Crude Assessor in Refinery

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About the Client

Bharat Petroleum Corporation Limited (BPCL), a Government of India enterprise, **Gyan Data** and **Process Systems Enterprise (PSE)** based out of London, UK were jointly awarded one of the four projects funded through a Indo-UK Joint Industrial Research and Development Programme [1]. The project aims to improve efficiency and yields in oil refineries. BPCL has several refineries across India that provide valuable data on products derived from a variety of crude. PSE is a spin-off from Imperial College London and has engineered systems from first principles model through its flagship product, gPROMS, for over a decade.

Motivation

Crude oil passes through several stages from well to the finished products that drive our industrial economy and daily lives. The most interesting phase in the crude's lifetime is at the refinery where it is split into the very useful components that provide direct energy. At the refinery, crude arrives from shipments that wait in storage tanks until they are fed to the Crude Distillation Units/Columns (CDUs). Different kinds of crude arrive at the refinery and wait in the storage tanks before they are blended and fed to the CDUs. The original crude quality may well be reported before it arrives at the refinery; but the waiting time in the storage tanks and blending adds additional complexity to characterize the crude fed to the CDUs. The True Boiling Point (TBP) curve of the crude fed to the CDU has a direct correlation with the distillates obtained from the CDU. The challenge is to derive the TBP curve of the blended crude that requires accurate knowledge of the crude composition. Besides, the crude is heated through a series of heat-exchangers in the pre-heat train before being fed to the CDU. The heat-exchangers' efficiency needs to be monitored in order to plan maintenance and therefore, requires accurate prediction of heat-transfer coefficients based on flow and temperature measurements on the tube and shell side. These measurements unfortunately have random and/or gross (bias) errors which calls for getting reconciled estimates.

Problem

The quality of the end products from a refinery is controlled by manipulating the operation parameters in the CDU. This requires accurate knowledge of the incoming crude from the storage tanks. There are a variety of aspects that characterize a crude. These include, source (tag name, e.g., Arab Light), light components, water concentration, specific gravity, cut maps (through analytic study in laboratory), etc. The cut maps are of high significance as it summarizes how the crude will distill at the CDUs. These include:

- True Boiling Point (TBP) curve
- Density curve

Although the incoming crude has a data base available from SPIRAL[2] that define these curves, mostly they change over time while the crude waits in a storage tank or is overlaid on top with a fresh supply of another crude. Consequently, an accurate prediction of the crude properties that is actually fed to the CDU must account for the crude fractions which must be updated. While there are several flow, temperature and density measurement sensors along the path of the crude from the storage tanks to the CDU, they themselves are beset with random and/or gross (bias) errors. Due to this reason, an accurate prediction of the crude composition in the blended stream requires reconciled estimates of the raw measurements.

The second part of the project involved applying data reconciliation to heat-exchangers in the pre-heat train, in order to monitor the heat transfer coefficient of the heat exchangers. This again required modeling the heat-exchanger circuit and using measurements of flow, temperature and crude thermodynamics within a data reconciliation framework to obtain consistent estimates of the heat transfer coefficients.

Solution

An object-oriented code architecture was implemented in Python at **Gyan Data** that accessed the SPIRAL data base for different crude properties, sensor readings from DCS in the refinery upstream of the CDU and formulated the data reconciliation problem as an optimization problem. The C++ based optimizer IPOPT [3] was integrated with the Python code framework that solved the constraint optimization problem.

The entire stream could be configured through an Excel interface, from which the Python code could read the measurements and plant configuration. Based on this, using the class definitions of the mixing and splitting units and crude streams, the entire constraint equations were assembled and for the measured variables, a scaled least-squares sum objective cost was formed (scaled with sensor's variance). The entire problem then was passed to the non-linear optimizer IPOPT to evaluate consistent estimates of the measurements and evaluate unmeasured variables that satisfy all the constraint equations.

This satisfied the flow and material balance equations. Once the reconciled estimates of the crude compositions were available, the TBP of the blended crude could be derived based on its additive property. The blended crude's density curve however, required a specialized estimation algorithm, since it is not a naive extrinsic property like the TBP curve. Besides, the reconciled estimates of the flow rates and other measurements helped identify measures to change the distillates downstream of the CDU. This could be through controlling the crude flow rate coming in from different storage tanks holding the different kinds of crude.

Applying the same data reconciliation principle on the crude pre-heat train helped identify heat-exchanger fouling independent of the inaccuracies in flow and temperature measurements.

References

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