

Operator Training System for Hydrocracking unit: Real world questions and Answers.

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Abstract

The paper presents a case study on development and implementation of the operator training system for a green-field Hydrocracker unit at a large North American refinery. The users wanted a realistic simulation for operator training and automation design validation. However, the project schedule was compressed and the refinery staff had no experience with developing or maintaining simulators. The challenge of the project team was to find an appropriate balance between a simple simulation model and sophisticated unit operations modeling that mirrored the real process. The solution for this challenge was in the use of a commercially available simulation package designed for operator training, with flexible high-fidelity modeling objects. For instance, the pressure-flow functions for the closed gas track of the unit, implemented using basic simulator, were augmented with models of the compressors and a simple reactor kinetics, taking into account the reactor topology and holdups. The separation block of the unit was simulated using a high fidelity distillation objects, integrated with the process simulator. The distillation package provided simulation of such features, as a real world pressure control for various configurations of the column overhead, weeping at the trays, and "heat shock" in the reboiler. The simulator was successfully used for the plant operator training before the unit start up, as ongoing tool for training in the critical situations (reactor temperature runaways, equipment and control loop malfunctions, e.t.c.), and for testing, tuning and fixing the errors of the DCS control strategies. Customer has used the simulator to find hidden issues in the control strategies that would cause unscheduled downtime as well as certify the operators on the control of the unit.

1. Introduction

Benefits of using Operator Training Systems (OTS) and simulation are proven and compelling. The benefits include faster project startups and time-to-market, improved product quality, reduced plant incidents, and improved operator proficiency. In most cases the cost of the simulation system is recovered well before the startup of the process unit, and investment in the simulation software has the greatest return of any capital investment.

This paper presents a case study on development and implementation of the operator training system for a green-field Hydrocracker unit at a large North American refinery. The users wanted a realistic simulation for operator training and automation design validation. The OTS should provide tools [1] that

- Assist in safe, environmentally sound and profitable startups, shutdowns and emergency response of the new Hydrocracking unit
- Reduce the number and severity of unplanned events
- Help with unit control and optimization

The OTS should allow the Hydrocracker process leads to train on the unit before it started up, and later be used to implement ongoing training and qualification of new Hydrocracker process leads.

The challenge before the project team was to develop a simulation model that would be adequate to the purposes of the operator training and provide additional functionality for process control and optimization.

2. Challenges of the Hydrocracking Process simulation

The dynamic model of the process should meet the goals of the operator training. In this section we will give a brief description of the simulated process, then consider the operator training situations (scenarios) user would like to implement, and, finally, evaluate the model functionality and complexity needed.

2.1 Process description

A Hydrocracking Unit (figure 1) catalytically cracks heavier petroleum fractions in the presence of hydrogen to make more valuable products. In the Reactor Section the hydrotreating reactions occur first and remove Sulfur, Nitrogen and the other undesirable components. The hydrocracking reactions convert some of the feed molecules into the smaller molecules that can be separated into valuable naphtha product streams. These components are separated then in the Fractionation Section of the unit into streams that will go into making finished gasoline and distillate products. A Recycle Gas Compressor returns non-reacted hydrogen to the reactors. A Make up Gas Compressor (reciprocal) supplies make-up hydrogen to replace the gas, consumed in the reactions.

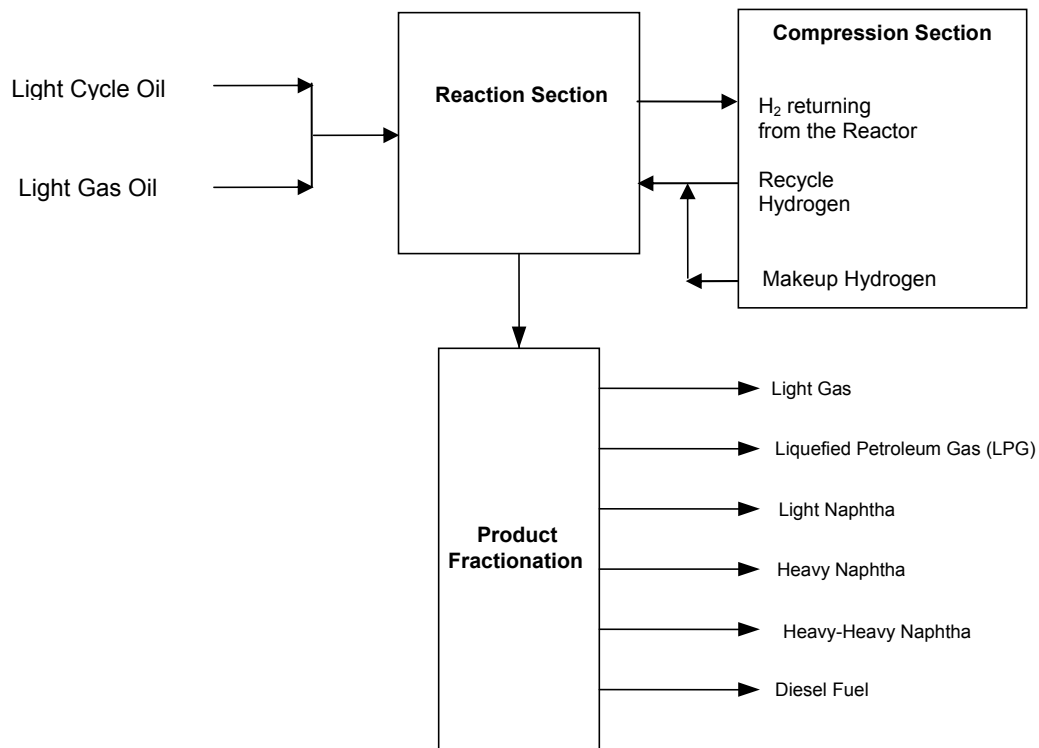


Figure 1. A Hydrocracking Unit schematic

The unit liquid feed can be represented by two generalized components, Light Cycle Oil (LCO) and Light Gas Oil (LGO) having different reactivity and heat of reaction. The unit gas feed, hydrogen, is used as both, a reagent and a cooling (quenching) agent.

2.2 Operator training scenarios

The user was interested in the development of realistic and effective scenarios for basic operator training and response to critical situations of the process operation (associated with unit upsets and malfunctions of equipment or instruments). The list of the upset situations includes:

- Reaction runaway due to the feed disruption or malfunction of the reactor quenching valves
- Recovery of the unit after runaway and depressurizing of the system
- Process upset due to sudden change of the feed composition

In these scenarios the operator should recognize the situation and take the actions to bring the process to normal operation or to safe shutdown conditions. The simulator can be utilized to train the operations engineers on basics of operation and control strategies for distillation, heaters, and/or reactors.

2.3 Model functionality and complexity needed

The operator training scenarios, suggested above, define the requirements for process model functionality and complexity. Particularly, in order to simulate the unit recovery after runaway and depressurizing the model should contain an adequate description of the hydrogen recycle and make up tracks, including the compressor models. The simulation of the reaction runaway due to malfunction of the reactor quenches assumes precise enough modeling of the individual reactor beds, including the heat of reaction and kinetics. The models of the feed composition propagation through the unit and kinetics/heat of reaction for the individual components are needed to simulate the process upsets due to sudden change of the feed composition or feed flow disruption. In order to provide basic operator training in distillation operation and control (product fractionation area) the multivariable column models for the main interacting process parameters (pressures, temperatures, and flow rates and compositions of the inlet/outlet streams) are needed.

A development of these models can require extensive time and resources. However, on this project the schedule was compressed and the workforce limited. Therefore, the challenge was to find an appropriate balance between a simple simulation model and sophisticated unit operations modeling that mirrored the real process.

3. Solutions: Flexible combining of the Process simulation complexity

The solution for this challenge was in the use of a commercially available simulation package designed for operator training, with flexible high-fidelity modeling objects. A balance of high and medium complexity models was selectively applied to the unit operations of the process. MiMiC Simulation Software [2], was used as the simulation solution for the project. MiMiC has utilities for auto generation of the model skeleton and a variety of embedded functions for simulation of common process unit operations (heat exchangers, vessels, mixers, flow rates of the vapor and liquid streams, e.t.c). It provides the tools for fast and easy development of medium complexity process model. The medium complexity models were augmented with high fidelity models for three main process areas: hydrogen recycle and make up tracks, reactors, and product separation.

3.1 Hydrogen recycle and make up tracks

The pressure-flow functions for the closed gas track of the unit, implemented in the simulation, were supplemented with models of the compressors. The Recycle Gas Compressor was simulated by the special models, employed the centrifugal compressor model using approximations of its design pressure- flow curves. The models were implemented in the simulation software User Calculation blocks.

The simulation of the Make up Gas Compressor, which contains several reciprocal compression stages, consists of a series of User Calculation blocks. Each block includes a model of the polytropical compression along with the interstage gas conditioning. The model also simulates the stage loading and unloading functions with realistic compressor performance simulation.

3.2 Reactor section

A number of a high fidelity features, taking into account a simplified reaction kinetics, reactor topology and holdups, were incorporated in the reactor section model.

The overall reactor model consists of the interacting models for the reactor beds. The model for each bed contains material and heat balances, which include transformation balances and heat of reactions for two generalized liquid components, LCO and LGO, and for the hydrogen gas component. The simplified reaction kinetics was modeled using the piece-linear approximation of the Arrchenius type equation for rate of reactions in the working interval of temperatures with correction coefficients for the reactor pressure and liquid holdup. Since the beds different in the roles, hydrotreating or hydrocracking, the model contains two sets of the reaction equations, respectively.

These equations of the reactor model were implemented using a set of interacting User Calculation blocks in the simulation software.

3.3 Distillation Package for the Product Fractionation

The Product Fractionation block of the unit was simulated using a high fidelity distillation objects, integrated with the basic process simulator. These objects were created, initialized, and integrated with the rest of the process simulation using the MiMiC Distillation Package [3].

The Distillation Package allows the user to build dynamic models for a full-scale distillation column simulation, including reboiler, condenser, and reflux receiver (figure2). The column can have up to five feed and side withdraw streams, three tray sections with different diameters, and up to ten components, separated in the column. The features of the column object include two liquid phase separation in the reflux receiver, constant or variable options for column pressure and tray pressure drop, tray weeping.

A distinctive feature of the model is the overhead section layout that makes possible simulation of a variety of the real world pressure control loops (described, for instance, in [4]) used in the distillation. Particularly, the column pressure can be controlled (see the basic column configuration, figure 2):

- By manipulation of cooling agent flow rate to the condenser
- Using control valve on the vapor bypass around condenser to the reflux drum
- Using directly control valve on the vapor stream to the condenser
- By manipulation of flow rate of the outside vapor stream from/to reflux drum (split range control commonly used with the partial condenser)

The Distillation Column Package offers to user a convenient interface to each of the objects, providing:

- Creation and configuration of the object
- Initialization and running of the object
- Visualization tools to monitor the object performance

An example of the run time user interface to the Debutanizer object is shown in figure 3. It contains a real time profile of the column liquid composition, offering a valuable insight into the object.

The distillation column model built with the Distillation Packages has the ability to be initialized and started from a Cold or Warm (near steady-state) status. User controls within the Distillation Modeling Package allow the user to perform initialization off-line and then launch the object to run on-line with a basic simulator.

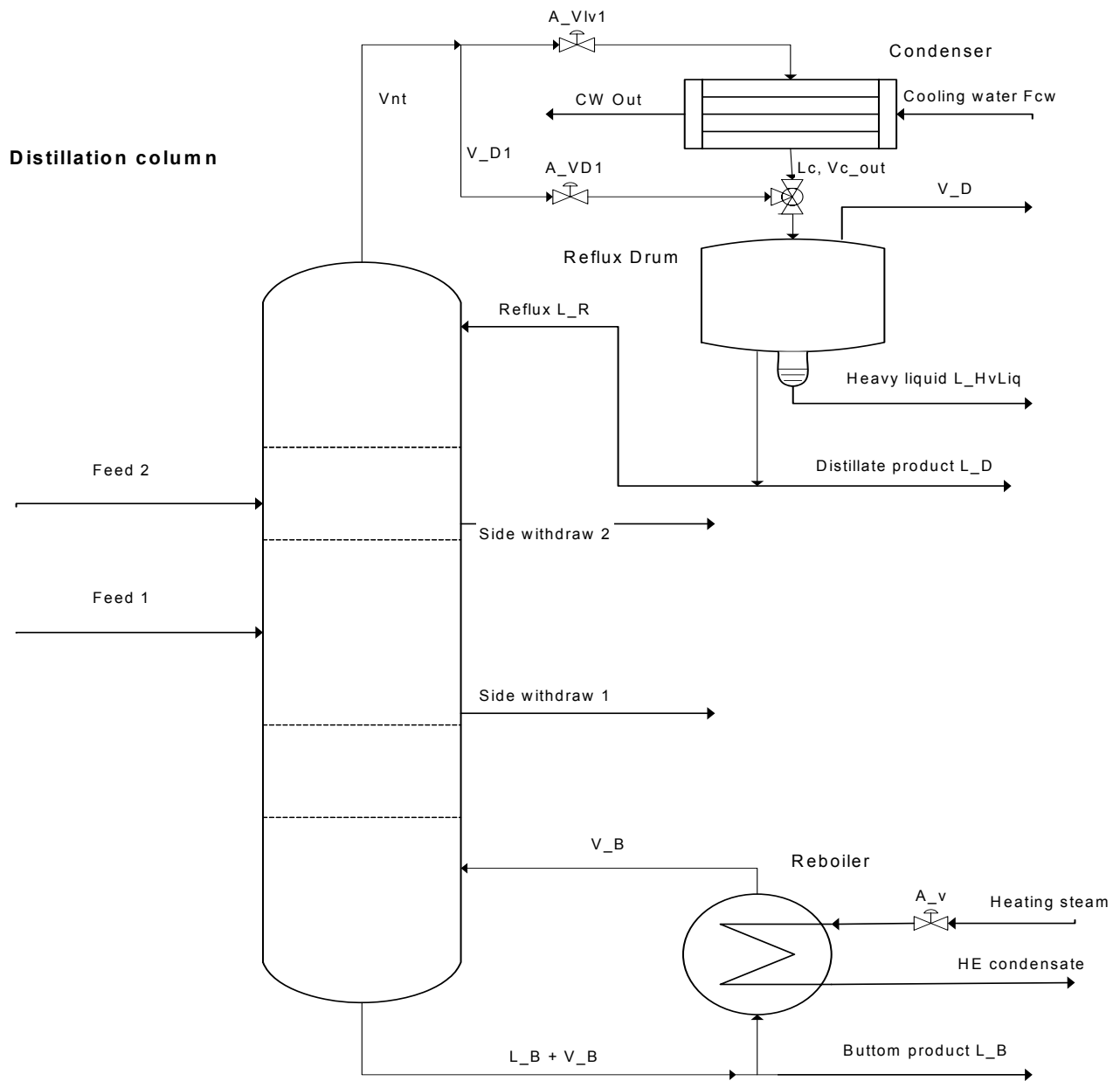


Figure 2. Basic Configuration of the Distillation Column with two liquid phase separation in reflux drum

The Distillation Column models for the Product Fractionation section were configured, initialized and launched on-line using the Distillation Package features, described above. Note, that the package allows creation and initialization of new models while the others are already running on-line, providing flexibility in the process of building and tuning of the entire plant model.

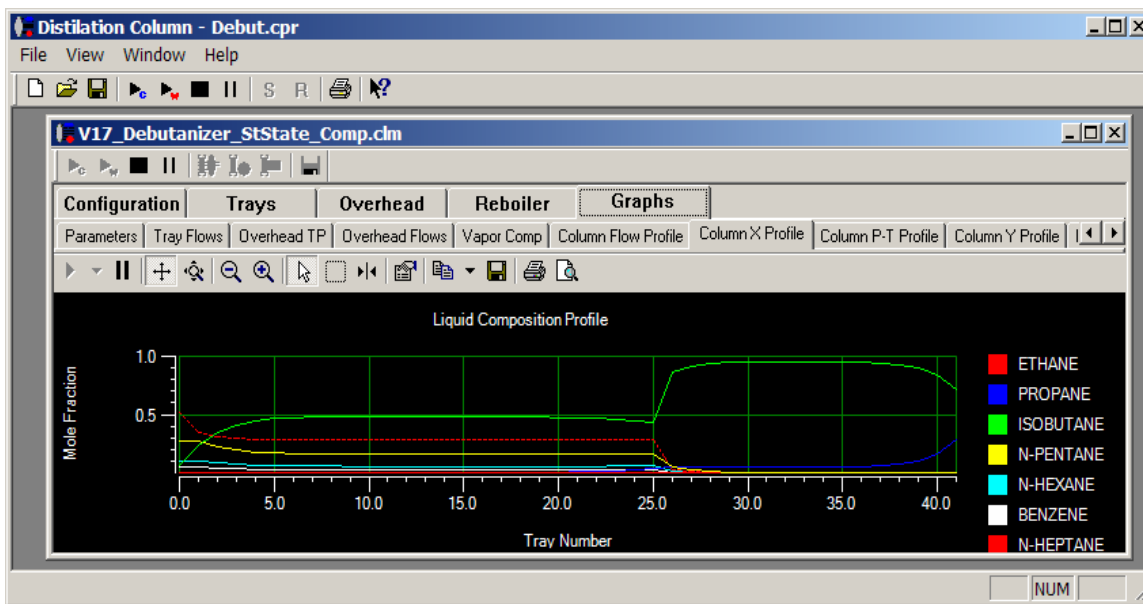


Figure 3. Object user interface with graph of the column liquid composition profile

The distillation package provided simulation of such features, as a real world pressure control for various configurations of the column overhead, weeping at the trays, and “heat shock” in the reboiler. An example of a complex pressure control scheme of the real process is shown in figure 4. It includes the column pressure control loop using the valve at the vapor inlet to the condenser and the pressure difference loop, controlled by the valve on the “hot vapor bypass” around condenser. Due to the flexibility provided by the Distillation Package, this scheme was implemented in the model without compromise.

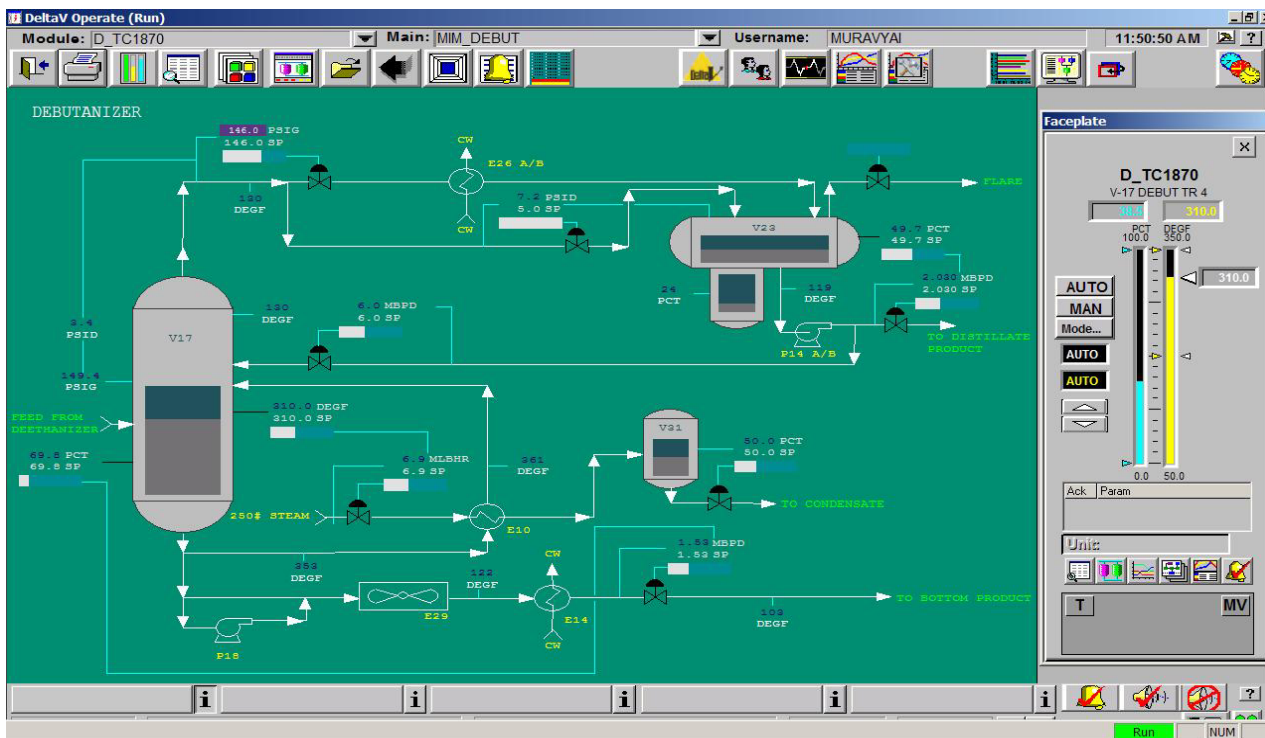


Figure 4. DCS screen of the column with the process controls

4 Conclusions

The Operator Training Systems for the new Hydrocracking unit was developed by means of combining of a commercially available simulation package designed for operator training, with flexible high-fidelity modeling objects. The selective application of high and medium complexity models to the unit operations of the process, provided simulator functionality that completely met or exceeded the customer expectations.

The simulator was successfully used for the plant operator training before the unit start up, as ongoing tool for training in the critical situations (reactor temperature runaways, equipment and control loop malfunctions, e.t.c.), and for testing, tuning and fixing the errors of the DCS control strategies. The customer has used the simulator to find hidden issues in the control strategies that would cause unscheduled downtime as well as certify the operators on the control of the unit.

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