

Final Technical Report

Project Title: Distillation Column Flooding Predictor

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Executive Summary:

The U. S. petroleum refining and chemical processing industries consume over 12 quadrillion BTUs of energy each year. Distillation is a low thermal efficiency unit operation (about 6% for easy separations) that currently accounts for 40% of the processing energy consumed in refining and continuous chemical processes. In spite of the high energy required for distillation, it is often chosen over other separation processes because of the relatively low initial capital investment, flexibility, and ability to yield high purity products.

Currently, every barrel of crude oil is subjected to an initial separation by distillation, and nearly every chemical process requires distillation for product recovery or purification. This high level of energy consumption and widespread utilization makes distillation column operations an extremely attractive area for optimization. The proposed research will develop a methodology that will optimize the energy input per barrel of feed to a distillation column. Widespread implementation of the

technology will make a significant impact on the energy consumption of the chemical processing industry.

The research validated the Flooding Predictor, an advanced process control strategy that utilizes a patented pattern recognition system to identify the onset of pre-flood conditions in distillation, absorption, and stripping columns. The strategy briefly relaxes column severity at the pre-flood state causing long-term operation to become significantly more stable and energy efficient. Potential energy wasting flood conditions are avoided, column stability is increased, and column throughput is increased.

The goals of the project were to develop the Flooding Predictor, a low cost, advanced process control strategy, into a universally useable tool that would:

1. Maximize the separation yield of a distillation column, thereby increase domestic refining capacity
2. Maximize throughput in separation columns
3. Decrease energy intensity (BTU per barrel of feed) of the separation process used extensively in the industry
4. Dramatically decrease and/or eliminate flooding phenomena which is prevalent in the separation process
5. Evolve into a commercial product

The goals will be accomplished using the Flooding Predictor, to predict the onset of hydraulic flooding and control the column at or very near its true hydraulic limit. The project is a multi-step approach that consists of:

1. Pilot plant-scale experimentation
2. Dynamic model development, and pattern recognition model constant generation
3. Industrial-scale validation

Goals and Accomplishments:

Extensive testing on the Flooding Predictor was conducted at the Separations Research Program (SRP) at the University of Texas at Austin. The report along with subsequent data analysis demonstrates that four of the five goals were achieved:

1. Separation yields (on-spec product volume) increase
2. Column throughput increased by over 6%
3. Energy intensity (BTU per barrel of feed) increases by approximately 10%
4. Flooding events were eliminated

Project Activities: 1. Pilot Plant-scale Experimentation

Experimentation

The Separations Research Program conducted a series of finite reflux distillation tests in an 18-in distillation column and holdup studies (static and dynamic) in an 18-in PVC air/water column to study pattern recognition software. The study objectives include determining the ability of the Distillation Column Flooding Predictor (DCFP) to control the column close to the flood point yet prevent flooding, to measure any significant increases in throughput, and to provide data for future modeling purposes. These models would serve as a guideline for the implementation of this technology in an industrial setting. In this test, both structured packing and sieve tray column internals were studied.

Distillation Column Configuration

The test system comprised a conventional distillation column operated at finite reflux and serviced by a kettle reboiler and a horizontal condenser. The reboiler was heated with 130 PSIA saturated steam and the condenser was cooled with 45 oF chilled water. Condensed overhead vapor is accumulated in a 75-gal tank and either pumped to the column as reflux or pumped to a receiving vessel as distillate product. A 1000-gal tank serves as both the feed and product vessel. Bottoms product is cooled before being pumped back to the tank. The system setup is shown in Figure 5. Pressure drop data were measured using a commercially available differential pressure cell (DPC) designed for ranges of 0-5 and 0-75 in H₂O. Both the high and low-pressure legs of the cells were purged with nitrogen to prevent hydrocarbon condensation.

Testing Procedures

To determine the amount of improvement generated by the predictor, the capacity of the trays and packing first had to be measured without the predictor enabled. Next, the critical constants for the derivative variables had to be determined. Initial values were taken by looking at the derivative plots generated in the process historian. Finally, the DCFP had to be enabled and the critical constants fine-tuned through empirical testing.

Determination of the baseline flood point was achieved by placing the column into composition control mode and slowly increasing the feed until the column flooded. This process was repeated several times to ensure the flood point had been accurately ascertained. Derivative values were recorded and these data served as the baseline critical constants. After the flood point condition has been determined, the column is returned to an unloaded state and the DCFP is enabled. Feed flow to the column is slowly increased in 2% increments and the column enters the loading region where

instabilities are more likely to cause the column to flood. The DCFP algorithm compares the critical constants to the actual value and relaxes the severity of column operations via a 5% reduction in reboiler duty when all DCFP criteria are simultaneously met. Composition analysis was performed on the points beyond the original flood point to ensure compositional integrity. The DCFP was pushed until the separation split began to taper off at an unacceptable level or the column flooded. If the column flooded, the critical constants were re-evaluated and the procedure repeated. Samples are analyzed by gas chromatography using a thermal conductivity detector (TCD); each sample is processed at least twice through the chromatograph. Standards for calibration of the chromatograph are prepared gravimetrically. Separate calibrations are made for the bottoms and reflux composition ranges. A program in the integrator selects the appropriate calibration curve for the composition range when a sample is processed.

Analysis of Results: Distillation Column

Baseline tests showed the maximum sustainable feed rate to the column was 7.03 gpm. Increasing the feed rate by 2% to 7.11 gpm resulted in a column flood. Enabling the DCFP allowed the column to be operated at 7.45 gpm. This equates to a 6.22% improvement in sustainable feed rate. The column was able to operate in a stable fashion beyond 7.45, but the separation efficiency faltered and the test was halted. Tests with structured packing were unable to conclusively demonstrate an increase in capacity. The packed tower study occurred during the month of January and significant ambient temperature swings made determining the baseline maximum capacity unachievable. However, the underlying principals and patterns that allow the DCFP to work were still present which allowed the software to prevent an uncontrollable flooding event.

Conclusions

The Distillation Column Flooding Predictor is an advanced process control strategy that utilizes a patented pattern recognition system to identify the onset of flood and pre-flood conditions in distillation and separation columns. This strategy briefly relaxes column severity at the pre-flood state causing the longterm operation to become significantly more stable and energy efficient. Potential

flood conditions are avoided, column stability is increased, and an increase in column throughput is achieved.

The results of the finite reflux test performed at the University of Texas Separations Research Program offer an alternative method for safeguarding against flooding in distillation towers. By implementing the software control strategy on an existing distributed control system, it may be possible to prevent flooding in distillation towers and in some cases see capacity improvements. These advantages will translate into energy and capital savings by preventing off-spec products, improving capacity (for certain applications) without the need for column internal replacement, and giving plant personnel confidence to operate the column near its flood point with a much smaller chance of flooding the tower. The logic for the Distillation Column Flooding Predictor is easily modified which gives it great flexibility to meet the needs of nearly any distillation tower (or the instrumentation on the tower).

Thorough testing at The University of Texas Separations Research Program conclusively indicate the Distillation Column Flooding Predictor can increase throughput and prevent flooding in distillation towers (standard sieve tray internals) while maintaining efficiency. Baseline tests showed the maximum sustainable feed rate to the column was 7.03 gpm. Increasing the feed rate by 2% to 7.11 gpm resulted in a column flood. Enabling the DCFP allowed the column to be operated at 7.45 gpm. This equates to a 6.22% improvement in sustainable feed rate. The column was able to operate in a stable fashion beyond 7.45, but the separation efficiency faltered and the test was halted.

The Distillation Column Flooding Predictor has been proven in a variety of situations including a pilot plant test facility and several industrial venues. However, further studies have merit. Packed beds need to be further investigated and inconsistencies with baseline testing need to be eliminated. This may be achieved by performing the test during a month with more stable ambient temperatures.

One of the primary variables in an industrial setting is a changing feed composition. Determining how the Distillation Column Flooding

Predictor reacts to a variable feed composition should be another focal point of future studies.

Project Activities: 2. Dynamic model development and pattern recognition model constant generation

Relevant correlations from literature for use in the dynamic model were collected. These correlations were derived for use in the pre-flood operation regime, and part of the work would be to determine if these correlations are still valid in the flooding regime.

A detailed dynamic equilibrium model simulating a pilot plant column operation at Separation Research Program at the University of Texas, Austin has been developed. This model is capable of predicting the dynamic response of key column parameters such as liquid holdup, pressure drop and mass transfer efficiency. Both downcomer flooding and entrainment flooding can be predicted from the model.

The model was simulated using a special simulation suite called general process modeling systems (gPROMS). In the model, a column separating an equimolar binary (cyclohexane-n-heptane) system was simulated in gPROMS and validated with similar simulations carried out using different mathematical algorithms in FORTRAN and AspenPlus.

Entrainment and downcomer flooding were simulated by increasing the reboiler duty and feed flow rates respectively. Time derivatives for the key pre-flood variables such as pressure drop, reboiler temperature and bottoms flow rate were calculated to determine whether the pre-flood event could be predicted. The results of this simulation were satisfactory.

The final phase of model development, which required data collected from a commercial-scale test, was never completed because the four commercial-scale demonstrations turned out to be non-ideal candidates for the technology.

Project Activities: 3. Industrial-scale validation

Over the course of the Cooperative Agreement four columns, at four sites in three companies were identified:

1. Equistar Chemical plant in Morristown, Illinois

2. Norco Refinery in Norco, Louisiana
3. Chevron Refinery in El Segundo, California
4. Chevron Refinery in El Segundo, California

Unfortunately all four of these test commercial-scale demonstrations turned out to be non-ideal test candidates for a variety of reasons.

Products Developed:

Publications	
2/03	Fortune Small Business
12/03	Mechanical Engineering
9/05	Chemical Processing
10/05	Petroleum Technology Quarterly
Presentations	
9/24/02	World Best Technologies, Pittsburg, PA
3/19/03	Texas Technology Showcase
4/16/03	Shell Deer Park Refining and Chemical Plant, Deer Park, Texas
10/28/03	Distillation Consortium, Separations Research Program UT at Austin
3/5/04	Air Products, Allentown, PA
2/5/05	Saudi Aramco, Ras Tanura Refinery, WebEx
4/12/05	AIChE Spring Meeting, Atlanta, GA
11/9/05	Chevron El Segundo, El Segundo, CA
11/10/05	Shell Refinery, Martinez, CA
12/6/06	Texas Technology Showcase, Galveston, TX
1/26/07	Rohm and Hass, Deer Park, TX
6/4/07	Chevron El Segundo Refinery, El Segundo, CA
7/22/08	Chevron Crude & Distillation BIN Meeting, Mobile, AL
4/29/09	AIChE National Meeting, Tampa, FL
5/22/10	Industrial Energy Technology Conference, New Orleans, LA
7/22/10	Valero Energy Company, San Antonio, TX
10/13/10	National Petrochemical and Refiners Association, Technology Forum, Baltimore, MD
Commercial demonstrations	
2004-2006	Equistar Chemical Plant, Morristown, IL (C2 Splitter column)

2005	Motiva Norco Refinery, Norco, LA (Depropanizer column)
2008	Chevron El Segundo Refinery, El Segundo, CA (C-720 column)
2008	Chevron El Segundo Refinery, El Segundo, CA (C-130 column)
Website	
	www.2ndpoint.com
Technologies	
	Developed a proprietary Windows application for analyzing column data for flood events and pre-flood patterns



Performance Evaluation of the Pattern Recognition Flooding Predictor

Sponsors: 2nd Point, Inc., DOE

Principal Investigator: J. Christopher Lewis, Dr. A. Frank Seibert

Status: Current

Introduction

The U.S. petroleum refining and chemical processing industries consume over 12 quadrillion BTUs of energy each year. Distillation is a low thermal efficiency unit operation (about 6% for easy separations) that currently accounts for 40% of the processing energy consumed in refining and continuous chemical processes.¹ In spite of the high energy required for distillation, it is often chosen over other separations processes because of the relatively low initial capital investment, flexibility, and ability to yield high purity products. Currently, every barrel of crude oil is subjected to an initial separation by distillation, and nearly every chemical process requires distillation for product recovery or purification. This high level of energy consumption and widespread utilization makes distillation column operation an extremely attractive area for optimization.

The Distillation Column Flooding Predictor (DCFP) is an advanced process control strategy that utilizes a patented pattern recognition system to identify the onset of flood and pre-flood conditions in distillation and separation columns. This strategy briefly relaxes column severity at the pre-flood state causing the long-term operation to become significantly more stable and energy efficient. Potential flood conditions are avoided, column stability is increased, and an increase in column throughput is achieved.

The origin 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). At the heart of the strategy lies a pattern recognition system that identifies patterns of transient tower instabilities. These instability patterns typically precede flooding in tray and packed columns. The pattern recognition system utilizes the mathematical first derivative of column process variables to identify the onset of liquid and jet flooding mechanisms.

All column variables experience random noise generated from the natural frequency of the process; however, a subtle pre-flood pattern develops as the process enters a transition phase between steady-state operation and pre-flood state. Prior to an actual flooding event, the random behavior of certain column variables momentarily disappears and a brief identifiable pre-flood pattern

* 2ndpoint, Inc., 9238 Olcott Avenue, St. John, IN 46373-9727. www.2ndpoint.com



emerges. The transient, pre-flood patterns are highly repeatable and found in a unique form in absorption, distillation, and stripper towers.

This report is the culmination of a series of tests performed by the Separations Research Program (SRP) at the University of Texas at Austin. The initial DOE sponsored (DOE-OIT Inventions and Innovation Program—Awarded during the 1999 fiscal year) validation of the flooding predictor methodology on a total reflux tower was conducted at the SRP facility during the summer of 2001. Based on the success of this study and general industrial support, the DOE funded further testing of the DCFP as a competitive research grant in 2002.

As a part of the competitive research agreement, the SRP conducted a series of air/water hydraulic tests and distillation tests to study the ability of a patented pattern recognition software algorithm to prevent flooding in distillation towers. The study objectives include determining the ability of the DCFP to control the column close to the flood point yet prevent flooding, to measure any significant increases in throughput, and to provide data for future modeling purposes. In this study, both structured packing and a sieve tray system were studied.

Recently conducted tests provided insight for key parameters that will certainly aide the development of a commercially viable product. A dynamic model will be used to determine the relationship between the pre-flood patterns and the controller response. It will also be used to evaluate the dynamic response of the column to flooding predictor induced process changes. This effort will build on existing modeling programs for reactive distillation columns.

Industrial and academic sponsors (Shell Global Solutions, Emerson Process Management, CDTech, Motiva, and the University of Texas at Austin) contributed in excess of \$450K (which was matched by the DOE) towards the completion of this project. The University of Texas and Department of Energy are extremely grateful for their participation.

Experimentation

The Separations Research Program conducted a series of finite reflux distillation tests in an 18-in distillation column and holdup studies (static and dynamic) in an 18-in PVC air/water column to study pattern recognition software. The study objectives include determining the ability of the DCFP to control the column close to the flood point yet prevent flooding, to measure any significant increases in throughput, and to provide data for future modeling purposes. These models would serve as a guideline for the implementation of this technology in an industrial setting. In this test, both structured packing and sieve tray column internals were studied.



Air/Water Column Configuration

The hydraulic performance and holdup of the Sulzer Mellapak 250Y structured packing was measured using a 16.8-in I.D. PVC air/water column attached to a 70 gallon capacity sump. The hydraulic system setup is shown in Figures 1a/1b. The packing elements were loaded into the column by dropping the elements onto a support ring for structured packing. The packed height was ten feet. Inlet and outlet temperatures were measured with type-K thermocouples. The water flow rate was measured using an orifice plate and differential pressure transmitter. Water was supplied to the top of the column from the re-circulation tank via a centrifugal pump capable of discharging 150 gpm. Water flow was regulated with a variable speed drive. A 40-hP blower with variable speed motor drive supplied air to the column. Air flow was measured with a standard annubar and two differential pressure transmitters (low range/high range). Pressure drop data were taken with a commercially available 0-30 inH₂O differential pressure transmitter. Taps were located directly above the packed bed (below the distributor) and just below the packed bed. Sump level was monitored with a 0-30 inH₂O transmitter.



The Separations Research Program
UT Austin
08/21/2001 Chris Lewis
DRW03082120011

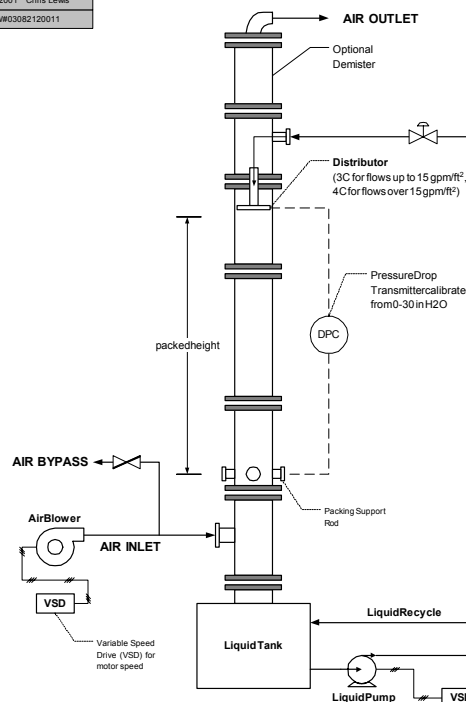


Figure 1a/b. Photograph and Schematic of the SRP Air/Water Contacting Device



The properties of the air/water system can be seen in Table 1.

Table 1. Physical Properties of the Air/Water System

Pressure (psia)	14.7
Liquid density, lb/ft ³	62.4
Liquid viscosity, cP	0.89
Vapor density, lb/ft ³	0.073
Vapor viscosity, cP	0.018
Surface tension, dynes/cm	72
Average Temperature, °F	85

Air/Water Run Procedure

Initially, a dry pressure drop test is performed to provide a baseline for the ensuing hydraulic tests. Only air is passed through the column during the test. The air rate is varied at approximately 100 cfm increments. The pressure drop is recorded upon reaching steady conditions. Hydraulic steady state is normally reached within a few minutes after a set point change. The air rate is increased until reaching 20 in H₂O pressure drop or upon reaching the blower capacity (approximately 1,200 actual cubic feet per minute).

After completion of the dry pressure drop run, the liquid rate is set and the air rate is increased until flooding is reached. The purpose of the initial flood is to wet the packing properly. Following the initial flood, the gas rate is reduced. Pressure drop data are obtained for a fixed liquid rate while varying the air rate at approximately 100 cfm increments until reaching the loading region. Smaller air rate increases are utilized in the loading region. The liquid was distributed using a pressurized Fractal distributor supplied by Amalgamated Research, Inc., with a density of 40 pts/ft².

Air/Water Results

The f-factor was calculated using the following equation:

$$\text{f-factor} = U_s \sqrt{\rho_v} \quad (1)$$

where U_s = superficial gas velocity, ft/sec
 ρ_v = vapor density, lb/ft³



The hydraulic performance of the Mellapak 250Y is shown in Figure 2.

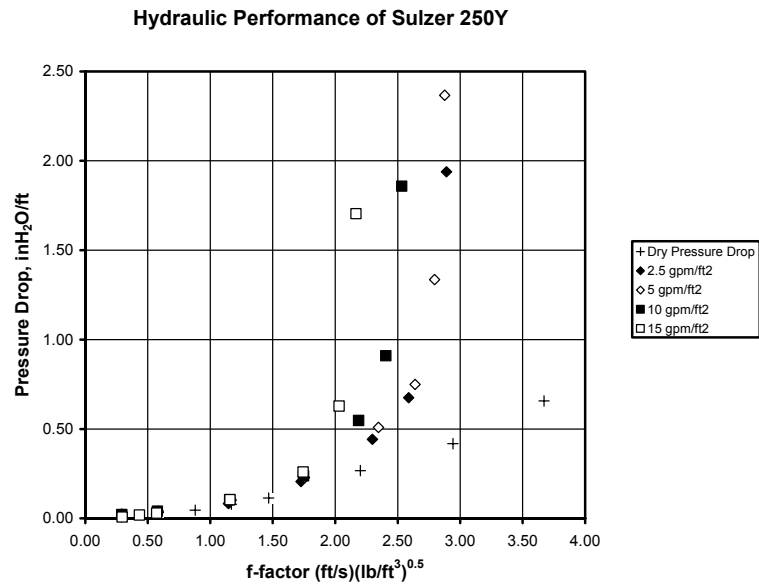


Figure 2. Hydraulic Performance of Sulzer Mellapak 250Y

Static holdup measurements (Figure 3) were recorded by measuring the sump liquid height during the run and comparing the difference after simultaneously turning off the water pump and shutting a butterfly valve on the sump. Measurements were recorded 5 minutes after pump shutoff to allow any liquid remaining in the packing to drain. The amount of liquid lost to evaporation was carefully calculated and monitored.

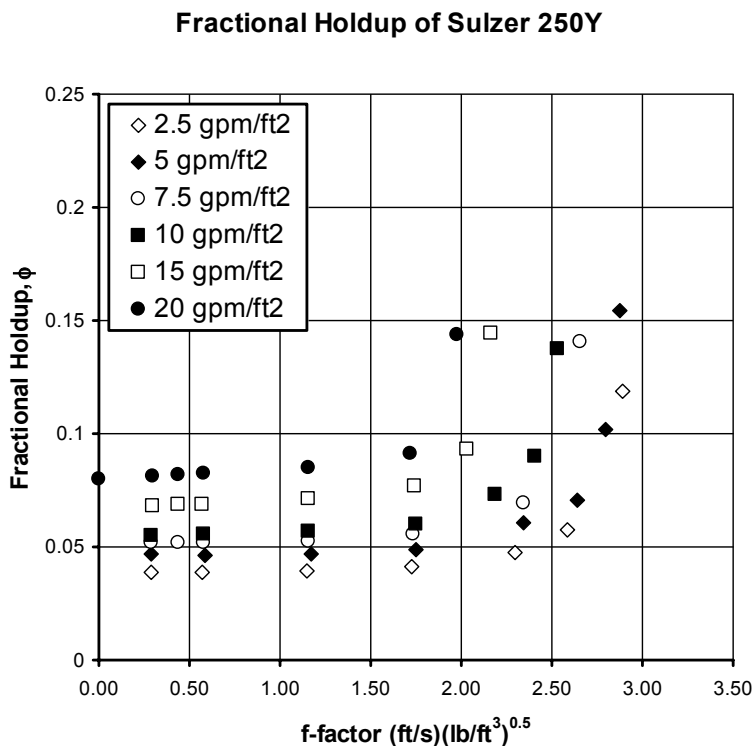


Figure 3. Static Holup of Sulzer Mellapak 250Y

Dynamic holdup studies (Figure 4) monitored the time required for the column to reach steady state after the air flow set point was changed. The change in liquid volume in the sump was measured which allowed the dynamic holdup to be calculated. Measurements were made at 5, 10, 15, and 20 gpm/ft² and various air rates.

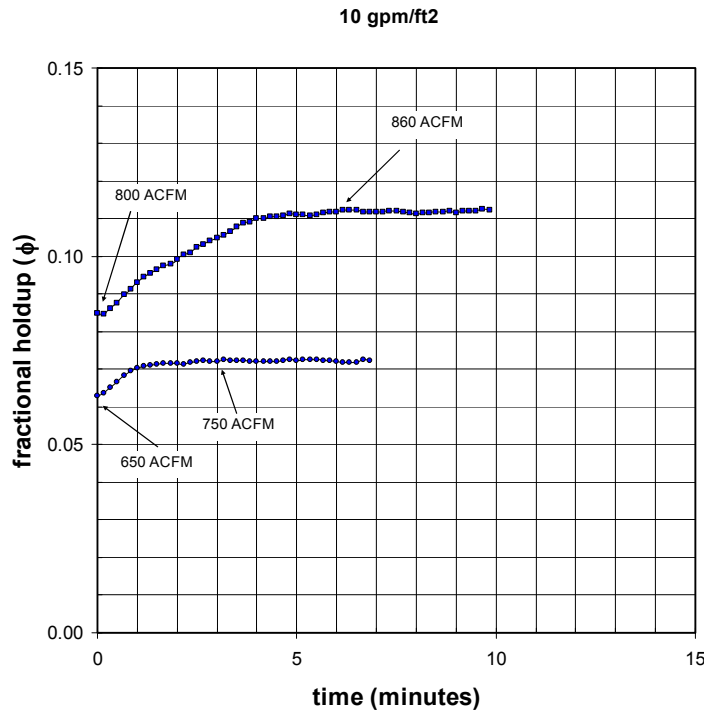


Figure 4. Dynamic Holdup of Water in Sulzer Mellapak 250Y at 10 gpm/ft²

Analysis of Results: Air/Water

Fractional holdup for the Mellapak 250Y was fairly constant for each liquid rate until the column reached the loading zone. Hydraulic studies at the SRP correlate well with other published data for the Mellapak 250Y. The static holdup ranged from 0.04 to 0.07 (2.5gpm/ft² and 20gpm/ft², respectively) at low f-factors and increased rapidly upon entry of the loading zone. Dynamic studies reveal that the time necessary to achieve steady state after a change in the gas rate is dependent upon the amount of holdup in the system. Changes with the loading region result in a longer time period before the column returns to normal, steady-state operation.

Distillation Column Configuration

The test system comprised a conventional distillation column operated at finite reflux and serviced by a kettle reboiler and a horizontal condenser. The reboiler was heated with 130 PSIA saturated steam and the condenser was cooled with 45 °F chilled water. Condensed overhead vapor is accumulated in a 75-gal tank and either pumped to the column as reflux or pumped to a receiving vessel as distillate product. A 1000-gal tank serves as both the feed and product



vessel. Bottoms product is cooled before being pumped back to the tank. The system setup is shown in Figure 5.

Pressure drop data were measured using a commercially available differential pressure cell (DPC) designed for ranges of 0-5 and 0-75 in H₂O. Both the high and low-pressure legs of the cells were purged with nitrogen to prevent hydrocarbon condensation.

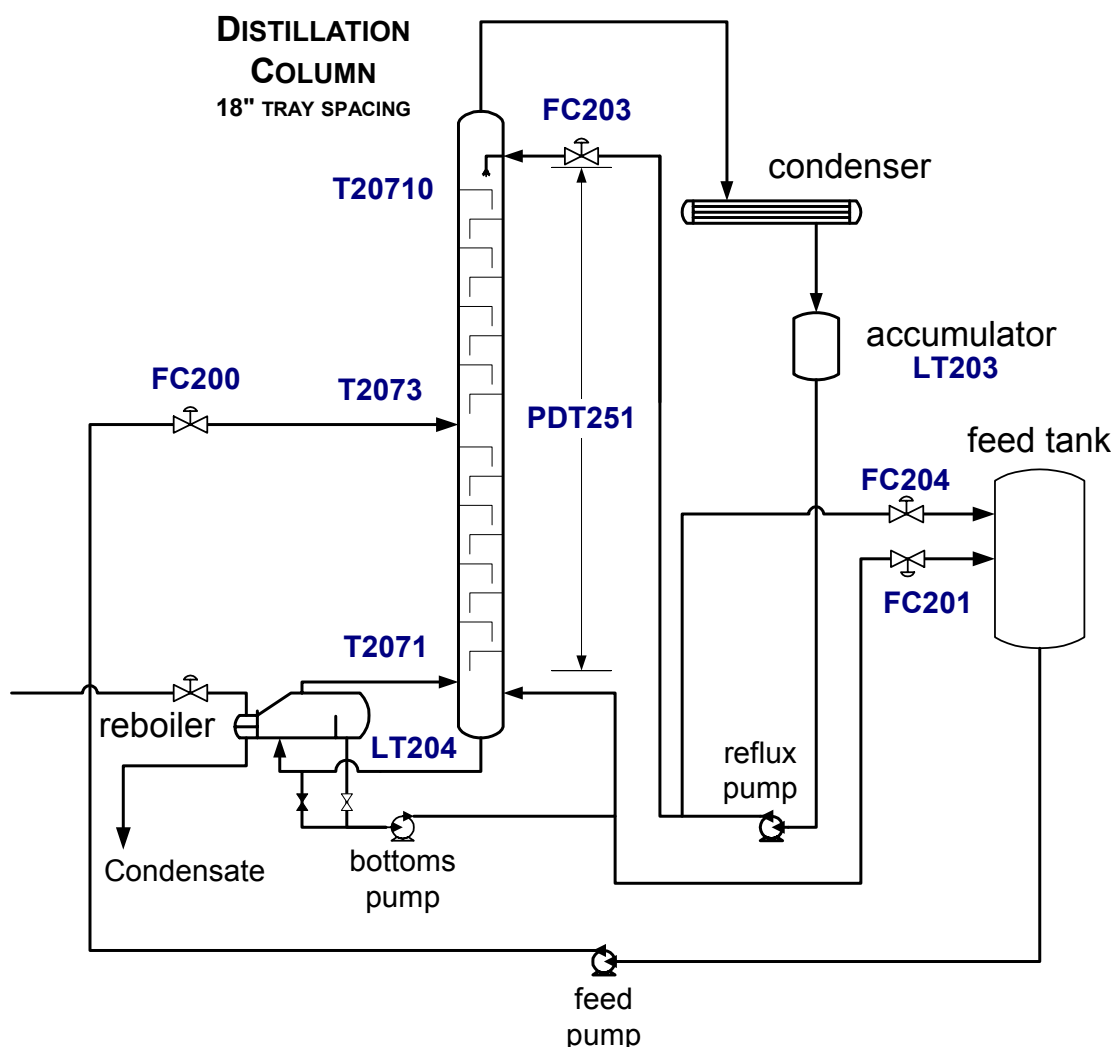


Figure 5. Schematic for the finite reflux distillation system.

Liquid samples were taken for each condition. Samples were taken directly below the packing support below the packing (bottoms product), from the distillate line, and from the feed pump discharge. For the lower sample, a 0.75 in bayonet-type (bottom) sampler was used. Temperatures were measured in the vapor space above the packed bed and directly below the bed.



Distillation Run Procedure

After packing installation and pressure testing are completed, 600 gallons of the binary test mixture (cyclohexane/n-heptane) are charged to the feed tank. The system properties at 24 psia are listed in Table 1. The reboiler and distillation column are then charged from the tank with approximately 200 gallons of feed. Distillation is started by admitting steam to the reboiler under heat duty control, at a load approximately 60% of that expected to flood the bed at total reflux conditions. When the column becomes stable, feed is supplied to the column above tray 7 or to the redistributor (packed test only). The ancillary pumps associated with distillate and bottoms product flow are then activated at the appropriate time.

Table 2. 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, °F	238

The control strategy for the distillation column maintained distillate and bottoms product composition by controlling the temperature at the top and bottom of the trays/packed bed. These temperatures were controlled by adjusting the reflux flow and the reboiler steam flow. Thus, an increase in feed would necessitate an increase in the reflux and reboiler steam flow (as well as an increase in distillate and bottoms flows to maintain level) to maintain the temperature set points. The thermocouple reading at the bottom of the bed is compensated to account for pressure change due to column loading.



To determine the amount of improvement generated by the predictor, the capacity of the trays and packing first had to be measured without the predictor enabled. Next, the critical constants for the derivative variables had to be determined. Initial values were taken by looking at the derivative plots generated in the process historian. Finally, the DCFP had to be enabled and the critical constants fine-tuned through empirical testing.

Determination of the baseline flood point was achieved by placing the column into composition control mode and slowly increasing the feed until the column flooded. This process was repeated several times to ensure the flood point had been accurately ascertained. Derivative values were recorded and these data served as the baseline critical constants.

After the flood point condition has been determined, the column is returned to an unloaded state and the DCFP is enabled. Feed flow to the column is slowly increased in 2% increments and the column enters the loading region where instabilities are more likely to cause the column to flood. The DCFP algorithm compares the critical constants to the actual value and relaxes the severity of column operations via a 5% reduction in reboiler duty when all DCFP criteria are simultaneously met.

Composition analysis was performed on the points beyond the original flood point to ensure compositional integrity. The DCFP was pushed until the separation split began to taper off at an unacceptable level or the column flooded. If the column flooded, the critical constants were re-evaluated and the procedure repeated.

Samples are analyzed by gas chromatography using a thermal conductivity detector (TCD); each sample is processed at least twice through the chromatograph. Standards for calibration of the chromatograph are prepared gravimetrically. Separate calibrations are made for the bottoms and reflux composition ranges. A program in the integrator selects the appropriate calibration curve for the composition range when a sample is processed.

Results

Table 3 lists the runs performed during the sieve tray flooding predictor test. It indicates whether the predictor was active, if the column flooded, the feed rate, pressure drop, reflux ratio, and the composition of each test location. Process history trends from the Delta V distributed control system are shown in Figures 6-10. The run numbers on each of these charts represent a run from Table 3.

Table 3. Distillation Column Flooding Predictor Performance Using Sieve Trays



RUN	PREDICTOR	FLOOD	FEED RATE	PRESS	DRP	REFLUX RATIO	COMPOSITION (C6)		
			(gpm)	(in H ₂ O)			FEED (%)	TOP (%)	BOT (%)
1	no	no	7.02	28.00	0.96		23.12	53.87	14.49
2	no	no	7.03	26.50	0.68		25.06	53.22	14.29
3	no	no	7.00	27.55	0.76		25.42	53.53	13.48
4	no	yes	7.11	60.40	0.72		24.68	49.75	13.55
5	yes	no	7.11	34.10	0.92		22.79	53.97	14.87
6	yes	no	7.25	36.58	0.89		21.27	54.25	15.59
7	yes	no	7.24	38.26	0.85		21.75	53.39	15.16
8	yes	no	7.25	29.62	0.77		23.68	53.00	14.72
9	yes	no	7.35	38.83	0.78		22.77	53.06	14.93
10	yes	no	7.44	40.34	0.89		21.94	52.79	14.66
11	yes	yes	7.55	49.10	0.96		20.35	51.55	15.73

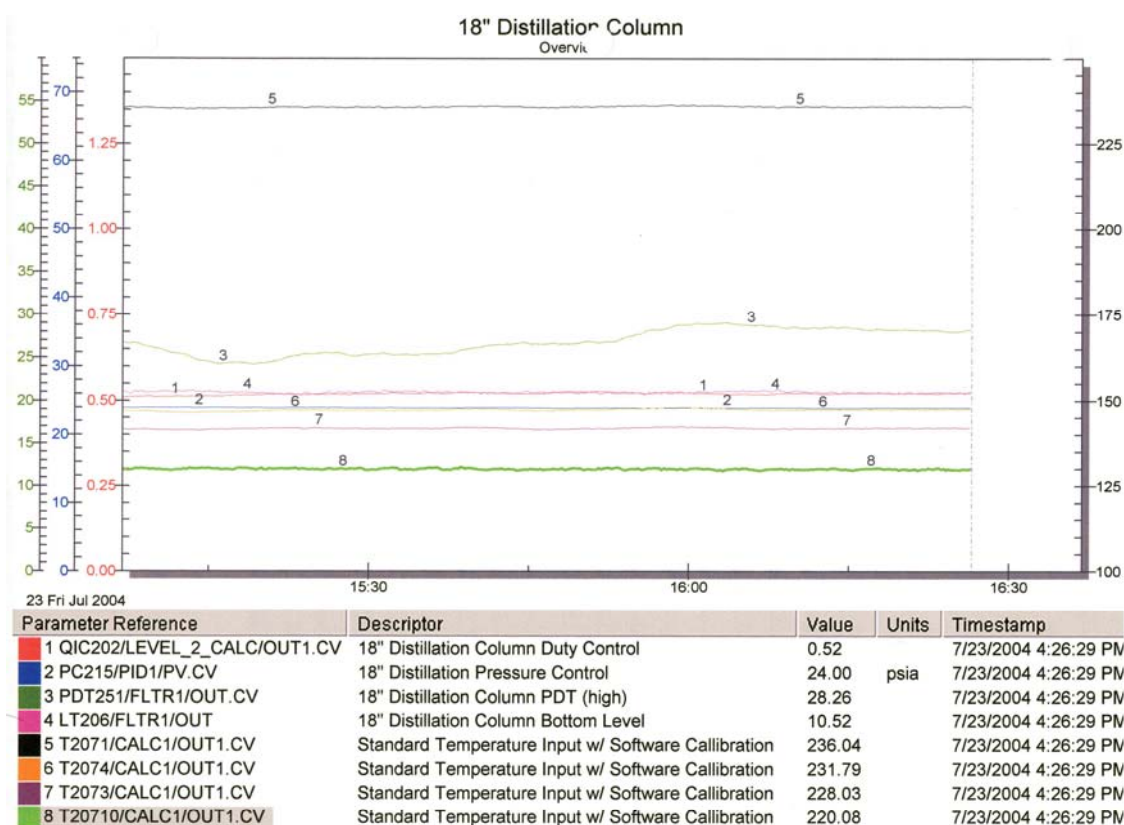


Figure 6. Distillation Column Overview for 7.03gpm feed rate (maximum controllable loading with the Flooding Predictor in STANDBY). Curve 3 represents the pressure drop for this trend. This corresponds to Run 2 from Table 3.

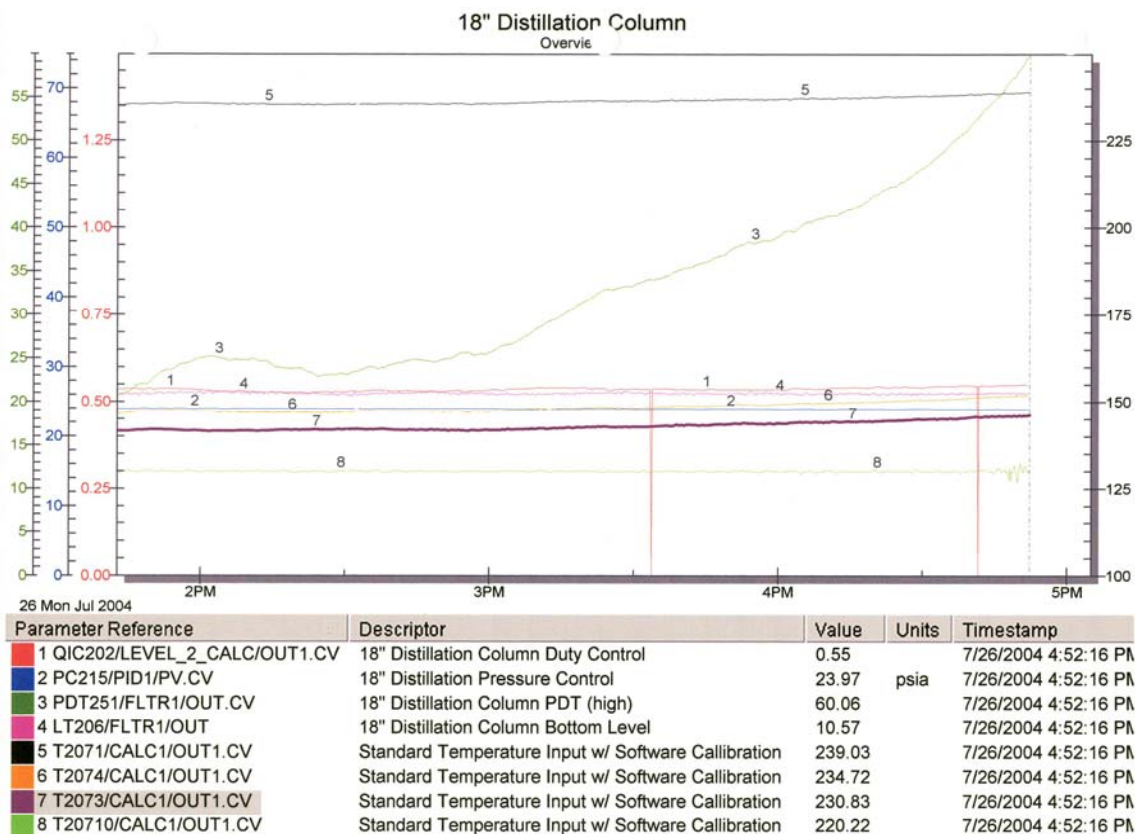


Figure 7. Distillation Column Overview for 7.11gpm feed rate (flood point with Flooding Predictor in STANDBY). Curve 3 represents the pressure drop for this trend. This corresponds to Run 4 from Table 3.

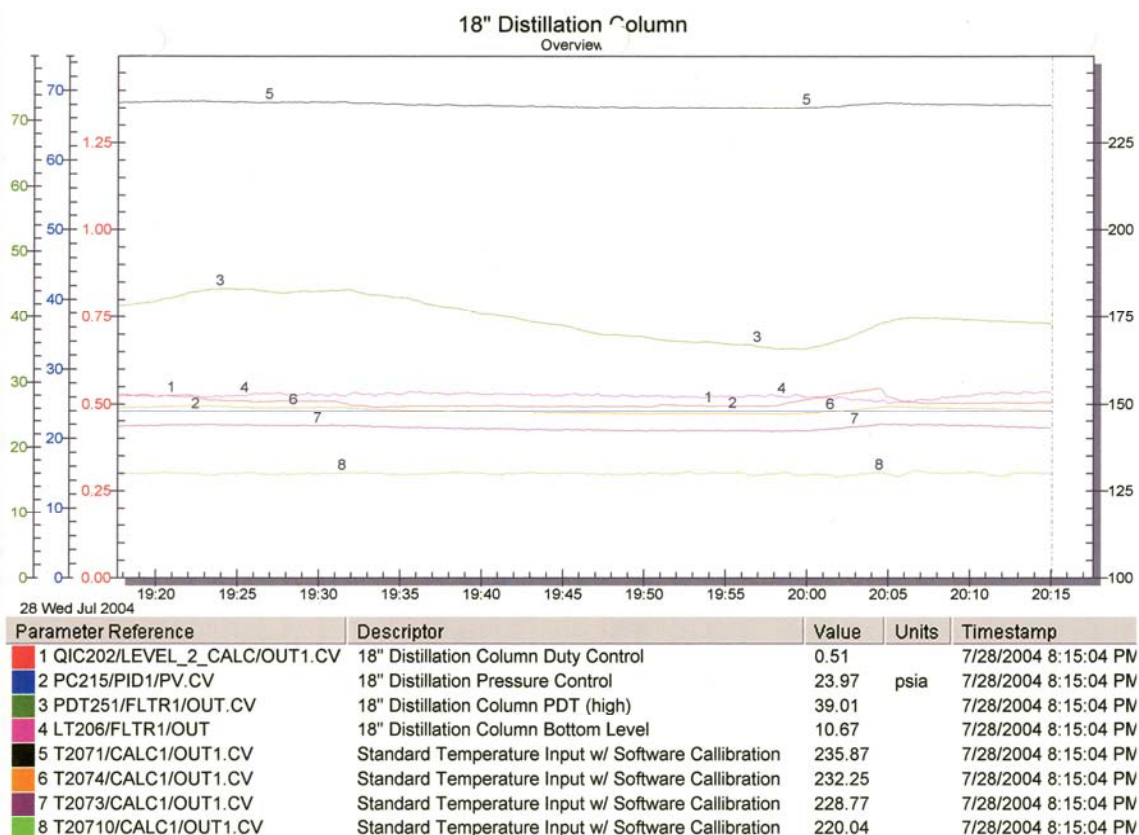


Figure 8. Distillation Column Overview for 7.35gpm feed rate (Flooding Predictor in ACTIVE). Curve 3 represents the pressure drop for this trend. The dips in the pressure drop represent Flooding Predictor control. This corresponds to Run 9 from Table 3.

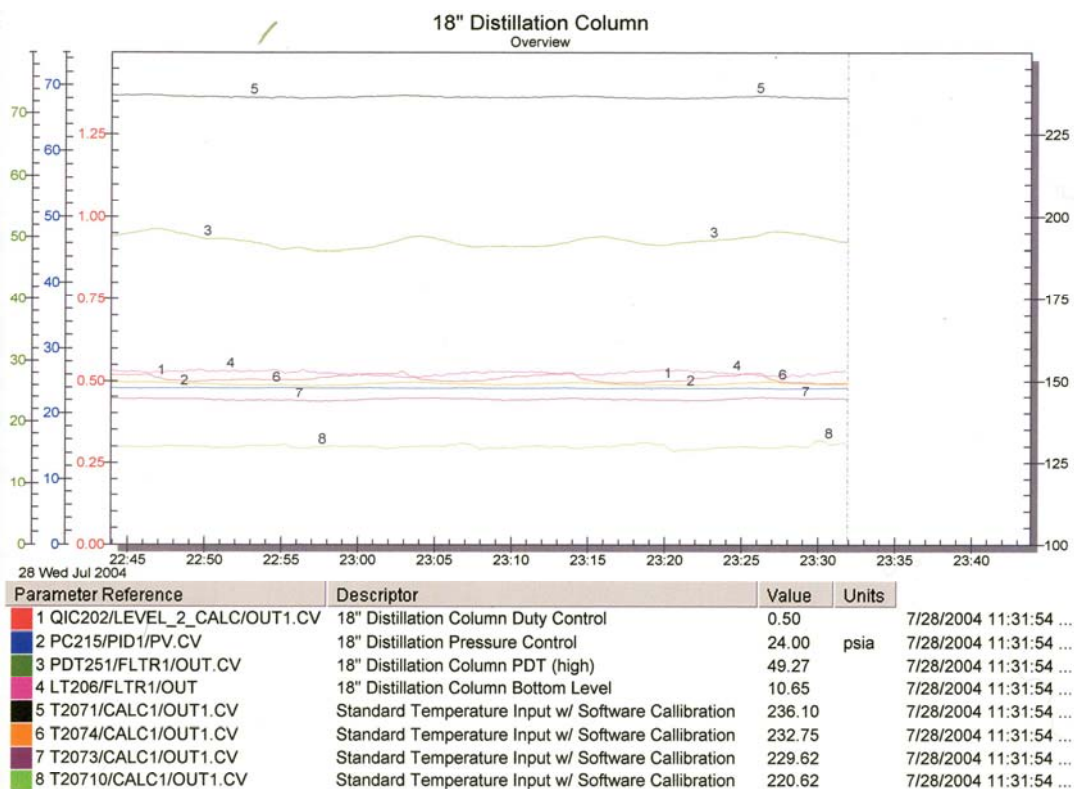


Figure 9. Distillation Column Overview for 7.55gpm feed rate (Flooding Predictor in ACTIVE). Curve3 represents the pressure drop. This corresponds to Run 11 from Table 3.

Analysis of Results: Distillation Column

Baseline tests showed the maximum sustainable feed rate to the column was 7.03 gpm. Increasing the feed rate by 2% to 7.11 gpm resulted in a column flood. Enabling the DCFP allowed the column to be operated at 7.45 gpm. This equates to a 6.22% improvement in sustainable feed rate. The column was able to operate in a stable fashion beyond 7.45, but the separation efficiency faltered and the test was halted.

Tests with structured packing were unable to conclusively demonstrate an increase in capacity. The packed tower study occurred during the month of January and significant ambient temperature swings made determining the baseline maximum capacity unachievable. However, the underlying principals and patterns that allow the DCFP to work were still present which allowed the software to prevent an uncontrollable flooding event.



Conclusions

The Distillation Column Flooding Predictor is an advanced process control strategy that utilizes a patented pattern recognition system to identify the onset of flood and pre-flood conditions in distillation and separation columns. This strategy briefly relaxes column severity at the pre-flood state causing the long-term operation to become significantly more stable and energy efficient. Potential flood conditions are avoided, column stability is increased, and an increase in column throughput is achieved.

The results of the finite reflux test performed at the University of Texas Separations Research Program offer an alternative method for safeguarding against flooding in distillation towers. By implementing the software control strategy on an existing distributed control system, it may be possible to prevent flooding in distillation towers and in some cases see capacity improvements. These advantages will translate into energy and capital savings by preventing off-spec products, improving capacity (for certain applications) without the need for column internal replacement, and giving plant personnel confidence to operate the column near its flood point with a much smaller chance of flooding the tower. The logic for the Distillation Column Flooding Predictor is easily modified which gives it great flexibility to meet the needs of nearly any distillation tower (or the instrumentation on the tower).

Thorough testing at The University of Texas Separations Research Program conclusively indicate the Distillation Column Flooding Predictor can increase throughput and prevent flooding in distillation towers (standard sieve tray internals) while maintaining efficiency. Baseline tests showed the maximum sustainable feed rate to the column was 7.03 gpm. Increasing the feed rate by 2% to 7.11 gpm resulted in a column flood. Enabling the DCFP allowed the column to be operated at 7.45 gpm. This equates to a 6.22% improvement in sustainable feed rate. The column was able to operate in a stable fashion beyond 7.45, but the separation efficiency faltered and the test was halted.

The Distillation Column Flooding Predictor has been proven in a variety of situations including a pilot plant test facility and several industrial venues. However, further studies have merit. Packed beds need to be further investigated and inconsistencies with baseline testing need to be eliminated. This may be achieved by performing the test during a month with more stable ambient temperatures.

One of the primary variables in an industrial setting is a changing feed composition. Determining how the Distillation Column Flooding Predictor reacts to a variable feed composition should be another focal point of future studies.