

Creeping Change: Liquid Accumulation in a Flare System at a Gas Terminal

Roger Berriman, Senior Process Safety Engineer, CSL, Woodland House, Woodland Park, Hessle, HU13 0FA, UK

An abnormally large flare accompanied by thick black smoke occured at the Easington Gas Terminal, a top tier COMAH site in East Yorkshire. The event occurred due to accumulated liquid (gas condensate) being carried over from the vent header to the ground flare during the start-up of the condensate stabilisation system. Though there was no impact to people, plant or the environment, an independent investigation team were tasked with finding the root causes of the event. This paper describes the themes and root causes determined during the investigation. Themes such as creeping change (change of plant design basis, isolation of flash gas compressor system), normalisation of deviation (unreliability of condensate stabilisation direct-fired heater, change in operating conditions to prevent process trips activating) and use of a pre-startup safety review process are discussed.

Keywords: Flare, Condensate, Management of Change, Pre-startup safety review.

Introduction

Site Overview

Centrica Storage Limited (CSL) is a wholly-owned subsidiary of Centrica plc. CSL operate the Rough gas production facility in the Southern North Sea and the Easington onshore gas processing terminal in East Yorkshire, a top tier COMAH site under the Control of Major Accident Hazard Regulations 2015 (COMAH).

The Rough field commenced gas production and processing in 1975. In 1985, the gas field was converted to store gas to meet seasonal supply/demand imbalances. The Rough reservoir is a depleted gas field, approximately 29km (18 miles) off the east coast of Yorkshire, in Rotliegendes sandstone, 2.7km under the Southern North Sea bed. It was the largest gas storage facility in the UK, but since the summer of 2017 it has been converted to a production only facility. Gas arrives at Easington Terminal via a 36" pipeline. An overview of the site location and layout is shown in Figure 1.

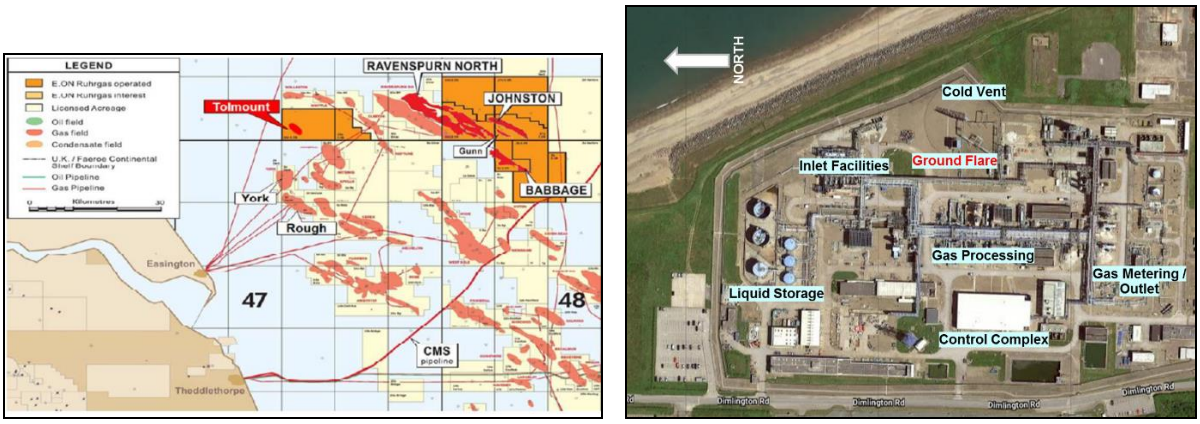


Figure 1: Location map of Block 47 & 48 of the Southern North Sea (left) and layout of CSL Easington Terminal (right).

Outline of the Event

An abnormally large flare was observed at Easington Terminal on 17th January 2018 at 13:48. The 20 metre large flame was accompanied by thick black smoke and a pool fire contained within the on site ground flare sterile area (see Figure 2). The site alarm was sounded and all 102 personnel mustered.

At the time that the flame from the flare was noticed, the condensate stabilisation plant known as the 'hot flash' process was being restarted by the duty Operations team to allow on an onsite team of Control & Instrumentation (C&I) technicians to troubleshoot reliability issues with the direct fired heater (H-1501) used in the process. On the morning of the event the Operations team had attempted to start-up the hot flash condensate stabilisation system four times unsuccessfully.

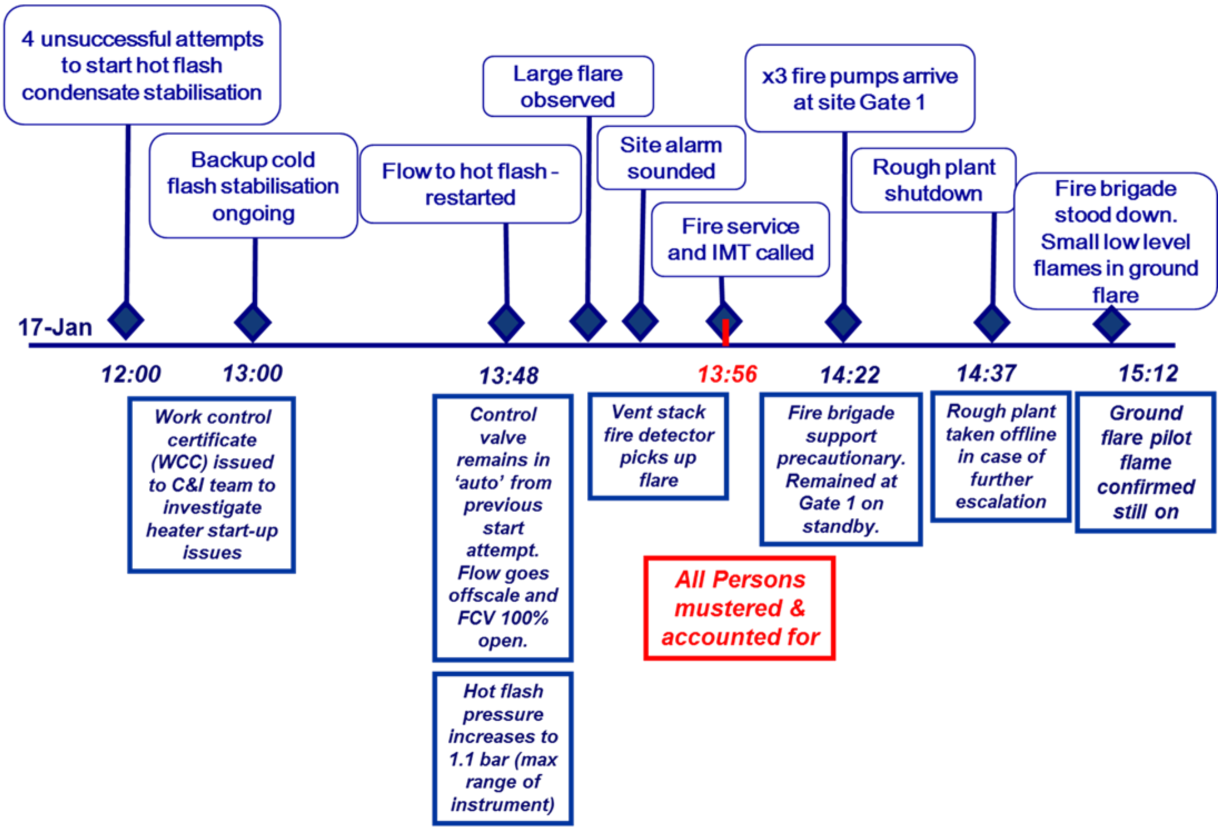
Figure 2: CCTV image from the large flare event on the 17th January 2018.

The event caused minor damage (i.e. scorched pipework) within the flare stack and left a soot film on the outer surface of the vertical flare 'box' (see Figure 3). No injuries were sustained to personnel during the event. The smoke from the flare could be observed offsite although the prevailing wind was from the West, taking the smoke cloud out to the North Sea.

Figure 3: Inspection photographs of the ground flare following the event. Internal fire bricks (left), pipework and scorched gravel (pool fire residue) (middle) and soot deposits on external structure surface of the ground flare (right).

Sequence of Events

The timeline below was created from the distributed control system (DCS) trends, emergency response boards and witness statements taken as part of the event investigation.



Condensate Stabilisation Overview

The design intent of the 'hot flash' system is to heat unstabilised liquid condensate (hydrocarbon liquid with similar properties to gasoline) and liberate light end hydrocarbon gases as the pressure is reduced in flash drums. An air cooled dual fin fan heat exchanger (E-2307) partially condenses hydrocarbon vapours before the collected stabilised condensate (now with a reduced vapour pressure) is pumped to site bulk storage tanks. An overview of the hot flash system is shown in Figure 4. A small back pressure of 0.5 Barg (7 Psig) is maintained in the system by a pressure control valve (PCV-23351) with any excess of pressure relieved to the ground flare for safe gas disposal.

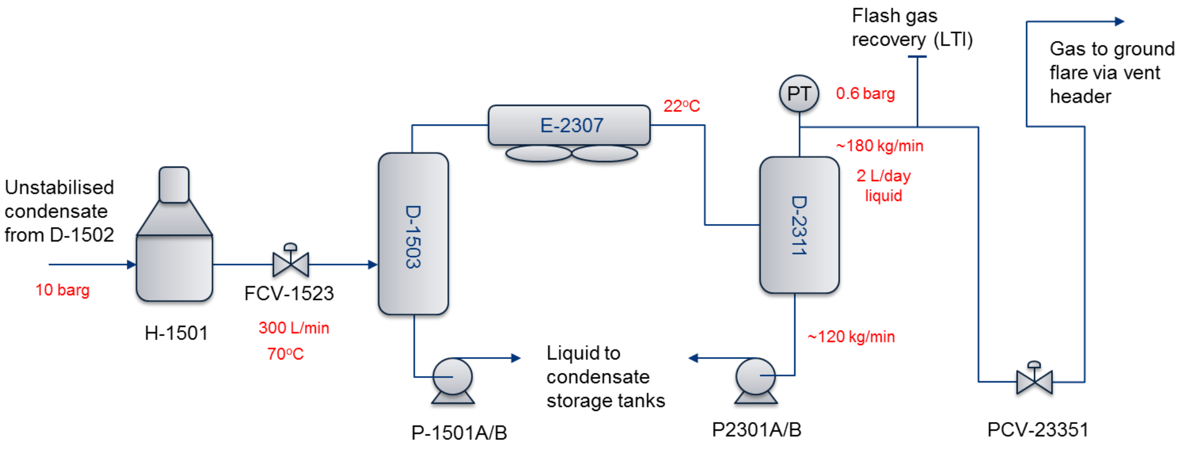


Figure 4: Simplified flow diagram for the 'hot flash' condensate stabilisation system.

Investigation Findings

An investigation team was convened to establish the direct and indirect causes of the event. A root cause analysis (RCA) of the event was conducted using the *Sologic*® root cause analysis method (1). The following sections detail the investigation findings as well as direct causes, indirect causes and root cause of the event.

Human Factors

Managing human failures

The hot flash system was started up (i.e. flow introduced) four times on the morning of the 17th January 2018 but the fired heater failed to start at each attempt. In shutting down the flow to hot flash system at the end of the fourth cycle the flow control valve (FCV) to the fired heater (H-1501) had been left in 'automatic' mode on the DCS and 100% open by the control room operator (CRO). The process operator training guide for the 'hot flash' process states the inlet flow control valve (see Figure 4, FCV-1523) should be '*placed in manual with an output of 0% on hot flash shutdown'*. As the FCV was 100% open this resulted in a large flow to the hot flash system at the start of the fifth restart attempt which coincided with observation of the abnormally large flare described in Section 1.2. Leaving the unit feed FCV 100% open was a lapse (memory based) by the CRO as the action was not carried out. The performance influencing job factors (PIF) that make this error more likely to occur include divided attention, the CRO was dealing with the demands of the outside troubleshooting team at the heater and also monitoring the 'cold flash' condensate stabilisation flowrates (an alternative backup process with limited use as the condensate specification reached is of a lower quality i.e. higher vapour pressure). Whilst the lapse by the CRO was undesirable, the DCS should have maintained the flow within set operational levels. This did not happen due to the hot flash flow transmitter associated with the FCV going 'out of range' and not failing safe (i.e. not closing the FCV) which was an unrevealed latent failure of the transmitter.

Operational failures

Whilst the process operator training guide for the hot flash stabilisation system shutdown states the inlet FCV should be placed in manual at 0% (i.e. closed) on hot flash shutdown, operation of a control loop in 'manual' is not good practice. The design intent should be that all control loops on a system should be configured to only operate in 'automatic' allowing the DCS to control process variables without direct interaction from the CRO. There should be no routine requirement to operate control loops in manual for a continuous process although the hot flash process is now operated as a batch process, a change from its original design intent. However, the operational failing of operating control loops outside of their desired state had already been recognised by the site management team and data from site data historian system has now been made available on control loops to identify undesirable modes of operation. A typical extract from this data is shown in Figure 5 and serves to highlight the 'service factor' (% of time the controller is not in the desired mode whilst the process is online) allowing management intervention if used effectively during performance reviews.

Terminal Process Maintenance PI Data.xlsm - Control Loops

								Service Factor (%)			Saturation (hrs)	Setpoint Changes
Area	Tag	Description	Mode	PV	SP	Units	OUT	Today	Yesterday	Current Month	Current Month	Current Month
Inlet	LICA-0245-A	Rough Surge Drum Level Controller	MAN	37.8	5.7	%	42.3	16	13	7	0	0
A2 Gas Processing Stream	LICA-0341-A	D0305 Inlet KO-Drum Level Controller	Auto	11.1	10.0	%	29.4	100	100	74	1	0
	FICA-0321-A	FICA-0321-A A2 Stream Flow Controller	Auto	0.012	0.251	Mm3/hr	0.0	99	100	100	0	1171

Figure 5: Extract from 'service factor' data now available for control loop performance monitoring at Easington Terminal.

Procedures

The hot flash system uses a dual fin fan cooler to condense vapour into a knock out drum (D-2311). One of the condensing fans on the hot flash system (E-2307/2) was found to be electrically isolated on investigation after the event. The fan motor had been isolated for maintenance activity within a shutdown that had finished three months prior to the event. Isolation of a single fan on the hot flash cooler reduced the effectiveness of E-2307 to cool and condense vapours into the collection knock out drum. During plant re-instatement activities following the shutdown, the isolation for the condensing fan motor had been marked as complete (i.e. removed) on the electronic control of work system whilst the field isolation lock remained in place. The action to check the fans were available was later included in the unit pre-start up safety review document (PSSR).

Design

Fin fan cooler exchanger (E-2307) had no confirmed fan/motor running indication available, or appropriate temperature indication upstream or downstream provided on the DCS to assist the control room operator (CRO) in ensuring effective hot flash condensation was taking place. Confirmation that the fans were operational on the coolers could only be achieved during a field check by the Operations technicians. The field check was carried out infrequently as the Operations Technicians believed the DCS provided feedback that the fans were running as the graphic changed if a 'run signal' was sent from the DCS, the investigation confirmed that no feedback signal was installed for E-2307. There are multiple fin fan coolers installed on the site as part of other projects/modifications which have both motor running feedback and temperature indication. Changing design standards has led to inconsistencies in DCS information which increases the potential for error for the CRO who monitors multiple coolers across site via the DCS.

System Factors

Design and changing operation of hot flash system

The hot flash condensate stabilisation system is currently operated in batch mode to process liquids produced from the gas production plant. The fin fan cooler (E-2307) used in the hot flash process was originally installed in 1983 as a precooler for a flash gas compression recovery system. E-2307 was designed as a continuous partial condenser where any vapour condensing out en-route to the flash gas recovery system would separate out in the condenser knock out drum (D-2311). The flash gas compressor system has since been isolated and air gapped from the hot flash system (see Figure 4). The current operation of the system still uses the flash gas knock out drum (D-2311) but the vapours are now sent to ground flare when the system pressure rises and back pressure controller PCV-23351 opens. The change to operate the process under batch conditions and to remove the route to flash gas recovery did not account for E-2307 being a partial condenser which has resulted in vapour from the hot flash system condensing in the pipework downstream of the knock out drum i.e. in the vent header to ground flare.

The vent header to ground flare from the hot flash system is approximately 100 metres long in the approach to main process units and is unlagged 16" pipework which will act as a long heat sink causing vapours within the gas stream to condense out. The vent header was originally a 1983 first gas production pipeline from site and was converted to its current duty as part a site enhancement project in 1995. The 'fall' of the converted vent header was therefore in the direction of the original gas flow, the change of duty of the line in 1995 therefore caused the vent line to fall back to the now installed hot flash stabilisation plant and not in the new direction of gas flow. Following the large flare event described, approximately 3.9m^3 of liquid condensate was later drained from the header pipework downstream of the hot flash system (after PCV-23351).

Further analysis utilising a HYSYS calculation model by the investigation team predicted that a liquid accumulation rate of 2 litres/day could be expected in the downstream vent header from D-2311 due to condensation of vapour in the pipework. This would be expected to occur whilst both fans are operational on the fin fan cooler E-2307. If only one fan was available on E-2307 liquids would condense within the vent header at a rate of 9 litres/day and up to 50 litres/day of condensation was predicted if no fans were in operation on E-2307 whilst the hot flash system was running. An effective draining/management process was required to prevent re-occurrence of this event.

Immediate Causes

- Release to the ground flare of gas (methane) and liquid (unstabilised condensate) which had accumulated in the 16" vent header from the hot flash condensate stabilisation system.
- Excessive forward flow to the hot flash system. Flow transmitter going out of range and reverting to 'manual' at last known FCV position (100% open). Operations team aimed to run hot flash at high flows due to issues with low flow switches and zero errors on instrumentation.

- High pressure rise in the hot flash system. Ineffective pressure control by back pressure controller (PCV-23351) resulted in pressure spikes.
- Unreliability of the hot flash heater (H-1501). Failure to start (x4 times on day of event, x14 times on 16th January 2018) which led to further demand on control room operator (CRO).

Underlying Causes

- Ineffective condensation in hot flash system. Heat exchanger E-2307 was designed as a partial condenser (2 pass, air cooled) originally sized for continuous duty. Batch operation of hot flash system at lower pressures resulted in higher liquid loadings in the vapour sent to the ground flare.
- Effective condensation in ground flare header pipework. 6" vapour line from knock out drum D-2311 joined a 16" header that ran approximately 100 metres across the gas processing plant before joining the main ground flare rundown header. This resulted in a large heat sink for condensing vapour and acting as a horizontal knock out drum.
- Low points in vapour pipework from the hot flash system to ground flare. The 6" vapour line from D-2311 dropped down to grade level and into back pressure controller PCV-23351 before heading back up to the pipe rack level (approx. 10 metres elevation). Condensed liquids accumulating in the main 16" header flowed back towards low point at PCV-23351. See Figure 6.
- The process operator training guide for the hot flash system instructed the operations teams to attempt another restart if hot flash (H-1501) start-up if unsuccessful. Multiple restart attempts were found to be common place (x14 attempts on 16th January 2018) with no feedback from the heater control panel to the teams on the causes of trip activation. The site operations and maintenance teams had attempted to solve reliability issues with H-1501 whilst overhaul/replacement plans were being developed by a central project support team.

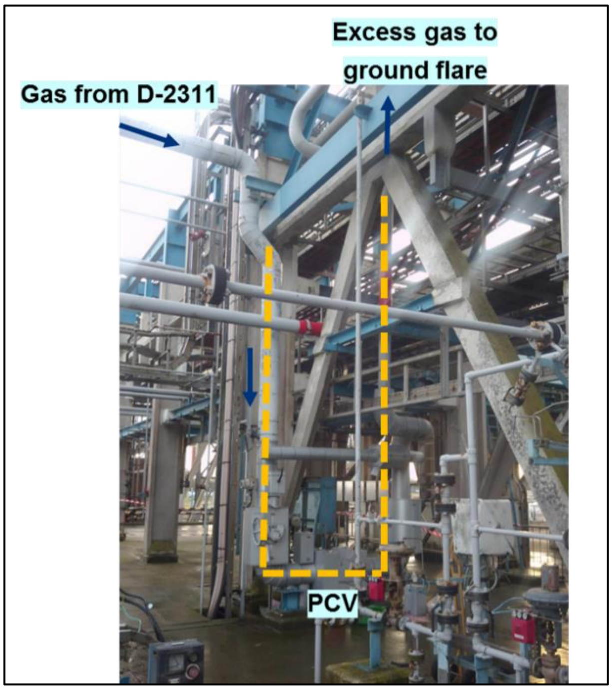


Figure 6: Overhead vapour line from the hot flash system. Dashed line represents low point or 'pocket' in the line for liquid accumulation. The vent header pipework to the ground flare is inclined back towards the PCV causing accumulated liquids to drain back to the low point.

Root Cause

Ineffective change management

In changing the operation of the continuous operation flash gas condenser (E-2307) to run in batch mode and removal of the route to the flash gas system and onto the ground flare instead, the potential for liquid condensation in the system outlet vent header was not initially recognised. The operations and maintenance teams at Easington terminal had not expected liquids to accumulate downstream of D-2311 which therefore resulted in condensation and accumulation of liquid in the low level 'pocket' (see Figure 6) at PCV-23351 and the vent header to the ground flare.

The 6" hot flash vent outlet pipework connects into an old 16" first gas production line. As part of the 1995 plant enhancement project the production line was air gapped and the remaining sections down rated to provide a vent header to the new ground flare from the flash gas/hot flash area of site. The orientation of the remaining section of the 16" line (which runs approximately 100 metres from West to East across site) has resulted in a natural fall in level back towards the hot flash system allowing liquids to build up at a low point (PCV-23351).

The changes in operation of the hot flash system were gradual in nature but eventually added up to a significant change i.e. creeping change. Revalidation of site hazards is a key requirement in maintaining a thorough understanding of the risks posed by the plant. A full re-HAZOP of the plant in light of significant modifications was conducted in 2017. During the HAZOP a scenario was discussed in which "*overfill of D-2311 with liquid which carries over into the vapour line off D-2311 to ground flare. Whether there is a potential lute section immediately downstream of D-2311 where discharge line rises into gantry before dropping back into ground flare. Upset flame conditions at ground flare and potential damage to burners. Smokey flame and possible injury at ground flare. Potential slugging flow through to ground flare*. The following action (number 28) was listed in the HAZOP report "*review routing and design of line from D-2311 to ground flare and determine if there are operational and potential liquid slugging issues associated with this current design that may need to be resolved*". In the case of the specific action highlighted an initial target completion date was agreed for 3 months after issue of the HAZOP report, the event occurred within this time period. A total of 152 recommendations were raised from the original study in September 2017 with some remaining open at the time this paper was written (Q1 2019). The effective closeout of HAZOP actions is important to risk management but should be placed into context with the changing risk picture within management of high hazard assets. The effect of a changing risk picture requires companies to re-prioritise and refocus on a regular basis which, without limitless resources, can lead to delays in the review and closeout of planned work streams including HAZOP action resolution.

Recommendations & Forward Plan

The investigation RCA raised 31 recommendations which were all supported by the site management team. All recommendations were linked to a specific cause generated detailed on the cause and effect chart produced as part of the *Sologic®* root cause analysis method. Linking causes to recommendations is a key tool in providing asset management with the origins of the resulting recommendation and promotes buy-in and support for enacting the resulting actions. The short term RCA actions were included in a pre-startup safety review (PSSR) conducted by the site team. Longer term actions had completion dates agreed with the recommendation owner and were added into the company event tracking system to provide closeout visibility for the management team. The following sections summarise the recommendations on a 'plant, people, process' basis.

'Plant' Recommendations

- Re-range and relocate the pressure transmitter in the hot flash system, recalibrate flow transmitters and ensure flow control valves fail safe (i.e. closed) in the event an error occurs with a flow transmitter, recalibration of level transmitters on the knock out drum (D-2301) and cleaning of level bridals, recalibration of back pressure controller (PCV-23351).
- Provide hot flash cooler (E-2307) fan running indication and temperature indication on the DCS for the control room operator to monitor.
- Provide operating instruction to ensure hot flash system lines are drained and free of liquids prior to start-up.
- Relocate back pressure controller (PCV-23351) from grade to vent header gantry to remove low point 'pockets' in the vent line through to ground flare.

'People' Recommendations

- Re-enforce hot flash shutdown sequence with operations teams and review training guides.

'Process' Recommendations

- Review the multiple restart attempts philosophy for the hot flash heater (H-1501) as described in the operator training guide. Consider approach aligned to a maximum number of attempts before seeking technical support.
- Provide a process to highlight the 'service factor' (% of time the controller is not in the desired state whilst the process in on line) and the number of 'set point changes' (to monitor how interactive the CRO is with the controller) visible for loops at Easington Terminal.

By combining the actions that were deemed necessary by the investigation team to be implemented immediately under a wider unit pre-startup safety review the plant and equipment limitations identified for safe operation of the hot flash stabilisation and ground flare system were resolved. Completion of the 'short term' recommendations prevented the combination of '*abnormally high pressure in the vent to ground flare from the hot flash system'* and '*liquids being present in vent header to ground flare'* which were the two initiating causes in the RCA chart. Preventing either one of these causes would stop the event from re-occurring in the future.

Completion of the 'medium' term actions allowed the site operations team to improve the human-machine interface arrangements with the hot flash stabilisation system operation and reset the normalisation of deviance that had occurred over time with the plant operating envelope. In particular the site could also review the efforts of the onsite maintenance team to preserve the desired reliability of the condensate stabilisation heater (H-1501). With ageing assets there is a balance between the ongoing maintenance requirements and the resulting economic and safety impact on the site. A capital project for the condensate heater replacement had already been initiated at the time of the event but the desire to reduce the risk associated with continued operation in its unreliable state has now secured investment for an inherently safer alternative heater to be installed and commissioned in 2019.

A further enhancement project at the site will enable processing of gas from the Tolmount gas field to start in 2020 (see Figure 1 for location of the Tolmount field in the Southern North Sea). Figure 7 shows the proposed modification that will remove the existing 'pocket' from the gas vent line to ground flare that has been incorporated into the detailed design for the wider site upgrade project.

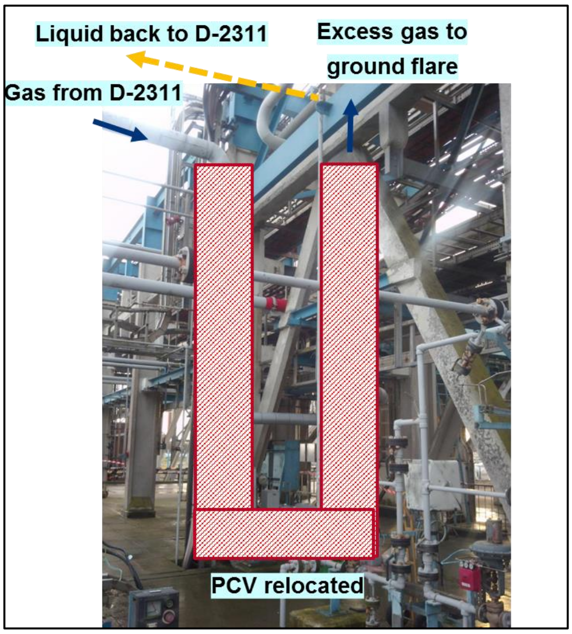


Figure 7: Overhead vapour line (with 'pocket' removed) from the hot flash system following proposed site upgrade project. Dashed line represents condensed liquids draining back from the vent header to the hot flash condensate stabilisation system knock-out drum (D-2311).

Creeping Change Management

The challenge of creeping change management affects wider industry and has been highlighted as a significant issue in HSE's review of offshore assets in *Key Programme 4: Ageing and life extension programme – A report by the Energy Division of HSE's Hazardous Installations Directorate* [(2)]. Guidance to identify hazards resulting from creeping change have been developed to counter this issue. A creeping change hazard identification (CCHAZID) methodology is available [(3)] following pilot studies at Centrica assets and will be used in future hazard identification studies at Easington Terminal.

Conclusions

Whilst the event discussed in this paper had no immediate process safety consequences to the site population at Easington Terminal the resulting investigation and pre-startup safety review (PSSR) provided the management team with opportunities to improve the safety and reliability of the asset. The management team have completed all short and medium term recommendations suggested as part of the investigation to ultimately prevent liquid accumulation in the vent header to the ground flare as well as improve the operability of the hot flash condensate stabilisation system. There has been no re-occurrence of the event in the 12 months since the PSSR took place. The opportunity to implement further risk reduction options as part of long term plant upgrades has also been taken in order to reduce the risk profile of the site.

Effective hazard identification remains key to risk management activities at high hazard facilities, with the development of new guidance emerging to combat threats from creeping changes. Fundamental to the success of the hazard identification technique is the risk ranking/priority management of the resulting recommendations and having resource available to complete actions within a suitable time frame.

References

(1) Sologic Root Cause Analysis, https://www.sologic-rca.com

(2) Key Programme 4: Ageing and life extension programme – A report by the Energy Division of HSE's Hazardous Installations Directorate, 2014, http://www.hse.gov.uk/offshore/ageing/kp4-report.pdf

(3) Guidance on Applying a Creeping Change Hazard Identification (CCHAZID) Methodology, 2017, Energy Institute.