UNPREDICTED PIPELINE EXPLOSION

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DRB Materials Technology (Mattech) of Lymington is a group of consulting engineers providing solutions to technological problems for industries of all types covering failure investigation, corrosion, welding engineering, maintenance, risk assessment etc. One of its recent investigations involving a pipeline explosion, see Fig. 1, provides valuable information for pipeline operators.

Pigging of lines is a common practice adopted either for cleaning or when different products are to be pumped down only one line.

The operation is normally accomplished as an everyday event without incident. The least risk procedure is to have the line purged with nitrogen as a precaution against the presence of explosive air/fuel mixtures.

Fig. 1. General View of Surface Pipeline Explosion

As will be seen from examination of the photographs in this article, under certain circumstances, there is the potential to cause serious explosions, even in controlled situations.

During an operation in which pigging was being performed on a 14 " line, an explosion was experienced, followed by several other explosions at different locations in the line.

Fig. 2. Side view of exploded pipe.

Mattech. were asked by the owners to independently investigate the cause of the explosion, to carry out a risk assessment and to recommend means of avoidance in future.

Procedure

The investigation commenced soon after the explosions with a preliminary survey. On of the principles adopted as a philosophy by Mattech is that it is important in any investigation to avoid premature conclusions. The purpose of the inspection visit was to gather as much information as possible and to

Fig. 3. Weld on main Line, residue beneath 1.5" valve, note cracking in the weld and Luder lines around weld indicating stress field. This was removed for metallographic investigation.

select parts of the line for removal to be sent to the Mattech Laboratory for metallographic, chemical and fractographic analyses.

The largest explosion was in the buried section of the line, see Fig.1. It was thought by the operators of the line to be the origin of the explosion and, initially, attention was concentrated here.

Fig. 4. Nozzle remote from explosion, note crack propagating from weld, investigated as possible source of air ingress

Specialists at Mattech undertook an initial review both on-site and after the sections of the pipe were received in the laboratory. From this assessment, a range of possible causes was highlighted. Some of these are more likely than others but in any investigation it is important to cover all eventualities.

Possible Causes.

- Failure to follow the safety procedure for pigging, thus allowing air ingress and producing an explosive mixture.
- Entry of air into the line via a gasket leak, faulty valve gland packing or crack producing an explosive mixture.
- Entry of air via a crack or a defect in a weld, as seen in Fig. 4 or from the detachment of a small bore connection as seen in Fig. 3. Around this small bore connection, Luder lines can be seen causing rusting in the paint film. These Luder lines are indicative of stress resulting from applied load. Load could have been applied in service or at the time of the explosion.

- Fatigue of the line at regions of stress concentration such as welds and this was a possibility in the crack seen in Fig. 4.
- Brittle fracture. This generally occurs at low temperatures. The line explosion had occurred in the month of February when

Fig. 5. Fracture on seat ring of isolating spade, investigated as possible origin of air ingress

temperatures were low but depending on the quality of the steel the occurrence of brittle fracture is possible even at normal ambient temperatures. Brittle fracture usually initiates at stress concentrators such as weld defects or laps in the pipe material.

- Hydrogen embrittlement caused by underground corrosion or incorrect cathodic protection of this partially buried line
- Sulphide Stress Cracking.

All the above are possible causes but would require a source of ignition. One source could result from the presence of pyrophoric compounds such as iron sulphides; the internals of the steel pipe were covered in scale as a result of corrosion. These compounds can spontaneously combust under favourable conditions and examples of fires and explosions which they have caused can be found in the literature. The following mechanism provide their own sources of ignition

- Electrostatic Discharge.
- Spontaneous combustion can occur in gases due to the presence of micro-organisms.
- Mechanical impact causing sparking.

A feature of the explosion in the line which was used to convey a range of hydrocarbons is that several explosions were noted in the incident. This is not uncommon and is often referred to as the Diesel Effect, in this, an explosion occurs and the shockwave travels along the pipe compressing the hydrocarbon gases ahead of it until it reaches the conditions (found in the diesel engine of a car) conducive to a second explosion. These recurring explosion can travel for miles along a pipeline.

Evidence found in the Investigation.

In Figs 1 & 2, the largest area of damage is seen and in Fig. 11 another example of damage is seen, both of these were shown by fractographic examination to have characteristics typical of ductile tearing, for this and other reasons, brittle fracture at these locations were therefore ruled out. Other examples of damage were less extensive and one of these is seen in Fig.5 where cracking of the seat on a spade used to isolate the line can be seen. It was possible that this cracking had been the source of ingress of air or alternatively it may have entered via the fracture of the small bore connection seen in Fig. 3. Another possibility was the cracking found on the welded region between the nozzle and the main line, see Fig. 4.

By following fractographic features, such as are shown in Fig 6, it is possible to identify the origin (the point from which the crack commenced) and the direction of travel of a propagated fracture. This was performed on all fracture faces and origins were found but metallographic examination indicated that none of these were defects in the material and thus they were the results of the explosion and not the causes.

Fig. 6. Fracture Face with Chevrons indicating origin of fracture and direction of travel.

Examination under optical microscopy of all the other examples of line degradation were performed and the evidence obtained showed that they were all of recent origin and thus were symptoms and not initiators of the explosions.

Fig. 7 Cracking in upstream side of plug valve this valve was located above an exploded region of the pipeline

As part of the investigation, valves were removed for examination. It was noted that the plug of one valve was cracked, see Fig.7. This was located on the upstream of the valve, which was positioned on the unused line above the explosion damage seen in Fig. 11. On the downstream side of this plug valve, large pieces of the plug were found to be missing. In the explosion, the pig trap door was blown off and was not recovered and it is probable that the parts of the plug were also blow out of this door.

Metallographic examination of the cast iron plug, see Fig. 10 revealed that

Fig. 8 Typical Cracking in plug on upstream side of valve.

the cast iron material of construction had suffered corrosion and this had resulted in intergranular cracking. It was therefore apparent that the fracture here had been present prior to the explosion.

Fig. 9 Fractured plug with downstream side missing

Further examination of the explosion damage, revealed a mark on the bottom of the line seen, immediately below the valve plug which had fractured, see Fig. 11. This section of the pipe was examined in the laboratory and, under microscopic examination, a small region was seen where impact damage had occurred had caused melting of the surface of the steel pipe and removal of the oxide layer, see Fig. 12.

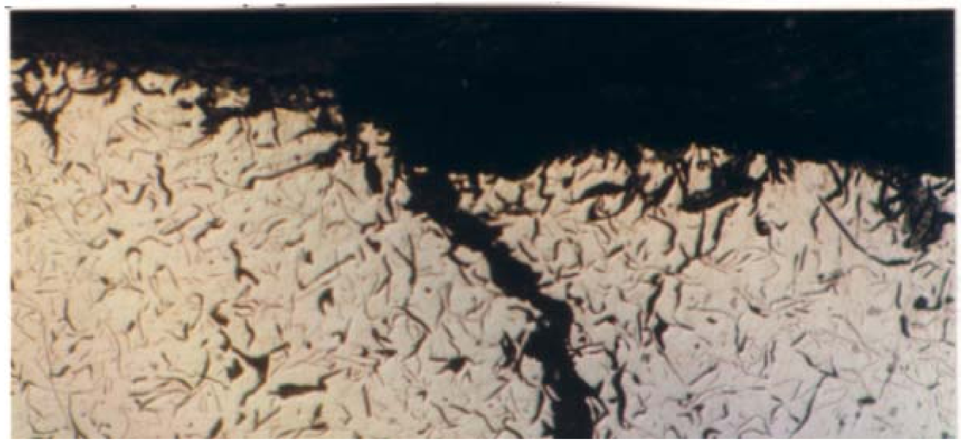

Fig. 10 Microstructure at 75X showing corrosion, along Graphite flakes and intergranular cracking.

Fig.11 Exploded region of pipework which was initially considered to be a secondary effect, note oxide

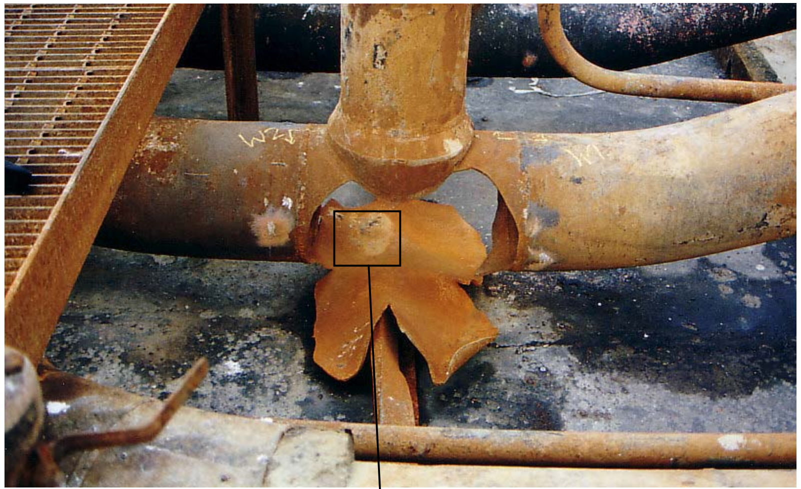

Fig. 12 View under microscope of exploded section of pipe, note melting of oxide layer. Indicative of initiation point of explosion.

Conclusions

For the explosion to occur, the line must have contained a mixture of hydrocarbons and air.

It was concluded that inadequate maintenance was the root cause of the explosion. The plug valve which had fractured did not appear ever to have been either lubricated or inspected since it was effectively bonded into its seat by corrosion products and the plug had suffered intergranular attack which had propagated to the extent that fracture eventuated.

In many investigations, there are a range of possible causes. The evidence from this investigation supports the view that at a time when the pipeline contained a potentially explosive mixture of air and hydrocarbon, the valve plug had fractured and fallen 1.5 metres to the main pipe beneath. This had produced a source of ignition which initiated the explosion.

Apart from the above results, the lessons that come from this incident are that safe operation of a plant or any potentially hazardous installation demands a continuous review of operation and maintenance to ensure that all safety needs are met. Because pipes and vessels are generally reliable it is possible for operators to become complacent and an audit, preferably by an independent organisation with detailed knowledge of operation and condition monitoring needs, is invaluable.

Following the result of this investigation, Mattech worked with the owners of the installation to implement changes in maintenance and operation of the line.

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