Letters to the Editor

Comments on "Merit Index for Gas-Cooled Reactor Heat Transfer"

The total rate at which heat is transferred to the coolant is

$$Q = G \cdot C_p \cdot St \cdot \overline{\Delta\theta} \cdot P_H L \quad , \tag{1}$$

where

G = coolant mass velocity

C_p = specific heat

St = Stanton number

P_H = heated perimeter

L = length of the channel.

$\overline{\Delta\theta}$ is a reference temperature difference between can and coolant; it is supposed to be constant, being determined by thermodynamic and materials considerations. The analysis is therefore limited to gas-cooled reactors. In, for example, sodium-cooled reactors, $\overline{\Delta\theta}$ is so small that it does not limit the design. The pumping power is

$$Q_p = G^3 \cdot f . L \cdot P_W/2\rho^2 \quad , \tag{2}$$

where f is the friction factor and P_W is the wetted perimeter.

The ratio Q/Q_p is proportional to (St/f), suggesting that this latter ratio is a measure of the merit of a heat transfer surface. This conclusion is depressing, since any modification of a smooth surface increases f more than it increases St. It would be valid if G were kept constant; yet Walker and Wilkie[1] pointed out that this is not the right thing to do. The correct strategy is to adjust G so as to keep Q constant. One then finds

$$Q_p = \frac{Q^3}{2(\overline{\Delta\theta})^3} \cdot \frac{1}{\rho^2 C_p^3} \cdot \frac{P_W}{P_H^3 L^2} \cdot \frac{f}{St^3} \quad . \tag{3}$$

From this relation, Walker and Wilkie deduced that

$$X = St^3/f \tag{4}$$

was a better measure of the merit of a surface.

This was a substantial advance, but if left unanswered the question of how much a given increase in X is "worth." Melese-d'Hospital[2] argues that since the average heat flux $Q/P_H L$ is proportional to $X^{1/2}$ (his Y), this quantity is a better figure of merit than X itself.

I submit that this view is oversimplified. Apart from safety, which is not at issue here, the only thing that matters about a nuclear power plant is its cost. Like high outlet temperatures, high heat fluxes are meritorious only to the extent that they reduce cost. The following argument quantifies this line of reasoning. Suppose that the cost of electricity from a reactor may be written

$$C = c_1 + c_2/Q + c_3 Q_p \quad . \tag{5}$$

Here c_1 represents those parts of the cost which are independent of rating, such as the turbines and fuel consumption; c_2/Q is the capital cost of the reactor, including the first fuel charge, which is supposed to be inversely proportional to rating; and $c_3 Q_p$ is the cost of pumping the coolant, including both the capital cost of the circulators and the value of the electricity or steam consumed in them.

The terms c_2/Q and $c_3 Q_p$ both vary with G, and G can be chosen so as to minimize their sum. This minimized sum proves to be proportional to

$$Z = X^{1/4} \quad , \tag{6}$$

and it is suggested that this is a better measure of merit than Melese-d'Hospital's $Y = X^{1/2}$. The analysis is no substitute for a proper optimization. However, it does give some feel for where the optimum will lie.

To illustrate the use of the criterion (6), I will analyze some data given by Poulter[3] on the performance of three different types of finned surfaces. He quotes the quantities

$$J_1 = \frac{Q}{GAC_p} = St \; \frac{P_H}{A} \quad , \tag{7}$$

A being the cross-sectional area of the channel, and

$$J_2 = \frac{\rho \cdot (\Delta p)_{\text{frict}}}{2 \cdot G^2 A^2 \cdot L} = \frac{f P_W}{4A^3} \quad , \tag{8}$$

$(\Delta p)_{\text{frict}}$ being the frictional component of the pressure drop. From Eqs. (7) and (8),

$$Z \propto (J^3/J_2)^{1/4} \quad .$$

TABLE I

Data on Smooth and Finned Surfaces

Type of Surface	J_1(ft^{-1})	J_2(ft^{-5})	$\left(\frac{J_1^3}{J_2}\right)^{1/4}$ (ft$^{1/2}$)
1. Smooth	0.0181	5.18	0.0327
2. Longitudinal fins	0.0193	6.77	0.0321
3. Transverse fins	0.0711	34.4	0.0568
4. Spiral polyzonal fins	0.0923	24.5	0.0752

[1] V. WALKER and D. WILKIE, paper in *High Pressure Gas as a Heat Transfer Medium*, Institution of Mechanical Engineers, London (1967).

[2] G. MELESE-D'HOSPITAL, "Merit Index for Gas-Cooled Reactor Heat Transfer," *Nucl. Sci. Eng.*, **50**, 83 (1973).

[3] D. R. POULTER, Ed., *The Design of Gas-Cooled Graphite-Moderated Reactors*, Oxford (1963).

In Table I, the data for surfaces 2, 3, and 4 are taken from Poulter, while the data for the smooth surface have been computed using standard correlations; the diameter of the smooth surface is identical with the tip diameter of the transverse fins. From Table I, we see that the longitudinal fins are worse than useless, because the fins are too long. The performance of the spiral polyzonal fins, which are used in the Magnox Reactors of the British Central Electric Generating Board, is quite outstanding. If these reactors had had to use smooth cans, the total cost of electricity from them might well have been twice as high as it actually is.

The comparable figure of merit for an advanced gas-cooled reactor (AGR) fuel element is ~0.05 $ft^{1/2}$. Thus, the roughened surfaces used in these later reactors are not as good as the spiral polyzonal fins of the Magnox Reactors. Such fins could not be used in AGR. This reactor has stainless-steel cans, and the neutron absorption in high fins would be excessive. In addition, the fins would be relatively ineffective, because the thermal conductivity of stainless steel is so much less than that of magnox. The merit figure of a stainless-steel duplicate of the spiral polyzonal can is only 0.038 $ft^{1/2}$, so that the roughened can is preferable on purely heat transfer grounds.

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Reply to "Comments on 'Merit Index for Gas-Cooled Reactor Heat Transfer' "

We certainly agree with D. C. Leslie that various figures of merit have and should be considered for heat transfer in gas-cooled reactors. For instance, in our own Note we mention the index $(N_S/f)^{1/2}$ for given flow area, and $(N_S^3/f)^{1/2}$ for given heat transfer area. Those two values correspond to maximum power for a given ratio of pumping power to thermal power. We also state in our conclusions that one would find a "different choice of optimal heat transfer improvement, where overall costs should be minimized rather than thermal output maximized." The criterion derived by D. C. Leslie, $(N_S^3/f)^{1/4}$, corresponds to a simple type of economic optimization, which, by the way, does not include extra costs incurred for enhancing heat transfer, or parasitic pressure losses. His criterion, just like ours, is only a first approximation to try to compare various types of heat transfer improvements. Our criterion has been found to be useful for a number of preliminary designs, but we have no quarrel with anyone else using other powers of the ratio (N_S^3/f), or even other combinations of the ratio of Stanton number to friction factor.

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