Evolution of predictive emissions in PETRONAS

A Rusman, TA Tuan Mat and N Shabudin
Group Technical Solutions, PETRONAS, PETRONAS Tower 3, 50088 Kuala Lumpur, Wilayah Persekutuan, Malaysia

Email: andriny@petronas.com, amansyah@petronas.com, normaya_shabudin@petronas.com

Abstract. The effect of global warming and unprecedented black swan events give rise to innovative solutions to keep manufacturing companies stay afloat. Many countries have started to employ more stringent emissions limits and stricter monitoring enforcements. PETRONAS is not spared from these policies and with the enforcement of Clean Air Regulation Act (CAR) 2014, PETRONAS embarked on its emissions monitoring via statistical modelling methods. Traditional analysers are still employed for the emissions monitoring, but the focus of the paper is to spotlight the efforts in utilising soft sensors in ensuring compliance to CAR2014. Soft sensors are predictive models developed to infer primary parameters. The models can be derived via statistical tools or based on first principles using chemical engineering knowledge. The use of soft sensors is not only pervasive in the manufacturing industry but is also widely used elsewhere as it provides an indication of the future position of the primary indicators for the specific industry. The paper will also provide some insights on potential next steps in supporting PETRONAS efforts in its Sustainability Agenda. It also tells the story of collaborative efforts in maintaining good positive governance and relationship with its stakeholders.

1. Introduction on emissions monitoring in Malaysia

All continuous emission monitoring method compliance and acceptance are subjected to regulatory framework within a particular country. Worldwide, the major regulatory framework on environment protection on air emission is defined by the U.S. Environment Protection Agency and associated standards issued by the European Union. Most countries in the world align their domestic regulations with these standards.

In the middle of 2014, the Malaysian government issued a new law called the Clean Air Regulation (CAR) 2014, making it mandatory for industries to monitor stack emissions continuously. It was a significant move from the Environmental Quality (Clean Air Regulations) 1978 where industries are required to self-regulate their own emissions with continuous reporting to the Malaysian Department of Environment (DOE). PETRONAS utilised this opportunity to work with the Malaysian Department of Environment (DOE) and a PETRONAS subsidiary and implemented its first PETRONAS-Predictive Emissions Monitoring System (or P-PEMS) in 2015. In December 2015, DOE provided certification of this application and ever since then, PETRONAS began to roll-out this application to all its facilities.
2. The Malaysian regulatory framework of CAR 2014
The Environmental Quality (Clean Air Regulations) 2014 (CAR 2014) was gazetted on June 4, 2014 and came into force on June 5, 2014. The aim of the regulation is to regulate emissions of air pollutants from industrial activities including power plants, waste fuel plants as well as Oil and Gas industries as specified in First Schedule of CAR 2014 document. The affected activities and industries shall comply with the limit value and technical standards as specified in Second and Third Schedules.

2.1. Compliance to CAR2014
Under this regulation, premises shall comply with the limit value and technical standards specified in the regulations. For existing premises, five (5) years of grace period is given for opacity and limit compliance as specified in regulations 12 and 13.

2.1.1. Continuous emissions monitoring
For continuous emission monitoring as specified in regulations 16, owner of the premise shall carry out continuous emission monitoring as specified in Second and Third Schedule in the regulation. As stipulated in regulation 17, pollutants’ limits value are complied to, if the following are met:
- a) No daily average of emission reading exceeds the emission standard within any one calendar year
- b) No half hour average of emission reading exceeds the emission standard more than two times within any one calendar year.

3. Emissions monitoring system
There are 2 different types of technology in emissions monitoring system defined under CAR 2014: Continuous Emissions Monitoring System (CEMS) and Predictive Emissions Monitoring System (PEMS). Each has its own merits and needs to follow the CAR2014 requirements for certification.

3.1. Continuous emissions monitoring system
In emissions monitoring, the common system utilized is the Continuous Emissions Monitoring System (CEMS). Continuous Emission Monitoring System (CEMS) is a hardware-based analyser system that comprises sampling system, transport line and analyser for online continuous emission monitoring. CEMS is the traditional, default solution for emissions monitoring. However, CEMS may face issues with reliability, mainly related to the sample conditioning system and complex installation especially for high moisture, high temperature systems as well as systems with long sampling lines. CEMS also requires preventive maintenance practices and parts replacement, to ensure it continues to operate effectively and under the conditions at which it was certified.

3.2. Predictive emissions monitoring system
An alternative to CEMS is Predictive Emissions Monitoring System (PEMS), a model-based prediction system to continuously monitor emissions using readily available plant process data. PEMS model/s is derived using various inferential techniques based on historical process data pattern, cause and effect relationship between process measurements and emission properties. PEMS can provide equal accuracy and quality of data comparable to CEMS. Typically, PEMS are installed due to lower operational and maintenance cost and higher reliability.

4. Background of PETRONAS PEMS (P-PEMS)
PETRONAS has been using predicted properties of process for over 20 years to control processes to meet its product specifications. Typically, properties prediction is developed in PETRONAS for the purpose of accurate and repeatable control of complex process systems and to achieve high levels of process optimisation. The prediction of properties is used to cater to issues of time delay in process analyser and unavailability of process analyser. The same proven technology used in process properties prediction is used in PETRONAS PEMS development.
4.1. PEMS technology

PETRONAS chose Statistical Regression method to for its emissions monitoring programme. In regression method, a relationship is developed between a target variable ‘Y’ against known ‘X’ values using statistical techniques. The relationship takes the form of a mathematical equation that can then be used to estimate ‘Y’ given a series of ‘X’ values. This modelling technique is used to describe relation between independent and dependent variables in scatter diagram or parity plot.

Simple linear regression is summary of relationship between one dependent and one independent variable. When there are more than one independent variables, Multiple Linear Regression (or MLR) is utilized to develop the relationship:

\[ Y = a + b_1 * X_1 + b_2 * X_2 + ... + b_n * X_n \]  

Where Y is the primary variable to be inferred (example, a component composition, e.g. CO₂, H₂S), and X is the input variables used to predict the Y (e.g. pressure, temperature or flow of the process). n indicates the multiple number of input variables that is utilised in the equation (1).

In the statistical methods, the goal is to find an equation that best summarizes the test data and predicts emissions to within an acceptable level of confidence. Linear regression statistical techniques have been used widely to develop PEMS

Other modeling techniques, e.g. First principle or combination of statistical and first principle, may be applied for a specific application to yield better models. This statistical/regression modelling technology is supplemented with several additional features to comply with regulatory requirements.

4.2. P-PEMS technology

PETRONAS first developed a P-PEMS proof-of-concept in 2013. Through collaboration with the regulatory body, the Malaysian Department of Environment (DoE) and with two trial sites, PETRONAS was able to achieve success in delivering two functional and regulatory approved applications by 2015. A typical P-PEMS architecture is as shown in figure 1:

![Figure 1. P-PEMS architecture.](image)

The above figure 1 indicates how the process data from the stack is used in the P-PEMS application (modelling the emitted NOₓ, SO₂ and/or CO). The predicted emission values are then sent to the Plant Historian (PIMS) server. The emission data is then sent to DoE Putrajaya office via the CEMS-DIS server which belongs to PETRONAS. During audit/modelling period, a mobile CEMS will be hooked up to the stack to measure actual emission readings to enable comparison between the prediction and actual values.
P-PEMS complies with US EPA 40 CFR Part 60 and Part 75 as a tool for continuous emission monitoring system. P-PEMS application runs in an operating unit’s highly secure server environment to protect the model, as well managing DoE’s confidence on compliance.

The P-PEMS server is a system that is made for the sole intent to provide continuous transmission of emissions to DoE, as per CAR 2014. Due to this critical activity, the server is made secure, with tight access control. In addition, to ensure that there is no single point of failure, it is equipped with redundancy and Uninterrupted Power Supply (or UPS) systems which allow automatic switching of servers and power in case of system failure to provide high system availability.

P-PEMS incorporates features such as input and output validation system to ensure prediction reliability and accuracy. A dedicated graphic is configured for the users to allow continuous monitoring of emission for a particular equipment. The application will trigger alarms to alert operation personnel should there be any abnormalities either to the system or to the emission prediction. A sample of the display is as below:

![Sample of P-PEMS DCS display.](image)

**Figure 2.** Sample of P-PEMS DCS display.

5. **Methodology**

PETRONAS developed a unique approach to modelling for Emissions Prediction. This included utilizing a third party for providing accurate stack measurements to support model accuracy, developing a rigorous approach to regression modelling with an improved understanding of model prediction limits.

5.1. **Initial phase: PEMS feasibility assessment**

To assess the applicability of PEMS, a Feasibility Assessment was developed in the initial phase. This structured assessment assesses the suitability of CEMS or PEMS for a particular stack and incorporates targeted areas such as the sufficiency of modelling inputs for PEMS and the physical modifications for CEMS. The assessment team looks at type of equipment, complexity of installation, physical dimensions, available sample results, operating modes, existing instrumentations (including reliability) and available infrastructure to support both technologies. In addition, the assessment may call for rectification to existing instrumentation, additional instrumentation, enhancement of data information systems, etc.
5.2. Implementation phase: PEMS implementation and certification

PEMS implementation phase is subjected to results obtained from initial assessment results. If initial assessment indicates PEMS is suitable technology, approval by DoE must be obtained prior to PEMS installation. The implementation of PEMS involved the coordination of activities by several stakeholders coupled with the technical aspects of the development itself. Its implementation consists of several critical stages as explained in figure 2 and the paragraph below:

Figure 3. PEMS development and maintenance workflow.

- **a. Emission Data Collection and Analysis**
  Both emission data from reference measurement or mobile CEMS and relevant plant process measurement are extracted on daily basis to ensure reliability and validity of data.

- **b. Modelling & Internal Validation**
  Identification of inputs to P-PEMS model and correlation to emission is carried out at this step. Input selection to the PEMS model is based on process and operation knowledge and offline validation is performed using different sets of data to ensure model robustness.

- **c. Configuration and Commissioning**
  During the system configuration and testing, all relevant personnel including Instrument, Process Control and Operation shall be on site to ensure the system loading is executed smoothly and verify the testing. P-PEMS model will be deployed and emission prediction model will be validated against actual measurement from mobile CEMS.

- **d. Certification**
  PEMS application shall undergo the initial certification test as stated in Section 2.1 of PS-16 before reporting any PEMS data as quality-assured Performance Specification 16 (PS-16) is used to determine whether PEMS is acceptable for use and compliance with applicable requirement. Full report on PEMS implementation shall be submitted to DoE for approval before PEMS is accepted as emission monitoring method for a particular stack.

6. Challenges

PETRONAS, being the first company in Malaysia to develop its own PEMS technology, required an excellent understanding of Malaysia’s Clean Air Regulation and US EPA specifically for PEMS. To overcome this, several engagements were organized with DoE and data verification with CEMS vendor.

The PEMS server application involved the development of numerous unique algorithms that were required to comply with specific sections of the US EPA PS-16 requirements. Each of these algorithms required a development, testing and documentation phase in order to ensure compliance and acceptance by regulatory body. Multiple engagement with development team to ensure modules execute...
concurrently and continuously to ensure input parameters and emission predictions are reliable and accurate.

PETRONAS-PEMS represents the first Malaysian-made predictive emissions application that is in full compliance to the Clean Air Regulations (CAR) 2014, leveraging on skills by Malaysian engineers to that venture into developing own product they believe has immense potential to grow and has positive impact to environment. From the first pilot implementation, a comprehensive Project Plan and Organization Chart was developed to achieve a successful project within the allotted timeframe. Through extensive collaboration between several organizations such as the premise owner, the Solution Provider, a third party CEMS vendor that provides accurate measurements for modelling, and DoE, PETRONAS has been approved as PEMS consultant by DoE.

In terms of application technology, P-PEMS initially was implemented in Plant Distributed Control System (DCS) taking into consideration of system security, internal capability of DCS coding by PETRONAS’ Automation Engineer, available features in DCS to satisfy with requirements in US EPA and less network communication requirements. However, upon increment in the number of P-PEMS implementation which covers different DCS brand (Honeywell, Yokogawa, Foxboro), housing the applications in DCS were no longer effective as the coding needs to be specific for different DCS brand. In addition, system troubleshooting will be dictated by DCS brand which is cumbersome for the personnel.

7. Sustainability

Upon successful implementation of P-PEMS and officially approved by DoE, it is mandatory for the application to be maintained accordingly to ensure the prediction accuracy and validity of the emission being reported. Malaysian DoE has outlined to all industries utilising PEMS as a monitoring and reporting tool on emission to follow US EPA 40 CFR Part 60 specifically under PS-16 for application audits and verifications. An overview of the mandatory actions required is as summarised in figure 4 below:

![Figure 4. Sustainability requirements as required under US EPA 40 CFR part 60.](image-url)
Due to this, PETRONAS has developed a sustenance program to comply to these requirements and most importantly keeping the applications continuously verified and validated by DoE. This sustenance program among others (not limited to), consist of the following:

a. To conduct a quarterly RAA
b. To conduct Yearly RATA
c. P-PEMS maintenance log/record
d. Sensors’ maintenance log/record
e. P-PEMS alarm journal
f. Capability development

The most important facet to ensure P-PEMS sustainability over the long run is to secure a long-term partnership with local Mobile CEMS services provider. PETRONAS has established a contract with one of the local Mobile CEMS service provider to conduct P-PEMS verification audit on quarterly basis (either RAA or Annual RATA). The activities are planned accordingly with inputs from sites on equipment/stack availability as well as any issues or constraints to be handled. Based on this Master Plan, the sustenance program is executed in a coordinated manner.

7.1. Example of quarterly RAA & annual RATA conducted

P-PEMS will be subjected to verification every quarter either for Relative Accuracy Audit (RAA) or Annual Relative Accuracy Test Audit (RATA). The frequency is 3 times RAA and 1-time Annual RATA for 1-year cycle. The verified audit result will be submitted to DoE for approval and the cycles continues. Figure 5 and figure 6 are samples of Quarterly RAA and Annual RATA result, indicating the number of runs, period of runs and results whether it passes the test:

![Figure 5](image-url)  
**Figure 5.** Sample quarterly RAA for NOx (nitrogen oxides).
8. Future
P-PEMS has undergone various transformations since its pilot inception in 2016. From just a handful, now a whole section has the capability to implement and maintain P-PEMS. In looking ahead, the challenges in Section 6 must be addressed to improve P-PEMS, as well as innovating the solution to assist PETRONAS in addressing our own Sustainability Agenda.

PETRONAS has embarked on consolidating all P-PEMS in one platform, housing the application in PETRONAS Centralised Data Centre and utilising Microsoft platform for programming. Latest, the applications have been migrated to the Cloud and it has been integrated with CEMS monitoring as part of PETRONAS Digital Transformation Journey. This system is now accessible via web with proper access granted to different viewer. This is depicted in figure 7 below.

Figure 6. Sample annual RATA for NOx.

Figure 7. Overview of P-PEMS current system.
As the P-PEMS application number increases drastically, it is important for PETRONAS to improve on the overall P-PEMS Work Processes in order to be more efficient, systematic and well documented. There is an on-going effort to streamline RAA/RATA execution template, audit planning and tracking, issues to be resolved and communication with DoE.

Almost all P-PEMS implemented so far are for the existing facilities, i.e. equipment already in operation prior to CAR2014. PETRONAS has successfully piloted P-PEMS for new boiler project recently and this has capped a major milestone in P-PEMS future growth and evolution.

Moving forward, the team is in the midst of improving the application one step further with the proposal of Emission Monitoring and Intervention Initiative (EMI). This is a 3-phase plan where in the 1st phase, it is to improve existing P-PEMS emission model (prediction) utilising more advanced and sophisticated modelling techniques from currently being used. Once the new techniques have been selected, tested and validated, the new model will be implemented as an advisory to Operations personnel to adjust combustion equipment handles to optimise energy required vs emission released. Later in Phase 3, a control strategy will be devised to automatically optimise energy (fuel gas) while still meeting the emission limit.

Acknowledgments
This work was supported by PETRONAS GTS Management to further advance PETRONAS’ Engineering Solutions.

References
[1] Department of Environment (DoE) Malaysia 2019 Guidelines for the installation & maintenance of continuous emission monitoring systems (CEMS) for industrial premises/ facilities

Department of Environment (DoE) Malaysia

[2] Department of Environment (DoE) Malaysia 2014 Environmental Quality (Clean Air) Regulations, Department of Environment (DoE) Malaysia

[3] Evans S 1994 Predictive monitoring: The way things ought to be Air & Waste Management Association Meeting, Cincinnati, OH