

The RETRAN & VIPRE Newsletter



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RETRAN Modification Removes Enthalpy Transport Model Limitation

The RETRAN enthalpy transport model is applied in heated volumes to account for the enthalpy distribution that occurs when a uniform heat flux is applied over the length of the volume. Use of this model yields more realistic volume temperature distributions for use in single-phase heat transfer calculations or a more accurate quality, which gives a more accurate mass distribution. The enthalpy transport option is frequently used in the reactor core region and steam generators. While the model is very useful, it can have limitations in application.

A Limitation in the Current Model

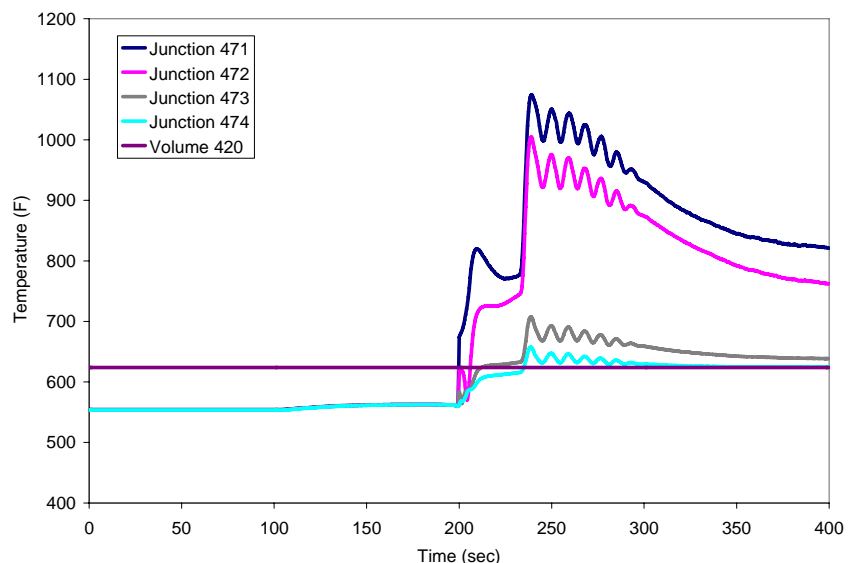
One well known limitation is that the enthalpy transport model can predict anomalous superheating when it is used in a tube bundle region that dries out. The problem occurs when the resulting wall heat flux yields superheated vapor at the exit junction. It is possible for the model to predict exit junction steam superheating hundreds of degrees higher than the temperature of the corresponding primary volume. This is nonphysical.

The adjacent figure shows a typical result from the situation described above. In the figure, temperatures for the secondary-side of a U-tube steam generator are shown during a tube uncover transient. Junctions 471 through 474 represent the exit flow paths for the secondary-side volumes in the steam generator. The problem is observed at about 210 seconds when the lower region (471) becomes highly voided and the junction temperatures begin to increase. The temperature in Junction 471 increases very rapidly, ultimately superheating by hundreds of degrees. Note that all of the secondary temperatures exceed the hot leg (Volume 420) temperature, while they should be lower. The temperature distribution is also inverted in that

the Junction 471 temperature should be the lowest rather than the highest.

The aphysical secondary-side temperatures cause 'reverse' heat transfer to occur, where the secondary-side volumes actually lose heat to the primary-side.

There are two issues that lead to the secondary temperature exceeding that of the corresponding primary volume. The first is the assumption that the heat addition source term in the enthalpy transport equation is treated as a known quantity. In reality, it is dependent on the junction enthalpy that is being computed, a limitation that is amplified when the conditions in the tube region change from two-phase to single-phase vapor. The other issue is that the heat transfer within a volume assumes a two-phase heat transfer regime, even though single-phase vapor conditions exist at the exit.



SGTB Uncovery with Enthalpy Transport (Original)

RETRAN Modification Removes Enthalpy Transport Model Limitation (Cont'd)

There are at least two distinct types of heat transfer occurring in such a volume, one that is driven by the saturation temperature (two-phase) and the other (single-phase) that is driven by the average temperature of the superheated vapor, which directly depends on the heat addition to the single-phase subregion. Simplifying assumptions in the standard enthalpy transport model neglect this coupling.

The New Model: A Subdivided Node

The anomalous superheating behavior is eliminated and accuracy improved by a new enthalpy transport approach that dynamically subdivides a secondary node undergoing a transition from two-phase to superheated conditions. The model computes the length of the two-phase and superheated subregions within the secondary volume and applies appropriate heat transfer fluid boundary conditions to the subregions.

The model is activated when enthalpy transport is active at a junction and when the donor volume is two-phase but the exit junction is superheated steam (as determined from the standard enthalpy transport model). Heat conductor(s) associated with the two-phase volume are required to be two sided for the current implementation. The left boundary volume(s) will be single-phase liquid (steam generator tube volumes). The right boundary will be the secondary volume.

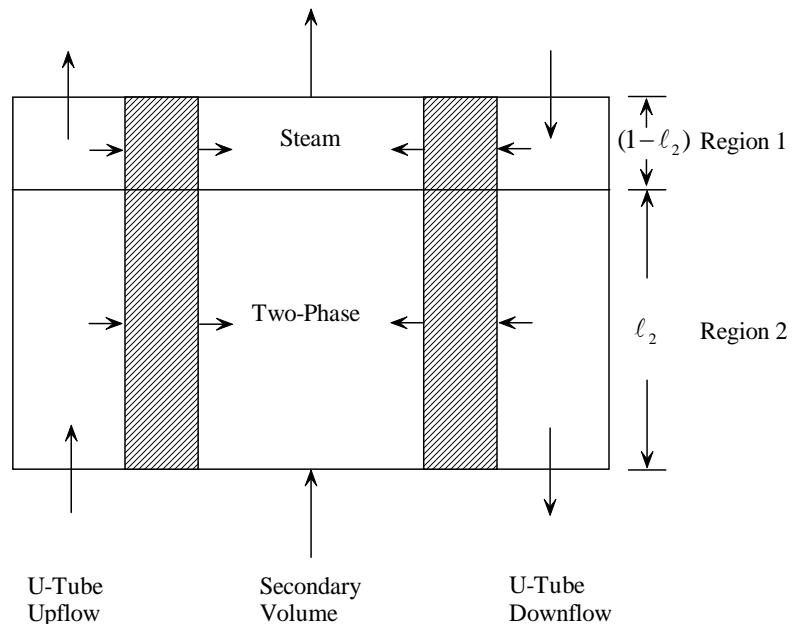
The adjacent figure illustrates a cross section of a typical steam generator model bundle region that is one node high. It is comprised of a volume representing the tubes on the upflow side, a volume modeling the tubes on the downflow side, a single secondary-side volume, and the two-sided heat conductors that allow for heat transfer between the tube volumes and the secondary-side volume.

In the new model, when the secondary volume exit junction dries out (superheats), the axial cross-section nodes are divided into two regions, a two-phase region (Region 2), and a superheated steam region (Region 1). Additional heat conductors (auxiliary conductors) are added automatically to Region 1. The base conductor will be applied over the two-phase length ℓ_2 and the auxiliary heat conductors over the superheated length $(1-\ell_2)$.

are solved over the subregions defined by ℓ_2 . The model assumes:

- (1) volumes are oriented vertically,
- (2) heat conductors are two-sided,
- (3) the two-phase volume is the right boundary for the heat conductors,
- (4) the tube volumes are on the left surface and they will be single-phase liquid,
- (5) axial heat conduction can be neglected,
- (6) the subregion (two-phase) length can be applied to the tube volumes and associated heat conductors,
- (7) all liquid in the secondary-side volume is below the dryout point, and
- (8) all associated exit junctions use enthalpy transport superheated length $(1-\ell_2)$.

When the two-region model is selected via user input, it is inactive until the normal enthalpy transport model predicts superheated steam for the junction exiting from a two-phase volume. The volume must also satisfy the geometry and modeling assumption stated above.



Typical Steam Generator Model Segment

Separate mass and energy equations

RETRAN Modification Removes Enthalpy Transport Model Limitation (Cont'd)

Result: An Improvement

The figure to the right shows the result when the new model is applied to the same tube uncover transient described above. The results show the expected behavior that the junctions become superheated but not excessively and the exit temperature (Junction 474) is lower than the hot leg temperature by a few degrees.

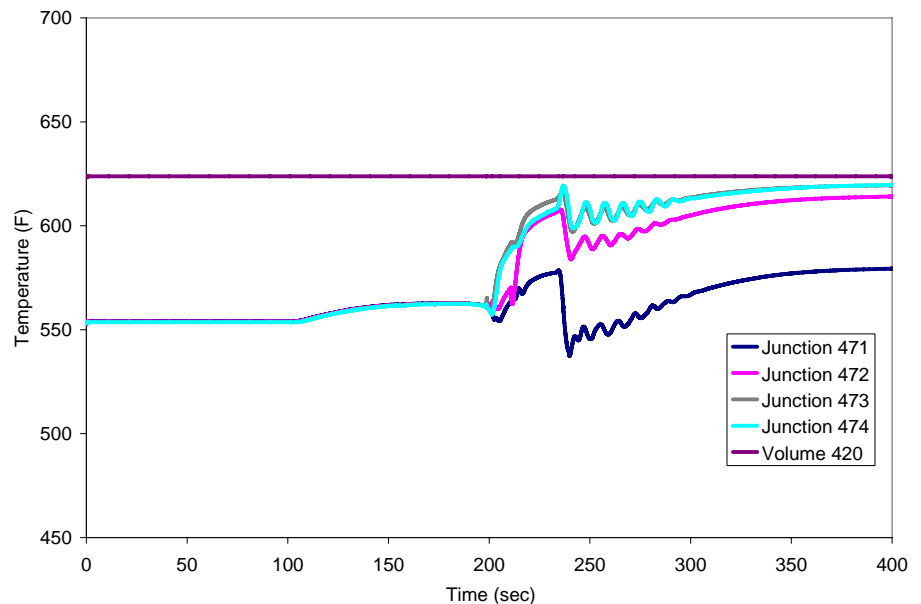
Summary

A two-region enthalpy transport model has been developed for RETRAN-3D. The model overcomes a known limitation of the enthalpy transport model when used in highly voided volumes.

The model:

- Automatically subnodalizes at the node dryout point
- Enthalpy transport is applied to each region
- Applies appropriate heat transfer correlations to each subregion
- Uses energy equation to determine temperature for single-phase subregions

Users of RETRAN-3D will have access to the new model when the next code version is released.



SGTB Uncovery with Enthalpy Transport (Corrected)



Dominion Hosts RETRAN/VIPRE User Group Meeting in Richmond

Last November, RETRAN and VIPRE users traveled east to attend the RETRAN/VIPRE User Group (RUG) Meeting in Glen Allen, Virginia.

Attendees were welcomed by Kerry Basehore, Director of Nuclear Analysis and Fuel at Dominion. The 31 attendees represented five US utilities, three international organizations, one U.S. commercial vendor, EPRI, and CSA.

Following introductory remarks by Gregg Swindlehurst, the RVUG Steering Committee Chairman, CSA made presentations summarizing the status of the RUG and VUG projects.

CSA discussed the financial status of RETRAN project, including a summary of the revenues and expenses for 2006. Summaries of the unresolved and recently resolved RETRAN-02 and RETRAN-3D trouble reports were given. The status of the development work being performed during 2006 included: alternate (optional) turbulent wall

friction models, two-region enthalpy transport model for u-tube steam generator dryout, code architecture modernization, enthalpy transport model studies, and improved time-step selection algorithms.

Summarizing the VIPRE project, CSA showed year-to-date expenses and the funding available to perform maintenance and development tasks during the remainder of the year. VIPRE 2006 development included an enhanced CHF calculation summary edit, reduced output file size option, and implementation of the RETRAN-3D water properties.

Following the organizational presentations, member organizations made formal and summary presentations of RETRAN and VIPRE activities.

- Duke discussed Feedwater Train Modeling in RETRAN. The presentation described a method for initializing feedwater piping networks that include feedwater heaters. The overall energy balance

Dominion Hosts RETRAN/VIPRE User Group Meeting in Richmond (Cont'd)

neglects heat addition by heaters. This method can be applied to both u-tube and once-through steam generators.

- Dominion summarized sensitivity studies with the VIPRE rod conduction model. A comparison of the transient MDNBR was given for locked rotor and complete loss of flow transients using dummy rods and rods using the heat conduction model.
- Duke described a VIPRE-01/MARK B-HTP CHF Correlation Evaluation. The Framatome BHTP Critical Heat Flux (CHF) correlation was added to VIPRE-01 MOD02 with the ability to switch from the BHTP CHF correlation to the Framatome nonmixing vane BWU-N CHF correlation and with an option of constant or variable axial Turbulent Mixing Coefficient (TMC). The VIPRE-01 BHTP results compared favorably with the original LYNX results.
- IBERDROLA showed results of a CRDA in a high burnup fuel core for Cofrentes NPP using RETRAN-3D. The current safety limits were developed using low burnup fuel data. With an industry trend toward longer fuel cycles, safety limits require additional evaluation. Analyses were performed for high burnup fuel under various inlet subcooling conditions.
- Westinghouse discussed RETRAN modeling of inactive loop flow stagnation during natural circulation cooldown. With loss of the reactor coolant pumps, natural circulation is the preferred method of removing stored energy and decay heat from the reactor core. An excessive cooldown rate can lead to flow stagnation under certain circumstances.
- Duke summarized their RETRAN and VIPRE activities which included reanalysis to support changing fuel vendors, examining rod ejection limits and Crystal River Unit 3 steam generator replacement.
- Duke's Catawba SGTR analysis with MSIV single failure was also discussed. A SGTR overfill analyses with RETRAN-02 determined the limiting single failure to be the secondary PORV on the ruptured steam generator. The analysis determined that steam generator overfill was not predicted, but additional evaluation of steam loads with the failed MSIV is necessary.



Steve Nesbit (Duke), Mike Howard (Westinghouse), and Craig Peterson (CSA)

- Westinghouse discussed the development of the RETRAN model development for Waterford Unit 3. The digital reactor protection system will be modeled using the CPC-Fortran program, which currently utilizes a manual iteration between RETRAN and CPC-Fortran. In the future it will be interfaced to RETRAN-02 using the PVM code.
- KEPRI summarized their RETRAN activities. The KNAP non-LOCA methodology development effort was described. Other work summarized included use of RETRAN to support a simulator updated required for power uprate of the KORI units, and Westinghouse three-loop plant equipment qualification for SLB and FLB scenarios.
- Duke gave a summary of the applications for which VIPRE is used at their facilities. VIPRE is used for seven units for both steady-state and transient DNBR analysis. Twenty-one different CHF correlations have been implemented to support the Duke units and over 75 cycles have been analyzed.
- Summarizing their RETRAN work, Westinghouse presented past and current RETRAN-02W applications. Plans include the development of methods for CE plants with digital protection systems.
- TEPCO gave an update of their activities and plans for RETRAN analysis. The work included use of RETRAN-3D to check vendor analyses, experimental data and other code comparisons, and training. TEPCO also uses RETRAN-3D and SIMULATE3/K as a coupled code system for analyzing events requiring three-dimensional kinetics. Benchmarking comparisons of the Peach Bottom tests were presented.

Dominion Hosts RETRAN/VIPRE User Group Meeting in Richmond (Cont'd)



Informal Discussion

- Duke discussed a modified Barnett CHF correlation application for steam line breaks. Duke is experiencing fuel failures with Mk-B10 and Mk-B11 fuel associated with the mixing vane design. They are evaluating HTP fuel which requires use of the BHTP CHF correlation. Since the lower pressure limit for the correlation is 1400 psia, vendor recommended use of the modified Barnett correlation for lower pressures.
- CSA reported on enthalpy transport use studies. The enthalpy transport model is commonly used in heated regions such as cores and steam generators. Model limitations often lead to solution errors in steam generator models when flow reversals and countercurrent flow patterns occur. Several studies were performed to establish guidance for use of the

model for typical u-tube and once-through steam generator models. Another study also examined use of the model for scenarios where u-tube steam generators dry out.

- CSA also discussed the Two-Region Enthalpy Transport Model (see lead article "RETRAN Modification Removes Enthalpy Transport Model Limitation" in this newsletter). Limitations with the enthalpy transport model can lead to a violation of the second law of thermodynamics when it is applied to the secondary side of steam generators that dryout. A model is being added to RETRAN-3D that accounts for the changes in heat

transfer that occur at the dryout point.

- CSA gave an update on the RETRAN-3D code modernization task and their progress to develop a plan for converting RETRAN-3D to Fortran 95. The purpose of the conversion is to replace FTB memory management with Fortran 95 allocate features and eliminate use of equivalence masks. Additionally, restructuring the code using Fortran 95 control structures will simplify code maintenance. The conversion plan was summarized.

The spring 2007 RVUG meeting will be held in San Diego, California, on April 23 & 24.

Sang Jun Ha's KEPRI Presentation



VIPRE-01 Modifications

Several modifications to the current VIPRE-01 version (VIPRE-01 MOD02.2.1) are available as a result of 2006 VIPRE-01 work scope development items or corrections for trouble reports.

Modification descriptions are provided below. VUG members that are interested in obtaining the modifications can contact Garry Gose at gcg@csai.com.

Modification 249 Error Correction for Trouble Report 241

An executable, installed using a newer compiler, resulted in run-time errors when executing sample problems. The errors are due to an array index that is not within the declared array dimensions. In these cases, the array index is 0. In addition, the compiler issues an error due to a missing comma in routine *recirc.f*. These problems have not been encountered on any previous Unix or PC compiler versions.

Modification 249 corrects "bounds checking" errors. A missing comma was also fixed in subroutine *RECIRC*.

Modification 250 Error Correction for Trouble Report 242

VUG requested work on the *CHFDMP* (Unit 17) CHF summary file (see Modification 252) and it was noted that using the SI output option yields different results which are not due simply to unit conversions (in the summary file). Investigation showed the parallel logic used to produce results in SI units (Subroutine *RESLT2*) is missing a variable definition for *smdnbr* which is used to determine the MDNBR location.

Modification 250 corrects logic used to produce results in SI units (Subroutine *RESLT2*).

Modification 251 VIPRE-01 Software Revision Request 009

This modification is a VUG requested effort to add RETRAN-3D water properties functions (subroutines taken from RETRAN-3D MOD004.2) as a user-selected option to use these newer functions in place of the current implementation of the EPRI water properties.

The properties from the new routines are obtained with new VIPRE-01 Option *NFPROP* = 3 (VIPRE-01 *PROP.1*, Word 4).

Testing from the VIPRE-01 sample problem test suite indicated no significant differences between *NFPROP* = 2 or 3. No differences should be expected unless pressures greater than *Pcrit* or lower than 15 psia are encountered.

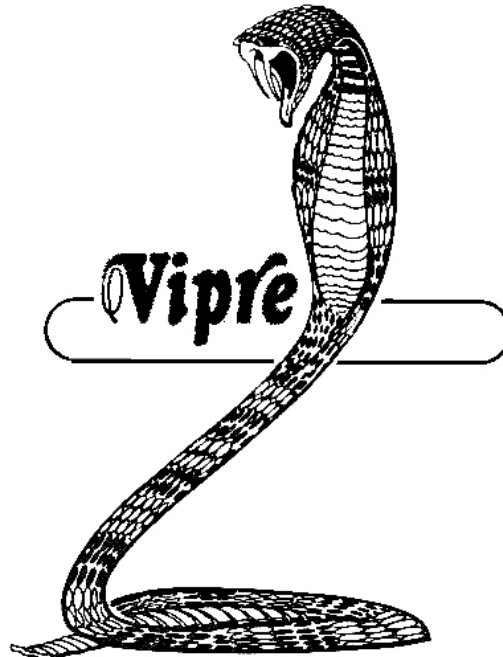
Modification 252 VIPRE-01 Software Revision Request 010

VIPRE-01 generates a CHF summary file ("*CHFDMP*") on Unit 17. This VUG requested modification cleans up the format of the *CHFDMP* file. The information is more organized

and the operating conditions are presented in units which match the input specifications. Also, a convergence indicator has been added to inform the user if the CHF data were produced by a nonconverged solution.

Modification 253 VIPRE-01 Software Revision Request 011

Modification 253 is a VUG requested modification to optionally suppress the input reflection, edit summary, and bundle summary edits from the VIPRE-01 output file. This option is obtained by setting the new Word 5 (*ISUPP* on *VIPRE.1*) card to 1. The default of 0 produces the normal, unsuppressed output.





Transforming Pump Data from Characteristic Curves to Homologous Curves

This tech tip illustrates how to get RETRAN centrifugal pump head and torque data from characteristic curves. The procedure focuses on the first quadrant but it can be applied to all of the regions in the four quadrants. Figure 1 is a reproduction of a typical four quadrant pump characteristic curve.

The first quadrant of the pump characteristics curve is called the 'normal' pump quadrant because the pump head and torque curves are supplied as functions of flow and speed. In this quadrant, both head and torque can range from positive to negative values.

The homologous curves are produced from the characteristics curves by a transformation of variables in which the resultant curves are dimensionless parameters. The parameters are normalized head and torque as functions of dimensionless parameters a, v, h, and b where these parameters are defined in the RETRAN-3D Theory Manual (Page VI-6) as

- a = Speed/Speed (Rated)
- v = Flow/Flow (Rated)
- h = Head/Head (Rated)
- b = Torque/Torque (Rated)

The desired homologous curves (Figure 2 for example) are produced by plotting the head and torque ratios as functions of pump speed and volume ratios.

$$h/a^2 = F_H(v/a)$$

$$h/v^2 = G_H(a/v)$$

$$b/a^2 = F_T(v/a)$$

$$b/v^2 = G_T(a/v)$$

As an illustration, we will define the homologous pump head data for the first quadrant. The torque curve will follow identically.

First, if one examines the homologous pump curve numbering system given by Table 1, the normal pump quadrant (+v, +a) requires two head curves for a complete description. These curves are numbered 1 and 2 in the RETRAN input. Head curves (3 through 8) are used for representing the other pump quadrants. Curves 9 through 16 are for the specification of torque.

The first curve specifies the normalized head as a function of v/a for values of v/a less than or equal to 1. Therefore, for Curve 1, the dependent variable is normalized head (h/a²) as a function of the independent variable (v/a). This is F_H defined above.

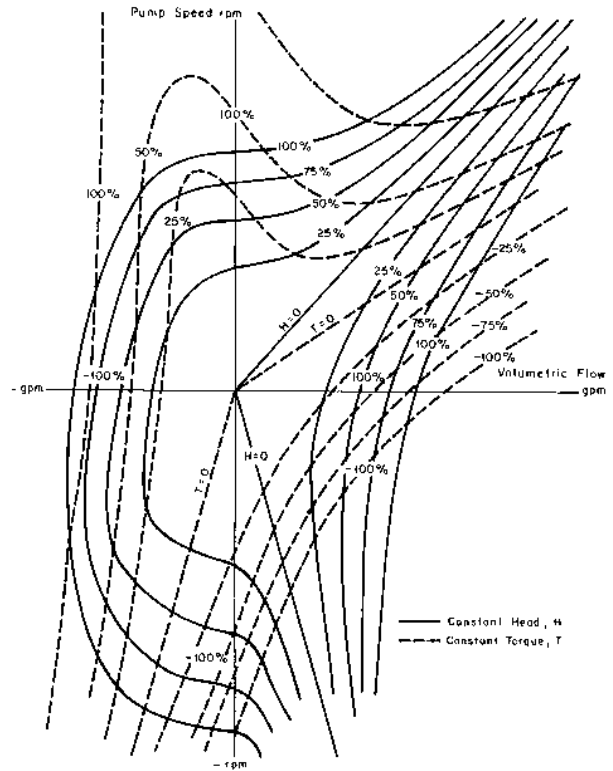


Figure 1. Four-Quadrant Pump Characteristic Curves

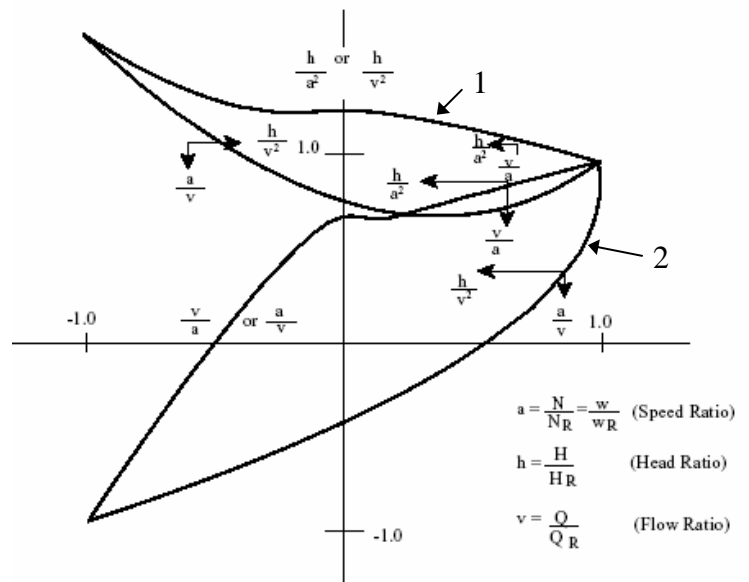


Figure 2. Homologous Pump Head Curves

Transforming Pump Data from Characteristic Curves to Homologous Curves (Cont'd)

Table 1. Homologous Curve Numbering System

Curve Quadrant	Type	v/a	Independent Variable	Curve Number
Normal Pump (+v, +a)	Head	≤1	v/a	1
		>1	a/v	2
	Torque	≤1	v/a	9
		>1	a/v	10
Energy Dissipation (-v, +a)	Head	≥-1	v/a	3
		<-1	a/v	4
	Torque	≥-1	v/a	11
		<-1	a/v	12
Normal Turbine (-v, -a)	Head	≤1	v/a	5
		>1	a/v	6
	Torque	≤1	v/a	13
		>1	a/v	14
Reverse Pump (+v, -a)	Head	≥-1	v/a	7
		<-1	a/v	8
	Torque	≥-1	v/a	15
		<-1	a/v	16

There are situations where v/a is greater than 1, but this will not be specified using Curve 1. As Table 1 shows, for data where v/a is greater than 1, Curve 2 is used. Curve 2 requires normalized head dependent (h/v²) as a function of the independent variable (a/v). This is G_H defined above.

There is a corresponding set of curves required for torque, using RETRAN Curves 9 and 10. Curves 11 through 16 would be used for the other quadrants for torque data.

As a specific example, if one examines the homologous head curve given in Figure 2, the first quadrant normalized head data is represented by two curve segments. For those values of v/a less than or equal to 1, the curve segment in the first quadrant marked (h/a², v/a) is used. Thus, values of v/a from 1.0 to 0.0 correspond to values of h/a² from 1.0 to about 1.3 or 1.4 terminating on the y axis. This is Curve 1 in the RETRAN input file.

The second curve of the first quadrant normalized head curve is indicated by (h/v², a/v). This curve is used when values of v/a are greater than 1. Values of a/v from 1.0 to 0.0, correspond to values of h/v² from 1.0 to about -.4 or -.5 terminating on the y axis. The curve crosses the zero head line at a value of a/v of about .5. This is Curve 2 in the RETRAN input file.

Typical values of the normalized head input are shown below (not to be used as real model input).

```

* CURVE 1
*CARD Num   v/a   Normalized Head (h/a**2)
101011      5
+           0.00   1.7
+           0.25   1.5
+           0.50   1.3
+           0.75   1.2
+           1.00   1.0
*
* CURVE 2
*CARD Num   a/v   Normalized Head (h/v**2)
101021      5
+           0.00  -2.0
+           0.25  -1.1
+           0.50  -0.4
+           0.75   0.30
+           1.00   1.0
    
```

There is a corresponding set of curves (9 and 10) for the normalized torque curve segments, but the process is exactly the same.

In practice, it is a matter of selecting values for the independent variables, a/v or v/a from 0.0 to 1.0 and making a determination of the corresponding normalized head and torque values from the characteristic curves and the rated speed, head, flow, and torque for the given pump. One may describe the curves with as many points as necessary to accurately describe the pump characteristics, but the curves are generally smooth polynomials.

About This Newsletter

RETRAN Maintenance Program

The RETRAN/VIPRE Maintenance Program is a program that provides for the support of software developed and maintained by CSA. The main features of the Subscription Service include:

- the code maintenance activities for reporting and resolving possible code errors,
- providing information to users through the User Group Meetings and this newsletter, and
- preparing new versions of RETRAN and VIPRE.

The RETRAN Maintenance Program now has 19 organizations participating in the program, including 13 U.S. utilities and six organizations from outside of the U.S. Eight U.S. utilities and three organizations outside the U.S. are currently participating in the VIPRE maintenance program. A Steering Committee, composed of representatives from the participating organizations, advises CSA on various activities including possible enhancements for the code and the scheduling of future code releases. Information regarding the Maintenance Program can be obtained from:

Mark P. Paulsen
Computer Simulation & Analysis, Inc.
P. O. Box 51596
Idaho Falls, ID 83405
paulsen@csai.com or (208) 529-1700

Newsletter Contributions

The RETRAN/VIPRE Newsletter is published for members of the Subscription Service program. We want to use the newsletter as a means of communication, not only from CSA to the code users, but also between code users. If this concept is to be successful, contributions are needed from the code users. The next newsletter is scheduled for December 2007 and we would like to include a brief summary of your RETRAN and VIPRE activities. Please provide your contribution to CSA, P. O. Box 51596, Idaho Falls, ID 83405, or to one of the email addresses below by December 4, 2007. We are looking forward to hearing from all RETRAN and VIPRE licensees.

Mark Paulsen paulsen@csai.com

Garry Gose gcg@csai.com

Pam Richardson pam@csai.com

The RETRAN web page is located at

<http://www.csai.com/retran/summary.html>.

The VIPRE web page is located at

<http://www.csai.com/vipre/summary.html>

Previous issues of the RETRAN/VIPRE Newsletter are available from the RETRAN or VIPRE web pages.

Steering Committee Members

Gregg Swindlehurst, Duke Energy (Chairman),
gbswindl@duke-energy.com
Andres Gomez Navarro, Iberdrola, agn@iberinco.com
Sama Bilbao y Leon, Dominion, Sama_Bilbao@dom.com
David Huegel, Westinghouse, huegelds@westinghouse.com
Adi Irani, Entergy Nuclear Northeast, airani@entergy.com
Daren Chang, STPNOC, dchang@stpegs.com

Calendar of Events

User Group Meeting
April 23 & 24, 2007
San Diego, California
<http://www.csai.com/retran/rvug/ugm.html>

RETRAN Training Session
June 18-22, 2007
Idaho Falls, Idaho
<http://www.csai.com/retran/summary.html>

ANS Annual Meeting
June 24-28, 2007
Boston, Massachusetts