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JET PUMP COMPLETION REPORT

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ABSTRACT

This report describes the development and testing of a jet mixing component, JETMIXER, for RELAP5. When the jet mixing component is used the momentum equations are modified to reflect the additional momentum flux terms that result from the one-dimensional mixing of two parallel fluid streams. The JETMIXER component is primarily intended to be the basic building block used to model the jet pumps present in boiling water. It could also be used to model the momentum mixing that takes place at ECC injection points or for aspirators in steam generators.

For check out, the new JETMIXER component is used, along with standard RELAP5 components, to model the 1/6-scale jet pump from the General Electric single loop test apparatus that was tested at the Idaho National Engineering Laboratory.

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Section 1

INTRODUCTION-JET PUMP PERFORMANCE

There are several components : a typical reactor plant where the momentum effects due to the mixing of two parallel streams of fluid at different velocities may be important. The primary component being the jet pump in a BWR. In this component the pumping action is caused by the momentum mixing of two fluid streams. Momentum mixing effects may also be important at ECC injection points or for the aspirators present in some steam generators. A new JETMIXER component was developed for these cases and tested out for a jet pump. The remainder of this report documents the jet pump application of the JETMIXER component.

1A. JET PUMP FLOW CHARACTERISTICS

Jet pumps are an important component in the design of boiling water reactors-BWR (Figure 1). Jet pumps provide a simple virtually maintenance free efficient primary pumping system.

Under normal operating conditions, a jet pump operates with a high fluid momentum in the drive line (Figure 2) generated by the auxiliary recirculation pump. This momentum creates the necessary suction at the nozzle exit plane to draw fluid from the suction region (the downcomer region in a BWR) into the jet pump. This suction flow then mixes with the high speed drive flow in the mixing region. The high momentum flow leaving the mixing section is converted to a pressure head in the diffuser section.

Figure 3 shows flow directions under normal operating conditions (first quadrant) and the five additional steady state flow regimes that could exist within the jet pump under abnormal conditions. (Two other possible flow regimes exists but they violate continuity assumptions for incompressible steady flow.)

It has been customary to identify jet pump operations in terms of two dimensionless parameters. Theses are the M and N parameters defined

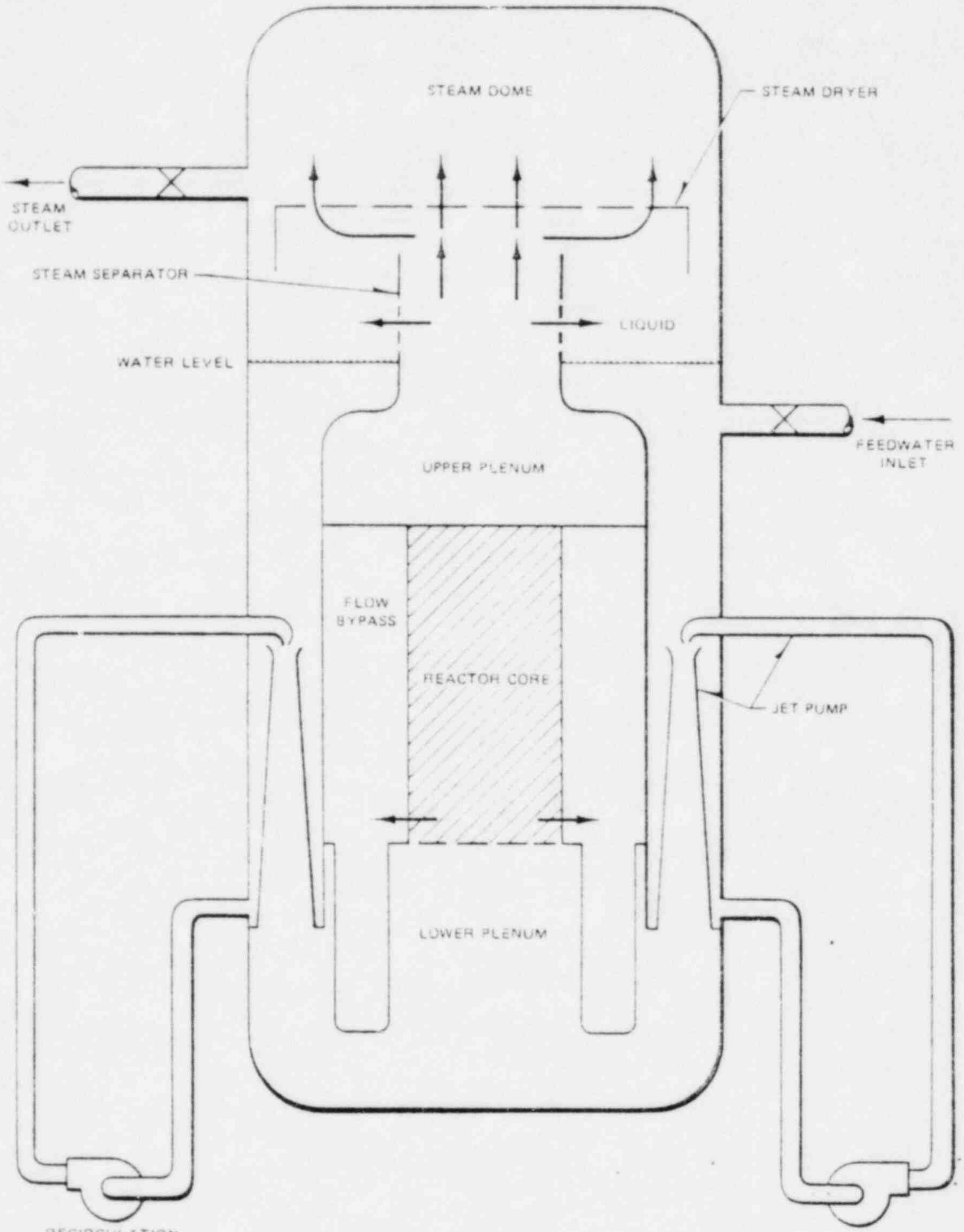

Figure 1. Typical BWR Structure

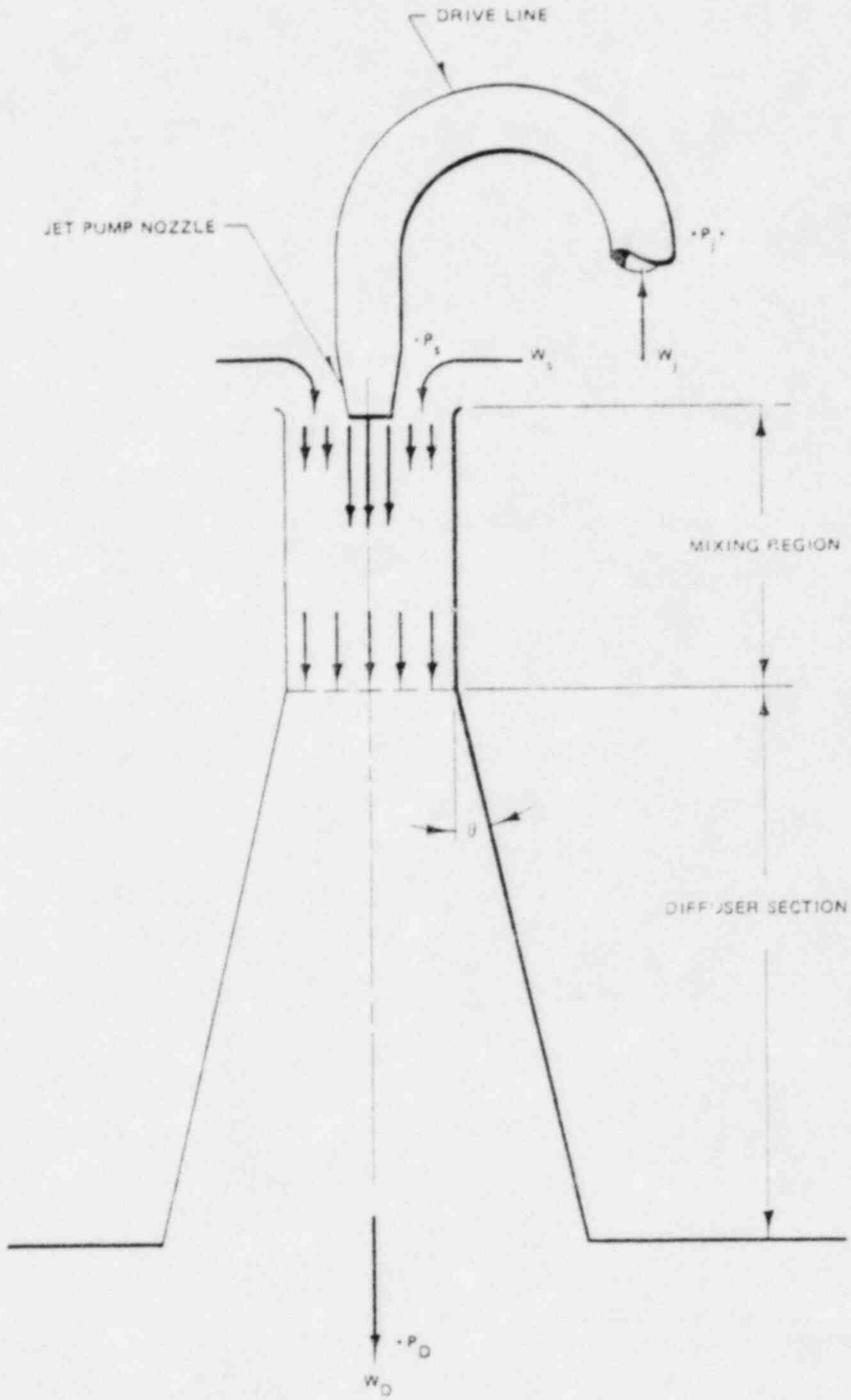

Figure 2. Normal Jet Pump Operation

as follows:

(1) The M - Ratio is the suction flow rate, W_S, divided by the drive flow rate W_j,[1]

$$M = W_S/W_j, \tag{1.1}$$

(2) The N - Ratio (head ratio) is the increase in dynamic pressure for the suction-discharge path divided by the loss of dynamic pressure for the drive-discharge path,

$$N = \frac{(P+\frac{1}{2}\rho v^2+\rho gh)_D - (P+\frac{1}{2}\rho v^2+\rho gh)_S}{(P+\frac{1}{2}\rho v^2+\rho gh)_j - (P+\frac{1}{2}\rho v^2+\rho gh)_D} . \tag{1.2}$$

1B. EXPERIMENTAL RESULTS

Figure 3 shows typical jet pump data in terms of the M-N parameters and the associated flow regimes. This data is for the 1/6-scale jet pump from the General Electric single loop test apparatus that was tested at INEL [1].

Data was collected in all six of the operating regimes shown in Figure 3 but the data scatter was execessive for the positive drive/negative discharge case. The experimental data analysis report [1] indicated that it would be inadvisable to use the M-N data base for positive drive with M less than -0.8 for the development and assessment of analytic models. We have therefore not plotted this data in Figure 3. The data in Figure 3 will be used to test the JETMIXER component developed in Section 2.

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1 Subscripts j, S, D, are used to indicate variables defined at the drive nozzle jet, the suction entrance, and the discharge at the exit of the diffuser section respectfully. If the intended application of the JETMIXER component is not a jet pump then the drive flow should be the high speed stream and the suction the low speed stream. For example, at an ECC injection point the injected fluid is the drive flow and the main upstream flow is the suction flow.

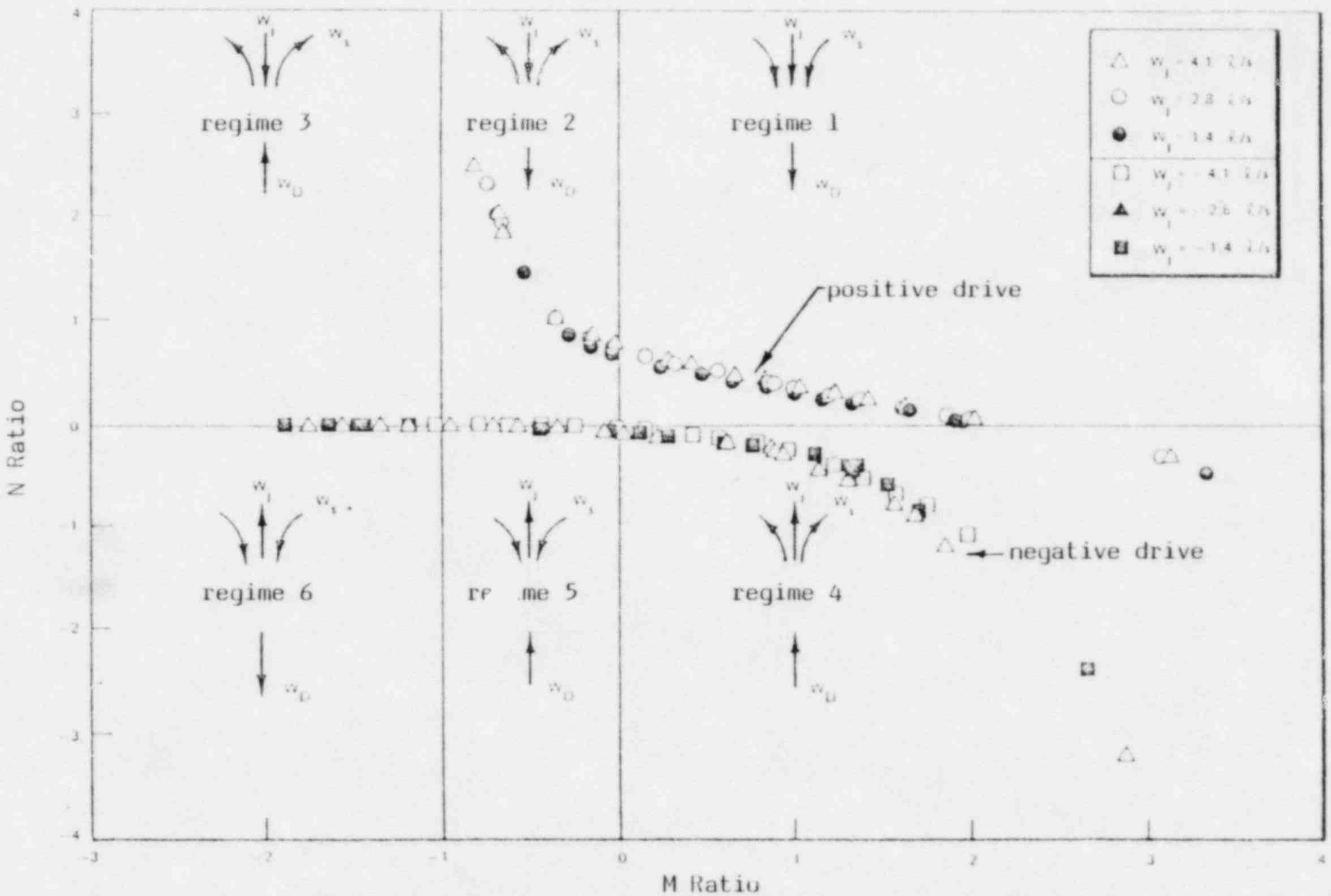

Figure 3. N-M Performance Characteristics of INEL Jet Pump

Section 2

BASIC JET MIXING MODEL

2A. MOMENTUM ANALYSIS FOR JET MIXING IN SINGLE PHASE FLOWS

To develop the momentum equations needed to model a jet pump we will consider the schematic of the drive and suction junctions[1] shown in Figure 4.

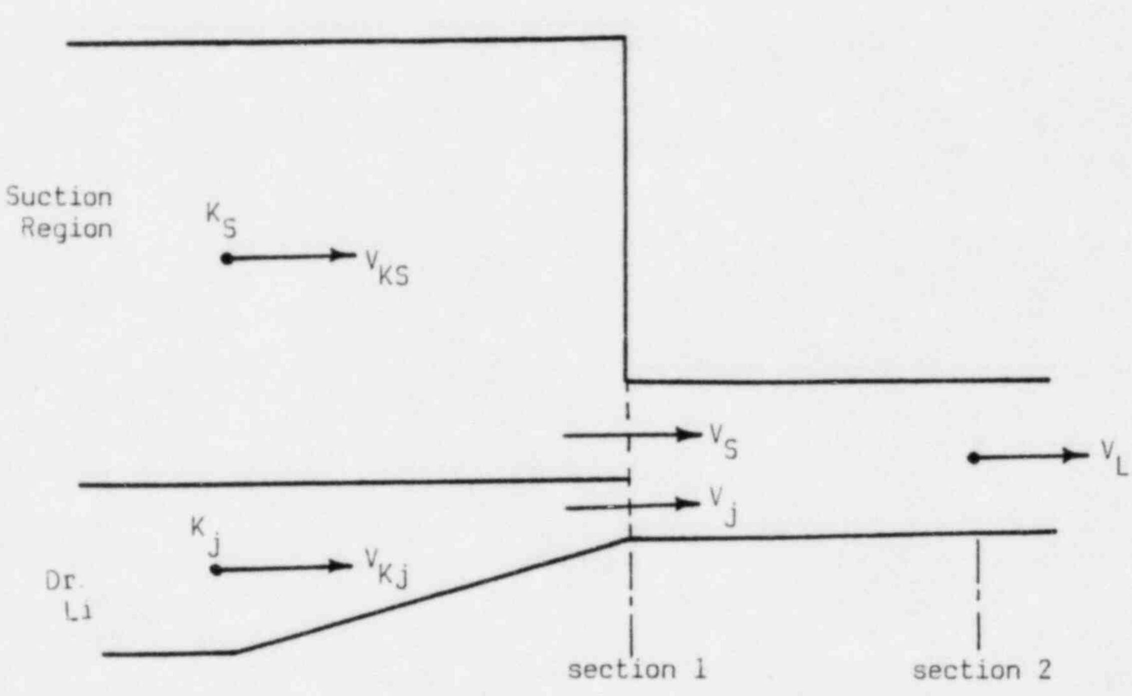

Figure 4. Schematic of Mixing Junctions

[1] The drive and suction junctions should be the high speed and low speed junctions respetively with the JETMIXER component is used for other than jet pump applications.

The suction junction (with velocity v_S and area A_S) connects the last upstream suction region volume, K_S, to the mixing volume, L. The drive junction (with velocity v_j and area A_j) connects the last upstream drive line volume, K_j, to the mixing volume, L. Figure 4 shows the drive junction as a smooth junction and the suction junction as abrupt. The user can model either junction either way if the appropriate loss factors are included (see discussion in Section 5). Void fractions and densities at junctions j or S when subscripted by a j or S are donored valves. If the subscript a is used they are then volume averaged values.

The mixing of the drive and suction flows between section 1 and 2 requires a re-evaluation of the momentum flux terms. The wall drag, interphase drag, temporal acceleration, momentum exchange due to mass transfer, and gravity head terms for the drive and suction junctions are treated exactly as they are at any other junction. Only the pressure and momentum flux terms will be examined in the following momentum equation development.

Consider a control volume in the mixing region between sections 1 and 2. If we apply the conservation of momentum principle for this control volume with the following assumptions:

(1) steady single phase flow,

(2) one-dimensional flow at sections 1 and 2,

(3) pressures at junctions j and S are equal, we obtain

$$(P_L - P_1)\, A_L + \rho v_L^2 A_L - \rho_S v_S^2 A_S - \rho_j v_j^2 A_j = 0. \qquad (2.1)$$

Conservation of mass applied with these same assumptions gives

$$\rho_L v_L A_L - \rho_S v_S A_S - \rho_j v_j A_j = 0. \qquad (2.2)$$

We now use Equation (2.2) to write Equation (2.1) in its "nonconservative" form, obtaining

$$(P_L - P_1) + \rho_S v_S A_S (v_L - v_S) / A_L + \rho_j v_j A_j (v_L - v_j) / A_L = 0. \quad (2.3)$$

Equation (2.3) gives the momentum equation (pressure and flux terms, that is) for the mixing volume. To develop the momentum equation for the suction junction we write a normal half cell momentum equation from K_S to section 1 i.e.

$$(P_1 - P_{KS}) + \tfrac{1}{2} \rho_{KS} (v_S^2 - v_{KS}^2) = 0. \quad (2.4)$$

and add this to the half cell momentum Equation (2.3) for section 1 to L. This gives

$$(P_L - P_{KS}) + \tfrac{1}{2} \rho_{KS} (v_S^2 - v_{KS}^2)$$

$$+ \rho_S v_S A_S (v_L - v_S) / A_L + \rho_j v_j A_j (v_L - v_j) / A_L = 0. \quad (2.5)$$

If the suction junction were a normal junction its momentum equation would be

$$(P_L - P_{KS}) + \tfrac{1}{2} \rho_{Sa} (v_L^2 - v_{KS}^2) = 0. \quad (2.6)$$

A completely parallel development is obtained for the drive junction equations. Comparing Equations (2.6) and (2.5) shows how the convective terms are modified at a suction or drive junction due to the mixing that is taking place there.

2B. MOMENTUM ANALYSIS FOR JET MIXING IN TWO-PHASE FLOWS

If a similar development is carried out for the pressure and momentum flux terms in the two-phase case the following equations are obtained for the liquid phase in the mixing region:

(1) Conservation of momentum (for section 1 to L)

$$\alpha_{fL}A_L(P_L - P_1) + \alpha_{fL}\rho_{fL}v_{fL}^2A_L - \alpha_{fS}\rho_{fS}v_{fS}^2A_S - \alpha_{fj}\rho_{fj}v_{fj}^2A_j = 0, \tag{2.7}$$

(2) Conservation of mass[1] (for section 1 to L)

$$\alpha_{fL}\rho_{fL}v_{fL}A_L - \alpha_{fS}\rho_{fS}v_{fS}A_S - \alpha_{fj}\rho_{fj}v_{fj}A_j = 0. \tag{2.8}$$

We now use Equation (2.8) to rewrite Equation (2.7) in its nonconservative form

$$\alpha_{fL}(P_L - P_1) + \alpha_{fS}\rho_{fS}v_{fS}A_S(v_{fL} - v_{fS}) / A_L + \alpha_{fj}\rho_{fj}v_{fj}A_j(v_{fL} - v_{fj}) / A_L = 0. \tag{2.9}$$

Equation (2.9) could now be combined with the appropriate half cell momentum equation for the upstream volume to obtain the final momentum equation for the liquid flow at the suction junction. In RELAP5 the phasic momentum equations are used as a sum momentum equation and a difference momentum equation. We will derive these equations directly from Equation (2.9).

To derive the sum momentum equation for the suction junction we add Equation (2.9) for the liquid phase and the parallel equation for the gas phase to obtain

$$(P_L - P_1) + \alpha_{fS}\rho_{fS}v_{fS}A_S(v_{fL} - v_{fS}) / A_L + \alpha_{fj}\rho_{fj}v_{fj}A_j(v_{fL} - v_{fj}) / A_L + \alpha_{gS}\rho_{gS}v_{gS}A_S(v_{gL} - v_{gS}) / A_L + \alpha_{gj}\rho_{gj}v_{gj}A_j(v_{gL} - v_{gj}) / A_L = 0. \tag{2.10}$$

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[1] As stated before, the momentum equation terms due to mass exchange are not being changed by this model addition, so the mass transfer terms in Equation (2.8) are not shown.

The normal half cell sum momentum equation for the upstream suction volume can then be added to Equation (2.10) giving

$$(P_L - P_{KS}) + \alpha_{fS}\rho_{fS}v_{fS}A_S\,(v_{fL} - v_{fS}) / A_L + \alpha_{fj}\rho_{fj}v_{fj}A_j\,(v_{fL} - v_{fj}) / A_L$$
$$+ \alpha_{gS}\rho_{gS}v_{gS}A_S\,(v_{gL} - v_{gS}) / A_L + \alpha_{gj}\rho_{gj}v_{gj}A_j\,(v_{gL} - v_{gj}) / A_L$$
$$+ \tfrac{1}{2}\,\alpha_{fKS}\rho_{fKS}\,(v_{fS}^2 - v_{fKS}^2) + \tfrac{1}{2}\,\alpha_{gKS}\rho_{gKS}\,(v_{gS}^2 - v_{gKS}^2) = 0. \qquad (2.11)$$

as the final form of the pressure and momentum flux terms in the new sum momentum equation to be used at junction S. A parallel equation must be used at the drive junction j. The pressure term in this equation is in exactly the same form as the pressure term in the normal sum momentum equation. Hence at the drive and suction mixing junctions we must replace the normal momentum flux terms by those in Equation (2.11).

To derive the difference momentum equation for the suction junction we divide the liquid mixing Equation (2.9) by α_{fL} and add it to the half cell liquid equation for the upstream suction volume (also divided by the appropriate void fraction, α_{fKS}) to obtain

$$(P_L - P_{KS}) + \alpha_{fS}\rho_{fS}v_{fS}A_S\,(v_{fL} - v_{fS}) / \alpha_{fL}A_L + \alpha_{fj}\rho_{fj}v_{fj}A_j\,(v_{fL} - v_{fj}) / \alpha_{fL}A_L$$
$$+ \tfrac{1}{2}\,\rho_{fKS}\,(v_{fS}^2 - v_{fKS}^2) = 0. \qquad (2.12)$$

We now divide Equation (2.12) by the average junction liquid density, ρ_f, and subtract it from the corresponding gas equation to obtain

$$\frac{\rho_f - \rho_g}{\rho_f \rho_g} (P_L - P_{KS}) + \alpha_{gS}\rho_{gS}v_{gs}A_S (v_{gL} - v_{gS}) / \alpha_{gL}\rho_g A_L$$

$$+ \alpha_{gJ}\rho_{gJ}v_{gJ}A_J (v_{gL} - v_{gJ}) / \alpha_{gL}\rho_g A_L + \tfrac{1}{2}\rho_{gKS} (v_{gS}^2 - v_{gKS}^2) / \rho_g$$

$$- \alpha_{fS}\rho_{fS}v_{fS}A_S (v_{fL} - v_{fS}) / \alpha_{fL}\rho_f A_L - \alpha_{fj}\rho_{fj}v_{fj}A_j (v_{fj} - v_{fj}) / \alpha_{fL}\rho_f A_L$$

$$- \tfrac{1}{2}\rho_{fKS} (v_{fS}^2 - v_{fKS}^2) / \rho_f = 0. \quad (2.13)$$

as the final difference momentum equation to be used at junction S. A parallel equation must be used at the drive junction. The pressure term in Equation (2.13) is in exactly the same form as the pressure term in the normal difference momentum equation. Hence we must replace the normal momentum flux at these junctions by the momentum flux terms in Equation (2.13).

2C. ASSOCIATED FLOW LOSSES

The flow taking place in the "mixing" region of volume L can in reality be either a true jet mixing, corresponding to regime 1 in Figure 3, or a flow split corresponding to regime 4 in Figure 3. The flow separation case is governed by different physics than the jet mixing case considered in the previous discussions. The redistribution taking place when the flow splits is primarily determined by the effective resistances downstream of the separation point in the suction and drive flow paths. The mixing terms derived above do not apply. For this reason and to preserve continuity on the respective performance curves in Figure 3 we apply the additional mixing terms only for the positive drive flow regimes. We use the normal momentum flux calculations for the negative drive flow regimes.

The junctions associated with the JETMIXER component can be modeled as smooth or abrupt. If the junctions are input as smooth then the appropriate flow resistances should be calculated in a standard fashion (see Reference [2]) and input as form loss coefficients at the appropriate junctions by the user. The junctions in the test calculation were modeled in this manner. (See the detailed discussion and user guidelines in Section 5). If the junctions in the JETMIXER component are input as abrupt then the code will calculate form loss coefficients as usual except that (1) the forward loss coefficients at the drive and suction junctions are set to zero. The forward losses at these junctions are really associated with the expansion from the vena contracta to the downstream mixing volume flow area. Because of the parallel mixing streams this loss is no longer appropriate. (2) The reverse loss coefficients for the suction and drive junctions are those associated with the expansions from the junction areas to the suction or drive inlet volume areas. The losses associated with any contraction from the mixing volume to the suction or drive junctions is also neglected for the same reason.

If one considers a typical BWR configuration (Figure 1) then two jet pump related accidents that must be considered are (1) loss of power for a recirculation pump and the resulting pump coastdown and (2) blowdown resulting from the rupture of a drive line. In the first case as the drive flow declines, so does the head developed by the pump and eventually the suction flow reverses. The pump is then operating in flow regime 2. In case 2 the jet pump will be operating in flow regime 5.

If normal flow losses are used in these two cases (as described above for smooth or abrupt area changes) it will be found that the jet pump performance in regime 5 is accurately modeled but that the N Ratio in flow regime 2 is significantly below the experimental data. The reverse flow loss coefficient applied in the suction junction has a significant effect on the jet pump performance in flow regimes 2 and 3. This loss coefficient (in addition to the normal loss coefficient associated with the expansion from A_S to area A_{KS}) represents all the irreversable losses associated with the turning and expansion of the flow from the drive junction. Because this flow regime is an important regime in the accident analysis of a BWR it was decided to include an approximation for this flow dependent loss in the jet mixing model.

This reverse suction flow loss was based upon the expansion losses experienced by the flow as it moves from the drive to the suction junction (Figure 5). In regime 2 the expansion loss associated with the area change A_j to A_S i.e.

$$K = (A_S/A_j - 1)^2 \qquad (2.14)$$

is added to the user input reverse loss coefficient (or the standard abrupt area change loss factor if the junction is input as abrupt) for the suction junction.[1] In regime 3 the effective area for the suction flow that comes from the drive junction is less than A_S because the discharge flow has reversed. In this regime the effective areas for the expansion loss are A_j and A_S ($|W_j/W_S|$). Hence for regime 3 the loss coefficient

$$K = \left(\frac{A_S|W_j/W_S|}{A_j} - 1\right)^2 \qquad (2.15)$$

is added to the user input reverse loss coefficient (or the abrupt area loss factor if the junction input is abrupt) at the suction junction

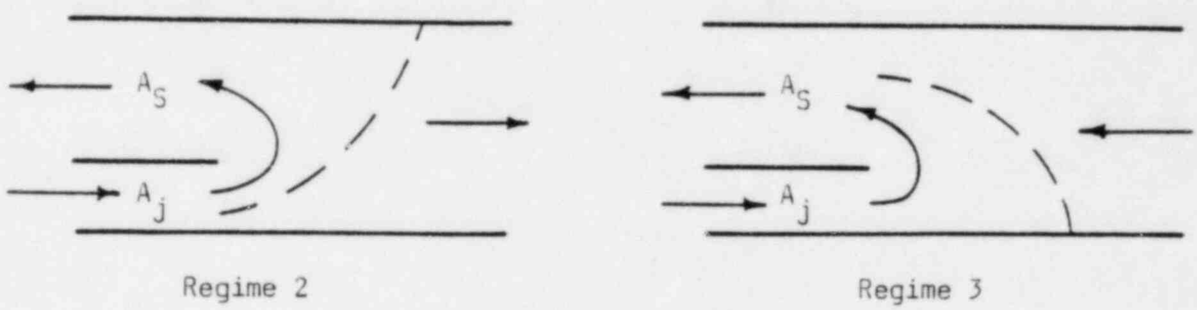

Figure 5. Flow Regimes and Dividing Streamline

1 In reality the expansion loss should be based upon the effective area change $A_j(W_S/W_j)$ to A_S. This form gives an infinitely large loss coefficient when $W_j = 0$ and approaches Equation (2.14) when W_S and W_j are the same order. A kink in the performance curve at $M = 0$ was removed using Equation (2.14).

so long as $A_S|W_j/W_S|$ is greater than A_j. If $A_j|W_j/W_S|$ is less than A_j the drive to suction flow is effectively a contraction and the additional loss coefficient is set to zero.

Since the jet mixing and effective resistances are handled with special terms in the suction and drive junction equations the normal losses associated with the partitioning of volume L are not included in these junction equations. The normal losses associated with the area ratios experienced by the flow upstream of the suction and drive junctions are retained in the junction momentum equations.

Section 3

NUMERICAL IMPLEMENTATION AND CODING CHANGES

The basic numerical algorithm used to evaluate the new momentum flux terms in Equations (2.11) and (2.13) is exactly parallel to the numerical evaluation of the normal momentum flux terms. The present momentum flux terms are calculated explicitly at time level n in the subroutine VEXPLT. The new momentum flux terms in Equation (2.11) and (2.13) are also explicitly evaluated in VEXPLT. The spatial location of each variable is indicated by its subscript.

When Equations (2.11) and (2.13) are examined it is found that the momentum equations for the suction junction S require a knowledge of the drive junction properties and velocities (a parallel statement holds for the drive junction momentum equations). In the present VEXPLT, when we are calculating the momentum terms for junction i, we have no available indices to obtain the properties at any other junction. For this reason it was necessary to define a new component, JETMIXER, and to require the user to input the drive and suction junctions in this component in a pre-assigned order (for details of the input preparation see section 5).[1] Because VEXPLT already contains an outer component loop (with an inner junction loop) no new structuring of the loops in VEXPLT was required. The special terms in Equations (2.11) and (2.13) are then easily built in VEXPLT when the component being processed is a JETMIXER and we know that the first junction in this component is the drive and the second is the suction.

The additional loss coefficients in Equations (2.14) and (2.15) are calculated in VEXPLT immediately following the special momentum flux calculations.

The added mass terms and any stratified flow forces that could be inadvertently included in the drive or suction junctions are set to

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[1] The drive junction must be the first junction input for a JETMIXER component and the suction junction input must be the second junction data input.

zero in the same section of coding. A Fortran listing of the appropriate section of VEXPLT showing these changes is included in Appendix A.

The only other routines modified are listed below with the appropriate changes noted:

HLOSS - several lines were added to flag a JETMIXER component and in this case to skip the normal loss calculation. See Appendix B for Fortran lisiting of appropriate changes.

RBRANCH - input checking and messages were added to see that the drive, suction and discharge junctions of the special JETMIXER branch component are properly connected by the user. Section 4 gives the input requirements and input error messages.

No new array variables were added to the code. Several local variables are used in the special section of coding for a JETMIXER component in VEXPLT. The only local variable used outside of this region of coding is FJET which contains the special JETMIXER resistance coefficient for reverse suction flow.

Section 4

INPUT PREPARATION AND OUTPUT CHANGES

The component name JETMIXER has been added to the component names that can be used. The input for a JETMIXER component is the same as that for a BRANCH component with the following modifications:

(1) For a BRANCH component the junctions connected to that branch can be input with the branch or as separate components. For a JETMIXER three (and only three) junctions, representing the drive, suction and discharge, must be input with the JETMIXER component, i.e. NJ = 3. If NJ $\neq$ 3 an input error message is printed.

(2) The three junction card sequences must be numbered as follows; cards ccc1101 and ccc1201 represent the drive junction, cards ccc2101 and ccc2201 represent the suction junction, and cards ccc3101 and ccc3201 represent the junction in the mixing section.

(3) The drive and suction junctions must be "pointing" into the JETMIXER volume i.e. these junctions must have to connection codes refering to the JETMIXER volume. If this is not the case an input error message is printed. The drive and suction junctions must be connected to the inlet side of the JETMIXER volume and the mixing junction must be connected to the outlet of the JETMIXER volume. If this is not the case an input error message is printed.

Although the junction and volume areas for a JETMIXER are not restricted, the JETMIXER will properly model a jet pump only if the drive and suction flow areas sum to the mixing volume area.

There is no special output for a JETMIXER component.

Section 5

APPLICATION TO JET PUMP MODELING

This section will describe the use of the JETMIXER component to model the 1/6 - scale jet pump test at INEL [1].

5A. MODEL DESCRIPTION

The model, as shown in Figure 6, has the following features:

(1) the suction region is represented by two equal volumes ($A = 5.088E-3\ M^2$, $L = 1.6\ M$) with the suction junction modeled as smooth.

(2) the drive line is also represented by two volumes ($A = 7.26E-4\ M^2$, $L = 1.6\ M$) with a smooth drive junction .

(3) a mixing section represented by two similar volumes ($A = 6.605E-4\ M^2$). The first is a JETMIXER component and the second is a normal volume.

(4) A three volume diffuser PIPE ($L = 4.26\ M$) component followed by a normal volume ($A = 40.7E-4\ M^2$).

The drive and suctions junctions could be modeled with smooth or abrupt area changes. If they are modeled as smooth junctions then the appropriate forward and reverse loss coefficients must be user input. Runs were made both ways with basically the same results. The use of smooth junctions gives the user more explicit control over the resistance coefficients and for this reason was used below.

The resistance coefficients used were calculated in a standard fashion from reference [2] for configurations similar to those of the jet pump. These additives resistance coefficients were taken as turning losses in the drive line ($K = 0.42$) entrance ($K = 0.02$) and exit ($K = 1.0$) losses in the suction junction, mixing ($K = 0.07$) and diffuser losses in the primary piping, and a reverse flow exit loss in the drive line. The expressions used for calculating the loss coefficient in the diffuser section were

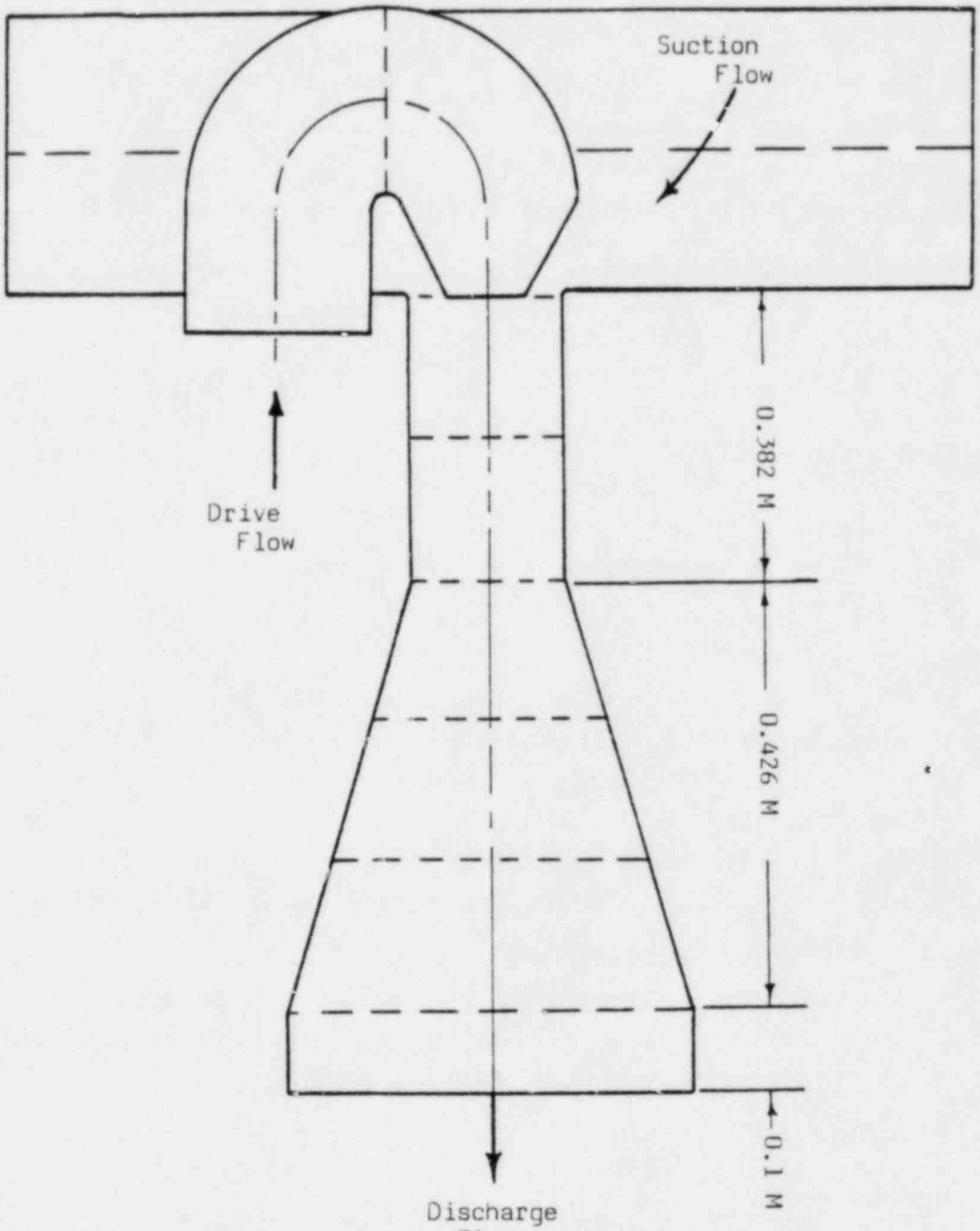

Figure 6. Schematic of Jet Pump Model

$$K_c = 0.8\sin\theta(1-\beta^2) \quad \text{(for contraction)} \quad (5.1)$$

and

$$K_e \; 2.6\sin\theta(1-\beta^2)^2 \quad \text{(for expansion),} \quad (5.2)$$

where β^2 is the area contraction ratio and θ is the half-angle of contraction. For this specific pump these evaluate to $K_c = 0.0337$ and $K_e = 0.0919$. The contraction loss associated with the drive nozzle was set to zero. This loss is really associated with the expansion beyond the vena-contracta point. For the merging of two streams taking place in the jet pump it was felt that this expansion loss was not really present. For reverse drive flow Equation (5.2) was used with a resulting $K_e = 0.238$.

5B. BOUNDRY CONDITIONS

To generate a point on the performance curve a transient was run to steady state. The boundry conditions used were:

(1) Diffuser discharge pressure, P = 75.85E5 Pa.

(2) Two drive mass flows $\pm$ 3.0611Kg/s (volumetric flow $\pm$ 4.1/s) with temperature T = 555.0°K.

(3) The suction inlet mass flows were varied between -3.048Kg/s (M = -.986) and 9.907kg/s (M = 3.22) with T + 555.0°K. A flow rate was imposed at the suction inlet because in this way a whole performance curve could be generated with a single computer run using a time dependent inlet flow table. Several points on the M-N curve were then rerun with the appropriate pressure boundry conditions replacing the imposed suction mass flow. There was no change in the predicted results using the pressure boundry conditions.

5C. CODE PREDICTIONS

Figures 7 and 8 shows the code predictions compared to the experimental data. Figure 7 shows the basic agreement in all four quadrants. A curve

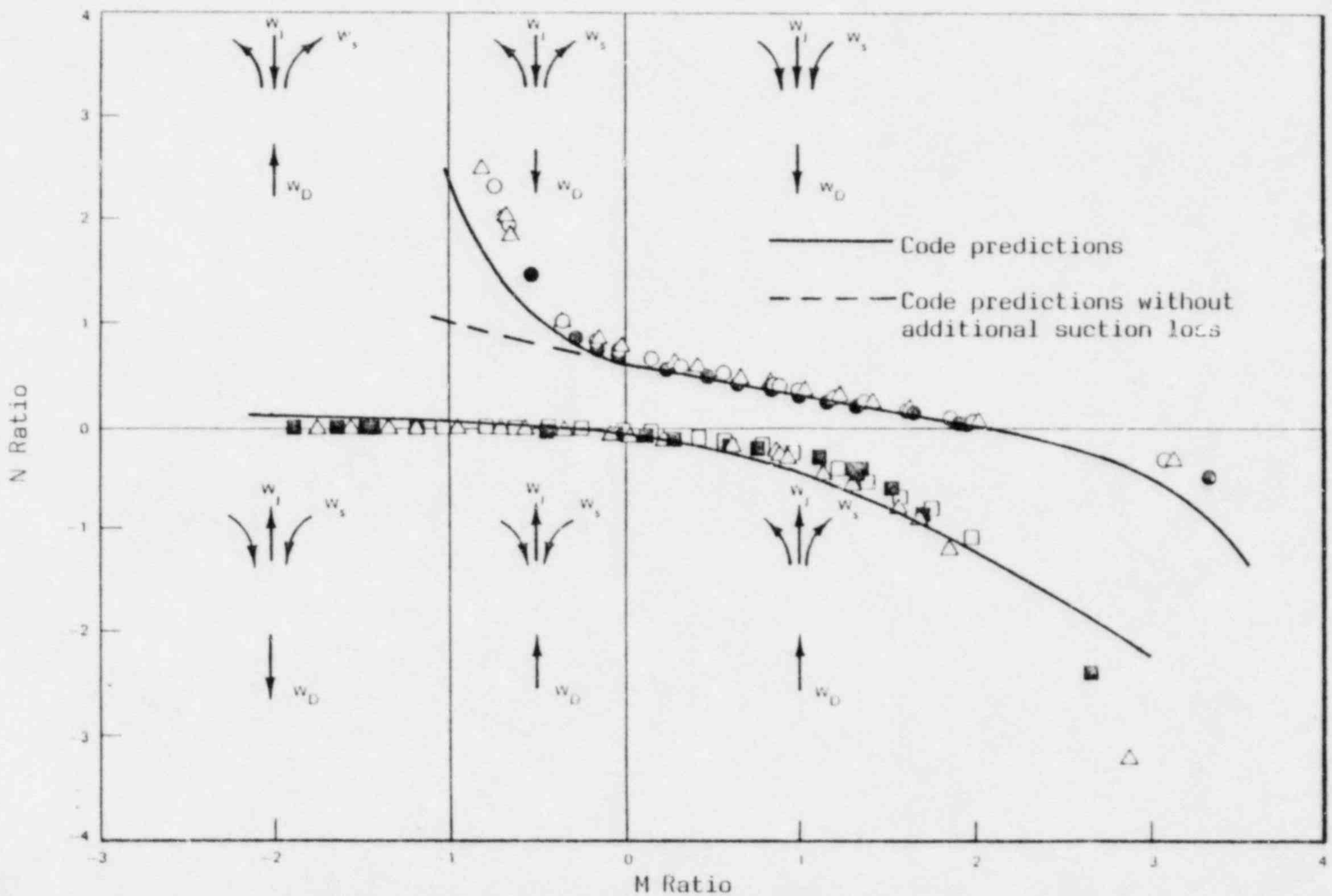

Figure 7. RELAP5 Predictions for INEL Jet Pump

is also plotted showing the disagreement that existed in regime 2 before the reverse suction loss coefficient described in section 2 was included.

Figure 8 shows an expanded view of the normal operating region with several curves representing different flow resistances. This figure can be used as a guide for modeling different jet pump geometries. Each curve shows the M-N performance generated with the loss coefficients discussed above plus a single additional loss coefficient (K = 0.2) added to either the drive or suction or mixing junction. This figure gives an indication of the quantitative change in performance caused by the respective drive, suction or mixing losses. Using this figure, one should be able (with a few preliminary code runs) to design a code model for his specific jet pump if he has the performance data available. If no specific performance data is available it is recommended that the standard losses used above be applied.

There is no special output printed for the JETMIXER component. It is recommended that control variables be used to set up the M and N parameters for minor edit purposes and that these parameters be printed with every edit. A listing of the input cards used to generate the positive drive flow branch of the M-N curves is shown in Appendix C. This input data also shows an example of the use of the control variables to print out the M-N performance parameters.

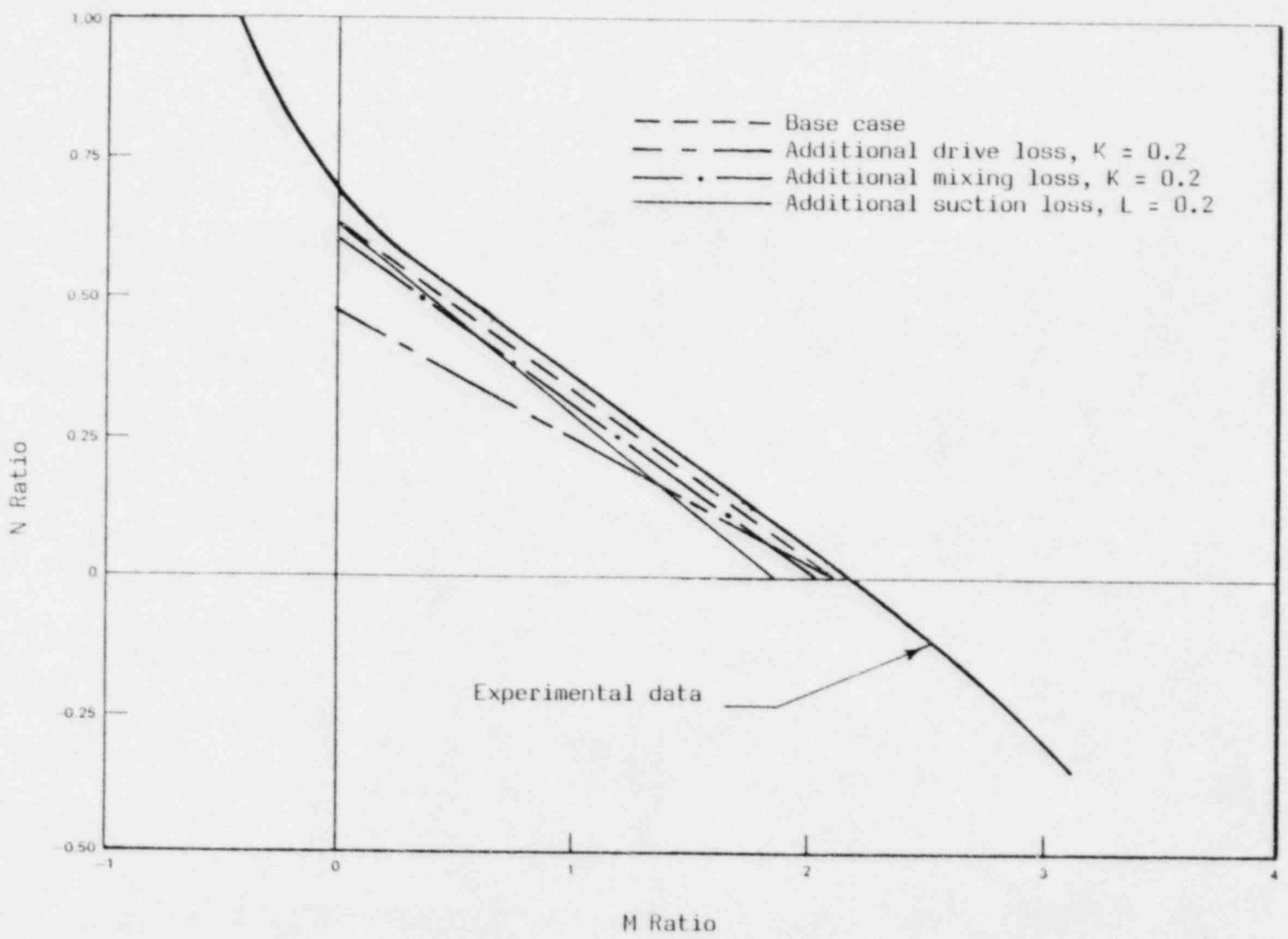

Figure 8. Jet Pump Model Design

Section 6

REFERENCES

1. G.E. Wilson, INEL One-Sixth Scale Jet Pump Data Analysis, EGG-CAAD-5357, EG&G, Idaho, Feb. 1981.

2. Flow of Fluids, Crane Company; Report No. 410, (1979).

```
      GO TO 116                                                      VEXPLT    129
C                                                                    VEXPLT    130
C         SMOOTH PIPE                                                VEXPLT    131
  112 AVK=AJUN(I)/AVOL(K)                                            VEXPLT    132
      AVL=AJUN(I)/AVOL(L)                                            VEXPLT    133
      FJFG=0.0                                                       VEXPLT    134
C                                                                    VEXPLT    135
C                                                                    VEXPLT    136
  116 DXK=DXK*AVK                                                    VEXPLT    137
      DXL=DXL*AVL                                                    VEXPLT    138
      DX=DXL+DXK                                                     VEXPLT    139
      AVKJ=AVOL(K)/AJUN(I)                                           VEXPLT    140
      AVLJ=AVOL(L)/AJUN(I)                                           VEXPLT    141
C                                                                    HXCX205     4
C        JUNCTION WALL FRICTIONS                                     HXCX205     5
      FRICFJ= (DXK*FWALF(K)+DXL*FWALF(L))*RFVFJ                      HXCX205     6
      FRICGJ= (DXK*FWALG(K)+DXL*FWALG(L))*RGVGJ                      HXCX205     7
C                                                                    HXCX205     8
      RFVFJ = RFVFJ*0.5                                              HXCX205     9
      RGVGJ = RGVGJ*0.5                                              HXCX205    10
C                                                                    VEXPLT    142
C  CONVECTIVE TERMS FOR LIQUID AND GAS PHASES                        VEXPLT    143
C                                                                    VEXPLT    144
C     CHECK FOR SPECIAL JETPUMP MOMENTUM FLUX CALCULATIONS IN DRIVE  JATX212     9
C     OR SUCTION JUNCTIONS                                           JATX212    10
      FJET = 0.0                                                     JATX212    11
      IF (ITYPE.NE.6 .OR. JX.EQ.3) GO TO 119                         JATX213     7
      IJET = I+(3-2*JX)*IJSKP                                        JATX212    13
      IF (JX.EQ.2) GO TO 118                                         JATX213     8
  117 DRIVEW = AJUN(I)*(VOIDF(K)*RHOF(K)*VELFJO(I)                   JATX213     9
     *                + VOIDG(K)*RHOG(K)*VELGJO(I))                  JATX213    10
      SUCTW  = AJUN(IJET)*(VOIDF(K)*RHOF(K)*VELFJO(IJET)             JATX213    11
     *                + VOIDG(K)*RHOG(K)*VELGJO(IJET))               JATX213    12
  118 IF (DRIVEW) 119,119,140                                        JATX213    13
C                                                                    JATX212    16
  119 CONVF=VELF(L)**2-VELF(K)**2                                    JATX213    14
      CONVG=VELG(L)**2-VELG(K)**2                                    VEXPLT    150
      IF(VCTRL(L).LT.0) GO TO 120                                    VEXPLT    151
      L4=.NOT.MASK(48).AND.SHIFT(IJ2(I),30)                          JATX210   166
      L4=IXPC+(L4-1)*4                                               VEXPLT    153
      CONVF=CONVF+ABS(VELF(L))*DIFVF(L4)*AVLJ                        VEXPLT    154
      CONVG=CONVG+ABS(VELG(L))*DIFVG(L4)*AVLJ                        VEXPLT    155
  120 IF(VCTRL(K).LT.0) GO TO 130                                    VEXPLT    156
      K4=.NOT.MASK(48).AND.SHIFT(IJ1(I),30)                          JATX210   167
      K4=IXPC+(K4-1)*4                                               VEXPLT    158
      CONVF=CONVF-ABS(VELF(K))*DIFVF(K4)*AVKJ                        VEXPLT    159
      CONVG=CONVG-ABS(VELG(K))*DIFVG(K4)*AVKJ                        VEXPLT    160
  130 CONVF=CONVF*RFVFJ                                              VEXPLT    161
      CONVG=CONVG*RGVGJ                                              VEXPLT    162
      CONVFS=AVRF*CONVF                                              VEXPLT    163
      CONVGS=AVRG*CONVG                                              VEXPLT    164
      GO TO 144                                                      JATX212    17
C                                                                    VEXPLT    166
```

New Coding

Appendix A - VEXPLT

New Coding
26

```
C *** SPECIAL CONVECTIVE TERMS FOR A JETPUMP                                VEXPLT    167
C                                                                           VEXPLT    168
C     HALF CELL FLUX TRERMS UNAFFECTED BY THE JETPUMP MIXING                VEXPLT    169
  140 AJUNT  = AJUN(I)*ATHROT(I)                                            JATX212    18
      AJUNIJ = AJUN(IJET)*ATHROT(IJET)                                      JATX212    19
      SCRACH = VELFJO(I)/ATHROT(I)                                          JATX212    20
      CONVF  = 0.5*(SCRACH**2 - VELF(K)**2)                                 JATX212    21
      CONVFS = 0.5*VOIDF(K)*RHOF(K)*(SCRACH**2 - VELF(K)**2)                JATX212    22
      CONVF  = CONVF*RHOF(K)/RHOFA                                          JATX213    15
      SCRACH = VELGJO(I)/ATHROT(I)                                          JATX212    23
      CONVG  = 0.5*(SCRACH**2 - VELG(K)**2)                                 JATX212    24
      CONVGS = 0.5*VOIDG(K)*RHOG(K)*(SCRACH**2 - VELG(K)**2)                JATX212    25
      CONVG  = CONVG*RHOG(K)/RHOGA                                          JATX213    16
C                                                                           VEXPLT    174
C     ADDITIONAL FLUX TERMS FOR HALF CELL CONTAINING THE JETPUMP MIXING     VEXPLT    175
      RAVOL  = 1.0/AVOL(L)                                                  JATX213    17
      FLUX   = VOIDFJ(I)*RHOFJ(I)*VELFJO(I)*AJUN(I)                         JATX213    18
      FLUXJT = VOIDFJ(IJET)*RHOFJ(IJET)*VELFJO(IJET)*AJUN(IJET)             JATX213    19
      FLUX   = FLUX*(VELF(L)-VELFJO(I)/ATHROT(I))                           JATX213    20
     *       + FLUXJT*(VELF(L)-VELFJO(IJET)/ATHROT(IJET))                   JATX213    21
      FLUX   = FLUX*RAVOL                                                   JATX213    22
      CONVF  = CONVF + FLUX/(AMAX1(VOIDF(L),1.0E-5)*RHOFA)                  JATX213    23
      CONVFS = CONVFS + FLUX                                                JATX213    24
      FLUX   = VOIDGJ(I)*RHOGJ(I)*VELGJO(I)*AJUN(I)                         JATX213    25
      FLUXJT = VOIDGJ(IJET)*RHOGJ(IJET)*VELGJO(IJET)*AJUN(IJET)             JATX213    26
      FLUX   = FLUX*(VELG(L)-VELGJO(I)/ATHROT(I))                           JATX213    27
     *       + FLUXJT*(VELG(L)-VELGJO(IJET)/ATHROT(IJET))                   JATX213    28
      FLUX   = FLUX*RAVOL                                                   JATX213    29
      CONVG  = CONVG + FLUX/(AMAX1(VOIDG(L),1.0E-5)*RHOGA)                  JATX213    30
      CONVGS = CONVGS + FLUX                                                JATX213    31
C                                                                           VEXPLT    192
C     STRATIFIED FLOW FORCES AND ADDED MASS REMOVED FOR JETPUMP             JATX212    36
      DIFSTF(IX+1)=0.0                                                      VEXPLT    194
      FAAJ(I)=0.0                                                           VEXPLT    195
C                                                                           JATX212    37
C     ADDITIONAL BUILT IN FORM LOSS FOR POSITIVE DRIVE REVERSE SUCTION      JATX212    38
      IF (JX.NE.2 .OR. DRIVEW*SUCTW.GE.0.0) GO TO 144                       JATX213    32
      RATION = AMIN1(SUCTW/DRIVEW,-1.0)                                     JATX213    33
      FJET = AMIN1(1.0+AJUNT/(AJUNIJ*RATION),0.0)**2                        JATX213    34
  144 CONTINUE                                                              JATX212    42
C                                                                           VEXPLT    197
C *** HEAD LOSS TERMS                                                       VEXPLT    198
C                                                                           VEXPLT    199
C  USER INPUTTED FORM LOSSES                                                VEXPLT    200
        SCRACH  = 0.01*ATHROT(I)                                            VEXPLT    201
        FLOSS   = 0.0                                                       VEXPLT    202
        IF((FJUNF(I) .EQ. 0.0) .AND. (FJUNR(I) .EQ. 0.0)) GO TO 453         VEXPLT    203
        IF(  AVRF*VELFJO(I)+AVRG*VELGJO(I) )451,450,452                     VEXPLT    204
C  REVERSE LOSSES                                                           VEXPLT    205
  451   FLOSS   =   FJUNR(I)                                                VEXPLT    206
        GO TO  453                                                          VEXPLT    207
  452   FLOSS   =   FJUNF(I)                                                VEXPLT    208
        GO TO  453                                                          VEXPLT    209
```

```
      IF ( VELGJO(I) .GE. 0.0 )  GO TO  8                               HLOSS      54
      KK        =  L                                                    HLOSS      55
      LL        =  K                                                    HLOSS      56
      IK        =  I + 1                                                HLOSS      57
      IL        =  I                                                    HLOSS      58
      GO TO  9                                                          HLOSS      59
    8 KK        =  K                                                    HLOSS      60
      LL        =  L                                                    HLOSS      61
      IK        =  I                                                    HLOSS      62
      IL        =  I + 1                                                HLOSS      63
C  SET JUNCTION AND UP-DOWNSTREAM VOLUME VARIABLES NOT DEPENDENT ON AREA HLOSS      64
    9 AT        =  ATHROT(I)*AJUN(I)                                    HLOSS      65
      RF        =  RHOFJ(I)                                             HLOSS      66
      RG        =  RHOGJ(I)                                             HLOSS      67
C  SET VARIABLES THAT DEPEND ON AREA RATIOS                             HLOSS      68
      AUP       =  AMAX1(AVOL(KK)*ARAT(IK),AT)                          HLOSS      69
      ADOWN     =  AMAX1(AVOL(LL)*ARAT(IL),AT)                          HLOSS      70
C                                                                       HLOSS      71
C     SPECIAL LOSSES FOR JETPUMP-ZERO LOSSES FOR DRIVE OR SUCTION       JATX212     2
C     JUNCTIONS WHEN FLOW IS POSITIVE INDEPENDENT OF AREA RATIOS        JATX212     3
      IF (ITYPE .NE. 6  .OR.  JX .EQ. 3) GO TO 15                       JATX212     4
      IF (JX.EQ.1) DRIVEW=VOIDFJ(I)*RHOFJ(I)*VELFJO(I)                  JATX213     1
     *                   +VOIDGJ(I)*RHOGJ(I)*VELGJO(I)                  JATX213     2
      IF (DRIVEW.LE.0.0) GO TO 15                                       JATX213     3
      IF (VOIDFJ(I)*RHOFJ(I)*VELFJO(I)+VOIDGJ(I)*RHOGJ(I)*VELGJO(I)     JATX213     4
     *   .GE. 0.0) GO TO 1990                                           JATX213     5
      AUP = AT                                                          JATX213     6
   15 IF (AT .EQ. AUP  .AND.  AUP .EQ. ADOWN) GO TO 1990                JATX212     7
      AJ=AMIN1(AUP,ADOWN)                                               HLOSS      76
      IF(VDF.GT.0.001 .AND. VDG.GT.0.001) GO TO 24                      HLOSS      77
C                                                                       HLOSS      78
C           SINGLE PHASE                                                HLOSS      79
      IF(AT.NE.AUP) GO TO 20                                            HLOSS      80
C                                                                       HLOSS      81
C           PURE EXPANSION                                              HLOSS      82
      FORMFJ(I)=(1.0-AUP/ADOWN)**2                                      HLOSS      83
      FORMGJ(I)=FORMFJ(I)                                               HLOSS      84
      IF(ATHROT(I).LT.0.01)                                             HLOSS      85
    1 DXUP(IX)=FIJ(I)*DIAMV(LL)*SQRT(ARAT(IL))*10.0                     HLOSS      86
      GO TO 1990                                                        HLOSS      87
   20 AO=AT+FORMLS(AT/AUP)                                              HLOSS      88
      FORMFJ(I)=((1.0-AO/ADOWN)*AJ/AO)**2                               HLOSS      89
      FORMGJ(I)=FORMFJ(I)                                               HLOSS      90
      IF(ATHROT(I).LT.0.01)                                             HLOSS      91
    1 DXUP(IX)=FIJ(I)*(AJ/AT)**2*(DIAMV(LL)*SQRT(ARAT(IL))*10.0         HLOSS      92
    1     +DIAMV(KK)*SQRT(ARAT(IK)))                                    HLOSS      93
      GO TO 1990                                                        HLOSS      94
   24 IF(VELFJO(I)*VELGJO(I).GT.0.0) GO TO 110                          HLOSS      95
C                                                                       HLOSS      96
C           COUNTER CURRENT FLOW                                        HLOSS      97
      IF(AT.NE.AUP) GO TO 28                                            HLOSS      98
      FORMGJ(I)=(1.0-VDG*AUP/((1.0-VDF)*ADOWN))**2                      HLOSS      99
      AO=   FORMLS(AJ/ADOWN)                                            HLOSS     100
```

New Coding

LISTING OF INPUT DATA FOR CASE 1

```
*JET PUMP TEST CASE
0000100 NEW TRANSNT
0000104 NONE
0000201 60.0  1.E-6  .05  00001  60  50  4000
*
*  MINOR EDIT VARIABLES
0000301 CNTRLVAR C15
0000302 CNTRLVAR C12
0000303 P 020010000
0000304 P 040010000
0000305 P 070010000
0000306 VELFJ 012000000
0000307 VELFJ 032000000
0000308 VELFJ 072000000
*
*  VOLUME CELLS
0100000 DIN TMDPVOL
0100101 7.26E-4  0.16  0.0  0.0  0.0  0.0  0.0  0.0  00
0100200 3
0100201 0.0  75.85E+5  555.
0200000 D1 SNGLVOL
0200101 7.26E-4  0.16  0.0  0.0  0.0  0.0  0.0  0.0  00
0200200 3  75.85E+5  555.
0210000 D2 SNGLVOL
0210101 7.26E-4  0.16  0.0  0.0  0.0  0.0  0.0  0.0  00
0210200 3  75.85E+5  555.
0300000 SIN TMDPVOL
0300101 5.088E-3  0.16  0.0  0.0  0.0  0.0  0.0  0.0  00
0300200 3
0300201 0.0  75.85E+5  555.
0400000 S1 SNGLVOL
0400101 5.088E-3  0.16  0.0  0.0  0.0  0.0  0.0  0.0  00
0400200 3  75.85E+5  555.
0410000 S2 SNGLVOL
0410101 5.088E-3  0.16  0.0  0.0  0.0  0.0  0.0  0.0  00
0410200 3  75.85E+5  555.
0500000 MIX1 JETMIXER
0500001 3
0500101 6.605E-4  0.181  0.0  0.0     -90.0  -.181   0.0  0.0  00
0500200 3  75.85E+5  555.
0501101 021010000  050000000  1.517E-4  0.000  0.238  0000
0501201 0.0  0.0  0.0
0502101 041010000  050000000  5.088E-4  0.02  1.0  0000
0502201 0.0  0.0  0.0
0503101 050010000  055000000  6.605E-4  0.07 0.07 0000
0503201 0.0  0.0  0.0
0550000 MIX2 SNGLVOL
0550101 6.605E-4  0.181  0.0  0.0     -90.0  -.181   0.0  0.0  00
0550200 3  75.85E+5  555.
0600000 DIFF PIPE
0600001 3
0600101 10.277E-4  1  20.028E-4  2  33.004E-4  3
0600201 14.75E-4  1  26.11E-4  2
0600301 0.142  3
0600401 0.0  3
0600601 -90.0  3
```

```
0600701 -0.142  3
0600801 0.0  0.0  3
0601001 00  3
0601101 0000  2
0601201 3  75.85E+5  555.  0.0   0.0   3
0601301 0.0  0.0  0.0  2
0700000 DISCH SNGLVOL
0700101 40.7E-4  0.1  0.0  0.0     -90.0  -.10  0.0  0.0  00
0700200 3  75.85E+5  555.
0800000 DISCHC TMDPVOL
0800101 40.7E-4  0.1  0.0  0.0     -90.0  -.10  0.0  0.0  00
0800200 3
0800201 0.0  75.85E+5  555.
*
*  JUNCTIONS
0120000 JDIN TMDPJUN
0120101 010000000  020000000  7.26E-4
0120200 0
0120201 0.0   0.0   0.0   0.0
0120202 2.0   5.63  5.63   0.0
0320000 JSIN TMDPJUN
0320101 030000000  040000000  5.088E-3
0320200 0
0320201 5.0 -.80 -.80  0.0
0320202 6.0 -.80 -.80  0.0
0320203 8.0 -.60 -.60  0.0
0320204 9.0 -.60 -.60  0.0
0320205 11.0 -.40 -.40  0.0
0320206 12.0 -.40 -.40  0.0
0320207 14.0 -.20 -.20  0.0
0320208 15.0 -.20 -.20  0.0
0320209 17.0  .00  .00  0.0
0320210 18.0  .00 .00  0.0
0320211 20.0 .20  .20  0.0
0320212 21.0 .20  .20  0.0
0320213 23.0 .40  .40  0.0
0320214 24.0 .40  .40  0.0
0320215 26.0 .60  .60  0.0
0320216 27.0 .60  .60  0.0
0320217 29.0 .80  .80  0.0
0320218 30.0 .80  .80  0.0
0320219 32.0 1.00 1.00  0.0
0320220 33.0 1.00 1.00  0.0
0320221 35.0 1.20 1.20  0.0
0320222 36.0 1.20 1.20  0.0
0320223 38.0 1.40 1.40  0.0
0320224 39.0 1.40 1.40  0.0
0320225 41.0 1.60 1.60  0.0
0320226 42.0 1.60 1.60  0.0
0320227 44.0 1.80 1.80  0.0
0320228 45.0 1.80 1.80  0.0
0320229 47.0 2.00 2.00  0.0
0320230 48.0 2.00 2.00  0.0
0320231 50.0 2.20 2.20  0.0
0320232 51.0 2.20 2.20  0.0
0320233 53.0 2.40 2.40  0.0
0320234 54.0 2.40 2.40  0.0
0320235 56.0 2.60 2.60  0.0
```

```
0320236 57.0 2.80 2.80  0.0
0320237 59.0 2.80 2.80  0.0
0320238 60.0 2.80 2.80  0.0
0220000 JD SNGLJUN
0220101 020010000  021000000  7.26E-4  0.42  0.42  0000
0220201 0  0.0  0.0  0.0
0420000 JS SNGLJUN
0420101 040010000  041000000  5.088E-3  0.0  0.0  0000
0420201 0  0.0  0.0  0.0
0520000 JMIX SNGLJUN
0520101 055010000  060000000  6.605E-4  0.0919  0.0337  0000
0520201 0  0.0  0.0  0.0
0620000 JDIFF SNGLJUN
0620101 060010000  070000000  40.7E-4  0.0  0.0  0000
0620201 0  0.0  0.0  0.0
0720000 JDISCH SNGLJUN
0720101 070010000  080000000  40.7E-4  0.0  0.0  0000
0720201 0  0.0  0.0  0.0
*
*  CONTROL VARIABLES FOR PLOT PURPOSES
20500100 VDE    SUM   1.0  0.0  1
20500101 1.0E-10   1.0   VELFJ  012000000
20500200 VSE    SUM   1.0  0.0  1
20500201 1.0E-10   1.0   VELFJ  042000000
20500300 VDSE    SUM   1.0  0.0  1
20500301 1.0E-10   1.0   VELFJ  072000000
20500400 RVVD  MULT  0.5  0.0  1
20500401 RHOF  020010000  CNTRLVAR      001  CNTRLVAR      001
20500500 RVVS  MULT  0.5  0.0  1
20500501 RHOF  040010000  CNTRLVAR      002  CNTRLVAR      002
20500600 RVVDS  MULT  0.5  0.0  1
20500601 RHOF  070010000  CNTRLVAR      003  CNTRLVAR      003
20500700 HEADD  SUM  1.0  0.0  1
20500701 0.0  1.0 P 020010000  1.0 CNTRLVAR 004  8.38 RHOF 055010000
20500800 HEADS  SUM  1.0  0.0  1
20500801 0.0  1.0 P 040010000  1.0 CNTRLVAR 005  8.38 RHOF 055010000
20500900 HEADDS  SUM  1.0  0.0  1
20500901 0.0  1.0 P 070010000  1.0 CNTRLVAR 006
20501000 TOP  SUM  1.0  0.0  1
20501001 0.0  1.0  CNTRLVAR  008  -1.0  CNTRLVAR  009
20501100 BOT  SUM  1.0  0.0  1
20501101 0.0  1.0  CNTRLVAR  007  -1.0  CNTRLVAR  009
20501200 N  DIV -1.0  0.0  1
20501201 CNTRLVAR  011  CNTRLVAR  010
20501300 WD  MULT  7.26E-4  0.0  1
20501301 RHOF  020010000  CNTRLVAR      001
20501400 WS  MULT  5.088E-3  0.0  1
20501401 RHOF  040010000  CNTRLVAR      002
20501500 M  DIV  1.0  0.0  1
20501501 CNTRLVAR  013  CNTRLVAR  014
. *=========================END OF INPUT =======================
```

Example of control variables used to give minor edit of M, N performance curves