EXPLOSION AT THE CONOCO HUMBER REFINERY – 16TH APRIL 2001

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An explosion and fire occurred at the Conoco Humber Refinery on 16th April 2001, following the catastrophic failure of a 6″ overhead pipe from a de-ethaniser column on the Saturate Gas Plant. Investigation revealed that the failure of the pipe was due to internal corrosion that had not been identified by the refinery pipework inspection regime. The paper describes the event and the emergency response. It also examines the immediate cause of the event, and how failures of the management of pipework inspection and management of change failed to prevent the accident occurring. The paper concludes with the lessons that can be learned from this event.

THE REFINERY

The Humber Refinery is located on the south bank of the estuary of the River Humber on the east coast of England, approximately 1.5 km north-west of the town of Immingham and 0.5 km east of the village of Killingholme. In 2001 Conoco Ltd owned the refinery. In August 2002 Conoco merged to form ConocoPhillips Ltd., the current owners of the refinery.

The refinery was constructed between 1966 and 1969 and commissioned in 1970. The current capacity of the refinery is about 225,00 US barrels per day of crude oil, or about 11.4 million tonne per year. The exports are the full range of refinery products, including LPG, Dimethtyl Ether, petrol, aviation kerosene, fuel oil, heating oil and petroleum coke.

The refinery is subject to the top tier requirements of the Control of Major Accident Hazards Regulations 1999, which implement the Seveso II Directive in the UK.

THE SATURATE GAS PLANT

In 1981, as part of the refinery expansion the Saturate Gas Plant (SGP) was commissioned, in order to increase the recovery of gas from crude oil. It formed part of the "White Oils" area of the refinery. It processed light hydrocarbons produced in other parts of the refinery, separating the product by distillation into butane, propane and gasoline, with an average flow through the plant of approximately 12,000 barrels per day (1,680 tonne.)

The SGP consisted of three distillation columns, W 413 (a de-ethaniser), W 414 (a stabiliser) and W 415 (a propane / butane splitter) (see Figure 1.) W 413 was fed from a feed drum (D457.) The overhead from W 413 passed through 6'' pipe P 4363 to heat

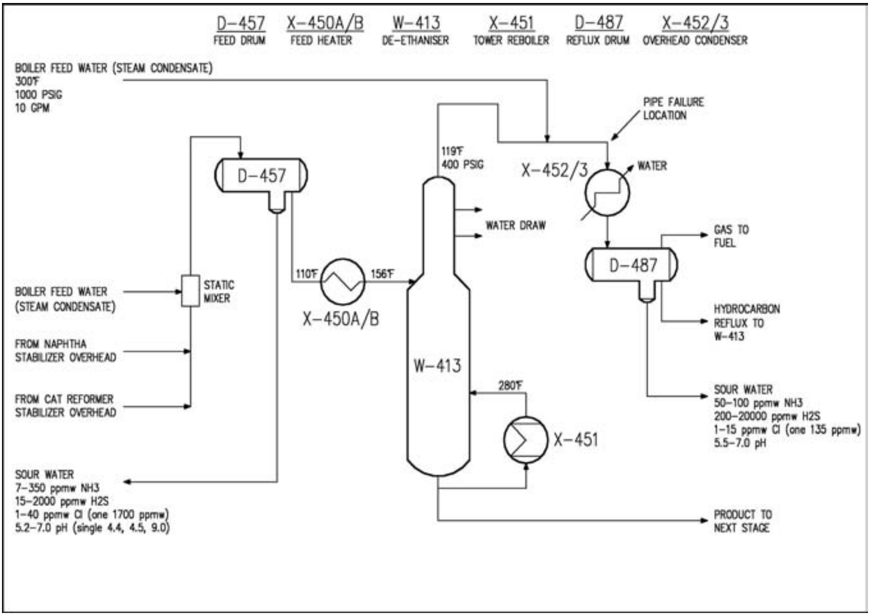

Figure 1. Simplified process flow diagram – saturate gas plant de-ethaniser (w-413) (prior to 16th April 2001)

exchangers X 452 and X 453 where liquid, mainly propane and ethane was condensed (see Figure 2.) The uncondensed vapour overhead from the SGP was passed on to the gas main to be used as fuel gas for the refinery.

16TH APRIL 2001

This day was Easter Monday, and therefore a Bank Holiday. For this reason there were only 185 staff working on the site. Shift handover was due to occur at 3 pm, so relatively few people were working around the plant in the open air when at 2.20 pm pipe P 4363 failed catastrophically. The 6″ overhead line carrying highly flammable gas at high pressure ruptured and released a huge cloud of vapour. About 20 to 30 seconds later the cloud found a source of ignition and ignited. As a result a massive explosion and fire followed. As the fire burned it caused failures of other pipework, which resulted in another explosion and a further fireball about 15 minutes later, and subsequent lesser explosions. It has been estimated that at the point that the released gas cloud ignited it would have measured up to 175 metre by 80 metre at ground level. It is thought most likely that a fired heater on an adjacent processing unit 70 metre away from the failed pipe was the

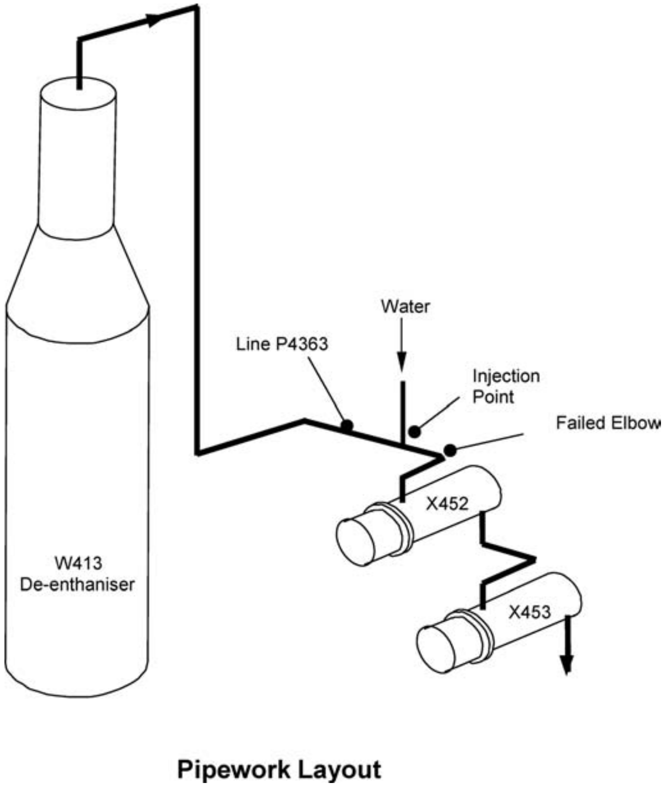

Figure 2. Diagram of the pipe P 4363 and the location of the pipe failure

source of ignition of the released vapour. In total, about 180 tonne of refinery product was released during the incident, including just over half a tonne of Hydrogen Sulphide, a component of some of the refinery process streams.

The SGP suffered very heavy damage as a result of the force of the blast, and the subsequent fire caused further and substantial damage. In addition, buildings normally occupied on the refinery up to 400 metre away from the source of the explosion were badly damaged. The contractor's canteen building suffered severe damage. The staff canteen, the Inspection Services Building and the toilet block suffered blast damage with windows blown in; doors and ceilings damaged; and some cracking and displacement of brickwork.

Properties in the surrounding areas, particularly South Killingholme, were significantly affected with some householders and businesses suffering major window breakages.

Local businesses were mostly closed for the Bank Holiday. The damage to the premises of the nearby garage consisted of broken windows, with ceiling tiles and parts of the ventilation system dislodged. The roof appears to have been displaced but then resettled on the joists. There was also serious deformation to the large metal roller shutter doors of the garage.

The Lindsey Oil Refinery, which is adjacent to the Humber Refinery, sustained damage to buildings although the process plant was unaffected.

Debris from the explosion was spread over a wide area. Some pieces of debris, mainly cladding, thrown into the air and caught in the wind, were found up to 5 kilometre away.

Fortunately no one was in the direct path of the released gas cloud when it exploded. Three people in buildings 175 metre away from the SGP were thrown off their feet by the blast; one banged his head on the reinforced glass panel in a door, sufficiently hard to fracture the glass. One person in the locker room was thrown across the room and suffered damage to his face and neck from the glass and to his eyes from dust. Contractors working on scaffold platforms were blown over and were dazed by the fall, also suffering coughing and choking from clouds of black soot that were raised by the explosion. All these people subsequently made a full recovery. Two people living in the vicinity of the refinery attended hospital as a result of injuries that they sustained, but were not detained for treatment, and other residents suffered shock and distress by the blast, but were not injured. In total 71 civil claims for injury were pursued by workers and members of the public.

Members of the local population expressed concern about the lack of communication; they did not know if there had been a release of toxic gas and what action they should take to protect themselves. The normal precaution of shutting doors and windows was not available to those whose doors and windows had been blown in.

EMERGENCY RESPONSE

The Conoco Emergency Response team (ERT) led the fire fighting effort with the Humberside Fire Service attending. A fire crew from the neighbouring Lindsey Oil Refinery also assisted in the fire fighting as part of the existing mutual aid scheme.

Members of the ERT were alerted by the explosion and made their way to the scene of the fire. The Plant Leader in the Central Control Room (CCR), seeing the subsequent fire on a monitor, gave an instruction for the Refinery General Alarm to be sounded, and then left the CCR to take up his role as incident controller. From the CCR control valves were put into manual mode. This enabled operators to isolate the SGP feed.

Twenty minutes after the initial release and explosion the Plant Leader called the Production Superintendent to advise him to shut down the Refinery because the fire appeared to be out of control. The Production Superintendent then assumed responsibility and put into operation the Refinery's "Significant Incident Plan" (SIP). The Fire Brigade Incident Commander was informed that all personnel onsite had been accounted for.

The incident had occurred at 14:21 hrs and by approximately 15:30 hrs the fire was under control. It was largely extinguished by 17:10 hrs and recorded by the Humberside Fire Brigade as "struck out" at 21:01 hrs.

The off-site emergency alarm (or Community Alarm) was not sounded at any point during the incident and the off-site emergency plan was not put into effect.

In addition to the Humberside Fire Service, the other emergency services committed significant resources to tackle the incident; police closed roads around the refinery; nearby residents were informed to close windows and remain in-doors; ambulances were summoned to the site; and the local hospital instigated its major incident procedure.

THE IMMEDIATE CAUSE

Subsequent investigation by the Health and Safety Executive revealed that the source of the release of the gas cloud, pipe P 4363 from the top of de-ethaniser column W 413 to heat exchanger X 452, had ruptured. The pipe contained about 90% ethane/propane/butane, plus methane, hydrogen sulphide and trace salts, and had been at about 400 psi (27.6 bar, 2.76 MPa.)

The pipe had failed at a 90° elbow that had been 67 cm. downstream of a water injection point (see Figure 3). Scientists at the Health and Safety Laboratories examined the failed section of pipe. They concluded that the pipe, when installed, met the requirements of the relevant API code for refinery pipework. They further concluded that the elbow on P4363 failed due to the effects of corrosion – erosion reducing the thickness of the pipe wall to such an extent that the elbow burst when it could no longer contain the pressure of its contents. The examination of the pipe revealed that its wall thickness had been reduced from originally being approximately 7.1 mm to a minimum of approximately 0.3 mm (see Figure 4). The extent of the metal loss of the elbow and neighbouring sections due to corrosion–erosion appeared to be directly associated with the injection of water upstream of the affected areas. It was consistent with the erosion of a protective layer of iron sulphide on the inner wall of the pipe by the physical action of the water injected into the pipe just upstream of the elbow.

WATER INJECTION

At the time of the incident there were two water injection points on the Saturate Gas Plant. From the start of operation of the SGP there was water injection into the liquid injection point on P 4347, prior to the feed drum. This was used continually. The purpose of this was to remove salts from the feed stream.

Following start-up of the SGP, problems with the operation of the condenser were experienced. The problems were diagnosed as being due to the deposition of ammonium bisulphide on to the process side of the heat exchanger tubes. (The process fluid was on the shell-side of the heat exchanger, with cooling water on the tube-side.) Following a study of the problem a decision was made to inject additional water into the vapour stream between the top of the de-ethaniser column and the heat exchanger, that is to say, into line P 4363.

Figure 3. Photograph of the failed pipe elbow in situ showing the location of the water injection point

The purpose of this was to dissolve any salt that may precipitate in the entry nozzle to the heat exchanger, on the surfaces of the tubes and on their support structure in the heat exchanger.

It appears that an available nozzle in pipe P 4363 was used to retrofit the water injection line. At this point P 4363 is about 9 metres above the ground without access facilities. The water injection was via a 1″ diameter pipe fitting vertically into P 4363. The water injection point was not fitted with a mixing device, but entered the pipe as a free jet of water by a simple vertical T-junction. The valve to open and close the water supply was operated by a chain mechanism. The water entered at a temperature of about 150°C and 300 psi (20.7 bar, 2.07 MPa). The pipe P4363 downstream of the water injection point included two right angle bends, the first to change the horizontal position of the pipe and the second to direct the flow vertically downwards into the heat exchanger.

Figure 4. Photograph of the failed elbow showing the degree of pipe wall thinning

In Conoco's studies of the problems encountered with fouling, the deposition on the condensers was attributed to ammonium chloride and ammonium bisulphide.

Following its installation, the use of the water injection in to P 4363 is not well documented. There is evidence that from the early 1980s water injection through the pipe was continuous, until 1995 when the decision was taken that it should only be used intermittently, as required (or not at all.) There is no evidence that the change in use of the water injection was subjected to the company Management of Change procedure, and therefore there was no evaluation of the effect that this might have on corrosion potential.

In February 2000 the decision was made to increase the water feed into the P 4363 injection point by increasing the size of the orifice on the feed pipe. This was subject to the Management of Change procedure, and a MoC form was completed. The intervention actually resulted in a reduction in flow rate of water due to confusion about the original orifice size, but the opportunity was not taken at this time to re-evaluate the effect that the water injection could have on downstream pipework.

Sometime during 2000 or early 2001 the water injection on P 4363 was put back into continuous use.

CORROSION HISTORY

Following the commissioning of the SGP, the earliest corrosion problems were encountered in the overhead heat exchangers. In September 1983, less than two years after the commissioning, tube leaks were experienced in X 453, and a new carbon steel bundle was fitted in November 1983. Subsequent inspection revealed heavy tube-side corrosion. In 1985, both X 452 and X 453 were fitted with upgraded duplex stainless steel bundles to improve tube side corrosion resistance. In February 1992 corrosion was found on the shell-side of the heat exchangers X 452 and X 453.

Pipe P 4363 carries the overhead stream to the heat exchangers X 452 and X 453. Conoco did carry out some routine ultrasonic thickness measurements of the nozzle and shell of X 452 to monitor deterioration. Tests carried out in 1987 showed some corrosion around the inlet nozzle N3, which is the nozzle located in pipe P 4363 where it meets the exchanger X 452.

In 1993 the company undertook a corrosion review of the plant that includes the SGP.

The review highlighted that water in drum D 457 (feed drum for the de-ethaniser W 413) was not monitored for corrodent levels and the review recommended that "water samples will be routinely monitored for corrodent levels to determine whether there are any problems."

The results of monitoring the water from D 457 revealed that samples had a ph value of 6 and were thus acidic, indicating that the level of the water wash was inadequate.

The SGP was shut down in 1994, and a corrosion review was undertaken that revealed severe corrosion to the heat exchangers X 452 and X 453. This resulted in the total renewal of the carbon steel shells and baffles. The exchangers were replaced in December 1994.

During the shutdown in 1994 Conoco's inspection services department carried out an inspection of the injection point into P 4363 and P 4347.

The report on the inspection of the boiler feed water injection into P 4373, prior to D 457 reads:

"An ultrasonic and radiographic survey of the BFW (Boiler Feed Water) injection into P 4347 and ultimately D 457 has revealed extensive corrosion and washing of the pipe wall. The minimum recorded thickness of the pipe was 0.140" which according to our calculation is above the retirement figure of 0.112″".

The 1994 report records that a similar survey of the injection point into P 4363 was also showing signs of corrosion washing but not to the same degree. The report then noted that the water injection point in P 4347 had a mixing device attached to it – a quill – whereas that into P 4363 had no such device fitted. The report ends by recommending that:

"Obviously with the corrosion seen both points will be subject to frequent inspections in order to determine corrosion traits and ultimately retirement and with this in mind I would request that scaffold access remain".

The elbow downstream of the injection point was not included in the scope of the inspection of P 4363.

This report represents the last documented assessment of the condition of the injection point on P 4363 prior to the catastrophic failure of the affected elbow in 2001.

The review meeting following the inspection activity in 1994 concluded that the explanation for the observed corrosion in the overhead heat exchangers (X452 and

X453) was related to inadequate water wash and water draw system on the de-ethaniser line resulting in increased concentrations of ammonium salts (chloride and sulphide) and acidic wash water. As a result of this, the corrosion review recommended that the rate of wash water to D 457 be increased to 20 gallons per minute. It also recommended a thorough review of the water wash system, though HSE, in gathering information following the accident did not find any evidence that this review was ever completed.

Conoco understand that there was a re-inspection of P 4363 and that the results of this led the Lead Inspector to conclude that further corrosion was not detected. It is not clear if this was an inspection of the pipe at the water injection point or included the pipe bend just downstream of the injection point, as no record of the further inspection have been obtained during the investigation.

It is understood that Conoco staff concluded that the wash water into the overhead line P 4363 had been stopped and a spectacle blind put into the 1″ line. An e-mail from the Corrosion Engineer to the Area Leader for the plant made this recommendation in 1994. This e-mail concludes, “If, however, the overheads show signs of salting up then this decision will need to be reviewed”.

There is no documentation recording the stopping of the water injection and the installation of a spectacle blind, or later any reinstatement of the water injection.

Conoco appear to have decided that there was no need for any further inspection on P 4363. It appears that the company concluded that, with the stopping of the water injection there was no longer a known mechanism of corrosion for the overhead pipe, and having concluded from the further inspection work that the pipe wall was no subject to significant corrosion, then the inspection interval could be extended to the maximum allowable by the relevant code, in this case the Institute of Petroleum Model Code of Safe Practice Part 13.

At this time the company had significant evidence that corrosion was occurring in the system, i.e.:

- Severe corrosion of carbon steel X 452/X 453 shells/baffle and tie rods;
- Severe corrosion of carbon steel nozzles, in particular N3 at the entry point for fluids in P 4363 into X 452;
- Corrosion washing around injection points P 4363 and P 4367;
- Water analysis in D 457 showing pHs as low as 4.4; and
- High corrosion rates at the inlet to X 452.

MANAGEMENT OF INSPECTION DATA

During the investigation following that accident HSE inspectors gathered information on the systems that Conoco had in place to collect, store and manage technical data to ensure compliant with their legal duties and to ensure continuing safe operation of their plant.

The company managed the inspection of plant and pipework by the application of Inspection Service Procedures. In particular they had procedures covering written schemes of examination, pressure piping, engineering standards and the inspection strategy.

In addition the company had a range of computer and paper systems for recording and managing information. However, there were considerable problems with some of these systems that resulted in important intelligence about the condition of plant and equipment being lost.

In 1999 Conoco commenced the introduction of a Risk Based Inspection regime. The company considered that such a regime would produce more structured and targeted inspections for vessels and pipework, and also make more efficient use of resources.

The company carried out an RBI study on the Saturate Gas Plant in November 2000 that included within its scope the pipework. Even though the water injection point on P 4363 was omitted because it was thought by the inspection department to be shut-off, the pipe P 4363 was still identified as a "high-risk" item. This took account of the potential consequences of a failure of the pipe, and the likelihood of failure derived from generic reliability data, in the absence of pipe-specific inspection data. As a result of this study an inspection was planned for July 2001, but the pipe failed before that inspection.

MANAGEMENT OF CHANGE

In 1999 the company produced a strategy for the Management of Change. There were two methods through which change was managed, an electronic Management of Change (MoC) form and the Technical Memoranda system.

The Technical Memoranda system was in place in 1981 when the SGP was commissioned. Technical Memoranda are used to describe the scope of proposed changes or additions to the refinery processes and equipment. They are generally prepared by process engineers and are circulated to an agreed list of approvers.

An electronic MoC form was introduced in 1999 for all changes made to the physical plant, its equipment, component parts or configuration, and process changes. This system involves the raising of a computer-based form that is circulated to selected specialised personnel for review.

The MoC system should have been used for the modification of P 4363 to verify the reasons for the change and to identify any implications for the safety of the plant. When it was used in February 2000 it confirmed that previous records of the water wash system were inaccurate, but the significance of this was not appreciated.

CONCLUSIONS AND LESSONS LEARNED

MANAGEMENT OF PIPEWORK INSPECTION

ConocoPhillips failed to implement an effective system for the inspection of pipework on the SGP, to complement that in place for process equipment. The system used fell far below recognised industry good practice at the time. In addition they failed to use knowledge and experience from other sections of the plant that should have identified the need for more inspection of the SGP pipework. Over time sufficient pipework condition data should have been obtained, and entered onto an inspection database, to verify the believed integrity and inform assessments of future inspection requirements. Without this both the system and the assessments were inadequate.

Key lessons:

- Effective pipework inspection systems are a vital major accident prevention measure for high hazard pipework.
- Such systems should at least meet current industry good practice standard.
- Decisions on inspection intervals should be informed by suitable and sufficient information on process conditions and previous inspection findings.

MANAGEMENT OF CHANGE

The design and installation of the water injection point in P4363 was not subject to any MoC assessment. Had such an assessment been carried out the corrosion risk that the injection point introduced for the downstream pipework could have been identified. Similarly no assessment was made of the changes in use of the water injection point, between continuous and intermittent, over the lifetime of the plant. The frequency of use was a major factor in the rate of the corrosion of the pipework. During periods of continued use more frequent or detailed inspections of the pipework should have taken place to adequately monitor the integrity of the pipe.

Key lessons:

- Effective management of change systems, which consider both plant and process modifications, are essential to prevent major accidents.
- Particular care is needed to ensure that 'quick fix' modifications, during the commissioning and early operation phases of new plant, are covered.

MANAGEMENT OF CORROSION

ConocoPhillips' corrosion management on the SGP was not sufficiently thorough or systematic to prevent the failure of P4363. Some positive actions were taken, including the appointment of a full time Corrosion Engineer for the Refinery, introduction of divisional corrosion reviews and monitoring of process streams by sampling and the installation of corrosion probes, following receipt of specific information in 1992 about the vulnerability of carbon steel pipework in the vicinity of water injection points. Unfortunately these activities were allowed to lapse with the result that there was both insufficient data on, and inadequate resource or focus applied to, corrosion as a potential major accident initiator on the SGP.

Key lesson:

- Systematic and thorough arrangements are necessary for the effective management of corrosion on major hazard installations.
- Such arrangements should ensure that any available information on relevant corrosion degradation mechanisms is identified and acted on.

- Adequate resource, including relevant expertise, should be applied to ensure that adequate standards are achieved and maintained.

COMMUNICATION

Two significant communication failings contributed to this incident. Firstly the various changes to the frequency of use of the P4363 water injection were not communicated outside plant operations personnel. As a result there was a belief elsewhere that it was in occasional use only and did not constitute a corrosion risk. Secondly information from the P4363 injection point inspection, which was carried out in 1994, was not adequately recorded or communicated with the result that the recommended further inspections of the pipe were never carried out.

Key lesson:

- Effective communication is an important element of any safety management system. In the context of major hazard establishments the accurate recording and effective sharing of information and data relevant to plant corrosion is essential for major accident prevention.

HSE SAFETY ALERT
PIPEWORK FAILURE AT AN OIL REFINERY

A recent incident at a UK oil refinery has reinforced the need for detailed attention to pipework integrity.

A hydrocarbon release from pipework within a saturate gas plant led to a major vapour cloud explosion and subsequent fire damage with further explosions. The initial source of the release is believed to have been from an overhead line from a de-ethaniser column at a forged pipework bend downstream from a water injection point. After the incident the bend was found to be ruptured with corrosion to the inside surface. The process stream is likely to have contained contaminants.

Operators of refineries are reminded to take all necessary measures to prevent major accidents including appropriate inspection and maintenance programmes. Industry codes such as API 570 Piping Inspection Code and IP Model Code of Safe Practice Part 13 give details of such practices. Attention is drawn to the need for inspection of piping systems that are susceptible to specific types and areas of deterioration such as at injection points.

Figure 5. Text of a HSE Safety Alert issued to industry following the incident