ETHYLENE PLANT REVAMP – TITAN'S EXPERIENCE

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INTRODUCTION

As margins rise and fall, as is expected in the ethylene industry, the decision to revamp existing plants versus building a new grassroots plants changes. When margins are high, new grassroots plants are built. When margins are lower, revamps of the existing plants may be the preferred option to increase current profitability. The goal is to optimize present operations by utilizing personnel and technology to improve product recovery and reduce energy consumption. A revamp of an ethylene plant can be initiated due to any number of reasons. These could include a combination of health, safety and environmental requirements, expansion of nameplate, and process improvements.

The chosen objective will be the driving force to sustain the momentum of the exercise. The first step in a revamp is a plant load test. This test needs to be conducted to establish the baseline scenario as well as to test the available margins in the system. Accurate data will need to be collected from this data or else, the effort put into the load test will be in vain. A proper test run is not a random affair to be carried out on the spur of moment. Test runs require forethought, planning and proper coordination to yield useful data.

Our goal is to cover the purposes of a revamp, the required planning and preparation for a load test, execution steps and a direction on where to move on after the load test. The authors will share Titan's experience in conducting a high load test, especially in the foundation framework established and the challenges faced during execution. The load test conducted at Titan's Cracker 2 was a success in identifying unit limits points and guiding future expansions.

OBJECTIVES OF THE REVAMP

When an ethylene plant has reached a degree of steady-state operations, it is best not to make any major adjustments in the operations of the unit. Being tightly integrated for efficient energy usage, there are no clear-cut divisions between the various sections of the plant. A minor upset in the demethanizer tower can propagate its effect to a swing in the furnace feed, resulting in a coil outlet temperature increase, and eventually more methane in the cracked gas to the demethanizer unit. Thus, a process engineer must have a very strong direction and objective before embarking into a revamp exercise.

The driving forces behind a revamp exercise may be a combination of the following items: safety and legislation requirement, expansion of nameplate, process improvement and deviation from original design basis.

Health, Safety and Environmental Requirements

In Malaysia, the Government passed laws through the Occupational Safety and Health Act (OSHA) as well as the Environmental Quality Act (EQA). Health, safety and environmental concerns should always be regarded equal to any economic consideration, if not of a higher priority. Certain aspects of safety and operability that has been overlooked during the Hazard and Operability Study (HAZOP) stage need to be addressed seriously and immediately. The required change may be small but sometimes reengineering of a certain unit is required.

Examples of revamps that require reengineering are systems that use chlorofluorocarbons (CFCs) as refrigerant, revamp of wastewater treatment system to meet the EQA requirement and redesign of the piping to a multi-stage compressor to reduce the noise level. Phasing out the use of nickel bed for methanation and copper beds for peroxide removal are also good examples as both catalysts have the potential of serious detonation and toxicity.

Expansion of nameplate

As plastic manufacturers continue to find new uses of polymers, the demand for its most basic building block namely, ethylene, propylene and other monomers, will continue to escalate the price of the monomers. This is a huge incentive for ethylene manufacturers to expand their nameplate in order not to lose out in the race. Building a new cracker will require massive initial capital, which may not be a feasible option with the Southeast Asia region still recovering from the lows of the 1998 currency crisis. Debottlenecking the existing unit becomes the most viable option to carry out.

Process improvement:

An ethylene plant being tightly integrated is the fruit of labor of the chemical engineers behind the original design. However, when the integration became the "destabilizing factor" of the unit causing lower on-stream time and potentially limiting the plant load, then, it became a necessity to forgo the original energy optimization factor to improve the on-stream time of the plant. For such scenarios, the concerned process engineer has a duty to evaluate if investing on a new refrigerant compressor to break the integration is feasible in the long run. Pinch analysis carried out may in fact shows the energy may be pinched from other process streams, which may not cause instability somewhat like the originally pinched stream.

As a plant ages, it may move to a state where it is so inefficient in energy consumption that it become uneconomic to run the plant anymore. In such revamps, other than replacing the old inefficient equipments, it become critical to test out newer technology that promises better energy efficiency.

Deviation from original design basis:

The market drives the need to change. In an ethylene plant, it is a common practice to recycle any lower value product back to the furnace to crack to extinction or to sell at heating value as fuel oil. For example, by integrating an aromatic recovery plant to the existing ethylene unit helps to add value to the pyrolysis gasoline stream of the unit. With relatively low utility cost, separating out the benzene, toluene and xylene fractions can tremendously increase the value of pyrolysis gasoline.

Feedstock deviation may also be the reason of a revamp. The ability to crack different feedstocks as margin change gives the plant additional flexibility. To process different feedstocks than what was originally considered in the design will require modification of the plant to absorb the changes in product distribution.

PRELIMINARY STUDIES

Before embarking to carry out a load test to move to uncharted territory beyond the perimeters of the design, it is essential to check the maximum available capacity based on design specifications and operating experiences.

Capacity check for theoretical bottlenecks

Information of maximum capacity of the equipment such as the compressor shaft power, tray liquid holdup, exchanger available heat transfer area, flow through control valves etc., should be tabulated before hand to know the available margins. Then, as the flow through the unit is scaled up to 110%, 120% and 130% above the design margins, theoretical bottlenecks can be identified. Based on this alone, a list of required modification can be generated for each overcapacity case. Preliminary cost estimation can also be made to give the management a direction whether to proceed or terminate the revamp effort.

Past experiences of reference plant:

More often than not, another ethylene unit that uses the same technology will serve as a good reference to identify potential bottlenecks. In Titan Petrochemicals, as the two ethylene units share the same Stone & Webster Advance Recovery System (ARS) technology, the 7 years of operating experiences of the No. 1 Cracker became the best reference in the Debottlenecking effort of the No. 2 Cracker. In return, any revamps implemented in the No. 2 Cracker may similarly be applicable to the No. 1 Cracker.

Acceptance Test Run Data:

Being relatively new, the Acceptance Test Run (ATR) data of the No. 2 Cracker became the best available baseline data of the unit. Any deviation from design that has been identified should be resolved before hand. In short, the unit should be optimized to best possible conditions before proceeding to the load test.

PLANNING THE LOAD TEST

The high load test is the climax of the debottlenecking study exercise. However, such exercise will not be a success without detailed planning and coordination. United and cooperative effort of all relevant parties is critical. Operators, process engineers, maintenance personnel, engineering personnel, lab chemists, planning analysts, shipping personnel, safety personnel as well as the top management, each plays a crucial role that will determine the success or failure of the load test. Communications between all relevant personnel need to be fast, clear and objective. Below summarizes the framework that Titan has established for a successful load test.

System boundary:

It is important to define the system boundary within the ethylene unit. Each section of the plant required different scenarios to test the limits. For example, the demethanizer section will need a light feedstock cracking at high severity whereas, the backend hydrogenation reactors will need a heavy feedstock cracking at low severity. It became clear that the cracker needed to be divided into individual sections and different modes of operation were needed to fully test each of these sections. Acquiring the suitable feedstock to test each section eventually decided the production schedule of the entire Titan complex for the few months of load test.

In the No. 2 Cracker load test, the plant was divided into furnace, quench, compression, depropanizers, ethylene recovery, fuel gas system, propylene recovery, C4 hydrogenation, gasoline hydrogenation, aromatic plant, utilities and the cryogenic storage terminal.

Manpower and expertise:

Manpower is the greatest asset of an ethylene unit. For the revamp exercise, Titan has formed a multi-discipline taskforce to steer the relevant personnel through the load test. Beginning with a small team of process engineers, operations engineers and superintendents, the task force grew in size as the expertise of other discipline like maintenance support, planning analysts, lab chemists etc, was required.

To further strengthen the team, process engineers from the constructor of No. 2 Cracker, JGC Corporation as well as Titan's sister company, Westlake Petrochemicals were engaged for technical support. Contract staffs from Yangtze Petrochemicals (YPC) and Shanghai Petrochemicals (SPC) of China complete the team with their vast operations and technical expertise.

Communication:

Communication was the essential point of the entire revamp effort. The speed of disseminating information to all relevant parties was important to keep the momentum of the exercise. Keeping all parties informed of the progress also maintained active participation from all quarters as well as establishing the much required 'esprit de corp'. Having one dedicated channel of communication enable constructive views to voice across the borders of individual departments as well as the layers of management. Thus, this cuts down the time required for decision-making and major instructions can be disseminated promptly.

In Titan's exercise, utilizing the local area network as backbone of information, daily activities and progress were summarized in an email message, which was distributed to all relevant personnel from supervisory level to top management level. A daily discussion session also served as a venue to discuss the observations made as well as to plan for the next move.

Safety and training:

To prevent any industrial accidents as well as process upsets, detailed written procedures for the debottlenecking exercise were prepared by the united effort of operations and the process engineers. Every section of the plant as well as every intended move was elaborated and discussed in a HAZOP fashion. Briefing and training of the operators were carried out to provide them with the understanding of the objectives, actions intended, potential bottlenecks to look out for as well as contingency plans when one is encountered.

Equipment Preconditioning:

It is necessary to have the process units to be in a good condition before hand or otherwise, a false bottleneck may be hit and severely hamper the entire load test effort. Among the necessary preconditioning required are:

- all critical instruments to be zeroed and calibrated.
- furnace zones with high tube metal temperature and/or coil pressure ratio to be decoked.
- sufficient standard gas of analyzer in field and at laboratory to be made available.
- molecular sieves and hydrogenation reactors that are in end-of-run condition to be regenerated.
- spare unit of shell and tube heat exchangers to be in clean condition and ready to be commissioned.
- filters, strainers and coalescers to be cleaned or replaced if plugged. Spares to be available in the warehouse
- laboratory instruments like gas chromatography units to be calibrated and conditioned.
- sufficient sampling bombs, fittings and tubings to be made available.
- sufficient storage tank space need to be made available.

Feedstock management:

As discussed above, different section of the unit requires a different quality of feedstock. Suitable feedstocks need to be purchased and blended to give a consistent feed to the cracker. The timing of the feedstock shipment as well as the blending of the feedstock need to be carefully coordinated to simulate the desired effect at the cracker. Feedstock management dictated the critical path of the entire load test schedule.

Product management:

During the high load test, higher than nameplate production will be recorded. The planning analysts have to project the extra olefins, aromatics and fuel oil produced during the event of high load test. Arrangements have to be made to ensure the extra production to be sold and shipped.

As the Titan complex is very much integrated, the stability of the downstream polymer plants is crucial as any sudden outage of a downstream unit will immediately cease the high load test. Inter-plant communications is also vital to allow the olefin consumers understand the objective of the load test. Any planned shutdown of the polymer unit has to be carefully planned as not to coincide with the intended load test.

Process simulation:

Using simulation packages like Aspen Plus, Hysim and Pro II, the high load scenario can be simulated. This is useful in investigating the maximum liquid load tolerable by a concerned tower and how the mode of operations should be adjusted to maximum throughput. Simulation also provides a guide on how to operate a unit without going off spec.

Data collection system:

From previous experience, it was found that manually recording data in log sheets is both time-consuming and counter-productive. In No. 2 Cracker's high load test, data collection was accomplished using the InfoPlus 21 software provided by Aspen Technology. Data from the distributed control system is continuously recorded by InfoPlus 21 and extracted into a Microsoft Excel spreadsheet for easy reference.

TO THE LIMITS

The high load test was divided into various stages according to the system boundary identified. Consistent feedstock was planned and mode of operations was adjusted to fully test the intended section of the plant but meanwhile, also not to upset other process units.

Furnace Load Test:

The furnace being the most expensive piece of equipment in the plant was the first to be tested. A furnace was selected to conduct the test. The two cracking zones were fresh from decoking. The idea was to maximize the feed to the two zones. As feed was steadily increased well above the design rates, inspection by the reliability engineers were carried out to check the mechanical and metallurgical integrity of the furnace. The test was declared over when the feed valve of the naphtha, dilution steam or fuel gas is wide open or when a mechanical/metallurgical limitation is faced.

Hydraulic test of critical towers:

After the limitation at furnace is known, it is important that the recovery section can sustain the similar load without compromising on the product quality. For this objective, hydraulic test was carried for the critical towers like C2 and C3 Splitter. Reflux rates were steadily increased to test the maximum allowable liquid load of the trays. The exercise was also the best time to test the tray efficiency of the concerned tower. This piece of information helps to correct the simulation models to match the actual operating conditions.

Increase steam-to-oil ratio:

The design margin of the quench section is typically defined in terms of the steam-to-oil ratio. This reflects the maximum heat removal capacity of the quench section. As such, increasing the steam-to-oil ratio at furnace operations is the best method of testing the capacity of the quench section. At the same time, it is also a good time to study the effect of viscosity change in quench oil to the heat transfer performance of the unit in the quench oil circuit.

Increase furnace feed-rates:

The cracked gas compressor unit is also one of the most expensive equipment in an ethylene plant. In many ethylene units, the cracked gas compressor is the biggest bottleneck. The best way of testing the capacity of the machine is by increasing the furnace rates to give it a uniformly distributed cracked gas. Using minimum flows to load up the compressor will only serve to test the maximum shaft power available but gives very little clue as to what plant load the machine can withstand.

As the furnace feed rate is increased, the recovery sections of the plant are also tested. If the cracked gas compressor is not biggest bottleneck, then, a limitation will be reached when one of the product splitters is flooded.

Increase severity:

The limits of the fuel gas and hydrogen recovery section are not likely to be hit before the cracked gas compressor or the product towers. Thus, to test this section of the plant will require using highly paraffinic naphtha cracking at high severity. Using tools like SPYRO, yield engineers can predict how the severity can be changed by raising the coil outlet temperature. However, care has to be exercised not to produce acetylene to a degree beyond the capacity of the front-end acetylene converters.

As the saturation state of the chilling train is established by maintaining the fuel gas pressure using a series of pressure control valves, it is important to pay special attention to these few control valves. A limitation is defined as when there is too much fuel gas that any of the control valves went wide opened. Other possible conditions are when the ARS dephlegmators and runback condensers do not have sufficient capacity to handle the extra fuel gas flow or simply when the maximum continuous speed of the expander/recompressor or the refrigeration compressor is reached.

Change feedstock:

At the other end of the spectrum, the maximum capacity of the back-end hydrogenation units should be tested using a low paraffinic naphtha cracking at low severity. The yield engineers once again need to define this region of low severity in terms of coil outlet temperature. While the hydrogenation reactors may not actually pose a limitation, more often than not, the limitation will be observed in the associated fractionators like the debutanizer, depentanizer, rerun tower, distillate stripper and etc.

Mechanical performance check:

During the high load conditions, it is important that the mechanical integrity of the turbines and compressors are not compromised. Being the most expensive equipment after furnace, the performance of the turbines and compressors must be critically evaluated. In the No. 2 Cracker's load test, the appropriate turbine and compressor vendors were brought in to check the mechanical integrity of the major rotating equipments.

DATA ANALYSIS

All DCS data collected were counter-checked against local readings. Any discrepancy observed was critically discussed to determine the correct instrument reading. After laboratory analysis data were received, mass and energy balance across the entire unit were made. Process simulations were run to determine if the equipments have indeed hit a limitation.

Identification of bottlenecks:

The equipment in the cracker is divided into different categories, namely furnace, tower, compressor/turbine, pump, heat exchanger, drum, reactor, packaged equipment and control valves. A comparison table of expected maximum capacity vs. actual load observed was made. This helps in evaluating if the equipment has reached its capacity or how much margin is still available.

Debottlenecking proposal:

A good revamp proposal will have a list of engineering and process changes required as well as the procurement and installation schedule. As the cost of modification of furnace, turbine and compressors will significantly increase the overall revamp cost, a critical evaluation of the highest possible throughput without modifying these equipment must be conducted. Several case of revamps would be proposed for economic evaluation.

Instead of just scaling up the existing setup, the process engineers have a choice of applying some alternative technology, which may be more cost-effective. This is where the experience of the process engineers come into play. In Titan's task force, people with knowledge of various background was assembled. In between the engineers, we have an array of experience in three different licensees' ethylene plants. Some also have background of refinery as well as polymer plants. This team of engineers will select the best possible technology to apply based on the criteria of economic feasibility, safety, operability and availability.

WHERE DO WE GO FROM HERE?

The natural progression of the debottlenecking study will be costing of the engineering and process changes proposed. From the costs presented, the management will be able to evaluate the feasibility to invest in a revamp. The following summarized the direction for the task force and management to proceed.

- Costing
- Approval
- Detailed Engineering
- Procurement
- Tie-ins
- Implementation

CHALLENGES

The high load test could not have been accomplished without opportunities or challenges along the way. However, with the swift decisions of the team, every crisis can be turned into a blessing in disguise. The following summarized two challenges faced by Titan and how the task force has worked together to make the best out of the situation.

Consistency of feedstock

Unlike some ethylene plants, that receive dedicated naphtha of a consistent quality from a refinery, Titan buys their naphtha from various sources. Without knowing the naphtha quality beforehand, it was difficult to plan the schedule of the entire test run. The size of naphtha storage area as well as the shipping piping configuration further complicate matters. Careful planning was required to blend a consistent quality of naphtha to last at least 7 days of operations so that the yield data acquire will be valid.

Being able to purchase naphtha from various sources enabled Titan to acquire naphtha of different density and paraffinic contents. Although this complicated the planning to ensure consistent feed quality, it provided the flexibility to test different sections of the plant with different naphtha quality. An ethylene plant with one dedicated feedstock from adjacent refinery will not have this flexibility.

Integration of Titan Complex

The Titan complex consists of two ethylene units, three polyethylene units and two polypropylene units. The seven plants are integrated in a symbiotic manner – one cannot do without another. It was crucial that during the high load test that the polymer plants are consuming the olefins that were produced. However, the outage of the downstream plant provided the team an opportunity to test the plant's ability to produce cryogenic ethylene.

The refrigerant compressors went to maximum continuous speed and the effect was felt by all the ethylene and propylene refrigerant users. Such scenarios would not have been witnessed if there were no outages of the polymer plants.

CONCLUSION

A high load test leading to a revamp exercise is not a simple exercise. The people involved in the revamp study must begin with an objective. Preliminary studies to be conducted based on the objective set. Planning and coordination work has to start months ahead of the intended high load test. Much equipment preconditioning must be carried out.

Process engineers involved must establish the system boundary within the ethylene plant and set the strategy as to how to test each section effectively. A multi-discipline task force will be most beneficial with pooled experiences from various sources. Communication between all relevant personnel has to be fast, clear and objective. As a high load test proceeds, some unexpected outturn is sure to happen and the task force faces the greatest challenge of reversing the tables and making every stumbling block a stepping stone. The revamp load test at Titan Cracker 2 was a success in finding unit limits and guiding the direction of future expansions.

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