Validation of DWPF MOG Dynamics Model -Phase I (U)

by

A. S. Choi

Westinghouse Savannah River Company
Savannah River Site
Aiken, South Carolina 29808

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VALIDATION OF DWPF MOG DYNAMICS MODEL - PHASE I (U)

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System, Dynamic Model,
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**M. N. Brosee, Manager
Defense Waste Processing Facility
High Level Waste Management Division**

Attention: S. F. Piccolo, 704-S

**VALIDATION OF
DWPF MOG DYNAMICS MODEL - PHASE I (U)**

The attached report documents the results of a study to validate the DWPF melter off-gas system dynamics model using the data collected during the Waste Qualification Runs in 1995. The study consisted of; (1) calibration of the model using one set of melter idling data, (2) validation of the calibrated model using three sets of steady feeding and one set of transient data, and (3) application of the validated model to simulate the melter overfeeding incident which took place on 7/5/95. All the controller tuning constants and control logic used in the validated model are identical to those used in the DCS in 1995. However, the model does not reflect any design and/or operational changes made in 1996 to alleviate the glass pouring problem. Based on the results of the overfeeding simulation, it is concluded that the actual feed rates during that incident were about 2.75 times the indicated readings and that the peak concentration of combustible gases remained below 15% of the lower flammable limit during the entire one-hour duration. Please contact A. S. Choi @ 7-7729 to address any questions regarding this study.

C. T. Randall, 704-T
Authorized Derivative Classifier

E. W. Holtzscheiter, Manager
SRTC-DWPT Section

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**VALIDATION OF
DWPF MOG DYNAMICS MODEL - PHASE I (U)**

September 23, 1996

Alexander S. Choi

**Defense Waste Processing Technology
Savannah River Technology Center
Westinghouse Savannah River Company
Aiken, SC 29808**

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DOCUMENT APPROVAL

A. S. Choi, Author
Defense Waste Processing Technology Section / SRTC

1/7/97
Date

R. A. Jacobs, Technical Reviewer
Defense Waste Processing Technology Section / SRTC

1/7/97
Date

C. T. Randall, Manager
Process Modeling and Control Group, DWPT / SRTC

1/7/97
Date

E. W. Holtzscheiter, Manager
Defense Waste Processing Technology Section / SRTC

1/7/97
Date

C. T. Randall, Authorized Derivative Classifier
Defense Waste Processing Technology Section / SRTC

1/7/97
Date

SUMMARY

The computer model which describes the dynamics of both primary and backup DWPF melter off-gas systems was validated using the data collected during the Waste Qualification Runs in 1995. The model was first calibrated using one set of data taken during the melter idling on 7/5/95 by matching the calculated pressure and temperature profiles to those measured throughout the system. In doing so, the air inleakage rates to the melter at -5 "wc and the Off-Gas Condensate Tank (OGCT) at -4 "wc were estimated to be about 50 lb/hr and 125 lb/hr, respectively. The actual gas temperature in the melter vapor space was also estimated to be only about 240 °C lower than the indicated temperature (TI4085D) of 877 °C during idling, which seems to suggest the existence of a foamy layer or solid residues floating on the melt surface.

The calibrated model was then validated in two steps. First, the non-dynamic elements of the model such as those describing the pressure drop versus flow rate relationship were validated by simulating steady melter operations run on 7/7/95 and 7/10/95 at three different feed rates, and the agreement between the model predictions and the data was excellent for all three cases. The dynamic elements of the model such as the actions of controllers and valves were validated by simulating the melter feed tube flush performed prior to the initiation of feeding on 7/7/95, and the overall agreement between the model predictions and the data was again excellent even for this highly transient case.

The validated model was next run to simulate the melter overfeeding incident which took place on 7/5/95 as a result of incorrect calibration of the feed pump. By matching the calculated pressure drop across the off-gas header to the measured data, the actual feed rates were estimated to be about 2.75 times the indicated values, and the peak concentration of combustible gases downstream of the Quencher was estimated to be less than 15% of the lower flammable limit (LFL) during the entire duration of overfeeding which lasted for about an hour. By comparison, the analysis performed by DWPF using the melt level data showed that the actual feed rates were slightly higher than 4 times the indicated values. At these increased feed rates, the peak concentration of combustible gases would have been just under 60% of the LFL.

This report presents the detailed results of the validation study along with the key features of the model. Readers should be aware of the fact that all the results presented in this report are strictly applicable only to the DWPF melter off-gas system before any hardware and/or software changes were made to alleviate the recent glass pouring problem.

OVERVIEW OF MODEL

The melter off-gas (MOG) dynamics model calculates the transient 5-component mass and energy balances for both primary and backup DWPF melter off-gas systems. A simulation flow diagram used by the model is shown in Figure 1. The model database currently contains 40 unit operation blocks, 120 process streams, 22 proportional-integral (PI) controllers, and 26 various types of valves to simulate all the major MOG system hardware shown in Figure 1 such as quencher, condenser and exhauster. The model also simulates all the major distributed control system (DCS) software logic such as ratio-biased exhauster speed control as well as those used to protect the system in case of various types of equipment failure modes.

The MOG dynamics model can also be used to predict off-gas flammability under transient conditions. To do that, it employs a 2-step global combustion kinetic scheme to describe the decomposition of aromatic carbon species and subsequent oxidation of CO and H₂ in the melter vapor space according to the empirical first-order kinetics.¹ To complete the description of organic carbon combustion in the melter, it requires an input from another model, called the 4-Stage Cold Cap model, which calculates the compositions of glass and calcine gases based on the thermodynamic equilibrium principles. The latter model can handle the solution nonideality that exists among various melt phases, and was validated earlier against the data obtained using the formic acid flowsheet feed.^{2,3}

The MOG dynamics model has been used extensively to characterize dynamic responses under new and/or revised design conditions and to identify critical process parameters and further define operating constraints. Recent dynamic studies successfully simulated the system startup and shutdown, off-gas surges, switchover and switchback between the primary and backup systems, equipment failures, and determination of the maximum allowable total organic carbon (TOC) in melter feed.⁴⁻⁶ The main program of the model and its subroutines are written in FORTRAN, and Bechtel's Dynamic Analysis Program (DAP) library is used for I/O and also to calculate the valve dynamics and fluid flow rates under various flow conditions.

CALIBRATION OF MODEL

The MOG dynamics model was calibrated using one set of melter idling data taken just prior to the feed startup around 17:15 on 7/5/95. The relevant data used in the calibration are summarized in Table 1. Since the melter was idling, the indicated melter vapor space temperature (TI4085D) remained steady at about 877 °C.

FIGURE 1. MELTER AND OFF-GAS SYSTEM SIMULATION FLOW DIAGRAM

TABLE 1. 7/5/95 Melter Idling Data Used in Model Calibration.

Data	Value
Melter Pressure, PIC3521 ("wc)	-5.04
Melter Vapor Space Temperature, TI4085D (°C)	877
Air Purge to Backup Film Cooler, FIC3221B (lb/hr)	400
Total Melter Air Purge, FIC3221A (lb/hr)	1,020
Off-Gas Temperature at Primary Film Cooler Exit, TIC3682 (°C)	371
Melter Pressure Control Air, FIC3691 (lb/hr)	499.6
Pressure Drop across Off-Gas Header, PDI3684 ("wc)	0.44
Off-Gas Condensate Tank Pressure, PI3485A ("wc)	-4.04
Pressure Drop across SAS's, PI3485A - PDI3388 ("wc)	5.69
Pressure Drop across HEME, PID3411 ("wc)	2.39
Pressure Drop across HEPA, PDI3400 ("wc)	0.54
Off-Gas Flow to HEPA, FI3401 (lb/hr)	1,664
Pressure Drop across Exhauster, PDI3582 ("wc)	20.12
Exhauster Speed, SIC3585 (rpm)	503
Pour Spout Pressure, PI3527 ("wc)	-0.83
Pour Spout Pressure Control Air, FI3526 (lb/hr)	47.7

Furthermore, with the air purges to the melter (FIC3221A) and to the backup film cooler (FIC3221B) set at 1,020 and 400 lb/hr, respectively, the off-gas temperature at the primary film cooler (FC) exit (TIC3682) also remained steady at 371 °C, so no steam was being added to the primary FC.

The MOG dynamics model computes the rate of fluid flow between two adjacent nodes, W , by:

$$W = CEQ \sqrt{\rho \Delta h} \quad (1)$$

where CEQ is the equivalent conductance in $(\text{lb.ft}^3/\text{psi.hr}^2)^{1/2}$, ρ the mean fluid density in lb/ft^3 , and Δh the driving head between two nodes in psi. In Eq. (1), the equivalent conductance of flow or a reciprocal of the resistance to flow is assumed to depend only on the characteristics of flow path such as pipe diameter or number of bends but not on the driving head. For simple fluid flows in pipe, CEQ 's can be readily estimated from the literature.⁷ For complex flow configurations such as those including a condenser or a HEPA filter, however, CEQ 's must be determined from the data. The main objective of dynamic model calibration was precisely to determine CEQ 's between adjacent nodes which are connected through a not-so-simple flow path so that all the calculated pressure drops match those measured.

Some of the key CEQ 's thus determined and subsequently used in the model validation are shown in Table 2. Refer to Figure 1 to locate the node numbers given in the table inside the symbol, Δ . When the main source of pressure drop in a flow path is a valve, CEQ 's were then either computed using the valve coefficient, C_v , or estimated from the pressure drop data. All the CEQ 's thus determined are denoted as $VCON$'s, and are shown in Table A-2 in Appendix along with other relevant valve data.

TABLE 2. Estimated Equivalent Conductance for Fluid Flows.

Upstream Node	Downstream Node	Major Equipment or Stream Name	CEQ 's ($\text{lb.ft}^3/\text{psi.hr}^2$) ^{1/2}
1	2	Primary FC	40,000
2	3	Off-Gas Header	49,218
7	1	Melter Air Inleakage	4,000
7	8	OGCT Air Inleakage	12,000
19	20	HEME	260,000
20	21	HEPA	1,200,000
24	1	Backup Film Cooler	38,570

The air inleakages to the melter and the Off-Gas Condensate Tank (OGCT) are the major system unknowns which also must be estimated during the calibration step. Since the actual gas temperature in the melter vapor space was not measured, and the pressure drop also depends on the mean fluid density which is a function of temperature, the rate of air inleakage to the melter had to be estimated by trial-and-error, i.e., find the pair of actual gas temperature and melter air inleakage until the calculated pressure drop across the off-gas header and the calculated off-gas temperature at the primary FC exit simultaneously match PDI3684 and TIC3682, respectively. It turned out that a close match was indeed found when the melter air inleakage rate at -5 "wc and the actual gas temperature were set at 50 lb/hr and 638 °C, respectively. Note that the melter air inleakage rate thus estimated is exactly 50% of the design basis rate of 100 lb/hr.

The rate of air inleakage to the OGCT was then determined simply by subtracting the calculated total vapor flow at the Quencher discharge from the measured off-gas flow to HEPA (FI3401). The OGCT air inleakage rate thus estimated is 125 lb/hr, which is close to the design basis rate of 105 lb/hr. Note that the CEQ's representing the melter and OGCT air inleakages in Table 2 were determined from Eq. (1) using the estimated inleakage rates and measured pressure gradients.

It is worth noting that the estimated actual gas temperature of 638 °C in the melter vapor space during idling is about 240 °C lower than the value indicated by TI4085D. During earlier pilot-melter studies, the actual gas temperatures were measured to be more than 400 °C lower than those measured in a thermowell during idling.⁸ Since those pilot-melter had the vapor space configurations similar to that of the DWPF melter, it is suspected that a foamy layer or solid residues may have been present on the melt surface, thereby inhibiting the radiative heat transfer to the vapor space. Had the TI4085D readings been taken during steady feeding with a well-established cold cap, the temperature difference would have been about 200 °C or smaller.

VALIDATION OF MODEL

The calibrated model was first run to simulate steady state melter operation at three different feed rates, and the calculated results such as pressures and exhaustor speed for each case were compared with the data. Besides the feed rate, the only other adjustment made to the model prior to each run was to set the gas temperature in the melter vapor space at the value predicted by the following correlation:²

$$T_{\text{gas}} = 0.91685 T_{\text{tw}} - 128 \quad (2)$$

where T_{tw} is the indicated vapor space temperature, TI4085D, which is measured in a thermowell. Eq. (2) was derived by correlating the measured melter vapor space temperatures in three different pilot melters against the corresponding gas temperatures, and is valid only under steady state feeding conditions with a well-established cold cap. In Table 3, the overall agreement between the model predictions and the data are shown to be quite good for all three cases, which indicates that all the non-dynamic elements of the model are sound and consistent.

The dynamic elements of the model such as the actions of controllers and valves were next validated using the data taken during the startup of melter feed loop #1 on 7/5/95. All the controller tuning constants and the valve data used in the model are given in Tables A-1 and A-2, respectively, in Appendix. Note that the reset rates for the PI controllers used in the model are given in repeats per minute, whereas those used in the DCS are given in repeats per second. Refer to Figure 1 to locate each controller whose I.D. number is given inside a circle.

TABLE 3. Comparison of Steady State Simulation Results.

Run Date	7/10/95		7/7/95		7/7/95	
Feed Rate (GPM)	0.35		0.4		0.8	
	Data	Model	Data	Model	Data	Model
Melter Pressure ("wc)	-5.3/-4.7	-5.0	-5.3/-4.7	-5.0	-5.2/-4.8	-5.0
Pressure Control Air (lb/hr)	487/548	500	470/550	500	460/514	500
ΔP Off-Gas Header ("wc)	0.62/0.85	0.61	0.54/0.85	0.67	0.92/1.13	1.07
OGCT Pressure ("wc)	-4.4/-3.9	-4.5	-4.8/-4.2	-4.6	-5.3/-5.0	-5.4
ΔP SAS's ("wc)	6.7/7.3	6.7	6.56	6.86	8.4/9.8	9.1
OG to HEPA (lb/hr)	1614/1674	1698	1585/1650	1696	1645/1714	1739
ΔP Exhauster ("wc)	21/22	22	20.8/21.8	22.5	24.1/25.9	25.9
Exhauster Speed (rpm)	482/507	505	480/500	508	510/530	534

FIGURE 2. Melter Pressure and Off-Gas Header ΔP during Feed Tube #1 Startup on 7/5/95.

In DWPF, the startup sequence for each melter feed loop is as follows: At $t = 0$, start the feed tube flush and continue for 102 seconds, open the feed pump prime H_2O valve at $t = 127$ second, start the feed pump at $t = 147$ seconds, and close the prime H_2O valve at $t = 177$ seconds. So, it takes a total of about 3 minutes before the real feed flows into the melter, and it takes another minute or two before the feed pump controller is set at auto. Figure 2 shows the variations in melter pressure and ΔP across the off-gas header during the melter feed tube #1 startup on 7/5/95, and it appears that the system dynamics remained pronounced only during the first 1 minute. The results of the feed loop #1 startup simulation are plotted in Figures 3 and 4 along with the data given in [o].

In DWPF, the set point for the flush H_2O flow controllers (FIC3320 & FIC3327) is set at 0.7 gpm. It is, however, noted that the profile of flush H_2O flow shown in Figure 3 includes a couple of peaks at the start of flush before settling at the set point of 0.7 gpm. This uneven flow profile was modeled based on the fact that the measured pressure of flush H_2O line at the 3-way valve is 78 psig when it is in the feed position. So, when the 3-way valve is turned to the flush position, the actual flush H_2O flow at time zero will be much higher than the set point due to a high pressure gradient across the valve. The resulting high-flow error signal is then

FIGURE 3. Results of 7/7/95 Feed Loop #1 Startup Simulation, Data [o].

JANUARY 22, 1996

RUN NUMBER: FF11

FIGURE 4. Results of 7/7/95 Feed Loop #1 Startup Simulation, Data [o].

likely to force the flush H₂O control valve to close down to the minimum 3% open position, thereby pressurizing the flush H₂O line just upstream of the control valve to the measured flush H₂O tank pressure of 59 psig. So, when the control valve opens up next due to a low-flow error signal this time, a second peak in the flush H₂O flow profile would result. In Figure 3, the intensity ratio of the second peak to the first was assumed to be 0.7, which is about the same as the ratio of the pressure in the flush H₂O tank to that in the flush H₂O line at the start of flush.

With the overall shape of the flush H₂O flow profile modeled as discussed above, both the intensity of the first peak and the total duration of each control loop action, including transmitter delays, valve stroke times, and dead times, had to be determined in order to completely define the flush H₂O flow profile. As shown in Figures 3 and 4, an excellent agreement between all the model predictions and the data was obtained by assuming that the maximum flush H₂O rate is about 3.3 gpm at a ΔP of 78 psi across the 3-way valve, and it takes about 10 seconds to execute the entire flush H₂O control loop actions from the transmitter to the flush H₂O flow control valve. It is noted that the agreement is remarkably good especially during the crucial first 1 minute of flush.

APPLICATION OF MODEL

Once validated, the MOG dynamics model was next put to use by simulating the melter overfeeding incident which took place on 7/5/95. The overfeeding was caused by an error during the feed pump calibration, and lasted for about an hour. The objectives of the simulation were to determine the degree of overfeeding or the actual feed rate and also to find out whether any potential for forming a flammable gas mixture in the off-gas system existed anytime during the incident.

DWPF made an attempt to estimate the actual feed rate from the melt level data (LI3523), and determined it to be about 4 times the indicated feed rate on FIC3309. The profile of actual feed rates thus determined is shown in Figure 5 for the entire overfeeding duration, and the model was run to simulate this feed rate profile. The resulting model predictions are shown in Figures 6 to 8 along with the measured data, and the agreement between them is not very good especially at the broad peak region. It is noted that all the model predictions such as pressure drops and exhaustor speed tend to overpredict the data. In particular, the calculated pressure drop across the off-gas header shown in Figure 8 grossly overpredicted PDI3684, which seems to indicate that the actual feed rate may have been less than what was predicted to be, i.e., 4 times the indicated. Figure 8 also shows that had the actual feed rate been this high, the peak concentration of combustible gases in the OGCT could have been nearly 60% of the LFL.

Next, a series of simulation runs were made by varying the feed rate until the calculated pressure drop across the off-gas header matched PDI3684 closely. As shown in Figure 11, a good match was found between them when the actual feed rate was set at 2.75 times the value indicated on FIC3309. The resulting model predictions are shown in Figures 9 and 10, and they all are seen to agree with the data much better. Especially, the calculated off-gas flows to the HEPA are shown in Figure 10 to be nearly identical to the data FI3401, which seems to justify the conclusion that the actual feed rate was likely to be about 2.75 times the indicated value. Figure 11 shows that at this reduced feed rate the peak concentration of combustible gases in the OGCT would have been less than 15% of the LFL.

The indicated melter vapor space temperature (TI4085D) was about 877 °C at the start of overfeeding, and it did not fall below the feed interlock set point of about 680 °C until one hour or so later. Since it takes a considerable amount of time to establish a high cold cap coverage, there would have been little chance for off-gas surges large enough to lead to potential off-gas flammability during this period. However, under these transient conditions, the actual gas temperature in the vapor space does not tend to correlate well with TI4085D at all, since the former is determined by the convective heat transfer at all vapor space internal surfaces involved, all of which have their own thermal inertia, including that of the thermowell. Under transient conditions, therefore, the rate of change in the true thermal state of the gas phase will not be adequately reflected by that in TI4085D, so setting the feed interlock based on TI4085D may not provide a sufficient protection against potential flammability even in the absence of off-gas surges.

CONCLUSIONS AND RECOMMENDATIONS

Despite some difficulties encountered due to insufficient or missing data as well as inadequate physical insight into the overall cold cap phenomena, the model was able to reproduce some of the most critical dynamic responses of the system within a reasonable degree of accuracy. The results of the overfeeding simulation further proved a point that once properly validated, the MOG dynamics model can be used as a valuable tool in estimating the system unknowns and also defining the safe operating windows for off-gas flammability control.

It is recommended that the MOG dynamics model be further validated under the current DWPF operating conditions by incorporating into the model all the design and/or operational changes made to the melter off-gas system since the efforts to resolve the glass pouring problem were first initiated. It is also recommended that the utility of the MOG dynamics model be expanded by improving the physics of glass pour control currently existing in the model.

FIGURE 5. Corrected Feed Rate Profile Based on Melt Level LI3523.

FIGURE 6. Results of 7/5/95 Melter Overfeeding Simulation at Actual Feed Rate of 4X Indicated, Data [o].

NOVEMBER 29, 1995

RUN NUMBER: 0F4X

FIGURE 7. Results of 7/5/95 Melter Overfeeding Simulation at Actual Feed Rate of 4X Indicated, Data [o].

NOVEMBER 29, 1995

RUN NUMBER: OF4X

FIGURE 8. Results of 7/5/95 Melter Overfeeding Simulation at Actual Feed Rate of 4X Indicated, Data [o].

MARCH 12, 1996

RUN NUMBER: 0F3X

FIGURE 9. Results of 7/5/95 Melter Overfeeding Simulation at Actual Feed Rate of 2.75X Indicated, Data [o].

MARCH 12, 1996

RUN NUMBER: 0F3X

FIGURE 10. Results of 7/5/95 Melter Overfeeding Simulation at Actual Feed Rate of 2.75X Indicated, Data [o].

MARCH 12, 1996

RUN NUMBER: 0F3X

FIGURE 11. Results of 7/5/95 Melter Overfeeding Simulation at Actual Feed Rate of 2.75X Indicated, Data [o].

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APPENDIX

CONT. NO.	MODE TYPE	COUT ACTION	SETPT CIN	GAIN RSET	DERIV SAMPLE	ZERO RANGE	COUTLL COUTUL	OINT MANIN	ANTI RESET WINDUP
1	AUTO P+I	.000 REVERSE	375.00 310.95	1.000 2.500	.000 3.000	200.00 600.00	.000 1.000	.020 .000	YES
2	AUTO P+I	.767 DIRECT	-5.00 -4.99	2.250 .900	.000 .250	-25.00 5.00	.000 1.000	.000 .767	YES
3	AUTO P+I	.765 REVERSE	-4.00 -4.00	2.000 5.000	.000 1.000	-10.00 10.00	.000 1.000	.000 .765	YES
4	AUTO P+I	.446 DIRECT	10.00 10.00	1.000 2.500	.000 3.000	.00 20.00	.000 1.000	.000 .446	YES
5	MAN P+I	.405 DIRECT	400.00 529.55	.500 2.000	.000 1.000	.00 800.00	.010 1.000	.000 .405	YES
6	MAN P+I	.436 REVERSE	40.00 40.00	2.000 5.000	.000 3.000	.00 100.00	.000 1.000	.000 .436	YES
7	AUTO P+I	.120 DIRECT	400.00 400.00	.500 2.000	.000 1.000	.00 800.00	.010 1.000	.000 .120	YES
8	AUTO P+I	.789 REVERSE	10.00 9.99	2.000 2.000	.000 3.000	.00 50.00	.050 1.000	.000 .789	YES
9	AUTO P+I	.558 DIRECT	10.00 10.00	1.000 2.500	.000 3.000	.00 20.00	.000 1.000	.000 .558	YES
10	AUTO P+I	.405 DIRECT	500.00 500.85	1.000 1.200	.000 .500	.00 1400.00	.010 1.000	.000 .405	YES
11	AUTO P+I	.477 REVERSE	10.00 10.00	2.000 2.000	.000 3.000	.00 50.00	.050 1.000	.000 .477	YES
12	AUTO P+I	.587 DIRECT	400.00 400.07	2.500 .200	.000 3.000	.00 1000.00	.000 1.000	.000 .587	YES
13	AUTO P+I	.187 DIRECT	960.00 960.00	.300 3.950	.000 .500	.00 1750.00	.000 1.000	.000 .187	YES
14	MAN P+I	.120 DIRECT	500.00 .00	.600 .600	.000 .500	.00 1400.00	.010 1.000	.002 .120	YES
15	AUTO P+I	.000 DIRECT	1100.00 1386.91	.500 2.000	.000 3.000	.00 2000.00	.000 1.000	-.014 .000	YES
16	AUTO P+I	.530 DIRECT	367.00 367.16	.500 5.000	.000 3.000	.00 500.00	.000 1.000	.000 .530	YES
17	MAN P+I	.000 DIRECT	367.00 .00	.500 5.000	.000 3.000	.00 500.00	.000 1.000	.000 .000	YES

TABLE A-1. DCS Controller Tuning Constants Used in Model Validation.

CONT. NO.	MODE ----- TYPE	COUT ----- ACTION	SETPT ----- CIN	GAIN ----- RSET	DERIV ----- SAMPLE	ZERO ----- RANGE	COUTLL ----- COUTUL	OINT ----- MANIN	ANTI RESET WINDUP
18	MAN P+I	.000 DIRECT	367.00 .00	.500 5.000	.000 3.000	.00 500.00	.000 1.000	.000 .000	YES
19	MAN P+I	.000 REVERSE	40.00 40.00	2.000 5.000	.000 3.000	.00 100.00	.000 1.000	.000 .000	YES
20	AUTO P+I	.530 DIRECT	367.00 367.00	.500 5.000	.000 3.000	.00 500.00	.000 1.000	.000 .530	YES
21	MAN P+I	.000 REVERSE	350.00 200.00	1.000 2.500	.000 3.000	200.00 600.00	.000 1.000	.000 .000	YES
22	AUTO P+I	.179 DIRECT	430.00 430.00	.300 3.950	.000 .500	.00 1150.00	.000 1.000	.000 .179	YES

TABLE A-1. DCS Controller Tuning Constants Used in Model Validation.

VALVE NUMBER	CV ----- VCON	F ----- Y	CHAR ----- DYNAMICS	STOPEN ----- STCLOS	TCOPEN ----- TCCLOS	DYDT ----- CTRL.
1	206.00 .00	.000 .000	EQL PCT 1ST ORD	5.00 5.00	1.00 1.00	.0000E+00 1
2	1193.20 499.15	.767 .767	EQL PCT 1ST ORD	1.00 1.00	.20 .20	-.1401E-04 2
3	112.50 46.58	.765 .765	EQL PCT 1ST ORD	1.00 1.00	.20 .20	.6855E-05 3
4	206.00 .00	.000 .000	EQL PCT 1ST ORD	5.00 5.00	1.00 1.00	.0000E+00 21
5	1440.00 257.90	.179 .179	LINEAR 1ST ORD	10.00 10.00	1.00 1.00	.1475E-05 22
6	2480.00 350.06	.477 .477	EQL PCT 1ST ORD	5.00 5.00	1.00 1.00	-.6855E-06 11
7	15378.00 .00	.000 .000	EQL PCT 1ST ORD	5.00 5.00	1.00 1.00	.0000E+00 0
8	3000.00 1362.18	.789 .789	EQL PCT 1ST ORD	5.00 5.00	1.00 1.00	.1174E-04 8
9	3000.00 100.00	1.000 1.000	EQL PCT RAMP	10.00 10.00	1.00 1.00	.0000E+00 0
10	3000.00 .00	.000 .000	EQL PCT RAMP	10.00 10.00	1.00 1.00	.0000E+00 0
11	100.00 100.00	.800 .800	EQL PCT 1ST ORD	5.00 2.00	1.00 1.00	-.5960E-05 0
12	6320.00 6320.00	1.000 1.000	EQL PCT RAMP	10.00 10.00	2.00 2.00	.0000E+00 0
13	265900.00 246701.80	.980 .980	EQL PCT 1ST ORD	10.00 10.00	2.00 2.00	.0000E+00 0
14	1193.20 .00	.000 .000	EQL PCT 1ST ORD	1.00 1.00	.20 .20	.0000E+00 0
15	265900.00 246696.30	.980 .980	EQL PCT 1ST ORD	10.00 10.00	2.00 2.00	.2980E-05 0
16	1440.00 269.88	.187 .187	LINEAR 1ST ORD	10.00 10.00	1.00 1.00	-.1490E-05 13
17	250.00 132.50	.530 .530	LINEAR RAMP	4.00 4.00	.00 .00	.0000E+00 20

TABLE A-2. Valve Data Used in the Model Validation.

VALVE NUMBER	CV ----- VCON	F --- Y	CHAR ----- DYNAMICS	STOPEN ----- STCLOS	TCOPEN ----- TCCLOS	DYDT ----- CTRL.
18	250.00 .00	.000 .000	LINEAR RAMP	4.00 4.00	.00 .00	.0000E+00 17
19	250.00 132.55	.530 .530	LINEAR RAMP	10.00 10.00	2.00 2.00	.0000E+00 16
20	250.00 .00	.000 .000	LINEAR RAMP	5.00 5.00	1.00 1.00	.0000E+00 18
21	12800.00 .00	.000 .000	EQL PCT RAMP	1.00 1.00	2.00 2.00	.0000E+00 0
22	15000.00 .00	.000 .000	EQL PCT RAMP	10.00 10.00	2.00 2.00	.0000E+00 15
23	12800.00 .00	.000 .000	EQL PCT RAMP	1.00 1.00	.00 .00	.0000E+00 0
24	100.00 .00	.405 .405	LINEAR RAMP	5.00 5.00	.00 .00	.0000E+00 0
25	100.00 .00	.120 .120	LINEAR RAMP	5.00 5.00	.00 .00	.0000E+00 0
26	12800.00 .00	.000 .000	EQL PCT RAMP	1.00 1.00	.00 .00	.0000E+00 0

TABLE A-2. Valve Data Used in the Model Validation.