R_1$ and a cylinderical envelope of radius $R_2$. It is assumed that the receiver is located horizontally and the axes of the absorber and the envelope are coincided. Assume that the envelope has a negligable thickness and has a surface temperature of $T_2$, while the absorber surface temperature is $T_1$ and the ambient air temperature is $T_f$. Figure (1) shows also the free air flow around the solar receiver.

The convective heat transfer from the absorber to the envelope through the air layer in between them is conditionally calculated by the formulae of heat conduction [3, 4], i.e.

$$Q_{1-2} = k_{eq}(2\ 1)(T_1-T_2)/\ln(R_2/R_1) \ , \qquad (1)$$

where $k_{eq}$ is the equivalent thermal conductivity of the air layer,

$$k_{eq} = \varepsilon k. \qquad (a)$$

The correction factor $\varepsilon$ can be given by the relation [3]:

$$\varepsilon = 0.18(Gr\ Pr)^{0.25}_{m,\delta} \ . \qquad (2)$$

Equation (1) can be rewriten in the following form:

$$\frac{Q_{1-2}}{2\pi R_1 l} = 0.18 \left[\frac{g\beta k^4}{\nu \alpha R_1}\right]^{0.25}_{m} \times \frac{\left[(R_2/R_1)-1\right]^{0.75}}{\ln(R_2/R_1)} \times (T_1-T_2)^{1.25} \ . \qquad (3)$$

The covective heat transfer from the envelope to the ambient air is given by Newton's law

$$Q_{2-f} = h\ (2\pi R_2 l)(T_2-T_f) \ . \qquad (4)$$

The convective heat transfer coefficient h can be obtained from the following expression [3] :

$$Nu_{fd} = \frac{hd}{K_f} = 0.5\ (Gr\ Pr)^{0.25}_{f,d}(Pr_f/Pr_s)^{0.25} \ . \qquad (5)$$

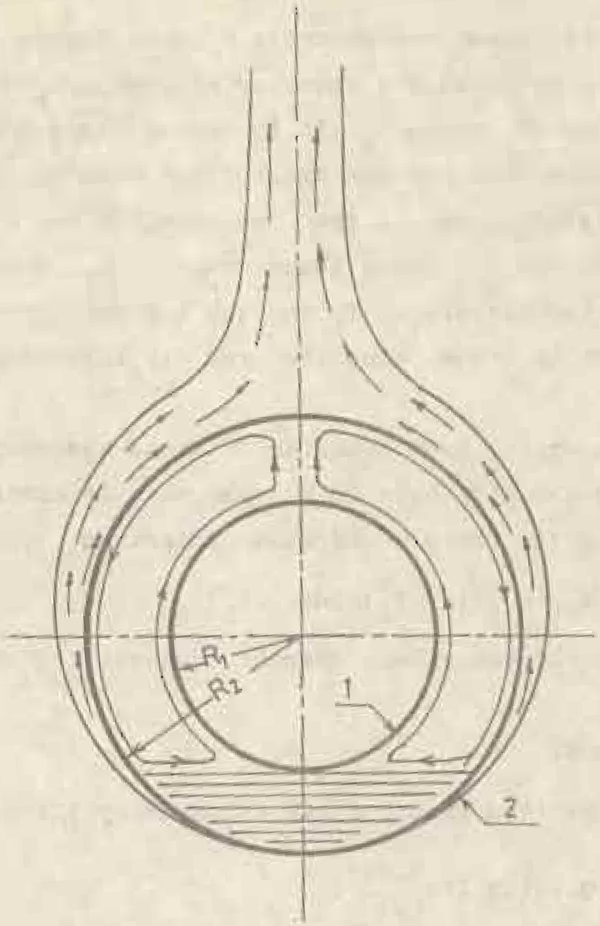


FIG. (1) FREE AIR FLOW AROUND HORIZONTAL CYLINDERICAL SOLAR ENERGY RECEIVER

1- absorber, 2- envelope.

In the case of the solar receiver and the ambient air it can be assumed that

$$(Pr_f/Pr_s)^{0.25} = 1.0 \; . \tag{b}$$

Equation (4) can be rewritten in the following form:by using equations (5) and (b):

$$\frac{Q_{2-f}}{2\pi R_1 l} = 0.42 \left[\frac{g\beta k^4}{\nu\alpha R_1}\right]_f^{0.25} (R_2/R_1)^{0.75} (T_2-T_f)^{1.25} . \tag{6}$$

Assume that the envelope is made of a material, which does not absorb and does not emit thermal energy. Therefore, it is assumed that the envelope radius has no effect on the radiative heat loss from the absorber to the surroundings and the convective heat transfer from the absorber to the envelope is equivalent to the convective heat transfer from the envelope to the ambient air, i.e.

$$Q_{1-2} = Q_{2-f} = Q \; . \tag{7}$$

Solving Equns. (3), (6) and (7) gives

$$\frac{Q}{2\pi R_1 l} = \left\{ \frac{(T_1-T_f)}{\left[\frac{\ln(R_2/R_1)}{0.18A_m\left[(R_2/R_1)-1\right]^{0.75}}\right]^{0.8} + \left[\frac{1}{0.42A_f(R_2/R_1)^{0.75}}\right]^{0.8}} \right\}^{1.25} , \tag{8}$$

where

$$A_m = \left[\frac{g\beta k^4}{\nu\alpha R_1}\right]_m^{0.25} , \tag{9}$$

and

$$A_f = \left[\frac{g\beta k^4}{\nu\alpha R_1}\right]_f^{0.25} , \tag{10}$$

For certain given conditions parameters $A_m$ and $A_f$ can be calculated and the ratio of the envelope radius to the absorber radius ($R_2/R_1$) can be estimated for the case of minimum heat loss. For example, it is required to estimate the optimum radius of the envelope for a case, in which the air layer in between the absorber and the envelope is maintained at atmospheric pressure and the temperature difference is small. In this case it can be assumed that the ambient air properties values are equal to those of the air layer in between the absorber and the envelope, i.e. it can be assumed that

$$\left[\frac{\varepsilon\beta k^4}{\nu\alpha R_1}\right]_m^{0.25} = \left[\frac{\varepsilon\beta k^4}{\nu\alpha R_1}\right]_f^{0.25} = A_m = A_f = A \;, \qquad (11)$$

and the convective heat loss from the absorber is given by

$$Q = 2\pi R_1 l\ (A^{0.8}/B)(T_1-T_f)^{1.25} \;, \qquad (12)$$

where

$$B = 3.94\left[(R_2/R_1)-1\right]^{-0.6}\left[\ln(R_2/R_1)\right]^{0.8} + 2(R_2/R_1)^{-0.6} \;.. (13)$$

In the case of uncovered cylinderical solar absorber the convective heat loss from the absorber to the ambient air takes the following (simillar to Eqn. 6) form:

$$\frac{Q_{un}}{2\pi R_1 l} = 0.42\ A\ (T_1-T_f)^{1.25} \;. \qquad (14)$$

Dividing Eqn. (12) by Eqn. (14) gives an expression for the reduced convective heat loss in the form

$$\frac{Q}{Q_{un}} = 2.38\ B^{-1.25} \;. \qquad (15)$$

Figure (2) shows the variation of the reduced convective heat loss from the solar absorber ($Q/Q_{un}$) with the variation of the ratio of the envelope radius to the absorber radius ($R_2/R_1$). From Fig. (2) it is shown that the redused convective heat loss

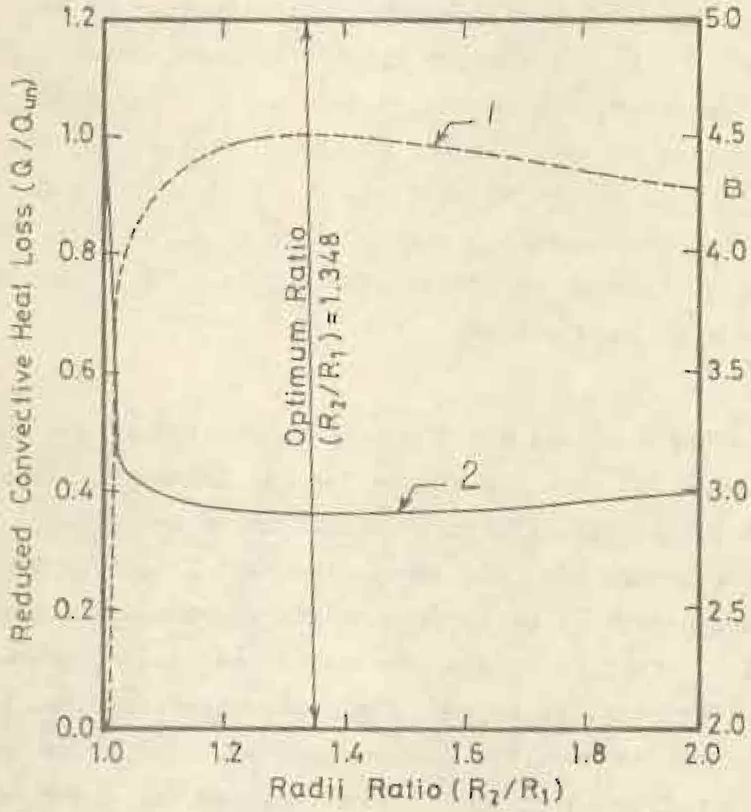


FIG.(2) EFFECT OF ENVELOPE RADIUS ON CONVECTIVE HEAT LOSS FROM HORIZONTAL SOLAR ABSORBER

1-parameter B, Eqn. (13)
2-reduced convective heat loss, Eqn. (15)

equal to unity when the radii ratio equal to unity, and the reduced convective heat loss decreases by increasing the radii ratio to a limitted value, after which the reduced convective heat loss increases by increasing the radii ratio.

The convective heat loss from the solar absorber at certain thermal and ambient condition will be minimum at the maximum value of the variable B, which depends only on the ratio of the envelope radius to the absorber radius. A simple computer program [5] was used to get the maximum value of variable B. The maximum value of variable B was found to be 4.496 (i.e. the minimum value of the reduced convective heat loss $(Q/Q_{un})=0.363$) at a radii ratio $(R_2/R_1) = 1.348$ .

CONCLUSION:

The presented analysis and the performed calculations show that the cylinderical envelope radius has an influence on the convective heat loss from the cylinderical solar energy absorber to the surrounding air. The convective heat loss from horizontal absorber decreases by increasing the envelope radius to a certain value, after which the convective heat loss increases by increasing the envelope radius. The convective heat loss has a minimum value at an envelope radius equal to 1.348 times the solar absorber radius in the case of unevacuated air layer in between the absorber and the envelope.

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