

# Safety Bulletin

U.S. Chemical Safety and Hazard Investigation Board



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*BP TEXAS CITY, TX REFINERY FIRE*

## POSITIVE MATERIAL VERIFICATION: PREVENT ERRORS DURING ALLOY STEEL SYSTEMS MAINTENANCE

### Summary

On July 28, 2005, 4 months after a devastating incident in the Isomerization (Isom) Unit that killed 15 workers and injured 180, the BP Texas City refinery experienced a major fire in the Resid Hydrotreater Unit (RHU) that caused a reported \$30 million in property damage. One employee sustained a minor injury during the emergency unit shutdown and there were no fatalities.

The RHU incident investigation determined that an 8-inch diameter carbon steel elbow inadvertently installed in a high-pressure, high-temperature hydrogen line ruptured after operating for only 3 months. The escaping hydrogen gas from the ruptured elbow quickly ignited.

This incident occurred after a maintenance contractor accidentally switched a carbon steel elbow with an alloy steel elbow during a scheduled heat exchanger overhaul in February 2005. The alloy steel elbow was resistant to high temperature hydrogen attack (HTHA) but the carbon steel elbow was not. Metallurgical analyses of the failed elbow concluded that HTHA severely weakened the carbon steel elbow.

The U.S. Chemical Safety and Hazard Investigation Board (CSB) issues this Safety Bulletin to focus attention on process equipment configuration control and positive material verification of critical alloy steel piping components. The CSB recommends that the refining, petrochemical, and chemical industries review material verification programs to ensure that maintenance procedures include sufficient controls and positive material identification (PMI) testing to prevent improper material substitutions in hazardous process systems.

Figure 1. Carbon steel RHU heat exchanger outlet pipe (arrow) ruptured after operating only 3 months in high-temperature hydrogen service.

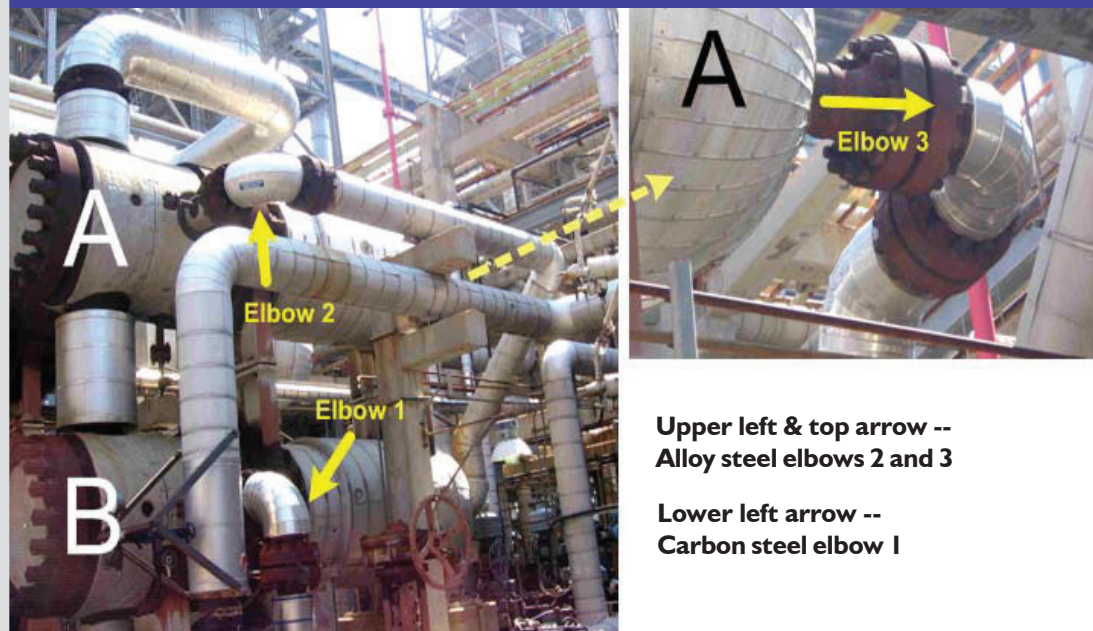


### BP Texas City Refinery

The Texas City refinery is the third-largest in the United States with a capacity in excess of 450,000 barrels per day of crude oil. More than 1,600 BP employees and hundreds of contract personnel operate and maintain the facility.

Residual material from the crude oil processing unit is processed in the RHU to remove nitrogen, sulfur, and metals. Hydrogen is pressurized to about 3000 psi, and then preheated in the RHU heat exchangers (Figure 2) to about 600°F. The preheated hydrogen next passes through a furnace to increase the hydrogen temperature, and then is injected into the reactor feedstock. Hydrogen combines with nitrogen compounds and sulfur within the feedstock in the presence of the catalyst inside the RHU reactors to form hydrogen sulfide and ammonia. Light hydrocarbon, such as gasoline, is then processed in downstream refinery units.

Figure 2. Dimensionally identical piping elbows on RHU heat exchangers A and B.



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## Incident Description

On July 28, 2005, at about 6:00 pm, an RHU hydrogen gas heat exchanger process pipe ruptured. The venting hydrogen gas ignited and a huge fireball erupted in the unit. One employee sustained a minor injury while assisting with the RHU emergency shutdown. The RHU sustained major damage from the hydrogen-fed fire that burned for two hours. There were

no offsite impacts but, as a precaution Texas City ordered a shelter-in-place for nearby residents until the fire was contained.

BP personnel examined the extensively damaged unit and determined that an 8-inch diameter pipe elbow on an RHU heat exchanger hydrogen gas outlet pipe ruptured (Figure 3). The BP investigation team recovered the elbow segments that remained attached to the pipe and three pieces found in the debris (Figure 4).

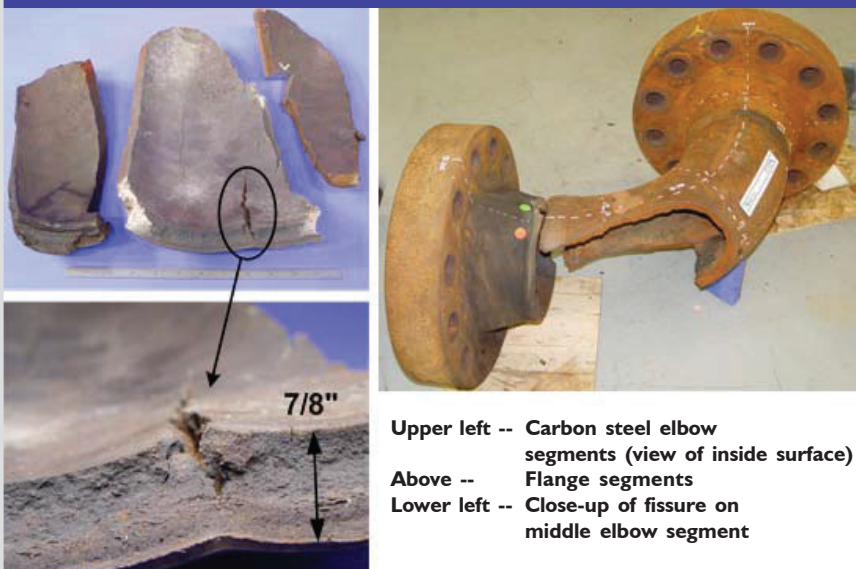
- *The venting hydrogen gas ignited and a huge fireball erupted in the unit.*

Figure 3. Ruptured 8-inch pipe elbow on heat exchanger A outlet.



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Figure 4. Ruptured 8-inch carbon steel pipe elbow pieces recovered after the fire



The BP investigation team recovered the elbow segments that remained attached to the pipe and three pieces found in the debris . . .

## Incident Analysis

### HTHA Failure Mechanism

Incidents involving HTHA date back to the 1940s. Carbon steel in hydrogen service at temperatures above about 450°F and pressures above 100 psia is susceptible to HTHA. At these operating conditions, atomic and molecular hydrogen permeates the steel and reacts with dissolved carbons or carbides<sup>1</sup> to form methane gas. The loss of carbon in the steel, or “decarburization,” significantly degrades the steel’s mechanical properties, including tensile strength and ductility.<sup>2</sup> The methane gas creates high localized stresses, which combine with the normal piping system stresses to create voids and fissures in the steel, which ultimately causes the pipe to rupture (API, 2004).

The American Petroleum Institute (API) Recommended Practice 941, *Steels in Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants*, recommends operating limits for carbon steel and low alloy steel piping systems in hydrogen service. Experiments and operating plant data show that HTHA is typically avoided by using low alloy steels<sup>3</sup> containing

<sup>1</sup> A carbide is a chemical compound formed between carbon and a metal or metals (e.g., chromium carbide, iron carbide).

<sup>2</sup> Ductility is the ability of a metal to plastically deform without breaking or fracturing.

<sup>3</sup> Low alloy steels typically contain less than 0.3% carbon and 2-8% total alloying elements.

1.25–3.0 percent chrome, as the chrome combines with carbon to form chromium carbide, which is resistant to reacting with hydrogen.

### Failed Elbow Metallurgical Analyses

The elbow segments recovered from the damaged unit were examined to identify the steel and the failure mechanism. Chemical analysis and microscopic examination determined that the elbow was made from carbon steel. Microscopic examination also revealed that the segments were severely decarburized and had deep fissures on the inside surface (see Figure 4). The decarburized steel and severe fissuring confirmed that HTHA caused the catastrophic elbow failure.

Detailed metallurgical examinations and micro-hardness testing quantified the extent of hydrogen damage to estimate the total time the elbow could have been in the high-temperature, high-pressure hydrogen service before it failed. The results, compared to existing experimental data and empirical service life predictions, concluded that the elbow failed after being in service for fewer than 3000 hours.<sup>4</sup>

<sup>4</sup> The metallurgical analysis did not calculate the actual service life of the carbon steel elbow. Rather, it compared the observed extent of carbon steel degradation to total time in service of more than 100,000 hours or fewer than 3,000 hours assuming the carbon steel and low alloy steel elbows were swapped either in the 1991 or 2005 maintenance overhaul.

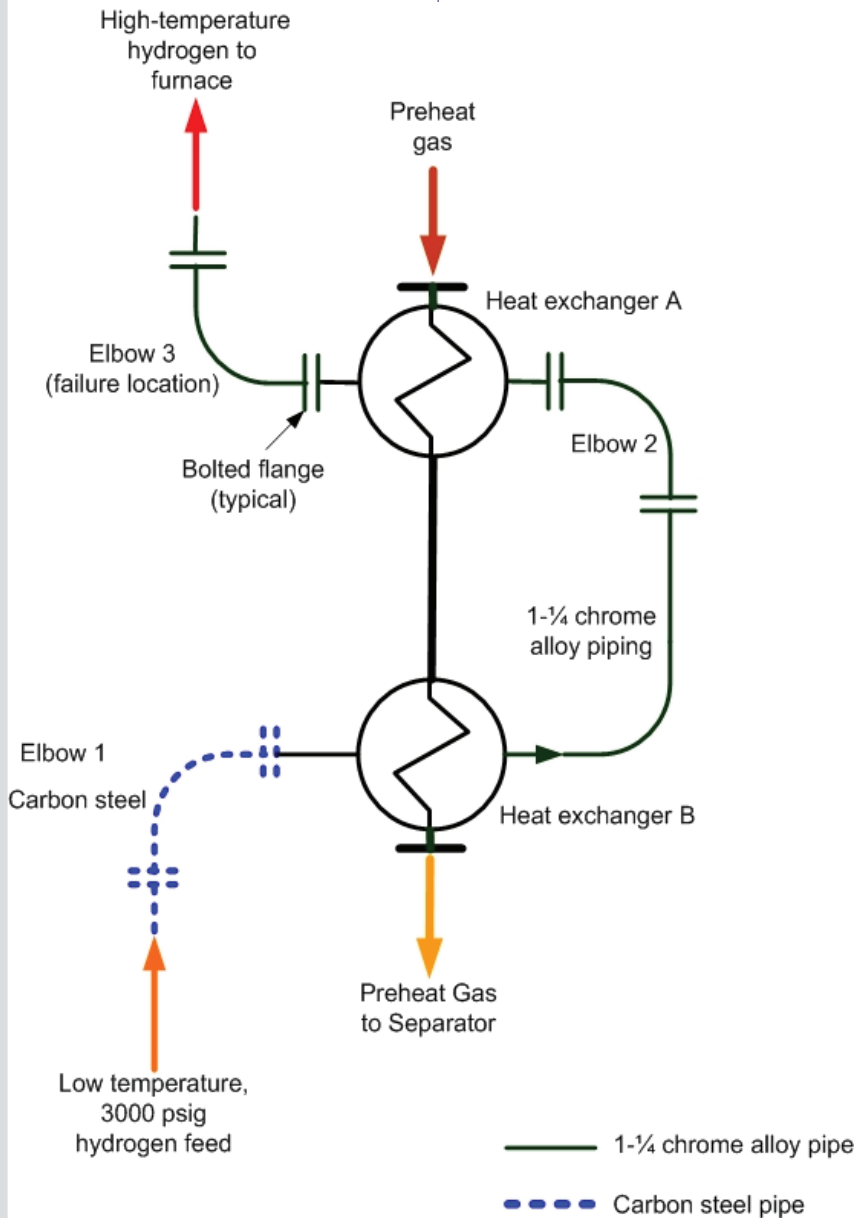
### RHU System Design

Designed in the early 1980s, the RHU has three parallel operating systems. Each system contains a heat exchanger assembly that consists of two series-connected heat exchangers to preheat the hydrogen. For high-temperature hydrogen gas service piping to resist HTHA, the piping design specification requires 1.25% chrome “low alloy” steel, but for piping in hydrogen service at low temperatures, or those below 450°F, non-HTHA resistant carbon steel is specified, as using this material minimizes material cost.<sup>5</sup> Because heat exchanger B inlet piping and components operate at temperatures below 450°F, they are carbon steel; heat exchanger B outlet and all downstream piping and components (Figure 5) are required to be low alloy steel because they operate at temperatures above 500°F.

Construction costs may have been saved by making elbows 1, 2, and 3 on each heat exchanger assembly dimensionally identical, as doing so requires fewer pipe assembly fabrication drawings and weld joints in each assembly. Because the elbows are dimensionally identical, the piping contractor had to ensure that the low alloy steel elbows 2 and 3 were installed in the correct locations when the RHU was built. Had the elbow 1 design

<sup>5</sup> The cost of 1.25 percent chrome low alloy pipe is approximately three to four times more expensive than carbon steel pipe.

Figure 5. RHU hydrogen heat exchanger piping material requirements.



dimensions been different, elbow 1 would not have been interchangeable with elbow 2 or 3 (see Figure 2).

Because of this component interchangeability, any heat exchanger piping disassembly/reassembly for maintenance or repair requires the maintenance crew to be careful to install each elbow in the correct location. Because carbon steel and low alloy steel are visually indistinguishable, special test equipment<sup>6</sup> is needed to distinguish the two low alloy steel elbows from the carbon steel elbow. Otherwise, to prevent switching elbow 2 or 3 with incompatible carbon steel elbow 1, the crew must clearly label or mark each elbow before removing them, then confirm that each has been reinstalled in the correct location.

● *The results, compared to existing experimental data and empirical service life predictions, concluded that the elbow failed after being in service for fewer than 3000 hours.*

<sup>6</sup> Portable hand-held test devices, such as an x-ray fluorescence instrument, quickly distinguish between carbon steel and alloy steel piping materials without damaging the test article.

## RHU Heat Exchanger Maintenance

The RHU heat exchangers were placed in service in 1984. Scheduled heat exchanger cleaning and inspection were performed in 1989 and 1991. Elbows 1, 2, and 3 were removed from the heat exchangers, set aside, and then reinstalled following the maintenance.

The next scheduled heat exchanger maintenance overhaul began in January 2005. The three elbows were removed, stored temporarily, and then reinstalled 39 days later. The maintenance contractor, JV Industrial Companies, was unaware of the material differences in the elbows and BP did not require the contractor to implement any special precautions to prevent inadvertently switching the elbows or any post-reassembly testing to confirm the alloy elbows were reinstalled in the correct locations.

Metallurgical analyses after the incident concluded that the carbon steel elbow could withstand the high-temperature, high-pressure service for only a few thousand hours. X-ray fluorescence testing confirmed that an alloy steel elbow was installed in the carbon steel elbow position on the heat exchanger B inlet. Therefore, the CSB concluded that carbon steel elbow

1 was inadvertently switched with alloy steel elbow 3 when the maintenance contractor reassembled the piping during the winter 2005 heat exchanger overhaul.

## Alloy Piping Material Verification

The BP Texas City refinery has a material verification program, and PMI test equipment that quickly differentiates carbon steel from alloy steel piping components. The BP procedure requires alloy steel components to be verified when they are received in the warehouse and when alloy steel components are shipped from the warehouse for use in new construction. However, it does not require PMI during maintenance, even when there is a risk of inadvertent substitution of the wrong material with alloy piping components.

As this incident demonstrated, merely disassembling and reassembling piping components during maintenance can result in unacceptable system modifications. Lacking post-installation PMI testing, or positive identification of the alloy steel components before and after installation (e.g., component tagging before disassembly), the maintenance crew's reassembly error went undetected until the pipe failed.

## Key Findings

- Piping systems can be designed such that incompatible components cannot be interchanged. All three elbows could have been made from the same low alloy steel material, even though this would have meant additional material expense. Alternatively, elbow 1 could have been dimensionally different from elbow 2 and 3, although this would have meant additional construction costs.
- In February 2005, a carbon steel elbow was installed in the high temperature, high pressure hydrogen line instead of the required 1.25 percent chrome low alloy steel elbow. HTHA caused the carbon steel elbow to rupture after the unit operated only a few months.
- The BP Texas City refinery material verification procedure did not require critical piping component PMI testing during equipment maintenance, even though the incompatible components could be inadvertently switched.<sup>7</sup> The test is simple to perform and quickly differentiates between carbon steel and alloy steel.

<sup>7</sup> The Mechanical Integrity Quality Assurance element in the OSHA Process Safety Management Standard requires "...appropriate checks and inspections to assure equipment is installed properly..." (OSHA, 1992)

- BP did not alert the maintenance contractor that two of the three elbows were alloy steel piping components and must not be interchanged with the carbon steel elbow.
- The maintenance contractor, JV Industrial Companies, did not adequately control the disassembly, storage, and reassembly of the piping components to ensure that all the piping components were returned to their original installed locations.
- The maintenance contractor inadvertently switched carbon steel elbow 1 (Figures 2 and 5) with the alloy steel elbow 3 during the January 2005 RHU heat exchanger overhaul.

• *As this incident demonstrated, merely disassembling and reassembling piping components during maintenance can result in unacceptable system modifications.*

## Lessons Learned

### Human Factors Based Design

Designers should consider the entire process system life cycle, including planned maintenance, to avoid piping configurations that allow critical alloy piping components to be interchanged with non-compatible piping components.

### Positive Material Verification Programs

In-situ alloy steel material verification using x-ray fluorescence, or other non-destructive material testing, is an accurate, inexpensive, and fast PMI test method. Facility owners, operators, and maintenance contractors should ensure that the verification program requires PMI testing, such as specified in API Recommended Practice 578, or other suitable verification process, for all critical service alloy steel piping components that are removed and reinstalled during maintenance.

At a minimum, piping components and their respective locations should be tagged or marked before removal, and the correct installed location is verified after reinstallation.

## Recommendations

### BP Texas City Refinery 2005-04-B-R1

Revise the maintenance quality control program to require positive material identification testing or another suitable material verification process for all critical service alloy steel piping components removed and reinstalled during maintenance, and inform work crews of special material handling precautions.

### JV Industrial Companies 2005-04-B-R2

Develop/update the written piping component installation quality control procedure to require positive material identification testing or other suitable verification or tracking process for all alloy steel piping components removed during maintenance.

• *At a minimum, piping components and their respective locations should be tagged or marked . . .*

## References

American Petroleum Institute (API), 1999. *Material Verification Program for New and Existing Alloy Piping Systems*, Recommended Practice 578, May 1999.

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