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1. Introduction to Integrity Operating Windows

1.1. In today’s operating environment, it is not enough to base future inspection plans only on prior recorded/known history of equipment condition. A fundamental understanding of the process/operating conditions and resulting damage mechanisms are required in order to establish and maintain an inspection program that yields the highest probability of detecting potential damage. It is imperative that the inspection plans be dynamic and account for changing process conditions and degraded equipment condition. A fundamental step is to frequently rationalize and align the developed degradation knowledge base of the materials of construction with the operation of the equipment, its inspection history, measured corrosion rates and known industry problems. With the move to risk based inspection programs, extending inspection intervals and pushing the operating envelope it is even more vital to identify and track process information that validates existing inspection plans.

1.2. In order to maintain the integrity and reliability of pressure equipment in the refining and petrochemical industry, management systems for several process safety initiatives are necessary. Many of those management systems are oriented toward having a rigorous inspection program, as well as all the supportive engineering activities, to maintain pressure equipment integrity and reliability. To that end, the Inspection, Corrosion/Materials, and Storage Tank Subcommittees of the API Committee on Refinery Equipment have produced a variety of codes and standards to guide the various stakeholders in maintaining pressure equipment integrity and reliability, including:

- API 510 Pressure Vessel Inspection Code
- API 570 Piping Inspection Code
- API RP 571 Damage Mechanisms Affecting Fixed Equipment in the Refining Industry
- API RP 572 Inspection Practices for Pressure Vessels
- API RP 573 Inspection of Fired Heaters and Boilers
- API RP 574 Inspection Practices for Piping System Components
- API RP 575 Methods for Inspection of Atmospheric and Low Pressure Storage Tanks
- API RP 576 Inspection of Pressure Relieving Devices
- API RP 577 Welding Inspection and Metallurgy
- API RP 578 Material Verification Program for New and Existing Alloy Piping Systems
- API RP 579 Fitness for Service
- API RP 580 Risk-Based Inspection
- API RP 581 Risk-Based Inspection Technology
- API RP 582 Welding Guidelines for the Chemical, Oil and Gas Industries
- API RP 583 Corrosion Under Insulation (pending publication)
1.3. However, well founded and well managed, inspection and mechanical integrity systems applying the above standards alone cannot maintain the integrity of pressure equipment in and of themselves. A number of other process safety management (PSM) systems are vital to support a rigorous inspection and mechanical integrity program in order to avoid /prevent pressure equipment damage/corrosion, leaks and failures and improve reliability. Three key elements of those supporting PSM programs include:

- The establishment, implementation and maintenance of Integrity Operating Windows (IOWs),
- An effective method of transferring all the knowledge about unit specific IOW's to all process unit operators and others that need to know, and
- An effective management of change (MOC) program to identify any changes to the process or the physical hardware that might affect the integrity of pressure equipment.

1.4. This recommended practice outlines the essential elements in defining, monitoring and maintaining IOW’s as a vital component of inspection planning, including RBI planning. The application of MOC is addressed herein only to the extent that it is needed in order to handle any changes that may be necessary to update or improve the IOW program. Though the role of MOC in the prevention of process safety incidents is very broad as it is related to pressure equipment failures and leaks, for purposes of this RP, the only aspect of MOC covered herein is related to updating i.e. making changes to IOW’s. Likewise for operator training, this RP covers only the PSM aspect of the necessary knowledge transfer on IOW’s to operators and others that need to know.

1.5. In order to operate any process unit, a set of operating ranges and limits are needed that are established for process variables, within which the process unit operators need to control the process in order to achieve the desired results, i.e. product within specification, safe operation, reliability, etc. These limits are generally called operating limits or operating envelopes. IOW’s are a subset of operating limits (in this case called operating windows) that address the controls necessary on any and all process variables that might affect the integrity or reliability of the process unit. Other operating windows (limits) are typically established to control the process.
in order to produce a quality product, but those limits are not included in the subset of operating limits called IOW’s.

1.6. For purposes of this document, maintaining the integrity of the process unit means avoiding breaches of containment, and reliability means avoiding malfunctions of the pressure equipment that might impact the performance of the process unit (meeting its intended function for a specified time frame). In that sense, integrity is a part of the larger issue of pressure equipment reliability, since most breaches of containment will impact reliability. As such, integrity operating windows (IOWs) are those preset limits on process variables that need to be established and implemented in order to prevent potential breaches of containment that might occur as a result of not controlling the process sufficiently to avoid unexpected or unplanned deterioration or damage to pressure equipment. Operation within the preset limits should result in predictable and reasonably low rates of degradation. Operation outside the IOW limits could result in accelerated damage and potentially equipment failure from any one or more of the numerous damage mechanisms covered in API RP 571 including general or localized corrosion, mechanical or metallurgical damage, high temperature deterioration, brittle fracture and environmentally assisted cracking.

1.7. Unconstrained by the need for economic use of resources, process units might be constructed of materials that were completely immune to any chemical interactions with the process, and therefore would not degrade over time no matter how the process conditions varied from the design conditions. Realistically pressure equipment is generally fabricated from the most economic materials of construction to specific design criteria based on the intended operation. The process should then be controlled within preset limits (IOW’s) in order to avoid excessive material degradation.

1.8. One of the simplest examples of IOWs is the establishment of furnace tube temperature limits to avoid premature rupture or replacement of the tubes. At some established limit, for example 1000 °F, a furnace tube designed for 950 °F operation would have a shortened service life, so when this limit is exceeded, operators would be directed to regain control of furnace firing to get back below 950 °F within a preset amount of time. That limit of 950 °F would be an IOW limit for those furnace tubes. At an even higher temperature, say 1050 °F, the operator might be directed to take more immediate actions to regain control or even shut down the furnace. There may be multiple levels of IOW limits for the same process parameter (in this case furnace tube temperature), as well as multiple responses with different response times, depending upon the degree of exceedance of the process parameter limit.

1.9. A robust, properly structured inspection program (standard condition based or more advanced risk based inspection program) depends on IOW’s being established and implemented to avoid exceedances having an unanticipated impact on pressure equipment integrity. Inspection programs are not generally designed to look for unanticipated impacts of processes that are not adequately controlled. Inspection programs generally assume that the next inspection interval (calculated based on prior damage rates from past operating experience) should be
scheduled on the basis of what is already known and predictable about equipment degradation from previous inspections. Without effective process control, based on a robust and complete list of IOW’s, inspections might need to be scheduled on a frequent time-based interval just to look for anything that might potentially occur from lack of process control. That would not be practical or safe, since it would be based largely on guess work.

2. Purpose and Scope of this RP

2.1. The purpose of this RP is to explain the importance of IOW’s for process safety management and to guide users in how to establish and implement an IOW program for refining and petrochemical process facilities for the express purpose of avoiding unexpected equipment degradation leading to loss of containment. It is not the intent of this document to provide a list of specific IOW’s for the numerous types of hydrocarbon process units in the industry (though some generic examples are provided in the text and in Appendix A), but rather to provide the user with information and guidance on the work process for development and implementation of IOW’s.

2.2. The scope of this standard includes recommended practices for:

- Definitions of IOW’s and related terminology,
- Creating and establishing IOW’s,
- Data and information typically needed to establish IOW’s,
- The various types of IOW’s needed for process units,
- Documenting and implementing IOW’s,
- Monitoring and measuring IOW’s,
- Communication of IOW exceedances,
- Reviewing, changing and updating IOW’s,
- How IOW’s should be integrated with other risk management practices,
- Roles and responsibilities in the IOW work process, and
- Knowledge transfer to operating personnel and others that need to know.

3. Definitions and Acronyms of IOW Related Terminology

3.1. Alarms – Audible sound (e.g. horn, buzzer, beep, etc.) along with a visual alert (e.g. flashing red light) in the control room that alerts operators to a potential upset or emergency issue that may need immediate attention. For this RP, alarms are related primarily to Critical IOW exceedances.

3.2. Alerts – A secondary level of communicating important (though perhaps not urgent) operating information to control room attendants that signifies a condition that will need attention in the near future to avoid a potential upset condition that could lead to process safety or reliability impacts. Alerts may include visual or audible sounds (though
not typically both) and/or other real-time process tracking charts/graphs with limits identified. For this RP, alerts are related primarily to Standard IOW exceedances.

3.3. **CCD:** Corrosion Control Document – Documents that contain all the necessary information to understand materials degradation issues in a specific type of operating process unit

3.4. **CCM:** Corrosion Control Manual – Same as CCD

3.5. **CLD:** Corrosion Loop Diagram – same as a CMD and PCD

3.6. **CMD:** Corrosion Materials Diagram – A modified process flow diagram (PFD) showing areas of similar corrosion mechanisms, similar operating conditions, and similar materials of construction in each portion of the unit, as well as the usual PFD information. Some CMD varieties are annotated with historic corrosion problem sites.

3.7. **Fixed Equipment** – Same as pressure equipment

3.8. **IOW:** Integrity Operating Window – Established limits for process variables (parameters) that can affect the integrity of the equipment if the process operation deviates from the established limits for a predetermined amount of time.

3.9. **IOW Standard Limit** – An established IOW level defined as one that if exceeded over a specified period of time could cause some specified undesirable risks (potential equipment damage or hazardous fluid release) to occur. At the standard IOW limit level, the operator will generally have some predetermined action to take, which may vary from process control activities to seeking operating guidance from supervisors or appropriate other technical personnel (SME’s). Other terminology for standard limits can be used such as Key Operating Limit or Reliability Operating Limit.

3.10. **IOW Critical Limit** – An established IOW level defined as one at which, if exceeded the operator must take immediate predetermined actions to return the process to a safe condition or significant defined risks of potential equipment damage or hazardous fluid release could occur in a fairly short timeframe. Other terminology can be used in place of Critical Limit, such as Safe Operating Limit.

3.11. **IOW Information Limit** – An established limit for other integrity parameters that are used primarily by SME’s to predict and/or control the longer term integrity/reliability of the equipment. These "Informational" IOW’s are typically only tracked by the appropriate SME’s and do not have alarms or alerts associated with exceedances. In some cases the Informational IOW’s are used for parameters that cannot be directly (or indirectly) controlled by operators, whose primary duty would be to make sure any exceedances are communicated to the designated SME. Other terminology can be used in place of Informational Limit, such as Corrosion Control Limit.
3.12. **MI: Mechanical Integrity** – All the management systems, work practices, methods and procedures established in order to protect and preserve the integrity of operating equipment.

3.13. **MOC: Management of Change** – The PSM system and work process that is used to agree upon acceptable changes to IOW’s.

3.14. **Notifications** – A message to an operator / SME that an IOW exceedance has occurred which may not necessarily have an alarm associated with it, but may require a specific required action and response from an operator or SME.

3.15. **PCD: Piping Circuit Drawing** – Same as CLD and CMD.

3.16. **PFD: Process Flow Diagram** – A simplified diagram of a process unit showing the main pieces of equipment and piping, with limited details of process design parameters.

3.17. **PHA: Process Hazards Analysis** – A work process to assess and document the hazards and risks associated with a operating a process unit, and to make recommendations on what actions may be necessary to mitigate unacceptable risks.

3.18. **PSM: Process Safety Management** – The implementation of all the work practices, procedures, management systems, training, and process safety information that are necessary in order to prevent the release of hazardous substances from process equipment.

3.19. **Pressure Equipment** – Stationary or fixed equipment for containing process fluids under pressure, not including rotating equipment. Pressure equipment includes, but is not limited to such items as piping, vessels, reactors, tanks, pressure relief devices, columns, towers, and filters.

3.20. **RBI: Risk-Based Inspection** – The work process for assessing the mechanical integrity risks associated with pressure equipment in order to prioritize inspection activities and to produce a detailed inspection plan.

3.21. **SME: Subject-matter-expert** – One who has in-depth knowledge and experience on a specific subject as it relates to IOW’s, e.g. corrosion/materials SME; process SME; operations SME, equipment type SME, etc. Various types of SME’s are necessary in order to establish IOW’s for each process unit.

3.22. **TAN: Total Acid Number** – A measure of potential corrosiveness of hydrocarbon feed steams containing various organic acids

4. **Types of IOW’s**

   4.1. Typically IOW’s fall into two categories of limits, physical and chemical.
5. IOW Criticality/Risks/Levels

5.1. IOW’s should be classified by criticality and/or risk into different levels in order to set priorities on notifications (including; alarms, alerts and/or e-mails) and timing of actions to be taken when IOW’s are exceeded. The criticality or risk of the established limits for a given operating parameter is a function of the event probability and consequence (i.e. risk) when the limit is exceeded. In each case or scenario there will be a number of risk sub-factors that need to be considered when establishing the criticality/risk levels which will be related to the probability of the event and the potential consequence if the event occurs. In this section, an approach to establishing three levels of IOW’s (“Critical”, “Standard” and “Informational” limits) is outlined in order to separate IOW’s for process parameters that may have shorter term process safety implications from those that have longer term process safety or reliability implications. After designating the highest risk IOW’S, i.e. Critical Limits, additional prioritization can be achieved through risk ranking of the “Standard” and even the “Informational” Limits in order to identify the standard limits that need quicker, more definitive action by the operator from those where there is more time to react to the information.

5.2. The primary difference between a Critical and a Standard limit is in the reaction time required to return the process to normal safe operation. For Critical limits, there will typically be visual and audible alarms for the operators and typically all Critical Limits will require specific predetermined actions to be taken by the operator to urgently return the process to normal safe operating limits. In some cases there may also be instrumented shutdown systems that automate a sequence of steps to regain control of the process. For some Standard limits, there may also be visual and/or audible alarms, depending upon the level of risk and time required to regain control associated with the limit. A risk assessment process such as that outlined in
section 5.6 can be used to determine the need for what alerts/alarms are appropriate for each IOW. Standard limits may in many cases be just more conservative limits set for operating parameters prior to reaching Critical limits in order to provide the operator with more time and options for regaining control before the more urgent measures required for exceeding a Critical limit must be implemented.

5.3. In addition to the predetermined operator intervention required for Standard and Critical limits that are exceeded, notifications for designated SME’s should be designed into the system, so that appropriate investigations and corrective actions can be implemented to prevent further exceedances and plan for necessary follow-up testing / inspection. These notifications should include designated inspection personnel in case inspection plans need to be adjusted, depending upon the magnitude of the exceedance.

5.4. A standard IOW level is defined as one that if exceeded over a specified period of time could cause one or more of the following to occur that requires predetermined operator intervention in order to regain control of the process:

- Eventual loss of containment,
- A release of hydrocarbons or hazardous fluids,
- Unscheduled or non-orderly shutdown,
- A negative impact to the long term unit performance and its ability to meet turnaround run length, or
- Unacceptable financial risk.

5.5. A critical IOW level is defined as one at which the operator must urgently return the process to a safe condition and, if exceeded, could result in one of the following in a fairly short timeframe:

- Larger and/or quicker loss of containment,
- A catastrophic release of hydrocarbons or other hazardous fluids,
- Emergency or rapid non-orderly shutdown,
- Significant environmental risk, or
- Excessive financial risk
- Other unacceptable risk.

5.6. A third level of IOW’s may be established that are “Informational Limits”. Most parameters that have defined IOW’s are controllable, especially for Critical and Standard Limits, but some are not and may not have an immediate designated operator intervention assigned to them. But deviations from mechanical or process design conditions could eventually lead to accelerated corrosion or other damage over a longer period of time. These parameters which may not be controlled by operators still may need to be reported to, reviewed by and trended by designated technical personnel (SME’s). For example, these Informational parameters may provide a secondary indication of process performance such as in an atmospheric overhead tower where the primary process control parameter for corrosion in the reflux may be the pH
of the condensate, but a secondary informational parameter may be the iron content measured periodically. When exceedances of these informational parameters are reported, the appropriate SME’s in turn may then specify that some type of engineering, process or inspection activities be planned or adjusted in order to control the rate of deterioration and prevent equipment deterioration over the longer term. These informational parameters do not normally have alarms or alerts associated with exceedances. In most cases, the limits for informational parameters would be established to provide a point where the operator (or implemented software) would initiate a notification to the appropriate SME that some informational parameter has exceeded a limit. Informational IOW’s would typically be associated with the following situations:

- Would not be directly related to a potential loss of containment,
- Provides for an secondary indication of operational performance or corrosion control issue, and/or,
- Used to track parameters that are not necessarily controllable by operators

5.7. Figure 3 below illustrates visually how various types of operating limits might create boundaries for any specific operating window. The middle zone between the standard levels (high and low), is the zone designated for long term safe, environmentally sound operation. Outside of those limits, operator intervention is generally required to return the process into the safe operating zone.

![Operating Window Diagram]

Figure 1. Zones of operation including target ranges with standard and critical limits.
5.8. IOWS may be risk ranked in order to help determine the appropriate priority of alerts, alarms and notifications to operating personnel and SME’s. This risk assessment would also help to determine what actions the operator needs to take and how fast the operator needs to act before the process gets too far out of control i.e. the higher the risk, the sooner the operator may need to respond and the more definitive the response may need to be. And the higher the risk the more levels of action might be designated for Standard IOW’s in order to provide the greatest chance of regaining control before a Critical level of alarm is reached. Tables 1 and 2 contain simplified examples of how a risk assessment matrix and process can be used to establish IOW’s.

Table 1  Generic Risk Matrix for Assessing IOW levels
<table>
<thead>
<tr>
<th>Risk</th>
<th>Type of IOW</th>
<th>IOW Guidance / Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Critical</td>
<td>IOW’s Required - Limits and durations established on all IOW process parameters for monitoring; IOW’s are alarmed / alerted and SME’s are notified of exceedances; Operations take urgent predetermined action to return process to normal operation</td>
</tr>
<tr>
<td>Medium High</td>
<td>Critical or Standard</td>
<td>IOW’s Required - Limits and durations established on all IOW process parameters for monitoring; IOW’s are alarmed / alerted and SME’s are notified of exceedances; Operations take predetermined action to return process to normal operation</td>
</tr>
<tr>
<td>Medium</td>
<td>Standard or Informational</td>
<td>IIL’s Identified - IOW’s identified suggested limits specified for each IOW; Operations and SME’s are alerted / notified of exceedances; Trouble shooting initiated with planned adjustments to operations, inspection / maintenance developed</td>
</tr>
<tr>
<td>Low</td>
<td>Informational</td>
<td>IIL’s Suggested - Normal operating parameters identified for analysis; Parameters tracked and trended by SME to determine long term effects on equipment reliability</td>
</tr>
</tbody>
</table>

Table 2 Suggested Risk Chart for IOW Types / Actions / Guidance

6. Examples of IOW’s

6.1. An example of an IOW set for high temperature hydrogen attack (HTHA) is shown in Figure 2, below. Note that mechanical design limits from the construction code for the vessel are outside the IOW limits for the process, which are set by applying the Nelson curves in API RP 941. Note also that although the start-of-run conditions (SOR) are within the IOW, the end-of-run conditions may be outside the IOW depending upon hydrogen partial pressure and the duration of the EOR conditions. In this specific case, some operators may decide that a short term operation at EOR conditions above the Nelson curve is acceptable based on the amount of time it takes for incipient HTHA to occur i.e. no significant HTHA damage will occur. Other operators may decide that the IOW should never be exceeded. Such decisions can be made using appropriate risk analysis and the input of knowledgeable corrosion/materials specialists.
6.2. In Figure 3 is another example of how critical and standard IOW limits interact for controlling furnace tube temperatures. Several damage mechanisms are possible in furnace tubes. In general the concern for furnace tubes is about the long term creep life and corrosion rates. However, at higher than design temperatures, failure can occur due to overpressure from the significant loss in material strength, i.e. short-term overheat and stress rupture.

![Figure 2. Example of IOW limits for HTHA in a hydroprocess unit](image)

<table>
<thead>
<tr>
<th>Critical IOW Set Points, Alert and Alarm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature Increasing &gt;</td>
</tr>
<tr>
<td>Design Metal Temperature from API-530</td>
</tr>
<tr>
<td>Long Term Creep Damage Concern and higher sulfidic corrosion rates</td>
</tr>
<tr>
<td>Short Term Creep Damage Concern potentially high sulfidic corrosion rates</td>
</tr>
<tr>
<td>Imminent Failure due to loss of material strength</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Standard IOW Set Points, Low, Medium and High</th>
</tr>
</thead>
</table>

6.3. Some examples of critical IOW limits would include:

- Delayed Coker Heater Pass Flows
  Minimums and maximums
- Boiler Feed Water Level
  - Loss of boiler feed water level could quickly cause boiler tube rupture
- Hydroprocess Reactor Temperature
  - Metal temperatures below the MDMT could give rise to brittle fracture
- Heater Tube Skin Temperature
  - Tube could rupture quickly if overheated, caused, for example, by a no flow or hot spot condition.
- Sulfuric Acid Strength in Alkylation
  - Too low acid strength could cause runaway reaction
- Atmospheric relief system on a major piece of pressure equipment
  - Over-pressure could result in major environmental and/or community impact

6.4. Some examples of standard IOW limits would include:

- HCU Reactor effluent air cooler (REAC) NH₄HS Concentration
  - Corrosion of the air cooler and downstream piping
- Heater Tube Skin Temperature
  - Metallurgical creep could lead to eventual tube failure.
- Crude Fractionator Dew Point Temperature
  - Sustained operation below dew point could cause damage to fractionator internals or potential loss of containment.
- pH of Crude Tower Overhead
  - Sustained operation below standard pH level could lead to corrosion of heat exchanger components, especially tubing and piping and potential loss of containment.
- Hydroprocess units
  - Water and/or chloride carry-over in hydrocarbon feed streams or hydrogen could cause accelerated corrosion from ammonium salts and hydrogen chloride solutions.
- Desalter Outlet Conditions
  - Sustained operation with salt content above standard level could lead to corrosion and potential loss of containment
    - Increased BS&W will also cause the crude heat exchangers to foul.
- Crude desalter temperature
  - Temperatures higher than 300 F will cause permanent damage to the Teflon bushings that insulate the electric grids. Deterioration of these bushings will cause grid shorting and rendering the desalter non effective.
- Alky DIB acid wash.
6.6. Some examples of IOW Informational Limits (IIL's) include:

- Sour water NH₄HS contents in hydroprocessing
- Ammonia content in a crude overhead system that could be assessed to determine if ammonium chloride fouling and corrosion may be occurring.
- Calculated heat transfer coefficients and pressure drops for heat exchangers
- Calculated dew points to avoid water drop out
- Calculated salt deposition temperatures to avoid salt drop out corrosion and fouling
- Calculated wash water vaporization rates for wash water effectiveness
- pH, chlorides, hardness, iron, cyanides in wash water to avoid corrosion
- IR surveys for flow distribution in REAC systems that could lead to accelerated corrosion
- Ammonia content in a crude overhead system that could be assessed to determine if ammonium chloride fouling and corrosion may be occurring.
- Carbonate content in the FCCU Gas Plant and Claus Quench Tower waters that would promote carbonate stress corrosion cracking.
- Cyanide content in FCCU and DCU Gas Plant waters. The presence of cyanide will promote wet H₂S cracking and promote general corrosion by destroying the protective iron sulfide layer.
- Iron concentration (ppm) in the steam condensate system. Iron will indicate accelerated corrosion due to low pH condensate. This could be an indication of upstream problems in either water treatment or neutralizing amine injection.
- Organic chlorides in purchased feeds. Organic chlorides can lead to very high corrosion rates in the NHT and other hydroprocess units.
- Temperature that has increased as a result of process creep. The temperature may have increased to a point that it now puts the equipment in the sulfidation range.

6.6. More detailed, specific examples of IOW’s for a few generic process units are included in Appendix A. A suggested tabular recording of IOW’s is shown in Appendix B, including the IOW parameter, the related damage mechanisms, the required response, the timing of the response, related information and responsible party. An example IOW work process for a hypothetical exchanger is shown in Appendix C.
7. **Suggested Work Process for IOW Development**

7.1. The IOW work process should be a documented procedure implemented with teamwork which includes integration with existing programs. It is important that the data used for establishing IOW’s be accurate, the design and operating analysis be complete, and the results be executed appropriately with sound engineering and operational judgment.

7.2. One of the first steps in defining IOW’s is to fully understand all the potential and likely types of degradation and modes of failure that could occur in each piece of process equipment. This usually takes the combined effort of personnel knowledgeable in corrosion and deterioration mechanisms with those knowledgeable in the particular process being evaluated. A multi-disciplinary team of subject-matter-experts (SME’s) should be utilized to create the IOW’s, and that team would typically consists of:

- Site corrosion engineer/specialist,
- Unit process engineer/technologist,
- Unit inspector,
- One or more experienced unit operations representatives,
- Unit Maintenance / Reliability Engineer (as needed, ad hoc),
- Process Chemical Treatment Vendor (as needed, ad hoc), and a
- Facilitator (typically a knowledgeable/experienced corrosion specialist that may be from an off-site or central location)

7.3. The quality of the team and the development process and therefore the quality of the IOW’s produced is dependent upon collaborative effort from the interaction of this group of knowledgeable, experienced SME’s.

7.4. Considerable information is needed by the SME’s on the IOW team in order to do a quality job of constructing each unit specific set of IOW’s. That information typically includes:

- Process flow diagrams to systematically review the process during IOW team meetings
- P&ID’s that show sample points, IOW monitoring instruments, etc.,
- Piping isometric drawings that show all injection points, mix points, deadlegs and other piping hardware details that are included in the inspection program,
- Existing operating windows that may already be in effect,
- Identification of startup lines, temporary use lines and normally closed valves,
- Operating and maintenance procedures,
- Process chemical treatment programs
- Feed sources, volumes, and compositions including intermediate products,
- Knowledge of damage mechanisms, possible and probable that could occur in the process unit,
- Historical operating, maintenance and inspection records for the process unit,
- Failure analysis and lessons learned reports for the operating unit and/or similar operating units
7.5. Examples of unit specific data that can be used during the IOW process include:

- Crude units: Historical crude assays, average sulfur composition for the raw feed and primary cuts or product streams, total acid numbers, furnace monitoring data (IR and process temperatures), sidestream temperatures, overhead process parameters such as velocities, pH, chloride contents, crude salt content, desalter efficiency and reliability, caustic injection rate (and strength) into desalted crude etc.
- Hydroprocessing: hydrogen and hydrogen sulfide partial pressures, wash water volumes, injection points, and sources and quality of water, etc.
- Amine systems: type of amine, loading, filtration, overhead bleed/purge rates, chloride content, HSAS content, % water in amine, steam temperature of amine reboilers, etc.
- Catalytic Crackers: Polysulfide injection systems, slurry solid content, HCN and carbonate concentration in Gas Plant System, etc.
- Clause Sulfur Unit: Acid gas feed temperature, temperature of cold wall thermal reactor, temperature of final condenser outlet temperature, acid gas loading, sulfur levels.
- Sour Water Stripper: Concentration of NH3 in Circulating Reflux
- Merox Units: Sodium content of DSO, air controls
- Selective Hydrogenation Unit: Di-Olefins content
- Sulfuric Acid Alkylation: Spent acid strength to storage, acid strength, acid temperature, water content of acid, acid/hydrocarbon ratio in contactors, Contactor Isobutane/Olefin ration, Acid Precipitator Amps & Voltage, Acid Circulation rate to DIB Feed Acid Wash, DIB Acid wash mix valve pressure differential, Caustic strength of Alky DIB Caustic Wash.
- Hydrofluoric Acid Alkylation - water content in acid, isostripper and depropanizer temperatures, defluorinator breakthrough monitoring
- Delayed Coking Unit: Sodium in feed, TAN, Velocity in Coker Heaters,
7.6. In order to facilitate the effectiveness and efficiency of the IOW work process, this information should be collected and brought to the IOW team meeting to the extent possible.

7.7. Once the process of identifying all the potential and likely equipment degradation mechanisms and failure modes is complete, then the process variables need to be reviewed that can have an impact on the type and rate of deterioration that can occur; and they begin to set the limits on those process variables that will avoid accelerated, unexpected or excessive degradation. These limits and appropriate response actions and timing become the IOW’s for the process unit. Process conditions at startup, shutdown, and during likely and/or historic operational upsets need to be considered.

8. General Considerations for Establishing IOW’s and Their Limits

8.1. Historical problems as well as changes that are anticipated in the process unit should be considered in the IOW development. There may be upper and lower limits that need to be established and there may be one or more levels of those limits with different actions within different time frames required as each IOW level is exceeded. Actual operating changes sometimes deviate from design operating conditions for various reasons. Those differences between design conditions and actual operating conditions can cause accelerated or unanticipated degradation over time, with the ensuing undesirable consequences that could occur from severely degraded construction materials.

8.2. There are numerous documented cases within the industry of accelerated corrosion and cracking rates of materials of construction under adverse conditions that range from 10-20 mils per year to a few inches per year (see Table 3 for a few examples). The materials/corrosion specialist needs to be aware of this type of information to help the team decide what the appropriate operator response needs to be and how fast the actions need to be implemented.

| Table 3 Accelerated Corrosion Rates That Can Occur Under Some Circumstances |
|-------------------------------|---------------------------------|------------------|
| **Unit: Corrosion / Damage Mechanism** | **Documented Out-of-Control Corrosion Rates** | **Time to Failure** |
| Crude Unit: HCL / Amine Chloride Corrosion in Ovhd & TPA | >2,000 mpy | Failed a new exchanger bundle in 18 days |
| Reformer: HCL / Ammonium Chloride | >3,500 mpy | New alloy finfan exchanger failure in 3 months, related to over injection of PERC and low operating temperatures |
| Catacarb Unit: Wet CO2 | >5,000 mpy | Failure can occur in days to weeks on the piping at a dew point |
| FCC Unit: Erosion of slurry system piping | >1,000 mpy | Multiple failures in slurry pumps and piping within 6 weeks after suspected cyclone failure |
| Alkylation: H2SO4/ Acid Esters | >15,000 mpy | Failure occurred in 11 days on a new pipe reducing elbow where H2SO4 was diluted with H2O + CL |
| HDS; HCL/Ammonium Chloride | >300 mpy | Failure occurred at a piping mix point combining H2+Cl and wet HDS H2 in approximately 2 years |
8.3. Numerous issues can cause these deviations between actual and design, including fouling of exchangers in series, operating with exchanger by-passes open, process conditions creeping upward without notice, lack of understanding of the nature and consequences of unanticipated degradation by operators, misunderstanding between construction code design conditions and material of construction design limits for specific types of degradation, and not appreciating the impact of end-of-run (EOR) conditions versus normal or start-of-run (SOR) conditions.

8.4. For example, if there are banks of heat exchangers in series in high temperature, high pressure hydroprocess service, designers sometimes assume design operating conditions will prevail over the life of the plant. However, if the inlet exchanger in the series fouls and no longer cools the hydroprocess stream sufficiently, the next exchanger(s) in the series might see higher temperatures than it was designed for, in which case it might become susceptible to HTHA, sulfidation or ammonium chloride corrosion, for which the materials of construction in the downstream bank may not be designed to handle. If those changes are not noticed, or not put through a management of change process, or if the proper IOW’s were not in place, then unanticipated and undetected materials degradation could occur.

8.5. If for some process reason, operators open a by-pass around an upstream exchanger causing hotter hydroprocess material to enter downstream equipment that was not designed for those hotter conditions, then again unanticipated and undetected materials degradation could occur, as for instance HTHA or sulfidation.

8.6. Another situation occurs when process conditions begin to creep upward over time; also known as “process creep”. This might entail scenarios such as periodic, but small increases in temperature, small increases in hydrogen sulfide content, or increases in hydrogen partial pressure. Over time, that sort of process creep can surpass the design levels of degradation resistance in the materials of construction. If those changes are not noticed, or not put through a management of change process, or if the proper IOW’s were not in place to prevent those changes, then unanticipated and undetected materials degradation could occur.

8.7. In some hydroprocess equipment, EOR conditions (e.g. temperature and hydrogen pp) are more severe than SOR or normal operating conditions. If actual EOR operating conditions were more severe and/or lasted much longer than original design or normal operating conditions, that could result in exceeding the HTHA resistance of the materials of construction.

8.8. The number of IOW’s for each different process unit will depend upon issues such as the:
   - number and extent of corrosion and deterioration mechanisms likely to be present,
8.10. The result of analyzing all this information and the team deliberations is typically a set of reasonable, practical IOW’s that are not too conservative and not non-conservative, both extremes of which are of course not desirable and need to be avoided. Five to ten percent of the total IOW’s may end up being designated by the team as “critical limits”, where the operator will need to take drastic and immediate action to control the process or shut down within a fairly short period of time, while the most of the IOW’s end up as “standard limits”, where the operator needs to take action within a specified timeframe to get the process back into control in order to avoid escalation of the issue to a critical limit. An important portion of the IOW team discussions will be oriented toward what specific actions the operator needs to take once a standard or critical IOW limit is reached, as well has how quickly the operator will need to respond. The higher the risk, the faster and more definitive the response will need to be. Finally monitoring limits may be identified for informational IOIW’s to allow for longer term evaluation of degradation issues where operator intervention may not be available, but do allow SME’s to assess potential changes in degradation rates.

8.11. Figure 3 illustrates visually how various types of operating limits might create boundaries for any specific operating window. The middle zone between the standard levels (high and low), is the zone designated for long term safe, environmentally sound operation. Outside of those limits, operator intervention is generally required to return the process into the safe operating zone. Not all IOW’s will have critical limits, and many may have only an upper or a lower limit. It will be up to the team of knowledgeable process, operating and corrosion specialists to determine whether each IOW needs to have both upper and lower limits, and if standard and/or critical limits need to be established for each IOW.

8.12. The team should suggest how IOW’s are to be monitored, which IOW’s require alarms or other types of operator notifications when they are exceeded, the frequency and timing for alarms, and other notifications. Typically critical IOW limits will have alarms associated with their exceedances, but not all standard IOW limits may require alarms.
8.13. Finally the team should decide how IOW exceedances will be communicated and to whom. Exceedances of critical IOW limits may have more formal communications and more extensive reporting including plant management. Responses to critical limit exceedances may require some formal investigation and reporting, and be treated similar to an incident investigation, whereas, standard limit and IIL exceedances may require reporting only to technical and inspection personnel for follow up and investigation. If systems are available, automated communication of IOW exceedances from on-line control and information systems directly to designated stakeholders improves the effectiveness and efficiency of the IOW communication process.

8.14. Periodic team meetings between Operations and SME’s to review the list of IOW’s, planned and recent operational changes, IOW exceedances, etc. may be useful to monitor the status and update the IOW list.

9. Documenting and Implementing Established IOW’s

9.1. Once the complete list of IOW’s has been established, the implementation process begins. Effective implementation of the IOW list is equally as important and establishing IOW’s, so that effective actions within a specified timeframe are taken each time an exceedance occurs. A comprehensive list of IOWs should be readily available and communicated to all those that need to know and effectively implemented for process control. All those that need to know would include:

- Operations personnel, especially operators
- Operations Supervision / Management
- Business / Oil Movements
- Inspection personnel
- Process and reliability engineers
- Corrosion/materials specialists
- Safety / PSM / Environmental personnel

9.2. There may be numerous ways to document each set of IOW’s for each process unit. Here are two suggested ways, one being more detailed (and thereby more useful from a broader perspective) and the other being a more concise (and therefore simpler, but less useful from a broader perspective).

9.3. More Detailed Method: Include the IOW’s as part of a comprehensive document on corrosion control in every process unit. These documents have been called Corrosion Control Documents (CCD’s), Corrosion Control Manuals (CCM’s), or Risk-Based Inspection (RBI) Data Files by some in the industry. Some of the possible inclusions in such a document include, but are not limited to:

- Description of the process unit and the normal process conditions
• Shutdown, start up, and abnormal operating conditions that may affect corrosion and other degradation mechanisms, including the possibility of inadvertent contamination of process streams with unexpected but possibly predictable corrosive species,
• Process Flow Diagrams (PFD’s) showing all construction materials,
• Corrosion Loop Diagrams (CLD’s) or Piping Circuit Drawings (PCD’s), which are areas of similar corrosion mechanisms, similar operating conditions, and similar materials of construction in each portion of the unit,
• Probable types of degradation, damage and fouling in each corrosion circuit, where each damage mechanism is expected to occur, the relative susceptibility to the damage mechanisms, as well as likely damage rates expected to occur and under what circumstances,
• A history of corrosion problems that have experienced in this process unit or similar units,
• Quantitative and predictive models for the degradation mechanisms,
• Vital corrosion control procedures and practices such as, injections, inhibitors, water washing, neutralizers, treatments, etc.,
• Recommended types of inspections focused on known specific material degradation issues, corrosion monitoring, process parameter monitoring process changes, construction materials, etc., Basis for each IOW, including any assumptions made,
• Risk analysis performed to prioritize the various IOW’s and their associated monitoring methods, and of course
• The IOW’s that must be adhered to by operations in order to protect and preserve the integrity of the equipment. These IOW’s would include the information in the simpler format for recording IOW’s that follows.

A Less Detailed Method: Simply compile a list of the specific IOW’s for each process unit, including:

• The specific limits established,
• The recommended operator intervention/control steps,
• The timeliness of each intervention/control action, and
• Required IOW exceedance communications.

Various combinations of the above two recommended documentation methods can be developed depending upon the needs and desires of the owner user. The more detailed documentation methods can become a resource for:

• The entire corrosion and degradation management strategy for the process unit,
• The implementation effort for all IOW’s that will be input into the process monitoring and control system,
• Training and reference material for operators, engineers, inspectors and others that need to know the background for why each IOW was established, especially when considering possible changes,
• Risk-based inspection planning,
• Management of change decision-making that may affect equipment integrity, and
• Process hazards analysis (PHA) discussions.

9.4. As noted above, the information assembled in the process to produce the more detailed IOW documentation can become part of the front end data input to the RBI process, which would in turn produce a detailed risk-based inspection plan for each piece of fixed equipment including: inspection scope, methods, techniques, coverage, frequency, etc. API RP 580 and 581 are the two API Recommended Practices that address Risk-Based Inspection. API RP 580 is the more generic boundary document for everything that needs to be included in an effective and complete RBI work process; while API RP 581 is a very specific step-by-step work process for doing RBI which has been developed into an RBI software package.

9.5. An important part of IOW implementation is operator training. Once integrity operating windows are established, operators need to become knowledgeable about all the unit-specific IOW’s in their sphere of operation, and especially knowledgeable in the reasoning behind them, so they can understand why it’s so important to take action within the specified timeframe. They also need to understand the undesirable consequences of failing to take action within the specified time frame. This operator training should include such things as:

• Why the IOW was established i.e. its purpose and intent,
• What damage mechanism is being prevented or controlled by the limits established,
• A clear understanding of the difference between standard limits and critical limits, as well as the reason for the different response actions and timing,
• If there are multiple levels of the IOW, i.e. upper and lower, as well as multiple levels of responses and response timeliness, then the reasons for each level of response needs to be fully understood,
• What can happen in the process unit, both short and long term, if the established responses are not implemented in a timely fashion when limits are exceeded,
• The desired exceedance communications, by what mechanism and with whom to communicate, in the event that an IOW limit is exceeded.

9.6. Another part of operator training should include the difference between Code design conditions (pressure and temperature) and materials selection design conditions. There sometimes is a fundamental misunderstanding for some personnel between the design conditions stamped on the nameplate of the equipment and the actual process operating limits of the equipment based on degradation mechanisms. The mechanical design limits for pressure and temperature per ASME Code construction stamped on the vessel may be much higher than the operating limits established for materials of construction degradation resistance. This difference is one of the many reasons that IOW’s are needed in the first place.
10. Monitoring and Measuring IOW Parameters

10.1. To monitor and measure IOW parameters, control systems and procedures need to be established to store the IOW's and notify the operator when an exceedance is being approached or has occurred. That will likely involve additional monitoring and control instruments and/or sampling points for some IOW variables. If it’s a monitoring instrument, then instrumented displays and some alarms will likely be needed. If it's a sample point, then procedures and practices will be needed to analyze a designated process stream and report it back to the operator within a predetermined amount of time so that the appropriate actions can be taken in the event of an IOW exceedance. A useful feature of such systems is the generation of trending data for IOW’s and automatic electronic notifications to a predetermined list of stakeholders when an IOW exceedance occurs.

10.2. The detection and monitoring controls need to be evaluated on the basis of desired performance characteristics including:

- Detector type and range
- Selectivity
- Response time
- Stability
- Reliability

10.3. The overall response time of the system needs to be considered when setting alarm, and "notification" limits / levels. The response time needs to account not only for the limitations on the instrument / detector response but the overall design and limits of the communication system (getting the message to the intended audience). System response time, which is the length of time from when a limit has been violated until the mitigation procedure is activated. This time will be a function of system deployment, device response time, and activation strategy. System response time should be scaled relative to the risk level for critical and standard IOW's. For example, if a vessel has a high level alarm designed to prevent overfilling, then the level for alarm needs to account for the maximum fill rate, communication time to the board operator, response time of the operator to correct the operation. The physical characteristics of the instrument and detection system also need to be considered. It is important to note that device response time may be significantly affected by ambient conditions. For example, humidity affects the response time of some detector types by many seconds, particularly at the lower end of the detection range. A detector should be capable of responding effectively under all conditions likely to be experienced at a given site. When site maintenance personnel service the sensors, the most common task performed is a calibration check. When this is done, a response time to span gas should be recorded.
10.4. Alarms will normally accompany all critical IOW’s and some standard IOW’s, depending upon necessary timing of IOW response. Process safety management may need to review the total number of alarms to avoid situations involving “alarm flood” in the event of an emergency. Notifications to specified stakeholders/SME’s should accompany all IOW’s.

10.5. Sample points may be an interim process monitoring application where more data is needed to understand the process parameter and refine required frequency of measurement or sampling in order to justify the installation of future control or measurement instrumentation.

10.6. For IIL’s, several types of corrosion monitoring methods may be considered, including: corrosion coupons, corrosion and hydrogen probes, infrared thermography, and thermocouples.

10.7. It’s important that the appropriate monitoring equipment be specified and installed at strategic locations to provide the information necessary to determine if an IOW exceedance may be occurring.

10.8. Typically an agreed upon list of IOW’s will involve capital investment for monitoring and sampling systems and/or increased workload for laboratory analysis. This is because adequate monitoring and control systems may not be in place for each necessary IOW that has been established. Risk analysis and risk ranking is useful for prioritizing those investments and comparing them to all other capital and expense needs of the plant.

11. Updating IOW’s

11.1. The IOW list should be updated as needed to account for process changes, hardware changes, exceedance feedback, inspection results or new information about degradation mechanisms, or perhaps even a variable that was overlooked in the original IOW establishment process (not uncommon).

11.2. The MOC process should be applied whenever IOW variables are being revised or updated, utilizing the same types of experienced SME’s that were used to generate the original IOW list. If the generic site MOC process proves to be too time-consuming or burdensome for IOW updates, then a modified, streamlined MOC process specifically addressing IOW updates has proven for useful for some owner users.

12. Roles, Responsibilities and Accountabilities for IOW’s

12.1. Numerous personnel at the plant site have roles and responsibilities for IOW creation, implementation, and maintenance including those in:

- Inspection
- Corrosion/materials
- Operations
• Process engineering/technology
• Plant management
• Process Safety Management
• Laboratory
• Control systems

12.2. Inspection personnel have a role bringing data to the IOW team for creating and updating IOW’s, as well as adjusting inspection activities as necessary when IOW exceedances are reported to them.

12.3. Corrosion/materials specialists have a role in bringing the materials/corrosion degradation information and analysis to the IOW team for creating and updating IOW’s. A corrosion/materials specialist should also supply the CLD/PCD (where they are available), and estimated corrosion rates where measured rates for the current operating conditions are not available. They also have a role in understanding exceedances and advising inspection personnel on how inspection activities might need to be revised to account for the exceedance, if any, as well as advising process engineers on process issues that may be needed to avoid long term materials degradation issues. A corrosion/materials specialist will often have the role and responsibility of facilitating the IOW team, as well as documenting and distributing the results of the IOW work process. The corrosion/materials specialist may also have a role in providing operator training on IOW’s.

12.4. Operations has a role in bringing information about current operating practices and data to the IOW team for creating and updating IOW’s. They will also have information about the frequency of upset conditions. But their main role is in monitoring and responding to any IOW exceedances in the manner designated in the IOW control system and documentation. This would include obtaining water and process samples which have been identified as IOW monitoring points. Additionally operations have the responsibility to communicate any IOW exceedances in the designated manner to other designated stakeholders for their potential actions.

12.5. The unit process engineer has the role of bringing process design and engineering data to the IOW team for creating and updating IOW’s. Often the unit process engineer is the designated “owner” of the IOW list and responsible to ensure that all IOW’s are properly and continuously implemented in the manner designated in the IOW documentation. The owner of the IOW work process would also have the responsibility to ensure that exceedances were properly reported to others and a role in responding to exceedances and ensuring that responses to exceedances were handled and implemented in a timely manner.

12.6. Plant management has the role and accountability of ensuring that the IOW work process is adequately staffed with knowledgeable, experienced SME’s, that the work process is carried out in a timely manner, that all IOW’s agreed upon are implemented in a timely manner, and that adequate resources for monitoring, sampling and control systems are designed,
purchased, installed and implemented. Operations management would have the responsibility to ensure that all unit operators are adequately trained on IOW’s and their required responses to exceedances.

12.7. PSM personnel would have a role and the responsibility for ensuring that the IOW work process is fully adequate to meet the PSI aspect of local and federal regulations, as well as ensuring that the MOC process is properly utilized for making changes to the IOW list.

12.8. Laboratory personnel have a role in implementing, recording and reporting any required sample analyses used for IOW monitoring in a timely manner, per the IOW documentation.

12.9. Control systems personnel would have a role and the responsibility for designing, purchasing, installing and maintaining any control and monitoring systems for IOW’s used by operators.

12.10. The IOW team facilitator is often best accomplished by an experienced corrosion/materials or mechanical integrity specialist, either from the plant, a central office, or a third party. One of the facilitator’s roles should be oriented toward eliciting information about what is actually happening in the field relative to what is in the documented records or what is “thought to be happening” by those who are not operators. The facilitator needs to have the skill for asking the right probing questions in order to fully understand issues that may impact the IOW work process.

13. Integrating IOW’s with Other Related Work Processes

13.1. The IOW work process should be closely integrated with pressure equipment integrity (PEI) work processes (inspection and maintenance) at the plant site. As indicated in the introduction, the pressure equipment integrity work process can only be adequately accomplished when both work processes (PEI and IOW) are performing effectively with close interaction between the two work processes.

13.2. The IOW list and documentation should be a resource for PHA reviews and IOW team members should be ad hoc members of the process unit PHA review team. Any IOW exceedance that has occurred since the last PHA update should be reviewed by the PHA team (or as prework by the IOW team) to determine if actions or limits may need to be revised.

13.3. The IOW work process and documentation should also be a resource for the RBI work process, (and vice versa) especially since both require the same level of analysis of potential corrosion/materials issues and damage mechanisms. The analysis of IOW exceedances may affect the inspection plans generated by RBI, or any other modes of inspection planning, including time-based and condition-based inspection plans.
13.4. As indicated in section 1.4 and 11.2, the MOC process must be closely integrated with the IOW work process for any changes, additions or deletions to be made to the IOW list.
Appendix A: Examples of Potential IOW’s (Critical, Standard or Informational) for Generic Process Units

Example list of a few potential IOW’s for a generic amine process unit

- Amine concentration
- Water content
- Rich amine acid gas loading
- Lean amine acid gas loading
- Regenerator steam to feed ratio
- Velocity in rich amine piping
- Reboiler steam temperature
- Lean Amine temperature from the bottom of the regenerator
- Heat Stable Salt (HSS) concentration
- Iron content in circulating amine
- Sour water velocity from regen O/H condenser to reflux drum
- Amount of reflux being purged (% vol)
- NH₃,HS and CN levels in the overhead
- Temperature of acid gas piping to SRU
- Total suspended solids
- % vaporization after pressure letdown CV (if piping is CS)

Example list of a few potential IOW’s for a generic crude distillation unit

- Crude furnace tube skin temperature limits
- Crude furnace outlet temperature, minimum pass flow and stack temperature
- TAN limits on crude feed and cuts
- Pressure drop across furnace coils
- Salt/chloride content in feed streams
- Inlet/outlet temperatures in feed preheat exchangers
- Sediment content of feed streams and desalted crude
- Water content of feed and various process steams
- Desalter wash water rate
- pH, O₂ and NH₃ contents of desalter water
- Desalter efficiency, operating temperature and outlet salt content
• Hydrolysable and organic chloride limits downstream of desalter
• Caustic injection rate in the desalted crude
• Various distillation column top temperatures
• Pressure drop across column trays
• Overhead wash water rate
• Filming and neutralizing amine injection rates
• pH in water boots
• Iron, sulfates, chlorides, ammonia, tramp amine and hardness in overhead water boots
• Tramp amines in straight run naphtha and kerosene
• Oxygen ingress in vacuum systems
• Inlet/outlet temperatures for specific exchangers

Example list of a few potential IOW’s for a generic hydروprocess unit

• TAN, nitrogen, chlorides, fluorides, sulfur and water contents of feed streams
• Water content at outlet of coalescer
• HCL content of hydrogen makeup
• Chloride content of feed
• Inlet/outlet temperatures for specific exchangers
• Tube skin temperatures, stack temperature and minimum pass flow rates for hydروprocess heaters
• Hydrogen purity
• Reactor bed temperatures and pressure drops
• Wash water flow rates
• Cold separator sour water NH4HS and Chloride contents
• O₂, iron, ammonia, chloride and calcium in injected wash water

• NH₄HS content

• Hydrogen sulfide content in effluent, recycle gas and high pressure separator overheads

• Water carryover into fractionation and side strippers

• Fractionation overhead chemical injection rates and carrier flow rates

• Fractionation overhead sour water NH₄HS and chloride contents

• Maximum temperature and pressures for start-up and cool down of reactors

Example list of a few potential IOW’s for a generic sulfuric alkylation process unit

• Water content of feeds and coalescer outlet

• Feed make up oxygenates, sulfur, and non-condensables

• Coalescer water boot pH and temperature

• Water in acid in reaction system and velocities in carbon steel piping

• Reactor temperature and contactor motor amps

• Settler operating pressure

• Effluent Exchanger outlet temperature

• Acid precipitator amps & voltage

• Acid loss and polymer production

• Fresh, circulating and spent acid strength

• Temperature and caustic strength in caustic wash system

• Temperature and velocity maximums for carbon steel piping in caustic wash system

• Acid and caustic carry over

• Water boot pH

• Delta P in some exchangers (salt deposition)
Example list of a few potential IOW’s for a generic steam methane reformer unit

- Feed gas condensate pH
- H₂S content of feed gas (if refinery gas is used)
- Hydrotreater & Desulfurizer – Temperatures and hydrogen partial pressures
- Heater furnace tube temperatures
- Heater steam to carbon ratio
- Temperature of syngas to low temperature shift reactor and PSA
- Chloride and ammonia (e.g. brass tubes present) content of process condensate
- Corrosion inhibitor limits in hot potassium carbonate solutions

Example list of a few potential IOW’s for a generic fluid cat cracker unit

- Catalyst hopper temperature
- Expansion joint maximum temperatures
- Fractionator bottoms slurry content, temperature and sulfur content
- Volumetric flow for cyclone underflows
- Delta P for slurry pump suction strainer
- Gas oil temperatures and sulfur maximums
- Fractionator overhead top temperature
- Fractionator wash water and polysulfide rates
- Fractionator overhead pH, ammonium bisulfide, sulfides, carbonates and chloride content
- Wash water rate for wet gas compressor interstage condenser
- Wet gas compressor interstage separator boot pH, sulfides, ammonium bisulfides, chlorides, and cyanides

Example list of a few potential IOW’s for a generic delayed coking process unit
• TAN, total sulfur and sodium of coker feed
• Coker furnace tubeskin temperatures
• Pressure drop across furnace coils
• Rate of velocity steam Injection or process flow rate through radiant coils
• Rate of water injection in fractionator overhead, compressor interstage and compressor final stage
• Ammonium polysulfide activity in injected water.
• Ammonia, iron, cyanide, carbonate, chloride, pH in water from fractionator overhead accumulator and compressor discharge receivers. Calculate ammonium bisulfide.
• Water fraction in stripper bottoms product and rate of water draw off of stripper water separator.
• Velocity in sour water piping.
• Maximum diffusible hydrogen in the compressor drums and absorber
• Water fraction in debutanizer overhead product and rate of water draw off in debutanizer overhead receiver
## Appendix B: Sample Format for Recording IOWs

<table>
<thead>
<tr>
<th>Equipment and/or process stream</th>
<th>Parameter to be monitored or controlled</th>
<th>IOW type and limit</th>
<th>Comments/Reasons/Actions</th>
<th>Party Responsible for monitoring and control</th>
</tr>
</thead>
<tbody>
<tr>
<td>e.g. FCCU feed, fractionator OH, slurry system, reactor, heat exchanger outlet, chemical injection, etc.</td>
<td>e.g. temperature, chlorides, sulfides, water content, cyanides, salts, flow rates, etc.</td>
<td>e.g. Standard max Standard min Critical max Critical min, etc. Informational Target range</td>
<td>e.g. Explain why the parameter is being measured and what can happen if it is exceeded. Explain how the operator needs to respond and how fast. Explain how the parameter is to be measured and how frequently. Explain who is to be notified in the event of an exceedance.</td>
<td>e.g. process engineer, operator, chemical treatment vendor, corrosion specialist, etc.</td>
</tr>
</tbody>
</table>
Appendix C: Example of an IOW Development for a Heat Exchanger

In this hypothetical example, a Crude Unit Fractionator Tower bottoms exchanger (X-1) is potentially under alloyed for future service (sulfidic corrosion concern). Based on the current feed slate to the unit, the actual measured corrosion rate is acceptable, but the refinery is planning to process additional higher sulfur crudes in the near future. This exercise will look at the data development and thought process involved to set appropriate IOW’s for this hypothetical exchanger.

Step 1 – Define the Operation

This Crude Unit has been receiving a steady diet of blended crudes containing 0.37 % total sulfur with a TAN averaging 0.75. This X-1 exchanger is utilized in the Atmospheric Gas Oil (AGO) stream (although it can also be used in Atmospheric Tower Bottoms (ATB) service) and has an operating temperature at 650 degrees F with little to no temperature variation. There is a desire to increase the total sulfur in the AGO in the future from 0.37 up to 0.50 wt% and trial operating runs are currently planned. The next full outage that would provide an opportunity to inspect, repair or replace this exchanger is 5 years from the proposed change.

Step 2 – Corrosion / Damage Mechanism Identification

The X-1 exchanger was fabricated from carbon steel on the shell side (receives an AGO or ATB stream) and operates at 650 degrees F with an estimated 0.75 wt% sulfur (total). The primary damage mechanism of concern is sulfidation; naphthenic acid has not been a concern in this Unit. The estimated corrosion rate potential utilizing the Modified McConomy Industry curves is approximately 25 mpy (the current measured corrosion rate is only 10 mpy). Differences between the theoretical/potential rate and the measured/observed rate are likely due in part to the amount of reactive sulfur available in the specific Crude slate. The metallurgy for this exchanger is may be under-designed for the new application. Changes in the crude slate which will increase the amount of reactive sulfur may produce significant changes in the corrosion rate even with the same/similar total sulfur concentration in the tower bottoms stream.

Step 3 – Determine the Parameters that will affect the Reliability of this Equipment (Long Term)

- Crude Slate / Blend
- Total Sulfur at AGO Cut
- Reactive Sulfur at AGO Cut
- Total Acid Number (TAN) at AGO Cut
- Operating Temperature (and time if variable) at X-1 Shell
- Velocity of Process Fluid
Step 4 – Define the Critical Operating Parameters (measurable & controllable)

Sulfidic corrosion is a co-dependent process that is based on the amount of reactive sulfur present and the temperature for a given material of construction. Sulfidation rates may be accelerated by naphthenic acid and velocity of the process fluid both which act to remove the protective iron sulfide scale that develops as a process of sulfidic corrosion. In general the refinery does not measure or monitor reactive sulfur species but relies on total sulfur measurements. There is a moderate to high corrosion rate potential based on a theoretical analysis. The operating temperature and total sulfur content of the AGO stream are the primary operating parameters that will be targeted (controllable by the crude slate being run).

- Total Sulfur at AGO Cut (primary IOW)
- Total Acid Number (TAN) at AGO Cut
- Operating Temperature (and time if variable) at X-1 shell

Step 5 – Safety Factor Basis (Considerations)

Currently this exchanger has a calculated remaining life of 10 years based on the historical measured corrosion rate. Utilizing the estimated corrosion rate of 25 mpy the remaining life drops to 4 years. Since the primary crude slate will not change significantly, only small additions of higher sulfur crude will be added into the overall mix, the corrosion rate is not expected to vary significantly from the historical measured rate. Based on these factors, a 2X (or ½ life) safety factor was selected as the basis for limiting the sulfur and temperature of operation for the IOW.

Step 6 – Set Limits on the Critical Reliability Operating Parameters

Based on a desired operating period of 5 years (Turnaround interval) with a 2X safety factor, the remaining or usable corrosion allowance is 0.100”. From a fixed operating temperature of 650 degrees F, the total sulfur amount in the AGO stream needs to be limited to 0.30 wt% in order to ensure reliable operation over the specified operating period. This limit then becomes an IOW for the X-1 exchanger.