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IMPROVING PRODUCT QUALITY AND MEG RECOVERY UNIT (MRU) EFFICIENCY BY APPLYING LEAN SIX SIGMA METHODS IN A FLOATING PRODUCTION UNIT

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Abstract

One of the challenges of managing gas from deep-water wells is ensuring that the flow from the subsea does not form a hydrate, which causes the production to stop due to blockage in the pipeline. Injection Mono Ethylene Glycol (MEG) is the technology used to prevent hydrates formation. The MEG Recovery Unit (MRU) is a system used to recover rich MEG from wells. However, after operating for four years, the MRU experienced a decrease in performance as indicated by lean MEG products that did not meet the specifications, and MEG losses exceeded the specified limit. This study examines the case by taking an effective approach to solving problems by applying the Lean Six Sigma method that focuses on improving product quality and MRU efficiency using Define-Measure-Analyze-Improve-Control (DMAIC) framework. The process starts by defining the problem of the MRU system with involves brainstorming consultation to select the root cause of the problem. Classifying and assessing these reasons has been done through the use of various tools, the fishbone diagram, Failure Mode and Effect Analysis (FMEA), and the 5 why analysis. The results show that Lean Six Sigma methodologies and tools effectively find the root causes of problems accurately and can provide continuous improvement. The quality of lean MEG products has increased with the cleanliness value below NAS 8 and Total Dissolve Solid below 100 ppm. This reduces operating costs to replace filters with savings of $42,000 per month. Meanwhile, MRU efficiency increased from 96% to 98%, and MEG losses reduced from 1500 liters/day to 750 liters/day equivalent to a savings of $36,000 per month.

Keywords: Lean Six Sigma, MEG Recovery Unit, Oil and gas industry.

Introduction

Lean Six Sigma is a two-staged business approach to continual improvement that focuses on reducing waste and product variation from manufacturing, service, or design processes (Hanna et al., 2020). Lean refers to maximizing customer value and minimizing

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waste. Six Sigma is the ongoing effort to continually reduce process and product variation through a defined project approach. The entire work is set to follow the DMAIC approach. One of the main concerns in offshore natural gas production, particularly at sea is the formation of hydrates in subsea pipelines. A hydrate is an ice-like compound with a structure consisting of air and light molecules (mainly methane). This has come to the attention of flow assurance, which is considered the most critical aspect of a flow assurance strategy. Gas flow line hydrate formation occurs as a consequence of favorable thermodynamic conditions, which are defined basically by three factors: (i) the presence of production water along with the gas, (ii) high operating pressures in flow lines, and (iii) low temperature close to 0 ^{O}C (Gupta & Singh, 2012). Those conditions are typically found in deep water subsea gas flow lines and therefore the prevention or control of hydrates formation is necessary to avoid safety hazards in flow lines and the consequent production losses (Sloan & Koh, 2008).

In this context, the most widely adopted strategy for hydrate inhibition is the injection of the hydrate inhibitor at the wellhead, so that the inhibitor flows with the production fluid and thus avoids hydrate formation. Concerning thermodynamic inhibitors, MEG injection has been widely used because MEG presents advantageous features when compared to other inhibitors, such as presenting low losses to the vapor phase as well as it can be effectively recovered, regenerate, and recycled, being an appropriate choice for this purpose (Haghighi et al., 2009). Supplying MEG to the wellhead is critical to gas production since interruption of MEG injection can lead to loss of wells production due to the risk of hydrate plug formation in the subsea production infrastructure. Maintaining the high reliability of MEG supply is heavily dependent on good MEG Recovery Unit (MRU) performance. MRU is designed to recover rich MEG (MEG mixed with production water from the reservoir) to remove salt deposits.

After operating for 4 years, the performance of the MRU experienced a decline in performance, both in quality and quantity, as indicated by the following:

- The quality of the lean MEG products from the MRU does not meet the specifications, namely Total Dissolved Solid (TDS) and Cleanliness (NAS) exceed the expected limits.
- Decreased MRU efficiency causes the loss of lean MEG products from the MRU system (MEG Losses) beyond the designed or designed limits.

The decline in product quality and MRU efficiency causes increasing operating costs to be incurred to ensure the continuity of the oil and gas processing. These costs include the purchase of a MEG filter as well as the purchase of a fresh MEG to replace the lost MEG. Total costs incurred in one month reached US $102,000.

The purpose of this research is to find the root cause accurately and carry out continuous improvement by applying a Lean Six Sigma approach, which aims to improve MEG product quality and MRU efficiency so that the process operation can run smoothly, efficiently, and safely. The methodology follows the Define-Measure-Analyze-Improve, and Control (DMAIC) framework. A team was formed for the project is a team-based technique. Selection is based on the contribution each member can bring to the process. The team began to identify the key parts of the current process by developing a Supplier-Input-Process-Output-Customer (SIPOC) diagram. Historical data is collected and reviewed. In the analysis phase of DMAIC, the aim is to develop a theory of root causes, confirm the theory with data and finally identify the root cause of the problem. The solution evolves from in-depth data analysis, including input from customers and stakeholders. The analysis identified four main causes of deterioration in MRU performance: Foaming, the presence of foreign particles escaping from the well, inadequate preventive maintenance programs, and design changes resulting in improper pressure and temperature regulation.

Research Method

1. Lean Six Sigma.

Lean Six Sigma is a two-staged business approach to continual improvement that focuses on reducing waste and product variation from manufacturing, service, or design processes (Hanna et al., 2020). Lean refers to maximizing customer value and minimizing waste. Six Sigma is the ongoing effort to continually reduce process and product variation through a defined project approach. The entire work is set to follow the DMAIC approach.

Lean Six Sigma is a systematic approach to improvement needed to improve performance as measured by quality, cost, delivery, and customer satisfaction. It is one of the latest generations of improvement approaches being used both by manufacturing and service industries (Ozcelik, 2010). Lean Six Sigma is a business strategy and methodology that increases process performance resulting in enhanced customer satisfaction and improved bottom-line results (Snee, 2010). In the past decade, the marriage between Lean and Six Sigma made an important excellent system for addressing problems on the shop floor (Baker, 2003). Lean Six Sigma has broad applicability, including manufacturing, service, healthcare, government, non-profits, and education. It is useful in small and medium size organizations as well as large organizations (Antony et al., 2017). (Davenport et al., 1998) acknowledged the fact that organizations always seek project success as the end goal for every project through various project improvement management mechanisms. To achieve that, organizations changed from what was been practiced before to embrace the LSS methodology, which offered continuous and effective improvement mechanisms and cost reduction (Näslund, 2008). As reported by (DSMC & Interagency, n.d.)

2. Application of Lean Six-Sigma in the Oil and Gas Industry

Several lean six sigma studies have been conducted in the oil and gas industry. One application was through a study that was carried out to optimize rig-move operations (JP et al., n.d.). A special task force team was assigned to identify and reduce inefficiencies in the rig-move process. As a consequence of this DMAIC approach, in Lean Six Sigma, a clear reduction of 13% of defects was noticeable, where total rig-moves were 23 and those that went beyond the business plan were 3, thus, sigma levels improved from 0.81 to 2.62. A 61 % improvement in rig-move performance was achieved starting in 2012. Also, it is important to note that an additional 258 days for oil production opportunity was achieved for the year 2013. (Atanas et al., 2015).

The Lean Six Sigma approach was also used to improve Propane C3 recovery in Gas Plants. Following the assessment of the low C3 recovery in NGL (Natural Gas Liquid) products, an implementation plan was generated and results showed a 70% increase in NGL total yield (Amminudin et al., 2011). Moreover, a lean six-sigma project was conducted to reduce the lead time for refurbishing wellhead valves. Following the data collection and analysis on the refurbishing process, a set of recommendations have been proposed, and the implementation resulted in reducing the refurbishment lead time from 53 to 3 days (Aldakhil et al., 2021). The approach was applied in a refinery to improve profitability by energy optimization and reduce the energy intensity index (WII) and reduce emissions. Following the implementation phase, the WII has improved, resulting in a cost avoidance of $1.4MM/year (Bhanumurthy, 2012).

A recent research was conducted that applied the concept of lean six-sigma to the process optimization of equipment maintenance. The researchers have built a model based on the design of the experimental approach. The outcome showed that the optimization model based on the design of the experiment is feasible and effective, however with some shortcomings and deficiencies in lean six-sigma management. It was recommended to introduce lean six sigma for process optimization system to accomplish the aim of continuous improvement for the equipment maintenance process (Zhao et al., 2012).

A drilling contractor Company in the GCC region also uses a lean six sigma approach to solve the excess and obsolete inventory that have a major negative effect on the efficiency of the supply chain and its management. Failures in inventory control management systems bear financial and managerial consequences. A lack of backstory visibility was observed since no one knew exactly how much inventory there was, in any of the rigs or storage areas. A special task force team was assigned to identify and reduce inefficiencies in the supply chain process. As a result, the recession was spooling up and parts are still being ordered based on date. All deficiencies were identified and addressed in the “improve” phase. The “improve “phase has resulted in increasing inventory visibility and control, requisitioning efficiency and accuracy as well as cycle counting which has been performed regularly and included as a process in the material requirements planning system. In 2012, the rollout of inventory management provided increased inventory visibility with improved cycle counting by up to 50% over 2 years. The Supplier Relationship Management Program drove suppliers to improve their on-time delivery performance and customer service, as well as increase communications with the Company (Atanas et al., 2015)

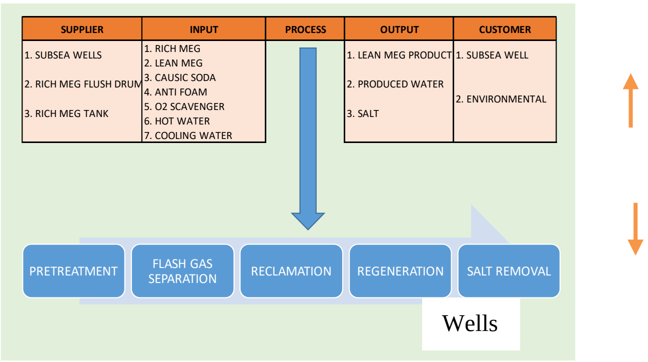
Result and Discussion

The project started with problem definition through statistical analysis of the current performance and quantification of decreasing MRU performance for a certain period. The problem definition breaks down into problem statement, project objective, and project benefits in the Project Charter. At this stage, a Project Charter is created which functions as an informal contract that helps the Lean Six Sigma team stay on track with the desired goals and targets. This involves using the Supplier-Input-Process-Output-Customer (SIPOC) diagram to gain a better understanding of the current process. The process also involved a brainstorming session to identify potential root causes of the problem. Classifying and rating these causes are achieved by the use of the following tools: a “Fishbone” diagram, cause-and-effect matrix, Failure Mode and Effect Analysis (FMEA) and 5 Why analysis. FMEA is a methodology used to evaluate failures in systems, designs, processes, or services. Identification of potential failures is carried out by assessing each failure mode based on its occurrence, severity, and detection. This is followed by the root cause analysis technique using the five (5) why's a concept. Finally, an implementation plan was generated incorporating all the process improvement recommendations.

A. Define phase

The project begins with the define phase, which provides a clear problem definition using the Supplier-Input-Process-Output-Customer (SIPOC) tool. This tool describes the process steps for the MRU cycle as shown in Table 1. The first process is the supplier: Subsea Well, Rich MEG Flush Drum, and Rich MEG Tank. The inputs for this process are Rich MEG, Lean MEG, Caustic Soda, Anti Foam, O2 Scavenger, Hot Water, and Cooling water. MRU processes are Pretreatment, Flash Gas Separation, Reclamation, Regeneration, and Salt removal. The outputs of this process are lean MEG, produced water, and salt. And the customers are subsea wells and environmental.

Table.1 SIPOC



SUPPLIER	INPUT	PROCESS	OUTPUT	CUSTOMER
1. SUBSEA WELLS 2. RICH MEG FLUSH DRUM 3. RICH MEG TANK	1. RICH MEG 2. LEAN MEG 3. CAUSIC SODA 4. ANTI FOAM 5. O2 SCAVENGER 6. HOT WATER 7. COOLING WATER		1. LEAN MEG PRODUCT 2. PRODUCED WATER 3. SALT	1. SUBSEA WELL 2. ENVIRONMENTAL

Figure.1 Process Block Diagram

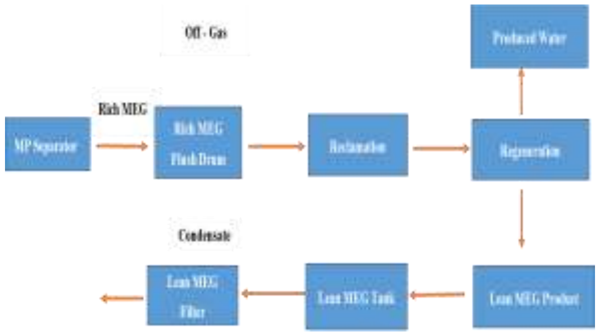


Figure 1 shows the block diagrams of MRU, the functional flow diagram can be used to target specific audiences when analyzing the detail within each functional area.

1. Pretreatment.
   Rich MEG is separated from gas and condensate in the Rich MEG Flush Drum. Hydrocarbon gas and condensate are channeled to the main processing section, while Rich MEG flows into the Rich MEG Tank.
2. Reclamation
   Rich MEG flows to the Vacuum Reclaimer Drum operated at vacuum pressure with a temperature of 120 – 130 ^{O}C to evaporate water and MEG, while the slurry will be retained at the bottom of the vessel for further processing.
3. Regeneration
   The evaporated water and MEG flow into the distillation column to be separated between the produced water and the lean MEG product. The product will be stored in the Lean MEG Tank, while the produced water will be discharged into the sea with predetermined specifications.
4. Salt Management
   The salt crystals that settle in the Vacuum Recliner Drum are separated by gravity to the bottom of the column, where they are transferred to the salt tank. The salt formed is then discharged through a centrifuge. Salts in produced water include a variety of species but are generally categorized as covalent salts.

Critical to Quality (CTQ) is a tool commonly used to break down consumer needs that are quite diverse into needs that can be quantified and are easier to process. From Fig 2, this CTQ shows that customer needs for the products produced by the MEG Recovery Unit are Lean MEG which has cleanliness NAS 8, Total Dissolved Solid below 100 ppm, PH 6.5 – 8, and density 1.1 – 1.2 kg/m3.

Figure 2. Critical to Quality of lean MEG product

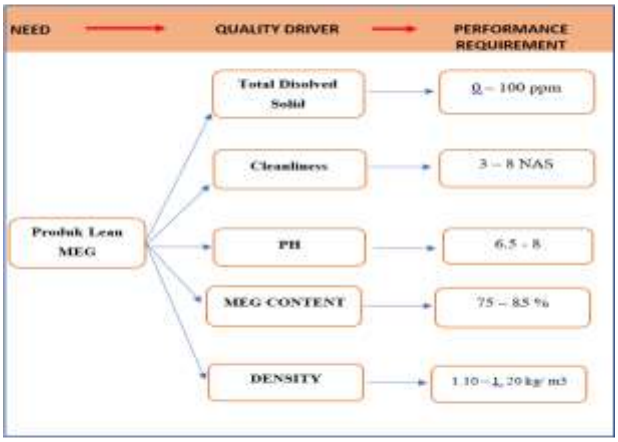


Figure 3. Pareto Diagram.bb

B. Measure Phase

The measure phase is the second step of the DMAIC improvement cycle, aiming to achieve the project objectives defined in the define phase. This step involves the measurement of available process record data, establishing basic process capabilities, and reviewing baseline performance against the set targets. In the Pareto diagram shown in Figure 3, the most prevalent defects are the cleanliness and TDS of lean MEG products that exceed the established standards. Based on Fig 4, the average monthly cost of using MEG filters due to a high NAS is US$ 21,000 per month.

Figure 4. MEG cleanliness vs material cost

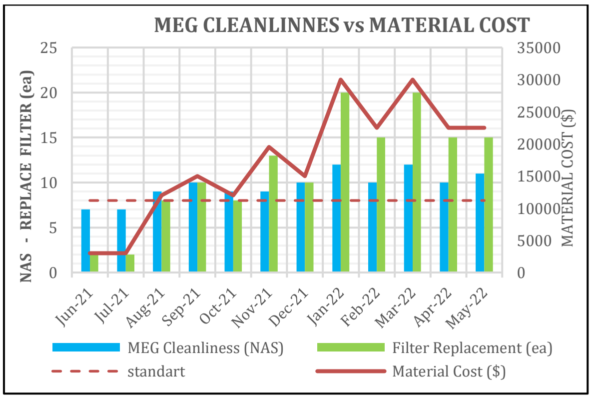
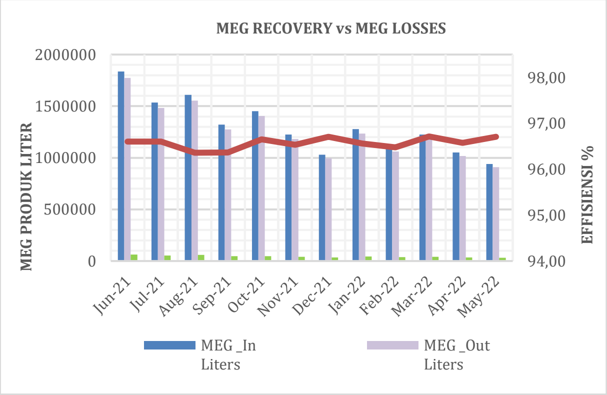


Figure 5. MRU Efficiency.



Additionally, based on the data collected shown in fig 5, during the month of June 2021 until May 2022 the average MRU efficiency is 96% due to MEG lost in the process exceeding the operating limits. With the above condition, the purpose of this research is to improve the cleanliness and TDS values of lean MEG products as well as to increase MRU efficiency as table below.

Table 2. Lean MEG Product specification

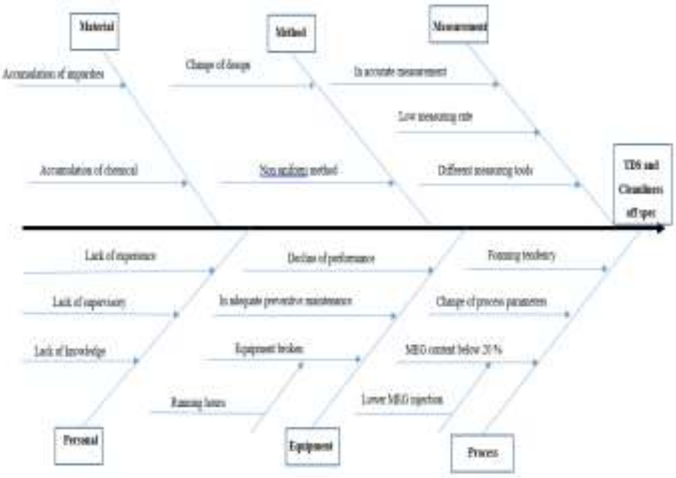
PARAMETERS	UNIT	VALUE
Max Cleanliness	NAS	8
Max *salts content*	ppmw	100
Maximum MEG losses	wt %	0.5
MEG recovery within the Package	%	99.5

C. Analyze Phase

Finding the root cause of the problem is the next step. This is achieved by the use of the following lean six sigma tools, fishbone diagram, Failure Mode Effect, and Analysis (FMEA). The fishbone diagram, which enables the team to explore the causes, is conducted in a brainstorming session among team members. The FMEA prioritizes the causes or identifies which elements contribute most to cause problems. This involves the use of rankings on all elements identified as having the potential of causing the problem. The Fishbone diagram and FMEA are shown in Figure 6 and Table III respectively.

The potential causes were classified into six main categories: material, method, equipment, measurement, personal, maintenance, and process. Each category has one or more sub-clauses. Under material, one sub-cause from the material was identified as an accumulation of impurities and chemicals. The sub-causes related to the method were the design has been changed during MRU upgrading. Some item identified under equipment is an inadequate preventive maintenance program and equipment broken. Foaming tendency, changing of process parameters and MEG content below 20 % are identified under process sub-categories. Lack of knowledge and experiences are identified under personal sub-categories. Fig 6 shows the fishbone diagram.

Figure 6. Fishbone Diagram



Next, the failure mode and effect analysis (FMEA) shown in Table III used to detail the causes, includes finding the potential failure mode, identifying the impact of this failure on the customer, identifying potential causes of this failure, and recognizing the current control mechanism to mitigate the failure. Each element in this FMEA analysis was rated according to FMEA standard rating guidelines, and the analysis was carried out in a brainstorming session. Based on table I, if ordered from the largest to the smallest RPN, loss of Loop Heater performance due to scale formed is a case that has high priority, because the RPN number reaches 168 RPN. Followed by foaming that occurs in Vacuum Reclaimer Drum due to high condensate content in the rich MEG and high condensate content in the Rich MEG Tank. The failure separation in Rich MEG Flush Drum is a case that is low priority.

Table 3. FMEA

Item / Function	**Potential Failure Mode(s)**	**Potential Effect(s) of Failure**	**SEV**	**Potential Cause(s)/ Mechanism (s) of Failure**	**OCC**	**Current Design Controls**	**DET**	**RPN**
Rich MEG Flush Drum	Failure in separation between condensate and rich MEG	Condensate carried over to Rich MEG tank.	4	Failure of instrumentation Level indicator.	4	Preventive maintenance.	3	**64**
Rich MEG Tank	Condensate/ impurities accumulation	Condensate/ impurities content in rich	6	Failure of the previous process operation.	5	Cleaning the Rich MEG Tank	4	**120**

		MEG is above design.				periodically.		
Vacuum Reclaimer Drum	The high condensate content in rich MEG.	Foaming occurs, and salt is carried over to the product.	6	Condensate content in the Rich MEG Tank is high.	6	Cleaning the Rich MEG Tank periodically.	4	**144**
	Level indicator incorrect reading	Failure process operation		Level transmitter plugging		Corrective maintenance		
Item / Function	**Potential Failure Mode(s)**	**Potential Effect(s) of Failure**	**SEV**	**Potential Cause(s)/ Mechanism(s) of Failure**	**OCC**	**Current Design Controls**	**DET**	**RPN**
Reclaimer Loop Heater	Scale is formed in the Reclaimer Loop Heater	Loss of performance from Loop Heater.	7	Accumulation of impurities, and salts in the system, Presence of excessive heat	6	Cleaning loop heater periodically.	4	**168**
Salt Sediment Vessel	Lower slurry circulation rate.	Lower salt formation in the slurry loop.	6	Failure of the slurry pump (damaged stator).	5	Preventive maintenance.	3	**90**
Parameters Proses Operation	Setting the operating process parameters is not correct	The operating process is unstable	5	Operator Lack of knowledge	5	Operator Training and refreshing	3	**75**

A 5-why analysis is then performed based on the fishbone diagram and FMEA results to determine the root cause of the problem. Afterward, effective corrective measures can be determined. The result of the 5 Why analysis shows in table IV.

Table 4. 5 Why Analysis.

PROBLEM	**WHY 1**	**WHY 2**	**WHY 3**	**WHY 4**	**WHY 5**
Off Spec Lean MEG Product	Salt carried over to the product	Foaming occurs at Reclaimer Drum	Higher Condensate content at Rich MEG.	Condensate Accumulation in Rich MEG tank.	
	Salt carried over to the product	Over evaporation at Reclaimer Drum	The process parameter is not correct	Changing of MRU design	
			Higher dT loop Heater	Scale formed at loop heater	
			Rich MEG content below 20 % wt.	Lower MEG injection	
	Salt carried over to the product	Salt accumulation at Reclaimer Drum	Salt formation (precipitation) is low.	Lower Slurry rate circulation	Slurry pump broken
Lower MRU Efficiency	Slurry bleeding	Slurry density above standard	Salt removal not working	Slurry pump performance decline	The pump stator is broken.
		Salt accumulation at Reclaimer Drum.	Salt formation (precipitation) is low.	Low Slurry rate circulation.	Slurry pump performance decline
			Salt formation (precipitation) is low.	PH Slurry too low below 10.5	Caustic soda injection valve broken
		Often Rejuvenation activities	Salt accumulation at Reclaimer Drum.	Salt formation (precipitation) is low.	

D. Improvement and Control Phase

The identified recommendations have been consolidated in an implementation plan, Table V, which contains the causes, actions required, responsible discipline, and expected time of completion. Upon completion of this plan, the control phase is started by monitoring the implemented improvements to maintain gains, and ensure corrective actions are taken when necessary.

Table 5. Improvement Plan

No	Cause	Action	Who	When	Status
1	Condensate/ impurities accumulation in Rich MEG tank	Inspect and clean up the Rich MEG tank.	Asset Integrity/ Marine / Production	Q3 2021	Closed Shown in Fig.7
2	Scaling on Loop Heater/ Declining performance	Inspect and clean up Loop Heater	Team Maintenance/ Production	Q4 2021	Closed Shown in Fig 8
3	Slurry pump stator broken	Replace the stator with the new one.	Maintenance Supervisor	Q1 2022	Closed Shown in Fig.9
4	Caustic soda injection valve broken	Rectification and order of the new spare part	Maintenance Supervisor	Q2 2022	Awaiting a spare part
5	Rich MEG content below 20 % and Process Parameter is not correct	MRU Optimization by adjusting process parameters.	Operation Specialist/ Supervisor	Q2 2022	Closed Shown in Fig.10

The below figures are some evidence of the execution of the improvement plan.

Figure 7. Inspect and clean up Rich MEG Tank

Figure 8. Inspect and clean up Reclaimer Loop Heater

Figure 9. Inspect and replaced the Slurry Pump stator

Figure 10. Lean MEG product.

Lean MEG product quality has been improved after some optimization as per the improvement plan shown in figure 10.

Figure 11. TDS lean MEG product

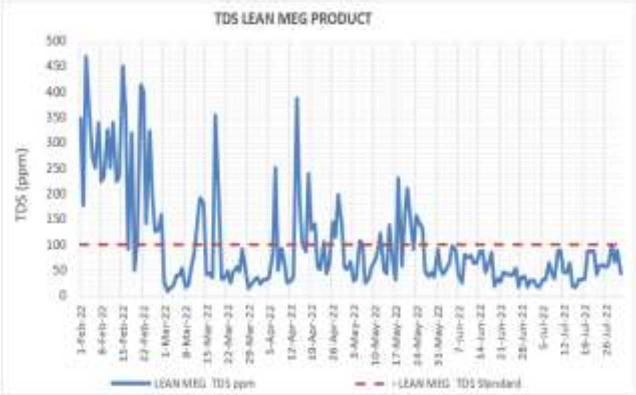


Figure 12. MRU Efficiency

Figure 11 shows the Lean MEG product from MRU has been improved with TDS below 100 ppm and the MRU efficiency increasing from 96 % to 98 % on average shown in figure 12.

Table 6. Improvement Result.

Item	Before LSS	Material Cost/ month	After LSS	Material Cost/ month	Cost saving /Month
MEG filter replacement	20 Filter/ month	$ 45,000	4 Filter/month	$ 3,000	$ 42,000
MEG Losses	1500 ltrs/day	$ 72,000	750 ltrs/day	$36,000	$ 36,000

In the control phase, improvements achieved during the improvement phase are maintained to ensure continuous improvement of the system. These are some of the steps taken:

1. Keeping Standard Operating Procedures up to date.
2. Continuous monitoring and measurement of the process ensure that the resulting lean MEG products meet both quality and quantity targets.
3. Perform a thorough analysis of the MRU's performance, including raw material inspections, operational processes, and production results. The measurements were carried out in an internal laboratory using standard measurement method.

Conclusion

The analysis identified four main causes of declining MRU performance after 4 years of operation, an accumulation of impurity and condensate in the Rich MEG Tank, scale formation at the Reclaimer loop Heater, low performance of the slurry pump, and process parameters not suitable due to changes on MRU design. The improvement that has been taken for each cause contributing to MRU performance has been established, which formulated the implementation plan for the process improvement. Preventive maintenance and spare part availability are one of the keys to maintaining the performance of the MRU. The company needs to collaborate with Axens as a vendor to conduct fields studies in the fields considering that the MRU has been operating for 5 years.

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