Originally appeared in:
December 2015, pgs 79-83.
Used with permission.
HYDROCARBON PROCESSING®

HP | Process Engineering and Optimization

T. BLEVINS, Emerson Process Management, Austin, Texas; **J. DOWNS,** Eastman Chemical Company, Kingsport, Tennessee; and **M. DONAHUE** and **B. ROACH,** University of Texas, Austin, Texas

Use model predictive control to achieve real-time management of a DWC

A dividing-wall column (DWC) can provide significant savings in energy and capital cost compared to a conventional distillation column design. However, very little has been published on the practical design and commissioning of the control for a DWC. A project was initiated by the University of Texas' Separation Research Program to study and document operation and control based on tests conducted using a 6-in.-diameter pilot DWC (**FIG. 1**).

Originally patented in 1949 by Richard Wright, the DWC is a distillation column with a vertical partition that divides the column into two sides—prefractionate and mainfractionate. This configuration reduces capital costs by utilizing only one column, and it reduces thermodynamic losses by partitioning between the feed and side product.

Numerous articles have been published over the last 10 years that address the potential savings in energy and capital costs that may be achieved in some applications using the DWC. However, very little has been published on the actual operation of a DWC. In a 2010 paper,[1] authors Ling and Luyben presented a design for DWC control and results achieved using a simulation of the DWC process. The basic design for DWC control proposed by Ling and Luyben is illustrated in **FIG. 2** for the case with an inferred measurement of composition based on column temperature measurements.

For the application at the University of Texas, significant changes were required in the control design to provide the flexibility needed to test different types of control. Also, it was desirable to address closed-loop control using wireless measurements provided by WirelessHART flow and temperature transmitters. In this article, we detail this column control strategy, the changes required and the results achieved in column operation using wireless measurements.

Reflux and distillate flow control. The design approach often used for the regulation of reflux and distillate flow is the Ling and Luyben method. With this technique, the accumulator level is maintained at setpoint, using a single loop manipulating the distillate flow valve. The composition of the distillate stream is inferred, using a temperature measurement at the top of the column. This inferred indication of distillate composition is maintained at setpoint by regulating the reflux flow using a temperature/flow cascade control strategy.

To minimize the impact of throughput changes, the column feed flow with dynamic compensation (lag) is used as a feed-forward input to the primary loop of the cascade. However, an alternate approach is to regulate reflux to maintain accumulator level, and to regulate distillate flow to maintain distillate composition.

FIG. 1. A DWC at the University of Texas' James R. Fair Pilot Plant.

The impact of control and manipulated parameter pairing for temperature (composition) and level (inventory) control at the top and bottom of the column has been analyzed.[2] To provide flexibility in the column operation, the control was designed to allow the control structure to be selected without changing the control configuration. The reflux and distillate flow control, and the selection of control structure and temperature measurement used in control, are shown in **FIG. 3.**

For the University of Texas installation, all column temperature measurements are made using WirelessHART transmitters. The control was designed to allow the temperature measurement used in temperature control to be selected without changing the control system configuration. Closed-loop control using this wireless temperature measurement was accomplished using PIDPlus, an enhanced proportional-integral-derivative (PID) algorithm designed for use in wireless automation systems. As has been documented,[3] the algorithm provides effective control using the slow wireless update rates (8 sec) required to achieve a five- to seven-year battery life.

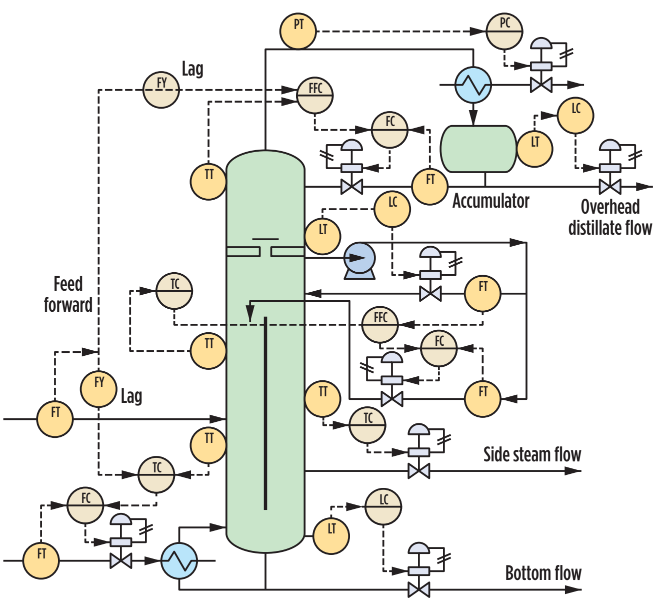


FIG. 2. Basic DWC control scheme, as proposed by Ling and Luyben in 2010.

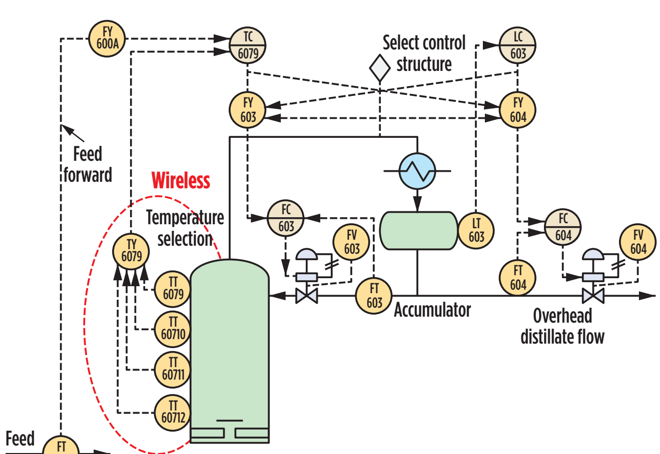


FIG. 3. Distillate and reflux flow control. The temperature transmitters are wireless.

The PIDPlus algorithm makes it possible to control using wireless measurements while delivering control performance comparable to traditional wired transmitters and wired final control elements. The PID modifications introduced by the algorithm are designed to handle loss of communication, and to enable control using relatively slow measurement and non-periodic measurement updates.

The FieldComm Group that developed the WirelessHART international standard (IEC 62591) has been granted the rights to use the PIDPlus patented technology originally developed by Emerson. The announcement of this transfer of patent rights was included in the October 2014 issue of *Hydrocarbon Processing*. WirelessHART is supported by ABB, Emerson, E+H, Siemens and many other companies in the process industry. Any of these control systems that use WirelessHART transmitters may freely implement PIDPlus for wireless control. PIDPlus is a standard feature of some distibuted control systems. Also, it is possible to implement PIDPlus using standard tools that are included in most control systems. This capability may be easily added to legacy control systems[3] when WirelessHART field devices are used to implement wireless control.

Trapout tray level and liquid split control. To control the liquid split across the dividing wall, a total trap tray is located above the dividing wall. The liquid is sent to an external accumulator, and then sent to two control valves to make it split across the prefractionate and mainfractionate. The level in the accumulator is maintained at setpoint by a single loop manipulating the valve for pumpout flow to the side-stream side of the column wall. A measurement of this flow is used in a ratio controller to set the flow setpoint of the single-loop controller regulating the valve controlling flow to the prefractionator side of the column wall.

This flow control loop was implemented using the proprietary algorithm and structured to allow either a wired or wireless flow measurement to be used as the process variable. Heater temperature control is based on the algorithm, and temperature measurement is provided by a WirelessHART transmitter. The separation in the prefractionator section can be inferred based on a measurement of temperature on the prefactionator

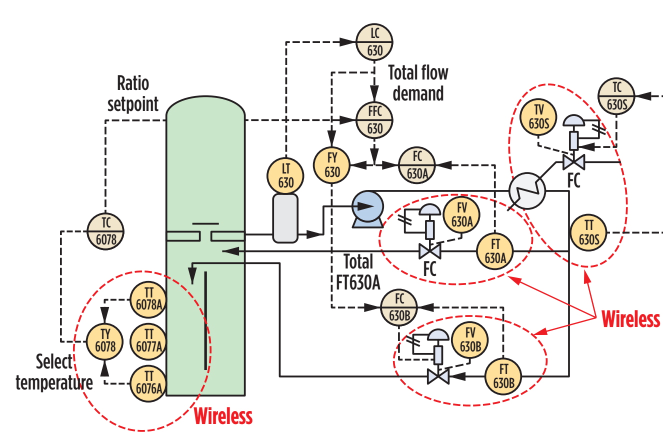


FIG. 4. Trapout tray level and liquid split control. Wireless temperature and flow transmitters are used.

side of the column. Based on this inferred measurement, a single-loop algorithm is used to maintain setpoint by manipulating the ratio controller setpoint, as illustrated in **FIG. 4.**

Side-stream flow control. The side-draw takeoff is performed with a total trap tray on the column's mainfractionate side. The flow is sent to an accumulator, and the level is maintained at setpoint by a single loop that manipulates the side reflux flow. A measurement of this flow is used in a ratio controller to set the flow setpoint of the single-loop controller regulating the valve to the side-product takeoff.

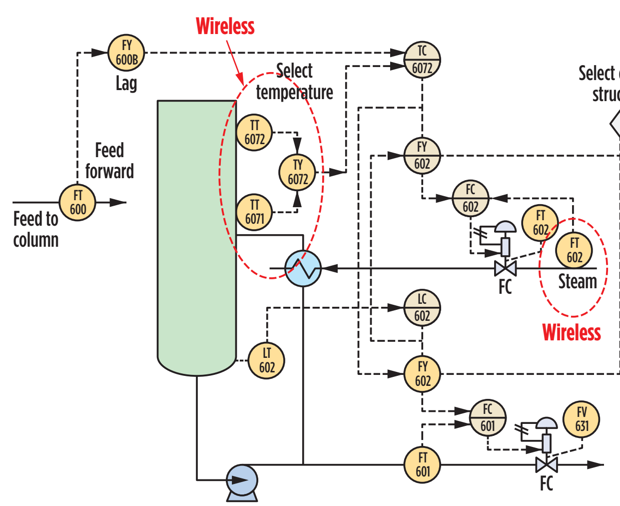
This flow control loop was implemented using the algorithm and structured to allow either a wired or wireless flow measurement to be used as the process variable. Heater temperature control is based on the algorithm, and temperature measurement is provided by a WirelessHART transmitter. The composition of the liquid/gas stream on the product side of the wall is inferred using a temperature measurement. Based on this inferred measurement, a single-loop algorithm is used to maintain temperature by manipulating the ratio controller setpoint, as illustrated in **FIG. 5.**

Bottoms level and composition. The liquid level in the bottom of the column is maintained at setpoint by using a single loop manipulating either the bottoms flow or the reboiler steam flow, depending on the selected control structure, as illustrated in **FIG. 6.** The composition of the bottom stream is inferred using a measurement of temperature at the bottom of the column.

Based on this inferred measurement, a temperature/flow (steam or bottoms flow based on control structure) cascade loop using the algorithm maintains the composition setpoint. The PIDPlus algorithm and a WirelessHART flow transmitter are used to regulate steam flow. To minimize the impact of throughput changes, the column feed flow with dynamic compensation (lag) is used as a feed-forward input to the primary loop of the cascade control strategy.

MPC control. The interactive nature of the DWC process presents challenges when composition control is implemented using single-loop PID control. The tuning necessary to minimize loop interaction may result in slow control response. Since model predictive control (MPC) accounts for process interactions, many researchers have reported that control performance achieved using MPC is better than single-loop PID control.[4] Therefore, MPC capability was incorporated into the DWC control installed at the University of Texas. Such capability may be added with no impact on the design or implementation of the basic control strategy.

As a starting point in using MPC for DWC control, a module was created in which the MPC was configured to only address composition control and energy consumption based on column temperature. Therefore, the MPC block only addresses control of the four temperature measurements (defined as controlled parameters), the column feed (defined as a disturbance parameter), and the four manipulated parameters (PID setpoint for reflux and bottoms flow control, and the ratio setpoints for liquid split and side takeoff), as illustrated in **FIG. 7.**



Independent loop	Loop manipulated based on control selection: DB/LSV	DV/LSV	LV/DSB	LB/DSV
LC602 bottom level	FC601 bottom flow	FC602 steam flow		FC601 bottom flow
FC602 bottom temp	FC602 steam flow	Fc601 bottom flow		FC602 steam flow

FIG. 6. Bottoms level and flow control.

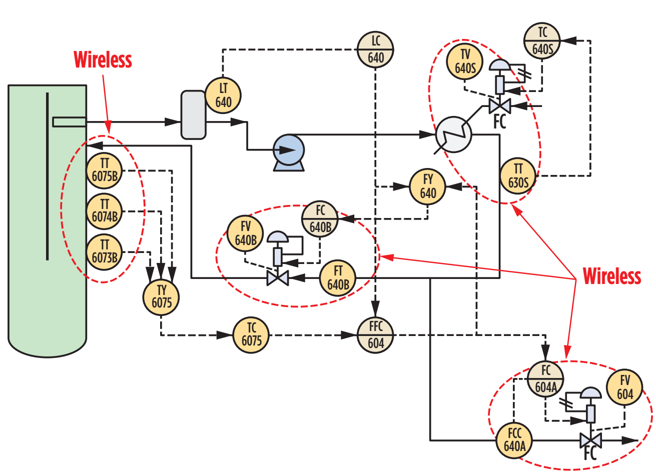


FIG. 5. Side-stream flow control.

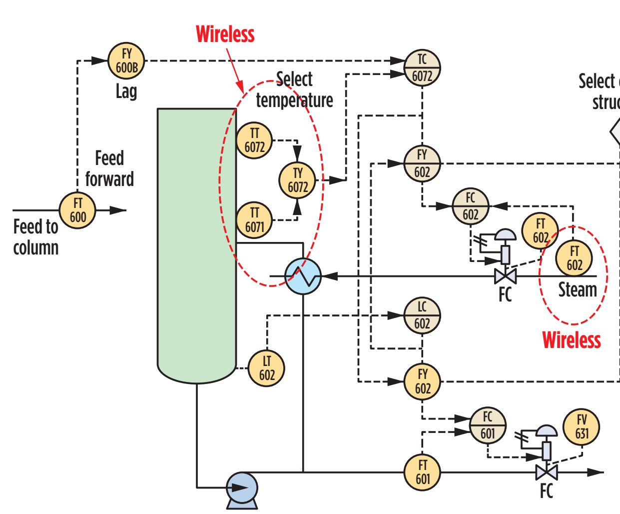


FIG. 7. MPC for DWC wireless temperature control.

Commissioning base level control. The compositions at three points in the column are controlled based on temperature. The energy consumption is reflected by a temperature measurement in the prefractionator section and is maintained at a target value through the automatic adjustment of the liquid split. Since many temperature measurements are available in the column, it is necessary to determine which measurements should be used in these control loops to best reflect changes in the processes.

> The tuning of the PIDPlus used in wireless control was based strictly on the process dynamics and process gain. The slower update rate of the wireless transmitter had no impact on the tuning.

This can be determined by stepping the four manipulated parameters (reflux flow, steam flow, liquid split and side-stream split) and then collecting data showing the changes in temperature to perform sensitivity analysis. The temperature measurements used in control were selected based on these step tests conducted during column commissioning.

The base level control was commissioned over a two-day time span. Much of this time was spent on the commissioning of the temperature loops used for composition control. This was due to the slow response of composition to changes in the column. Control performance achieved using wireless measurements in control was comparable to that achieved using a wired transmitter, as illustrated in FIG. 8 for the liquid flow loop FC630B (see FIG. 4) used to maintain liquid split.

After commissioning the base level control, stable operation was observed even though the target composition was changed over a wide operating range. The impact of the liquid split was found to have a very significant impact on the column operation. Therefore, limits were placed on the prefractionator temperature setpoint and on the range over which the liquid split could be adjusted when using automatic control.

Commissioning MPC. The MPC composition control was commissioned in approximately 8 hr. During this time, an automated test was run during which pseudo-random variations were introduced into the four manipulated parameters associated with the column composition control and operating efficiency.

The testing signals were applied on all process inputs simultaneously, making testing time relatively short (approximately 5 hr), as shown in FIG. 9. The model automatically generated from the collected data is in the form of process output step responses.

FIG. 8. Wired vs. wireless control of FC630B liquid flow.

FIG. 9. The process test shown here developed the MPC model used for the University of Texas DWC.

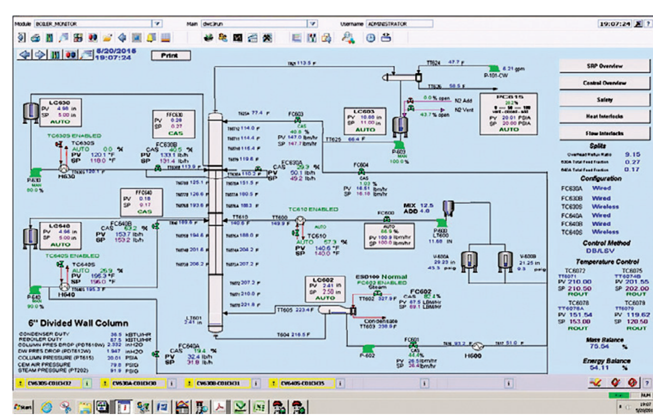


FIG. 10. Operator screen for DWC operation.

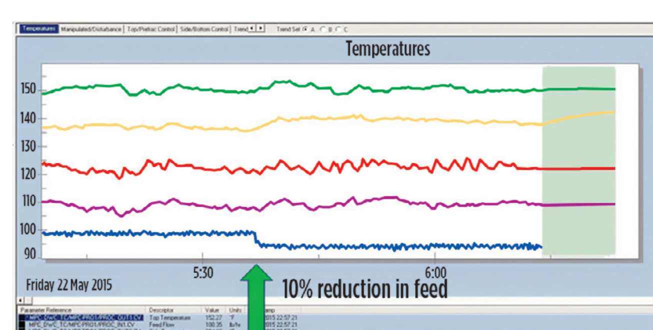


FIG. 11. Temperature trends for a 10% change in feed flow.

Subsequently, the MPC controller generated from the model was downloaded for online operation. The improvement in temperature control provided by MPC was immediately visible compared to that achieved using single-loop control. MPC control provided stable operation with temperature variations within 0.5°F for most of the test. The operator interface to the DWC base level and MPC control is shown in **FIG. 10.**

MPC control performed well in response to a process disturbance of a 10% reduction in feed flow. Very little variation in top, side, bottom and prefractionator temperature was observed after making this change, as shown in **FIG. 11.**

Separation parameters achieved with MPC control were significantly better than with PID control. Side-product mole fraction achieved with MPC is higher (about 0.9) than with PID control (about 0.8), as shown in **FIG. 12.** Trends demonstrate that side fraction variability with MPC control is significantly smaller than that observed using single-loop PID control for temperature control.

A similar reduction in the variation of top composition was observed with MPC for temperature control compared to using single-loop PID to control column temperature, as illustrated in **FIG. 13.**

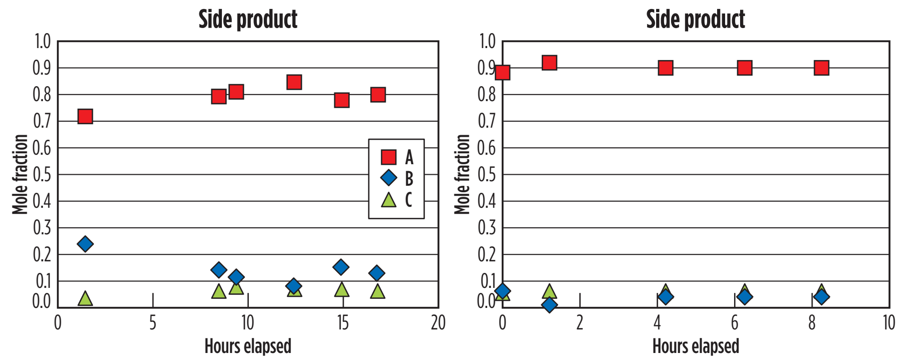


FIG. 12. Side-product mole fraction trends with PID and MPC control. With MPC, side fraction variability is significantly smaller than with PID.

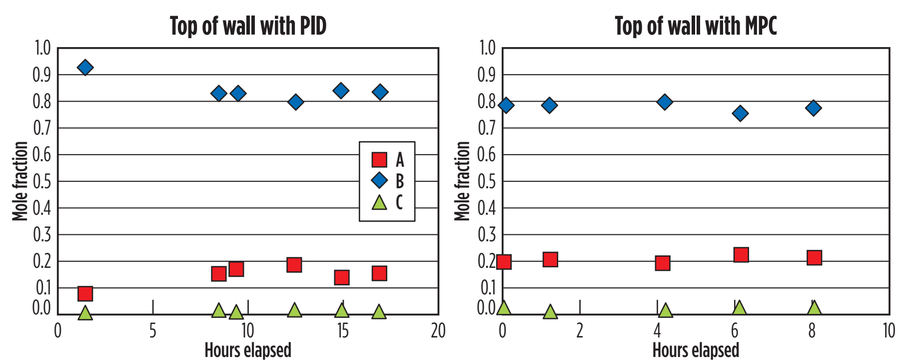


FIG. 13. Top of the wall mole fraction trends with PID and MPC control.

Takeaway. The control design implemented on the DWC at the University of Texas has proven to be effective in providing stable column operation. Experience with the column operation over a variety of operating conditions has shown the following:

- Closed-loop control using wireless measurements and the PIDPlus algorithm effectively addresses fast processes, such as liquid flow and steam flow, as well as slower processes, such as temperature control, using an 8-sec. periodic communication update rate.
- MPC satisfies process control requirements using wireless instrumentation. For the DWC control, MPC has been shown to outperform single-loop control.

Further field tests are scheduled at the University of Texas over a six-month period. HP

ACKNOWLEDGMENTS

The authors gratefully acknowledge the cooperation from the University of Texas and Eastman Chemical Co.

LITERATURE CITED

[1] Ling, H. and W. Luyben, "Temperature control of the BTX divided-wall column," *Industrial and Engineering Chemistry Research,* Vol. 49, 2010.

[2] Tututi-Avila, S., A. Jiménez-Gutiérrez and J. Hahn, "Analysis of multi-loop control structures of dividing-wall distillation columns using a fundamental model," *Processes,* Vol. 2, No. 1, February 2014.

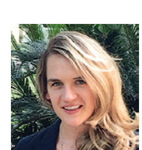
[3] Blevins, T., D. Chen, M. Nixon and W. K. Wojsznis, "Wireless control foundation—Continuous and discrete applications," ISA 2014, http://www.wirelesscontrolfoundation.com/

[4] Buck, C., C. Hiller and G. Fieg, "Applying model predictive control to dividing-wall columns," *Chem. Eng. Technol.,* Vol. 34, No. 5, December 2010.

TERRY BLEVINS leads the development of DeltaV advanced control products at Emerson Process Management. He coauthored the book *Wireless Control Foundation,* and the ISA bestselling books *Advanced Control Foundation* and *Control Loop Foundation.* Mr. Blevins received an MS degree in electrical engineering from Purdue University. He is a member of *Control* Magazine's Process Automation Hall of Fame and is an ISA fellow. At present, he works as a principal technologist in the applied research team at Emerson Process Management.

JAMES J. DOWNS is an engineering fellow and manager of the Advanced Controls Technology group at Eastman Chemical Co. He has 33 years of experience in the design, startup and support of industrial processes. His research interests include plantwide control strategy design, plantwide process optimization and the process design/process control interface. Dr. Downs was recognized by the American Institute of Chemical Engineers, which honored him with a CAST Computing Practice Award in 1996 for his contribution to the profession.

MELISSA DONAHUE is pursuing a PhD in chemical engineering at the University of Texas (UT) under Dr. R. Bruce Eldridge and Dr. Michael Baldea. She graduated from the University of Massachusetts in Amherst in 2014 and is a second-year graduate student. Her research focuses on the dynamic simulation and control of the pilot plant distillation column at UT's Process Science and Technology Center.



BAILEE ROACH is pursuing a PhD at the Process Science and Technology Center at the University of Texas. A Virginia Tech graduate, she held an entry-level engineering position with ExxonMobil prior to entering graduate school. Her PhD studies involve building a pilot-scale dividing-wall distillation column that will be used to develop basic simulation, design and control methodologies.

ePrinted and posted with permission to Emerson Process Management from *Hydrocarbon Processing*
December © 2015 Gulf Publishing Company