Digital Emission and Efficiency Monitoring Through Modeling Improves Sustainability and Margins at BPCL's Kochi Refinery

Bharat Petroleum | aspentech | White Paper

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The Business Challenge

Today, refineries face the difficult challenge of maintaining and improving their gross refinery margin, calling for enhancement of the refinery's complexity. This is especially challenging in an uncertain economic climate. At the same time, emission limits are already known, and refineries need to work in anticipation of new limits, which must be strictly followed. Achieving these two targets optimally requires data and models to evaluate the tradeoffs. Monitoring of refinery stack emissions for a complex refinery is increasingly problematic. While online analyzers are widely used for NOX, SOX, and CO, more information is required to ensure compliance. The introduction of dynamic limits established by India's regulators presents the current challenge—moving emissions limits close to the operating value of units. Consequently, management pressure to ensure correctness of the analyzer value has intensified. Hence, the need for a real-time emission monitoring and data acquisition system was escalated as a priority at Bharat Petroleum Corporation Limited (BPCL).

Furnace efficiency monitoring is crucial to attain cost optimization of fired furnaces. Traditional monitoring of furnace efficiencies with Excel sheets is insufficient, as heavier duty, high-fuel consumption furnaces have become common. Every fuel-saving opportunity improves refinery margins and sustainability. Real-time, constantly calculated efficiency values have an important role to play to support management objectives.

A Refinery-wide Emission Model

Bharat Petroleum Corporation Limited-Kochi Refinery, Ambalamugal (BPCL-KR) has an installed capacity to process 15.5 Million Metric Tonnes Per Annum (MMTPA) crude oil. BPCL-KR is currently executing a green field petrochemical project "Propylene Derivatives Petrochemical Project (PDPP)," introducing more complexity. Excel-based workflows could no longer handle refinery emissions, heater efficiencies, and stack emissions. It was clear that a modeling-based approach was the right answer.

Challenges Facing the Kochi Environmental Team

Typical continuous emission monitoring systems in use at plant sites are analyzers, which provide continuous information, but only at limited points, and are not predictive. This creates a critical gap as emissions rules get more stringent and plants more complicated.

Challenges presented by the organization's needs include:

- Validating correctness of the emission values provided by analyzers.
- Increased business need for accuracy of analyzer values due to regulations.
- Reliability of the theoretical values predicted.
- Prediction of actual emissions with fuel switching.
- Availability of historical data for CO_2 emissions and the need to assess progress against the Paris climate change scenario of the carbon footprint.
- Direct evaluation of implemented energy-saving schemes with furnaces.
- Scenario planning for quantitative emission proposed by statutory agencies.
- Time savings for HSE personnel via a simple, intuitive emission data bank.
- Verification of O_2 analyzer for reliability and accuracy of heater efficiency calculations.

Dynamic Limit Concept Based on Fuel Quantity and Fuel Type

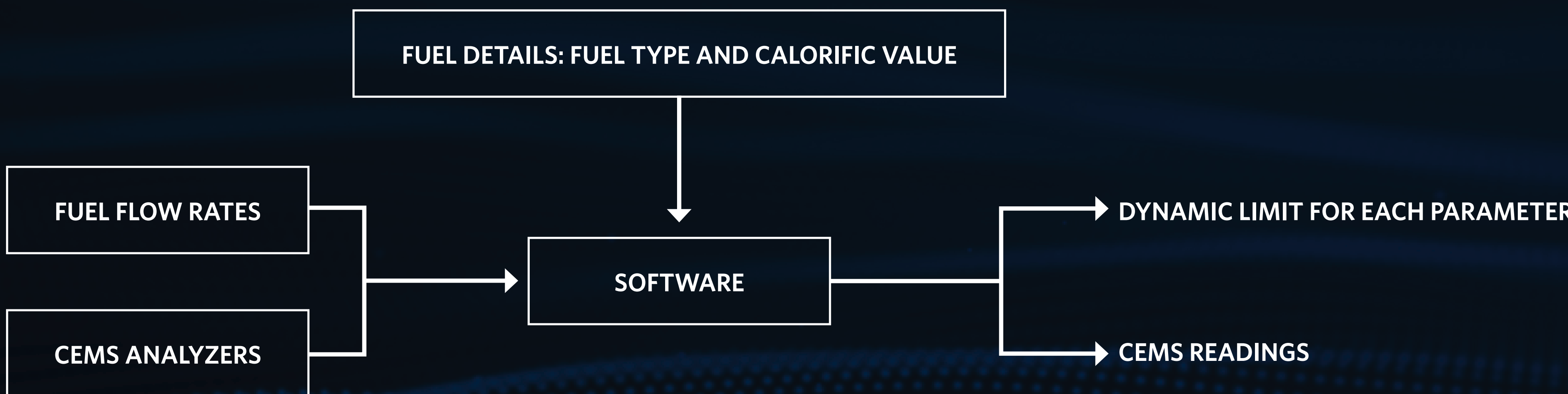


Figure A: Emission Model Conceptual Diagram, *CEMS Continuous Emission Monitoring System

Emission Digital Twin Model Concept

BPCL-KR's environmental team conceived of a refinery-wide emission model based on the current requirements. The project was initiated in February 2019. Within six weeks, the team created an operating-validated Aspen HYSYS® model that computed steady state emission calculations. AspenTech worked with BPCL-KR, beginning in April 2019, to achieve online implementation of the validated model—the refinery-wide emission model was completed on August 3, 2019. Aspen OnLine® technology was used to access the correct data and run the model at scheduled intervals.

After successful updates and accurate mapping of each area, the values obtained from this model closely matched the analyzers. An added benefit: parameters such as excess air helped to improve margin along with emission reduction. The emission model is comprised of the following software: the first phase of the project, already complete, identified significant scope for expansion and utilization in the field of cross-verifications and included Aspen HYSYS for refinery digital twin, Aspen OnLine for the online real-time deployment, Aspen InfoPlus.21® for big data storage, and aspenONE® Process Explorer for the visualization dashboard.

Refinery-wide Emission Model: Overview

Digital twin models, which are first principle-based and thermodynamically validated, represent an alternative to sensor and testing approaches. They are accepted by many environmental regulatory bodies globally for monitoring and reporting on air pollution levels. The BPCL emission model is an innovative approach that estimates emissions instantaneously by picking up live values from the process historian. It calculates required air emission levels with models based on thermodynamic first principles resulting in higher accuracy and benefit than traditional approaches, including a greater ability to react in operations. The Aspen HYSYS platform was used to develop the emission prediction model.

Twenty-six heaters, six boilers, two sets of FCC regenerators, four sets of Claus reactors, and three sets of HRSGs were modeled together to make up a single Aspen HYSYS model flow sheet, thus composing a single model with higher accuracy. Live data from the Aspen InfoPlus.21 process historian have been input from the model and calculated, while pertinent emission values are written back to the historian. The values are displayed on Aspen InfoPlus.21 graphics dashboards with a simple, powerful, and intuitive layout. Access to live values and trends are also made available.

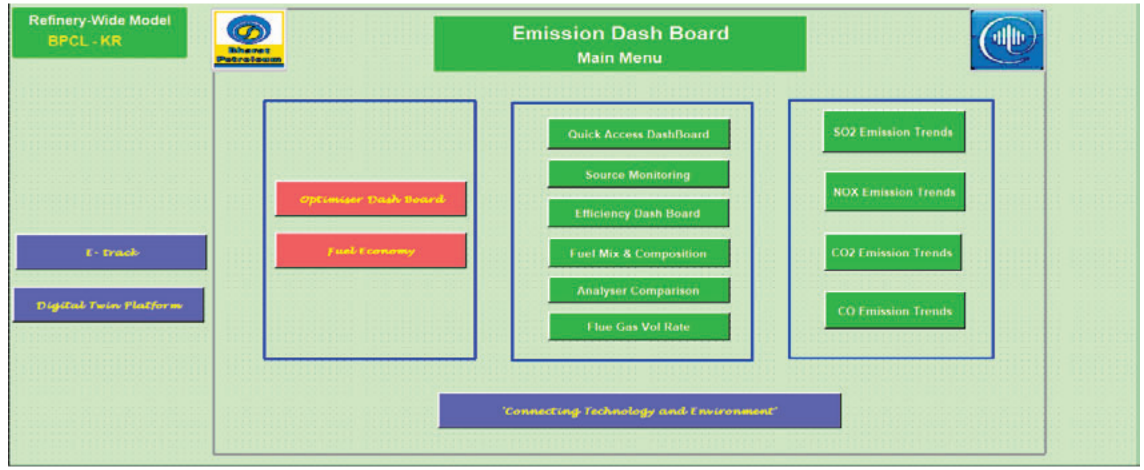


Figure B: Emission Model Main Menu Dashboard Created in Process Explorer Editor

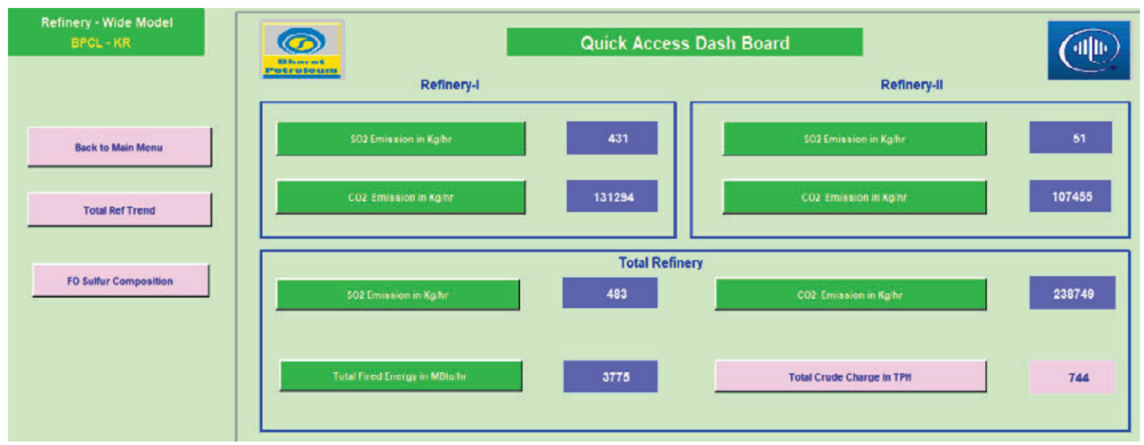


Figure C: Emission Model Quick Access Dashboard Showing Current Refinery Emission Levels

Advantages of the Emission Model for BPCL's Environmental Compliance

The BPCL environmental model offers a number of advantages, with significant potential for expansion:

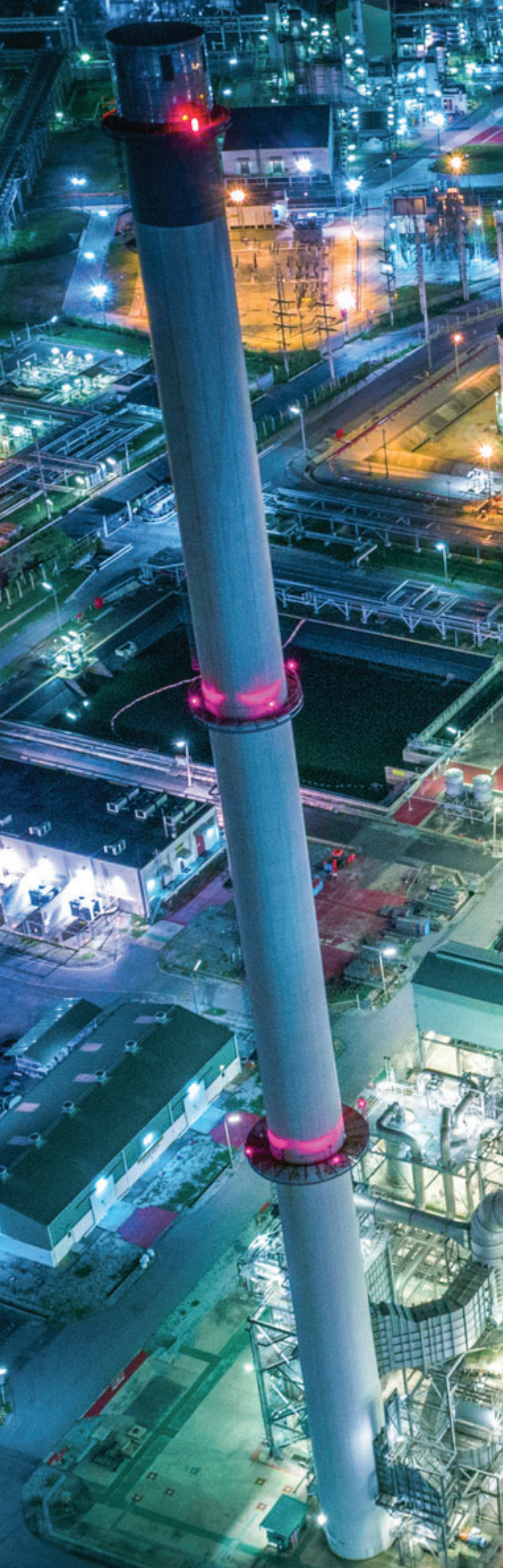
- Built on the widely accepted platform of Aspen HYSYS, resulting in high-accuracy data and easy regulatory authority acceptance.
- Dependable comparison for analyzer values.
- Live fuel and air values are used for predicting the emission values for higher accuracy. As the fuel quality monitoring frequency has increased for the PAT implementation, reliable fuel quality data are available in the Lab Information and Management System (LIMS). Direct values from the lab analysis portal are used for updated fuel quality inputs. Density-based proximity analysis values are used in case of liquid fuels.
- Standardized curves are incorporated for NOx and CO for emission prediction.
- Cross-verification of air flow, SO_2 values, and O_2 values against the instrument's values is possible.
- A parallel way of predicting furnace efficiency provides cross-check for furnace efficiency calculations in addition to the verification of O_2 and air flow values. By improving furnace efficiency estimation through this model, BPCL can improve their margin as well as reduce emissions. This is of twofold benefit. In the refining industry, typical energy consumption is approximately 0.32 MMBTU/bbl of crude oil processed. This translates into 2,667 MMBtu/hr for a 200,000 bpd refinery. Even a one percent improvement in thermal efficiency translates into energy savings of $600K USD per year.
- A more efficient and less costly alternative to analyzers: the model's values can substantiate the analyzer's values, meaning we can eliminate the need for expected verification surveys and reduce costs.

In case of non-availability of analyzers for a longer period, model values can be substituted. The model's reliability is acceptable to statutory agencies in this case:

- Zero maintenance and manpower requirement, in contrast to analyzers that require frequent maintenance and calibration.
- No consumption/utility requirements.
- As the data outputs are written back to Historian, emission data at fingertips concept is realized.
- For crude planners, emission data for a particular selection is often a grey area. This prevents them from taking the challenge of choosing better opportunity of crude selection to protect emission numbers. Emission models avoid this grey area. This completes the data cycle of emission values.
- The emission model is not only a tool to verify whether the emissions have crossed the stipulated emission levels prescribed by statutory agencies, but it can also be a solution for building proactive steps to find opportunities to reduce/plan future emissions.
- The emission model helps create a more efficient fuel mix that can reduce emissions while keeping profitability in mind. This could be provided only by a model-based system capable of monitoring instantaneous values. The models for regenerators and sulfur recovery units (SRUs) are incorporated for maximum advantage.

How the BPCL Model Improves Over Current System

1. The current system relies on a vast number of analyzers across the refinery, which cannot be easily cross-verified. The emission model relies on recent, accurate data based on undisputable principles.
2. Since analyzers give qualitative values and statutory agencies are now stepping up for quantitative emission numbers, the industry seeks better model-based solutions.
3. Models provide reliable data, higher accuracy, and transparency.
4. Tremendous scope for efficiency optimization lies in a model that can be easily explored.
5. Previous furnace efficiency calculations were done using standard Excel sheets. The efficiency monitoring feature of the emission model can be used as a helping tool for live observation efficiency values.



The BPCL emissions monitoring system features a simple and practical architecture, largely due to the integrated nature of the AspenTech suite of tools. Figure D represents the workflow and data collection elements:

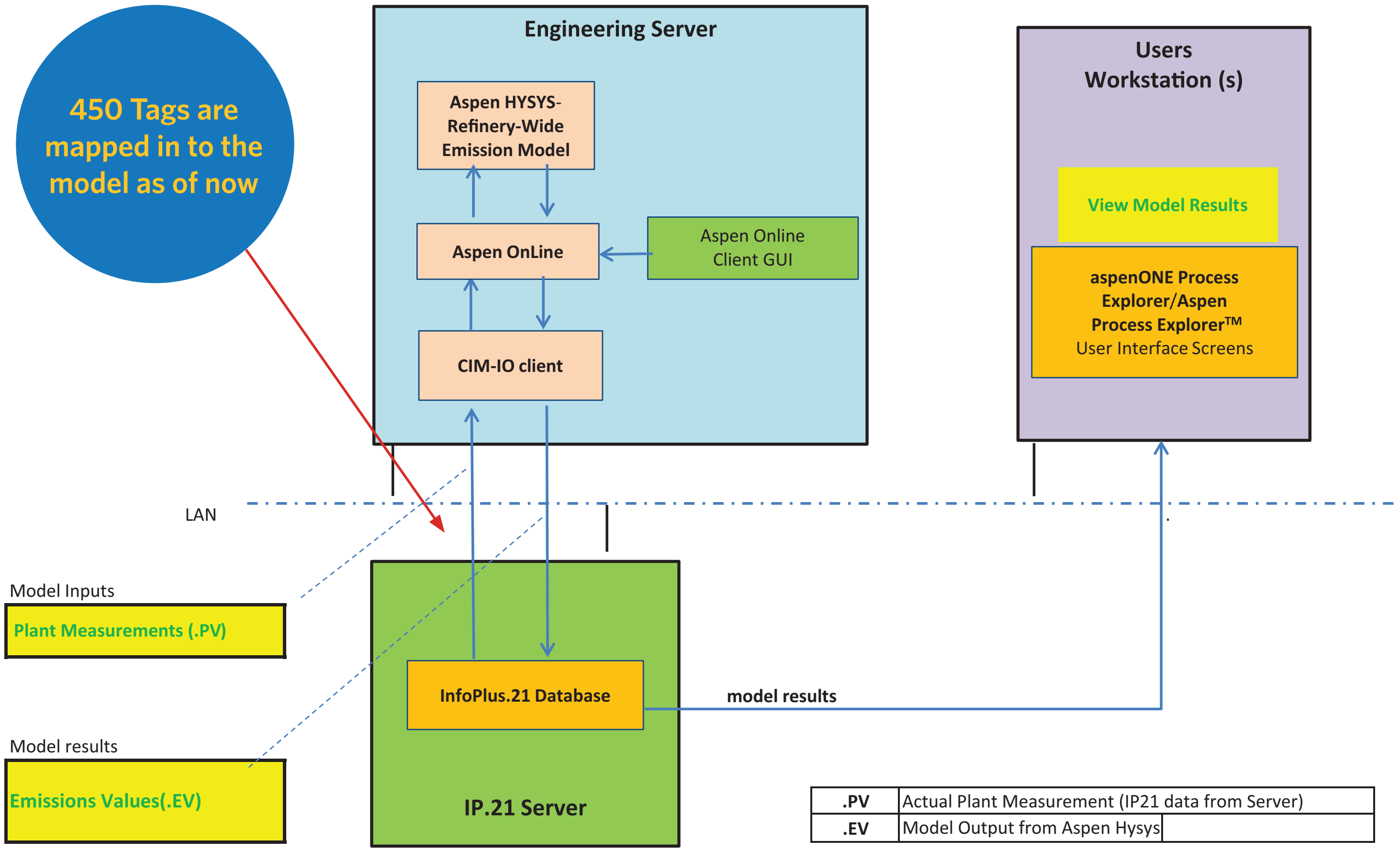


Figure D: Digital Twin System Architecture of Emission Model

Comprehensive Scope of the Digital Twin Model

The total emissions estimation involves some complexity because of the large scope of the network of heaters, boilers, regenerators, and incinerators. Each heater has been carefully modeled in Aspen HYSYS using the best practices and distinct approaches for FCC and SRU stacks.

Another challenge for effective model building is NOx and CO representation. The NOx generation mechanism is so complex that no practical manual solution other than analyzers can be used. The NOx generation mechanism has three kinds:

1. Thermal NOx
2. Prompt NOx
3. Fuel NOx

Out of the three mechanisms, fuel NOx is fairly minor and the only one that can be manually computed. The Aspen HYSYS model has the capability to predict NOx and CO emissions from stacks based on excess O_2 using reliable prediction curves. Because the model provides good results in the case of excess O_2, it is a reliable method for prediction based on standard curves. The curves can be remodeled based on actual emission data obtained through manual sampling or analyzer reading. Similarly, the model predicts CO emissions. Additionally, accurate flue gas volume can be obtained, which is also helpful in mass emission calculation.

The heater efficiency is calculated in the model using the actual specific heat quantity based on parameters of amount of fuel and air taken. The efficiency can be predicted live using Aspen OnLine; output is available in historian trends.

One important benefit of this system—it can provide the current fired energy level of the refinery based on current fuel mix. This tool, combined with emission figures, can lead the planner through a more enlightened way of emission-based crude optimization.

How Does the Digital Twin Solution Support Sustainability and Digitalization Plans for the Refinery?

The digital twin system is a highly accurate way to understand the refinery's performance on a day-to-day basis with respect to air emissions, including carbon emissions. It supports energy efficient operating strategies in the reactors.

Currently, BPCL-Kochi is looking to use the Aspen PIMS planning system on a monthly basis. Using the accurate emissions information generated, this parameter can be incorporated into the refinery planning—yielding increased optimization of margin, emission compliance, and carbon reduction.

Emission numbers have already been cross-verified with calculation sheets and can be incorporated and utilized in crude procurement plans.

The digital twin emission model can support sustainability plans like carbon neutrality and sulfur reduction. Additionally, it can suggest a better fuel mix for the refinery that can reduce sulfur emissions with targeted GRM. As the fuel mix decisions are so dynamic in a complex refinery, digitalization can only provide stronger results.

Typically, analyzers are not transparent. They provide concentration values in mg/Nm3 and do not refer to actual quantity emitted unless volumetric flow rate is being measured in parallel. This digital twin model provides a much better option to broadly make available values in quantitative as well as concentration terms. Quantitative values better support sustainability plans as BPCL sets milestones for emission reduction.

Apart from man-hour savings, digitalization makes emission accounting simpler, more target-oriented, and more productive. In their experience to date with this model, BPCL Kochi is able to maintain enough cushion in emission levels below regulated amounts, which can be converted into margin benefits with a better choice of fuel mix.

Notes on Model Validation Methodology

The model's results are validated against standard calculation sheets considering fuel inputs, carbon number, sulfur composition, etc. The model is also verified against calibrated instruments. Over a variety of test dates, CO_2 emission rates exceeded 95 percent accuracy, attributable to the model having accounted for all the fuel types with compositions on a broad level. BPCL-Kochi Refinery currently uses almost 21 fuel types to satisfy its energy requirement. Modeling accounted for all these types with 450-plus input tags. Similar results were obtained with SO_2 emission. Excess O_2 levels were verified with calibrated instruments. Model compositions are obtained from Lab Information Management System (LIMS). As the number of composition mapping points increased, the emission values had a higher accuracy rate. Model standard flue volume data has also been verified against manual data samples with calibrated instruments. Efficiency values are calculated on a real-time basis considering air and flue gas temperatures. These values are verified against standard Excel sheets.

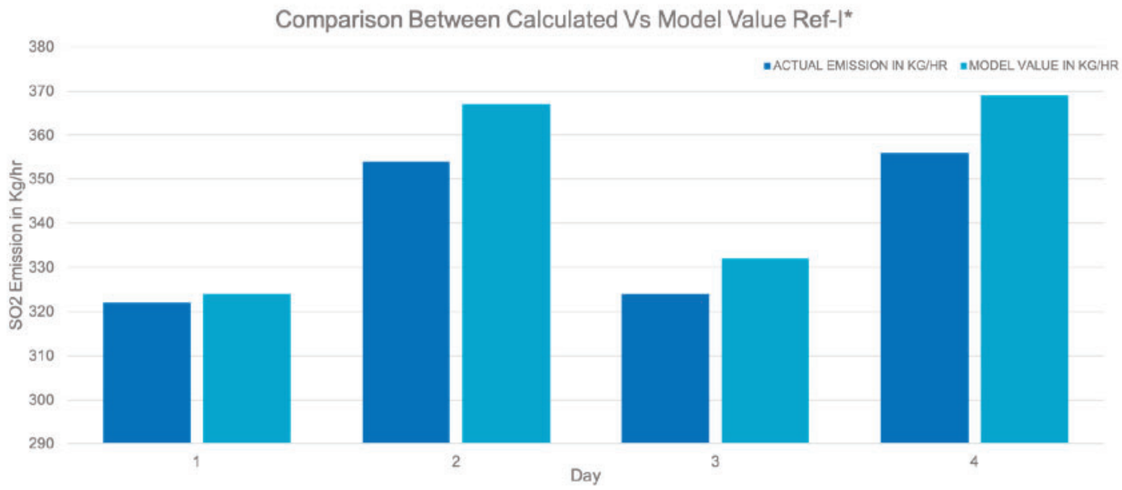


Figure E: SO_2 Emission from Ref-1 on 4 Various Sample Days

BPCL-Kochi reported CO^2 emission rates exceeded 95 percent accuracy.

*BPCL-KR has two refinery sections, Ref-1 & Ref-2

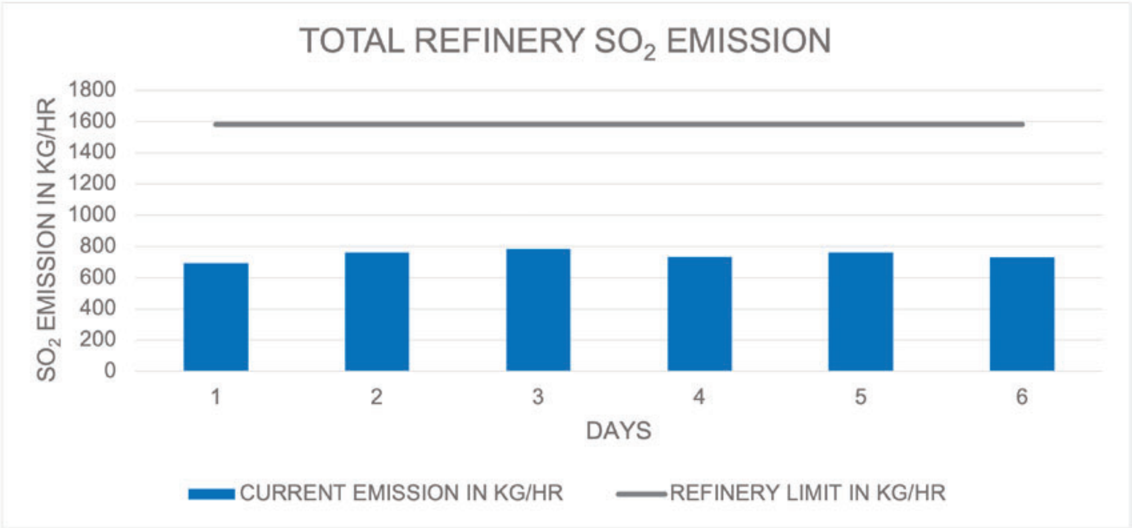


Figure F: SO^2 Total Refinery Emissions on Various Sample Days

The above chart shows that emission levels were kept well within limits, with the help of this system.

Bottom Line Benefits

Based on historical data run to validate this model, BPCL found that the model computed and predicted values, which are reliable for operating and compliance purposes. It is particularly valuable in cases with refineries that are using different types of crudes. This modeling approach is the only reliable and easy-to-implement source of comprehensive, refinery-wide emission data as it considers fuel composition along with mass flows.

This collaborative approach between AspenTech and a refinery site can be implemented in any refinery as it uses standard, off-the-shelf software currently used by refineries, globally. This represents a major breakthrough in emission monitoring and optimization of furnace operations. Wide use of this approach will go a long way in improving refinery margins, reducing emissions, and decarbonizing refineries.

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