ON INDIRECTLY IRRADIATED SOLAR RECEIVER-REACTORS FOR HIGH-TEMPERATURE THERMOCHEMICAL PROCESSES

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A solar receiver-reactor concept for high-temperature thermochemical applications involving gas and condensed phases is presented. It features two cavities in series. The inner cavity has a small aperture to let in concentrated solar power. It serves as the solar receiver, radiant absorber, and radiant emitter. The outer cavity is a well-insulated enclosure containing the inner cavity. It serves as the reaction chamber and is subjected to thermal radiation from the inner cavity. A radiation heat transfer analysis based on the radiosity enclosure theory is formulated and results are presented in the form of generic curves that indicate the design constraints.

1 THE TWO-CAVITY CONCEPT

A solar cavity-type receiver is basically an enclosure designed to capture effectively the incident solar radiation by allowing entry of radiation only through a small opening, the *aperture*. Solar reactors may feature direct irradiation of reactants to provide an efficient means of heat transfer. However, a major drawback when working with reducing or inert atmospheres is the requirement for a transparent window, which is a critical and troublesome component in high-pressure or severe gas environments. The introduction of a protecting inner cavity between the window and the reaction chamber (outer cavity), as shown in Figure 1, can eliminate this problem. Such an inner cavity serves as the solar receiver, radiant absorber, and radiant emitter. The reaction chamber is subjected to thermal radiation from the inner cavity. With this "two-cavity" arrangement, the optionally windowed aperture is protected from the severe chemical environment existing inside the reaction chamber.

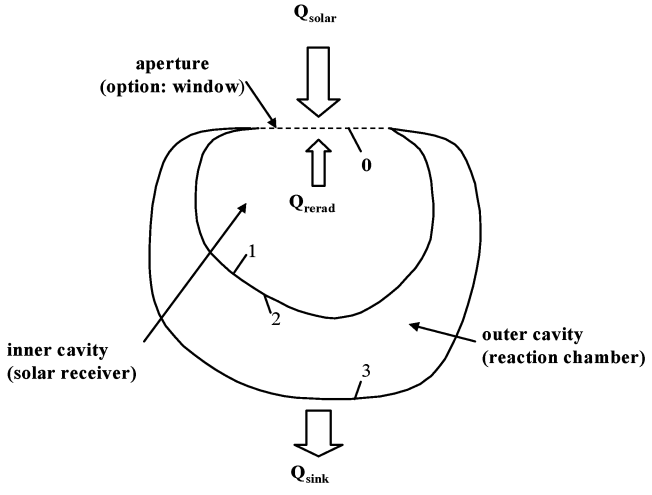

Fig. 1: Sketch of a generic two-cavity reactor with surfaces 0-3 (areas A_i, temperatures T_i, emissivities ε_i, I = 1-3). Q_{solar}, Q_{rerad}: Energy in and out through aperture, Q_{sink}: Energy into reaction and heat losses.

2 SOLAR REACTOR EFFICIENCIES

Using the radiosity method for enclosures, the solar energy absorption efficiency η_{2C} of the two cavity arrangement is [1]:

$$\eta_{2C} = -\frac{Q_{sink}}{Q_{solar}} = \frac{1-\dfrac{T_3^4}{T_{\max}^4}}{1+\dfrac{A_0}{A_2}\cdot\left(\dfrac{2}{\varepsilon_2}-1\right)+\dfrac{A_0}{A_3}\cdot\left(\dfrac{1}{\varepsilon_3}-1\right)} \qquad (1)$$

which $T_{max}=(Q_{solar}/A_0/\sigma)^{0.25}$, $\sigma = 5.6705 \cdot 10^{-8}$ $Wm^{-2}K^{-4}$.

The variation of η_{2C} as a function of T_3/T_{max} is plotted in Figure 2 for different surface area ratios A_2/A_0 and for $\varepsilon_2 = \varepsilon_3 = 1$. For a given A_2/A_0, η_{2C} decreases with T_3/T_{max} because of the higher re-radiation losses through the aperture. For a given temperature ratio T_3/T_{max}, the efficiency η_{2C} increases with the surface area ratio A_2/A_0 because Q_{sink} is proportional to the surface area A_2 and increases with increasing temperature difference T_2-T_3.

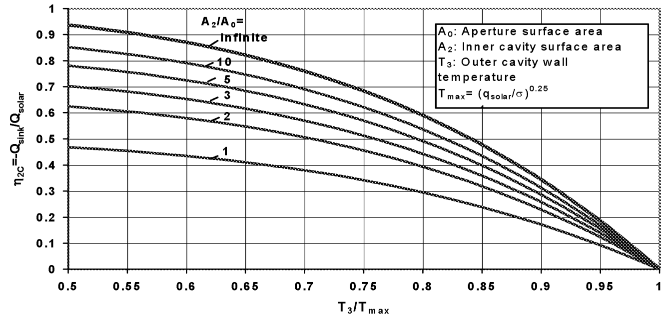

Fig. 2: Variation of the efficiency η_{2C} as a function of T_3/T_{max} for different A_2/A_0.

3 CONCLUSION

General design rules for two-cavity reactors are:

1. The surface area ratio A_2/A_0 should be as large as possible.
2. The emissivities of the inner and outer cavity, ε_2 and ε_3, should be as high as possible.

4 ACKNOWLEDGMENTS

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5 REFERENCE

[1] C. Wieckert, A. Meier, A. Steinfeld, J. Solar Energy Engineering **125**, February (2003).