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of the ISHR Core

TO: C. B. Graham

FROM: I. Spiewak

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Preliminary studies suggest that the optimum flow arrangements for the ISHR core would be slug flow. The advantages of this type of flow are:

1. Heat is removed from all parts of the reactor in an orderly manner.
2. The average temperature of a well-designed system is half way between inlet and outlet, which results in some nuclear advantage over a well-mixed reactor, operating at outlet temperature. The lower temperature also decreases the volume of saturated gas in the core.
3. The pressure drop can probably be limited to two pipe velocity heads.
4. The gas holdup is about half that of a well-mixed core and close to that of a rotating type core. This consideration becomes quite important at high power densities.

In order to produce slug flow in a sphere, it is necessary to provide a smooth fluid expansion from the inlet pipe to the core. Flow separation in the inlet pipe can be prevented by:

1. Small angle diffusers - If the included angle of the expander is 8° or less, there is no flow separation. This is impractical here because of the large holdup and the poor geometric shape of the reactor.
2. Vanes producing rotation - This system has been proposed by Wislicenus(1). In theory this is a very attractive method of obtaining slug flow of any desired axial velocity distribution. In practice, a stagnant region has always developed in the center of the system, for example along the central axis of a vane-type gas separator, in the outlets of rotating type cores, and in a cylindrical core model where rotation was produced in slanted holes in an inlet plate.
3. Vanes to fill the inlet diffuser without rotation - A crude attempt to do this has been carried out with a series of coaxial cones, but it was not successful(2). The literature reports two-dimensional expanders in which separation was prevented(3), but no three-dimensional systems.

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4. Screens - Screens have been used to produce slug flow in wind tunnel diffusers⁽⁴⁾. It is believed that this work can be applied to reactor cores, and this memo presents the preliminary basis for the design of a diffuser for the ISHR core.

In the ISHR, it is desired to expand from a 12-in. schedule 20 (12.25-in. inside diameter) inlet pipe to a 48-in. inside diameter sphere. The total included angle of the diffuser is arbitrarily selected to be 90° . This angle is very convenient for placing the core symmetrically at the center of the 8-ft. blanket as shown in Figure 1. Diffusers with a 90° angle have been investigated by Schubauer and Spangenberg⁽⁴⁾, and found to be workable.

The screens are placed in the conical expander in such a manner that the static pressure drop across each screen is equal to or greater than the static pressure rise in the expansion between screens. The net pressure gradient across the system acts to keep the diffuser filled, whereas a static pressure rise would cause separation. The total energy loss in an ideal system would be equal to the difference in kinetic energy of the initial and final streams; the static pressures would be equal. However, the design of a practical diffuser includes a small static pressure loss as a factor of safety.

It is also desired to minimize the number of screens for mechanical reasons. The minimum is governed by the consideration that screens with solidity ratios - (metal to total area) above 0.5 lead to unstable hydrodynamics.

The energy balance across a section of diffuser from just after one screen to just after the next is as follows:

$$\frac{v_1^2}{2g} + p_1 = \frac{v_2^2}{2g} + p_2 + k \frac{v_2^2}{2g} + \epsilon \left(\frac{v_1^2}{2g} - \frac{v_2^2}{2g} \right) \quad (1)$$

where

v = velocity, ft./sec.

g = gravitational constant = 32.17 ft./sec².

p = static head, ft. of fluid

k = screen constant

ϵ = 1- efficiency of expansion = 0.1 from Schubauer and Spangenberg⁽⁴⁾

1, 2 refer to upstream and downstream, respectively.

In equation (1), $k v_2^2/2g$ is the static head loss across the screen. The value of k depends on the solidity ratio of the screen, the angle of attack, and the Reynolds number. Figure 2 is a plot of k vs. solidity for turbulent flow normal to screens as presented by Baines and Peterson (5). Interpretation of the Schubauer and Spangenberg data indicate that k in a 90° expansion is greater than in normal flow by a factor of 1.2.

Going back to equation (1), if $p_1 = p_2$, which is the ideal case, the equation reduces to

$$\frac{1 + k - \epsilon}{1 - \epsilon} = \frac{0.9 + k}{0.9} = \frac{v_1^2}{v_2^2} \quad (2)$$

Since $v_1^2/v_2^2 = A_2^2/A_1^2$, the squared area ratio, and since the same energy balance can be made for every screen:

$$\left(\frac{A_1}{A_0} \right)^2 = \left(\frac{A_2}{A_1} \right)^2 = \dots = \left(\frac{A_n}{A_{n-1}} \right)^2 = \frac{0.9 + k}{0.9} \quad (3)$$

where the subscript 0 refers to the inlet pipe area, and the numbers 1 through n refer to the screens.

From equation (3), it follows that

$$\left(\frac{A_n}{A_0}\right)^2 = \left(\frac{0.9 + k}{0.9}\right)^n \quad (4)$$

If the "n"th screen of the ISHR expander is placed at the point of tangency of sphere and cone, $A_n/A_0 = 7.67$. The limiting solidity ratio, 0.5, gives a k of 1.9 from Figure 2. The actual k is $1.9(1.2) = 2.28$, and solving for n, $n = 3.23$.

The ideal system is modified in practice. It is believed that the probability of hydrodynamic instability is increased by the diffuser angle, so it is desired to reduce the solidity ratio. The first standard screen size below 0.5 solidity consists of 1/4-in. round bars at 1-in. center-to-center distance (solidity = 0.438). The effective k is 1.58, and a practical screen system has 5 screens.

These screens are deployed as indicated in Table I.

TABLE I

Screen Position and Static Pressure Distribution

Screen Number	Position in.	A/A ₀	A _n /A _{n-1}	Static Head/Inlet Velocity Head	
				just before screen	just after screen
0	0	1		0	0
1	1.19	1.426	1.426	+0.457	-0.320
2	2.90	2.17	1.523	-0.068	-0.403
3	5.01	3.31	1.523	-0.294	-0.438
4	7.62	5.04	1.523	-0.391	-0.453
5	10.85	7.67	1.523	-0.433	-0.460

The first screen is placed somewhat closer to the pipe than is justified theoretically, based on the experience of Schubauer and Spangenberg.

The pressure drop through the screens amounts to 1.46 velocity heads. The outlet pressure loss in a smooth contraction is about 0.05 velocity heads, so that the total pressure drop is 1.51 velocity heads. For flow through the ISHR of 5000 gpm., inlet velocity is 13.62 ft./sec. and pressure drop, at 250°, is 1.51 psi.

An 18-in. scale model of this system is being built. This will be used to verify the ISHR design. The most important considerations which must be examined are:

1. Screen spacing - The close spacing of the screens may cause interaction of the wake of one screen on the next, resulting in poor performance. This can be corrected by reducing the wire size at constant solidity.
2. Flow separation at the equator- After the last screen there still remains an expansion in the sphere. A small amount of separation near the wall at the equator is likely. Residence time at this point should be evaluated.
3. Reynolds number - By varying mesh size and flow rate, a variation in Reynolds number of a factor of 10 can be attained.
4. Axial velocity profile - The velocity distribution in the sphere can be used to predict the temperature distribution.

I. Spiewak
I. Spiewak

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PROPOSED I.S.H.D. WITHOUT CONTROL ROD

FIG. 1

Fig. 2

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