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FE Analysis and Visual Presentation Methodology of Mechanical Systems

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Abstract

The operation of a large industrial or other complex mechanical system incorporates a variety of mechanical and electrical subsystems to perform a given task, some of which require interaction by an operator or worker to oversee and control the process. As with anything mechanical, the system also requires periodic maintenance and replacement of worn parts. During the operation of industrial systems, problems can occur and result in catastrophic failures and/or injury. When applying forensic analysis to such failures, a methodical approach is necessary to allow for a deeper understanding of the overall operation of the system. However, once the forensic analysis has been performed, conveying the findings of such a complex system can be challenging. To assist in describing the system and failure, the use of visualization is a powerful tool to clearly convey the findings as well as normal operation. The following paper outlines the process of building a methodology to investigate and lay the proper foundation for visually presenting the findings. To demonstrate the methodology outlined in this paper, a case study involving a boiler system will be used.

Keywords

Mechanical, visualization, failure, operator, maintenance, animation, graphics, boiler, design, pressure vessel, forensic engineering

Introduction

Before any detailed graphics or animation can be produced, a forensic analysis must be performed of the mechanical system. For the purposes of this paper, an outline will be discussed to assist with the steps needed to produce a compelling visualization.

There are three main areas of focus: operation of the system during normal operation (including the interaction of the operators and maintenance performed); operation of the system at the time of the failure (including the actions of operators and any work or maintenance performed leading up to the failure); and analysis of the failure (including specific components, processes, maintenance, or operator error).

Analysis of mechanical systems failures requires an engineer to first understand the processes, components, and materials that comprise the system — and what functions they perform during normal operation. While there are endless types and variations of mechanical systems, a basic understanding of the parts and steps performed can be developed through reviewing available resources and creating a simple model of the order of operations. When a mechanical systems analysis is required, a failure in the system and/or an injury to an operator or bystander has occurred. Therefore, it is beneficial to start with identifying the likely locations or components in the system that were involved in the failure or injury. Focusing the analysis on specific components or subsystems can simplify the analysis process of a larger system.

Normal Operation

The first step in performing a forensic analysis is to determine the operation of the system under normal circumstances. Forensic engineering investigations include varying levels of documentation, such as photographs or drawings of the system. It is common to encounter systems that are commercially available, in which case research into the product or system can provide significant information on the operation and components. However, some failure analyses will be performed on proprietary systems or something adapted without formal documentation during operation to improve function of the system. In these cases, reviewing operator and witness statements, formal and informal notes, technical drawings, and/or any available photographs or video is the best resource for developing an understanding of the system operation.

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Identifying Failure

Identifying the point of failure or injury during operation of a mechanical system begins with reviewing six possible sources of mechanical failure: system design, construction/installation, maintenance, operator actions, modifications, and passive safety (such as safety guards, warnings, and labels).

System Design: The original design of a system can be analyzed through review of provided technical drawings, proposals, or requests for bids for construction and statements or testimony from the manufacturer, architects, or engineers involved with the design of the mechanical system. There are times when the design has not been fully vetted prior to the introduction into the public, and a failure due to design can occur. However, most designs are thoroughly reviewed and tested prior to distribution with factors of safety incorporated into the system for their intended use. Therefore, it is important to review the original design intents of the system or its components, as this can aid the engineer in determining possible failure modes in the system.

Construction/Installation: Mechanical system construction or installation is a potential source of failure and/or injury. Improper installation or construction can introduce unintended failure points that were not part of the initial design or intent. Review of “as-built” drawings, if available, and comparison with photographs of the system at the time of failure can provide insight as to whether the installation or construction meets the requirements of the system manufacturer — or if there are any deviations from original design that may introduce issues in the system that result in failure or injury.

Maintenance: System maintenance should be considered and reviewed for its adherence to manufacturers’ specifications or service intervals, along with the actual maintenance performed. Determine if maintenance was conducted properly with the correct components or with the appropriate repairs. Deferred or incorrectly performed maintenance is an obvious point at which problems can begin for a complicated mechanical system, such as ignoring a low oil pressure warning light on a vehicle’s dashboard until the engine seizes due to lack of lubrication.

Operator Actions: Most mechanical systems require human interaction at some point in the processes for proper function, or, at a minimum, require oversight and analysis of system conditions during operation. Identifying the locations and functions of each operator associated with the system is important to defining the normal operation of the system, since the points at which operators or monitors are present can often be keys to determining where the process began to go wrong during a failure or injury incident. Much like the pilot of a plane, at times, the most vital cog in a mechanical process is the person interacting with the system.

Modifications: There are times when the design and construction or installation was done properly but was modified at some point during operation. Sometimes, the operator may bypass a safety feature for convenience, the parts for replacement were not available, and the system was changed to accommodate continued operation. The demands of the system or equipment may change from the original intent, resulting in overexerting the design and failure. Modifications can be determined by understanding the original intended operation or design and comparing it to the operation or design at the time of the failure.

Passive Safety: The design or operation of a mechanical system, at times, may pose certain hazards to operators or the public due to the utility of the system. Controlling operator exposures to hazards can be achieved using a safety hierarchy. The safety hierarchy has been expressed in several ways by various authors and governing bodies; however, the main ideal is the same: design, guard, and warn. One example of this principle is from the National Institute for Occupational Safety and Health (NIOSH).

NIOSH focuses on controlling the exposure to occupational hazards to implement feasible and effective control solutions. NIOSH outlines a hierarchy of controls that rates the most effective solution to the least effective[1]. The following outlines the NIOSH Hierarchy of Controls:

1. Elimination — Physically remove the hazard.
2. Substitution — Replace the hazard.
3. Engineering Controls — Isolate people from the hazard.
4. Administrative Controls — Change the way people work.
5. PPE — Protect the worker with personal protective equipment.

In *Safety and Health for Engineers*, Brauer lists a set of priorities that is helpful in selecting controls for hazards that some call the “Design Order of Precedence” as[2]:

1. Eliminate the hazard.
2. Reduce the hazard level.
3. Provide safety devices.
4. Provide warnings.
5. Provide safety procedures (and protective equipment).

Manuele, in *On the Practice of Safety,* cites the hierarchy of controls from ANSI/ASSE Z590.3, the Prevention through Design standard[3]. The standard outlines the following as:

1. Eliminate hazards and risks through system design and redesign.
2. Reduce risks by substituting less hazardous methods or materials.
3. Incorporate safety devices (fix guards, interlocks).
4. Provide warning systems.
5. Apply administrative controls (work methods, training, etc.).
6. Provide personal protective equipment.

The above provides a general outline to the safety hierarchy; however, there are more specific standards for differing types of equipment, such as ANSI B11.19 (Performance Criteria for Safeguarding), ANSI B11.0 (Safety of Machinery-General Requirements and Risk Assessment), ANSI Z244.1 (Control of Hazardous Energy: Lockout), and ANSI Z10 (Occupational Health & Safety Management Systems) to list a few.

During the design process, any potential hazards should be eliminated through design revisions. However, there are times when the hazard cannot be removed without taking away the utility of the machine/process or introducing unintended consequences. When the potential hazard cannot be eliminated, the manufacturer should guard against it with physical devices and/or electric switches. Many exposed hazards, such as rotating machinery or pinch points, can be physically guarded to prevent inadvertent interaction from an operator. If access is needed into the guarded area, a movable guard equipped with electrical interlocks can be installed to assure that the guard is in place before the machine is operated. As a next layer of protection from a hazard, warnings, labels, training, and procedures should be used to inform the operator of the potential for injury and the steps to prevent hazards from occurring.

While analyzing the failure, review the potential hazards, warnings, and procedures to determine relevance to the incident and adherence by the operator. At times, the guards designed by the manufacturer are circumvented by the operator or owner of the machine, or the warnings are ignored. The owner of the machine is typically responsible for the equipment maintenance and complying with the manufacturer’s recommendations on the proper use and operation of the machine. At other times, the guards and warnings are not present, and the user unknowingly places him or herself in harm’s way.

Operation at the Time of the Failure

After a failure has occurred, there can be catastrophic damage system-wide that complicates finding the source of the failure. Therefore, the first step in the analysis is to focus on what took place right before the failure occurred to assist in narrowing down the root cause. Compare the conditions of the system and the personnel leading up to the failure. There are three main areas to focus on: recent maintenance, operation parameters, and operators/personnel.

Recent Maintenance or Repairs: Starting from the time of the failure, review any recent maintenance that was performed or any changes in process that may have occurred just prior to the failure. Work backward in time by reviewing the history of the maintenance or repairs, and determine if there is a pattern or reoccurring issue that caused or contributed to the ultimate failure. If there is a reoccurring issue presented in the maintenance records, the cause could be due to the parts installed, the original construction/installation, or the repairs performed. It may be found that the maintenance or repair was proper; however, the application of that part or system was undersized or under-designed to accommodate the requirements of the system.

Operation Parameters: This leads to the next phase of evaluating the failure — the controls and operating conditions of the system at the time of the failure. Review any reports, statements, recorded data, and/or video that may show what the operating conditions of the system were at the time of the incident. Compare the operating temperatures, pressures, speeds, and sequences to that of normal operation. If any of the parameters differ from that of normal operation, determine if they contributed to or caused the ultimate failure.

Operators and Personnel: The operators may have also contributed to the incident. A procedure or step in the process may have been omitted for the sake of time, apathy, or miscommunication. The operator may be required to perform a safety check that was skipped or did not notice warnings presented. Additionally, an inexperienced or inadequately trained operator may not understand the proper and safe operation of the machine. Review of the operator's training records may be helpful in determining whether the operator had proper training prior to the incident.

Sometimes, the cause of the incident or failure can be a combination of the above that occurred in the right sequence to lead to an unstable condition. For example, the replaced part was in the process of failing; however, the monitoring systems showed a drop in pressure or reduction in speed that was missed, ignored, or misinterpreted. The problem persists and is allowed to continue until the ultimate failure occurs.

Case Study

To help illustrate the analysis procedure, the following case study outlines a failure of a boiler system. It does not incorporate every aspect of potential failure sources in a mechanical system, but it does encompass many of the areas associated with a catastrophic failure. It discusses the events leading up to the failure, but, more importantly, the time line and analysis are explained with the use of graphics. Unfortunately, dynamic animations of the operation of the system cannot be included due to the limitations of a static paper.

The incident, which occurred in April 2017, involved a storage tank that stored steam condensate, which was used in a commercial manufacturing process. The tank measured 30 inches in diameter and 17.5 feet tall and weighed approximately 2,000 pounds. At the time of the incident, the tank contained approximately 510 gallons of condensed steam at a temperature of 330°F and pressure of 100 psig[1]. The tank, which is referred to as a "semi-closed receiver" or SCR, received surplus steam from the plant, and allowed additional hot water makeup from an external reservoir with a vent to the environment. **Figure 1** shows an exemplar tank highlighted with a yellow circle.

Figure 1
Exemplar SCR highlighted by the yellow circle
(photograph taken by Kineticorp).

At the time of the incident, the bottom cap of the tank failed, allowing the pressurized water in it to flash instantly into steam. The volume of steam produced was approximately 75 times that of the water volume of the tank[4]. The amount of energy instantaneously released was equivalent to 350 pounds of TNT, which was mainly directed in rocketing the tank through the roof of the building and propelling it 425 feet into the air. The tank traveled in a parabolic trajectory for more than 10 seconds and landed 520 feet laterally away from its original location at a speed of approximately 120 mph at impact[4]. The tank crashed through the roof of a neighboring commercial building and fatally injured three individuals. **Figure 2** shows the final resting location of the SCR tank in the commercial building.

System Design: The system is semi-closed, which means that some of the steam (energy) is lost due to use by the machines in the plant and environment. The steam

Figure 2
Resting location of the SCR tank through
the roof of the commercial building[4].

is produced by heating water in a steam generator, which is powered by natural gas, and then fed into a separator. The steam to the plant operates at 175 psi and 375°F. The separator splits the steam into dry steam, which feeds the machines in the plant, and wet condensate, which is fed back into the top of the SCR tank. In order to recoup energy in the system, the SCR tank also receives excess steam from the plant, which is fed into the top of the SCR. The SCR tank stores the condensed steam at 100 psi and 330°F, and feeds the steam generator during operation, creating a loop.

Due to various inefficiencies (such as venting when the pressure is too high or leaks present in the system), the process loses steam. When a sufficient loss of water occurs — and the level in the SCR tank drops below a specified limit — an atmospheric temperature-controlled makeup tank (labeled a Hotwell) feeds heated water into the top of the SCR. The makeup water supplied to the SCR tank is filtered and treated to reduce impurities and maintain a proper pH balance. **Figure 3** shows a diagram of the steam generating process with annotations by the author showing the flow direction of the steam. This sketch was created as an early step of system understanding and documentation.

SCR Tank Design: The entirety of the SCR tank was constructed of SA-516-70 carbon steel and designed to meet ASME Section VIII Div. 1 recommendations of Construction of Pressure Vessels[5]. The SCR was inspected and registered with the National Board of Boiler and Pressure Vessel Inspectors (NBBI) in February of 1997[4].

The SCR tank is vertically mounted and capped at both ends with an ellipsoidal steel dome. The bottom of the tank is fitted with a steel skirt that allows the tank to rest level on the ground and room for a drain at the bottom of the tank. According to provided plant operations procedures, the tank was drained weekly to remove any sediment or contaminants that accumulated during use.

At the upper portion of the tank are two spargers that receive condensed steam from the boiler and recovered steam from the plant. The bottom portion of the tank has an outlet to the boiler and a drain mounted to the very bottom of the ellipsoidal dome. **Figure 4** shows the SCR labeled with the respective components and a shadow outline of an average male adult for scale.

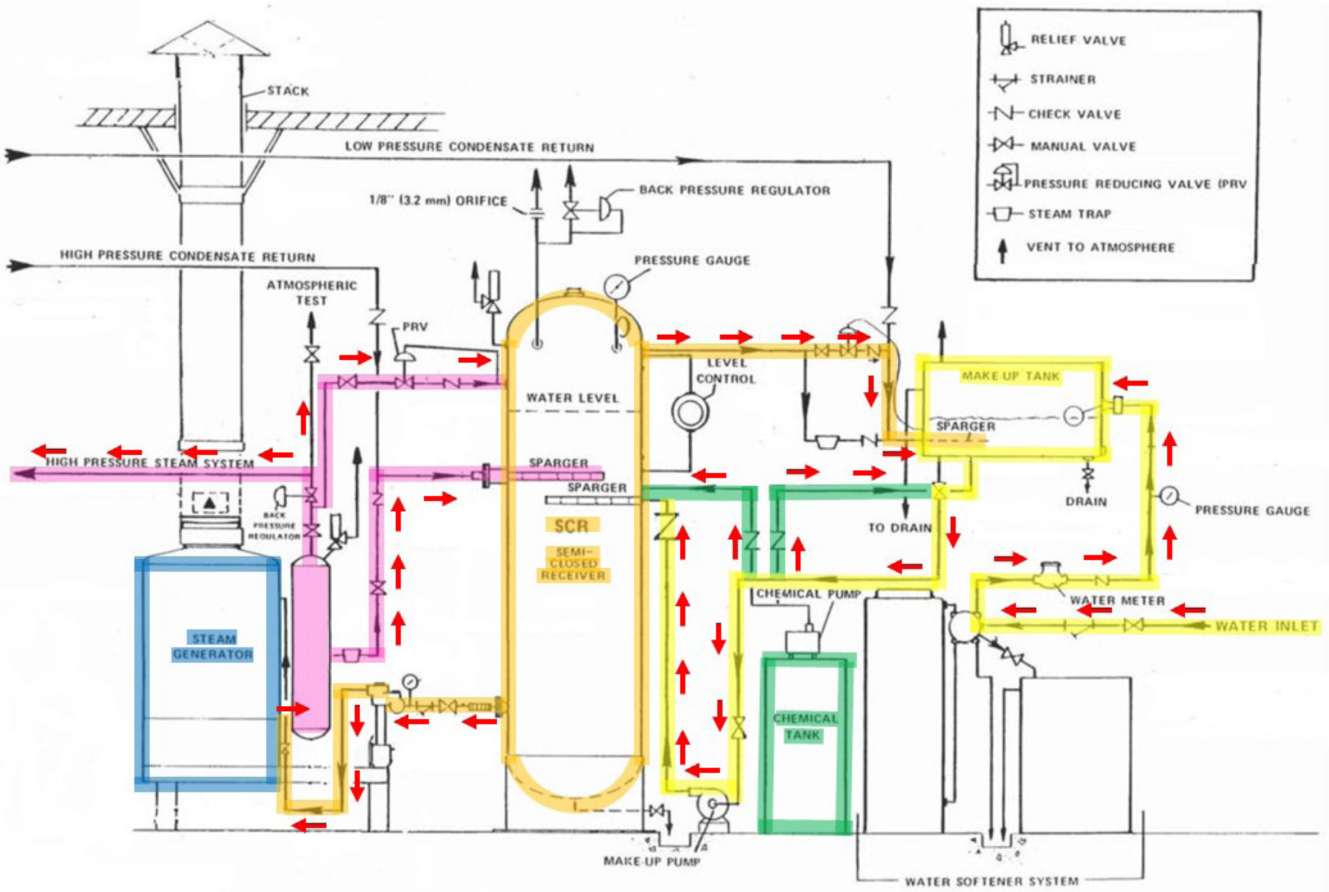

Figure 3
Schematic of the steam generation process, showing direction of flow highlighted by the author.

Repair and Maintenance: In 2012, plant maintenance engineers noticed a leak originating from under the skirt of the SCR tank. They preliminarily inspected the source of the leak by cutting a small access hole in the side of the skirt and determined that the source of the leak was originating from the bottom of the tank. The engineers then contacted an independent engineering company to perform the repairs in the SCR tank.

Inspection of the inside of the tank showed that the lower ellipsoidal dome became pitted and had the appearance similar to the "surface of the moon"[4]. It was decided that the bottom of the head should be sectioned off and repaired. The location of the cut was made at the welded union between the skirt and the side of the tank for ease of repair. The lower section of the skirt (as well as the bottom) were removed. See **Figure 5** for location of the cut on the skirt and the bottom cap.

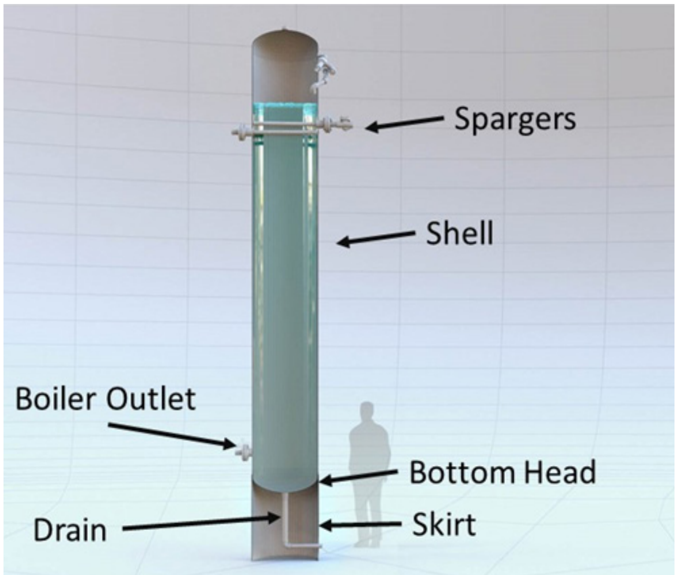

Figure 4
SCR with labeled components with a shaded outline of an average adult male (image produced by Kineticorp).

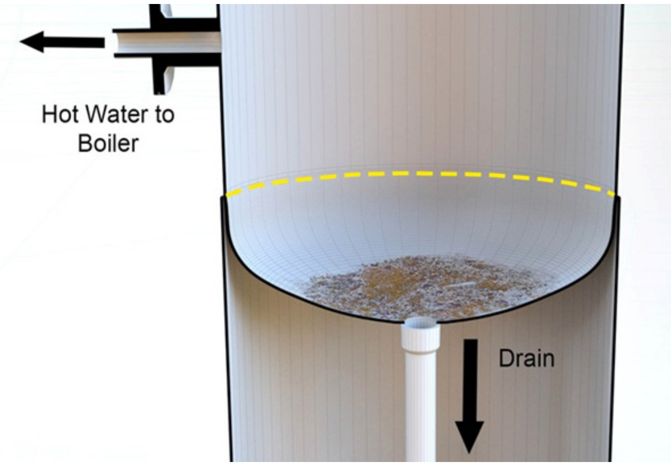

Figure 5
The yellow line shows where the skirt was cut to access the bottom cap (image produced by Kineticorp).

After removing the skirt, a 24-inch-diameter circular section was cut and removed from the center of the bottom cap and replaced with a new steel piece to act as a patch. After the removal of the 24-inch diameter section, 6 inches remained of the original bottom cap. **Figure 6** shows the 24-inch-diameter section removed with 6 inches of the original bottom cap remaining.

The new patch was then welded to the remaining 6-inch ring from the original ellipsoidal cap, and a hole was cut in the patch where the drain was then welded in place. The repaired bottom cap and the skirt were then reattached to the tank of the SCR using a 1-inch-wide and 0.25-inch-thick backing ring behind the weld. **Figure 7** shows the backing ring, 6-inch ring, and patch after the repair.

The repair company followed up 25 days later with a proposal to fabricate and replace the entire lower 4 feet of the tank, including the bottom cap with a new 2:1 elliptical design. The material used would also be 50 percent thicker to allow for corrosion. The 4-foot tank bottom replacement never occurred[4].

Failure: Four and half years after the repair was performed, the plant engineer again noticed a leak originating from the bottom of SCR tank on March 31, 2017. Using the access hole cut in the skirt in 2012, the plant engineer took a picture of the bottom cap of the SCR tank to

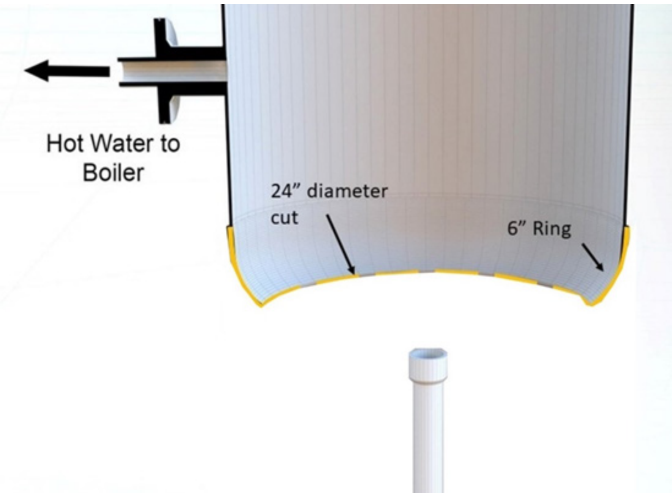

Figure 6
24-inch diameter section removed from bottom cap with the original 6-inch ring of cap remaining (image produced by Kineticorp).

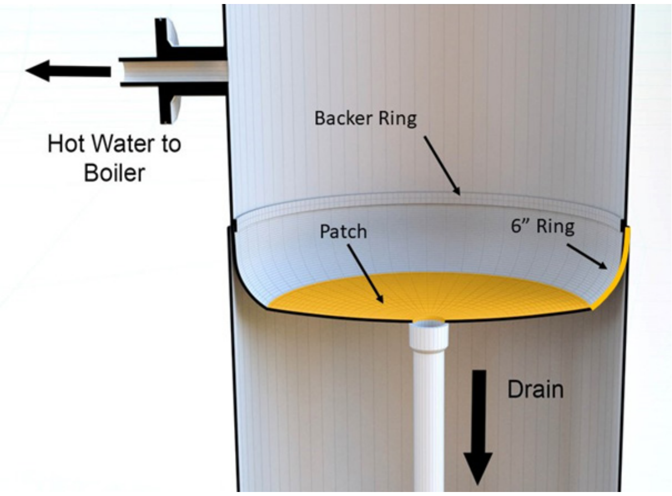

Figure 7
Backer ring, 6-inch ring and repair patch
(image produced by Kineticorp).

document the leak. **Figure 8** is the photo taken by the plant engineer showing the leak. In the photograph, the seam can be seen where the 24-inch-diameter patch was welded to the original 6-inch bottom cap. The image shows two locations where the wet and rusted paths originated from the seam where the patch was welded to the bottom cap.

The system was shut down, and the repair company was contacted to come out and perform repairs the following afternoon on April 3. That morning, the steam generation system was started up, and the catastrophic failure occurred at the end of the startup process — three days after the initial leak was first found.

Analysis of the Failure: The cause of the mechanical failure can be attributed to several issues present in the tank. The Chemical Safety Board (CSB) investigated the incident and found that "the vessel failed due to corrosion of the 6-inch ring of the original bottom head, resulting in the circumferential split of the ring and subsequent separation of the entire tank circle from the SCR."[4] The CSB found the original 6-inch ring that was left in place during the repair was heavily corroded, and the reduced thickness of the material provided an inherent circumferential weakness that allowed the patch to separate from the tank.

Figure 8
Picture taken by the plant engineer
showing the leak from the bottom cap of the SCR.

Inspection of the bottom cap shows that the separation occurred above the weld and originated on the 6-inch ring. **Figure 9** shows the repaired bottom cap with the 24-inch patch after the failure with labels showing the patch, weld, and original 6-inch ring. An image from the CSB report, **Figure 10** shows the steel shell (patch), which was clean, and the original 6-inch ring, which was heavily corroded.

The thickness of the 6-inch ring at the time the SCR

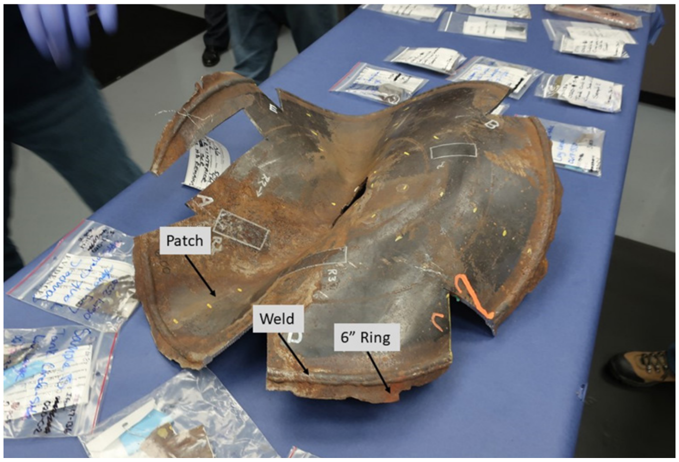

Figure 9
Repaired bottom cap with the 24-inch patch
after the failure (photograph taken by Kineticorp).

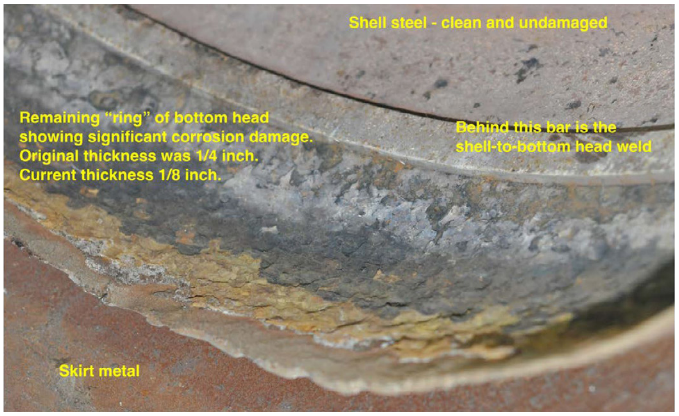

Figure 10
An image from the CSB report showing
the corrosion of the 6-inch ring.

tank was manufactured was ¼ inch. After the failure, the thickness of the 6-inch ring was measured at $^1/_8$ inch, a reduction in material of $^1/_8$ inch. To better visualize the reduction of thickness, **Figure 11** shows a cross-section of the skirt, the original 6-inch bottom cap, and the backing plate.

Although the reduction in the thickness due to corrosion of the original 6-inch bottom cap was the ultimate cause of the failure, the shape and design of the 24-inch patch also played a role. When the patch was installed, the size was sufficient to cover the removed bottom section; however, the shape did not match the original ellipsoidal profile. **Figure 12** shows the shape of the bottom cap with the repaired patch piece compared to the original bottom cap. As can be seen in **Figure 13**, the patch piece is much flatter compared to the original ellipsoidal-shaped bottom cap with the maximum deviation of 2.4 inches measured at the apex.

The ellipsoidal bottom cap is also called a 2:1 ellipsoidal head due to the relationship of the height of the head relative to the diameter (D), where the distance to the top of the head is a quarter of the diameter (d = 0.25D). The standards and codes related to pressure vessels are prescribed by the American Society of Mechanical Engineers (ASME). The design of the ellipsoidal head is outlined by ASME in paragraph UG-32 Code Section VIII, Division 1[5]. The height to the center of the cap in the original bottom cap measured approximately 6.8 inches while the new patch height measured 4.4 inches. The difference in height changes the distribution of the forces along the surface of the bottom cap, which, in turn, increases the stress. The combination of the reduced wall thickness and the increased stress results in an accelerated failure.

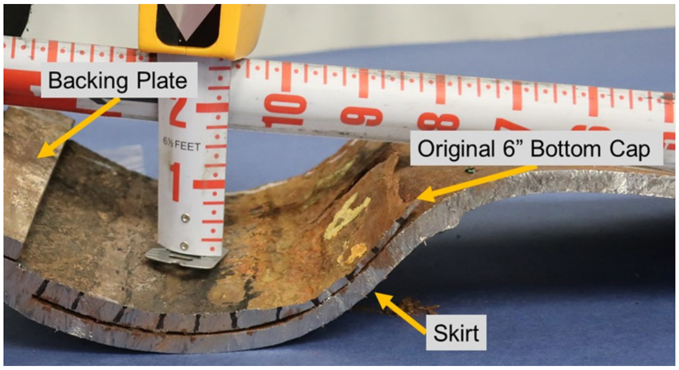

Figure 11
Cross-section of the skirt, the original 6-inch bottom cap, and the backing plate (image taken by Kineticorp).

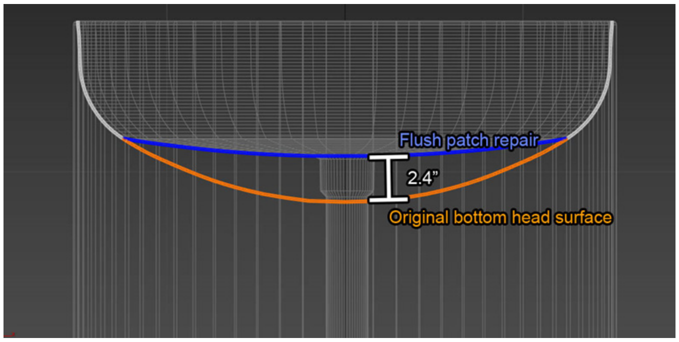

Figure 12
Comparison of the flat patch piece to the original ellipsoidal bottom cap (image produced by Kineticorp).

The repair to the head of the pressure vessel changed the shape. The original certified shape was a 2:1 ellipsoidal. After the repair, the shape of the head became torispherical. A torispherical surface is obtained from the intersection of a spherical cap with a torus tangent. The radius of the sphere is called the crown radius, and the radius of the torus is called the knuckle radius. The torispherical shape of the head of the pressure vessel increased the stress and reduced the safe operating pressure. **Equation 1** below is the calculation for the max allowable internal pressure of a 2:1 ellipsoidal head[6], and **Equation 2** is the calculation for the max allowable internal pressure in a torispherical head[6].

$$p = \frac{2SEt}{KD_0 - 2t(K-0.1)} \quad \text{Equation 1}$$

Where: p = pressure in psi
S = allowed stress in psi
E = efficiency
t = wall thickness in inches
K = factor (K=1 for 2:1 ellipsoidal heads)
D_0 = outside diameter in inches

$$p = \frac{2SEt}{ML - t(M-0.2)} \quad \text{Equation 2}$$

Where: p = pressure in psi
S = allowed stress in psi
E = efficiency
t = wall thickness in inches
M = factor, $M = \frac{1}{4}\left(3 + \sqrt{\frac{L}{r_k}}\right)$
L = crown radius in inches
r_k = knuckle radius in inches

When comparing the maximum pressure allowed with the two formulas in **Equation 1** and **Equation 2**, the maximum pressure is reduced 78% from changing the head from an ellipsoidal to a torispherical shape. The change in the geometry of the head at the time of the repair was a contributing factor in the cause of the failure.

The failure of not replacing the temporary bottom cap with the properly designed ellipsoidal cap was a significant factor in the ultimate cause of the failure. Additionally, the procedural failure of not initiating a lockout/tagout of the system — and allowing the boiler to be restarted after the additional leak was identified — also contributed to the failure.

Case Summary: The above case study was one example of a mechanical failure that led to a catastrophic failure. The full details of the events leading up to the incident, the research performed to determine the normal operation of the boiler system, and the events leading to the failure (as well as the analysis performed) are too great for the scope of this paper. The point of the case study was to show all the various entities and parties involved that led to the ultimate failure.

What the case study shows is that although the ultimate failure was sudden and spectacular, the events leading up to the event took place over a long period of time. A problem with the tank was recognized early on, and the repair to the bottom cap was insufficient. However, when a proper repair proposal was submitted to the plant, it was ignored. Even with the insufficient repair, the SCR tank stayed in operation for another 4.5 years before another problem occurred. When the final leak was found, the system was shut down, and a request was made for repairs. However, the boiler was started back up in the morning before the repair could be made. There were multiple signs of problems along the road to the ultimate failure — had any of them been properly addressed, the sudden rupture of the tank may not have occurred.

Presentation

Once an understanding of the system operation has been developed, articulating its basic design and function to others is the next challenge. Presentation of mechanical systems analysis to the layperson is a complicated undertaking, as the system is often technical and involves physics, thermodynamics, or statics to perform a function or output a final product.

Boiling down the system operations and components into a basic flow chart is the first step toward producing a system diagram that outlines the main components, functions, and operators (if required) for normal operation of the mechanical system. Utilizing simplified models of the components of a system in visual form helps relate the models to their real-life counterparts seen in photographs or video of the system. Simple 3D models of components in the system can be placed into an environment where the flow chart of system functionality can be presented from various angles or perspectives, allowing the presenter to show different segments of the system dynamically. **Figure 13** shows the boiler system from the above case study, along with the simplified 3D model of the system.

As shown in **Figure 13**, the steam generator, semi-closed receiver, makeup tank, and associated piping are all present in the 3D model with similar sizes and shapes as the actual components. However, the wire frame model is easier to digest for viewers (with color coding of components and labels for clarity and identification).

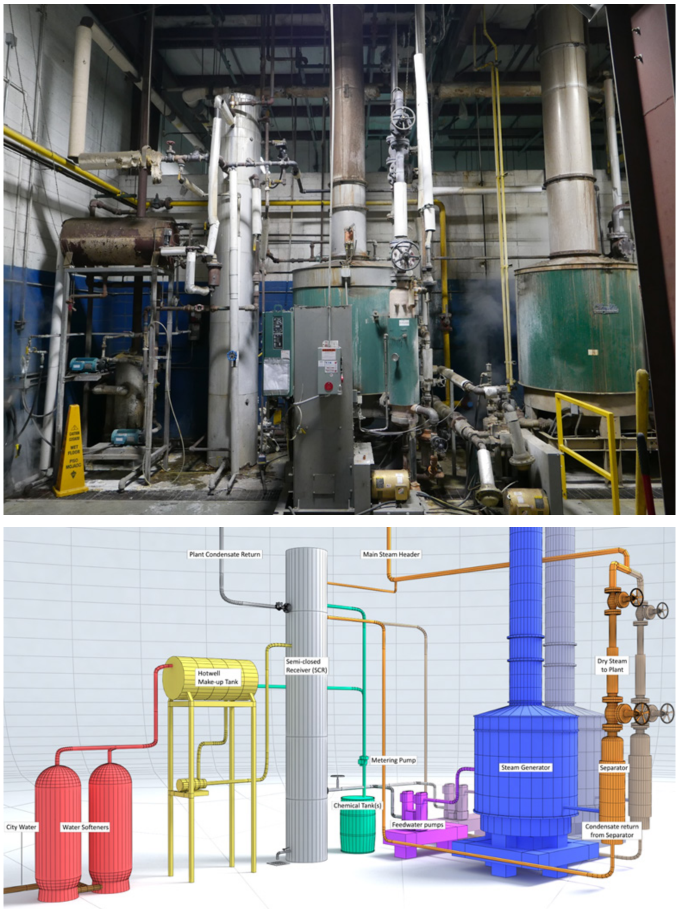

Figure 13
3D model flow (image produced by Kineticorp)
with comparison photograph (taken by Kineticorp).

The 3D model animation style has additional benefits, such as being able to isolate sections of the system for further detailed visualization. In the case of the example, the semi-closed receiver is of particular interest. In the 3D model, the section of the system encompassing the semi-closed receiver and its associated components in the system processing sequence can be isolated and shown with additional information, as shown in **Figure 14**.

In addition to isolating sections of the system, alternate camera perspectives can be applied to the same 3D models to illustrate other functional components or features — in this case, the blow-down process for the semi-closed receiver. As shown in **Figure 15**, the initial camera position showing the entire 3D model of the system can rotate and focus in on the bottom of the SCR tank to show the drain out the bottom of the tank and through the tank skirt, along with the blow-down valve for draining the tank.

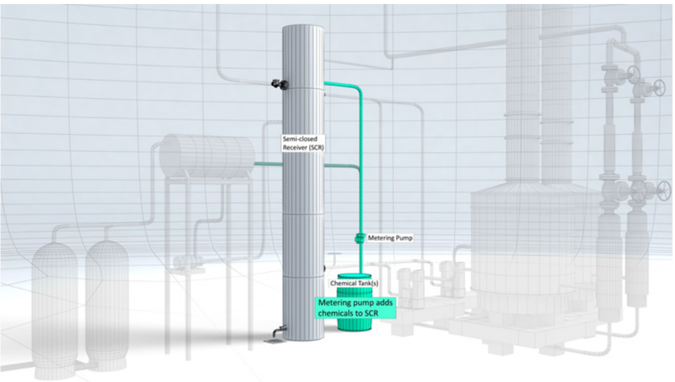

Figure 14
3D model isolating SCR and chemical tanks
(image produced by Kineticorp).

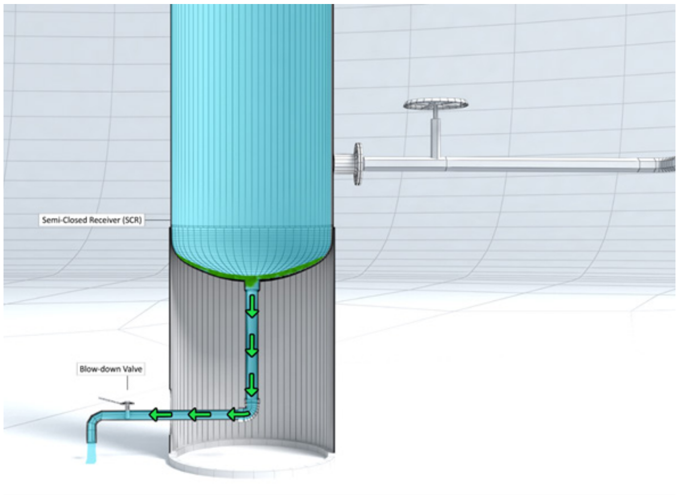

Figure 15
Secondary camera perspective of 3D model
(image produced by Kineticorp).

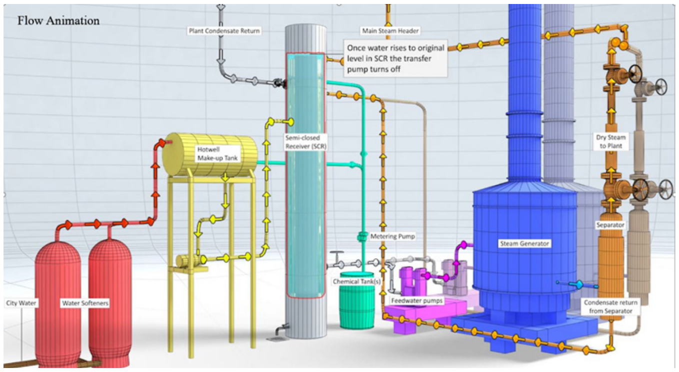

Figure 16
Graphic showing the direction of flow with
equipment labeled (image produced by Kineticorp).

In the animation that the image is taken from, the arrows move to show fluid flow in the drain piping, and the water level and sediment (green) inside the SCR tank flow out through the drain valve as the animation progresses. The ability to articulate flow visually with animations offers a more easily understood explanation of system functionality to the end viewer than just still images or diagrams. **Figure 16** shows the system in operation with arrows, depicting the direction of flow and labels for the corresponding equipment.

Conclusion

The takeaway of this paper is that when you are first presented with a mechanical failure, there is a process to follow to determine the cause of the incident. The first step is to understand how the system or design was intended to operate and then determine the cause of the failure by looking at the six possible sources of failure: system design, construction/installation, maintenance, operator actions, modifications, and safety guards, warnings, and labels.

Once an understanding of how the system operates and the cause of the failure are determined, the next step is conveying that understanding to others. This last step cannot be overlooked: Conveying your understanding of the system to others is really the main purpose of the investigation. It does not matter how much you understand; it matters what your audience understands. Presenting your findings clearly with graphics and animations is an essential part of showing your knowledge of the system and ultimate failure to others who have little concept of what any of these mechanical systems do. Ultimately, these large mechanical system failures reduce to a few core issues that can be explained and shown simply in visual form.

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