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Optimizing Ethanol Production for Improving Sustainability of Sugar Industry

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ABSTRACT

Alcohol production was considered as method of disposal of molasses produced during sugar production and was neglected as By-product. Decision of mixing of ethanol in petrol suddenly brought this into main stream and now ethanol production is one of the main income source. Ethanol is produced by fermenting sugars by yeast and distillation and subsequent processes purifies it to obtain ethanol. There is significant scope to improve fermentation by understanding yeast and making conditions suitable for yeast. Factors that can influence alcohol production is being discussed with results obtained in the paper. Storage of the feed stock, especially syrup for prolong period without deterioration is also discussed with results. Similarly how much ethanol can be produced from sugars is also discussed.

Keywords : Ethanol production, sugar industry, sustainability

INTRODUCTION

Government of India announced EBP couple of years back to tackle two important problems: saving of foreign exchange for oil purchase and to rescue / helping sugar industry from excess sugar production. Prices of ethanol have been kept quite lucrative so that sugar factories come forward and divert sugarcane juice / syrup / B heavy for ethanol production so that there will be reduction in sugar production to control excessive sugar stocks. Our sugar industry responded quickly and it looks that aim of 20% ethanol blending is likely to be achieved well before targeted date 2025. The journey is not over yet and there are challenges ahead. Diversion of syrup is not found to be easy and excepted yield has not been achieved by many however, diversion of B heavy molasses is quite successful. There are issues of ethanol yield per ton, preservation of B heavy and / or syrup for longer period and spent-wash treatment for zero discharge.

How much ethanol should be produced per kg reducing sugar (RS)

This is the main question and is quite confusing or lot of varied answers are given to this question. Basic chemistry and simple mathematical calculations should give correct answer to this.

Ethanol is produced by the fermentation of glucose / fructose (RS or reducing sugars) by yeast and stoichiometrically one kg RS should produce 644 ml ethanol on 100% basis.

However, the conversion will never be 100% as yeast will require some energy for its own growth / metabolism including in pre-fermenter stage. This requirement is calculated to be about 5%, hence we will obtain 95% conversion of RS to ethanol.

Fermentation occurs in 3 phases, one log phase – initially when reaction is just starting at slow speed, second Log phase – where reaction occurs

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at exponential phase and lastly stationary phase – where rate of reaction is very low. Hence, we cut off the fermentation in 24 hours and take the broth to distillation.

Some RS is likely to be remained unfermented / unconsumed, which should be nevermore than 1%. Especially for purer feed stock such as syrup it should be less than 0.5%.

There is a mis-concept in distillery called Nonfermentable Sugar. While calculating expected ethanol yield technologists always reduce this from TRS of the feed stock. For example – if B Heavy has got 56% TRS, then fermentable sugars (FS) are taken as 56 – 4 = 52% and this 52 TRS (FS) is used for further calculations. TRS is glucose and fructose only and both are totally fermentable.

Facts about unfermentable / nonfermentable sugars, they do exist. Complex sugars like starch, pentoses, glucans, pectin, galactose, cellulose etc. are present in sugarcane juice and remains in all feed stock in such small amounts that these can be ignored. There are many polysaccharides present in sugarcane juice or formed during processing that also can be called as unfermentable sugar. However, when we measure RS or TRS, none of the above sugars are estimated as they do not react with Felling's solution. Thus, deduction of 4 units from TRS is definitely baseless.

RS found in spent-wash due to stopping of fermentation at 24 hours should be termed as unfermented / unconsumed sugars or left over sugar.

Why fermentable sugars remain in spent wash: Fermentation is biological process which do not follow chemical engineering norms. Many factors are responsible for such leftover sugar:

- *Initial concentration of sugar:* every yeast has ability to tolerate certain amount of sugar only and if we try to feed more sugar to get more ethanol, it doesn't work. One should remember that sugar is preservative and not many microbes can tolerate it.
- Ethanol is final product of the fermentation which is also toxic, and it inhibits yeast also after certain concentration. As ethanol accumulates, yeast growth or rate of fermentation slows and at certain point is remains almost stationery. This factor is very lucrative as concentration of ethanol within yeast cell is crucial. Although it depends on ethanol concentration of the broth, it is partly correct, if the pressure of slats and other matter is reduced, possibly one can obtain slightly more ethanol in broth. Hence, purer the feed stock, better is the fermentation. (Amorim et al. 2011)
- Presence of calcium is known to interfere with yeast growth and can influence fermentation adversely. (Alminderej et al. 2022)
- Considering these points normally we keep brix of the wash not more than 24% with TRS of about 20 – 21% to obtain ethanol yield of 12 – 12.5%, provided calcium is well below 800 ppm (Walker et al. 1996). Unfermented sugars after such fermentation in spent wash are found be very less often about 0.5 or less, we have obtained 0.1%.
- Volatile acids in feed stock is found to be one of the major factors while diverting syrup for fermentation. Although unsulfured syrup is being diverted for fermentation; high VA often do not allow proper fermentation and ethanol yield is substantially reduced. VA above 5000 ppm makes fermentation extremely difficult.
- Sulfur is another toxic substance that affects fermentation negatively. B heavy molasses of double sulfitation sugar process can have high sulfur that can reduce ethanol yield, especially with having high VA.
- Microbial contamination reduces availability of sugar to yeast to produce ethanol. Contaminants convert sugar to various organic acids; proliferation of lactobacillus often results into souring of fermenter. Bad quality of dilution water is also responsible along with contaminated feed stock. (Wongsurakul et al. 2022).
- Higher organic matter, polysaccharides, calcium etc. affects distillation and increases frequency of cleaning apart from higher steam requirement and also are responsible for sludge formation that reduced ethanol recovery. Some factories have reported sludge above 10 – 15%

- Yet another very important factor is fermentation temperature. Ethanol fermentation is an exothermic reaction, means heat is liberated while ethanol is produced, hence it is essential to control temperature by proper cooling. It is observed that highest ethanol production efficiency is obtained at temperature 310C even ½ 0 change in temperature can affect ethanol production and / or affects time of fermentation.

Considering all these points, amount of ethanol per MT RS sugar should be:

- 1000 kg TRS (1MT) can produce 644 lit ethanol
- 5% sugars will be required for yeast for its growth and metabolism
- Thus, sugar available is 1000 – 50 = 950 kg
- There is 1% unfermented / leftover sugar in spent wash
- Therefore, sugar fermented to ethanol will be 940 kg
- So, ethanol produced should be 940 X 644 = 605.36 lit
- Considering distillation efficiency 99%, we should obtain 600 lit ethanol per MT sugar

We have considered all factors in above equation, unfortunately yield using this equation is taken as 100% efficiency and few technologists deduct 5 % as yeast growth requirement and 1% distillation efficiency and 530 lit ethanol per MT TRS is considered as best possible result.

Ethanol production or distilleries were treated as secondary industry and less importance was given till just couple of years back. Rising importance of energy sector and EBP 20% program with lucrative ethanol price have changed scenario suddenly and there is need to adopt to technologies to maximize ethanol yield, reduce pollution and / or adopting ZLD, even diversion of sugarcane juice and old sugar stocks are also thought to be used for fermentation. This increased race of technologies to improve fermentation industry which has already become backbone of sugar industry and is in lime light.

However, it should be remembered that there are limitations in fermenting bad quality feedstock such as molasses having excessively high VA, calcium, sulfur, higher acidity, high organic matter, starch / polysaccharides and contaminating bacteria, especially lactobacillus. It is rather too late to treat such feed stock and maximizing yield is possible by balancing sugars with other solids to optimize fermentation. Recycling spent wash increases these problems and lot of unused RS are wasted in spent wash.

Hence, to enhance ethanol yield, best way is to improve feed stock quality with respect to all above factors and it is possible only during sugarcane processing and not in distillery. The only addition required in distillery is of N source – DAP / Urea or ammoniacal salt and yeast. Thus, the key to improve ethanol yield is to improve sugarcane processing.

Possible changes in sugarcane processing to improve ethanol yield

Most important factor responsible for lower ethanol yield is controlling microbes in sugar house, this does not mean only mill sanitation. This subject has not gained much importance as in current evaluation practices it is difficult to notice benefits or losses that can be avoided. This subject is often debated only on limited sector i.e., milling section only. Although wealth of information is published by many scientists about its downstream effects or even effects in sugar refinery, the subject is still limited to mill sanitation only. This subject is too vital and too big besides not in the scope of this subject, deserved to be discussed separately, however salient features worthwhile to mention are:

- Total microbial control program ensures lowest RS in every step including that of primary juice.
- Minimal rise in RS throughout process including in molasses.
- Lower acidity by titration in primary juice and minimal rise in acidity during entire processing including in molasses.
- Lower acidity is responsible for lowering lime requirement.

- Allows to reduce lime significantly, we have reached to lime % cane of 0.075%.
- Lowe lime reduces sulfur requirement to neutralize, we have achieved 0.015% sulfur on cane successfully.
- CaO rise from mixed juice to clear juice is minimal, we have obtained less than 100 ppm; averaging just 80 ppm only.
- There is reduction of VA in every stage, VA in syrup should be less than 2000 ppm; we have achieved below 1000 ppm.
- VA in B-heavy molasses should be less than 5000 for better fermentation, we have achieved less than 2000 by total microbial control.

Once we have good feed stock, the job is relatively easy as yeast can ferment TRS to ethanol rapidly, only one may provide N source by way of slight addition of DAP or Urea or any other available product. We have to take care that we do not overload the fermenter. We have observed that 12 – 12.5% ethanol can be produced within 24 hours of stipulated / provided time, hence sugar loading is restricted to about 20% only which corresponds to 23 – 24^0 brix. There is no need to add anything apart from nitrogen source as mentioned and maintain temperature to 31^0C; fermentation will be fine and will not have more than 0.5% unconsumed TRS and you will obtain optimum ethanol yield as per formula TRS(MT) X 600 lit. For example, if syrup of 60 brix, 55% TRS is diverted for fermentation, one must obtain 330 lit ethanol per MT syrup. or B-heavy of 85 brix, 57 TRS, ethanol yield is 342 lit.

Use of enzymes to improve ethanol yield is waste of high end technology. Basically, enzymes are catalyst (proteins) that performs degradative reactions which otherwise are not possible in NTP conditions. Enzymes are extremely host specific and they do not harm similar molecule. Hence for every reaction step different enzyme is required. There is no enzyme that can degrade all proteins, or fats or sugars. Well known photosynthesis reaction requires 10 different enzymes. It can be said that complex system involving many enzymes may be required to perform single reaction, but you can’t haveone enzyme performing many reactions / complex degradations.

Recycling of spent-wash. Such recycling of spent wash is followed / suggested so as to reduce fresh water requirement by technology providers / technologists. Its effect on fermentation or on yeast may have been ignored? Although, water conservation / recycling is very important and is also essential for sustainability of the industry, it should not affect fermentation negatively.

While attempting recycling spent wash directly back for diluting feed stock, quantity of dissolved solids s increased, this creates unwanted osmotic pressure on yeast cell wall and can affect fermentation and reduce alcohol production. For maintaining high alcohol % in fermented wash there is a tendency to increase sugar/ feed stock and this again creates more osmotic pressure on already strained yeast. This results in more leftover / unfermented sugars in spent wash.

Best way to solve this riddle is to adopt spent wash drying technology after bio-methanation to recover potash rich fertilizer. Condensed water from evaporators can be recycled back safely – without fear of increasing salt concentration.

Optimizing ethanol do not mean to increase ethanol% in wash, however this should mean maximum ethanol production by utilizing maximum possible sugars from feed stock. Thus, addition of feed stock should be optimized so that no sugar is left unconverted in spent wash. Spent wash should contain TRS less than 0.01%. This is possible when one is using syrup as feed stock. Ethanol% in wash depends on yeast quality and we have found that 12.5% ethanol yield is suitable while maintaining residual TRS in spent wash below 0.2%

Storage of feed stock / syrup

Molasses deterioration is neglected and reduction of TRS in 6 months by couple of units is considered to be normal. It is also known that old molasses is difficult to ferment and ethanol yield is poor, however, this was never taken seriously as income from alcohol was not significant. There were many

Table 1 : Specifications of anhydrous ethanol as per IS15464:2022

Sl. No.	Characteristics	Requirements
1.	Appearance	Clear, bright & free from any sediment
2.	Relative density at 15.6 0C, Max	0.7961
3.	Ethanol percent v/v, Min	99.5
4.	Methanol % Max	0.5
5.	Residue on evaporation % by mass, Max	0.005
6.	Acidity (as CH3COOH), mg/kg, Max	30
7.	Alkalinity, mg/kg, Max	NIL
8.	Aldehyde (as CH3CHO) mg/l, Max	60
9.	Copper, mg/kg, Max	0.1
10.	Sulfur content, mg/kg, max	10
11.	Water content %, Max	0.5
12.	Miscibility with water	Miscible

instances where molasses foaming was noticed, many storage tanks were blown by Maillard reaction with many calsualties. B heavy molasses is more susceptible and reduction in TRS is significant loss to the factory.

Such deterioration is due to microbial growth and possibly is responsible for triggering of Maillard reaction. This deterioration can be reduced substaintially by using appropriate biocide formulation treatment while sending molasses / syrup into tank and also during storage at appropriate intervals. We have stored about 60000 MT B heavy for 8 months without any deterioration at Vishwaraj Sugars where ethanol yield on the last day was 328 liters per MT for 55% TRS.

Storage of syrup is considered to be difficult task as if we increase brix, chances of sugar crystallization is high and there is big risk of microbial growth at lower brix storage. We have developed special formulation for preventing such deterioration of syrup at 60 brix and we could store 18000 MT syrup of about 65 brix in Jamkhindi Sugars for 62 days, 12000 MT syrup of 48 brix for 48 days and 15000 MT of 60 brix for 72 days in Vishwaraj sugars.

CONCLUSION

Implementation of good practices as enumerated in technical paper it will give value addition for incremental rise in ethanol yield with respective feed material. Fermentation / distillation yield of 600 ml per kg TRS is achievable and it is possible to store any feed stock for prolong time with proper treatment.

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