Crude Assessor and Heat-exchanger Monitoring in Refinery

Sam Mathew
Consultant
Gyan Data Private Limited
Chennai - 600 113 India
sam@gyandata.com

Senthil Kumarasamy
Manager, Process Technology
Gyan Data Private Limited
Chennai - 600 113 India
senthil@gyandata.com

About the Consortium

Bharat Petroleum Corporation Limited (BPCL), a Government of India enterprise, **Process Systems Enterprise (PSE)** based out of London, UK and **Gyan Data** were jointly awarded one of the four projects funded through the Indo-UK Joint Industrial Research and Development Programme [1]. PSE is a spin-off from Imperial College London and has engineered systems through first principles models usings its flagship product gPROMS for over a decade. The objective of the project was to improve efficiency and yield in oil refineries owned by BPCL across India.

Motivation

Crude oil typically passes through several stages from the production-well to the finished products that drive our industrial economy and daily lives. The most interesting phase in the crude's lifecycle is at the refinery where it is split into the very useful components that provide direct energy. Crude is sourced from various locations and waits in storage tanks at the refinery before it is fed to the Crude Distillation Units (CDUs). Though the crude quality is known apriori based on its source location, the characterization of crude that is fed to the CDUs is unknown. This is owing to the fact that the waiting time of the crude in storage tanks results in blending between the different sources which ultimately alter the crude characteristics.

The True Boiling Point (TBP) curve of the crude fed to the CDU has a direct correlation with the distillates obtained from the CDU. 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 for maintenance activities 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 cements the need for reconciled estimates.

Problem

The quality of the end products from a refinery is controlled by manipulating the operational 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, moisture content, specific gravity, cut maps (through analytic study in laboratory). The cut maps are of high significance as it summarizes how the crude will distill at the CDUs including:

- True Boiling Point (TBP) curve
- Density curve

Although the incoming crude has a data base available from SPIRAL[2] that define these curves, they typically change over time while the crude is stored 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 are in turn beset with random and/or gross (bias) errors. Due to these reasons, 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. Gyan Data 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 constrained 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 interface and using the class definitions of the mixing units, splitting units and crude streams, the entire set of constraint equations was assembled. A scaled least-squares sum objective cost was formed (scaled with sensor's variance for the measured variables). The entire problem was then passed to the non-linear optimizer IPOPT to evaluate consistent estimates of the measurements and also to 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. Additionally, the blended crude's density curve 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 enacted through controlling the crude flow rate coming out from various 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

[1] Leena Arora. Deputy prime minister announces new uk-india partnerships to tackle some of the worlds biggest problems. https://goo.gl/ALa5HB. Accessed: 2017-09-19.

[2] Crudesuite. https://goo.gl/zBMPPG. Accessed: 2017-09-19.

[3] Andreas Wächter and Lorenz T Biegler. On the implementation of an interior-point filter line-search algorithm for large-scale nonlinear programming. *Mathematical programming*, 106(1):25–57, 2006.