USE OF OPERATIONAL DATA FOR THE VALIDATION OF THERMAL HYDRAULIC MODELS

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ABSTRACT

Thermal hydraulic models used to predict Primary Heat Transport (PHT) System behaviour have traditionally been applied with design conditions to predict transient responses of accident scenarios in safety analyses. Recently, the use of reactor operational data has been integral in the development of thermal hydraulic codes to improve the quality of the predictions. The basis of accurate thermal hydraulic predictions is the use of appropriate models with accurate input data. An operating reactor provides a wealth of information, therefore, the models can be validated against operating conditions specific to the field of application. Thus, agreement between prediction and plant data continue to improve due to constant update of the thermal hydraulic models and/or the input data. The ability to accurately predict thermal hydraulic responses with the code provides the analyst with a powerful tool in reactor performance monitoring.

The primary objective of this paper is to describe the validation process of the Mini-SOPHT (Simulation Of Primary Heat Transport) Header to Header Model with the use of reactor operational data. The secondary objective is to illustrate the effectiveness of the code as a performance monitoring tool by discussing the discoveries that were made during the validation process.

INTRODUCTION

The validation process consisted of validating both the SOPHT Four Quadrant Model, which models the complete power train, from the fission process to the turbine, and the Mini-SOPHT Header to Header Model, which is employed to predict thermal hydraulic behaviour in a reactor channel. This paper will primarily discuss the Mini-SOPHT model although reference will be made to the SOPHT model.

A four unit comparison of the PHT thermal hydraulic conditions was performed using reactor data. Global power train conditions were obtained and used to update the SOPHT Four Quadrant Model input data to reflect the current operating conditions. The updated model was validated against normal operating conditions and observed station transients.

Observed reactor channel flow data was compared to the Mini-SOPHT Header to Header model predictions to validate the appropriate thermal hydraulic options for the Darlington Reactor. Flow rates from forty four Fully INstrumented CHannels (FINCH's), twenty four ShutDown System (SDS) channels and twelve Emergency Coolant Injection (ECI) channels were compared to Mini-SOPHT predictions for each unit using different thermalhydraulic options. The combination of two phase multiplier option and pipe roughness option which most accurately predicted flow in the single channel model have been incorporated into the model used to predict system performance under normal steady state and transient operating conditions.

Plant operational data for the validation was obtained for the parameters of interest primarily using the Plant Data Distribution System (PDDS). This system obtains the online operating data and stores it in a peripheral from which it may be retrieved at any time. The system has the capability of varying the sample time from two seconds to hourly based on predefined intervals.

MINI-SOPHT HEADER TO HEADER MODEL VALIDATION

Methodology

The methodology for obtaining the input data was similar in nature for all channel types, i.e. SDS, FINCH and ECI. Operational data was gathered using the SDS computer system displays (for SDS channel flow) and the PDDS system (FINCH & ECI channel flows, RIH/ROH temperatures and pressures). The data was gathered over a period of operation where normal operating conditions existed, i.e. no power maneuvers or transients occurred. Wherever the instrumentation permitted, data was obtained for more than one temperature RTD or pressure transducer. The data was analyzed to obtain an accurate average process parameter value. The channel power for the period of observation was obtained using a reactor physics code, Simulation Of Reactor Operation (SORO) which accurately predicts channel power.

Validation With SDS Channel Data

Two options were of interest during this validation process; the two phase multiplier option and the pipe roughness option. To assess the accuracy of each option, two sets of cases were performed with the Header to Header model varying only one thermal hydraulic option at a time. The first case consisted of varying the two phase multiplier option from option 7 to option 8: option 7 employs the Lorenc-Leung model which assumes the two phase multiplier is discontinuous at zero quality and the multiplier is non-zero for small amounts of sub-cooling, and option 8 employs the Lorenc-Leung model where the multiplier for sub-cooled fluid is ignored. Simulations with all twenty four SDS channels were performed and the results were analyzed to obtain average values for unit 3. (This was only performed for unit 3 data at the time but was verified with further runs using the FINCH channel data.) The results of the analysis are illustrated in Table 1.

Comparing the actual observed flow in the channels to the flow predicted by the single channel model it is demonstrated that the selection of option 8 is an accurate representation of the phenomenon occurring in the channels. The FINCH analysis performed with the variance of the same option resulted in the same outcome, option 8 provided a closer prediction to actual flow than option 7.

The single phase skin friction factor option was varied in the second case to determine which option, smooth pipe or rough pipe, accurately predicted channel flow. The rough pipe calculation employs the Colebrook equation whereas the smooth pipe calculation employs the smooth pipe wall calculation. Based on the above results the two phase multiplier was set to option 8 which ignores the multiplier for sub-cooled fluid. Simulations for all twenty four SDS channels were performed for all four units the results of which were analyzed to obtain average values representative of each unit. The results of the analyses are illustrated in Table 2.

Based on the comparison of the actual observed flow in the channels to the values predicted by the single channel model it is demonstrated that the selection of the smooth pipe option accurately represents the piping surface roughness characteristics (with the exception of unit 4). This was the expected result since the station has only been operating for a few years not having been affected by time and age as yet. Unit 4 was an anomaly to the expected result due to an erroneous observed header to header delta P which was a boundary condition in the analysis. This will be discussed later under Thermal Hydraulic Models as a Reactor Performance Monitoring Tool.

Therefore, based on the analysis of the SDS channels, option 8 is a more accurate representation of the two phase multiplier option and the smooth pipe option is a more accurate representation of the single phase skin friction factor for the piping. Furthermore, based on observations of the results for the individual channels, several channels were identified which required calibration. Upon completion of calibration, the affected channels were re-analyzed and it was confirmed that the predicted flows matched the observed flows.

Validation With FINCH Channel Data

To gain further confidence that the SDS validation process provided accurate results simulations were performed with the FINCH channels to determine which single phase skin friction factor option, smooth pipe or rough pipe, accurately predicts channel flow. A summary of the analyses results are illustrated in Table 3 where the individual channel data has been averaged for comparison purposes.

Based on the comparison of the actual observed flow in the FINCH channels to the values predicted by the single channel model, it is demonstrated that the selection of the smooth pipe option accurately represents the piping surface roughness characteristics, again, with the exception of unit 4.

Therefore, based on the analysis of the FINCH channels and the SDS channels, it appeared that the smooth pipe option more accurately represents the single phase skin friction factor for the piping. Similar to the SDS analysis, several channels were identified which required calibration. Once they were recalibrated, the observed flows were in agreement with the predicted flows using smooth pipe and option 8.

Validation With ECI Channel Data

Similar to the FINCH channel validation, to ensure that the validation process provided accurate results simulations were performed with the ECI channels to determine which single phase skin friction factor option, smooth pipe or rough pipe, accurately predicts channel flow. A summary of the analyses results are illustrated in Table 4.

When the FINCH and SDS channel flowrates were compared to the Mini-SOPHT predictions, the results were in good agreement. Conversely, the ECI channel flowrates versus predicted flowrates do not demonstrate the same degree of accuracy. No conclusion could be drawn based on the above results as to the effectiveness of either option for accurately predicting channel flows. The measured ECI flows were lower than expected and despite the recalibration performed they were still reading low. This observation will be discussed in detail in the following section.

Conclusions

Based on the validation analysis performed for the two phase multiplier option and the single phase skin friction option, with a few exceptions, the results demonstrate that option 8, which ignores the two phase multiplier for sub-cooled fluids, and the smooth pipe option, predict channel flow with a degree of accuracy higher than using option 7 and/or the rough pipe option. These options (option 8 and smooth pipe) now represent the default options for performing single channel analysis using the Mini-SOPHT Header to Header model.

The observation that unit 4 measured station data did not agree with the Mini-SOPHT predicted data and the inability to draw any conclusions based on the validation with the ECI channels, resulted in two investigations where the "tuned" Mini-SOPHT code was used as a tool to assist in determination of the root causes. The use of the Mini-SOPHT code as a performance monitoring tool in these two investigations will be the subject of the remainder of this paper.

OBSERVED STATION PHT THERMAL HYDRAULIC CONDITIONS

To obtain a reference point for future observations and to assist in the validation of the SOPHT Four Quadrant Model global power train conditions were obtained from all four units. The data was obtained using the PDDS system ensuring that all of the units had the same operating conditions to allow for comparison of results between units. Table 5 illustrates the station parameters that were obtained and their respective values.

Comparing the data for the different units, units 1 and 3 appear to display the same thermalhydraulic characteristics. The most notable difference between parameter values exists between the data for unit 4 with that of the other units. This observation resulted in an investigation to determine the root cause of the observed differences of which will be described in detail in the following section.

USE OF THE MINI-SOPHT CODE AS A PERFORMANCE MONITORING TOOL

Unit 4 High Header Delta P Investigation

During the validation of the SOPHT Four Quadrant Model and the Mini-SOPHT Header to Header Model, the Fuel Handling Department was reporting an increased frequency of high delta P alarms during fuelling operations at unit 4. This report of alarms along with the observed high header to header delta P resulted in safety significant questions being raised, primarily, Is there a core wide blockage problem occurring in unit 4? The basis for this question was that, if it were true, it would invalidate the safety analysis documented in the Safety Report thus questioning the ongoing operation of unit 4. It appeared that there were a few possibilities: the channel flow and the delta P were correct, suggesting that there is a core wide blockage due to the flow/delta P mismatch, or, the flow is correct and the header pressure instrumentation was erroneous, or the reverse of the latter.

The possibility of a correct delta P indication and an erroneous flow measurement was dispelled since FINCH channel flow measurements are used for reactor power calculations and the neutronic/thermal power mismatch would have been discovered by the secondary side heat balance. Since the header to header delta P was high for a duration that extended through the last heat balance this hypothesis does not hold.

Statistical data gathered for all units were compared to unit 4 data to assist in establishing several hypotheses for determining the root cause of the observed high header to header delta P. Data obtained during fuelling operations for several channels (see Figure 1) illustrated that the channel delta P appeared to be rising over time. Upon reviewing the results a request was made to re-calibrate all of the pressure transmitters. They had not been calibrated since installation and this would provide a reference point from which to start the investigation. Until the execution of the calibration was to be completed the investigation continued .

Assuming the observed delta P and flow was correct, analysis was performed with the SOPHT Four Quadrant Model to determine the size of blockage required to produce the observed high delta P. Knowing the size of blockage would indicate the severity of the blockage and suggest the magnitude of the mechanism causing the blockage. Using SOPHT, to reproduce the observed high delta P in unit 4 and maintain the observed flow a 20% obstructed core flow path was required. The analysis was also performed on a single channel scale with different channels in the PHT loop using Mini-SOPHT. The single channel model also predicted that based on the observed header delta P, a blockage of approximately 20% was required to match the predicted flow with the observed. Since the unit 4 observed flows were predicted during the validation process using the observed delta P for units 1&3, the single channel predictions suggested erroneous header readings or a large systemic blockage. Several theories for blockage that would result in the observed effects were as follows: shield plug corrosion, debris caught in the fuel, debris in the liner tube/endfitting annulus, presence of Flow Straightening Inlet Shield Plugs (FSISP), drifting pressure transmitters.

Several tests were performed to investigate the probability of the above theories being the root cause of the high header to header delta P and a source of the alarms received by Fuel Handling during the fuelling of unit 4, all of which, provided no indication of channel/core blockage.

Of interest were the tests to determine if shield plugs were the root cause, where fuelling machine tests were performed which removed shield plugs to observe the change in the channel thermal hydraulic parameters. During the test channel data was gathered through the PDDS system, such as, channel flow, delta T, channel outlet temperature, inlet and outlet header temperature, F/M delta P, Flow Injection flowrate and header pressures. The tests were simulated using Mini-SOPHT in an attempt to obtain a relationship between predicted and actual measured values. Based on the changes in delta T before and after the shield plugs were removed, it was concluded that the shield plugs were not the source of the increased delta P. An observation that resulted from the analysis of the test was that delta P was a poor means of detecting channel blockage. As Figure 2 illustrates, a large blockage can be present thus reducing flow with only a minor increase in delta P!

The probability that drifting transmitters were the root cause of the high delta P increased, so it was investigated further. Data was retrieved for the header pressures for the entire operating history of unit 4 for all pressure transmitters. As Figure 3 illustrates, the unit 4 header delta P's were observed to be increasing with time. Based on these results, accurate delta P transmitters were installed promptly on three out of four header pairs in unit 4 (the calibration of the pressure transducers had not been completed as yet). The transmitters displayed delta P's in agreement with units 1 and 3. Based on the new observed delta P, the Mini-SOPHT predictions of flow were now in good agreement with the observed FINCH flows.

Conclusions

The root cause of the high header to header delta P in unit 4 was drifted transmitters resulting in no real change in thermalhydraulic conditions thereby absolving the nuclear safety concern, and the high frequency of delta P alarms reported by fuel handling were due to a reduced margin to the delta P alarm setpoints. Intuition, as well as the SOPHT and Mini-SOPHT models, suggested that the observed flow was correct and that there was an instrumentation problem. The failure to recognize the significance of recalibrating the transmitters resulted in approximately a person year of effort wasted. Furthermore, it was observed that an improved technique for identifying the presence of channel flow obstructions was required.

ECI Channel Low Flow Investigation

The validation results of Mini-SOPHT using the ECI channels were the basis for suspecting that a generic problem existed with the ECI flow instrumentation. As illustrated in Table 6, there are several channels in all of the units which display extremely low flows compared to the predicted flows.

Upon initial investigation, it was discovered that the ECI flow transmitters are not routinely calibrated, therefore, selected transmitters displaying the lowest readings were recalibrated resulting in no change in indication. To establish the accuracy of the flow measurement, channel data was gathered for the twelve ECI channels (delta T, channel power and header delta P) and compared to Mini-SOPHT predictions using the header to header models. The predictions demonstrated that based on the above parameters, the flow was adequate for fuel cooling and that the instrumentation was reading incorrectly.

To improve the accuracy of the flow predictions a "generic" mini-SOPHT channel model was developed that consists of the channel and endfittings only (i.e. less the feeders), providing a single channel model which may be used on any channel in the core. The fuelling machine delta P reading for the specific channel is utilized as a boundary condition (as well as channel power and inlet enthalpy) to predict the channel flowrate. The FINCH model, as it was called, was validated against unit 2 FINCH channel data at 100%FP and 10%FP conditions. The validation results outlined in Table 7 indicate that the flow predictions are in good agreement with the measured values. At 100%FP the average predicted flow deviation is -0.02 kg/s with a maximum deviation of 0.3 kg/s, and at 10%FP the average predicted flow deviation is -0.3 kg/s with a maximum deviation of 0.7 kg/s. The larger average flow deviation of 0.3 kg/s was accepted as the simulation uncertainty based on the above validation.

The validated model was used to predict the ECI channel flowrates and confirm the inaccuracy of the present flow instrumentation. As illustrated in Table 8, the largest error in flow occurred in channel V06 where the predicted flowrate is 6.2 kg/s greater than the measured flow. The root cause investigation into why the instrumentation problem exists is presently continuing.

Conclusions

During this investigation, it was demonstrated that mini-SOPHT was an effective performance monitoring tool by illustrating how it was implemented to determine that there was a generic ECI flow instrumentation problem and then used to verify this via the development and validation of the FINCH channel model.

SUMMARY

The validation of the Mini-SOPHT model demonstrates how the use of reactor operating data is integral in the development of the thermalhydraulic models to improve the quality of the predictions. Furthermore, the discoveries that were made during the validation process as well as the use of the Mini-SOPHT model as a tool to resolve the problems illustrates that the code provides the analyst with a powerful tool in reactor performance monitoring.

TABLE 1 - UNIT 3 TWO PHASE MULTIPLIER OPTION COMPARISON

Actual Ave. Flow (kg/s)	Option 7 (kg/s)	Option 8 (kg/s)	Deviation Actual / 7	Deviation Actual / 8
28.0	27.2	28.1	0.8	-0.1

TABLE 2 - SINGLE PHASE SKIN FRICTION FACTOR OPTION COMPARISON FOR SDS CHANNELS

Unit	Actual Ave. Flow (kg/s)	Smooth Pipe (kg/s)	Rough Pipe (kg/s)	Deviation Actual/Smooth	Deviation Actual/Rough
1	28.2	28.0	26.9	-0.13	1.26
2	27.5	27.9	26.8	0.39	0.68
3	28.0	28.1	27.2	0.08	0.72
4	27.9	29.2	28.3	1.3	-0.41

TABLE 3 - SINGLE PHASE SKIN FRICTION FACTOR OPTION COMPARISON FOR FINCH CHANNELS

Unit	Actual Ave. Flow (kg/s)	Smooth Pipe (kg/s)	Rough Pipe (kg/s)	Deviation Actual/Smooth	Deviation Actual/Rough
1	27.1	27.0	26.0	0.07	1.11
2	26.8	26.7	25.7	0.05	1.1
3	27.0	27.1	26.2	-0.17	0.76
4	26.8	27.9	27.0	-1.1	-0.12

TABLE 4 - SINGLE PHASE SKIN FRICTION FACTOR OPTION COMPARISON FOR ECI CHANNELS

Unit	Actual Ave. Flow (kg/s)	Smooth Pipe (kg/s)	Rough Pipe (kg/s)	Deviation Actual/Smooth	Deviation Actual/Rough
1	21.3	22.5	21.3	-1.2	0.2
2	19.5	22.1	20.9	-2.6	-1.5
3	20.5	22.9	21.8	-2.4	-1.2
4	21.1	23.3	22.3	-2.2	-1.0

TABLE 5 - FOUR UNIT COMPARISON

Unit	Hdr-Hdr DP* (MPa)	Boiler DP* (MPa)	Pump DP* (MPa)	Actual Ave. Flow (kg/s)
1	1.36	0.49	1.85	27.1
2	1.30	0.51	1.90	26.8
3	1.36	0.48	1.83	27.0
4	1.43	0.43	1.82	26.8

*Note: These are average values based on unit measurements of all header, boiler and pump DP's.

TABLE 6 - ECI MEASURED VS. PREDICTED FLOW RATES

Unit-Channel	Actual Flow (kg/s)	Smooth Pipe (kg/s)	Rough Pipe (kg/s)	Smooth Deviation (kg/s)	Smooth Deviation (%)	Rough Deviation (kg/s)	Rough Deviation (%)
1 - B12	21.3	23.1	22.3	1.9	8.1	1.0	4.5
1 - N23	20.2	23.0	21.8	2.8	12.2	1.6	7.3
1 - V19	20.1	21.5	20.1	1.4	6.5	0.0	-0.2
1 - D07	21.6	24.0	22.5	2.4	10.1	0.9	4.0
2 - N23	19.6	23.4	22.1	3.8	16.3	2.6	11.5
2 - V06	15.5	21.9	20.4	6.4	29.0	4.9	23.9
2 - D07	19.6	23.5	22.4	3.9	16.7	2.8	12.4
2 - D18	19.8	23.5	22.4	3.7	15.8	2.6	11.6
3 - N23	19.1	24.3	23.0	5.2	21.3	3.9	16.8
3 - V06	17.5	22.9	21.4	5.4	23.7	3.9	18.3
3 - V19	20.1	22.8	21.3	2.3	11.7	1.2	5.5
3 - D07	20.4	24.6	23.5	4.2	17.1	3.1	13.1
4 - N23	20.2	24.7	23.4	4.5	18.4	3.2	13.8
4 - V06	18.6	23.4	21.9	4.8	20.6	3.3	15.0
4 - V19	19.5	23.2	21.7	3.7	16.0	2.2	10.1
4 - D07	22.2	25.1	24.0	2.9	11.7	1.8	7.5

Table 7 - FINCH Model Validation Results

Channel	Measured DP (kPa)	Measured Flow (kg/s)	Predicted Flow (kg/s)	Flow Deviation (kg/s)
		Reactor operating at 100%FP		
O08	973	27.4	27.5	0.1
K03	830	25.1	25.3	0.2
C10	793	25.0	24.7	-0.3
Average		***25.85***	***25.84***	***-0.02***
		Reactor operating at 10%FP		
O08	906	28.0	27.3	-0.7
K03	819	25.5	25.9	0.4
C10	755	25.1	24.8	-0.3
Average		***24.5***	***24.2***	***-0.3***

Table 8 - Measured vs. Predicted ECI Channel Flows

Channel	Measured DP (kPa)	Measured Flow (kg/s)	Predicted Flow (kg/s)	Flow Deviation (kg/s)
Reactor operating at 100%FP				
V19	621	18.2	21.8	3.6
V06	576	14.8	21.0	6.2
N02	672	19.0	22.7	3.7
Reactor operating at 10%FP				
V06	551	15.5	21.1	5.6
N02	627	19.4	22.6	3.2

Figure 1

FUELLING HISTORY - NORTH LOOP W-E CHANNELS

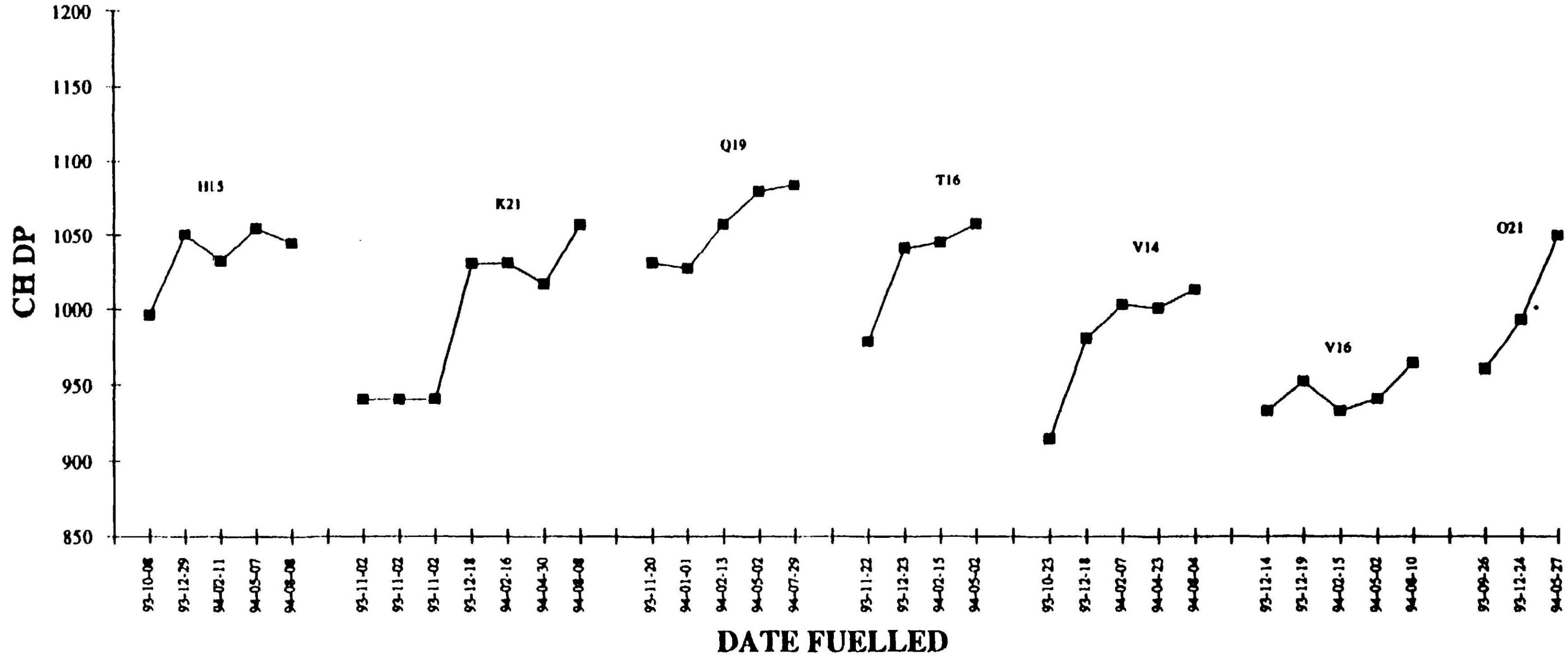

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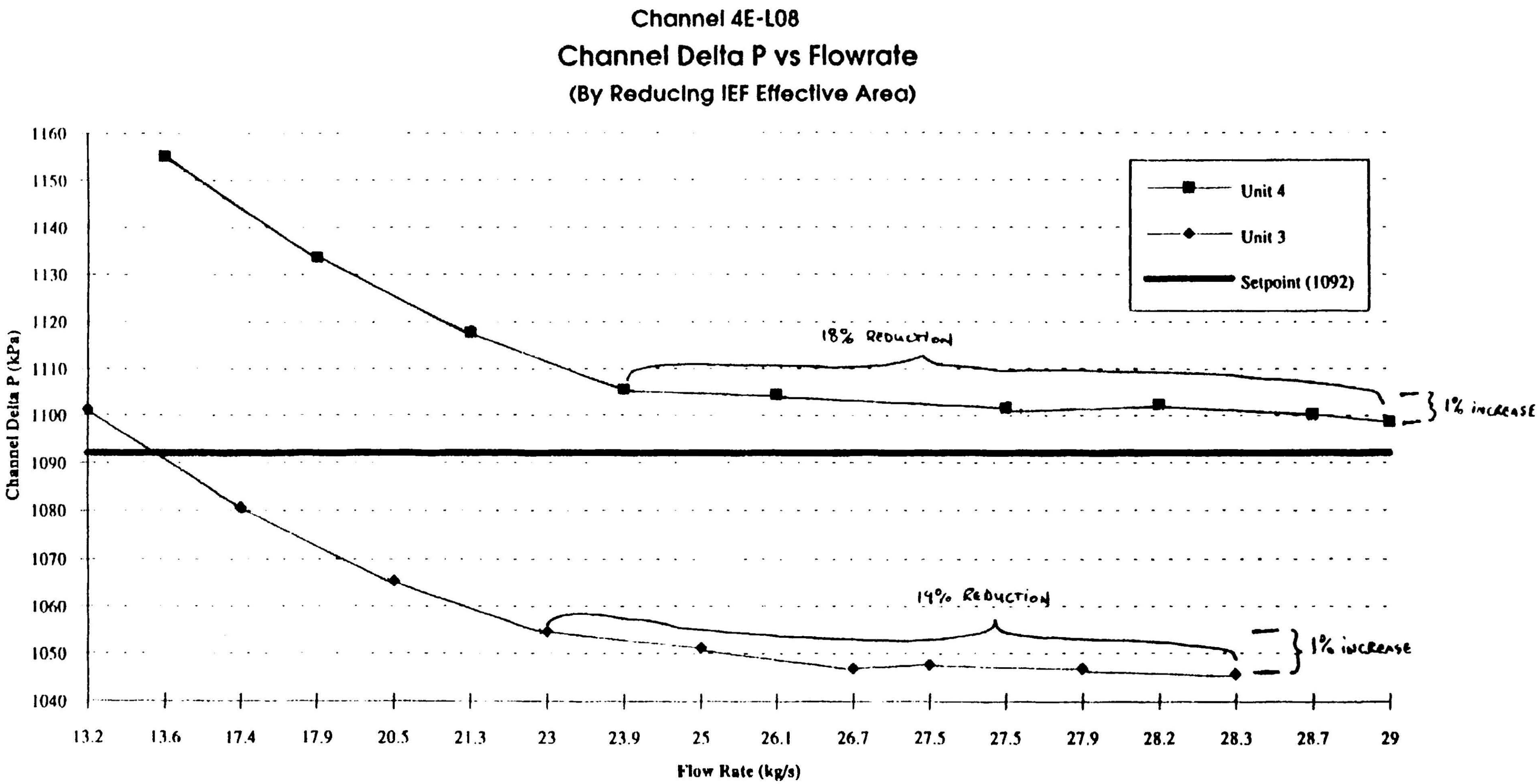
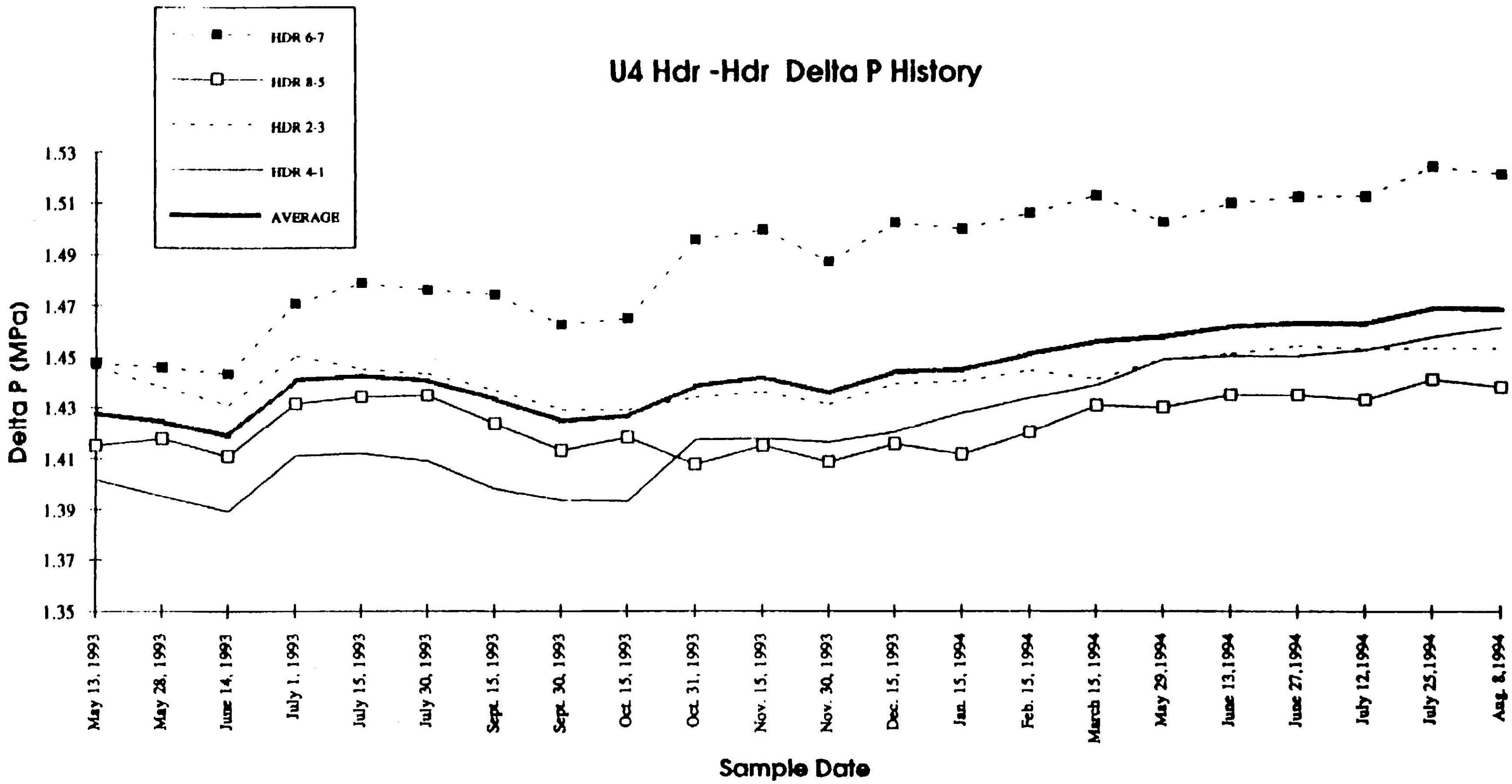
Figure 2



DPVSFLW4.XLS Chart 6

Figure 3



g:/deltap/excel/unit4/[HISTORY2.XLW]HSUMMARY.XLS Chart 6