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PROCESS DESIGN CHALLENGES IN PRODUCING CLEAN FUELS PROJECTS IN BROWNFIELD REFINERY

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ABSTRACT

In Asia, with increasing pressure to meet environmental Diesel Euro 5 fuel specifications, older refineries have the choice of upgrading their plants to prepare for this change. Changes that have to be thought off are not limited to the technology to be selected. Still, the more complex issues would be the brownfield elements, plot constraints, utilities, and offsite constraints. Older refineries will face a dilemma in meeting the more current design standards, especially those related to safety. Another key consideration is to scope the project's boundary, which has to be considered is the brownfield process unit limitations. The obsolete plant documents are also another challenge. Test run data has to be obtained to define the plant's current performance and determine the current efficiencies of the equipment instead of assuming the equipment as new. This report provides insight into the challenges faced in designing old plants to meet Euro 5 requirements.

INTRODUCTION

The Malaysian Government issued a mandate to produce fuels that conform to Diesel Euro 5 specifications by 2020. The previous specification used was Euro 2M. Several existing Refinery complexes in Malaysia have upgraded the Diesel products into Euro 5 standard, meeting sulphur content in Hydrotreated product of 10 ppm weight (wt) and other specifications as in Table 1.

The refineries in Malaysia have been built for more than 20 years. Upgrading the refineries to meet specifications from Euro 2M to Euro 5 specifications requires significant changes to the existing plant. This poses various challenges to the design team. In this paper, the challenges are discussed as lessons learnt for future brownfield projects.

Case Study Boundary Definition

At the beginning of the project, it is crucial to understand the gaps in the processing capability about the difference between Euro 2M and Euro 5 Diesel specifications. Table 1 provides the detailed specification for Diesel Euro 5 as mandated in Malaysian Standards.

Some key specification changes are Sulphur Content, Nitrogen Oxide (NO) Content, Particulate Matter (PM) Levels, and Cetane Number, as Table 2. Table 2 summarises the differences within the Diesel specifications that affected the case study project.

Current available crude oil higher in its sulphur content imposes more considerable challenges towards refineries in meeting Diesel Euro 5 specification especially to existing Diesel Hydrotreating Unit.

PROCESS DESIGN CHALLENGES

This section discusses the process design challenges faced while upgrading the refinery complex in meeting Diesel Euro 5 specifications.

Documentation and Basis

With most brownfield projects, especially for refineries operating for more than 20 years old, engineers would find retrieving existing document a challenge.

Table 1 Diesel Euro 5 Specification [1]

Properties	Minimum	Maximum	Test Method
Acid Number, mg KOH/g	-	0.25	ASTM D-664
Ash, mass%	-	0.01	ASTM D-482
Carbon Residue on 10% Bottoms, mass%	-	0.20	ASTM D-4530
Cetane Index[a] or Cetane Number[b]	49 49	- -	ASTM D-4737 ASTM D-6890
Cloud Point, °C	-	19.0	
Copper Corrosion (3hrs @100°C)	-	1	ASTM D-130
Colour	-	2.0	ASTM D-1500
Density at 15°C, kg/L	-	0.845	ASTM D-4052
Electrical Conductivity, pS/m	50	-	ASTM D-2624
Flash Point, °C	60	-	ASTM D-93
Kinematic Viscosity at 40°C, mm^2/s	1.5	5.8	ASTM D-445
Lubricity, µm	-	460	ASTM D-6079
Palm Methyl Ester (PME) content[c], %(Volume/Volume)	-	7.0	ASTM D-7371
Physical Distillation at 95% recovered volume, °C or Simulated Distillation at 95% recovered mass, °C	- -	360 386	ASTM D-86 ASTM D-2887
Polycyclic Aromatic Hydrocarbons, mass%	-	8.0	EN 12916
Sediment by extraction, mass%	-	0.01	ASTM D-473
Total Sulphur, mg/kg	-	10.0	ASTM D-5453
Water by Distillation, V%	-	0.05	ASTM D-95

[a] Cetane Index is not applicable for biodiesel blend
[b] Derived Cetane Number
[c] PME shall meet the requirements of MS 2008

Table 2 Diesel Euro 2M and Euro 5 Differences

Diesel	Sulphur Content	NO Content	PM Levels	Cetane Number
Euro 2M	500 ppm wt	730 mg/km	100 mg/km	49 min
Euro 5	10 ppm wt	180 mg/km	5 mg/km	51 min

Some documents were either obsolete, unavailable, or illegible. With this challenge, further validation and investigation were required to strengthen the basis. For example, unavailable equipment datasheets required retrieving from the original manufacturer, which took time. In some cases, original equipment manufacturer companies have ceased business. Hence original equipment design document was no longer available. To overcome this, a name plate at the site could be referred. However, it had limited information and would not have the details of the internals. Inspection and performance test records would also need to be referred for the latest equipment condition and performance information.

In some cases, the latest basis, documents and drawings required could be found in another plant change and project documents. Approved and agreed upon assumptions had to be made between design engineers and the owner.

Design Standards

The other challenge faced in the brownfield project was that some of the design standards used in the existing refinery would be different to the current standards. For example, in the case of the flare system, the design pressure was 3.5 barg. The current standard requires 7 barg. New designs would adopt the current standard, but it would be costly to change the older existing equipment to current standards. To overcome this, philosophy has to be set upon which standards to be used, i.e., in general, all equipment, be it old or new, were designed to current standards. However, in cases where major changes were imposed to existing equipment and where not feasible, risk assessment was conducted to reduce the risk to As Low As Reasonably Practicable (ALARP).

Licensor Technology Selection

In the case study for Diesel, Euro 5 specification required a hydrotreated desulphurised Diesel of < 10 ppm wt compared to the previous approximately < 500 ppm wt. Another Diesel Hydrotreater Unit (DHT) was required to achieve such specifications, and for the increased hydrogen demand required supplementing DHT technology, a new Hydrogen Production Unit (HPU) was required.

Since DHT and HPU are licensor proprietary units, the evaluation of licensors was done to evaluate the technology proposed and the units' performance. The challenges faced was that owner was more comfortable with the original licensors of the previous DHT and HPU units. To overcome this, technology selection was done to know the available technology by other licensors and compare parameters such as yield, plot space, number of equipment, guaranteed specifications, relief load, utility requirement, etc. Technology risk assessment was conducted on each of the Licensors.

Process Simulation

For a refinery project, linear programming may be developed at an early stage in the feasibility study. However, that was not sufficient in basic design, as detailed heat and mass balance were unavailable with linear programming models. A full scope process simulation needed to be developed to reflect tray to tray modelling and determine the brownfield unit capability and constraint in processing the new crude mix whilst ensuring that the product specifications were met.

A base case simulation model was developed based on actual performance test run data. The challenge was to establish the current performances/efficiencies of the plant brownfield equipment. This was done by matching the simulation process conditions (temperature, pressures, flow rates, and qualities) with the test run data. Once the current equipment efficiencies were established, the simple assay was synthesised to generate the future design blend.

Another challenge faced was in the optimisation of the simulation model to process the new crude mix to produce clean fuels. A simulation model which incorporated consideration of pressure drop across equipment and heat integration was developed. This required reference made to datasheets and specifications. The inadequacy of current equipment was then identified. Detailed discussions with plant personnel were vital to ensure that the simulation reflected current plant operation. New equipment was added to the simulated process stream during revamp projects, which were not updated in the main document.

Test Run Data

For brownfield, a Performance Test Run (PTR) is conducted to verify the current performance and efficiency of the existing equipment. PTR data sets a basis of current performance for the brownfield project.

The first challenge was to gather sufficient data from plant PTR. It was imperative to obtain test run data within the same time frame before the design stage. This was where refineries did not have the luxury of time and window to perform PTR for the entire refinery, resulting in test run data at different times for different units. Planning to include time to deliver PTR in the project schedule was therefore essential.

Another challenge faced with test run data is the data itself. Upon further analysis, some data were questionable and required further validation as there were associated instrumentation and troubleshooting issues. Further discussion with plant personnel was conducted to evaluate whether the test run data was relied upon. In some cases, test run data at a different period was used.

Evaluate Existing Equipment Performance

Existing equipment adequacy needs to be assessed. A screening exercise was done by comparing the required equipment capacity against its design and current PTR values. Equipment was designed with margins provided by the designer and manufacturer. In brownfield projects, the challenge was that these margins might have been used up during various upgrading or debottlenecking throughout the plant life. To ensure that the eaten-up margin was considered in the design, a thorough check was conducted to incorporate all upgrading and debottleneck to a unit/equipment when equipment evaluation was performed.

Changes in feed, hence stream properties, also impacted equipment. Capacity comparison alone was not enough. Density affects almost all equipment, such as pumps, compressors, and column performance. Significant changes in viscosity affect pump performance, and the changes in gas molecular weight affect the compressor performance.

For rotating equipment, an increase in flow or duty, resulting in higher power demand, may also change to the driver. The tricky part of changing or upgrading equipment was the available plot space and access. Therefore, keeping track of the history of modifications and revamps performed on the equipment, e.g., the column, was vital to ensure that the column adequacy was evaluated accordingly.

Underground facilities were always an issue during the Detailed Engineering and Construction phase. Some were known too late and caused changes to the design, and documents had to be reissued. Thorough underground scanning of all areas affected by the Project, including at pipe rack routing. 3-dimensional laser scanning for the above-ground was done to avoid field engineering changes to avoid clashes as some documents were not updated. For example, underground piping that was not known early on resulted in changes to the shape of the Effluent treatment plot later during the detailed engineering stage.

Utility Requirement

Adding new equipment and unit in the refinery complex had increased overall utility consumption. As a start, utilising existing available utilities such as electric power, instrument air, nitrogen, cooling water, water, and steam would reduce additional CAPEX due to installing a new utility system/equipment. The overall utility balance for the whole refinery complex was required to be revisited to ensure adequate utility balance was utilised. The addition of new utility equipment or system will be opted if new utilities demand were higher than the available utility balance.

For this case study, several challenges were faced before the finalisation of the overall plant utility balance.

1. Insufficient existing transmitter
   Challenges in getting overall existing utilities consumption were faced as insufficient existing transmitters to monitor utility consumption at interest locations. This hindered the design team in validating the existing utility demand.

2. Uncertainty on actual utility demand
   One of the major concerns in the brownfield plant was the uncertainties of actual utility utilisation. This may be due to additional consumption from new equipment added through small plant changes and improper usage of utilities by field operators for other means. These had eaten up the available design margin provided during the original design, which was sometimes not documented in the latest utility balance.

3. Obsolete references
   Throughout the operating years, there was a lot of small plant change which resulted in modifying the existing utility system. However, some modifications such as utilising future tie-in valves and small-bore piping/valve were made in utility systems were often overlooked and not captured/updated in the plant as-built document such as Piping and Instrumentation Diagram (PID), Process Flow Diagram and operating manual. This would impose change order during the construction phase if the verification were not done during the basic engineering phase.

Inadequacy of Existing Flare System

A flare system is an arrangement of piping and specialised equipment that collects hydrocarbon releases from relief valves, blowdown valves, pressure control valves, and manual vents and disposes of them by combustion remote and safe location [2]. Given this, the flare system in the existing refinery will be directly affected due to the addition of a new DHT unit, HPU and other additional equipment, which contribute to increased flare capacity.

Below were challenges faced throughout this case study and mitigation proposed in overcoming the challenges,

1. Compatible existing flare system metallurgy
   In this case study, the existing refinery was having two types of flare systems that handle non-sour flare and sour flare gas. Every relief streams were assessed to determine their relief destination to ensure the selected flare systems were compatible with the relief properties. Relief from sour services equipment was routed to a sour gas flare system, which had Stainless Steel as the system material to avoid corrosion attack due to the presence of H2S in the flare gas.

2. Higher back pressure and inadequacy of existing flare header and sub-header
   The increased number of equipment and unit had contributed to increasing load to the relief system. This lead to higher backpressure of the flare system during relief and inadequacy of header and sub-header. Before any mitigations were proposed assessment or adequacy check of these flare system components was performed to ensure the existing refinery complex is safe to operate after Diesel Euro 5 project was executed.

   a. Flare header and Sub-header
      The flare header and sub-headers adequacy were checked based on the latest governing design scenario of the flare system. Mach number not exceeding 0.7 was used as one criterion for assessing the header and subheader adequacy. If the calculated Mach number was exceeded, several mitigation actions were implemented, such as increasing the sub-headers size, introducing a High Integrity Pressure Protection System (HIPPS) or adding a new sour gas flare system. The selected mitigation would be based on the most feasible and economical option.

   b. Flare knock-out drum and associated pump
      With the new load, existing and new flare knock-out drums shall be capable of meeting project requirements such as the knock-out drum being economically sized, located upstream of subsonic flare tip, and designed to disengage entrained droplets of 300 µm [3] and more considerable. Associated knock-out drum pump was checked to ensure an optimised liquid transfer out facility was provided.

   c. Fuel Gas Treatment Skid for Pilot Burner System
      In freezing the basis of fuel gas feed for the flare pilot burner system, the plant owner usually uses the old fuel gas composition without realising that fuel gas composition fluctuates depending on refinery feedstock over the years. For example, there was an increase in water content in fuel gas which was based on operators' feedback and frequent sampling. These changes had been incorporated in the design to avoid design change during the detailed design phase.

3. Finalisation location of the new sour flare stack
   A new flare system was added due to sour vapour relief, and the existing sour flare capacity was inadequate for the increase in demand. Finalising the new flare stack location had been a challenge to the engineering team considering the limited area available in the refinery complex. To finalise the location engineering team needed to perform heat radiation study to ensure resultant heat from new and existing flare were within the acceptable limit, which inline with existing refinery philosophy where new equipment should be located outside of 3.15 KW/m^2 heat contour.

Offsites

Offsites requirement needed to be assessed carefully due to the increase in demand for offsite facilities. This includes tank (feed, intermediate, and product tanks) inventory adequacy, chemical injection facility, drainage, wastewater treatment system, firefighting & protection system, and export facility.

Most of the offsite's package scope and detail requirements were not address in the project specification. Instead, the project team only referred to codes & standards. This could be mitigated by including the clear requirement in project specifications.

Minimum information such as expected equipment in any package unit shall be listed out (bare minimum requirement as per existing) or else, the existing package shall be the precedence, and the new package shall be off-par and better off than the existing package.

Plot Constraints

There were no luxuries of the area to accommodate new units and equipment in the brownfield refinery complex. With limited space available, several challenges faced by the engineering team in locating new equipment in the brownfield area are discussed as below:

1. Meeting the hydraulic requirement
   A common challenge for brownfield refinery was to meet hydraulic requirements specified in heat and material balance. Piping hydraulic loss/gain calculation performed before finalisation of equipment location. In some cases, where new equipment required to be added quite far from the source of pressure, enlarging the interconnecting pipes or adding pressure booster equipment such as pumps and compressors was used to ensure the fluid can be fed the following processing equipment.

2. Minimising heat loss
   In this case study, a new furnace was required to be added due to the limited capacity of the existing furnace. Considering there was inadequate space in the existing unit plot, this new furnace was located quite a distance from the required processing unit. Heat loss calculation had been done to ensure the required temperature for the processing unit was met. To minimise heat loss, a comparison was performed between insulating the interconnecting line or having a higher capacity of furnace would give more economical given life cycle cost.

3. Maintaining existing refinery zoning
   Maintaining existing refinery zoning was a challenge considering an inadequate plot within the brownfield area to accommodate new equipment. The existing refinery zoning such as process area zone, utility zone, flare zone, storage zone and non-process area zone should be maintained. For example, the DHT unit had been located within the processing unit near to existing DHT unit. The new sour gas flare was located adjacent to the existing flare system while meeting the resultant heat radiation requirement. Considering there was not much space available at the existing utility system, the new utilities required for this case study were located within the available safe area location and declared a new utility area. The newly added equipment would have harmonised interaction with existing facilities and reduce operation/maintenance complexity by maintaining existing refinery zoning.

4. Adequate coverage for firefighting facilities
   The addition of a new DHT unit, additional utilities, additional intermediate tank and new equipment will change the overall layout of the existing refinery complex. These had imposed a challenge to the design team to locate new equipment to ensure they were adequately protected and would not affect the existing fire protection to existing equipment. A proper assessment of the plant-wide road network system shall be performed to ensure that firefighting response duration would not be affected. Extension of firewater ring main and foam network was done to ensure all new unit and equipment added are sufficiently protected as specified by National Fire Protection Association (NFPA) and another international standard.

5. Constructability issues/constraint
   There were not many constructability issues faced for a new DHT unit added, considering there was adequate empty plot to locate this unit in the existing refinery complex. However, challenges are faced for newly added equipment that requires to be added within the existing plot. Detailed assessment of existing underground facilities such as piping/electrical and instrumentation cables and structure needs to be identified through existing underground drawing, underground scanning, and a certain extent that manual excavation must be performed to ensure the existing underground facilities do not be affected during construction. In addition, an assessment of above-ground equipment, structures, pipes and

cables were required to be performed to ensure the installation of the new equipment would not affect the integrity of existing facilities. In certain scenarios, some of the piping and cables required to be rerouted to accommodate the installation of new equipment and ease the construction activities.

6. Compliance to Codes and Standards
   This challenge was faced when adding new equipment in the brownfield plot while meeting the requirement as recommended in Global Asset Protection (GAP 2.5.2: Oil and Chemical Layout and Spacing). In some scenarios, where the added equipment did not meet the spacing requirement as per GAP 2.5.2, a risk assessment had been performed to ensure the selected location of the new equipment had a tolerable safety risk with several mitigations in place.

SUMMARY

In summary, more challenges were seen in executing Clean Fuel projects to brownfield refinery as compared to greenfield plants. The scope boundary of the project and its impact on existing units had to be established. Existing documents need to be retrieved, and in the absence of reliable information, more verification work would have to be done. Performance test runs on existing refinery units has to be done, which sets the basis of the project. Interaction between existing and new units will have to be assessed. Existing equipment adequacy in process, utilities, and offsites units must be evaluated before designing new equipment. Plot assessment should also be performed concurrently with the finalisation of the process scheme.

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