

OVERVIEW OF CONTINUOUS ALCOHOL FERMENTATION AND MULTIPRESSURE DISTILLATION TECHNOLOGY

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Abstract

Ethanol production from agro-based raw materials normally involves two major steps, fermentation and distillation. These steps are reviewed, mainly in relation to molasses, which is the most common raw material in tropical countries.

The specific effect on fermentation efficiency of molasses quality in terms Fermentable Sugars, the ratio of fermentable to non-fermentable solids, Volatile Acids, Caramel and other inhibitors and Calcium and other inorganic elements are discussed. The improvement in fermentation kinetics by using efficient yeast strains and hygienic yeast propagation with cell recycle is also discussed.

Major aspects of ethanol fermentation by various techniques are discussed. The advantages and limitations of batch fermentation, its variants, and those of continuous fermentation, based on operational experiences from commercial scale ethanol plants are discussed.

The concept of Pressure cascading distillation (multi pressure distillation) and its advantages over atmospheric distillation is described.

It is concluded that an efficient fermentation plant coupled with multi pressure distillation system can provide competitive advantage for ethanol producers.

Keywords: fermentation, distillation, continuous, distillery, ethanol, energy efficiency

Introduction

Fermentation

Yeast can grow aerobically as well as anaerobically. Aerobic conditions favors yeast cell production, which is not of interest to ethanol producers. However, growth during anaerobic condition is very marginal and major reaction is conversion of sugar to ethanol for energy production. For growth and multiplication, yeast requires utilizable organic carbon (sugars), nitrogen source, various organic and inorganic trace growth factors. Proper nutrition, as for any living organism, is the key to making yeast thrive and obtain optimum performance. In reality, distillers often nutritionally stress the yeast. The two most important nutrients for growth are nitrogen and oxygen. Stillage and purified adjuncts lack sufficient free amino nitrogen (FAN). Yeast extract, protein digests and oats are good sources of FAN. In addition to this optimum, environmental parameters are also required. During the conversion of sugar to ethanol, energy is produced, which is utilized by cells for different functions. Thus, overall metabolism of yeast is catabolism (energy production and cell multiplication). This is called fermentation.

Yeast has major importance in fermentation. The length of individual yeast cell ranges between 20 upto 30 micron and width, one to five microns. There are different types of yeast having different morphological and biochemical properties. Yeast is identified by its single cell nature.

Each yeast cell by itself is an independently existing live entity and cells possess different shapes such as spherical, globular, oval, elongated, etc.

Of the different types of yeast, *saccharomyces cerevisiae* is the industrially important yeast for alcohol fermentation. *Saccharomyces cerevisiae* consists of different strains and varieties, which are used for different industrial applications. Yeast, which is used for ethanol production, is called “Bakers strains”. Those used in beer making are called “Brewing strains” and wine making are called “wine strains”. This differentiation is based on specific properties of yeast required by the particular industry.

Traditionally, batch fermentation was being used in almost all the distilleries in Asia. In batch fermentation, the industry was facing the following problems:

- Low fermentation efficiency.
- More by-product formation.
- Higher residence time for reaction to reach completion.
- Requirement of yeast for each batch.

To solve the problems of batch fermentation, Praj introduced the concept of continuous fermentation for molasses in Asian distilleries around the year 1985-86. Initially, this technique of fermentation was adopted in India. Subsequently, a few other distilleries in Asia followed suit. Now, there are over one hundred continuous fermentation plants for alcohol in India alone, with additional plants in the Caribbean, Central and South America.

Distillation Practices

Distillation of fermented mash is the next important step in production of alcohol after fermentation. This step consumes a considerable amount of energy and is also a deciding factor in the quality of ethanol produced. Hence, in line with the demand of the industry, efforts have always been to minimize requirement of energy and to improve the basic quality of alcohol produced. Ease of operation, reliability, lower down time and flexibility of operations are other parameters considered during the design. Three basic types of plant are designed. One is to produce primary quality of alcohol, usually referred to as 'rectified spirit' (RS) from the fermented mash using mainly one step. Such plants are also referred to as 'primary distillation' plants. Second is to produce finer quality of spirit usually referred to as 'extra neutral alcohol' (ENA) or 'neutral spirit' (NS) starting from RS. Such plants are also referred to as 'secondary distillation' plants.

Third is to directly produce fine quality alcohol (ENA) from fermented mash. Such plants are referred to as 'wash (mash) to ENA' plants, where the two steps of primary and secondary distillation are combined. Such plants usually have lower consumption of energy than two separate plants. Praj has set up more than 175 plants in all the three categories together.

Observations and practical experiences

Continuous fermentation

In batch fermentation, feed material is diluted to appropriate sugar concentration. Yeast is inoculated into this diluted substrate and fermentation is allowed to take place. In continuous fermentation, feed is continuously pumped into fermentors and an equal volume of fermented mash flows out continuously, for recovery of alcohol, into distillation. Yeast is inoculated only at the beginning of the fermentation cycle. The process continues for long periods without stopping. A cascade system of continuous fermentation is used where three to seven fermenters are used in series. Concentration of alcohol in the first fermenter is at five to six % v/v, while it is around seven to nine % v/v in the last fermenter. This kind of profile helps in two ways. Productivity of yeast is

higher in the initial fermenters at lower concentration of alcohol. The later fermenters ensure higher level of concentration as well as well as completion of reaction of conversion of sugar to alcohol.

Higher concentration of alcohol helps in lower consumption of steam in distillation. When the system is used with granulating yeast, this yeast forms granules at the end of fermentation and, thus, can be separated from the fermented mash simply by gravitational settling. This settled yeast, then, is reactivated with additives like nutrients etc. and recycled to fermentation. Recycle of yeast builds up higher population of yeast in the fermenting mash, thus giving higher productivity as well as robustness of operation.

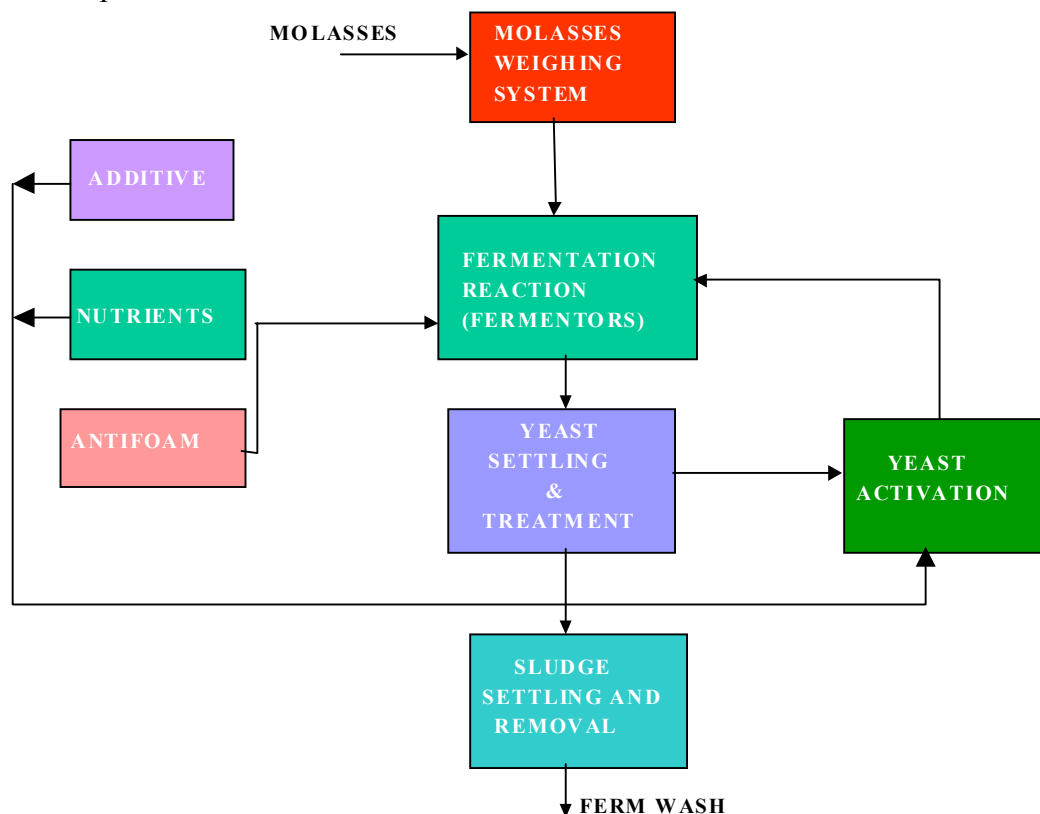


Figure 1. The fermentation process.

Evolution of the continuous fermentation process

Initially, in two of its plants, Praj adopted continuous fermentation technology with yeast recycle employing nozzle type disc-stack centrifugal separators. Pre-clarification of molasses was employed, as well, in these plants. The operating experience at those plants showed that pre-clarification consumed significant amount of energy for heating and acid for lowering the pH of the molasses. The high-speed centrifugal machines used for recycle of yeast required significant amount of power and frequent attendance for maintenance.

In line with Praj's philosophy of tropicalising the process and lowering cost of production, a system was developed, where recycle of yeast is done based on settling by gravity and there is no requirement of pre-clarification of molasses. The process was initially conceptualized on laboratory scale. After firming up the parameters, a pilot plant was set up to work out scale-up parameters. Subsequently, the process was established on a commercial level plant. This process has now been in use in several plants and has been used successfully.

Some observations

While these continuous fermentation plants were being set up and operated, it was observed that two input parameters for utilities were of significance. One was temperature of cooling water. As the temperature of fermentation was to be maintained below 33 degrees Celsius, cooling water temperature had to be well below this value. However, in tropical countries, ambient temperatures as well as wet-bulb temperatures being high, especially during summer and rainy seasons, this posed a problem. This was resolved by installing cooling towers with close approach to wet-bulb temperature and by employing plate-heat-exchangers having close approach. Another parameter was quality of process water. Where subsoil water was used, it usually had no problems. However, where river or canal water was used without treatment, sometimes high level of bacterial activity was encountered. This was remedied by installing a filtration and chlorination system for process water.

Various parameters of inputs have been encountered at the commercial scale plants. Fermentable sugar content of molasses has been between 38 to 53 % w/w. Ratio of fermentable to non-fermentable (F/N) substance in molasses has been ranging between 0.9 and 1.9. Efficiency of fermentation has been around 90 % of theoretical value. The fermentation cycle usually runs between 45 and 120 days in one stretch. Concentration of alcohol ranges between 7.5 to 9.5 % v/v, depending upon the F/N ratio. Plants have been set up with capacities ranging from 20,000 litres of alcohol per day to 225,000 litres of alcohol per day.

Organic volatile acids usually suppress activity of yeast. Thus, whenever organic volatile acids are present in high concentration in molasses, this could slow down the reaction of fermentation of sugars to alcohol. This phenomenon was experienced on some of the plants.

The concentration of volatile acids in molasses went up in some of the plants, at times, unpredictably. Whenever the concentration went beyond 5,000 parts per million in molasses, the effect was noticeable. Such effect has to be nullified by increasing the period of fermentation to compensate for the reduced rate of fermentation. Concentration of alcohol in fermenting mash is also reduced to minimize simultaneous suppressing effect of alcohol and volatile acids on activity of yeast. This method could remedy the occurrence.

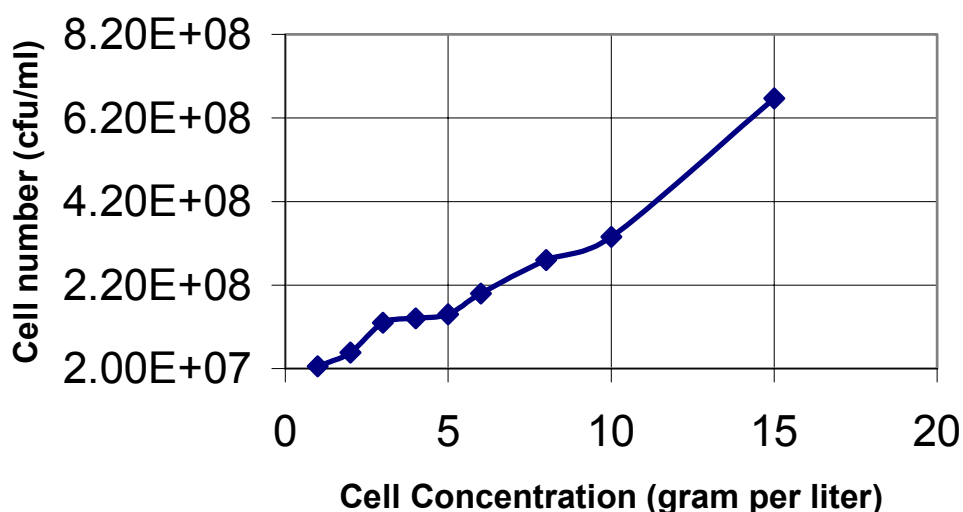


Figure 2. Curve for yeast cell concentration versus cell number.

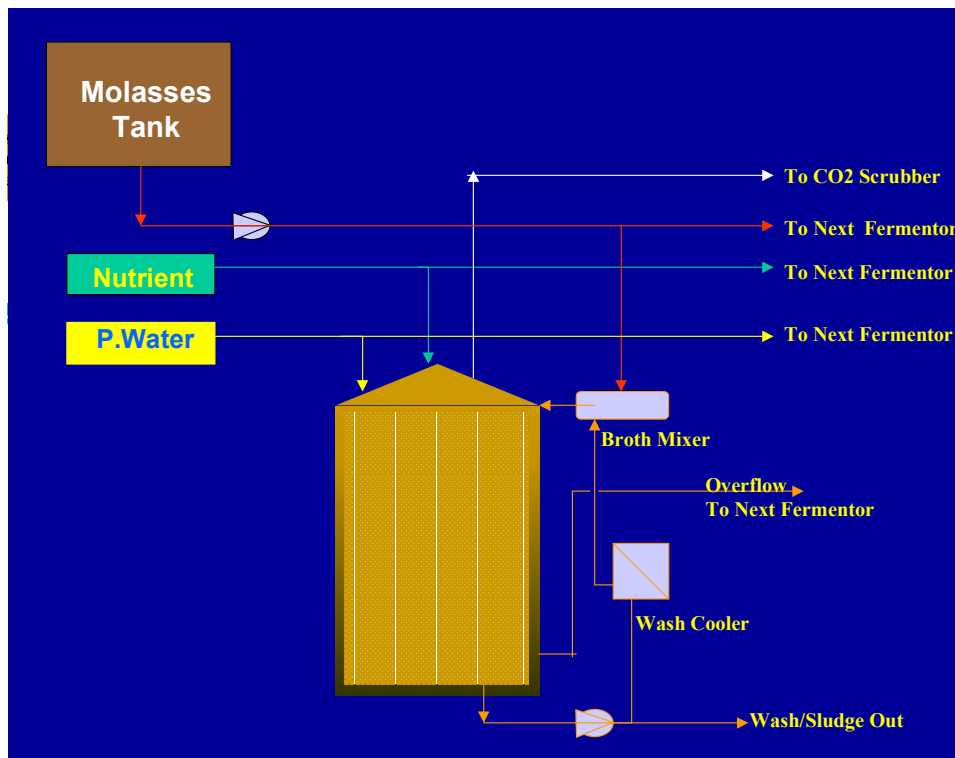


Figure 3. Continuous fermentation.

Distillation

Primary distillation

The plants to produce RS have been designed usually with stripping column (mash column or stripping column) in stainless steel as the material of construction. It has been observed that stainless steel has higher resistance to corrosion by mash than copper. Furthermore, it was observed that there was no negative effect on the quality of alcohol produced due to the use of stainless steel for this column. The concentration column (Rectification column) is usually fabricated in copper as material of construction. It has been observed that use of copper in this column helps in minimizing the presence of mercaptans (organo-sulfur compound) in the product, mainly in molasses based distilleries. However, another way for the liquid being processed to react with copper would be by introducing copper in another sacrificial form in this distilling zone. This helps to prolonging the life of this column. In the absence of this second approach, it has been observed that the fusel-oil separation zone or the top portion of the column corrodes faster due to presence of the organo-sulfur compounds. These compounds were analyzed, in some of the plants where corrosion was noticed and found to be complex organo-sulfur compounds generated by reaction of the various components present in the fermented mash. A few specific steps were taken to route concentrated streams of these compounds to specially designed columns, in such a manner as to eliminate their corrosive effects. Another smaller column in the scheme to concentrate the streams containing low-boiling impurities is the 'heads concentration column', which is fabricated out of stainless steel. Usually, vapors to this column are fed from the upper part of the stripping column called the 'de-gasifying column'.

Secondary distillation

Plants to produce ENA from RS have been designed based on the specific requirements of customers in terms of the impurity level permitted. These specific requirements determine the number of columns in the system to recycle the streams and to concentrate the streams. This also determines the reflux ratio of various columns as well as consumption of energy. One variation, which is frequently employed, is to use 'hydro-selection' or 'hydro-extraction' for the 'purifier

column', which is the first step in separating low-boiling impurities. Experience shows that hydro-selection helps in separation of fusel-oils as well. However, a column to concentrate the overhead impurity stream is required. There have been instances where all the columns in the plant have been fabricated in copper, as a specific requirement of the customer. However, experience has shown that only the concentration section in the rectifying column, above the fusel-oil zone should be in copper, while the rest of the columns can be in stainless steel. In the situation, where there is a separate column for concentration and separation of methanol at the end of the scheme (also known as 'refining column' or 'simmering column'), then that should also be in copper. In some of the plants, which were associated with sugar-mills, it was noticed that the steam produced in the boiler using condensate from the sugar-juice evaporators had a peculiar smell. Thermo-siphon reboilers were employed in such plants at the bottom of the columns to prevent the smell from steam to being transferred to the alcohol produced. By increasing the reflux ratio at the top of the columns, reduction in the flow-rate of the stream containing impurities (commonly called 'technical alcohol' or TA) was achieved. However, this increased the energy consumption and the economic viability of this step depends on the cost of the additional energy required versus the enhanced price obtained for fine ethanol produced.

Distillation of mash to ENA

It has been observed that the trend is now to set up distillation plants producing ENA directly from fermented mash. This procedure eliminates the stage, where the alcohol is concentrated (rectified) in the primary distillation. This scheme is cheaper to install and to operate.

It has been observed in the various plants that have been installed by Praj Industries Ltd. in India and elsewhere that very low levels of each impurity are attainable in these plants, for example less than five ppm for methanol and below one-ppm level for each other impurity. Such plants are also amenable to automation. Hydro-selection is usually employed in these plants.

Energy-saving multi-pressure distillation plants

These plants have the following advantages:

- Lower steam consumption.
- Lower scale formation
- Reduced by-product formation in the mash column.

Distillation columns could be operated, on a similar principle to that of multiple-effect evaporators, to save energy. Such a 'multi pressure' scheme is particularly interesting for 'wash to ENA' plants. Here, usually, the mash column is operated under vacuum and is heated by overhead alcohol vapors from the rectifying column. Thus, steam supply to the mash column is saved. Similarly, other columns are also operated 'in-pair' using overhead vapors from one to heat the other. There could be nearly a 50% saving in energy. Many years ago a plant of 120,000 litres per day capacity in Indonesia was set up and is operating very successfully, along with a DCS-based (Distributed control system) control system. It was also observed that the level of impurities in alcohol from such plants is far lower, compared to plants with mash column operating at normal pressure. This is attributed to a much lower extent of reactions among components in mash at the bottom of the mash column because the bottom is around 80 degrees Celsius.

Scaling and column internals

The phenomenon of scaling is attributed to precipitation of calcium salts in the presence of ethanol and high temperature. Both these parameters reduce solubility of calcium salts, thus causing deposition. Bubble-caps were used in all the columns in the distillation plants, initially installed. However, it was observed that with variation in composition of molasses, there were instances when the fermented mash had very high levels of calcium salts, which precipitated and deposited on the trays of the mash column. Columns with sieve trays had the disadvantage of not being able to

operate at low turndown. Thus, 'Hyperstat' grid trays were developed after considerable hydraulic studies. These trays offered the advantage of easy cleaning while ensuring high efficiency as well as lower downtime than sieve-trays. These trays have been used in several plants and have been found to be very good from the point of view of ease of cleaning. The Hyperstat trays also had the advantage of horizontal flow of vapour, thus sweeping the tray surface as well as ensuring a longer path for vapour through liquid to achieve better mass transfer.

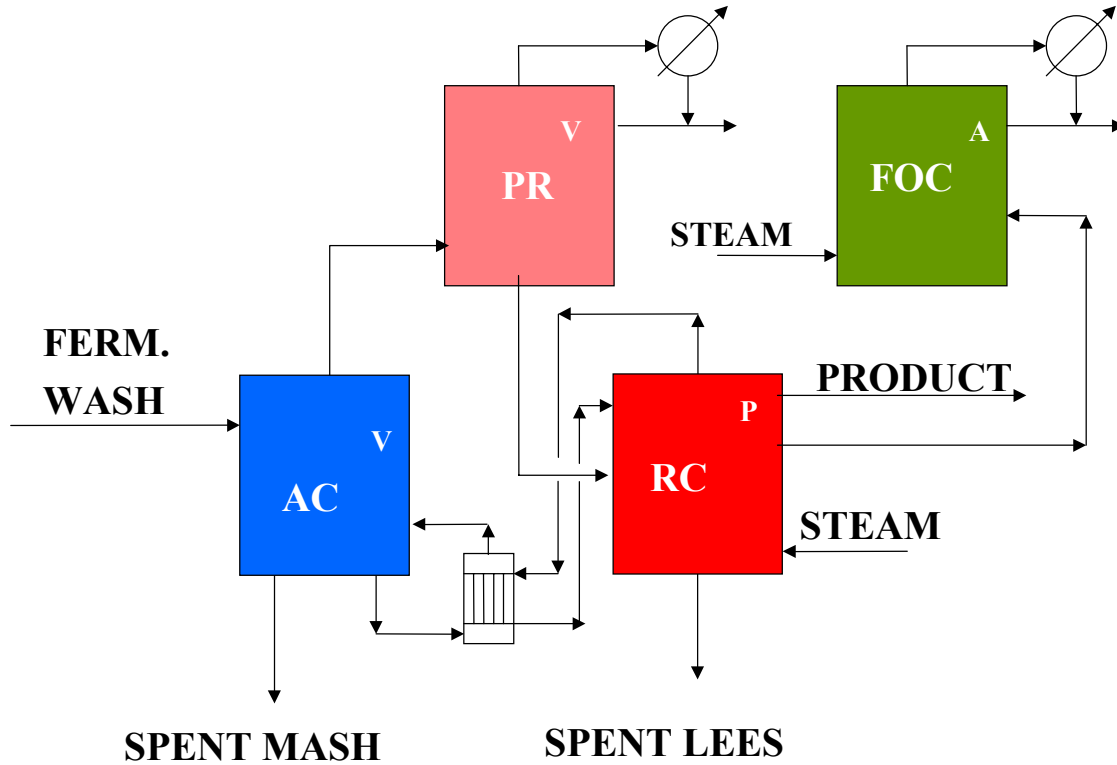


Figure 4. Process flow diagram (typical) of a multi pressure distillation plant.

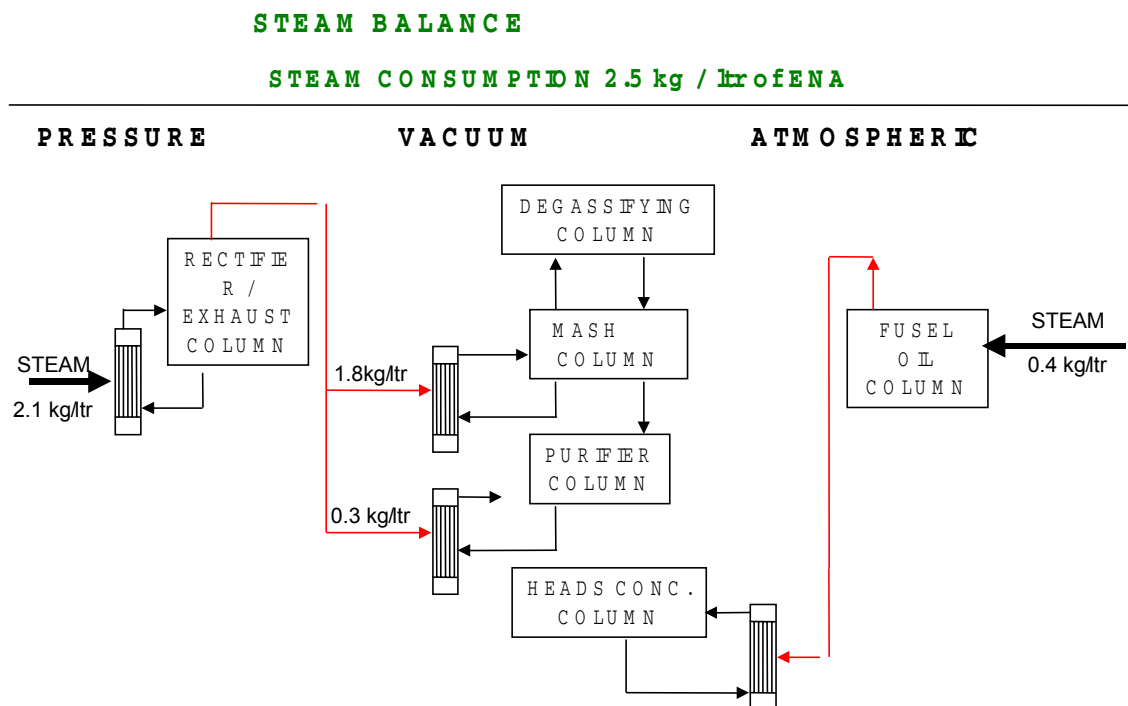


Figure 5. Steam balance diagram (typical) of a multi pressure distillation plant.

Conclusion

It has been a long, learning experience through plant operation, research and developmental trials and by commissioning of nearly 100 plants in various countries like India, Sri Lanka, Philippines, Indonesia, Caribbean and South Central America. This helped perfect the technology and engineering of equipment for fermentation of molasses to produce alcohol in these regions. Technology lends itself perfectly for modernization and expansion of existing batch-type fermentation plants. The plant can also be designed to alternatively operate on sugar-cane juice or on starch-bearing materials, with suitable additional equipment.

The multi pressure plants have distillation columns operating under different pressures. Thermal energy from columns operating under pressure is recycled to columns under vacuum to conserve energy. The multipressure distillation plant of 120,000 litres per day capacity designed for a client in Indonesia requires only 2.6-2.8 kg per litre of steam for producing Superfine Extra Neutral Alcohol. The vacuum operation of the Mash column and other critical columns also helps in separating low boiling impurities to a great extent. Six plants in India are now operating with multi pressure technology and are running successfully.