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Importance of Condensate Recovery in Industrial Operations "AMOC CASE"

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Abstract:- Condensate recovery is a crucial aspect of industrial processes that involves the collection and reuse of condensed steam, a byproduct of heat exchange systems. This research paper explores condensate recovery's significance in industrial operations. It discusses the benefits, challenges, and best practices associated with condensate recovery, emphasizing its environmental, economic, and operational impacts. This research also examines various technologies and strategies used for efficient condensate recovery and highlights the importance of incorporating such practices into industrial settings for sustainability and resource conservation.

The walk-through sample survey for the Scoping study of Steam Traps & condensate recovery system was carried out at AMOC, plant from 24th Dec-2017 to 26th Dec-2017. the audit study was in a total number of 4675 steam traps, the result of the audit found 50% failure of these traps.

AMOC consists of a lube oil complex and a gas oil complex with tank farms and a utilities section, 1st stage of the study was finished in the lube oil plant with [1] Total Savings Potential (in USD) = 234745, [2] Total Investment (in USD) = 245521, and [3] Total Payback for the System = 12.5 months.

I. INTRODUCTION

Heat transfer is an integral part of industrial processes, enabling the exchange of thermal energy between fluids through various heat exchange systems. A vital product of these heat exchange mechanisms is steam, which loses its latent heat and converts into a condensed liquid phase known as condensate.

Although composed primarily of water, condensate may also contain minor concentrations of process chemicals or impurities acquired during steam generation. Nonetheless, condensate retains significant value owing to its high purity relative to other industrial wastewater streams.

The heat exchange processes used across industrial facilities aim to efficiently generate steam and channel its latent energy into various production systems. As this steam inevitably condenses and yields hot condensate, capturing and reusing this condensate, rather than discarding it as waste, represents an opportunity for industries to recover a valuable resource.

With its high temperature and purity, condensate serves as an excellent medium for heat transfer and water reuse in industrial contexts. Condensate recovery is therefore a crucial consideration for sustainable and efficient thermal management in modern industrial practice.

- *Definition and Significance of Condensate in Industrial Processes:*

Condensate, in the context of industrial operations, refers to the water formed when steam loses heat energy and transitions back into its liquid state. This water, although often treated as waste, holds immense value due to its thermal energy content and purity, making it an excellent source for feedwater in boilers or for various other industrial purposes.

The significance of condensate lies in its properties primarily, its purity and high temperature. It typically retains a significant amount of the energy input used to create steam, making it an efficient heat transfer medium. Furthermore, condensate is relatively pure compared to raw water sources, which reduces the need for additional treatment before reuse.

- *Importance of Efficient Heat Exchange Systems:*

Efficient heat exchange systems are vital in industrial settings for multiple reasons. They facilitate the transfer of thermal energy between different mediums, ensuring optimal operation of various industrial processes. These systems are utilized in a wide array of applications, including heating, cooling, power generation, and chemical processing.

The efficiency of heat exchange systems significantly impacts the overall performance and energy consumption of industrial operations. Well-designed and maintained systems optimize energy utilization, reduce operational costs, and enhance process reliability. Additionally, they play a crucial role in reducing environmental impact by minimizing energy wastage and emissions.

II. LITERATURE REVIEW

A. Overview of Condensate Recovery and its Role in Resource Conservation:

Condensate recovery involves the collection, treatment, and reuse of the condensed steam (condensate) generated by heat exchange systems. Instead of considering condensate as

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waste, recovery processes aim to harness its thermal energy and high purity for reuse within industrial operations.

The role of condensate recovery in resource conservation is paramount. By efficiently capturing and reusing condensate, industries can significantly reduce their demand for freshwater sources, thus conserving a precious natural resource. Additionally, reusing condensate minimizes the energy required to heat feedwater for boilers, contributing to energy conservation and cost reduction.

In essence, condensate recovery aligns with sustainable practices by minimizing water consumption, energy usage, and the environmental impact of industrial processes. It represents a critical aspect of resource optimization and environmental stewardship in industrial settings.

In conclusion, understanding the significance of condensate, the importance of efficient heat exchange systems, and the role of condensate recovery in resource conservation sets the stage for comprehending the broader implications and benefits of incorporating condensate recovery practices in industrial operations.

B. Benefits of Condensate Recovery

Condensate recovery offers several significant advantages to industrial operations, encompassing environmental, economic, and operational aspects.

➢ *Environmental Impact: Reduction of Water Consumption and Discharge*

Condensate recovery plays a pivotal role in reducing water consumption and discharge in industrial processes. By capturing and reusing condensate, industries can minimize their reliance on freshwater sources for specific applications, such as boiler feedwater. This reduction in freshwater intake helps preserve natural water resources and alleviates the strain on local water supplies, particularly in regions facing water scarcity or high demand.

Moreover, the reclamation of condensate reduces the volume of wastewater discharged from industrial sites. Since condensate is relatively clean compared to raw water sources, its reuse minimizes the release of pollutants or contaminants into the environment. This translates to a decrease in the environmental impact associated with industrial discharge, contributing to cleaner waterways and ecosystems.

➢ *Economic Benefits: Cost Savings through Energy and Resource Conservation*

Condensate recovery brings about substantial economic advantages for industrial facilities. One of the primary cost-saving benefits is derived from reduced energy consumption. Condensate, being preheated and possessing a significant portion of the energy initially used to produce steam, serves as a high-quality source of heat energy. Reusing condensate in boilers or other heating processes decreases the energy required to heat fresh water, leading to substantial energy savings and lower utility costs.

Additionally, condensate recovery mitigates the need for purchasing and treating large quantities of freshwater, thereby reducing water-related expenses. It minimizes the costs associated with water treatment chemicals and wastewater disposal, contributing to overall operational cost reductions for the facility.

➢ *Operational Advantages: Improved Efficiency and Equipment Reliability*

Efficiency and reliability are critical factors in industrial operations. Condensate recovery directly contributes to improved efficiency by optimizing the utilization of energy and resources. The reuse of condensed steam enhances overall process efficiency by conserving thermal energy, allowing for better utilization of equipment, and reducing downtime associated with maintenance and inefficient processes.

Moreover, condensate recovery positively impacts equipment reliability. The use of clean condensate as boiler feedwater reduces the potential for scale formation and corrosion within the system. This, in turn, extends the lifespan of equipment, reduces maintenance frequency, and enhances operational reliability.

In conclusion, condensate recovery offers a range of benefits across environmental, economic, and operational dimensions. It aids in environmental conservation by reducing water consumption and discharge, contributes to cost savings through energy and resource conservation, and enhances operational efficiency and equipment reliability, making it an indispensable practice for sustainable and efficient industrial operations.

C. Challenges in Condensate Recovery

While condensate recovery presents numerous benefits, several challenges must be addressed to ensure its successful implementation within industrial processes.

- **Contamination and Quality Issues:** One of the primary challenges in condensate recovery is the potential for contamination. Condensate, although relatively clean compared to raw water sources, can still contain traces of chemicals, dissolved solids, or other impurities picked up during the steam generation process. These impurities can degrade the quality of the recovered condensate, making it unsuitable for certain applications without proper treatment. Contamination may lead to scaling, fouling, or corrosion in equipment, impacting operational efficiency and reliability.
- **Corrosion and Material Compatibility:** Corrosion is a significant concern in condensate recovery systems. The presence of dissolved gases, oxygen, or acidic components in condensate can cause corrosion in pipelines, storage tanks, and other equipment components. Additionally, material compatibility issues arise when selecting components for condensate recovery systems. Choosing materials that are compatible with the composition of the condensate and resistant to corrosion is essential to ensure the long-term integrity and reliability of the system.

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- **System Design Complexities and Maintenance Requirements:** Designing an efficient condensate recovery system requires careful consideration of various factors, including the type of industrial process, condensate quality, flow rates, and temperature variations. Complexities in system design may arise due to the need for specialized equipment, such as separators, pumps, heat exchangers, and control systems. Moreover, maintenance of condensate recovery systems is crucial to prevent operational disruptions. Regular inspection, cleaning, and upkeep are necessary to address issues like fouling, blockages, or leaks that could hinder the system's performance.
- **Addressing these challenges requires a comprehensive approach that involves:**

✓ Quality Monitoring and Treatment: Regular monitoring and analysis of condensate quality to identify and address contaminants through appropriate treatment methods like filtration, chemical treatment, or ion exchange.

✓ Material Selection and Corrosion Prevention: Careful selection of materials resistant to corrosion and compatible with condensate composition to prevent degradation of system components.

✓ Robust System Design and Maintenance: Thorough system design considering the specific requirements of the industrial process, coupled with routine maintenance and proactive measures to ensure system integrity and performance.

Successfully overcoming these challenges in condensate recovery is crucial to maximizing its benefits while minimizing the risks associated with poor quality condensate or system failures, ensuring the sustainability and efficiency of industrial operations.

D. Technologies and Strategies for Efficient Condensate Recovery

Efficient condensate recovery relies on various technologies and strategies designed to optimize collection, treatment, and reuse. Two primary methods for condensate recovery, direct and indirect, are employed in industrial settings, along with best practices for effective implementation.

➢ *Condensate Recovery Systems: Direct and Indirect Methods*

- Direct Condensate Recovery: This method involves directly collecting and reusing condensed steam from the point of condensation without mixing it with other fluids. It often requires minimal treatment due to the relatively high purity of the condensate. Direct recovery systems include simple traps and collection tanks installed near equipment where condensation occurs. This method is suitable for relatively clean condensate streams, such as those from steam lines in heating systems.
- Indirect Condensate Recovery: Indirect methods involve using recovered condensate indirectly by mixing it with other fluids or using it in heat exchange processes. This method might involve treating the condensate to meet specific quality requirements before reuse. Indirect systems often use heat exchangers to recover thermal energy from the condensate before it is reused as feedwater in boilers or other industrial processes.

➢ *Best Practices for Condensate Collection, Treatment, and Reuse*

- Collection: Implementing proper collection systems that efficiently gather condensate from various sources is crucial. This includes using steam traps, condensate lines, and collection tanks at strategic points in the system to ensure maximum recovery without causing backpressure or steam loss.
- Treatment: Treatment processes may be necessary to address impurities or contaminants in the condensate that could affect its quality or suitability for reuse. Filtration, chemical treatment, ion exchange, or other specialized treatments can be employed to improve condensate quality.
- Reuse: Determining the most appropriate reuse of recovered condensate based on its quality and the specific need of the industrial process is essential. Condensate can be reused as boiler feedwater, for preheating incoming water, or in other processes requiring high-quality water.
- Monitoring and Maintenance: Regular monitoring of condensate quality, system performance, and maintenance of equipment is crucial to ensure optimal operation and prevent issues such as contamination, corrosion, or blockages. Implementing a proactive maintenance schedule helps in identifying and addressing potential problems before they impact system performance.

Efficient condensate recovery systems combine these strategies and technologies to maximize the capture, treatment, and reuse of condensed steam, contributing to resource conservation, energy efficiency, and cost savings in industrial operations. Adopting best practices tailored to the specific requirements of each facility is essential for successful and sustainable condensate recovery.

E. Importance of Incorporating Condensate Recovery in Industrial Settings

Incorporating condensate recovery within industrial settings holds paramount importance, attributed to several compelling factors that span environmental, regulatory, and economic spheres.

- **Sustainability and Environmental Responsibility:** The integration of condensate recovery systems aligns profoundly with sustainability objectives. By capturing and reusing condensed steam, industries substantially reduce their reliance on freshwater sources, consequently curbing water consumption. This practice contributes to the conservation of natural resources, mitigating the strain on local water supplies and ecosystems. Moreover, by diminishing the discharge of wastewater laden with pollutants or contaminants, condensate recovery aids in maintaining water quality and ecological balance.

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- **Regulatory Compliance and Corporate Social Responsibility:** Incorporating condensate recovery measures often corresponds to adherence to regulatory standards and corporate social responsibility (CSR) initiatives. Many regions mandate stringent regulations pertaining to water usage, discharge, and environmental impact. Implementing efficient condensate recovery systems allows industries to comply with these regulations, thereby avoiding penalties and legal ramifications. Furthermore, from a CSR perspective, companies demonstrating a commitment to sustainable practices, including condensate recovery, enhance their reputation and stakeholder perception, fostering goodwill within the community.
- **Long-term Cost Savings and Operational Efficiency:** The adoption of condensate recovery systems yields substantial long-term economic benefits. By reusing condensed steam as feedwater for boilers or other processes, industries significantly reduce the energy required to heat fresh water. This directly translates into lowered utility costs and improved energy efficiency. Additionally, the minimized need for purchasing and treating large volumes of freshwater leads to reduced operational expenses associated with water procurement and treatment chemicals. The efficient utilization of resources not only drives cost savings but also enhances overall operational efficiency by optimizing equipment performance and minimizing downtime due to maintenance issues related to scale, corrosion, or inefficiencies.

III. BACKGROUND OF THE COMPANY

Alexandria Mineral Oil Company (AMOC) is a petroleum corporation located in Alexandria, Egypt and operates under the umbrella of the Egyptian General Petroleum Corporation (EGPC).

Established in 1997, AMOC began operations in 2000 and today houses two main production complexes at its facility - the Lube & Special Oils Complex and the Gas Oil Maximization Complex.

The facility is equipped with three large main boilers, each with a 60 ton per hour maximum steaming capacity. Additionally, there are two smaller waste heat boilers that produce 5 and 10 tons per hour respectively.

By utilizing waste heat recovery, AMOC demonstrates a commitment to energy efficiency and sustainable practices. The company's extensive steam generation assets provide the high-pressure steam required to support AMOC's core production processes and objectives.

As a leading regional player in the petroleum industry, AMOC leverages technological capabilities and operational excellence to maximize resource utilization. The company's journey over the past two decades highlights its emergence as a key producer meeting the demand for refined petroleum products.

IV. RESEARCH METHODOLOGY

A walk-through sample survey was conducted at the Alexandria Mineral Oils Company (AMOC) plant from December 24-26, 2017 to scope the steam traps and condensate recovery system.

The audit examined a total of 4675 steam traps installed across the facility.

Preliminary findings revealed concerning results - the survey detected a failure rate amongst the steam trap population. This indicates significant losses and inefficiencies in steam delivery and condensate recovery at the plant.

The scope of this vital survey was to thoroughly quantify steam trap installations, assess their functional integrity, identify failure modes, pinpoint areas of substantial loss and map out the steam/condensate system.

As a critical first step before rectifications, this data-driven audit provides empirical insights into the performance gaps and improvement opportunities in AMOC's steam infrastructure. The high failure rate underscores the urgency of remedial actions to optimize the system.

Moving forward, a phased implementation of upgrades based on a cost-benefit analysis of these survey findings will help AMOC modernize its steam trap network and condensate recovery infrastructure. This will generate major savings while enhancing energy efficiency.

➢ *Main Objectives of the Audit:*

- To quantify the steam trap population in AMOC and find out the failure rate of steam traps thereby quantifying the amount of steam loss through Trap modules.
- To determine the steam loss through leaking trap locations, No Traps locations, Trap module leaks, and direct pinhole leaks arising from a Steam Trap module.
- To identify the root cause of steam trap failure and recommend best-suited solutions for improvement.
- To find out the steam-saving potential and the areas with major steam losses.
- To gather the specific data related to traps such as application, upstream & and downstream pressure, trap type, make, etc. to recommend a suitable trap to avoid steam trap operation failure shortly.
- To understand the entire steam and condensate distribution system of AMOC
- To identify indirect and direct steam users and quantify their respective consumptions to account for the overall steam and condensate mass balance.
- To find out the areas of condensate loss from unrecovered indirect steam users and steam traps

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- To identify the root cause of failure to recover the condensate and recommend best-suited solutions for improvement.
- To gather the specific data related to steam heating equipment such as the operating pressure, temperature, steam flow, and type of steam to recommend a suitable system to avoid failure in the near future.

➢ *The Audit Divides the Hole Project into Five Stages:*

- Raffinate Extract Unit (Unit 100) and Oil Dewaxing Unit (Unit 200).
- Vacuum Distillation unit (VDU), Middle Dewaxing Distillation Unit (MDDU), and Feeding Tank Farm (Farm G Area).
- Three Boilers units.
- Oil hydrotreating Unit (Unit 300), Wax Hydrotreating Unit (Unit 400), and Hydrogen production Unit (Unit 550).
- Rest of Tank Farms (Farm from A to F).

V. RESULT AND DISCUSSION

A. Baseline Data

The following data illustrated in (Table 1) used for calculating the yield of losses during the audit.

Table 1: Cost Parameters for Steam, Condensate and Fuel used in Boilers

Parameter	Rate	Unit
Cost of Steam	15	USD/Ton
Cost of Condensate @ 90Deg C	1.5	USD/M3
Annual Operating Hours	8500	Hours/Year
Average Fuel bill for Boilers	9.2	Million USD/Year
Fuel Cost	233.4	USD/Ton

*The above figures have been given by Utilities Operations team.

** Figures mentioned in the above table are approved and the same are considered for audit report savings.

B. Present Overall Steam & Condensate Mass Balance

The study shows that the average steam and condensate mass balance was recorded during the audit period was approximately about 82.7 ton/hr steam generation capacity, with around 16.6 ton/hr of condensate being recovered, and approximately 7.3 ton/hr of steam loss from traps and around 20.5 ton/hr of unrecovered condensate (as illustrated in Fig. 1). while depicts the proposed improved mass balance after implementing recommendations, with the projected condensate recovery of 37.1 ton/hr of recovered Condensate and flash steam, and the steam generation reduced to 73.2 ton/hr (as illustrated in Fig. 2).

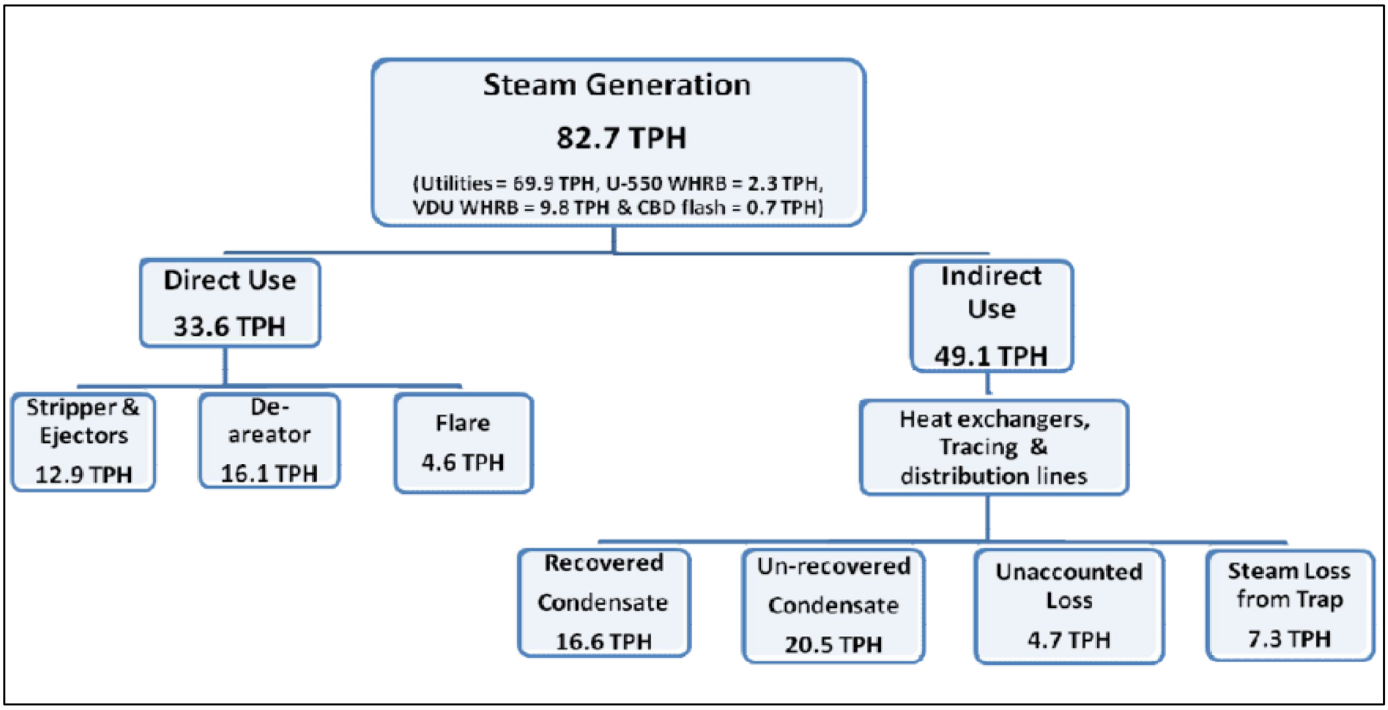

Fig 1: Average Steam & Condensate Mass Balance Recorded during the Audit

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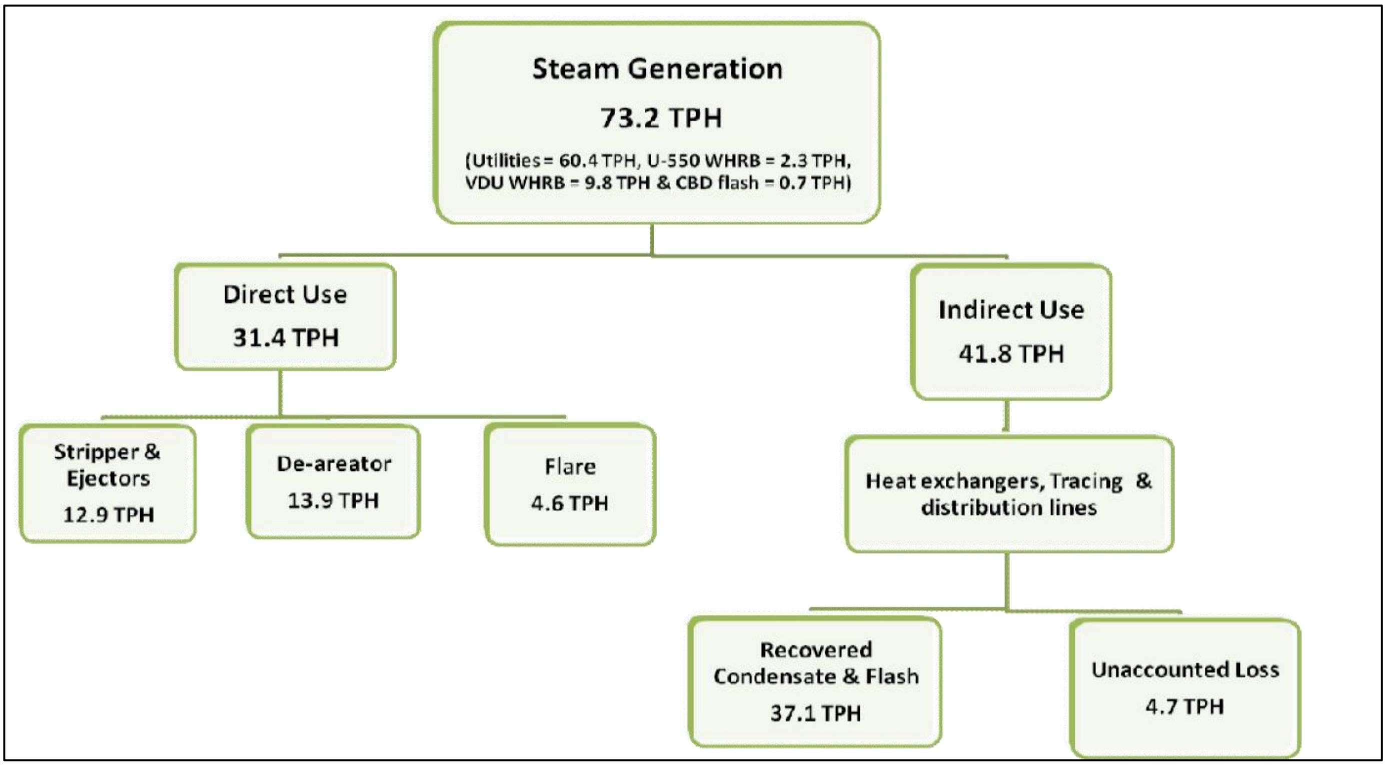

Fig 2: Proposed Overall Stem & Condensate Mass Balance

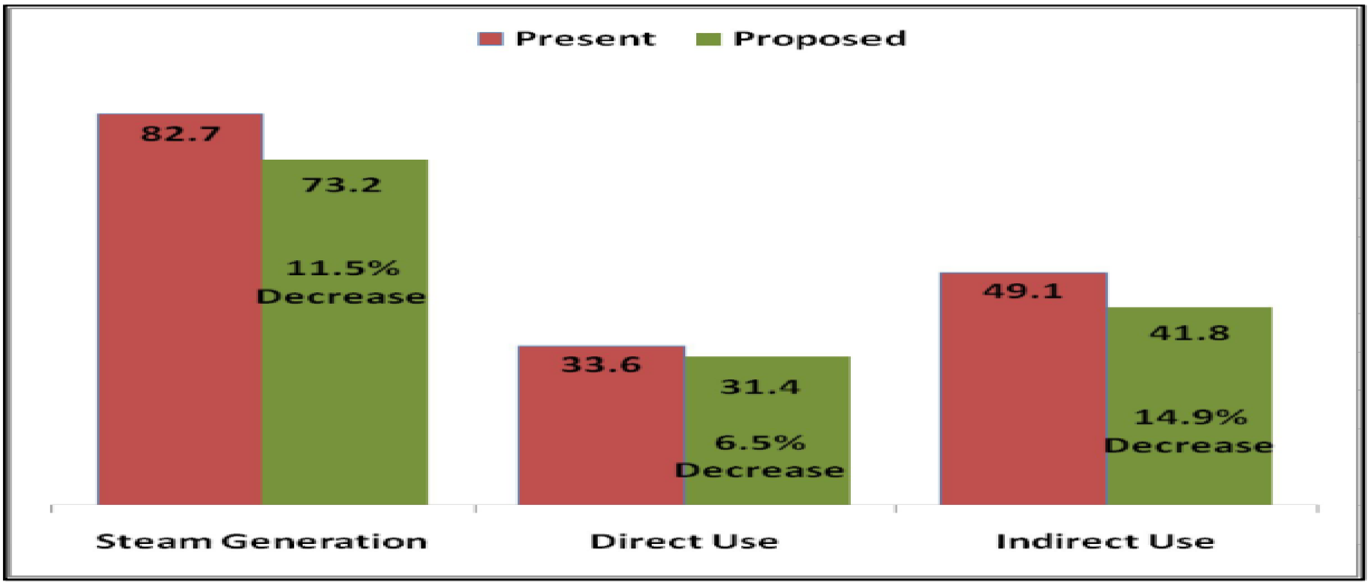

Fig 3: Comparison between Present Value and Proposed Value

Table 2 summarizes the overall steam trap health status based on the audit. Out of 4675 traps surveyed, only 43% were in good working condition. The failure rate was over 50%, with around 22% being leaking traps and 27% being cold traps. The remaining 7% were out of service.

Table 3 explains the codes used in Table 2 to categorize trap conditions like leaking, flooded, cold, etc. Figure 5 shows the percentage performance rate versus failure rate of traps in different complexes. Figure 6 graphs the quantities of different trap types and their conditions.

Table 2: Shows Overall Steam Trap Health Status

Steam Trap Status	Good Traps	Leaking Traps (fail open)			Flooded Traps	Cold Traps (fail close)		Not Trap	Out of Service	Grand Total
	OK	BT	LK	RC	FL	PL	WL	NT	OS	
Nos.	2012	119	766	138	4	879	403	44	310	4675
Percentage	43.04	21.88			0.09	27.42		0.94	6.63	7.57
Performance Rate = 43.04 %					**Failure Rate = 50.33 %**			**Out of Service = 6.63**		

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Table 3: Shows "Table 1" codes Explanation.

Codes	Description	Codes	Description
OK	OK – Good Steam trap	PL	Plugged
BT	Blow thru – 100% passing steam trap	WL	Water Logged
LK	Leaking – 25% passing steam trap	OS	Out of service (Not in Line)
RC	Rapid cycle – 20% passing steam trap	NT	No Trap
FL	Flooded		

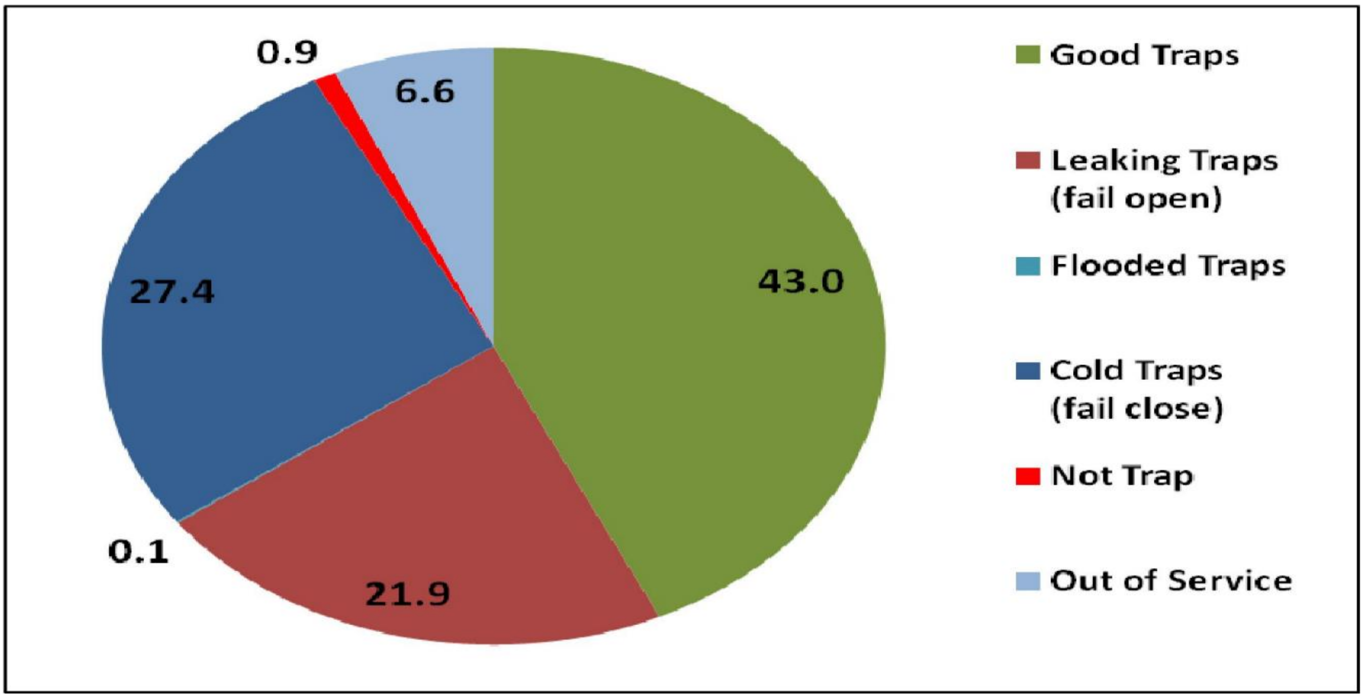

Fig 4: The percentage of Steam Traps Examined during the Audit

In summary, the data indicates high failure rates across AMOC's steam trap population, poor condensate recovery, and significant steam losses. The proposed upgrades aim to rectify this through improved condensate collection infrastructure and steam trap replacements, projected to substantially increase condensate recovery and decrease steam losses.

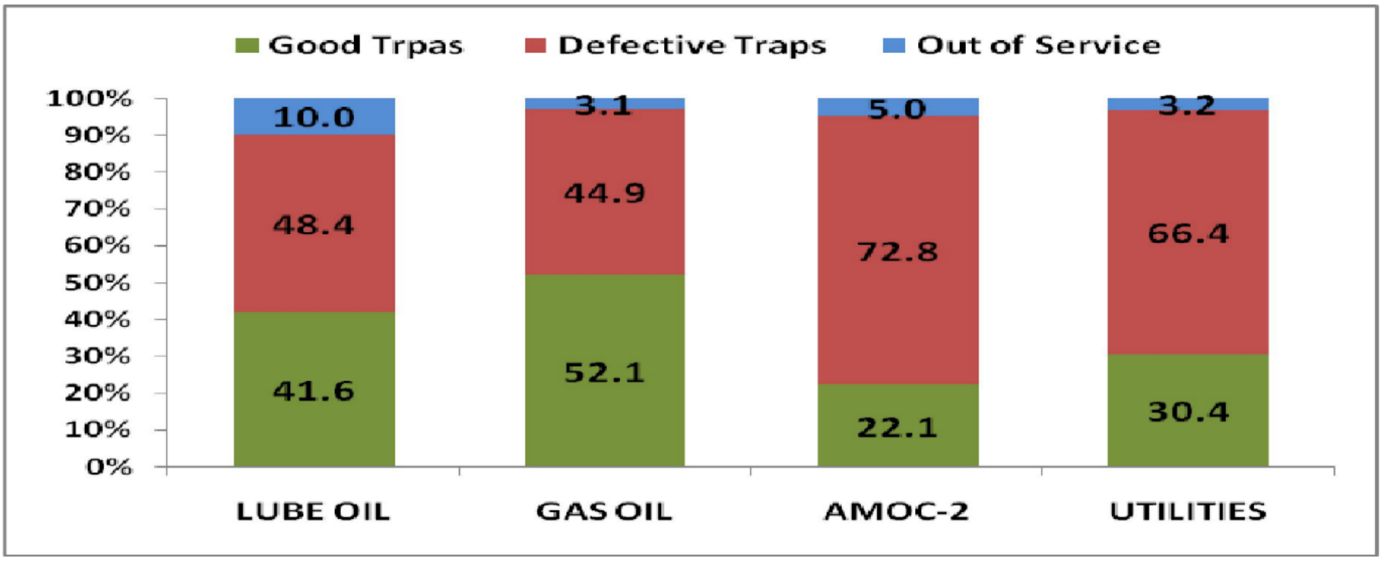

Fig 5: The Percentage of Steam Traps Examined during the Audit for Each Section in AMOC

Table 4 provides a priority-wise implementation plan listing the top priority complexes as Lube Oil and Utilities Complex and Gas Oil Complex. It states the monetary losses associated with each complex, with the Lube Oil and Utilities Complex resulting in $0.88 million in losses per year and the Gas Oil Complex resulting in $0.58 million in losses per year.

Table 4: Priority wise Implementation Plan with Cost Benefit Analysis

Priority	Complex	Monetary Loss (mn USD/Year)
1	Lube Oil and Utilities Complex with Tank farm & Pipe Rack	0.88
	Gas Oil Complex with Tank farm & Pipe Rack	0.58
2	AMOC-2 Tank Farm & Pipe Rack	0.10
Total Monetary Loss =		**1.56**

Table 5 show details the steam traps, condensate, and flash steam losses for specific plants and complexes. It shows the Lube Oil Complex has the highest steam trap loss at 2.9 TPH, total condensate loss of 11.5 TPH, and flash steam loss of 0.8 TPH. Across all complexes, it states the total steam trap loss is 7.3 TPH, total condensate loss is 19.3 TPH, and total flash steam loss is 1.3 TPH. The estimated annual monetary losses are provided, with steam traps at $930,750, condensate at $246,075, and flash steam at $165,750.

Table 5: Complex Wise Steam & Condensate Loss

Plant	Steam Traps Steam Loss (TPH)	Total Condensate Loss (TPH)	Total Flash Steam Loss (TPH)
Lube Oil Complex with Tank Farm & nearby Pipe Rack	2.9	11.5	0.8
Gas Oil Complex with Tank Farm & nearby Pipe Rack	3.1	4.6	0.3
Utilities & nearby Pipe Rack	0.9	0.7	0.0
AMOC – 2 Tank Farm & Pipe Rack	0.4	2.5	0.2
Grand Total	7.3	19.3	1.3
Monetary Loss (USD per year)	930750	246075	165750

Table 6 focuses on potential utility savings from reducing steam demand of the deaerator by 1.16 TPH, resulting in $147,900 in savings per year, and reducing soft water demand by 17.9 TPH, resulting in $76,075 in savings per year.

Table 6: Total Monetary Loss in USD per Year

Utilities Saving	TPH	Monetary Loss (USD per year)
Reduction in Steam Demand of De-aerator	1.16	147900
Reduction in Soft Water Demand of De-aerator	17.9	76075
Total Monetary Loss = 1.56 million USD per Year		

So, Tables 4, 5, & 6 provide details on priority complexes, quantify losses from steam, condensate, and flash steam, and estimate potential utility savings from reducing steam and water usage. Let me know if you would like me to clarify or expand on any part of the table descriptions.

Based on the recommendations from the audit, Alexandria Mineral Oils Company decided to implement a pilot test of the proposed condensate recovery system optimizations in Stage 1, encompassing the Raffinate Extract Unit (Unit 100) and Oil Dewaxing Unit (Unit 200).

The objective was to validate the hypothesis that upgrades to the condensate collection infrastructure and reducing back pressure on steam traps would result in substantial performance improvements.

The pilot yielded encouraging results. Installing new flash vessels, condensate pumps, optimized headers, and piping layouts led to increased condensate recovery and significant reductions in back pressure on the steam traps of Units 100 and 200.

Quantitative measurements during the test phase proved that the projected reductions in back pressure due to lower flash vessel pressures, decreased piping lengths and friction losses were achieved. This in turn provided greater differential pressure for the steam traps to operate efficiently.

➢ *Points Considered for Designing an Effective Condensate Recovery System:*

- Doing so will ultimately reduce the present back pressure due to elevation from 1.2 barg to 0.9 bar. This will reduce the total back pressure (neglecting the back pressure due to live steam) on steam traps of U-100 & U-200 from the present 2.5 to 1.6 bar. Even then, 1.6 bar of back pressure on 3.2 bar of available upstream pressure at steam trap inlet equals to 50%, which is very much on the margin.
- It is important to note that, increasing the set point of this pressure reducing station only to recover condensate is not advisable because increase in pressure reduces the latent heat of steam which in turn will increase the tracing steam consumption in U-400.mThereby one steam operated pumping station is recommended for U-300,400 & 550 and another pumping station combined for U-100 & U-200.
- For practical purposes, the back pressure on the steam traps should not exceed 50% of the upstream pressure.
- It is important to note that, even if few steam traps are designed to work when the back pressure is up-to 80% of the upstream pressure that means the available differential pressure across the steam trap will be lower.

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- As a common rule, lower the differential pressure means lower will be the condensate evacuation capacity of any steam trap.
- For example, a steam trap having 50% delta P. can evacuate condensate load of 100 kg/hr and the same steam trap having only 20% delta P. will evacuate only 20 kg/hr of condensate.
- Also, a steam traps should always be designed to cater the running load as well as the startup load.
- The startup load is always 1.5 times more than that of the running load and if the differential pressure is low, steam traps will fail in closed (water-logged) condition during the start-up.
- This results in waterlogging and hammering, thereby forcing the operators to open bypass valves & drain valves of steam traps causing enormous steam & condensate loss.
- For a thermodynamic steam trap that is working at a lower differential pressure, the number of strokes or cycles required to remove the defined condensate load will increase.
- As a result of this increase in no. of strokes per hour, these TD traps get more prone to failure and fail in open (leaking live steam) more frequently.
- Steam trap system is a dynamic system and the possibility of all steam traps working satisfactorily at all the times requires critical & thorough monitoring.
- An effective condensate recovery system, having many steam traps connected to it, is to be designed considering that around 25% of the steam trap will fail and leak live steam in the condensate recovery system. This shall pressurize the condensate headers & sub-headers and put back pressure on the remaining 75% of the steam traps.

However, if the condensate system is properly designed by keeping the theoretical back pressure as minimum as possible and by correctly sizing the condensate headers, only then this problem can be taken care of.

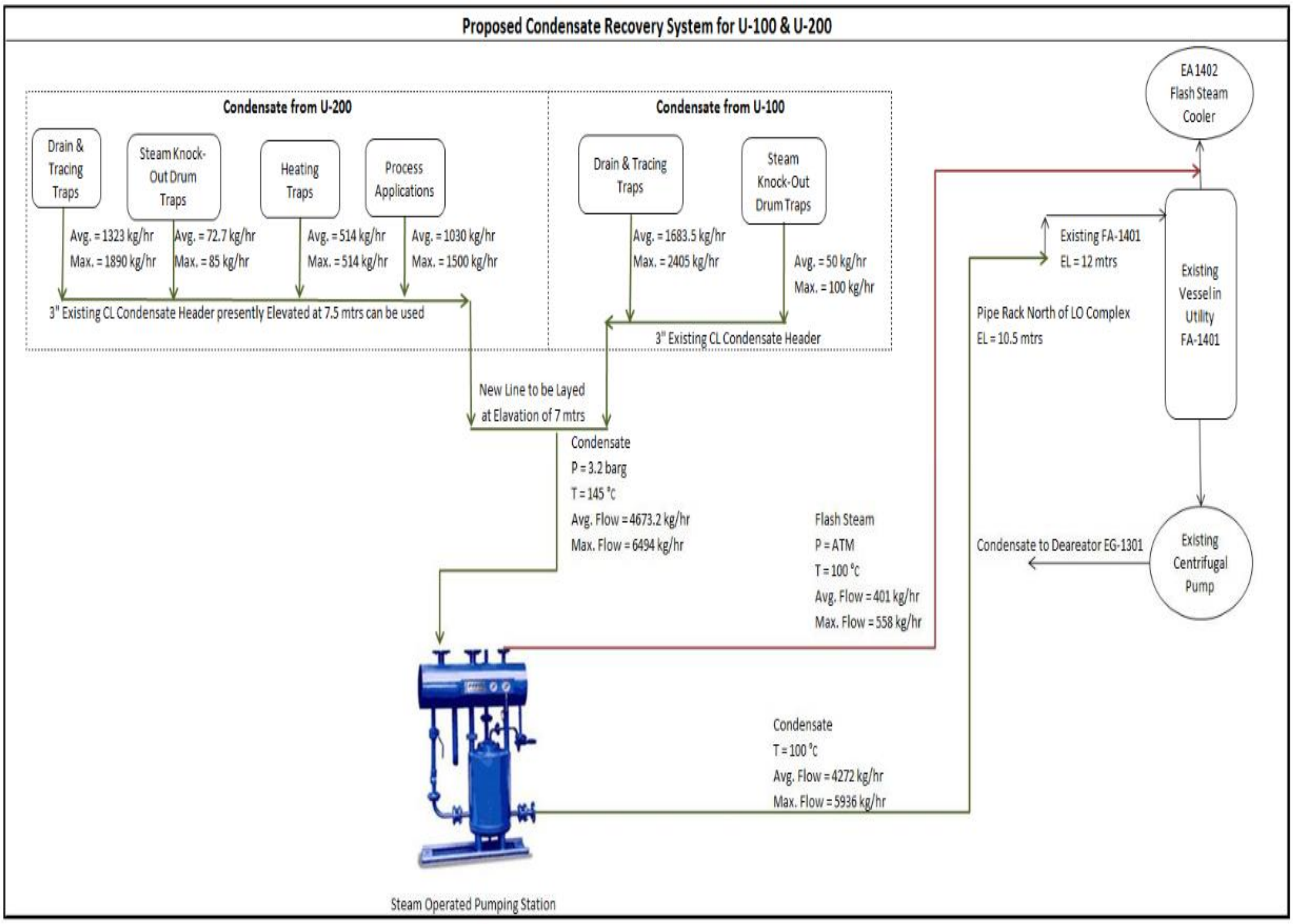

Fig. 6: A Schematic Diagram and Exact Parameters for Units 100 & 200

Note: Condensate from steam traps located in the nearby pipe rack of U-100 & U-200 will be routed to this pumping station as per site feasibility. The details of the same shall be shown in the new engineering drawings.

Tables 3 and 4 illustrate the difference in back pressure exerted on steam traps from the condensate header, before and after implementing recommendations to improve the condensate recovery system at the Alexandria Mineral Oils Company (AMOC).

Table 7 shows the present back pressure situation. At the U-100 plant, the total back pressure amounts to 2.5 kg/cm2g, stemming from 0.8 kg/cm2g pressure in the flash vessel, 1.2 kg/cm2g maximum head height, and 0.5 kg/cm2g from piping friction and straight length losses. With 3.2 kg/cm2g pressure available at the steam trap inlet, this leaves only 0.7 kg/cm2g of differential pressure across the trap. Similarly for the U-200 plant, the total back pressure is 2.42 kg/cm2g, resulting in just 0.78 kg/cm2g of available differential pressure across steam traps.

In contrast, Table 8 depicts the projected back pressure after implementing all recommendations to optimize the system. Upgrades like new flash vessels reduced piping lengths/heights, and lower friction losses will significantly cut down the back pressure. At U-100, the total back pressure is estimated to reduce to 1.23 kg/cm2g, increasing the differential pressure across traps to 1.97 kg/cm2g. For U-200, the total back pressure is projected to become 1.16 kg/cm2g, raising the differential to 2.04 kg/cm2g.

The recommendations are targeted to drastically reduce the back pressure on steam traps arising from the condensate header. This will improve the operating capacity and reliability of steam traps by providing greater differential pressure. The comparisons in these tables quantitatively highlight the positive impact of implementing an improved condensate recovery system.

Table 7: Show The Present Back Pressure on Steam Traps from Condensate Header

Plant	Present Back Pressure on steam traps from Condensate header (in kg/cm²g) due to -						
	Flash Vessel Pressure	Max. head height	Pipe straight length	Pipe friction losses	Total Back Press.	Available Ups. Pressure at Steam Trap	Available Delta P.
U-100	0.8	1.2	0.35	0.15	2.5	3.2	0.7
U-200	0.8	1.2	0.3	0.12	2.42	3.2	0.78

Table 8: Show The Future Back Pressure on steam traps from Condensate Header after Implementing

Plant	Future (after implementing all the recommendations) Back Pressure on steam traps from Condensate header (in kg/cm²g) due to -						
	Flash Vessel Pressure	Max. head height	Pipe straight length	Pipe friction losses	Total Back Press.	Available Ups. Pressure at Steam Trap	Available Delta P.
U-100	0.2	0.75	0.2	0.08	1.23	3.2	1.97
U-200	0.2	0.75	0.15	0.06	1.16	3.2	2.04

The successful implementation of Stage 1 created a positive business case to continue with recommendations in the remaining units and facilities. The pilot demonstrated the feasibility of the proposed solutions and laid the foundations for full-scale optimization of condensate recovery at Alexandria Mineral Oils Company.

VI. CONCLUSION

Condensate recovery represents a crucial practice for sustainable and efficient industrial operations. As highlighted in this research, condensate formed during steam generation retains immense value due to its high purity, thermal energy content, and suitability for reuse. The recovery and reuse of this condensed steam aligns strongly with principles of resource conservation and environmental stewardship.

By implementing condensate recovery systems, industries can substantially reduce their freshwater demand, minimize wastewater discharge, decrease energy consumption for heating boiler feedwater, and enhance equipment reliability. Although condensate recovery presents certain challenges around contamination, corrosion, and system design complexity, these can be effectively addressed through proper quality monitoring, treatment methods, material selection, and robust system maintenance.

The environmental, economic, and operational benefits of efficient condensate recovery practices make their widespread implementation in industrial facilities critically important. As industries aim to enhance sustainability, cost-effectiveness, and technological capability, the innovation and adoption of newer condensate recovery technologies must be encouraged. Governmental support through regulations, incentives and knowledge exchange platforms can further promote the integration of efficient condensate recovery.

In conclusion, condensate recovery systems need to become an integral component of every industrial facility's commitment toward responsible resource utilization. Continuous improvements and advancements in this domain will be vital for industries to achieve higher standards of sustainability and efficiency in the future. The time to act is now by implementing best practices, collaborating across sectors, and investing in better technologies to fully realize the far-reaching benefits of industrial condensate recovery.

FUTURE TRENDS AND RECOMMENDATIONS

As industries continue to focus on sustainability, efficiency, and technological advancements, several trends and recommendations emerge in the domain of condensate recovery for optimizing processes and achieving better outcomes.

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➢ *Advancements in Condensate Recovery Technologies:*

- Innovative Treatment Methods: Continued research and development in treatment technologies, such as advanced filtration, membrane processes, and electrochemical methods, aim to enhance the quality of recovered condensate, making it suitable for an even wider range of industrial applications.
- Energy-Efficient Recovery Systems: Advancements in heat exchanger design, condensate pumps, and recovery systems aim to improve energy efficiency and increase the recovery rate of condensate from various processes, thereby reducing energy consumption and operational costs.
- Integration of Renewable Energy Sources: Integration of renewable energy sources, such as solar thermal energy, in condensate recovery systems to provide additional heat for steam generation and enhance overall efficiency.

➢ *Integration of Smart Systems and Predictive Maintenance for Improved Efficiency:*

- IoT (Internet of Things) and Data Analytics: Utilizing IoT sensors and data analytics for real-time monitoring of condensate recovery systems to optimize performance, detect anomalies, and predict maintenance needs. This enables proactive actions to prevent downtime and maximize efficiency.
- Predictive Maintenance: Implementing predictive maintenance strategies using machine learning algorithms and predictive analytics to forecast potential failures in condensate recovery systems. This allows for timely interventions, reducing unplanned downtime and maintenance costs.

➢ *Recommendations for Industry-Wide Adoption and Promotion of Condensate Recovery Practices:*

- Education and Training: Industry-wide initiatives for educating professionals and operators about the importance of condensate recovery, its benefits, and best practices. Training programs can help disseminate knowledge and encourage adoption.
- Regulatory Support and Incentives: Governments and regulatory bodies can incentivize industries to adopt condensate recovery practices by offering tax benefits, rebates, or subsidies for investing in efficient systems and achieving certain performance benchmarks.
- Collaboration and Knowledge Sharing: Encouraging collaboration among industries, research institutions, and technology providers to share best practices, case studies, and technological innovations. Platforms for knowledge exchange can accelerate the adoption of efficient condensate recovery practices.
- Industry Standards and Certification: Developing industry standards and certification programs for condensate recovery systems to ensure quality, reliability, and adherence to best practices. Certifications can serve as benchmarks for quality assurance and promote trust in technology.

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