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SUBJECT: Interim Report on Development of Jet Pump and Shroud as a Recirculation Device Within the Blanket of a Two Region Reactor Vessel

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FROM: J. K. Hayes

SUMMARY

The feasibility of utilizing a jet pump and a shroud as a recirculation device within the blanket of the proposed reactor pressure vessel for the HRE-3 was examined. A Schute-Koerting designed jet pump was tested in conjunction with a 1/3 scale plastic model consisting of a core vessel, two constant area shrouds, and a blanket vessel.

In the development program it was found necessary to replace the single nozzle in the jet pump with a multi-nozzle design to eliminate flow reversal and eddying that existed in the diffuser. With this design change no gross separation was evident in further tests.

Recirculation ratios (Q_s/Q_p) of 1.65 and 2.3 were obtained when using two constant area shrouds having flow annuli areas of 24 and 34.4 square inches, respectively. It was concluded that when using this particular system the recirculation ratio is a function of the area of the shroud annulus as long as turbulent flow is maintained. An expression revealing this relationship was obtained. Pressure drop data was also taken across the shrouds, the jet pump and jet pump and nozzle assembly for various flow rates. Equations were then derived for predicting pressure drops for geometrically similar components.

It was concluded that, a jet pump utilizing a multi-nozzle in conjunction with a shroud designed with a sizeable annulus flow area, provides a very satisfactory recirculation device within the blanket of a two region reactor pressure vessel. A larger circulating pump head is required but the fluid flow in the external circuit may be reduced considerably depending on the shroud used.

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NOMENCLATURE

A	Area of primary jet, in. ²
d	Annulus thickness at equator, ft.
F	Momentum of primary jet, lbs. of force
L	Mean radius of annulus flow area at equator, ft.
W	Flow rate through nozzle, ft./sec.
V	Average velocity of fluid in shroud, ft./sec.
V'	Velocity through nozzle, ft./sec.
ρ	Density of fluid, lbs/ft. ³
μ	Viscosity of fluid, centipoises
ν	Kinematic viscosity, ft. ² /sec.

Dimensionless Ratios

f	Friction factor
K	Flow coefficient
R	Reynolds number
U	Recirculation ratio (Q_s/Q_p)
λ	$\frac{\text{Area of jet pump mixing section}}{\text{Area of primary jet}}$
σ	$\frac{\text{Secondary density}}{\text{Primary density}}$

Flow Rates

Q_s	Secondary flow rate (amount pumped by jet pump) - gpm
Q_p	Primary flow rate (flow through nozzle) - gpm
Q_p'	Flow in external piping in a system wherein the flow is admitted directly to the shroud annulus - gpm
Q_t	Total flow rate through shroud annulus - gpm

Pressure Drops

H_j	Jet pump head - In. H ₂ O
H_{jn}	Pressure drop across jet pump and nozzle assembly - In. H ₂ O
H_{fs}	Pressure drop across jet pump system (from pump discharge to pump suction) - In. H ₂ O
H_{fA}	Pressure drop in "A" shroud - In. H ₂ O
H_{fB}	Pressure drop in "B" shroud - In. H ₂ O

INTRODUCTION

It is necessary to maintain a relatively high velocity of the slurry blanket adjacent to the core tank in a two region reactor vessel to insure that the volume generated heat is removed and that adequate heat transfer occurs at the core blanket interface to maintain the core wall temperature within certain limits. In addition relatively high circulation rates are required within the blanket vessel to assure slurry homogeneity.

The use of a jet pump and shroud suggested a most desirable way to achieve the above specifications while at the same time maintaining a minimum flow in the external piping. This would necessitate a higher circulation pump head but the pump horsepower would be reduced since lower flow rates in the external piping and components would be required.

A design and development program was initiated to determine the feasibility of adopting the above concept to the HRE-3 design. A 1/3 scale aluminum model of the HRE-3 pressure vessel and core tank was designed. After consultation with various vendors, an order was placed for a jet pump designed such as to have a maximum velocity in the nozzle of 45 ft/sec at a flow rate of 300 gpm and a recirculation ratio ($\frac{Q_s}{Q_p}$) of 1.5. (See Figures 14 and 15 in Appendix A).

Also a spherical core tank, three constant area shrouds, a diffuser assembly, and a blanket vessel were designed and fabricated of plexi-glass to be used in preliminary tests with the jet pump nozzle. (See Figure 10 for assembly drawing). The primary objectives which were to be determined through tests of the plastic model and the aluminum pressure vessel are listed below:

1. Determine recirculation ratios for the jet pump with each of the constant area shrouds. (It was questionable whether or not a jet pump could be designed with a reasonable recirculation ratio within the physical limitations required by the vessel geometry).

2. Measure pressure drops across shrouds, diffuser unit, and jet pump assembly.

3. Observe flow pattern within vessel by use of dye injections with special emphasis on flow separation, flow reversal and eddying.
4. Measure slurry concentrations at various locations within the aluminum pressure vessel.
5. Measure heat transfer coefficients at the core wall by the use of specially designed heat meters.
6. Determine locations within the vessel where slurry will tend to settle out.

EQUIPMENT

Figure 10 in Appendix "A" is an assembly drawing of the core tank, shroud, diffuser assembly, nozzle and blanket vessel. (See Figures 11, 12 and 13 for detail drawings of shrouds and other components). For purposes of visual observation all of the above components except the nozzle were made of plexi-glass.

The shroud was designed to have essentially a constant annulus flow area such that the fluid would flow around the core tank at the same velocity. The velocity profile was assumed to be radially perpendicular to the core tank as the fluid swept around the core. This is not entirely true as is seen from a study of the equi-potential lines of flow around a sphere. (See Ref. 2, page 67). Hence, there is some deviation from the shrouds having "constant area" annuli. This was necessary due to the physical limitations existing in the vessel geometry. See Appendix "B" for shroud computations.

Water supplied from the building water supply and metered through a 300 gpm rotometer was used as the fluid within this system. An air pressurized blue dye injection apparatus was connected upstream of the nozzle and by means of tubing to various other locations on the shroud for study of the flow pattern within the vessel. A flexible hose connection and jacking device made it possible to raise and lower the nozzle within the vessel.

In order to measure the total quantity of fluid flowing through the shroud annulus, a salt velocity apparatus was employed. A cylindrical section was attached to the top of the shroud and salt velocity probes located one foot vertically apart in the cylinder. An air pressurized cylinder of sodium chromate dissolved in water was located upstream of the nozzle. Two solenoid valves were used to inject the salt solution into the water before it entered the vessel. Two wheatstone bridges and a brush recorder were used to record the change in conductivity of the solution at the probes (that is, to record the instant the salt solution reached the location of each of the probes). With this information the velocity could be computed and knowing the area of the cylindrical annulus, the total quantity of fluid flowing through the shroud annulus could be determined. (See Figures 8 and 9 in Appendix "A" for photographs of the apparatus).

Three manometers were utilized for various pressure drop measurements. The manometers were connected to the desired locations by means of tygon hose and copper tubing. (See Figure 10 for locations of pressure taps).

Figure 14 is a drawing of the aluminum pressure vessel with the single nozzle jet pump. Figure 15 is an assembly drawing of the pressure vessel and loop design.

TEST PROCEDURE

The loop was first assembled using the single nozzle supplied by the jet pump manufacturer and the "A" shroud. (See Figure 10 for an assembly drawing of the loop and Figure 11 for a detail drawing of the shroud). A sheet metal baffle was fabricated and installed to close the pump suction. A calibration procedure was then initiated for the salt velocity apparatus. With the suction of the jet pump closed the quantity of fluid flowing through the shroud annulus and past the salt velocity probes could be adjusted in known increments by means of the throttle valve and rotometer. Knowing the area of the cylindrical annulus at the location of the probes and the quantity of fluid flowing, the velocity was readily calculated for various flow rates.

A slug of salt solution was injected at each incremental increase in flow which, upon arrival at the location of a probe, effected a change in the resistance in one leg of a wheatstone bridge circuit which was then recorded by a brush recorder. Having the brush recorder set at a particular speed, the time was recorded for the salt solution to travel from one probe to the other. The velocity was thus experimentally determined. (See Figure 7 for the calibration curve).

After the calibration procedure had been completed, the sheet metal baffle was then removed thus opening the suction of the jet pump. Flow was then admitted to the loop in increments of 25 gpm to a maximum flow rate of 300 gpm. By the use of dye injection equipment, it was observed that flow reversal, eddying, and fluid separation were occurring at the diffuser to shroud junction. This existed at all flow rates and varying the distance from the nozzle to the diffuser assembly did not eliminate this condition. However, the flow pattern within the shroud annulus appeared satisfactory. It was concluded that the length of the mixing section upstream of the diffuser was not of sufficient length. However, due to the physical limitations within the proposed vessel prototype for the HRE-3, the length could not be increased. To determine if increasing the mixing length would possibly alleviate this flow condition in the plastic model a sheet metal slip joint was installed in the mixing section of the jet pump which permitted physically lengthening of this section. This was installed within the vessel with the slip joint at its maximum length. Flow was then again admitted to the vessel and by means of the dye injection the flow pattern observed. The former undesirable flow pattern was not evident. The length of the mixing section was decreased until flow separation and flow reversal again occurred. It was concluded that in order to eliminate this condition, the mixing section must have an L/D equal to or greater than 4.

As stated previously, it was not possible to lengthen the mixing section so an alternate method was required to insure adequate mixing. The use of

multiple jets to shorten the required mixing length, as discussed by McClintock and Hood¹ for air craft ejectors, suggested a possible solution. A multi-nozzle, consisting of six jets, was designed and fabricated to replace the single nozzle of the jet pump (See Appendix "B" for design calculations and Figure 10 in Appendix "A" for a detail drawing). It was then installed in the vessel and flow again admitted in 25 gpm increments up to a maximum flow rate of 300 gpm. No flow reversal, eddying, or separation was observed in the shroud or diffuser.

After the flow pattern was deemed satisfactory, manometer lines were then connected to the locations shown on Figure 10. After purging these lines of air, flow was admitted to the loop by means of the throttle valve and pressure drop data obtained across the shroud, the jet pump and the jet pump and nozzle assembly at various flow rates. The salt velocity apparatus was also used to determine the total flow rate through the shroud annulus and then the quantity of fluid computed which was actually pumped or recirculated within the vessel. (See data sheet 1).

After obtaining the above data the "A" shroud was removed and the "B" shroud installed. (See Figure 12 for a detail drawing of the shroud). Pressure drop data and velocity data were again obtained. (See data sheet 2). The flow pattern did not change upon installing the "B" shroud.

DISCUSSION OF RESULTS

From the data obtained in the first test with the multi-nozzle and "A" shroud a graph of total flow rate (Q_t) and secondary flow rate (Q_s) versus primary flow rate (Q_p) was plotted. (See data sheet 1 and Figure 1). It was determined from the graph that the jet pump had a recirculation ratio ($\frac{Q_s}{Q_p}$) of 1.65 when used in conjunction with the "A" shroud.

Also from this data a plot of the jet pump head (P_3) versus the primary flow rate was obtained (See Figure 3). The below expression was resolved from the experimental data:

$$\begin{aligned} H_j &= C Q_p^m \\ &= .00068 Q_p^2 \quad (\text{In. H}_2\text{O}). \end{aligned}$$

The jet pump head may also be defined, as by McClintock and Hood¹ for aircraft ejectors, in terms of the dimensions of the pump, the primary flow rate, and the recirculation ratio.

$$H_j = \frac{F}{A} \left[\frac{1}{\lambda} + \frac{U^2}{\sigma \lambda (\lambda - 1)} - \frac{(1+U)(1+U/\sigma) K}{\lambda^2} - \frac{U^2}{2\sigma (\lambda - 1)^2} \right]$$

$$\frac{F}{A} = \frac{WV}{\frac{g}{A}} = .0463 \quad Q_p^2 \quad \frac{\text{lbs.}}{\text{ft}^2}$$

$$\begin{aligned} \lambda &= 7.46 \\ \sigma &= 1 \end{aligned}$$

Substituting values -

$$H_j = .0089 \left[(.134 + .0088 U^2 - .018 K (1+U)^2) \right] Q_p^2 \quad (\text{In. H}_2\text{O}).$$

Having experimentally determined the value of the constant ($C = .00068$) and the value of the recirculation ratio ($U = 1.65$), it was then possible to compute the flow coefficient for the pump.

$$.0089 \left[.134 + .0088 U^2 - .018 K (1+U)^2 \right] = C$$

$$K = .64$$

It was also possible to express the system pressure drop (from jet pump discharge to jet pump suction) in terms of the primary flow rate, the recirculation ratio, and the area of the shroud annulus as below:

$$\begin{aligned} H_{fs} &= C_1 V^n \\ &= C_2 \left[.321 \left(\frac{1+U}{A_s} \right) Q_p \right]^n \quad (\text{In. H}_2\text{O}) \end{aligned}$$

$$\begin{aligned} V &= \left(\frac{144}{60(7.48)} \right) \left(\frac{Q_p + Q_s}{A_s} \right) \\ &= \left[.321 \left(\frac{1+U}{A_s} \right) Q_p \right] \frac{\text{ft.}}{\text{sec.}} \end{aligned}$$

Since the jet pump head (H_j) and the jet pump system (H_{fs}) pressure drop are equal, the above equation was revised as below:

$$\begin{aligned}
 H_j &= C Q_p^n & H_j &= H_{fs} \\
 &= .00068 Q_p^2 \\
 \therefore C_2 \left[.321 \left(\frac{1+U}{A_s} \right)^2 \right]^2 &= .00068 \\
 C_2 &= .543 \\
 H_{fs} &= .543 \left[.321 \left(\frac{1+U}{A_s} \right)^2 \right]^2 Q_p^2 \quad (\text{In } H_2O).
 \end{aligned}$$

Two equations now existed for the jet pump head which, when equated, permitted recirculation ratios to be calculated for shrouds having different annuli flow areas.

$$\begin{aligned}
 .543 \left[.321 \left(\frac{1+U}{A_s} \right)^2 \right]^2 Q_p^2 &= .0089 \left[.134 + .0088 U^2 \right. \\
 &\quad \left. - .018 (.64) (1+U)^2 \right] Q_p^2 \\
 A_s &= \sqrt{\frac{5560}{\frac{7.81 U^2 + 119}{(1+U)^2} - 10.23}} \quad \text{in}^2
 \end{aligned}$$

Using the above expression and assuming various recirculation ratios the corresponding areas were calculated. These values are plotted on Figure 2. The annulus flow area for the "B" shroud is 34.4 square inches and from Figure 2 this indicated a recirculation ratio of 2.26. Using this value, it was possible to obtain the expression below for the jet pump head (or jet pump system pressure drop):

$$H_{fs} = H_j = .543 \left[.321 \left(\frac{1+U}{A_s} \right) \right]^2 Q_p^2$$

After substituting values for "B" shroud, we obtain:

$$H_{fs} = H_j = .000483 Q_p^2 \quad (\text{In. H}_2\text{O})$$

The above values were plotted on Figure 3 along with the experimental data. Tests with the "B" shroud revealed a recirculation ratio of 2.3 as opposed to a calculated value of 2.26 (See Figure 1).

From data sheet 1, a graph of the pressure drop in the shroud versus the average shroud velocity was obtained (See Figure 4). The below equation was obtained which describes the relationship between these variables:

$$\begin{aligned} H_{fA} &= C V^n \\ &= .078 V^{1.725} \quad (\text{In. H}_2\text{O}) \end{aligned}$$

It was also possible to express the shroud pressure drop in the below form:

$$\begin{aligned} H_{fA} &= 2 K' \frac{L}{d} \frac{V^2}{2g} \frac{v^{m-2} d^{m-2} e^{m-2}}{\mu^{m-2}} \\ &= \left[2 K' \left(\frac{v}{e} \right)^{2-m} \frac{L}{d^{3-m}} \frac{1}{2g} \right] V^m \\ \therefore C &= \left[2 K' \left(\frac{v}{e} \right)^{2-m} \frac{L}{d^{3-m}} \frac{1}{2g} \right] \\ K' &= C g \frac{d^{3-m}}{L} \left(\frac{e}{v} \right)^{2-m} \\ &= .078 \end{aligned}$$

Having the value of K' then permitted a plot of friction factor (f) versus Reynolds Number (R) from the below equation (See Figure 5).

$$f = 2 K' R^{n-2}$$

$$R = \frac{Vd}{\nu}$$

$$= \frac{.156}{R^{.275}}$$

With the value of K' it was also possible to derive the below equation for the pressure drop in the "B" shroud:

$$H_{fB} = \left[\frac{K'}{\left(\frac{1}{\nu}\right)^{.275}} \frac{L}{d^{3-n}} \frac{1}{g} \right]$$

$$= .0554 \nu^{1.725} (In, H_2O)$$

For "B" shroud

$$L = 7.3''$$

$$d = .8''$$

A plot of the above equation is shown on Figure 4. Test results using the "B" shroud are found on data sheet 2 and on Figure 4. The pressure drops, as calculated, were small and hence a greater inaccuracy in taking readings existed. However, the pressure drop data was sufficiently close to the calculated values that the equation is assumed reliable.

Knowing a particular shroud and core tank's dimensions, it is also possible to obtain the pressure drop for a particular flow rate by referring to the friction factor plot (See Figure 5). It is first necessary to calculate the Reynolds Number (R) and then after obtaining a friction coefficient (f) from the graph obtain the pressure drop from the below equation:

$$H_f = f \frac{L}{d} \frac{V^2}{2g}$$

Pressure drop data was also taken across the jet pump and nozzle assembly (P2) for both the "A" and "B" shrouds. (See data sheets 1 and 2, respectively). The only difference between the two tests were the recirculation ratios, which were 1.65 for the "A" shroud and 2.3 for the "B" shroud. This presented a negligible effect in the pressure drop as is seen in Figure 6. The below equation, which expresses the total pressure drop across the jet pump and nozzle assembly for a particular primary flow rate, was obtained from the data:

$$H_{jN} = .00083 Q_p^{1.86} \quad (\text{ft. } H_2O)$$

Objectives four through six, as listed in the introduction, were not accomplished at this time due to a higher priority given other assignments. The loop has been constructed and this data may be obtained at a later date.

CONCLUSIONS

A jet pump, utilizing a multi-nozzle in conjunction with a sizeable annulus flow area, provides a very satisfactory recirculation device within the blanket of a two region reactor pressure vessel.

In comparison with a system wherein the flow passes directly from the external piping to the shroud without any recirculation within the blanket, the external flow (Q_p) may be reduced by a factor of $\left(\frac{Q_p}{1+U}\right)$; however, a larger circulating pump head (Maximum of $.00083 Q_p^{1.86}$ ft. of H_2O) will be required.

RECOMMENDATIONS

It is recommended that the empirical equations and development experience presented in this report, be used as a basis for the design of a full scale jet pump and shroud for testing with slurry prior to this particular recirculation device being instituted as part of a two region reactor system. Small changes in pressure drop affect the operating characteristics of a jet pump considerably thus the recirculation ratio for a full scale jet pump and shroud using slurry should be verified.

REFERENCES

1. McClintock, F. A., and Hood, J. H., Aircraft Ejector Performance, Journal of the Aeronautical Sciences, Vol. 13, no. 11, November, 1946; reprinted Fluid and Particle Mechanics by C. E. Sapple.
2. Streeter, V. L., Fluid Dynamics, McGraw-Hill Publication in Aeronautical Science, 1948, p. 67.

APPENDIX "A"

Data Sheets	1-2
Figures	1-15

Data Sheet 1PRESSURE DROP AND RECIRCULATION DATA FOR "A" SHROUD

Q_p	Q_t	Q_s	P_1	P_2	P_3	V
50	132	82	.2	1.2	1.8	1.76
75			.65	2.45	3.7	
100	288	188	.72	4.2	6.3	3.53
125			1.3	6.5	9.7	
150	370	220	1.6	9.4	13.8	5.3
175			1.85	12.8	20.5	
200	548	348	2.3	16.5	28.0	7.6
225			2.7	21.0	35.4	
250	638	388	3.1	25.5	45.2	8.83

Note: All above data average of three runs.

Q_p Primary flow rate through nozzle - gpm

Q_t Total flow rate through annulus (from salt velocity apparatus) - gpm

Q_s Secondary flow rate - gpm

P_1 Pressure drop across shroud - In. H_2O

P_2 Pressure drop across jet pump and nozzle assembly - ft. H_2O

P_3 Jet pump head (pressure drop from jet pump discharge to jet pump suction) - In. H_2O

V Average velocity in shroud based on Q_p and a recirculation ratio of 1.65 ($V = .01332 Q_t$ ft/sec)

PRESSURE DROP AND RECIRCULATION DATA FOR "B" SHROUD

<u>Q_p</u>	<u>Q_t</u>	<u>Q_s</u>	<u>P₁</u>	<u>P₂</u>	<u>P₃</u>	<u>V</u>
50	169	119	.14	1.2	1.4	1.54
75	282	207	.3	2.47	3.2	2.31
100	317	217	.4	4.2	5.0	3.08
125	---	---	.5	6.6	8.4	3.85
150	420	270	.6	9.5	11.0	4.62
175	---	---	.7	12.76	16.0	5.4
200	644	444	.8	16.5	20.0	6.16
225	820	595	.9	21.5	24.0	6.94

Note: All above data average of three runs.

Q_p Primary flow rate through nozzle - gpm

Q_t Total flow rate through annulus (from salt velocity apparatus) - gpm

Q_s Secondary flow rate - gpm

P₁ Pressure drop across shroud - In. H₂O

P₂ Pressure drop across jet pump and nozzle assembly - ft. H₂O

P₃ Jet pump head (pressure drop from jet pump discharge to jet pump suction) - In. H₂O

V Average velocity in shroud based on Q_p and a recirculation ratio of 1.65 (V = .00934 Q_t ft/sec)

TOTAL FLOW (Q_t) AND SECONDARY FLOW (Q_s) - GALS./MIN.

PRESSURE DROP IN SHROUD - INCHES OF WATER

Fig. 4 Plot of Shroud Pressure Drop
Versus Average Fluid Velocity
in Shroud.

Fig. 5 Plot of Friction Factor (f) Versus Reynolds Number (R)

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Fig. 6 Plot of Pressure Drop Across Jet Pump Assembly Versus Primary Flow Rate.

VELOCITY - Ft./Sec.

3

2

1

— Calculated velocity for various flow rates.

○ Experimental values obtained by salt velocity apparatus.
(All values are averages of five runs)

○ ← Maximum inaccuracy - 10%

Fig. 1 Calibration curve for salt
velocity apparatus.

100

200

300

 Q_p - Gals./Min.

Figure 8

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Figure 9

Figure 14. 30 " Low Pressure Model of HRE-3 Blanket

Figure 10

Figure 12

Figure 13

Figure 15

APPENDIX "B"Detailed Computations -

- a. Design of Multi-Nozzle for
Jet Pump
- b. Constant Area Shroud
Computations

DESIGN OF MULTI-NOZZLE FOR JET PUMP

A. Objective - Design a multi-nozzle to replace single nozzle in jet pump to achieve adequate mixing within the fixed length of the mixing section.

B. Tests with Single Nozzle -

1. Angle of Spread of Single Nozzle -

L_2 adjusted by means of slip joint to 17 25/32" at which time adequate mixing occurred and a desirable flow pattern existed in jet pump.

$$\tan \theta = \frac{\frac{d_2 - d_1}{2}}{(L_2 + L_1)}$$

$$= \frac{4.447 - 1.6}{2(24.063)}$$

$$= \frac{1.411}{24.063} = .0586$$

$$d_2 = 4.447"$$

$$d_1 = 1.625"$$

$$L_1 = 6.275" \text{ (fixed for this part. jet pump)}$$

$$\theta = 3.36^\circ \text{ Included angle } 6.72^\circ$$

2. Multi-Nozzle Design -

Assuming same angle of spread for each nozzle as in a single nozzle jet and picking arbitrarily six nozzles, the following design was achieved:

$$A = .7854 d^2 = .7854 (1.625)^2$$

$$= 2.135 \text{ in}^2 \text{ (area single nozzle)}$$

$$A = 2.135 \div 6 = .356 \text{ in}^2 \text{ (area of one nozzle in multi-nozzle unit)}$$

$$A = .7854 d^2$$

$$d = .674 \text{ in. (dia. of multi-nozzle)}$$

$$\tan \theta = \frac{d_2 - d_1}{2} \cdot \frac{1}{(L_2 + L_1)}$$

$$L_1 = 6.275''$$

$$L_2 = 2'' \text{ (fixed dimensions in jet pump)}$$

$$d_2 = 2(8.275) \tan \theta + d_1$$

$$= 1.644 \text{ in.}$$

Locating the nozzles on a 1 1/2 inches radius will produce the following mixing spread at the end of the mixing section:

CONSTANT AREA SHROUD COMPUTATIONS

- A. Assumptions - Velocity profile of fluid flowing around core is perpendicular to core wall.
- B. Specifications for Shrouds - Shrouds shall be designed such that at a primary flow rate of 300 gpm and a recirculation ratio of 1.5 (total flow of 750 gpm), the maximum velocity in "A" shroud will be 10 ft/sec and "B" shroud 7 ft/sec.
- C. Calculation Procedure

$$\text{Therefore } t = \frac{a}{2\pi(R+t) \sin \theta}$$

I "A" Shroud

$$a = 750 \frac{\text{gals}}{\text{min}} \times \frac{1 \text{ ft}^3}{7.48 \text{ gals}} \times \frac{1 \text{ min}}{60 \text{ sec}} \times \frac{1 \text{ sec}}{10 \text{ ft}}$$

$$= 24 \text{ in}^2$$

$$t = \frac{a}{2\pi(R+t) \sin \theta}$$

$$\text{After simplifying } t = \frac{-13 \pm \sqrt{169 + \frac{30.680}{\sin \theta}}}{2}$$

<u>θ-degrees</u>	<u>t-inches</u>	<u>θ-degrees</u>	<u>t-inches</u>
5	4.9 ²	35	.96
10	2.8	40	.87
15	2.03	50	.72
20	1.55	60	.65
25	1.43	70	.60
30	1.15	80	.58
		90	.56

II "B" Shroud

$$a = 750 \frac{\text{gals}}{\text{min}} \times \frac{1 \text{ ft}^3}{7.48 \text{ gals}} \times \frac{1 \text{ min}}{60 \text{ sec}} \times \frac{1 \text{ sec}}{7 \text{ ft}}$$

$$a = 34.4 \text{ in}^2$$

$$t = \frac{a}{2\pi(R+t) \sin \theta}$$

after simplifying

$$t = \frac{-13 \pm \sqrt{169 + \frac{43.84}{\sin \theta}}}{2}$$

<u>θ-degrees</u>	<u>t-inches</u>	<u>θ-degrees</u>	<u>t-inches</u>
5	6.47	50	1.02
10	3.75	60	.91
15	2.70	70	.85
20	2.11	80	.83
25	1.76	90	.8
30	1.5		
35	1.33		
40	1.2		

III Comments

The above calculated values of t will be used in the shroud design except at the connections with the diffuser and outlet at the top of the shroud. The valves will be adjusted to form smooth junctions (using an appropriate radius).

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