Root Cause Analysis

Booster Station 150 Stainless Steel Piping Failure

Kuwait Oil Company

Gas Management Group

GPA–GCC (Corrosion in Gas Plants)

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Description of Failure at BS 150

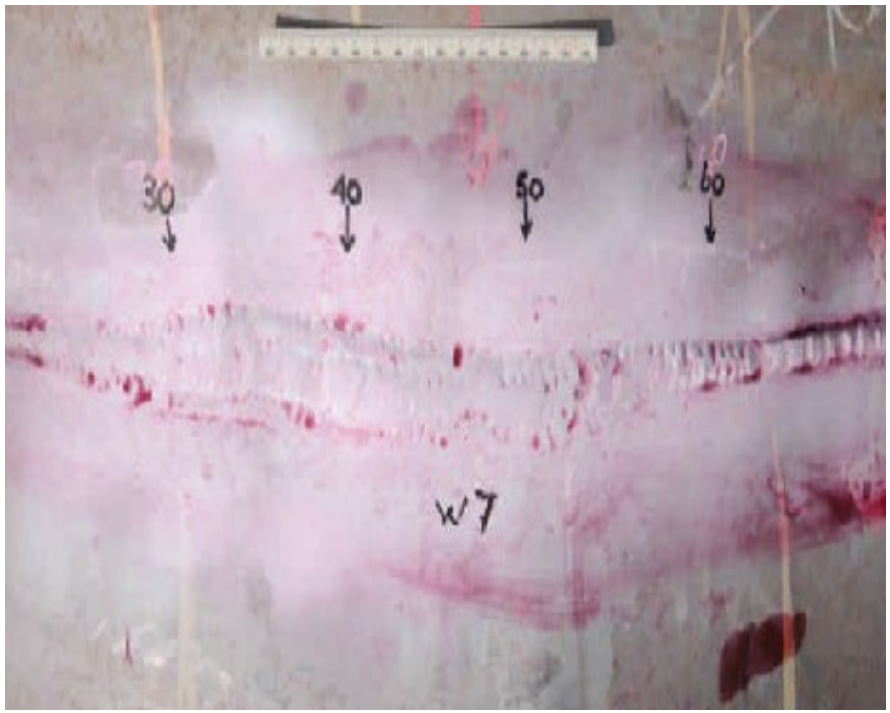
- On March 9, 2005 minor oozing of gas & oil occurred from the bottom portion of weld joint inlet piping (42”dia, stainless steel 321) of a low pressure gas suction scrubber of Gas Booster Station (BS) 150 Train III.

Visual Examination

- Crack was visible at 6 o’clock position on scrubber inlet pipe
- Corrosion products is visible on the inside pipe in the weld area

Non Destructive Examination

- External surfaces of welding seam was cleaned and visually inspected using Soap Solution and Dye penetrant. Presence of any surface indication was not revealed.



Ultrasonic Examination

- **Ultrasonic scanning with special calibration was used to detect the presence of indications in the wall thickness of the piping. Several linear indications were observed having characteristics similar to that of Stress Corrosion Cracking (SCC).**

Immediate Action

- Due to the above observation, it was recommended to immediately stop the operation of concerned gas stream piping and replace with new piping.

- All the other piping in the plant and similar piping in another gas booster station was also extensively inspected to detect for similar cracking present at any other location.

Other Evidences in Similar Trains

- A crack was also observed in Train II by ultrasonic scanning. This crack had not penetrated the entire wall thickness but had become quite large & deep to give a leak in the near future.

- This train was also recommended for a shutdown for carrying out the replacement.

Formation of Investigation Team

- A committee comprising of team members from varied disciplines like
  - ***Design,***
  - ***Gas Operations,***
  - ***Gas Services,***
  - ***Production Operations,***
  - ***HSE and***
  - ***Inspection & Corrosion Team***

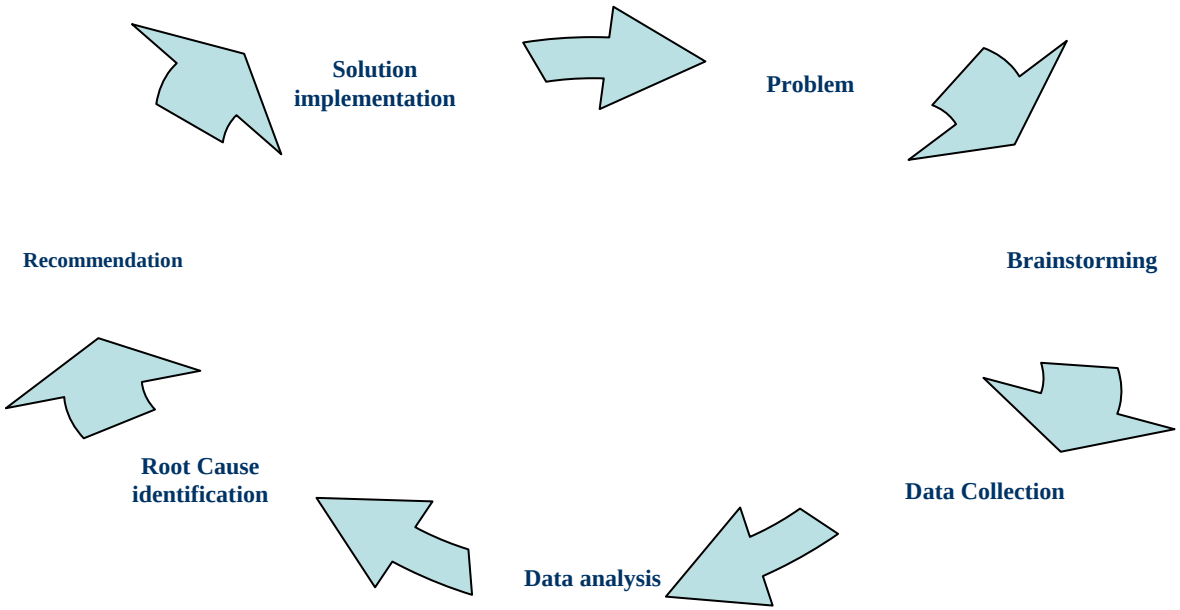
  was formed, to conduct a Root Cause Analysis (RCA) of this failure.

Root Cause Analysis

- ***Root Cause Analysis*** **(RCA) is a methodology for finding and correcting the most important reasons for performance problems.**

- **The primary methodology deployed for conducting the *Root Cause Analysis* (RCA) by the committee was *Events & Causes Analysis*.**

Primary Aspects of the Methodology



Criticality of the Failure

- Criticality of the failure was analyzed based on the relative measure of the consequences of a failure mode & its frequency of occurrence.
- Level IV : Minor
- Level III : Marginal
- Level II : Critical
- Level I : Catastrophic
- The criticality of this failure was categorized by the committee as Level I failure.

Events & Causal Factor Analysis

- Several events & causes which may have led to the final failure were listed, analyzed, brainstormed & finalized.

- Main factors such as:
  - Gas,
  - Material of Construction of piping,
  - Design conditions,
  - Operational parameters &
  - time factor were considered

Data Collection & Analysis

- Data regarding
  - **Gas Quality,**
  - **Liquids entrained in the gas streams,**
  - **Quantity of liquids observed in the drains of scrubbers;**
  - **Pigging activities,**
  - **Draining frequency of scrubbers,**
  - **Liquids carry over to the consumer networks,**
  - **Identification of GC's / wells contributing to higher chloride contents in liquids etc.**

  were discussed & analyzed in detail.

RCA Steps

- The RCA was conducted by using a four step process involving:
  - Data collection
  - Causal factor charting
  - Root cause identification
  - Recommendation

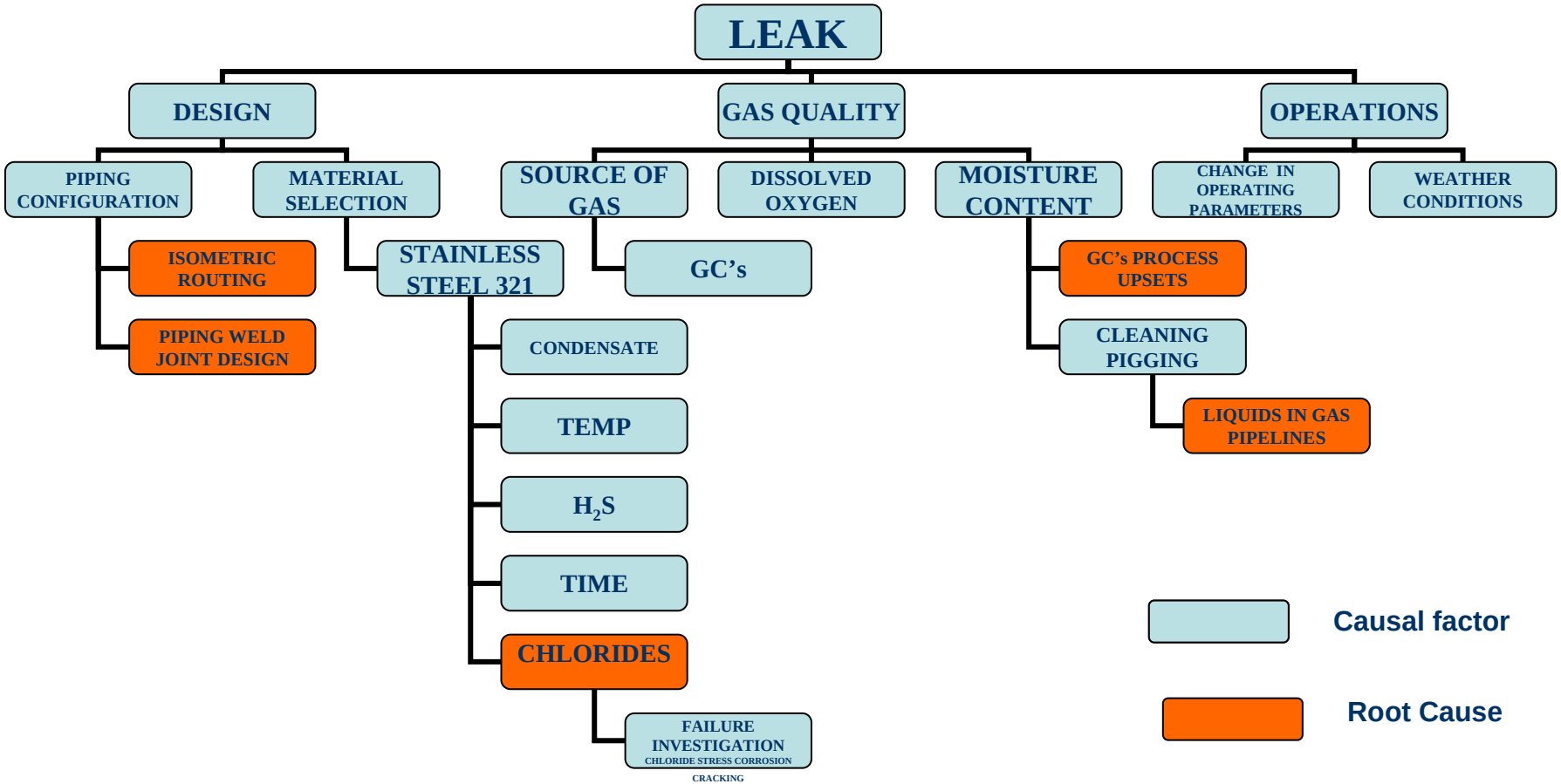
Root Cause Map

- ***Equipment Problem (Main Event):***

- **Design Problem**
  - Original Design documents
  - Design philosophy
  - Document control
- **Reliability Problem**
  - Equipment reliability program
  - Preventive maintenance
  - Predictive maintenance

- **Operations Problem**
  - Operating / maintenance history
  - Operating procedures / neglect
- **Process Problem**
  - Change in process parameters
  - Change of source
  - Safety / hazard review
- **External Factors**
  - Environment
  - Administrative Management Systems
  - Tampering / misuse

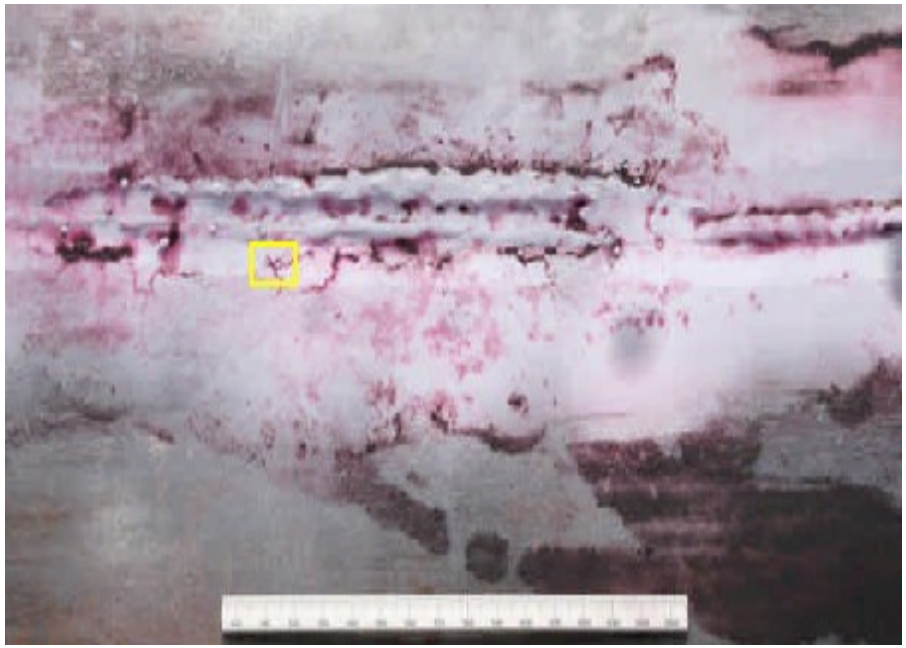
Summary Fault Tree for the Incident



Laboratory Investigation

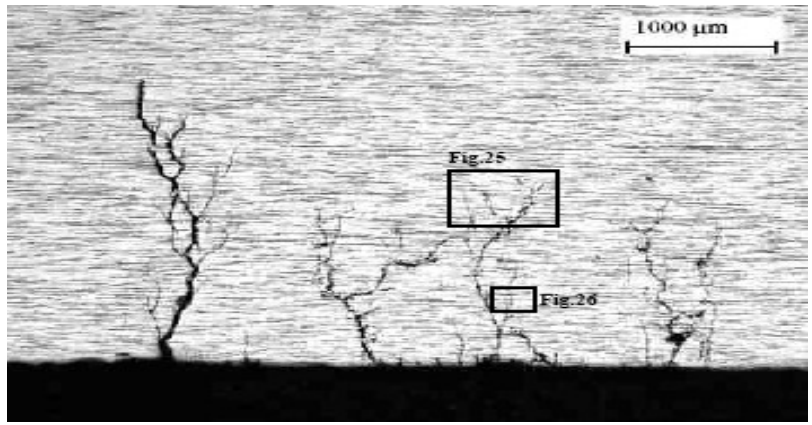
- **Investigation of Failed Piping**

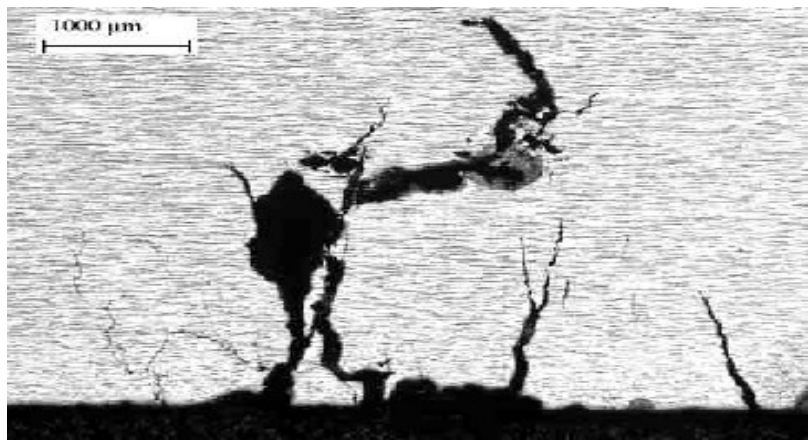
  A spool piece was cut from the (42” dia.) affected piping and the internal surface was subjected to dye penetrant testing which revealed several cracks having typical pattern of stress corrosion cracking.



Metallographic Micrographs

- **Metallographic Micrographs conducted by TWI (The Welding Institute, UK) revealed:**
  - **The presence of several branched in both intergranular and transgranular cracks due to SCC and**
  - **Large amount of deposits inside the piping which can be the probable source of corrosion mechanism**





Influencing Factors for Branched Cracks

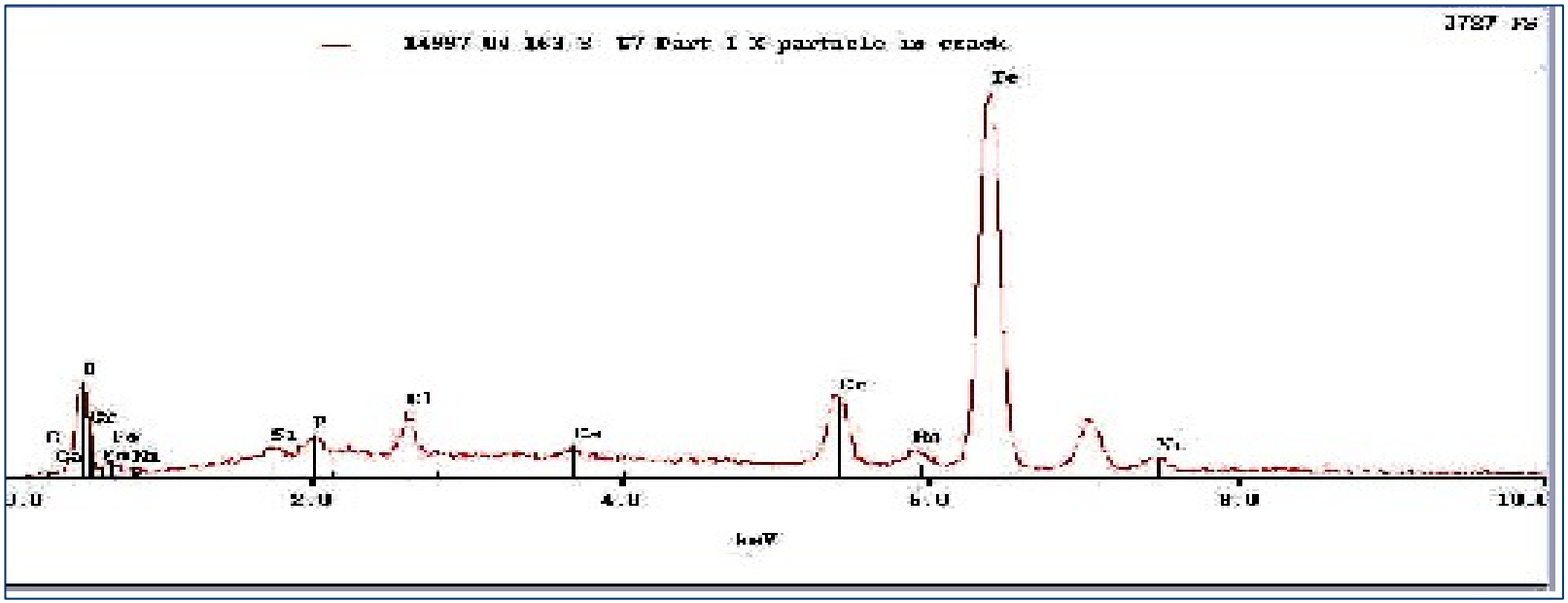
- Position in pipe where corrosion had initiated,
- Material of construction being stainless steel,
- Chloride content in the gas stream,
- Carry over of large amount of sludge and liquid particles,
- Condensation and accumulation of deposits at the bottom most position.

Micrographic results

- Cracks are initiating from the parent metal crossing the weld metal and propagating on the other side into the parent metal.
- Large pits are also visible with several cracks originating from the same.
- It can also be revealed that the severity of cracking is more in HAZ than in weld metal or parent metal.
- Microphotographs also reveal the cracks to have a transgranular pattern.

EDX-Ray Analysis

Energy Dispersive X-Ray analysis (SEM-EDX) conducted by TWI (The Welding Institute, UK) showed the corrosion products to be rich in oxygen and chloride species



Hardness Surveys

- The mean weld metal, HAZ and parent material hardness were all below the maximum ISO 15156/NACE MRO175 (1) limit of 22HRC

Chemical Analysis

In Feb. 2006 Condensate samples were taken & analyzed, where the common HP Gas Scrubber drains liquid analysis revealed the presence of ~ 54000 ppm of chlorides.

Tests	C-201 Bottom		C-202 Bottom		C-203 Bottom		Common HP Scrubber	
	Water	Oil	Water	Oil	Water	Oil	Water	Oil
Appearance	No water separation	Dark Brown	Turbid,Oily	Dark Brown	Turbid, Oily	No oil available	Turbid, Oily	Dark Brown
pH	--	5.8	6.5	6.2	6.67	--	5.18	--
Cl^-	--	788	92	23	14	--	54000	100
H_2S	--	5.83	3.85	6.8	17.9	--	10.4	--
CO_2	--	12	20	12	120	--	200	--
TDS	--	1327	415	50	320	--	87000	220

Discussion

- Based on the boundaries for investigation, data analysis, rating; it was concluded that the most probable Root Cause for the failure is due to the presence of chlorides in the liquids entrained in gas streams & liquids carried over to the Gas booster stations.

- Evidence of corrosion and collection of deposits at the 6 O’clock position were of a corrosive nature to initiate SCC.

Conclusion

The failed joint was the result of Chloride Stress Corrosion Cracking

- ***The cause of the failure was a combination of:***
  - **Chloride containing corrosive environment**
  - **Residual stresses associated with the weld**
  - **Excursion of temperature to at least 55-60 C, which lead to chloride SCC**

Recommendations

- As a short term solution so as to “live with the root cause of failure” identified in the investigation, the committee recommends a study on suitable material of construction of piping handling the current gas streams.

- It is noted that the replaced piping was constructed from carbon steel material which is suitable from chloride stress corrosion cracking point of view.

Recommendations

- As a **long term** solution & to provide a reasonable confidence in operating the Gas Booster Stations as designed; the committee recommends following changes to the system:

(1) Evaluate performance of the existing design of old Separators in Gathering Centers to ensure effective removal of the liquids associated with gas. Existing horizontal conical separators do not have any internal arrangement for liquids removal from the gas phase.)

- **Action By:**
  - **Production Operations (SK/EK)**
  - **Operations Technical Services (SK/EK)**

Recommendations

(2) Evaluate the efficiency of Gas Scrubbers in Gathering Centers so as to minimize the liquids entrainment in the gas streams to Gas Booster Stations.

- **Action By:**
  - **Production Operations (SK/EK)**
  - **Operations Technical Services (SK/EK)**

(3) Data base regarding frequency of cleaning pigging, quantity and quality of liquid pigged out to be generated and maintained.

- **Action By: Gas Operations**

Recommendations

(4) Water & liquids carried over to Gas Booster Stations at the time of cleaning pigging of gas pipelines to be controlled / avoided.

- **Action By: Gas Operations**

(5) Specifications for vane packs and mist elimniators to be reviewed and spares from original equipment manufacturer (OEM) to be maintained.

- **Action By: Operations Technical Services (SK/EK)**

Awareness & Importance of this Study

- Increase awareness of the factors to consider when managing equipment containing hazardous fluids under pressure, and to help those responsible for equipment to understand and assess the risks of accumulated damage and deterioration.

- In addition to the engineering aspects, the operating culture and defined roles and responsibilities are discussed in relation to managing equipment. These are affected by staff demographics, along with skills, training and competencies. The importance of maintaining documentary information and records throughout equipment life is also highlighted.

Root Cause Analysis

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Thank you!