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Chemical Engineering in the Alcohol Industry: Alcohol and Society

Alcoholic beverages date back to 2000 BC when the Egyptians would heat wine to produce what are known as arden spirits. This procedure was passed from the Egyptians to the Arabs, and the English word alcohol was derived from the Arabic words “al kohl” which refers to the product obtained from heating wine. Today, beer and distilled spirits are manufactured by a chain of processes including milling, mashing, conversion, fermentation and distillation. Chemical engineers, with their knowledge of separations, are well suited to mass produce distilled-spirits; the impact of their distillation efforts has had a large impact on culture. This paper describes the role of chemical engineers in the production of distilled-spirits and the cultural impacts resulting from their consumption.

Alcohol Production

Ethyl alcohol (CH_3CH_2OH) is the primary form of drinking alcohol, although in distilled-spirits fusel oils (higher alcohols) are also present to contribute to the flavor profile. Ethyl alcohol is produced via fermentation of substances that contain sugar, primarily starch and fruit. Production of distilled-spirits requires malt (germinated barley, rye or wheat) and cereal grains. Before milling, grain is sorted and sifted to remove those grains that have undesirable odors and foreign particulates. The grain is then milled by a hammer or cage mill, to remove the cellulose on the outside of the grains exposing the starch for cooking and conversion in later processes. After milling, mashing ensues; cooking the grains to gelatinize the starch and to saccharify it into maltose. Saccharification is a process which breaks down the glycosidic bonds in complex carbohydrates reducing them to their monosaccharide components. Once cooled, malt is added to the saccharified starch and the mixture is pumped into the converter where 75-85% of the total starch present is saccharified. This is achieved by introducing enzymes that liquefy starch by hydrolyzing certain linkages in the starch chains. Necessary particle size and cooking conditions vary depending on the type of spirit to be distilled. Once the conversion process is complete, the mixture is cooled and sent to a fermentor where yeast (saccharomyces cerevisiae) is introduced to inoculate the mash. The yeast metabolizes the maltose and glucose sugars into ethanol and other secondary products, known as congeners; these include aldehydes, esters, fusel oils and lactic acid bacteria. The fermented grain mash contains ethanol, desired congeners, solid particulates, salts, lactic and fatty acids, and trace amounts of glycerol and succinic acid. Distillation, the final process step, separates and concentrates the desired products (ethanol and desired congeners) from the fermented grain mash.

Several distillation processes are used globally. Distilled-spirits in the U.S. are produced primarily from continuous whiskey separating columns, also known as stills. Figure 1 shows a process flow diagram for a typical continuous wiskey separating column.

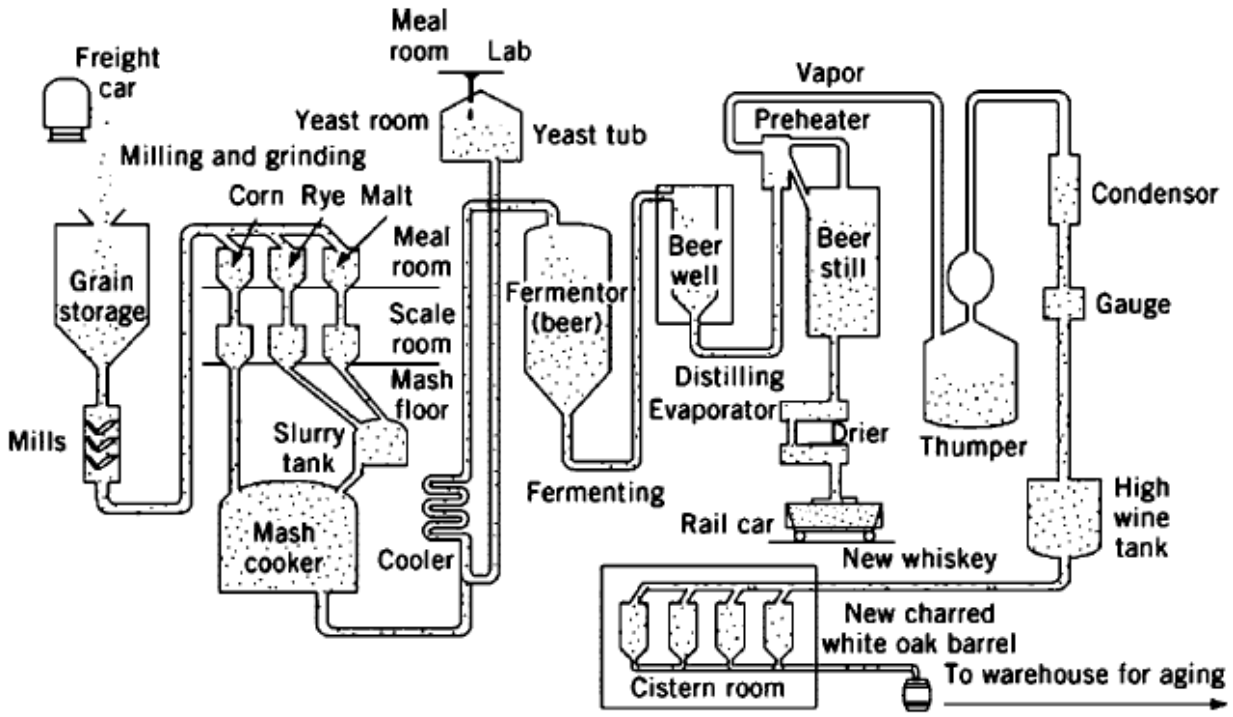

Figure 1: Distilled-beverage (whiskey) plant process flow sheet[1].

Distillation

Distillation is the key operation for producing distilled spirits like whiskey. Because of their expertise in distillation, chemical engineers contribute to the distilled-spirits industry. Figure 2 shows a continuous distillation column with a reboiler, condenser and continuous reflux.

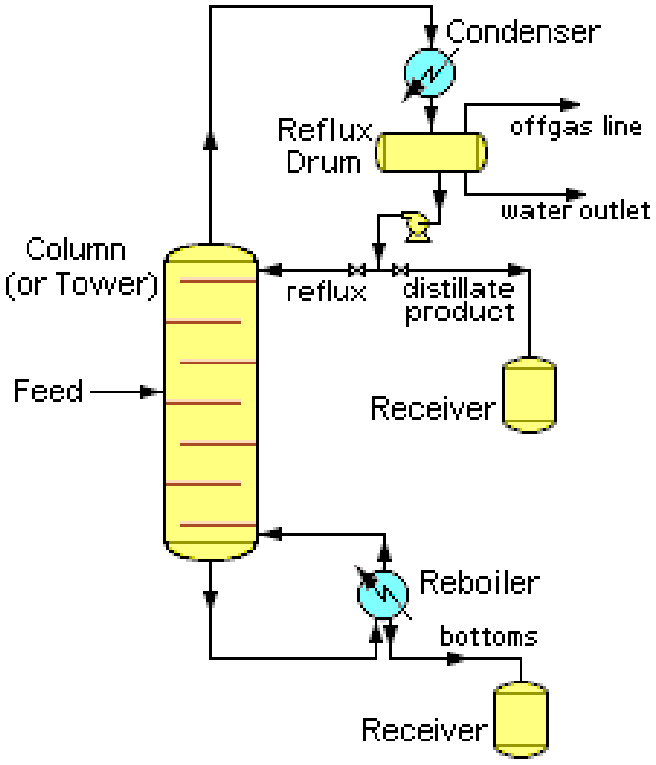

Figure 2: Continuous distillation column with reboiler, condenser and continuous reflux[2].

For the production of beer and distilled spirits, fermented grain mash is fed to the column at the feed plate. Initially, this liquid flows down to the reboiler where heat is supplied, producing vapor that rises up the column and condenses as heat is removed by the condenser. The vapor is higher in concentration of the light boilers (substances with low boiling points) than the liquid, because the light boilers require less energy to vaporize than the heavy boilers. The desired purity is often not achieved initially and the condensed liquid is refluxed back into the column, flowing counter current to the vapor. The column contains a number of stages, or trays, where the downward flowing liquid and the rising vapor are in contact with each other.

At each stage, the concentration of a light boiler in the entering vapor is less than the concentration attained when the vapor reaches equilibrium with the liquid. Mass transfer of a light boiler from the liquid to the vapor prevails until equilibrium has been achieved. The opposite is true for the concentration of a high boiler in the entering vapor. The heat of vaporization (heat required to vaporize) for the light boilers is supplied by the heat of condensation (heat released by condensation) from the heavy boilers. Once steady state has been achieved, the column is in total reflux and the minimum number of required stages can be determined. Once the condensed product (distillate) is collected, the system is no longer in total reflux, and the number of trays used in the column depends on the optimum reflux ratio (ratio of condensate refluxed to condensate collected).

As the reflux ratio rises, operational costs increase because the reboiler now requires more energy to vaporize the increasing downward flow of liquid. The optimum reflux ratio is determined by finding the most economically feasible ratio that produces the desired product purity.

Column temperature increases from top to bottom because upon proceeding down the column, the liquid phase contains a higher concentration of high boilers. The pressure at the bottom of the column is larger than that at the top, raising energy requirements. The portion of the column above the feed plate is referred to as the rectifying section, where the vapor is enriched in low boilers through contact with the reflux. The lower portion of the column is referred to as the stripping section where the downward flowing liquid is "stripped" of low boilers and enriched in heavy boilers.

Short-Term Effects of Alcohol Consumption

Alcohol presents a short-term intoxicating effect on the human body while its long-term effect damages mental and physical health. Ethanol is a potent central-nervous-system depressant; excessive consumption leads to impairment of both the mind and body. Short-term effects of alcohol consumption range from increased feelings of relaxation, jubilation, confidence, aggression, anger and depression to poor physical coordination and vision impairment. The specific short-term effects vary both with individual response to alcohol, and with the quantity consumed over a short period of time. In social settings people often drink as a way of lowering their social inhibitions, resulting in behavior that is not characteristic of how they behave when they are sober. The resulting range of behavior is vast. For those who become more relaxed, jubilant and confident, drinking provides a means to increase social interaction. For those who become aggressive, angry and depressed, drinking has the opposite effect, leading to anti-social behavior or to a decrease in social interaction. In many cases, the underlying factor that motivates many of these people to drink alcohol is the desire to "escape" the monotony of daily life. Intoxication changes normal behavior and, regardless whether the changes are for better or worse, many people desire that escape.

Physical and mental impairment from alcohol intoxication have a very large impact on society. Along with lowering inhibitions, alcohol is known to cause "difficulty in walking, blurred vision, slurred speech, slow reaction times, impaired memory"[3] and impaired judgment. Under the influence of alcohol, people often act in ways detrimental to the health and safety of themselves and those around them. Table 1 summarizes the contribution of alcohol to deaths in the world through impaired judgment.

Means of Death	Percent Attributed to Alcohol Intoxication
Accidental Fire	30
Accidental Drowning	30
Suicide	30
Accidental Falls	40
Automobile Accidents	45
Homicides	60

Table 1: Percent of deaths attributed to alcohol intoxication[3].

Long-Term Effects of Alcohol Consumption

Long term alcohol effects depend on age, duration of habitual drinking, the age that habitual drinking began, gender and genetic background. Scientific research has shown that alcohol damages both the brain and the liver, causing effects ranging from memory slips to permanently debilitating conditions. Blackouts and memory loss are short term effects of binge drinking that illustrate that alcohol damages the brain. Blackouts are defined as "an interval of time for which the intoxicated person cannot recall key details of or entire events"[3] that occurred while they were intoxicated.

80% of habitual binge drinkers (people that frequently consume more than 4-5 drinks in a two-hour period[3]) experience a deficiency in thiamine (vitamin B) which can lead to the Wernicke-Korsakoff Syndrome (WKS). WKS consists of a severe short-term condition known as Wernicke's encephalopathy and a debilitating long-term condition known as Korsakoff's psychosis. The former condition is characterized by "mental confusion, paralysis of the nerves that move the eyes, and difficulty with muscle coordination"[3]; the latter condition is characterized by "persistent learning and memory problems, difficulty walking, and poor coordination."[3] People who develop Wernicke's encephalopathy may find that they are too confused to navigate themselves out of a closed room, and those who develop Korsakoff's psychosis may not remember things that happened to them within an hour of the event. 80 to 90% of alcoholics suffering from Wernicke's encephalopathy also develop Korsakoff's psychosis. Liver damage from habitual binge drinking leads to cirrhosis of the liver, that can lead to a brain disorder known as hepatic encephalopathy, a condition characterized by "changes in sleep patterns, mood, personality, increased anxiety and depression, shortened attention span, uncontrollable shaking, and potentially fatal comas."[3]

Underage Drinking

Advertising encourages drinking through the use of images that portray alcohol consumption in an unrealistic manner where drinking is "cool." For example, a TV commercial may show a group of people on the beach, all drinking and having a great time. This can cause a serious misconception of the realities of alcohol consumption, especially among the younger generation who are easy influenced by the desire to be popular.

Underage drinking is a big problem in the U.S. A study conducted amongst 5^{th} and 6^{th} graders revealed that those students who were aware of alcohol ads had more favorable beliefs about drinking alcohol when they grew up than those who have not seen the ads[4]. Approximately 50% of students in junior high school and in high school recognize that alcohol advertising encourages them to drink[4]. Statistics have shown that for students in their senior year in high school, approximately 80% have consumed alcohol, and approximately 60% have been drunk at least one time[4]. In the U.S. alone, underage drinking costs roughly $50 billion dollars annually in affiliated damage, court costs, rehabilitation, abstinence education, etc. [4]

Conclusion

Considering their understanding of distillation, chemical engineers are key contributors to the current production of distilled spirits. For those who know their limits and drink responsibly, alcohol can be a way to enjoy a nice evening, increasing both relaxation and sociability. For those who limit themselves to 1-2 drinks per day, alcohol consumption has been shown to increase cardiovascular health. The problem lies in excessive drinking.

Currently there is no way to regulate alcohol consumption because legal adults (over the age of 21 in the U.S.) have no limit to the amount of alcohol they can purchase, and consumption in restaurant or bars is often not monitored. Each person has to know his or her own limits and adhere to them. Unfortunately, intoxication is inversely proportional to good judgment, leading to bad decisions that often result in destruction of property, illness or injury, and death.

Alcohol consumption has some benefits and disadvantages. For better or worse, the effect of drinking alcohol is determined by the personal judgment of the consumer. Whether the choices made are done so responsibly or not, it is clear that the underlying impact on culture is huge; whether that impact be increasing relaxation and sociability, or the misfortunate event of property damage, physical illness or injury, or death.

References

1. Beverage Spirits, Distilled, *Kirk-Othmer Encyclopedia of Chemical Technology* , John Wiley & Sons, Inc., 2001
2. http://upload.wikimedia.org/wikipedia/commons/1/13/Continuous_Binary_Fractional_Distillation.PNG (figure 2 - image of continuous distillation column)
3. http://www.come-over.to/FAS/alcdeath.htm (death statistics in table 1)
4. W. McCabe, J. Smith, P. Harriott, Unit Operations of Chemical Engineering, 7th Edition, McGraw-Hill Companies, Inc., New York, New York, 2005
5. http://pubs.niaaa.nih.gov/publications/aa63/aa63.htm (alcohol's long and short term effects)