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A Case Study of Optimization of Fresh Water Consumption by Recycling UV Treated Water, CO_2 Water and Spentwash in B-Heavy Molasses Fermentation

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ABSTRACT

The primary aim of this study is the optimization of freshwater consumption in a distillery unit. The RRR (Reduce, Reuse and Recycle) technique is effectively used on an industrial scale. This technique reduces waste drain water (fermenter washing, condensate, spent lees, and cooling tower blowdown, etc.) treated by the Condensate Polishing Unit (CPU) plant. Treated water (UV Water) is recycled to fill fermenters, spent wash is reused in fermenter filling, and the Multi-Effect Evaporator (MEE) converts low concentrate spent wash to high concentrate slop for use as boiler fuel. The permeate water of the CPU plant is recycled in cooling tower makeup, and CO_2 scrubber water is also recycled in fermenter filling. The benefits of recycling UV Water, spent wash, and CO_2 water to fill fermenters include a significant reduction in freshwater consumption. The results of these studies are shared and discussed here for the benefit of technocrats who may not have exposure to such systems.

Keywords: Condensate polishing unit, multi-effect evaporator, fresh water consumption, molasses, fermentation.

INTRODUCTION

Balrampur Chini Mills Ltd., Unit Balrampur, is an integrated plant with a capacity of 12,000 TCD sugar and a 330 KPD distillery, located near Balrampur, Uttar Pradesh. Balrampur Chini Mills group is a leading sugar and ethanol producer in Uttar Pradesh, committed to sustaining ESG (Environmental, Social and Governance) standards and maintaining natural resources in their original state.

In earlier days, the freshwater consumption in distilleries used to be around 8-9 kl/kl. Gradually in the distillery industry it was reduced to about 6-7 kl/kl after the implementing MEE plant condensate recycling. In 2022-23 seasons, the freshwater consumption at Balrampur unit was 6.71 KL/KL. In the last season by implementing various corrective measures in the recycling of UV water, CO_2 water and spent wash recycling, we are able to reduce the fresh water consumption considerably.

Many distilleries use spent wash recycling with cane syrup and grain feedstock, but recycling spent wash in B-heavy molasses has been challenging. Balrampur Chini Mills, including the Gularia unit, struggled to recycle more than 5-10% of spent wash. Typically, the fermentation cycle lasts 34-36 hours, but adopting SHIFT Technology increased it to 46-52 hours and raised VA levels, necessitating sanitization every 8-10 days and disrupting production.

Probable causes included storage issues with UV-treated water, ineffective UV systems, and sludge accumulation in the wash charger and spent wash recycle tank. Similar issues occurred at the Balrampur unit in the 2022-23 seasons.

To address these problems, both CPU and fermentation areas installed UV systems with regular cleaning and hygiene maintenance. An agitator in the wash charger reduced VA by minimizing stagnant sludge. Enzymes, biocides, and preservatives were used to

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control VA levels and microbial contamination. This enabled continuous recycling of 20% spent wash in fermenters. Additionally, trials succeeded in recycling UV-treated water and CO_2 plant reject water without using freshwater, even in the pre-fermenter stage in the 2023-24 seasons.

The details of the measures taken by us and results obtained are discussed in this paper.

Actual work done by us

The work done by us during the 2023-24 seasons for optimization of freshwater consumption was basically in the following areas of the distillery processes (Table 1), using Bh molasses as feed stock;

- UV treated water recycling,
- CO_2 water recycling
- Spent wash in B-heavy molasses fermentation

Table 1 : Use of fresh and waste waters and spent wash in fermentation section

Sr. No.	Particulars (KL)	Mode	Place of Use	
			2022-23	2023-24
1	Fresh Water	Direct	Culture Vessel + PF + Fermenter	In Culture vessels
2	UV treated Water	After treating in CPU & pass through Ultra-violet rays	--	In Pre-fermenter & Fermenters
3	CO_2 Reject Water	Direct	--	In Fermenters
4	Spent wash	Through Shift Reactor & PHE	--	In Fermenters

The steps taken by us in each of these operations and problems faced are broadly discussed in the following paragraphs.

UV treated water recycling

Earlier status (2022-23): The initial attempt to recycle about 900 KL/day UV-treated water from CPU for fermentation failed due to micro-biological contamination. The microbial count of the UV water was high *i.e.* in the range of (160 cfu/ml) in (Figure 3). During this period, the fermentation process was significantly slowed in (Table 3).

Present status (2023-24): Now we recycle the 100% UV water to fill the Pre-fermenter and fermenter due to 2nd UV system install in fermentation.

Problems faced: Many types of problem facing at initial stage to start the UV water recycle e.g.

- *High gravity:* The fermentation stalled at a high specific gravity, indicating that the sugars in the wort were not being efficiently converted to alcohol.

Low alcohol percentage: The low conversion rate of sugars to alcohol resulted in a lower-than-expected alcohol content.

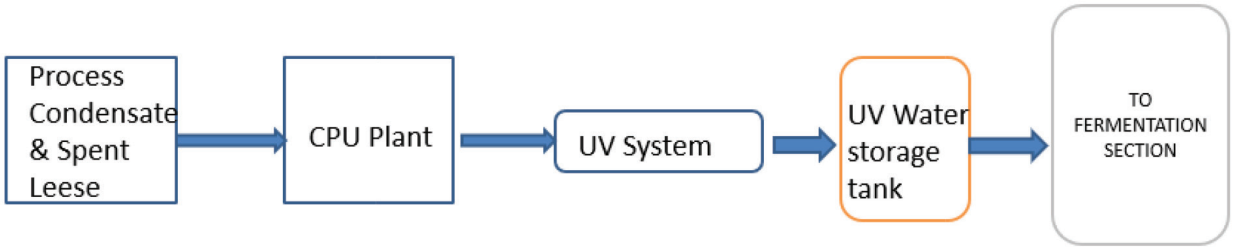
High Residual Sugar (RS) percentage: A significant amount of unfermented sugars remained in the wort.

High Volatile Acidity (VA): Increased levels of volatile acidity, which often result from contamination, were observed.

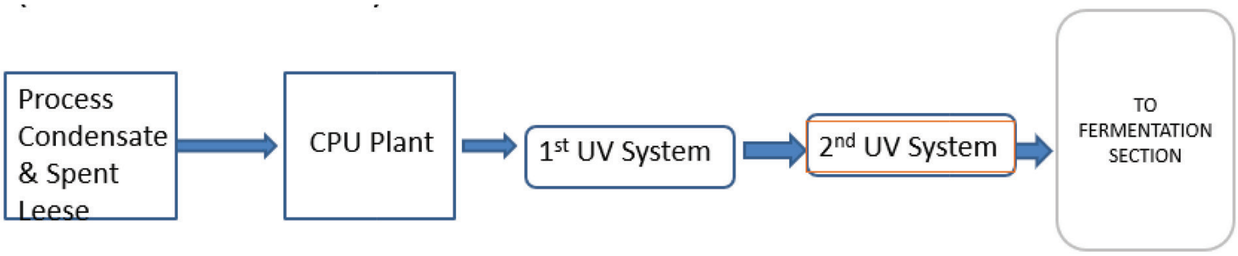
These issues are quantified in (Table 3), which details the specific values for gravity, alcohol percentage, RS percentage and VA.

Corrective measures taken: - 2nd UV system install in fermentation (Figure 4) to control microbial contamination.

Result (2023-24): Many benefits found to UV Water recycle in fermentation after 2nd UV system installation (Table 3).



Flow Diagram 1A – UV water recycle in fermentation (Before implementation)



Flow Diagram 1B – UV water recycle in fermentation (After implementation)

Installation of 2nd UV system in fermentation section and removal of UV water storage tank to avoid contamination

Figure 1 : Picture showing left to right-1. Control, 2. 1st UV water of CPU plant and 3. 2nd UV water in fermentation section

Table 3 : Performance of fermentation plant with UV water usage (1st UV and 2nd UV systems)

Date	**22/12/23**	**25/12/23**	**26/12/23**	**27/12/23**	**02/01/24**	**03/01/2024**	**04/01/2024**
Used in trial	**Fresh water**	**UV Water 1st UV system in CPU**			**UV Water 2nd UV system in fermentation**		
Parameter	**Trial**	**Trial-1**	**Trial-2**	**Trial-3**	**Trial-4**	**Trial-5**	**Trial-6**
Yeast cell count in PF	2.85×10^8	2.6×10^8	2.6×10^8	2.65×10^8	2.95×10^8	2.8×10^8	2.75×10^8
Fermenter Initial Setup Gravity	1.043	1.052	1.057	1.058	1.048	1.049	1.052
Fermenter Initial pH	5.1	5	5.07	4.92	5.11	5.15	5.12
Fermenter Final Gravity	1.022	1.039	1.042	1.045	1.028	1.026	1.025
Fermenter Final pH	4.8	4.17	4.25	4.08	4.8	4.76	4.86
Alcohol	12.5	11.2	10.9	10.57	12.43	12.48	12.5
RS%	1.4	2.24	2.36	2.54	1.5	1.45	1.42
VA (ppm)	1000	1457.13	1542.85	1559.99	1114.28	1079.99	1114.28
Fermentation Efficiency%	92%	86.20%	84.10%	82.30%	91.88%	91.92%	92%
Fermentation Cycle (Hr.)	35hr	43hr	44hr	46hr	36hr	35hr	36hr
Yeast cell count in Fermenter Setup	1.7×10^8	1.55×10^8	1.3×10^8	1.35×10^8	1.7×10^8	1.8×10^8	1.65×10^8
Yeast cell Viability after complete cycle in Fermenter	Nil	Nil	Nil	Nil	Nil	Nil	Nil

Accelerated Fermentation Reaction: With the contaminants removed, the yeast could ferment the wort more efficiently.

Decreased Gravity: The specific gravity of the wort consistently decreased as the sugars were converted to alcohol.

High Alcohol Percentage: The improved fermentation process resulted in a higher alcohol yield.

Low Residual Sugar and Volatile Acidity: There was a significant reduction in the levels of residual sugar and volatile acidity, indicating a more complete and clean fermentation process.

Table 5 : Characteristic of UV water in physical, chemical and microbiological

Sr. No.	Test Name	UOM	UV Out Water (CPU)	UV Out Water (Fermentation)
1	Aspect		Water	Water
2	Odour		Odourless	Odourless
3	Colour		Light Yellow Colour	Light Yellow Colour
4	pH		8.43	8.43
5	TDS	ppm	1162	1155
6	Conductivity	Micro Siemens	2324	2310
7	TBC	Cfu/ml	1.60×10^2	2.0×10^1

Analysis of UV water on daily basis: Continue chemical and Microbial analysis done (Table 5).

CO_2 water recycling

Earlier status (2022-23): The fermenter releases CO_2gas, which goes via the CO_2 scrubber. CO_2 gas is sent to a CO_2 plant, and some alcohol and other impurity get up in the water of the plant's CO_2 scrubber. At initial stage this water send to CPU plant

Present status (2023-24): Now the CO_2 plant rejects this CO_2 water to fill the fermenter, reducing waste water.

Problems faced: At initial stage this water send to CPU plant and caused the negative impact to digester due to 0.2-0.4% alcohol content and increase the wastage quantity.

Corrective measures taken: To recycle the CO_2 water in fermentation (Figure 5) to reduce the fresh water consumption in fermentation.

Result (2023-24): CO_2 water 0.2-0.4% alcohol is increased to alcohol recovery of system.

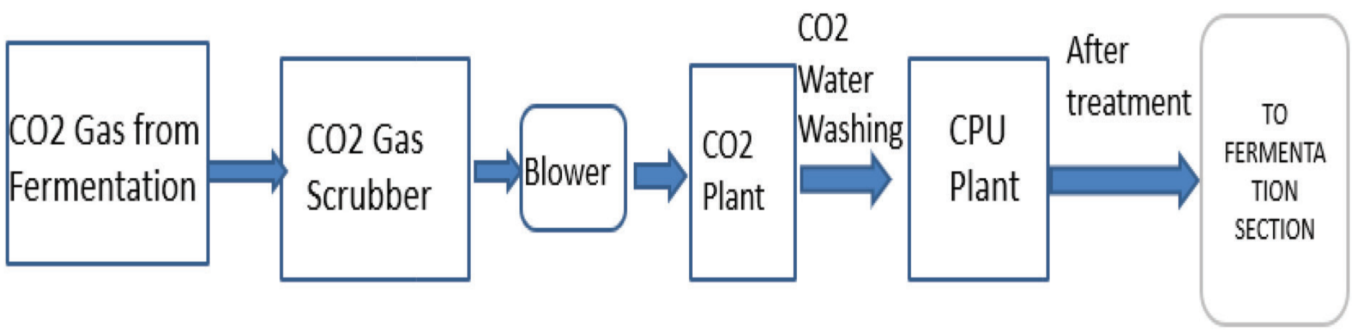
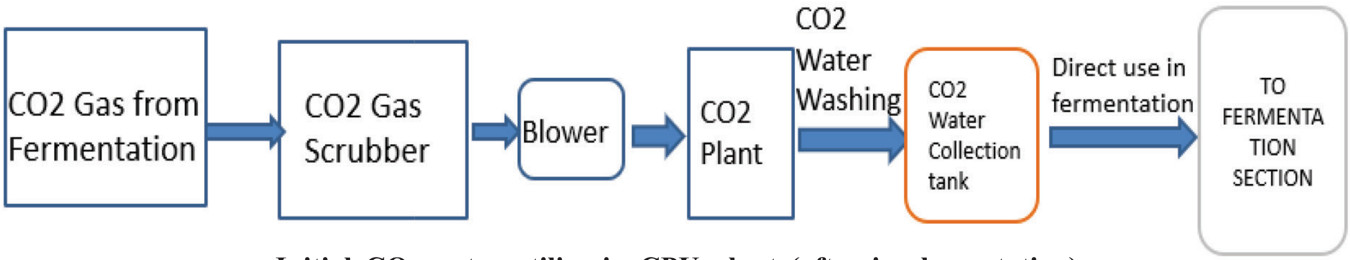


Figure 2A : Initial CO_2 water utilize in CPU plant (before implementation)



Initial CO_2 water utilize in CPU plant (after implementation)

Figure 2B : CO_2 wastewater and rinse water direct use in fermentation section to recover the alcohol loss

Spentwash recycling

Earlier status (2022-23): Initially, we began recycling spent wash in the fermenter, but the fermentation reaction was unsatisfactory due to microbial contamination. This contamination led to high volatile acidity (VA) and clumping problems in the yeast cells, as (Table 4).

Present status (2023-24): Now we recycle the 20% spent wash in fermentation due to new filling pattern, with the dose of chemical and new shift reactor.

Problems faced: Many types of problem facing at initial stage to start the spent wash recycle e.g.

- *Microbial contamination:* The presence of unwanted microorganisms disrupted the fermentation process.
- *High volatile acidity (VA):* This is indicative of microbial contamination, which can produce off-flavors and spoil the fermentation.
- *Yeast clumping:* Contaminants caused the yeast cells to clump together (Figure 1). Impairing their ability to ferment efficiently.
- *Low alcohol percentage:* The low conversion rate of sugars to alcohol resulted in a lower-than-expected alcohol content.

Corrective measures taken: This new approach involved changing the way the fermenter(refer to Picture-6) is filled to optimize the fermentation conditions. These are the following changes.

- *Fermentation enzyme:* We used 2.5 ppm in fermentation, but it had no effect, therefore we increased the dose to 3.0 ppm in the fermenter.
- *Biocide:* Initially, no biocide is used in the fermenter. However, when a problem arises, a 5 ppm dose is mixed with UV water in time.
- *Temperature:* When we recycle spent wash in a fermenter, the temperature should be 32-35°C.
- *CIP System:* After emptying the fermenter and PF, we do CIP of the process to kill the bacterial infection.
- *Chemical analysis of spent wash:* We analyses the chemical parameters (specific gravity, pH, RS%, ALC%, and VA) of spent wash daily (Table-6).

Filling pattern step of fermenter

- 1st we take UV water in pre fermenter at fixed quantity.

Table 6 : Spent wash analysis

DATE	SP.GR.	PH	ALC%	RS%	VA (PPM)
04/02/2024	1.073	4.59	NIL	2.1	1208.56
05/02/2024	1.071	4.53	NIL	2.03	1225.71
06/02/2024	1.073	4.43	NIL	1.96	1259.99
07/02/2024	1.074	4.4	NIL	1.96	1337.13
08/02/2024	1.075	4.41	NIL	2.03	1217.13
09/02/2024	1.071	4.48	NIL	2.03	1268.57

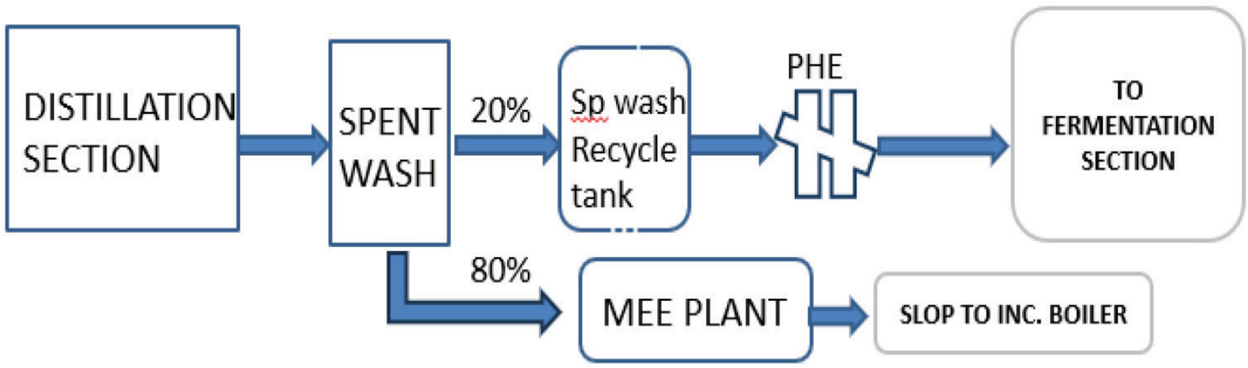
10/02/2024	1.075	4.32	NIL	1.9	1242.85
11/02/2024	1.074	4.42	NIL	2.03	1285.71
12/02/2024	1.076	4.48	NIL	2.1	1234.28
13/02/2024	1.073	4.55	NIL	2.03	1251.42

- Adjust the pH -4.5 to 4.8 of UV water with sulphuric acid.
- After mixing the UV water we start the 20 m^3 molasses and add culture vessels.
- When pf cell count found approx. 2.5-2.8 × 10^8 then transfer it into fermenter.
- 2nd we take UV water in fermenter at fixed quantity.
- Adjust the pH -4.5 to 4.8 of UV water with sulphuric acid.
- After mixing the UV water we start the 10 m^3 molasses flow rate for 2 hr and add culture PF and chemicals.
- After 5 hr. start to recycle the spent wash at 14 m3 for 17 hr and CO_2 water at 3-4 m^3 for 17 hr.
- Fermenter is setup at 22 hr.
- Yeast cell picture shown the microscope (Figure 2).
- *Addition of a shift* reactor:* Introducing a shift reactor helped in managing the fermentation process more effectively.

*Shift - Synchronized High Brix Fermentation Technology

No contamination found in fermentation due to use the new filling pattern.

Flow Diagram 3A : Initial spent wash recycling in rermentation section (before implementation)



Flow Diagram 3B : Initial spent wash recycling in fermentation section (After implementation)

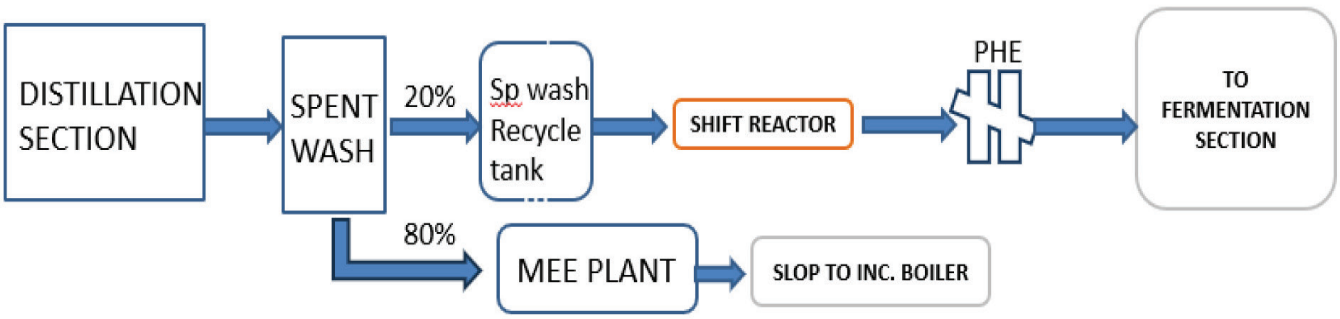


Figure 3 : Addition of shift reactor and agitator provided in Sp wash recycle tank

Table 4 : Performance parameters of fermentation plant with spent wash recycle – initial vs modified filling pattern

Date	06/01/2024	10/01/2024	11/01/2024	03/02/2024	04/02/2024	05/02/204
Used in trial	Spent Wash Recycle			Spent Wash Recycle with New Filling Pattern and Shift Reactor		
Parameter	**Trial -7**	**Trial -8**	**Trial -9**	**Trial-10**	**Trial-11**	**Trial-12**
Yeast cell count in PF	2.65×10^8	2.85×10^8	2.7×10^8	2.75×10^8	2.85×10^8	2.7×10^8
Fermenter Initial Setup Gravity	1.061	1.063	1.059	1.053	1.05	1.051
Fermenter Initial pH	5	5.12	4.98	5.13	5.06	5.1
Fermenter Final Gravity	1.049	1.049	1.046	1.037	1.04	1.039
Fermenter Final pH	4.4	4.32	4.29	4.5	4.84	4.73
Alcohol	11.8	11.54	11.7	12.34	12.44	12.4
RS%	1.94	2.5	2.32	1.86	1.82	1.79
VA(ppm)	1285.71	1371.42	1414.28	1148.56	1105.71	1165.71
Fermentation Efficiency %	88.40%	86.20%	87.80%	91.50%	91.89%	91.94%
Fermentation Cycle(Hr.)	47hr	45hr	46hr	36hr	36hr	37hr
Yeast cell count in Fermenter Setup	1.4×10^8	1.45×10^8	1.35×10^8	1.65×10^8	1.6×10^8	1.5×10^8
Yeast cell Viability after complete cycle in Fermenter	Nil	Nil	Nil	Nil	Nil	Nil

- Fermentation cycle, alcohol% is similar as to use fresh water filling cycle.
- VA is slightly high but under control.
- Fresh water consumption is low in fermentation.
- Steam consumption is low due to initial spent wash brix is high to feed in MEE plant.

RESULTS AND DISCUSSION

Recycling spent wash back into the fermentation process can mitigate these challenges and offer several benefits:

Comparison of 2022-23 and 2023-24 distillery season

The key performance data for both the distillery seasons have been given at (Table – 7 and 8).

Result (2023-24): Many benefits found to spent wash recycle in fermentation (Table 4).

Table 7 : Fermenter's parameters average data freshwater Vs recycle stream water

S. No.	Parameter	Filling With Fresh Water	Filling with UV Water + Spent Wash + CO_2 Water
1	Yeast cell count in PF	2.8×10^8	2.8×10^8
2	Fermenter Initial Setup Gravity	1.043	1.060
3	Fermenter Initial pH	4.8	4.9
4	Fermenter Final Gravity	1.024	1.040

5	Fermenter Final pH	4.70	4.85
6	Alcohol%	12.5%	12.5%
7	RS%	1.40%	1.80% (High due to RS% recycle in S/W)
8	VA(ppm)	1000	1100
9	Fermentation Efficiency%	92%	92%
10	Fermentation Cycle (Hr.)	34 hr	36 hr
11	Yeast cell count in Fermenter Setup	1.7×10^{8}	1.7×10^{8}
12	Yeast cell Viability after complete cycle in Fermenter	Nil	Nil

Table 8 : Plant performance data 2022-2023 Vs 2023-2024

S. N.	Parameter	Data without Spent Wash Recycle July 22 – June 23	With Spent Wash recycling (SHIFT) July 23 – June 24
1	Alcohol concentration	12.34 %	12.29%
2	Recovery of Plant	31.4 BL / Qtl	31.35 BL / Qtl
3	Enzyme dose	2.5 ppm	3 ppm
4	Residual sugar left	1.4 – 1.5 %	1.86 %
5	FE	92.0 – 92.5 %	92.23 %
6	DE	98.5 %	99.19 %
7	Spent wash generation	6.62 ltr / ltr of Alcohol	5.30 ltr / ltr of Alcohol
8	Spent wash recycling through Swift Technology of M/s Praj	-	20 – 21 %
9	Spent wash Brix on B heavy	10	13 - 15
10	Process condensate COD	4500 PPM	4500 PPM
11	RO permeate COD	50	50
12	RO Recovery in 03 stages	Ist RO -70 % &IInd RO - 50%	Ist RO -71 % &IInd RO - 65%
13	Fresh water requirement	6.71 ltr/ ltr of Alcohol	3.34 ltr/ ltr of Alcohol
14	Steam	4.35 kg/ltr of AA	3.86 kg/ltr of AA

Reduction in water usage

By recycling spent wash, the overall water consumption in the fermentation process is significantly reduced. This contributes to water conservation and lowers the dependency on freshwater resources (Table 2).

Nutrient recovery

Spent wash contains valuable nutrients that can be utilized in the fermentation process. Recycling these nutrients can enhance the efficiency of the fermentation and reduce the need for additional nutrient supplements.

Waste minimization

Recycling spent wash reduces the volume of waste generated, alleviating the burden on wastewater treatment facilities and decreasing the environmental footprint of the distillation process (Table 8).

Impact on solid content and steam consumption

Recycling spent wash in the fermentation process offers several advantages, including improved resource efficiency and cost savings. One notable benefit is the increase in inlet solid content in the spent wash, which leads to a reduction in steam consumption in the multi-effect evaporator (MEE) and overall steam consumption in the distillery.

Inlet solid content in spent wash

Higher solid content

When spent wash is recycled back into the fermentation process, the concentration of solids in the spent wash increases. This is because the residual solids and nutrients are reused, leading to a higher solid load in subsequent fermentation cycles.

Steam consumption in multi effect evaporator

Efficient evaporation process:

The multi-effect evaporator (MEE) is used to concentrate spent wash by removing water through evaporation. With higher inlet solid content, less water needs to be evaporated to achieve the desired concentration. This reduces the overall volume of water that must be evaporated.

Lower steam requirement

Since less water needs to be removed, the amount of steam required for the evaporation process decreases (Table-2). This leads to significant energy savings, as the MEE operates more efficiently with higher solid content in the feed.

Enhanced fermentation efficiency

The increased solid content can provide additional nutrients that support the fermentation process, potentially improving the yield and efficiency of alcohol production.

Cost saving:

By reusing wastewater recycling and spent wash recycling, distilleries achieve cost savings in terms of steam consumption; water procurement, nutrient supplementation, and wastewater treatment (Table 2 and Table 8).

Table 2 : Quantities of UV & CO_2 water, spent wash and cost saving in 22-23 and 23-24 seasons

S. No.		UOM	2022-23	2023-24
1	AA Production	KL	27839.14	75412.65
2	UV water recycle	KL/KL	NIL	3.37
3	CO_2 water recycle	KL/KL		
4	Spent wash recycle	KL/KL		
5	Fresh water consumption	KL	186819	251998
6	Fresh water consumption per KL of AA Production	KL/KL	6.71	3.34
7	Steam consumption	MT/ KL	4.35	3.86
8	Chemical Cost			
a	Fermentation Chemical Cost	Rs/ BL	0.18	0.23
b	Condensate Polishing Unit Cost (including MEE)	Rs/ BL	0.50	0.48
c	Total Chemical cost in distillery	Rs/ BL	0.68	0.71

- Reduction in water consumption – 3.37 kl/kl of ethanol production.
- Reduction in Steam Consumption: 0.49 mt/kl of ethanol production. In saving terms of amount for 330 KLD production – Rs. 0.88 Lakh per day. Considering steam cost –Rs.550.
- Reduction of spent wash generation 1.32ltr/ltr of alcohol.

CONCLUSION

Recycling of treated water from CPU – UV water, CO_2 plant wastewater and spent wash into the fermentation process represents a sustainable and economically viable solution for managing this challenging by-product (Table 7 and Table 8). By leveraging the nutrient content of spent wash and reducing freshwater consumption, distilleries can enhance their operational efficiency and minimize environmental impact. Adopting this approach aligns with global sustainability goals and regulatory requirements, paving the way for a more sustainable and responsible alcohol production industry.

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