

## **BASICS OF BEER BREWING PROCESS AND RELATED ALCOHOL CHEMISTRY - AN OLD BEER IN A NEW BOTTLE**

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### **ABSTRACT**

Beer is one of the favorite beverages produced by the fermentation of grains. The global production figures indicate an increasing trend during the last decade. This article highlights the beer brewing process, chemistry concepts involved, and problems and prospects. The emphasis is on conceptual understanding of both theory and practice, and the chemical perspectives and possibilities to provide an appreciation of alcohol chemistry exposure in our daily lives that have particular significance and several positive effects to enrich the learning experience. [*African Journal of Chemical Education—AJCE 10(2), July 2020*]

## DROPS OF DESIRE

Beer is one of the oldest and the third most consumed beverage in the world after water and tea. It is a signature drink in many cultures, and now there are about 400 types of beer in the world. Traditional types of beer include bitter, mild, stout, porter, lager, stout, and strong ale [1, 2]. Beer is typically sold in bottles, cans or kegs. The global beer production in 2016 was about 1.96 billion hectoliters, and total alcohol consumption per capita is about 6.3 Liters, according to the World Health Organization. It has a distinctive appearance, smell, and taste because of the compounds present in it. Alcohol people consume, alter the mood, and emotional state and affect normal body functions. The unpleasant aftereffects of drinking alcohol is called a hangover, which is caused by the breakdown of alcohol in the body. The four primary ingredients used in making beer include carbohydrates, hops, yeast, and water. The percentage of alcohol by volume in beer varies from 4 – 15 % and the water content is roughly 92 % (Fig. 1).

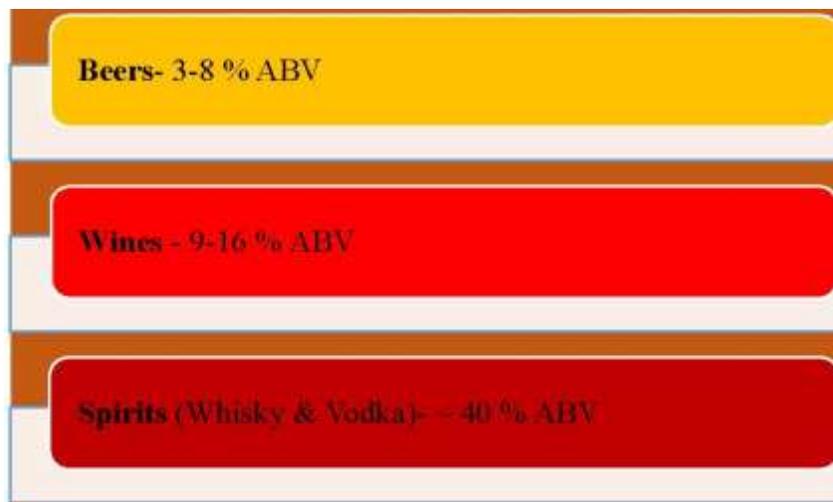


Fig.1. The three classes of alcoholic beverages typically contain 3-40% alcohol by volume (ABV)

The study of beer and beer-making is known as zythology. Cenosillicaphobia is the fear of an empty beer glass. The proof is a measure of the amount of alcohol in a beverage and is double

the percentage of alcohol. The world's largest beer festival is held annually in Munich, Germany. Its consumption is often considered to be a social evil in some countries because of the draining of physical, mental, and moral energies of human life. Thousands of people die every year worldwide from drinking and driving, leading to fatal accidents, and because of spurious liquor consumption. Some people are driving under the influence of alcohol, causing nearly 50 % of all vehicular accidents. This short-chain alcohol crosses the placenta in pregnant women and can cause mental retardation or physical defects in the baby. Excessive drinking increases the risk of cancer of the liver, mouth, esophagus, and larynx. Drinking alcohol while on medication can speed up the metabolism of certain drugs, reducing their intended effectiveness and sedative can become deadly.

Alcohol Anonymous (AA) is a self-help group for alcoholics trying to stop drinking. The beer cans take up a lot of landfill space on disposal that harms the environment. Pollution of effluent from breweries poses environmental problems, and hence it is crucial to reduce the biological oxygen demand (BOD) level of effluent as low as possible. The intent is to clear the brain fog and mist and decode the beer and alcohol jargon in just one article by presenting a fair, authentic, and very balanced perspective of beer-related chemistry and sharing relevant information on health-related consequences and capture current trends in a spirited manner. The content of the paper provides a fragrance of the crucial message of the right choice we make to the target audience. In a sense, it is a blend of basic and applied learning, while revisiting the story of beer brewing and the potentially life-threatening consequences of heavy drinking.

## **BEER BREWING PROCESSES**

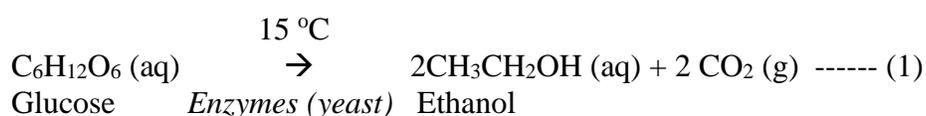
We have visited the Staropramen visitor center in Prague that provides an educational audiovisual exhibition leading to an informative experience for the visitor. Beer brewing is both a science and an art. The necessary ingredients involved in the beer brewing process involve barley, hops, water, and yeast. The process includes a series of steps, including malting, mashing, filtering, boiling, hops addition, cooling, fermentation, maturing, packaging and shipping. Initially, barley grain is soaked in water to germinate for about five days, dried at high temperature, and then milled to a suitable size in a roller mill or malt grinder to break the kernel of the barley and expose the endosperm.

The resulting flakes in this malting step are mixed with water in a mash mixer, and the mixture is heated to 35 to 45 °C to activate enzymes that convert the starch to sugar. During this stage of mashing, an enzymatic reaction occurs involving amylase that breaks down protein and starch into fermentable sugars. It is known as the wort, and the whole wort is now filtered to separate the insoluble spent grain. The clear liquid is boiled with hops in a brewing kettle to obtain flavor, aroma, and a characteristic bitter taste. Hops also act as a preservative, clarifying agent, and antiseptic for beer. It is further transferred to the whirlpool separator for the settling of solid particles. The resulting clear solution is cooled to 7 to 9 °C in a plate heat exchanger. Yeast is added to the sweet liquid in a fermentation vessel where the slow process takes place after 7-9 days, and sugar is converted into alcohol, carbon dioxide, and other products. Higher alcohols and esters generated as by-products add flavor to the product. Secondary fermentation at lower temperatures removes undesirable aldehydes and other by-products, yielding a less hazy product. The excess yeast is separated by filtration, and the resulting green beer is allowed to mature in a maturation tank. In the conditioning step, the beer ages and the flavor become smoother. Several

chemicals are added to enhance taste and quality, and the beer is finally filtered. Carbon dioxide is inserted in a carbonation process and is sent to a beer tank. It is bottled or canned and pasteurized at the 60 oC for 30 minutes to obtain the finished product ready for distribution and marketing. Today, it is a global and fiercely competitive business [3-6].

### PROFITABLE POINTERS

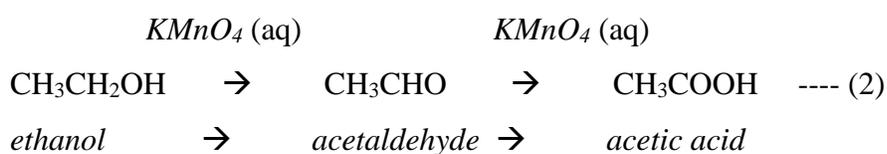
The chemical reactions can be slow, moderate, or fast. We should measure the amount of a reactant used per unit time or the amount of product produced per unit time to determine the reaction rate. The fermentation of sucrose is a slow process taking a few weeks, while the rusting of iron takes a few months. Rusting, photosynthesis, fermentation, and weathering of marbles by acid rain are slow reactions. In contrast, combustion, fireworks, precipitation of silver chloride, the reaction between reactive metal and water, and the reaction between hydrogen and oxygen are examples of faster reactions. Browning of cut fruits, food spoiling, baking a cake, and food digestion are examples of moderately fast reactions. Ethyl alcohol (ethanol) is produced biologically by the enzyme-catalyzed fermentation of carbohydrates (sugar or starch) (eq -1).



It is the active ingredient of alcoholic beverages such as beer, wine, and whiskey. It is used as a solvent in many organic reactions and raw material for the manufacture of many drugs, dyes, glues, explosives, and cosmetics. A blend of 90 % gasoline and 10 % ethanol, known as gasohol, is used as an alternative fuel [7]. The amount of heat evolved by burning ethanol is 30 KJ/g. Neat

ethanol acts as a disinfectant as it kills germs, and a surgical spirit is used to sterilize wounds. It also acts as a preservative and prohibits the growth of pathogens.

Ethanol is a liquid at room temperature because of strong hydrogen bonding between its molecules. Lower molar mass alcohols are water-soluble (completely miscible) because of intermolecular hydrogen bonding between water molecules and the – OH group of the alcohol. The increase in disorder after mixing plays a significant role in the formation of the solution. Methanol dissolves in glycerol because of the hydrogen bonding between methanol and glycerol molecules. The boiling point of ethanol (78.5 oC) is lower than that of water (100 °C) because ethanol has only one – OH hydrogen atom available for hydrogen bonding, whereas water has two. The solubility of the alcohol in water decreases as the length of the carbon chain increases, and the polar OH group becomes a smaller part of the molecule. Stepwise oxidation of primary alcohol form aldehydes, which are then oxidized to carboxylic acids (eq-2). The intermediate product, acetaldehyde, contributes to the toxic effects of alcoholism, as the same products are formed by the liver's enzymes in our body. This alcoholic beverage many induce symptoms of allergic rhinitis in some individuals.



## PLEASURES AND PROBLEMS

Alcohol is the most widely used non-medical sedative drug in the world and one of the most potent and addictive drug. Alcoholic drinks such as beer promote relaxation in moderate amounts, absorbed into the bloodstream, and quickly reach the brain. About 5 % is excreted unchanged in urine, sweat, and breath. The molecular mechanism of action is quite complicated,

and it is thought to affect many receptors and modify neuronal membranes. We get hydration from a glass of beer, but in more significant quantities, this becomes more dehydrating. Water, minerals, and vitamins are eliminated from the body, causing dehydration. It can be addictive when used in more than average doses as it alters the body chemistry. It can result in behavioral and emotional disorders and also result in physical health complications. These behavior transitions happen near-threshold points beyond which the body system will not be able to return to its original state, and suitable psychological and medical intervention is required. Alcohol abuse can lead to both suicides and homicides. Blood alcohol levels of 0.30 - 0.40 % by volume may lead to unconsciousness, and more than 0.5 % may be fatal. Alcohol metabolism in the liver disrupts the normal workings of glycolysis and the Krebs cycle. The cell fermentation builds up lactic acid, and blood becomes acidic, leading to liver deterioration and liver cirrhosis in extreme cases. It also interferes with neurotransmitter release or uptake in the brain. Alcohol intoxication is a significant cause of vehicle accidents, severe injuries, and death. Excessive use of alcohol is one of the cancer risk factors, especially of the throat, mouth, larynx, and esophagus. It can severely damage the liver, stomach, heart, nervous system, and brain. The life-threatening symptoms of alcohol poisoning include the inability to wake up, confusion, vomiting, slow or irregular breathing, hypothermia, and seizures. It is treated with benzodiazepines, such as chlordiazepoxide, lorazepam, diazepam, and naltrexone.

Beer can bring people or families together to sign business proposals and can cause couples to divorce, driving them apart. This drink inspired poetry, fiction, and non-fiction by many individuals and created many problems, including painful conditions, court battles that plagued our society. Though alcohol drinking is socially acceptable pleasures in many countries, alcohol dependence or abuse is quite common that impairs individual health, social relationships, job

efficiency, or judgment. It is entirely legalized in most countries, partly legalized in some others, while wholly banned in several countries. Alcohol abuse on university campuses is on the rise. The individuals who occasionally drink as part of community gatherings are called social drinkers. Regular drinkers within their limits as part of a group activity are known as social alcoholics. The habitual alcohol drinkers who cannot do without alcohol are categorized as alcoholics. Their communicative behavior pattern changes and have difficulty concentrating, solving a problem, and making decisions. This alcoholism can destroy careers, families, and individual health. Contamination of alcohol and methanol poisoning in illicit liquor is the leading cause of multiple accidental deaths due to its consumption. It is essential to raise awareness of the damaging effect of alcohol addiction on personal health, disorders due to psychoactive substance use, drinking and driving leading to accidents, and frame additional regulations to control the adverse effects of alcohol on the family and society.

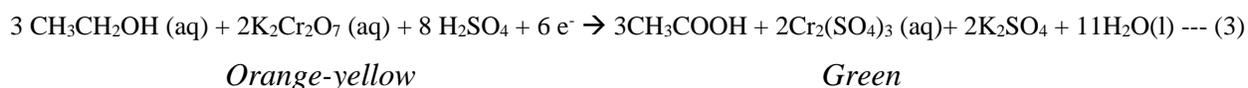
A crash course in alcohol addiction and rehabilitation from experts may assure and liberate, inspire and motivate several vulnerable individuals towards progress in modern nations. Capacity building through workshops, awareness programs, lecture sessions, campaign activities, and information brochures by facilitators can help us to control the current trend of the younger generation becoming alcohol addicts. The survey of beverage habits, family and microbreweries, socioeconomic conditions, and real-time monitoring to know consumption patterns would help us to identify the region-specific presence of alcoholism and find out long-term solutions to improve the present scenario and the quality of life. Proper planning and execution, meticulous observation, and time management are crucial in engaging individuals in constructive and creative activities. The family members should maintain a positive attitude towards alcoholics so that they can cope with the situation, and the beer consumption patterns are influenced by cultural factors as well.

The bottom line is that alcoholism is a global issue, and hence, it is imperative to take the world out of this cycle and put the wheel in the growth path to ensure a dignified life for all. The education and awareness of the entire population are essential for the progress of the whole world. It is essential to take care of workplace stress, stay healthy, and maintain our immune system's optimal functioning. It is essential to avoid alcohol while boating and before swimming. Taking aspirin before drinking alcohol increases alcohol absorption and reduces the activity of stomach enzymes that breaks down alcohol. Alcohol dependency therapies include individual treatment, medication to counter withdrawal reactions, group therapy sessions, detoxification, social support, psychotherapy, aversion therapy, and complete abstinence from alcohol. It is essential to concentrate on mindful creation, conscientious consumption, lower carbon footprints, less waste, and organic living. Multinational companies incorporating sustainability and corporate social responsibility into their DNA are standard now [8-10].

### **CHEMISTRY IN PRACTICE**

The breathalyzer test by the traffic police can detect the drinking and drive cases on the road, and it makes use of the oxidation of alcohol by dichromate ion. The breathalyzer device consists of orange crystals of sodium/potassium dichromate (VI) packed in a plastic tube that is connected to a plastic bag. When the person intoxicated blows through the device, exhaled ethyl alcohol ( $\text{CH}_3\text{CH}_2\text{OH}$ ) reacts with dichromate (VI) ion ( $\text{Cr}_2\text{O}_7^{2-}$ ) reducing them to the green  $\text{Cr}^{3+}$  ion [eq-3], under acidic conditions. From the color change, it is possible to determine the alcohol content present in the driver's breath, and the higher the intensity of the green color, the more alcohol the person has consumed. Measuring the level of alcohol in the blood using UV/visible or infrared spectroscopy, gas chromatography, and other electrochemical methods will help with the

quantitative determination of consuming the chemical drink. For instance, the absorbance of the resulting red color of the 1;1 complex that forms between low-molar-mass aliphatic alcohols and cerium (IV) can be used for the quantitative estimation of such alcohols. The infrared spectrum of alcohol has the characteristic broad absorption peak in the range 3650-2500 cm<sup>-1</sup> indicating the hydroxyl functional group's presence. Methanol is highly toxic, and adding methanol to ethanol as in illicit or spurious liquors can cause blindness (~ 10 mL) and death (~ 30 mL). Most of the low molar mass alcohols are highly flammable. The higher alcohols are less toxic, and their toxic effects reduce as the number of carbon atoms increases.



There are various types of alcohol, including primary (RCH<sub>2</sub>-OH), secondary (R<sub>2</sub>CH-OH), tertiary (R<sub>3</sub>C-OH), aliphatic, and aromatic alcohols that exhibit different chemical properties.

Table 1 lists some selected alcohols and their applications.

Table 1. Typical examples of some important alcohols in everyday life along with their formulas and applications

| <b>Name</b>                             | <b>Formula</b>  | <b>Use</b>  |
|---|---|---|
| Methanol {Methyl alcohol}               | CH <sub>3</sub> OH  | a common industrial solvent, gasoline additive                    |
| Isopropyl alcohol {2- propanol}         | CH <sub>3</sub> CH(OH)CH <sub>3</sub>   | rubbing alcohol, solvent  |
| Ethylene glycol {1,2-Ethanediol}        | CH <sub>2</sub> OHCH <sub>2</sub> OH  | antifreeze in car radiators, manufacture of some synthetic fibers |
| Glycerol {1,2,3-Propanetriol}           | CH <sub>2</sub> OHCHOHCH <sub>2</sub> OH  | Cosmetic preparations (creams & ointments), moisturizer in foods  |
| Phenol {Benzenol}                       | C <sub>6</sub> H <sub>5</sub> OH  | antiseptic, preparation of nylon, epoxy adhesives, and resins     |
| Decanol {1-Decanol}                     | CH <sub>3</sub> (CH <sub>2</sub> ) <sub>9</sub> OH  | manufacture of surfactants, lubricants, and plasticizers          |
| Thymol {5-Methyl-2-(propan-2-yl)phenol} | 2-[(CH <sub>3</sub> ) <sub>2</sub> CH]C <sub>6</sub> H <sub>3</sub> -5-(CH <sub>3</sub> )OH | dental varnish, flavoring agent                                   |

Biological applications of alcohol include many steroids present in the human body, such as cholesterol, estradiol, estrone, and testosterone, contain alcohol functional groups. If cholesterol is present in excessive amounts, it precipitates against the walls of arteries and veins, causing high blood pressure and other cardiovascular problems [11-13].

The aliphatic alcohols of six or more carbon atoms are known as higher alcohols finds applications in detergents, plasticizers, surfactants, cosmetics, pharmaceuticals, and automobile lubricants. Alcohols containing two hydroxyl groups per molecule are known as dihydric alcohols. Ethylene glycol, trimethylene glycol, and the 1,4-butanediol are industrially relevant glycols. Polyhydric alcohols are used in a wide variety of varnishes, coating, and paints. Resveratrol (3, 5, 4'-trihydroxy-trans-stilbene) is a type of natural phenol found in the skin of grapes, raspberries, blueberries, and mulberries. It is also present in red wines and is an antioxidant that helps to fight cell-damaging free radicals. Resorcinol is one of the primary natural phenol in argan oil, and it is an antiseptic and disinfectant used in the treatment of some chronic skin diseases.

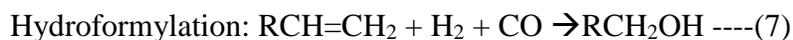
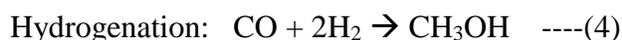
Ethanol is used to dissolve small quantities of sodium metal left after the purification of organic solvents as it reacts much more gently with the metal, unlike water. If the solution catches fire due to the presence of water, the addition of ethanol to destroy sodium would be like adding fuel to the fire that results in a flash fire [14]. To test for the  $-OH$  group in alcohols, we have to add a tiny piece of sodium metal to a neutral liquid free of water in a dry test tube and observe the bubbles of hydrogen (eq-19). The confirmatory test for the presence of an alcohol functional group is an esterification test in the systematic qualitative organic analysis (eq-14) [15]. When alcohol is treated with a carboxylic acid and an acid catalyst, an ester is formed. After taking the test substance in a dry test tube, add a few drops of concentrated  $H_2SO_4$  and glacial acetic acid. Warm

gently for 2-3 minutes, cool, and pour slowly into five mL of sodium carbonate to obtain the ester's fruity odor. The iodine oxidizes the alcohol to a methyl ketone to give a positive iodoform test. Iodine solution is added to a test solution followed by a sodium hydroxide solution and gently warm the mixture. The formation of the yellow precipitate of triiodomethane (iodoform- $\text{CHI}_3$ ) with a characteristic smell indicates the presence of either ethyl alcohol or secondary alcohols and tertiary alcohols do not give a positive iodoform test (eq-20). This test can distinguish methanol from ethanol, as the latter is the only primary alcohol to provide the iodoform reaction.

The structures of the compound with the same molecular formula  $\text{C}_2\text{H}_6\text{O}$  are different- $\text{CH}_3\text{CH}_2\text{OH}$  (Ethanol) and  $(\text{CH}_3)_2\text{O}$  (Dimethyl ether)-called constitutional/structural isomers. Both of these compounds are quite stable. Ethanol is a liquid, while dimethyl ether is a gas at room temperature. Ethyl alcohol is slightly intoxicating, while dimethyl ether is quite poisonous. There are three methyl protons, two methylene protons, and one hydroxyl proton in ethanol. The low resolution nuclear magnetic resonance (NMR) spectrum of ethyl alcohol exhibits three resonance signals with an intensity ratio of 1:2:3, indicating the three sets of nonequivalent protons which correspond to the number of protons in OH,  $\text{CH}_2$ , and  $\text{CH}_3$  in the molecule. The intermediate resolution NMR spectrum provides the fine structure consisting of a triplet, quadruplet, and a singlet due to  $\text{CH}_3$ ,  $\text{CH}_2$ , and OH proton bands, respectively. The high-resolution NMR reveals a splitting of the OH band into three signals from the spin-spin coupling of the  $\text{CH}_2$  protons, and further splitting of the four  $\text{CH}_2$  peaks into doublets due to spin-spin coupling with the OH proton. Thus the NMR technique can be used in the identification and structure elucidation of various types of alcohols.

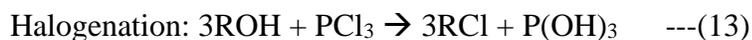
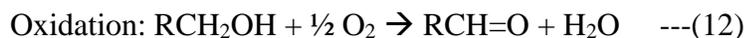
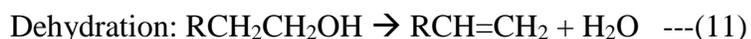
## SYNTHESIS OF ALCOHOLS

There are several methods used in the production of alcohols, as listed below [16]. Industrial sources of alcohol include hydration of alkenes (eq-5), the oxo process (hydroformylation) from alkenes (eq-7), and fermentation of carbohydrates (Sugar cane → Molasses → Sugars → Alcohol) (eq-10). Ethanol is made available to the chemical industry in a form unfit for human consumption by adding a denaturant such as methanol or acetone.



## CHEMICAL PROPERTIES

The reactions that alcohols undergo can be categorized into a few general types [17-20].



## **CONCLUSION AND PROSPECTS**

The strength of a robust network of breweries for local and global distribution and strong market position will help in expanding the market share for this alcoholic beverage, leading to substantial growth prospects. Preparing and dispensing in microbreweries has become a large business, and technological advancements will raise the bar for the entire beer industry. Growing beer market and changing consumer preferences provide excellent opportunities for growth in the beer industry. The message is to energize or uplift one's mood of the moment and feel the surge of power to open a realm of new possibilities.

There is the need to be in touch with the ground realities of alcohol consumption and take a sensible view to tackle global alcoholism with a human touch. It is important to remember that sometimes one's full quota of drinks cannot do what just a sip can achieve another time and exercise restraint of mind, body, and spirit that allows people to drink less or not at all and keep a sense of social responsibility. The public awareness about alcoholism and its personal and health effects on society helps us to prevent accidental injuries or death related to drunk driving and alcoholism.

The remedial measure of an explicit prohibition of alcohol is not practical. It can be controlled by the social awareness of the people towards the negative consequences of addiction to drinking. We have to fight alcohol abuse at the regional, national, and international levels by discouraging illegal production, distribution, purchase, and transit operations to have better living conditions and progressive nations. An approach consisting of a hefty dose of common sense, motivational messages, moderate drinking habits, planning, and timely action can go a long way toward transforming lives.

Observing and analyzing chemical phenomena enables a deeper understanding of neural activity and neural response patterns of alcohol consumption at multiple times during many windows of opportunity and offers a unique perspective on the complex human relationships involving good/lousy chemistry. It is essential to pay attention to the principle of “moderate drink or total delete” in the drinking habits or successful rehabilitation program. There are three stages in the recovery cycle, including the restriction stage when we ban all alcoholic beverages. Second, reintroduction stage when we reintroduce alcoholic drinks to see which ones suit us and which ones do not. The third stage of personalization involves monitoring the quantity and the type of alcoholic beverages our body can tolerate. As long as self-regulation is possible in drinking, it can provide some health benefits. Some areas of the brain that control judgment, reasoning, and instincts are being suppressed, after drinking alcohol. However, once the alcohol starts managing our lives, intense craving for it develops. Therefore, it is better to choose an alcohol-free life to avoid the adverse effects of alcohol.

The supplementary learning materials help in student development to evolve into a modern, independent, and distinctive individual with a self-regulating mechanism in academic practice. The broad objective is introducing learners to core issues and perspectives that will benefit them in creativity and innovation in their chosen area of specialization and impact reactions and thoughts for general learning. Fostering alcohol awareness in healthcare professionals during the education process via a specific and non-specific transfer will help broaden and deepen their chemistry knowledge, skill, and attitude to enable a better living experience. The approach offers a new perspective on the social and ecological impacts of present-day drinkers to move towards better practices. The most exciting aspect of the article is the role of alcohol in society, and it is more of an exploration of life in the 21st century.

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