Performance Evaluation of the Pattern Recognition Flooding Predictor

Presented to:

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INTRODUCTION

The genesis of this project is innovative work by Mr. George Dzyacky, owner of 2ndpoint, Inc.,[*] which attracted funding by The U. S. Department of Energy (DOE). The thrust of the Dzyacky work is a control methodology, which permits distillation columns to operate in a stable fashion very close to the flood point. The methodology is called the *pattern recognition flooding predictor*, and the purpose of the present work was to demonstrate the value of the predictor when applied to an operating distillation column. Funding for the work was by the DOE. Mr. Dzyacky was present as an observer for the test run by SRP.

BACKGROUND

The Separations Research Program (SRP) conducted a series of distillation tests to study pattern recognition software (PRS), which permits stable operation up to the incipient flood point of a distillation column. The objective of the study was to determine whether the PRS could control the column close to the flood point without allowing the column to flood. In this test, both structured packing and sieve tray column internals were studied.

The packing was supplied by Julius Montz GmbH and installed by SRP personnel. The sieve trays were fabricated by Koch-Glitsch, Inc. and were also installed by SRP personnel. Prior to this study, both the packing and trays had been tested by SRP to determine their hydraulic and mass transfer characteristics.

COLUMN CONFIGURATION

The test system comprised a conventional distillation column operated at total reflux and serviced by a kettle reboiler and a horizontal condenser. The reboiler was heated with 130 psia steam and the condenser was cooled with 50ºF chilled water. The column is insulated with two inches of calcium silicate. For run SRP0105, the structured packing test, the system set up is shown in Figure 1. In this run, the reflux was returned to the column by gravity. The Montz B1-250 stainless steel packing was installed by carefully lowering the elements onto a packing support. For run SRP0106, the sieve tray run, the

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system setup is shown in Figure 2. For this test, the column configuration was modified to provide reflux into the downcomer on the first tray. The 3/16-in hole sieve trays were assembled as a cartridge and loaded into the column with the aid of a crane.

Pressure drop data were measured using commercially available differential pressure cells (DPC) designed for ranges of 0-5 and 0-30 inches of water. Both the high and low-pressure legs of the cells were purged with nitrogen to prevent hydrocarbon condensation.

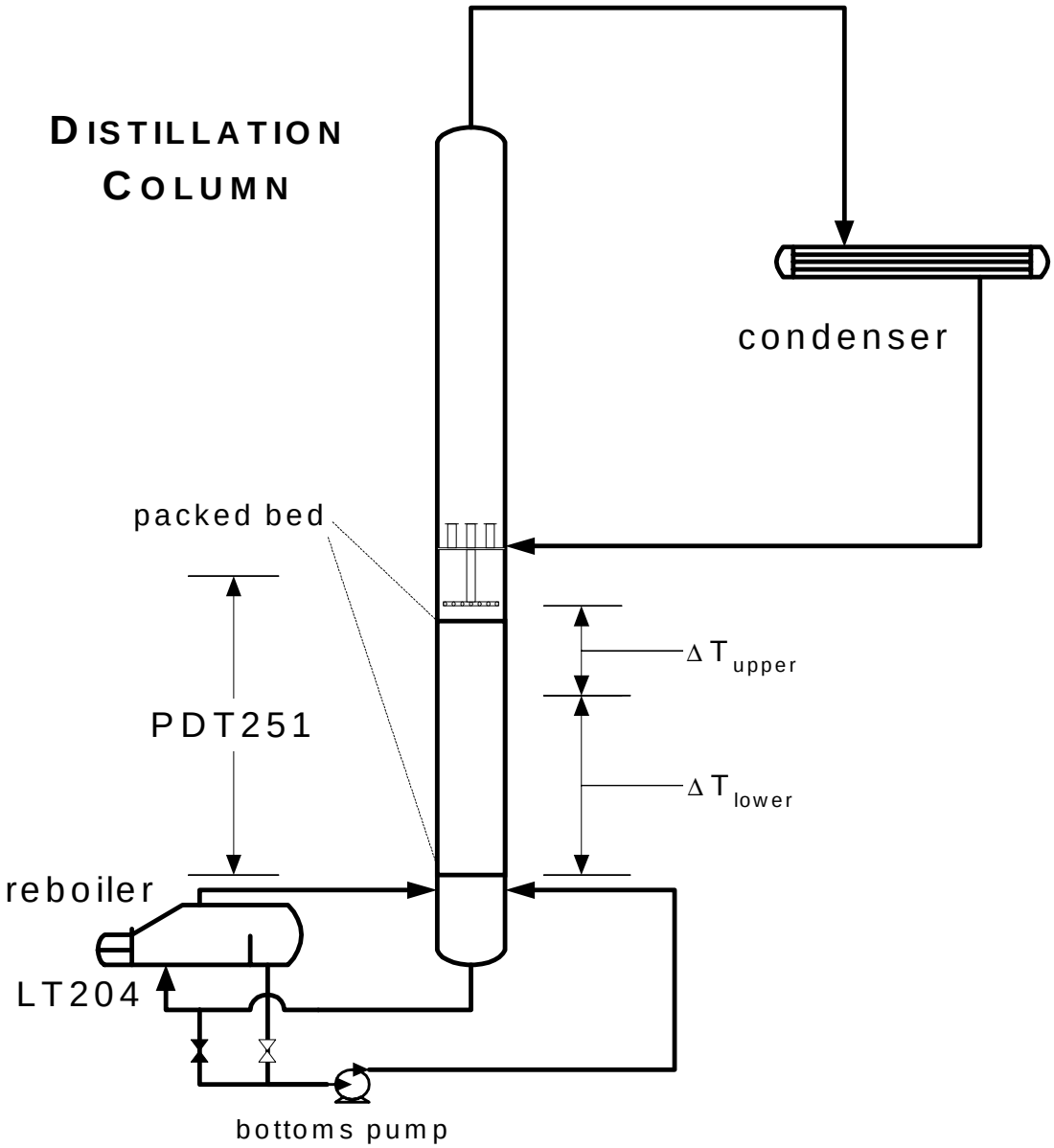

Figure 1. 18" distillation column configuration shown with parameters used in Dzyacky packed column test.

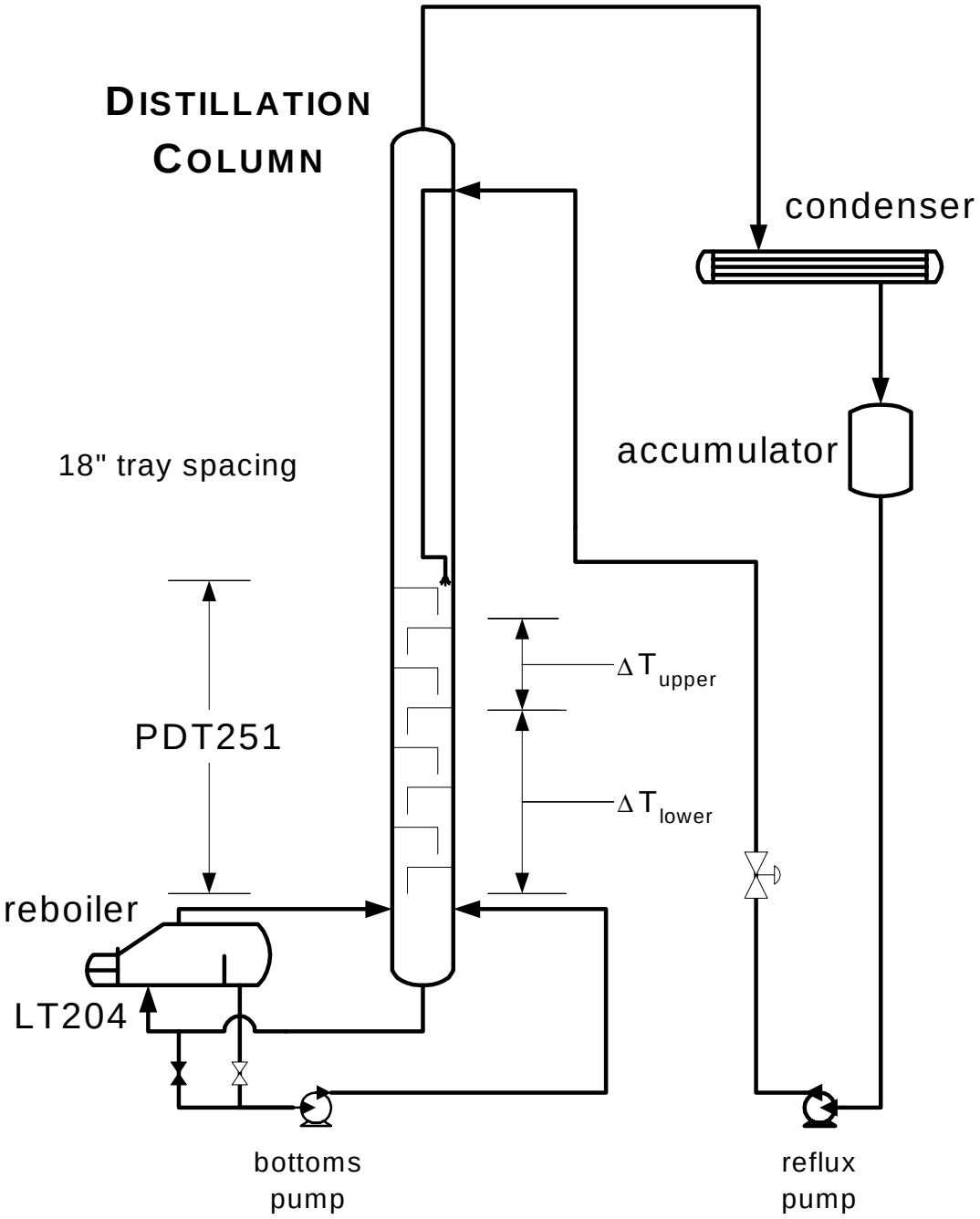

Figure 2. 18" distillation column configuration shown with parameters used in Dzyacky tray column test.

EXPERIMENTAL RUN PROCEDURE

The Pattern Recognition System (PRS) is dependent on various process parameters. The process by which these parameters are chosen is based on careful observation of a column as it approaches and enters flood. Each column is different. For example, a tray column will have parameters different from those of a packed tower, and a column operating at total reflux will have parameters different from those of a column that has a feed stream and a product streams. For purposes of this total reflux experiment, the column pressure drop and derivatives of the reboiler level, column pressure drop, column bottoms level, and column temperature differences (see Figures 1 and 2) determined when the PRS decreased the reboiler duty.

The PRS logic was developed and partially optimized during the course of the project. The packed column was the first to be tested. The logic for this configuration was based entirely on the derivatives of the following: reboiler level, temperature differences across the column, and pressure drop. The PRS compares the calculated derivatives with a PRS critical number entered by the user for each process parameter. If the predictor is enabled and the criteria met, the predictor responds by reducing the reboiler duty to the column by a predetermined value. In the case of the packed column, the reboiler duty was decreased 1-5%. When the actual value of the reboiler duty was within 0.004 MMBtu/hr of the reduced set point, the control module increased the reboiler duty 50% of the amount it was originally reduced. For example, if the original set point was 0.800 MMBtu/hr and the predictor fired, the reduced set point (assuming a 5% reduction) would be 0.760 MMBtu/hr. When the actual duty reading reached 0.764 MMBtu/hr, the duty set point would automatically increase to 0.780 MMBtu/hr. Figure 3 illustrates the logic in this module.

The advantage of using this method in a process environment is that a reboiler duty can be entered that is slightly higher than the flooding duty. The PRS will then decrease the duty until the derivative values are within the PRS critical numbers. However, this control scheme does not allow for the continual maximization of the unit's duty capacity.

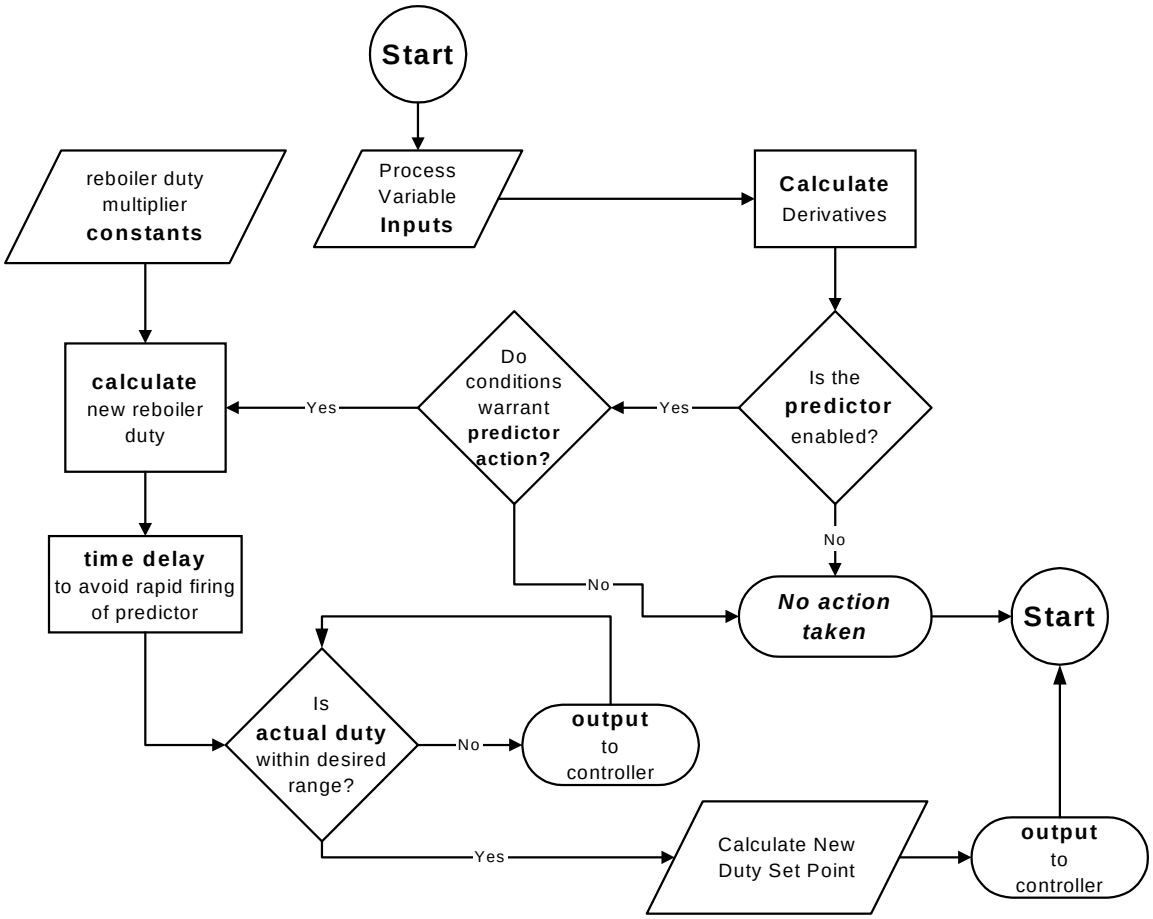

Figure 3. Logic flowchart for Dzyacky packed column pattern recognition software.

In the second set of tests the PRS performance was studied using a sieve tray column. Following the packed column operation, several changes were incorporated into the PRS that refined its capabilities. The most significant modification was the addition of a secondary predictor. The primary predictor is based on derivative values calculated by the computer whereas the secondary predictor is based on the actual pressure drop and time. Either predictor may run independently of the other. The PRS compares the calculated derivatives or field-generated values with a PRS critical number entered by the user for each process parameter. If the predictor is enabled and the criteria met, the predictor responds by reducing the reboiler duty to the column by a predetermined value. The logic driving this software is given in Figure 4.

To facilitate test work and push the column towards flood, a control module, called *MAX DUTY*, was created which increments the reboiler duty. The user specifies the amount of duty added to the reboiler set point and the time between duty additions.

After packing or tray installation and pressure testing, a binary mixture of cyclohexane and n-heptane is pumped to the bottom of the column as an initial charge. Steam is then

admitted to the reboiler under heat duty control until the column floods. The column is briefly held in a flooded condition to ensure that all packing surfaces are wetted or that the trays have a good liquid seal. The reboiler duty is then set to a condition approximately 75% of the flood point and allowed to run until the pressure drop falls to a reasonable pre-flood level. In the packed column case, the reboiler duty is then set equal to the flood point and the predictor is enabled. The column is then allowed to reach "steady state." For the tray column, the predictor(s) and the duty addition module are enabled. The column is then monitored for an extended period of time to determine whether the PRS works properly and to ensure the user entered PRS constants are adequate. If the column floods while the predictor(s) is enabled, new constants are entered and the experiment repeated.

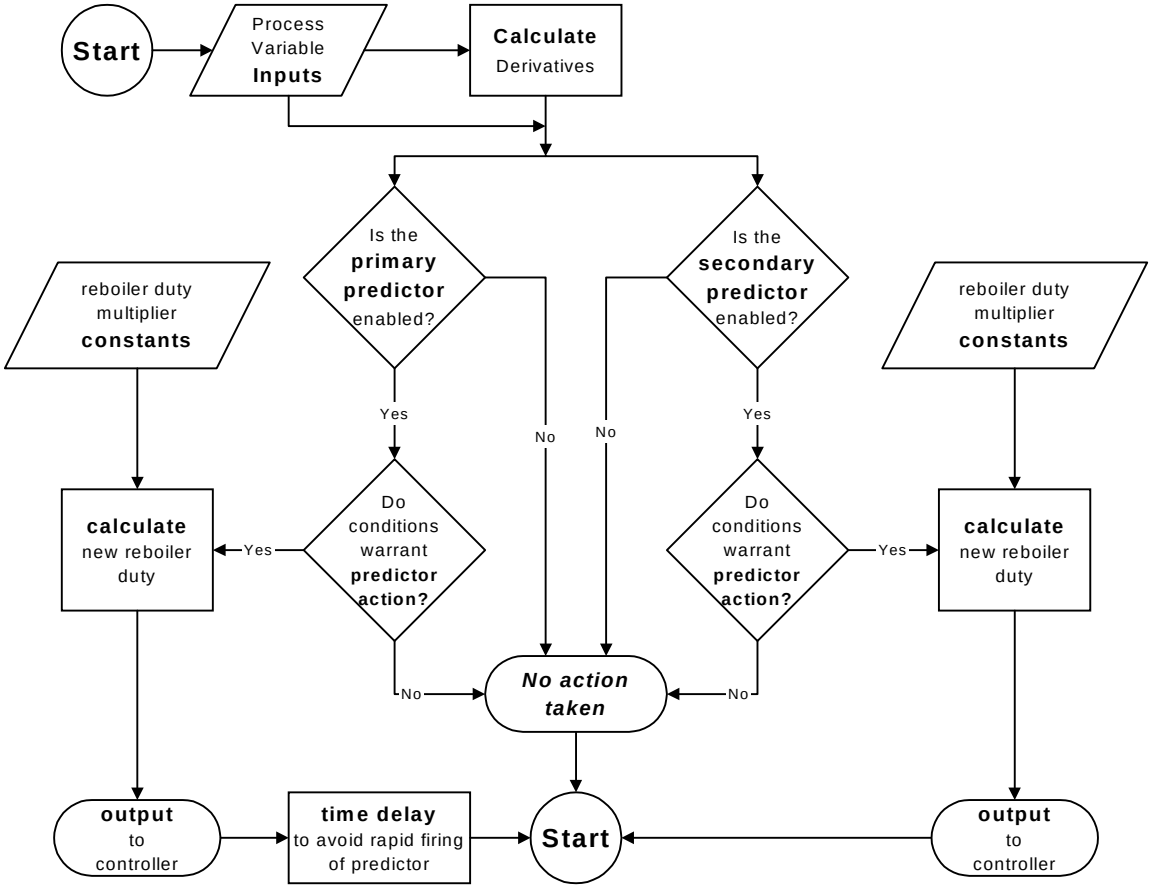

Figure 4. Flowchart illustrating Dzyacky pattern recognition software logic.

EXPERIMENTAL RESULTS

Tests were carried out at 24 psia using the cyclohexane/n-heptane system. The physical properties of this system are given in Table 1.

Table 1. Physical Properties of the Cyclohexane/n-Heptane System (Average at Column Bottom)

Pressure (psia)	24
Liquid density, lb/ft^3	38
Liquid viscosity, lb/ft-hr	0.56
Liquid diffusivity, ft^2/hr	2.4e-4
Vapor density, lb/ft^3	0.34
Vapor viscosity, lb/ft-hr	0.020
Vapor diffusivity, ft^2/hr	0.114
Surface tension, dynes/cm	12
Relative volatility	1.57
Slope of equilibrium line	1.21
Average Temperature, ^{o}F	238

PACKED COLUMN

Figure 5 shows a two-hour derivative data plot for Dzyacky PRS. The average duty for this run was 0.8235 MMBtu/hr (see Figure 6). Flooding was achieved at 0.83 MMBtu/hr. The vertical black lines represent action by the PRS to reduce reboiler duty by 1%. After each firing of the predictor, there was a 35 second recovery period during which the predictor was unable to fire again. This delay prevented the PRS from overreacting and reducing the heat load too much. At approximately 15:05, the predictor missed a pattern; therefore, the predictor was enacted manually. New constants for the PRS were entered into the Delta V distributed control system, and further tests had no misses. The predictor fired approximately 4 times per hour.

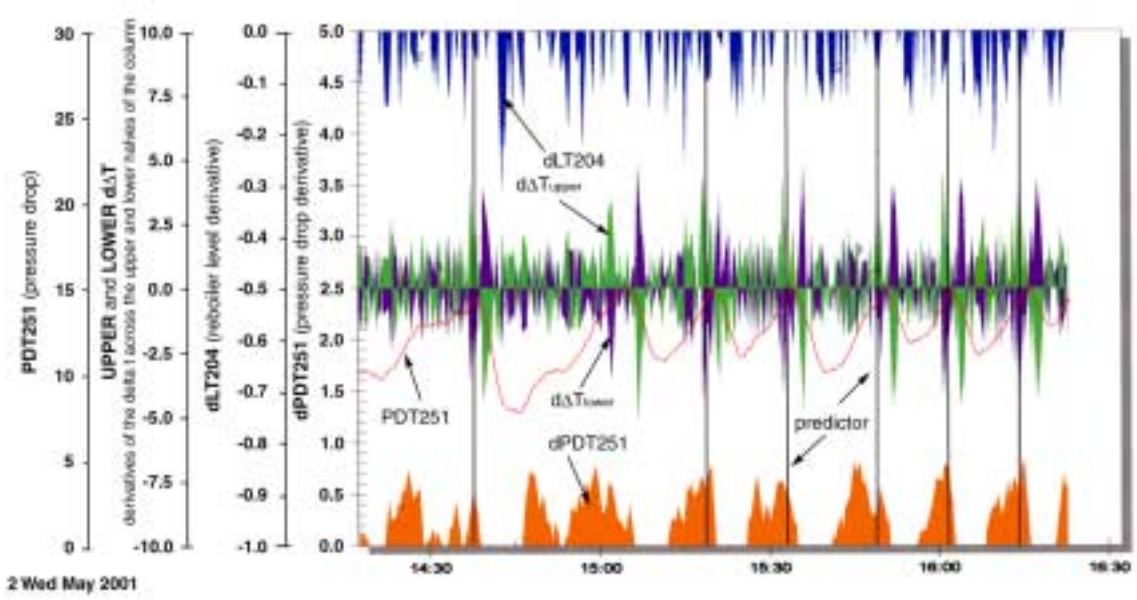

Figure 5. Flooding predictor and control for the first structured packing test.

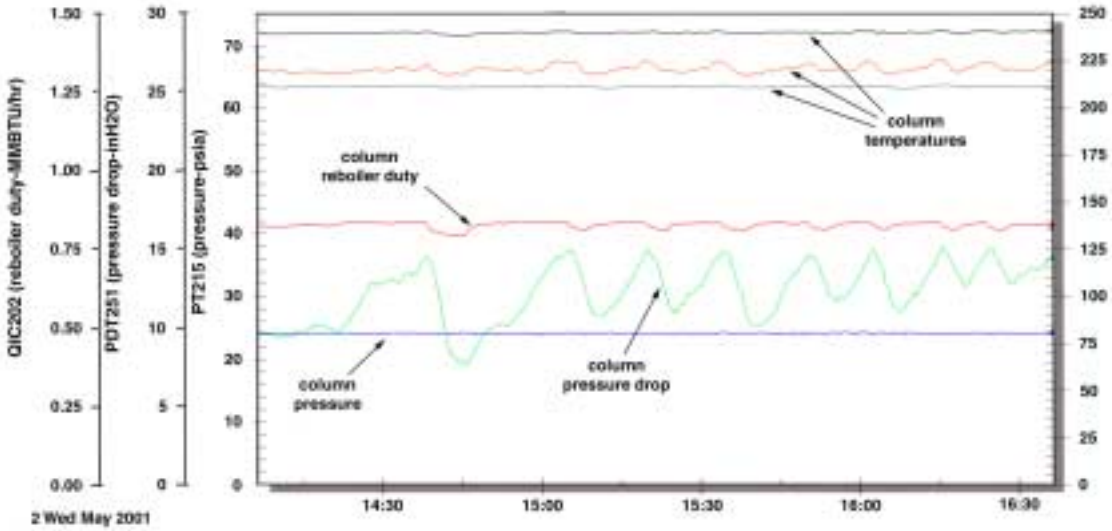

Figure 6. Column process parameters for the first packed column test.

By varying the constants for the Dzyacky PRS, the column became more stable. Figure 7 demonstrates the results of the second test on the structured packing. The Dzyacky PRS constants were modified which reduced the firing frequency to less than 3 times per hour and also steadied the temperature profile. Figure 8 shows a 2 hour trend that is much more stable than in earlier runs (see Figure 6 for comparison). A relatively constant temperature difference across the entire packed bed was maintained during both tests, however, there is much less variation in the middle temperature in the second test. The final constant values used can be seen in Table 2.

Table 2. Dzyacky PRS critical values for SRP's 18" packed column study.

Control	Set point
ILT204	-0.24 in/second
IPDT251	0.45 inH2O/second
IT_{upper}	0.01 °F/second
IT_{lower}	-0.01 °F/second
Predictor Reduction Fraction	0.99
Delay Time Interval	35 seconds

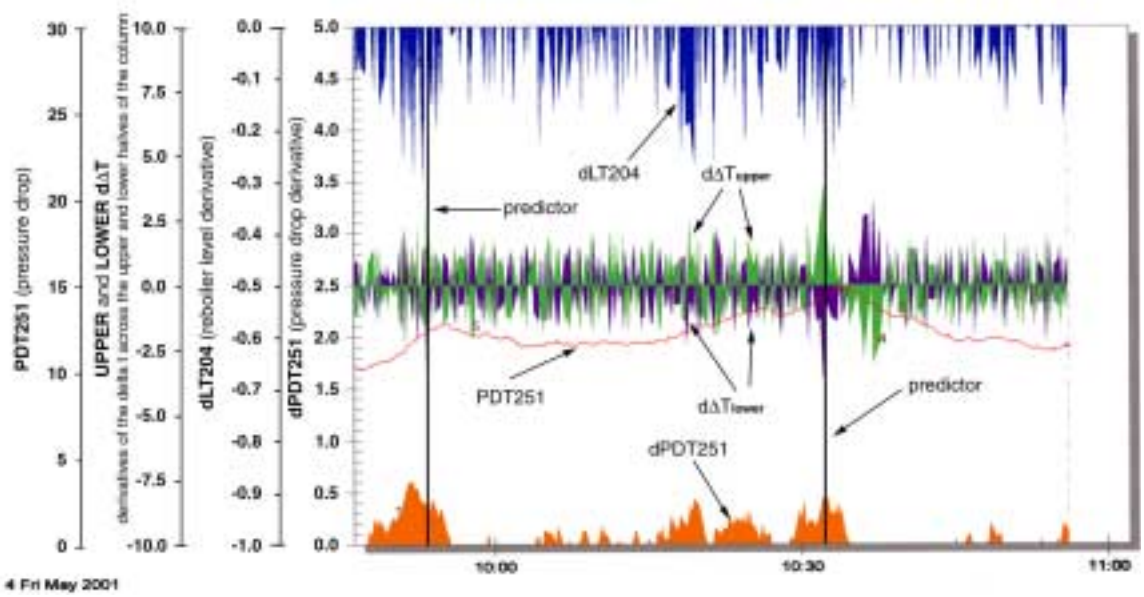

Figure 7. Flooding predictor and control for the second structured packing test.

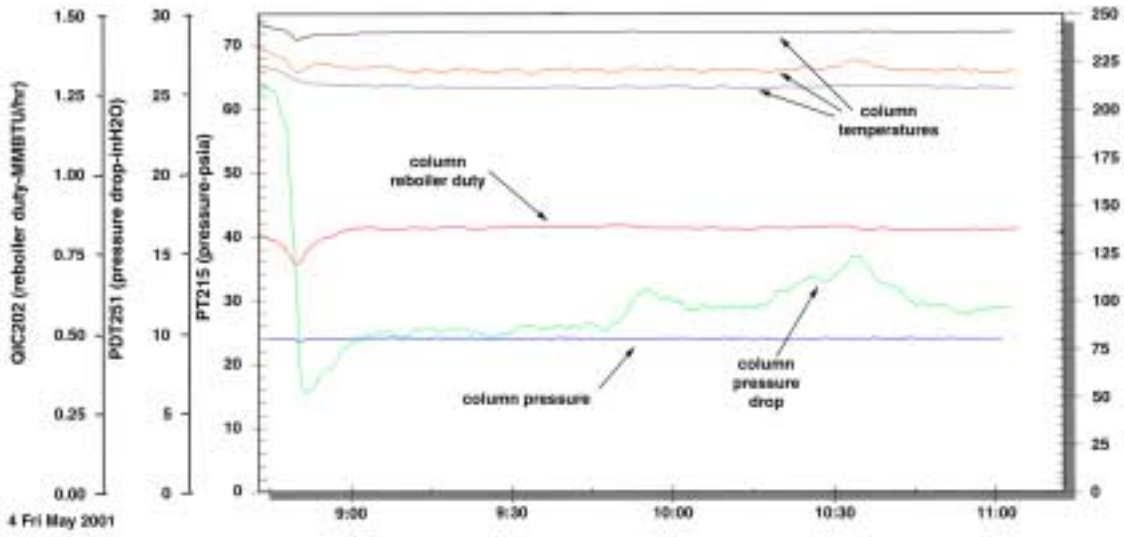

Figure 8. Column process parameters for the first packed column test.

TRAY COLUMN

Figure 9 illustrates the historical data acquired over a 2.5 hour time span from 8:30AM until 11:00AM. It shows the derivative values for the reboiler level, pressure drop, temperature difference across the top half of the column and the temperature difference across the bottom half of the column, and each predictor firing. It also displays the actual value for the pressure drop. The set point for this run may be seen in Table 3. The "MAX DUTY" module made incremental additions to the duty set point (1,000 Btu/hr) every minute. Constantly incrementing the duty over time would eventually cause the column to flood, but the Dzyacky PRS "senses" the column loading and responds

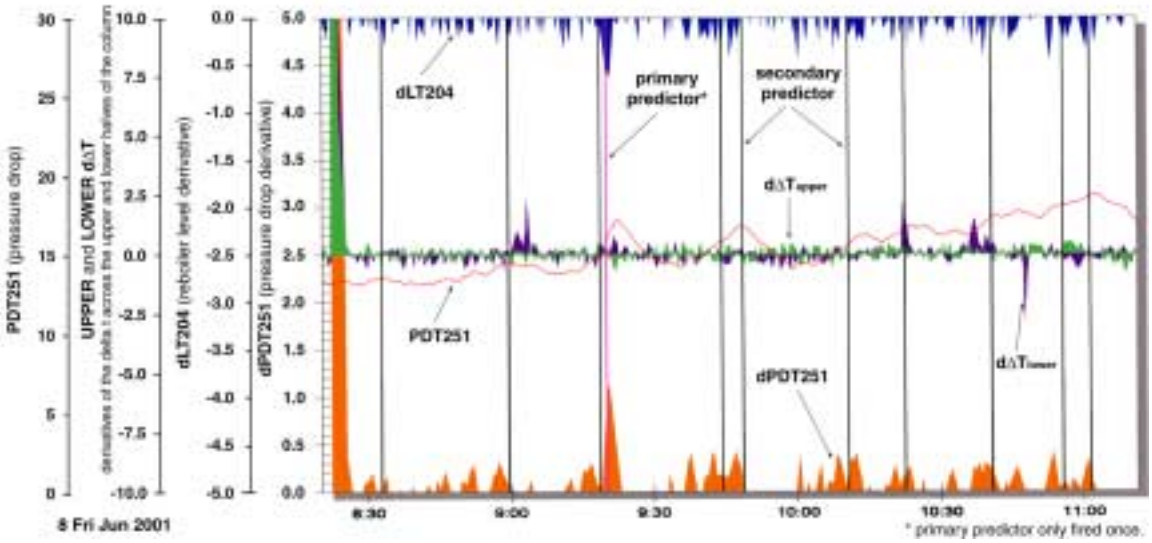

Figure 9. Flooding predictor and control for the first sieve tray test.

Table 3. Dzyacky PRS critical values for SRP's initial 18" tray column study.

Control	Set point
ILT204	-0.5 in/second
IPDT251	0.5 inH2O/second
IT_{upper}	0.4 °F/second
IT_{lower}	-0.4 °F/second
Primary Predictor Reduction Fraction	0.93
Secondary Predictor Reduction Fraction	0.975
Secondary Time Interval	240 seconds
MAX DUTY incremental value	1,000 BTU
MAX DUTY incremental time	60 seconds

accordingly. At approximately 9:20AM, the primary predictor fires, reducing the duty by 7%. The primary predictor fired only once during the two tray tests. As was the case in the packed column test, the primary predictor had a recovery period of 35 seconds, which kept it from firing repeatedly over a short span of time. The secondary predictor, which reduced the duty by 2.5%, was primarily responsible for maintaining the column. This fact is evidenced by the 9 times it fired during the duration of this test. Also, several very sharp spikes appear in the upper temperature difference derivative on the chart. These spikes are a result of rain cooling the column. The average duty over the course of the test was 0.509 MMBtu/hr. The flood point was determined to be 0.515 MMBtu/hr.

Figure 10 shows the overall column parameters over the same time period as Figure 9. This gives a clear picture of what is happening in the column over the course of the test run. At approximately 8:15AM, 8:50AM, 10:15AM, and 10:30AM, there were sudden

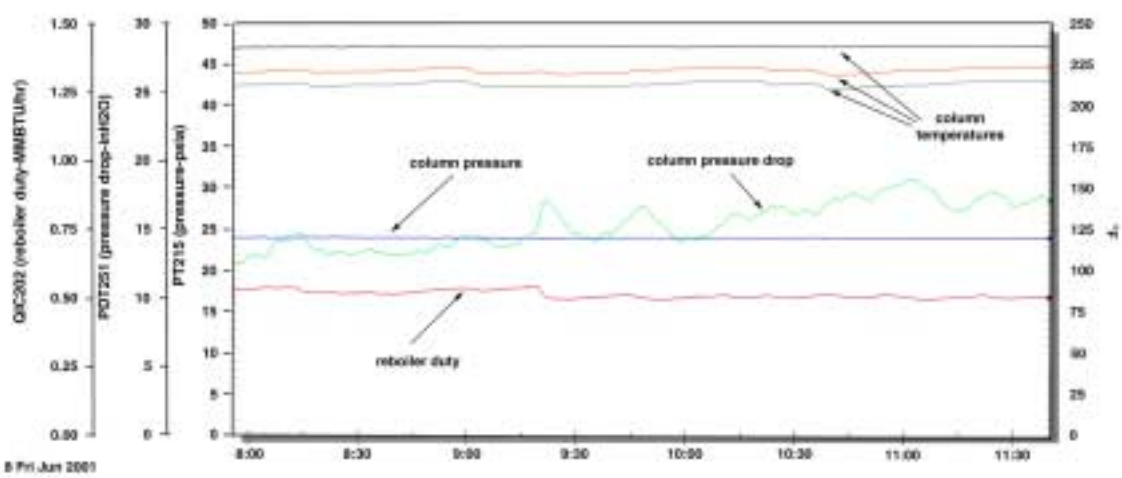

Figure 10. Column process parameters for the first packed column test.

decreases in the column temperatures. These sudden decreases were the result of sporadic rainfall, which rapidly cooled the top half of the column (Figure 10). The temperature at the bottom of the trays remains constant. Excluding periods of rainfall,

the overall temperature profiles for the sieve tray tests were constant. The Dzyacky PRS took advantage of this by allowing the *MAX DUTY* module to increase the duty to the reboiler immediately following each rainfall until 1) the rain stopped and the column temperatures returned to normal or 2) the duty increase caused the either the primary or secondary predictor to fire.

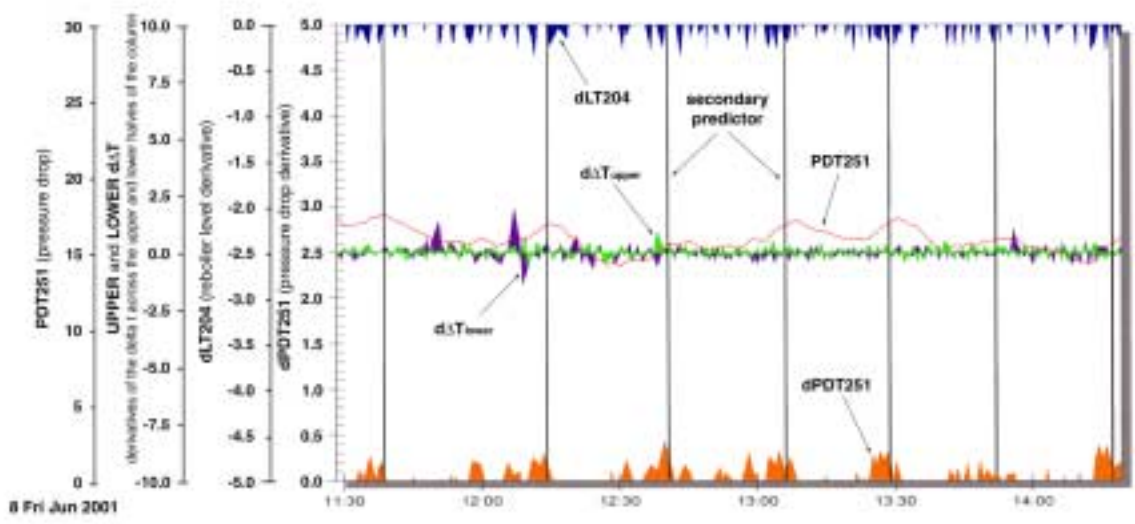

Figure 11. Flooding predictor and control for the first sieve tray test.

The chart illustrated in Figure 11 is taken from the Fisher-Rosemount Delta V distributed control system over a 3 hour time span from 11:30 AM until 2:30 PM. The set point for this run may be seen in Table 3. The only difference between the set point for this run and the previous run is that the duty is incremented every other minute versus every minute. During this run, the pressure drop appeared much steadier. As a direct result of lowering the heat input, the primary predictor never fired and the secondary predictor fired only 7 times.

Table 4. Dzyacky PRS critical values for SRP's second 18" tray column study.

Control	Set Point
ILT204	-0.5 in/second
IPDT251	0.5 inH2O/second
IT_{upper}	0.4 °F/second
IT_{lower}	-0.4 °F/second
Primary Predictor Reduction Fraction	0.93
Secondary Predictor Reduction Fraction	0.975
Secondary Time Interval	240 seconds
MAX DUTY incremental value	1,000 BTU
MAX DUTY incremental time	120 seconds

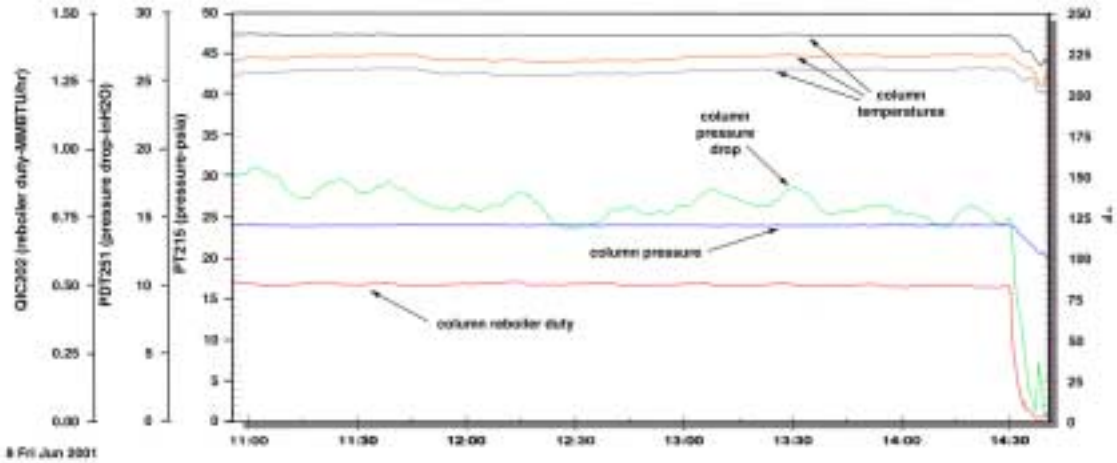

Figure 12. Column process parameters for the first packed column test.

Figure 12 shows the overall column parameters during the same time period shown in Figure 11 and gives a clear picture of what is happening in the column over the course of the test run. After decreasing the amount of heat added to the system by the *MAX DUTY* module, the stability of the column increased.

ANALYSIS OF RESULTS

Based on the data that was generated in this test, several observations can be made. The pattern recognition software works well with both with packing and with trays, even though it has not been thoroughly optimized. The Dzyacky Pattern Recognition Software maintained an average duty 99% of flood for the packed column tests and 99% of flood for the tray test with relatively few difficulties. Heat duty, and thus capacity, can remain higher for longer periods of time. Column flooding that results from minor upsets can be avoided in many cases, illustrated by the sporadic bursts of rain that occurred throughout the tray test. The column pressure drop remained relatively stable and more heat was added to the column during the brief periods of rain.

CONCLUSIONS

The purpose of this test work was to provide independently established performance data that determined whether the idea of pattern recognition software was viable. The research was supported in whole by a grant from the Department of Energy, Office of Industrial Technologies, Inventions and Innovation Program. The tests performed at the Separations Research Program prove that the software will work both with a packed column and a tray column running in a total reflux mode.

Many modifications were made to the software package, between the packed column test and the tray column test, which enhanced the ability of the PRS to control the process.

The addition of a secondary predictor stabilized the column. Further optimization of the software could lead to even greater stability in the distillation column. Additional studies of packed and tray columns should be performed that focus on the software optimization and focus on creating a more generalized model. More studies should be considered that involve industrial distillation columns running with a feed stream and product streams. The tests performed by the Separations Research Program were based primarily on the first derivative of process variables. A test that focuses on second derivatives or a combination of first and second derivatives is also advised.

One major benefit of this software package is having the capability to run very close to the flood point, where the highest efficiency and highest capacity occur. Another positive aspect of the software package is that it can be installed on nearly any process control computer, in addition to and working with any other software packages already on the computer.