Implementation of Process Hazard Analysis at SINOPEC-SABIC Tianjin Petrochemical Company Ltd, China

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Abstract

The SINOPEC and SABIC joint venture in Tianjin, is a large petrochemical complex including eight plants that produce ethylene, linear low density polyethylene, high density polyethylene, polypropylene, ethylene glycol, ethylene oxide, phenol, acetone, butadiene, MTBE, and other products. The units started up in 2009. SABIC introduced their safety, health and environment management system which includes their best practices in process safety and initially have focused on completing the necessary PHAs. In addition, the local government is increasingly adding more regulations such as requiring adherence to SIS standards, and requiring PHAs and LOPA. This paper provides insights into the challenges faced while implementing process hazard analysis at SS-TPC and shares lessons learned on how to get best practices implemented in such joint ventures and across very diverse cultures.

Background on SS-TPC

SS-TPC is a joint venture established in 2009 with 50:50 partnerships between SINOPEC and SABIC; it is located in Tianjin city, China. SS-TPC produces 4.2 MTPY of various products, and it has a workforce of more than 3000 of direct hire and contractors.

The process plants at SS-TPC currently are:

- Ethylene (ET)
- MTBE & Butadiene (BD/MTBE)
- Phenol/Acetone (PHAC)
- High Density Polyethylene (HDPE)
- Linear Low Density Polyethylene (LLDPE)
- Polypropylene (PP)
- Pyrolysis Gasoline (DPG)
- Ethylene Oxide & Ethylene Glycol (EO/EG)
- Tank farm and Storage
- Utilities

At the time of construction, a process hazard analysis (PHA) for the facility was not mandated for the design period for these processes. Some plants had a PHA during the process development phase (as required by licensor) and others did not. None of the processes had a complete, initial PHA before startup and none have had the initial PHA completed following startup of the plants in 2009. In 2012, SABIC safety, health and environment management system which includes best practices in process safety were introduced at SS-TPC and the first major action item was to conduct the initial PHA for all SS-TPC plants. A detailed plan was developed in 2012 for completion of the PHAs of the eight operating plants and the auxiliary process areas. SS-TPC also began development of a systematic, detailed PHA procedure in 2012.

Organizing for PHA Implementation in a multi-national JV

Before the PHA process began at SSTPC, some forms of risk assessment were used to help manage risk; these included Job Hazard Analysis and Safety Checklist in the high risk areas and high risk jobs. Further, a management of change (MOC) process was implemented after startup of the unit; for these MOCs, SS-TPC staff conducted risk assessment on the critical parameters and critical procedure changes by using a method similar to What-if. The assessment team for these reviews was made up of process/safety/mechanical engineers and operators. But it was recognized by SS-TPC staff that these assessments that were done during the MOCs were not rigorous, when compared to a PHA approach.

Defining Process Hazard Analyses for SS-TPC

Of course, a PHA[1] is a systematic approach for identifying, evaluating and controlling process related EHS hazards of SS-TPC plants/systems. But what does this mean to plant staff? To establish understanding of PHAs and awareness of the value, many changes were necessary at SS-TPC. First, SS-TPC, helped by their partner SABIC who has considerable experience in PHAs, sought out the best resource for providing PHA training and for leading and documenting the PHAs. SS-TPC chose Process Improvement Institute, Inc. (PII) for this assistance. This selection was in no small part due to the assistance provided by PII staff to many global petrochemical companies for more than a decade, and because PII also helped developed the standards for process safety, including PHAs worldwide. SS-TPC decided that PII had considerable background of how to find hazardous scenarios during all modes of operation.

Implementation Strategy

So, the basic definition of PHA developed at SS-TPC, mimics the one from CCPS, in the 3rd edition of the *Guidelines for Hazard Evaluation Procedures* (2008)[1], which includes a rigorous PHA of all modes of operation and analysis of all damage mechanisms and human factors. The team composition and approaches for HAZOP, What-if, Checklist, and also adaptations of these to non-routine modes of operation (as noted in Chapter 9 of that book), all followed CCPS guidelines (and also, Bridges[2, 3])

The major challenges faced by SS-TPC were:

- SS-TPC staff required more experience in conducting PHA systematically.
- Many process safety information (PSI) developed during the detailed design phase of the project were only in Chinese; these documents had to be translated into English for the PHA. And some information was missing.
- Language is another challenge for PII and SS-TPC staff. Interpreters help to keep the meeting moving efficiently.
- Some plants had a PHA during the process development phase and others did not. The PHAs commissioned for PII to lead would each be a complete ReDo.
- The team members have their normal jobs of keeping the plants running efficiently

To overcome these challenges and to accomplish the goal stated earlier, in 2012 SS-TPC made a plan to complete the PHA of the main plants from 2013 to 2014. We updated our schedule with PII as follow:

- Complete the PHA study of ET/DPG plant, PH/AC plant and HDPE plant at the end of 2013.
- Complete PHA study of PP, EO/EG, BD/MTBE and Storage plants in 2014.
- Complete PHA study of LLDPE and Utility plants in 2015.

SS-TPC next established plans for the detailed execution of each PHA. This included making sure all of the process safety information was up-to-date, accurate, and translated to English and making sure the operating procedures were up-to-date, accurate, and translated to English. (Note that we attempted to use Google-translate for conversion between Chinese and English for selected PSI; the results for these technical documents were poor.) Nearly all of this up-front effort was completed by SS-TPC staff ahead of the PHA meetings; as would be expected, the ease of preparation increased with each successive PHA in the schedule.

Before starting the PHAs, it was decided to provide basic training on PHA methodologies to most of the SS-TPC critical employees. The training covered the disciplines starting from operations and HSE, but included other technical functions such as instruments, mechanical, electrical inspection, process engineering, etc.

Implementation Status

The PHA training was of 3 days duration. It was delivered by PII staff, using simultaneous translation of English and Chinese. This training was given before the start of the PHAs in 2013 and was repeated for more staff before the start of the PHAs in 2014. So far, 65 staff from SS-TPC has been trained in the basics of PHAs. (In 2015, it is planned to start training and coaching PHA leaders and scribes from among SS-TPC staff.)

The PHAs for 2013 and 2014 were completed on schedule with a high degree of participation by SS-TPC staff; the PHAs for 2015 are pending. PII led and documented the PHA meetings; discussions were facilitated with the help of professional translators and also with the help of SS-TPC who could speak both Chinese and English. The results were documented in English into *Hazard Evaluation LEADER* software; a Word report was generated for each unit's PHA. This report contains the typical entries, with considerable detail developed for each scenario. The follow pages provide excerpts from the PHA analysis:

No.: 2 XXXX storage spheres xxx-T-XX A/B/C/D/E/F/G/H/I/J/K/L (1 of 12)					
#	**Deviation**	**Causes**	**Consequences**	**Safeguards**	**Recommendations**
2.1	High level	Too much flow to one sphere from XX Plant (through their pump; about 40 bar MDH)	High pressure (see 2.5)	High level SIF with level sensors voted 2oo2, to close inlet valve - SIL 1 Overflow thru pressure equalization line to other spheres (through normally open [NO] valve) - IPL Line from XXX plant is blinded, at XXX plant	
		Misdirected flow - Liquid from xxx Plant(s) to spheres (see 1.4)	Overpressure of sphere not credible from high level, for normal operating pressure of the column (which is 1.75 MPa), unless all spheres are liquid filled and then thermal expansion of the liquid could overpressure the spheres	High level SIF with level sensors voted 2oo2, to close inlet valve - SIL 1 Overflow thru pressure equalization line to other spheres (through normally open [NO] valve) - IPL Spheres rated for 1.95MPa (19.5 Bar, approx) and the highest pressure possible from the column feeding the spheres is 1.75 MPa Level indication and high level alarm in DCS, used by operators to manually select which tank to fill - IPL	
			Overflow into the equalization line will interfere with withdrawal from the column, but this is an operational upset only		
			Excessive pressure on inlet of high pressure liquid pumps, leading to excess load on pumps and trip of pumps on high pumps, causing trips of xxx, xxx, etc. - significant operability issue		
2.2	Low level	Failing to switch from the sphere with low level in time (based on level indication)	Low/no flow - Liquid from spheres through high pressure product pumps to the vaporizer (see 4.2)	Level indication and low level alarm, inspected each year, per government regulation (not IPL; part of the cause) 9 other spheres with possibly enough level to switch to Feeding from two spheres at all times, so unlikely for BOTH spheres to have low level at the same time - IPL Two level indication from SIS level transmitter, with low level alarm, with more than 60 min available to switch tanks (SIF driven alarm and response) - possible IPL, if action of the operator is quick enough	Rec 4. Make sure the Human IPL of response to low level in all spheres and tanks is described in a trouble-shooting guide (like an SOP) and practiced once per year per unit operator. This will make this response a valid IPL.
			Low/no flow - Unqualified liquid from spheres back to Plant (see 6.2)		
2.3	High temperature	Large area of damaged insulation Loss of	High pressure - vapor from spheres through condenser and return to liquid pump out line		

No.: 2 XXXX storage spheres xxx-T-XX A/B/C/D/E/F/G/H/I/J/K/L (1 of 12)					
#	**Deviation**	**Causes**	**Consequences**	**Safeguards**	**Recommendations**
		cooling. when the tank is isolated from column	(only used when plant is shutdown) (see 3.7)		
2.4	Low temperature	Deviation during startup (see 2.9)	Loss of containment - due to sudden flashing to -100 °C; if there is also a sudden vibration (such as by the flashing from liquid to gas) (see 2.8)	Temperature indication	Rec 5. Consider adding an IPL, such as an interlock, to prevent opening of the isolation valves for liquid into a sphere (following maintenance or an outage), until the sphere has been pressurized with vapor, to prevent brittle fracture of the sphere and to prevent thermal shock of the sphere. Currently a safeguard does not exist for this scenario; there is only the procedure for pre-pressurization that should be followed by the field and control operators. But the lower limit of operator error in such conditions as described in the HAZOP table is about 1/30 to 1/100; so the residual risk is still about $300,000 to $2,000,000 per year.
2.5	High pressure	Liquid filled and left blocked in	Loss of containment (see 2.8)	Pressure indication and high pressure alarm in DCS (1 on each of the 12 spheres); with operator response (with practice/drills) - IPL (Note: The pressure control valve to the flare is normally blocked in; and is only used when the standby cooling system is used)	
		High pressure in the gas equalization line from column	Loss of containment (see 2.8)	(Note: The pressure control valve to the flare is normally blocked in; and is only used when the standby cooling system is used)	
			More losses to flare from sphere - economic consequence		

To help the teams make consistently good judgments on risk, each safeguard was judged to determine if it met the definition on an independent protection layer (IPL) or not. The team then qualitatively judged the risk and decided if the risk was controlled well enough; if not, then recommendations were made to reduce the risk to tolerable levels. As a cross-check of these judgments, SS-TPC required the PHA team to also score (using a calibrated risk matrix or LOPA), any scenario that had catastrophic consequences. The team also determined if a safety instrumented function (SIF) is needed or if one was intended in the design (based on the configuration of the dedicated safety instrumentation). If there was a SIF, the PHA team assigned the SIL based on either the risk reduction needed by the SIF or again by the existing instrument configuration.

It was noted in some cases that the SIF that was installed for protection against scenarios during continuous mode of operation did not protect against even more catastrophic and much more likely consequences during startup or online maintenance. For such situations, additional IPLs, including SIFs specific to startup or online maintenance, were recommended by the PHA team.

The PHA covered all modes of operation for the units; besides a HAZOP or What-if of continuous modes of operation, the PHA team also used the Two Guideword or What-if approach to complete a PHA of startup, shutdown, and online modes of operation. The PHA of the non-routine modes of operation took about 25% of the total meeting time and was done at the end of the unit PHAs. But, some PHA of non-routine modes could not be completed as thoroughly as the team wanted, because the procedures would need to first be re-written.

Once the PHA meetings were completed, the PHA Recommendations were returned to SS-TPC from PII within one week of the close of the meetings. SS-TPC began closing each recommendation immediately by developing timelines for closure and tracking closure by the responsible parties.

The Draft reports were delivered on schedule and with good quality and thoroughness. SS-TPC safety and technical staff reviewed the reports very thoroughly and immediately; the comments (on nearly every node) were returned to PII in one consolidated summary report from SS-TPC which indicates the high commitment of SS-TPC Managements to improve SSTPC in the process safety. A final report was then developed by PII that reflected the resolution of the comments between PII and SS-TPC. The final reports were also delivered on time.

Observations and Issues During Implementation

During the initial PHAs in 2013 and 2014, SS-TPC faced other hurdles besides the ones mentioned earlier in this paper. The approach by PII was to not waver on what was necessary to result in a thorough and accurate PHA of each unit. The response by SS-TPC was equally stead-fast on providing the up-to-date resources necessary to meet the goals, recognizing that since PHAs are new to SS-TPC, there were some growing pains and this resulted in many meetings at interim points through 2013 with senior management, PHA (including PII) staff, and production staff.

Because of the vigorous support by senior staff and management at SS-TPC, each problem or barrier to success was resolved relatively quickly. Below is a partial summary of the issues faced during the PHAs (especially during 2013) and resolutions and observations.

Issue faced	Resolution	Observation/Comment
PSI not up-to-date. This was highlighted as a potential problem before the first PHA started; and many PSI issues were resolved ahead of the PHAs; but during the first PHA, SS-TPC staff and their management learned more exactly what was needed by seeing the effect that missing information has on team discussions and risk evaluations.	Management dedicated resources to find any missing PSI and to ensure it was up-to-date before the start of the meetings. Management applied enough resources to resolve issues during the first PHAs quick enough to not affect the quality or schedule for completion.	Commitment by senior management and the technical team to pull together to resolve these issues was exemplary. Such positive commitment by the company leaders also in turn builds a strong process safety culture.
P&IDs are not consistent in content and many times do not have the information necessary to facilitate efficient PHAs.	SS-TPC found the information needed from other resources to help quickly close open items generated during PHA sessions, related to missing information from the current P&IDs.	With the sponsorship of management, SS-TPC is developing a standard for the content and format of P&IDs that takes into account the needs of PHA teams.
SS-TPC does not have a core group of trained PHA leaders and scribes to perform risk reviews of changes and to perform future PHA revalidations.	SS-TPC management have plans to train PHA leaders and scribes before the 2015 PHAs, and then to use these new leaders/scribes to complete the 2015 PHAs, with PII staff serving as coaches.	Having risk reviews of changes meet the same standards as PHAs, ensure smooth incorporation of the results of MOCs in the Master PHA, so that it stays evergreen; this leads to better basis for the control of risk.
No requirements for ensuring Human IPLs (responses to alarms) are valid.	Recommendations were written and accepted by SS-TPC management to develop missing trouble-shooting guides and require drills once per year for response to critical alarms	This will comply with the requirements in the new CCPS textbook, *Guidelines for Initiating Events and IPLs* [4], 2015. One first step is to develop a comprehensive list of critical alarms for which the operator must respond in time.
Car seal and chain locked valves are not always shown on P&IDs and/or are not always enforced.	Operations staff helped resolve each unknown quickly during the PHA.	SS-TPC will include notation of car seals and locks in the future P&ID specification, and will also enhance their current program to ensure these are in place in the field.
The datasheets for cases other than the limiting case, for PSV sizing, were not available within SS-TPC. In the first PHA, the PSV datasheets were not readily available to the team.	Via resolution of recommendations, SS-TPC staff will ensure that datasheets necessary for validating the sizing for critical scenarios will be completed promptly.	In the future, SS-TPC will specify that EPCs and vendors provide all alternative sizing cases for PSVs, not just the limiting design basis.
SIFs not noted in PSI for some plants	There is a vigorous effort in 2015 to resolve with all plants, including a check of the SIL determination using the PHA results as the starting point (if the PHA team did not resolve this already)	The local government, via urging through SINOPEC, is moving towards requiring adherence with SIS standards.
Operating procedures have many gaps and missing or misplaced steps, making it difficult to complete a PHA of non-routine modes of operation. Further, the procedures are not written per the best practice rules for clarity of the steps.	The operators explained how it typically gets done in practice and the PHA team developed recommendations for improvement of the IPLs protecting against the scenarios and for improvement of the specific procedures.	Managements are demonstrating their support to operating and maintenance staff on how to write and validate effective procedures.

Lack of validation of all IPLs (instruments and PSVs are well maintained though)	The PHA team made recommendations for validation of IPLs (check valves, mechanical stops, SIS, etc.)	SS-TPC has a new initiative for 2015 focused on mechanical integrity that will include validation of each IPL.
Nearly all of the design changes and other recommendations made by the PHA should have been caught during the design of the process unit	The thoroughness of the PHAs performed in 2013 and 2014 likely caught the great majority of scenarios.	SS-TPC has a program that requires number of PHAs during a major capital project, so that a valid, complete PHA is delivered before startup of the plant.

A 1-day presentation was held for more than 100 staff and management (including senior management of SS-TPC) to discuss the observations above, and to provide an overview of process safety management best practices and human factors best practices. This training was well received.

Future Implementation Plans

In 2015, SS-TPC plans to carry out PHA, LOPA[6], and SIL identification (and verification) for the LLDPE plant, increase the qualified staff in PHA leadership. SS-TPC has a long term plan to carry out PHA revalidations (2018 - 2019), and to follow-through with LOPA and SIL verification for the remaining plants in the coming three years (through 2018).

Conclusions

Because of the vigorous support by senior management and staff at SS-TPC, PHA studies since 2013 through 2014 have been achieved according to plan for ET, DPG, PHAC and HDPE plant in 2013; and PP, EO/EG and BD/MTBE Plant and Tank Farm in 2014. Further to this, a total of 314 recommendations were generated and 72.9% of those are already closed so far; remaining open items are tracked with fixed target dates. The awareness of the SS-TPC team in risk identification has been improved significantly; and the reliability of SS-TPC plants has been improved dramatically. The process safety performance in the recent years has improved as there was no major or significant process safety incident in 2014 and the company has achieved the best EHS performance in its history. Stewardship of the SS-TPC management team in process safety is very obvious and results/gains reflect this commitment. Nevertheless, the teams are still putting more efforts to continuously keep learning from stakeholders and learning and adopting newly introduced regulations from national governments for improving the process safety aspects in this JV for the years to come. SS-TPC, as a JV, is adopting the best in class of best practices locally and internationally and targeting to be the best in process safety performance.

Acronyms Used

AIChE– American Institute of Chemical Engineers
CCPS – Center for Chemical Process Safety (of AIChE)
BD - Butadiene
DPG - Pyrolysis Gasoline
EG - Ethylene Glycol
EHS – Environment, Health, and Safety (includes process safety)
EO - Ethylene Oxide
ET - Ethylene
HAZOP – Hazard and Operability Analysis
HDPE - High Density Polyethylene
IPL - Independent protection layer
JV – Joint venture
LLDPE - Linear Low Density Polyethylene
LOPA – Layer of Protection Analysis
MOC – Management of Change
MTBE - Methyl-tertiary butyl ether
PHA – Process Hazard Analysis
PHAC - Phenol/Acetone
P&ID – Piping & Instrumentation Diagram
PP - Polypropylene
PSI – Process Safety Information
PSM – Process Safety Management
SABIC – Saudi Arabia Basic Industries Corporation
SIF - Safety instrumented function
SIL - Safety integrity level
SIS - Safety instrumented system
SS-TPC – Sinopec SABIC Tianjin Petrochemical Company

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