9.12.3 Distilled Spirits

9.12.3.1 General[1-2]

The distilled spirits industry includes the production of whisky, gin, vodka, rum, and brandy. The production of brandy is discussed in AP-42 Section 9.12.2, "Wines and Brandy". Distilled spirits production also may include the production of secondary products such as distillers dried grains used for livestock feed and other feed/food components.

Distilled spirits, including grain spirits and neutral spirits, are produced throughout the United States.[1] The Bureau of Alcohol, Tobacco, and Firearms (BATF) has established "standards of identity" for distilled spirits products.[2]

9.12.3.2 Process Description[3-4]

Distilled spirits can be produced by a variety of processes. Typically, in whisky production, grains are mashed and fermented to produce an alcohol/water solution, that is distilled to concentrate the alcohol. For whiskies, the distilled product is aged to provide flavor, color, and aroma. This discussion will be limited to the production of Bourbon whisky. Figure 9.12.3-1 is a simple diagram of a typical whisky production process. Emission data are available only for the fermentation and aging steps of whisky production.

9.12.3.2.1 Grain Handling And Preparation -

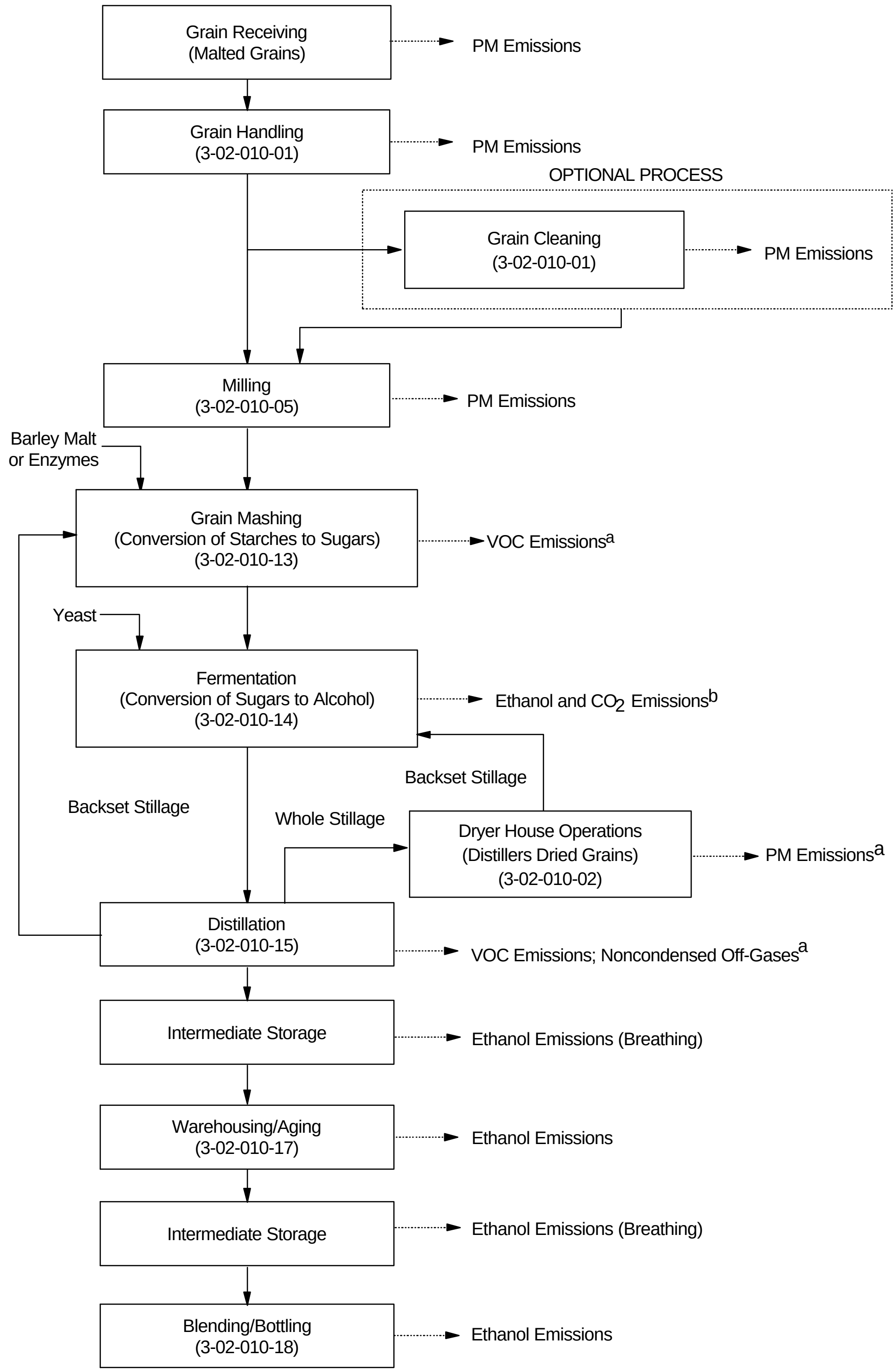
Distilleries utilize premium cereal grains, such as hybrid corn, rye, barley, and wheat, to produce the various types of whisky and other distilled spirits. Grain is received at a distillery from a grain-handling facility and is prepared for fermentation by milling or by malting (soaking the grains to induce germination). All U.S. distillers purchase malted grain instead of performing the malting process onsite.

9.12.3.2.2 Grain Mashing -

Mashing consists of cooking the grain to solubilize the starch from the kernels and to convert the soluble starch to grain sugars with barley malt and/or enzymes. Small quantities of malted barley are sometimes added prior to grain cooking. The mash then passes through a noncontact cooler to cool the converted mash prior to entering the fermenter.

9.12.3.2.3 Fermentation -

The converted mash enters the fermenter and is inoculated with yeast. The fermentation process, which usually lasts 3 to 5 days for whisky, uses yeast to convert the grain sugars into ethanol and carbon dioxide. Congeners are flavor compounds which are produced during fermentation as well as during the barrel aging process. The final fermented grain alcohol mixture, called "beer", is transferred to a "beer well" for holding. From the beer well, the beer passes through a preheater, where it is warmed by the alcohol vapors leaving the still, and then to the distillation unit. The beer still vapors condensed in the preheater generally are returned to the beer still as reflux.



[a] Processes require heat. Emissions generated (e.g., CO, CO_2, NO_x, SO_2, PM, and VOCs) will depend on the source of fuel.
[b] Other compounds can be generated in trace quantities during fermentation including ethyl acetate, fusel oil, furfural, acetaldehyde, sulfur dioxide, and hydrogen sulfide. Acetaldehyde is a hazardous air pollutant (HAP).

Figure 9.12.3-1. Whisky production process.
(Source Classification Codes in parentheses).

9.12.3.2.4 Distillation -

The distillation process separates and concentrates the alcohol from the fermented grain mash. Whisky stills are usually made of copper, especially in the rectifying section, although stainless steel may be used in some stills. Following distillation, the distilled alcohol spirits are pumped to stainless steel tanks and diluted with demineralized water to the desired alcohol concentration prior to filling into oak barrels and aging. Tennessee whisky utilizes a different process from Bourbon in that the distillate is passed through sugar maple charcoal in mellowing vats prior to dilution with demineralized water.

9.12.3.2.5 Grain And Liquid Stillage (“Dryer House Operations”) -

In most distilleries, after the removal of alcohol, still bottoms (called whole stillage), are pumped from the distillation column to a dryer house. Whole stillage may be sold, land applied (with permitting), sold as liquid feed, or processed and dried to produce distillers dried grains (DDG) and other secondary products. Solids in the whole stillage are separated using centrifuges or screens; the liquid portion (thin stillage) may be used as a backset or concentrated by vacuum evaporation. The concentrated liquid may be recombined with the solids or dried. Drying is typically accomplished using either steam-heated or flash dryers.

9.12.3.2.6 Warehousing/Aging -

Aging practices differ from distiller to distiller, and even for the same distiller. Variations in the aging process are integral to producing the characteristic taste of a particular brand of distilled spirit. The aging process, which typically ranges from 4 to 8 years or more, consists of storing the new whisky distillate in oak barrels to encourage chemical reactions and extractions between the whisky and the wood. The constituents of the barrel produce the whisky's characteristic color and distinctive flavor and aroma. White oak is used because it is one of the few woods that holds liquids while allowing breathing (gas exchange) through the wood. Federal law requires all Bourbon whisky to be aged in charred new white oak barrels.

The oak barrels and the barrel environment are key to producing distilled spirits of desired quality. The new whisky distillate undergoes many types of physical and chemical changes during the aging process that removes the harshness of the new distillate. As whisky ages, it extracts and reacts with constituents in the wood of the barrel, producing certain trace substances, called congeners, which give whisky its distinctive color, taste, and aroma.

Barrel environment is extremely critical in whisky aging and varies considerably by distillery, warehouse, and even location in the warehouse. Ambient atmospheric conditions, such as seasonal and diurnal variations in temperature and humidity, have a great affect on the aging process, causing changes in the equilibrium rate of extraction, rate of transfer by diffusion, and rate of reaction. As a result, distillers may expose the barrels to atmospheric conditions during certain months, promoting maturation through the selective opening of windows and doors and by other means.

Distillers often utilize various warehouse designs, including single- or multistory buildings constructed of metal, wood, brick, or masonry. Warehouses generally rely upon natural ambient temperature and humidity changes to drive the aging process. In a few warehouses, temperature is adjusted during the winter. However, whisky warehouses do not have the capability to control humidity, which varies with natural climate conditions.

9.12.3.2.7 Blending/Bottling -

Once the whisky has completed its desired aging period, it is transferred from the barrels into tanks and reduced in proof to the desired final alcohol concentration by adding demineralized water.

Following a filtration process that renders it free of any solids, the whisky is pumped to a tank in the bottling house, bottled, and readied for shipment to the distributors.

9.12.3.3 Emissions And Controls[3-6]

9.12.3.3.1 Emissions -

The principal emissions from whisky production are volatile organic compounds (VOCs), principally ethanol, and occur primarily during the aging/warehousing stage. In addition to ethanol, other volatile compounds, including acetaldehyde (a HAP), ethyl acetate, glycerol, fusel oil, and furfural, may be produced in trace amounts during aging. A comparatively small source of ethanol emissions may result from the fermentation stage. Smaller quantities of ethyl acetate, isobutyl alcohol, and isoamyl alcohol are generated as well; carbon dioxide is also produced during fermentation. Particulate matter (PM) emissions are generated by the grain receiving, handling, drying, and cleaning processes and are discussed in more detail in AP-42 Section 9.9.1, Grain Elevators and Processes. Other emissions, including SO_2, CO_2, CO, NO_x, and PM may be generated by fuel combustion from power production facilities located at most distilled spirits plant.

Ethanol and water vapor emissions result from the breathing phenomenon of the oak barrels during the aging process. This phenomenon of wood acting as a semipermeable membrane is complex and not well understood. The emissions from evaporation from the barrel during aging are not constant. During the first 6 to 18 months, the evaporation rate from a new barrel is low because the wood must become saturated (known as "soakage") before evaporation occurs. After saturation, the evaporation rate is greatest, but then decreases as evaporation lowers the liquid level in the barrel. The lower liquid level decreases the surface area of the liquid in contact with the wood and thus reduces the surface area subject to evaporation. The rate of extraction of wood constituents, transfer, and reaction depend upon ambient conditions, such as temperature and humidity, and the concentrations of the various whisky constituents. Higher temperatures increase the rate of extraction, transfer by diffusion, and reaction. Diurnal and seasonal temperature changes cause convection currents in the liquid. The rate of diffusion will depend upon the differences in concentrations of constituents in the wood, liquid, and air blanketing the barrel. The rates of reaction will increase or decrease with the concentration of constituents. The equilibrium concentrations of the various whisky components depend upon the humidity and air flow around the barrel.

Minor emissions are generated when the whisky is drained from the barrels for blending and bottling. Residual whisky remains in the used barrels both as a surface film ("heel") and within the wood ("soakage"). For economic reasons, many distillers attempt to recover as much residual whisky as possible by methods such as rinsing the barrel with water and vacuuming. Generally, barrels are refilled and reentered into the aging process for other distilled spirits at the particular distiller or sealed with a closure (bung) and shipped offsite for reuse with other distilled spirits. Emissions may also be generated during blending and bottle filling, but no data are available.

9.12.3.3.2 Controls -

With the exception of devices for controlling PM emissions, there are very few emission controls at distilleries. Grain handling and processing emissions are controlled through the use of cyclones, baghouses, and other PM control devices (see AP-42 Section 9.9.1). There are currently no current control technologies for VOC emissions from fermenters because the significant amount of grain solids that would be carried out of the fermenters by air entrainment could quickly render systems, such as carbon adsorption, inoperable. Add-on air pollution control devices for whisky aging warehouses are not used because of potential adverse impact on product quality. Distillers ensure that barrel construction is of high quality to minimize leakage, thus reducing ethanol emissions. Ethanol recovery would require the use of a collection system to capture gaseous emissions in the warehouse and to process the gases through a recovery system prior to venting them to the atmosphere.

9.12.3.3.3 Emission Factors -

Table 9.12.3-1 provides uncontrolled emission factors for emissions of VOCs from fermentation vats and for emissions of ethanol from aging due to evaporation. Because ethanol is the principal VOC emission from aging, the ethanol emissions factors are reasonable estimates of VOC emissions for these processes. Emission factors for grain receiving, handling, and cleaning may be found in AP-42 Section 9.9.1, Grain Elevators and Processes. Emission factors are unavailable for grain mashing, distillation, blending/bottling, and spent grain drying. An emission factor for carbon dioxide from fermentation vats is also unavailable, although carbon dioxide and ethanol are theoretically generated in equal molecular quantities during the fermentation process.

Table 9.12.3-1. EMISSION FACTORS FOR DISTILLED SPIRITS[a]

EMISSION FACTOR RATING: E

Source[b]	Ethanol	Ethyl acetate	Isoamyl Alcohol	Isobutyl Alcohol
Grain mashing (SCC 3-02-010-13)	NA	NA	NA	NA
Fermentation vats (SCC 3-02-010-14)	14.2[c]	0.046[c]	0.013[c]	0.004[c]
Distillation (SCC 3-02-010-15)	ND	ND	ND	ND
Aging (SCC 3-02-010-17)				
- Evaporation loss[d]	6.9[e]	ND	ND	ND
Blending/bottling (SCC 3-02-010-18)	ND	ND	ND	ND
Dryer house operations (SCC 3-02-010-02)	ND	ND	ND	ND

[a] Factors represent uncontrolled emissions. SCC = Source Classification Code. ND = no data available. To convert from lb to kg, divide by 2.2. NA = not applicable.
[b] Emission factors for grain receiving, handling, and cleaning processes are available in AP-42 Section 9.9.1, Grain Elevators and Processes.
[c] Reference 5 (paper). In units of pounds per 1,000 bushels of grain input.
[d] Evaporation losses during whisky aging do not include losses due to soakage.
[e] References 6-7. In units of lb/bbl/yr; barrels have a capacity of approximately 53 gallons.

Recognizing that aging practices may differ from distiller to distiller, and even for different products of the same distiller, a method may be used to estimate total ethanol emissions from barrels during aging. An ethanol emission factor for aging (total loss emission factor) can be calculated based on annual emissions per barrel in proof gallons (PG). The term “proof gallon” refers to a U.S. gallon of proof spirits, or the alcoholic equivalent thereof, containing 50 percent of ethyl alcohol (ethanol) by volume. This calculation method is derived from the gauging of product and measures the difference in the amount of product when the barrel was filled and when the barrel was emptied. Fugitive evaporative emissions, however, are not the sole difference between these two amounts. During the aging period, product soaks into the barrel, test samples are drawn, and other losses (e. g., spillage, leakage) may occur. Estimates of ethanol loss due to evaporation during aging based only on the gauging of product will produce an overestimate unless soakage and sampling losses (very small losses) are subtracted. The emission factor for evaporation loss in Table 9.12.3-1 represents an overestimate because only data for soakage losses could be calculated; data for other losses were not available.

References for Section 9.12.3

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