and the fermentation slow. In most, however, the temperature is allowed to advance about twenty degrees in the first twenty hours. The temperature is never permitted, however, to exceed 90° F. Since the distillers’ yeast is very active, a sweet rye fermentation, for example, is usually complete in 72 hours.

It is observed that high and rapid fermentations on the one hand are more likely to exhaust the sugar in the wort, but on the other hand, it is claimed that they are responsible for the formation of larger amounts of the congeneric substances including esters, fusel oil and aldehydes.

Aeration.—Some form of aeration is necessary both before and during fermentation. It may vary from the simple raising of buckets full of wort and pouring them back, to elaborate perforated pipe and air pump assemblies. The results of aeration and the objects of the practice include: 1. thorough stirring and intermingling of wort and yeast, 2. maintenance of uniformity of temperature throughout the vat, 3. expulsion of carbon dioxide from the wort, 4. stimulation of yeast in vigor and multiplication, 5. flocculation of suspended matter.

Distillation.—On the conclusion of the fermentation, the liquor, now called “wash,” is ready for distillation. In Scotch pot still practice two distillations are required for preparing whiskey from the wash. The first takes place in the wash still. The distillation is continued until all the alcohol has been driven off from the wash and collected in one distillate. The liquor remaining in the still is termed “pot ale” or “burnt ale”; and is either run to waste or dried for fertilizer. The distillate, which is technically termed “low wines,” contains all the alcohol and secondary constituents from the wash, and considerable water. The low wines are transferred to a second and smaller still and are redistilled. Three fractions are obtained from this distillation. The first is termed “foreshots,” the second constitutes the clean or finished whiskey, the third is called “feints.” The foreshots and feints are collected together, while the residue in the still, called “spent lees” is run to waste like the pot ale.

The judgment and experience of the distiller determine the point at which the collection of foreshots is stopped, and that of
whiskey commenced, and similarly that at which the latter is stopped and the collection of feints begun.

The strength at which the whiskey fraction is run is of great importance as regards the character of the spirit. In Scotland this is generally from about 11 to 25 degrees over proof (11–25° o.p.).

The foreshots and feints from one distillation are mixed and added to the charge of low wines for the next distillation and so throughout the distilling season. The feints collected from the last distillation of the season are kept to be added to the low wines from the first distillation of the succeeding season.

In some distilleries in Scotland the whiskey is produced in three distillations. This practice is very general in the Low-lands; the spirit being then run at 40 to 45 degrees over proof.

The volatile secondary constituents, which pass over with the alcohol into the low wines receiver, on the distillation of the wash, are thus incorporated as far as possible with the finished whiskey finally produced. There can be no doubt, however, that a portion escapes with the spent lees since it is known that partial decomposition is undergone during the process of distillation, e.g., certain esters are easily decomposed when boiled with water under such conditions as those which obtain during distillation in the wash or low wines stills and the products of decomposition may wholly or partially remain in the spent lees and may consequently be absent from the whiskey.

Again, some of the constituents which boil at much higher temperatures than water, may not wholly pass over with the alcohol in the distillation of the low wines, but may remain in the spent lees, and so also be lost to the finished whiskey.

The extent to which the loss of secondary constituents may thus occur and affect the character of the whiskey depends largely upon the variety of pot still employed, and the manner of its operation; whether, for instance, the process of distillation be carried on slowly or rapidly; and it also depends on the strength at which the whiskey fraction is run.

In Irish pot still practice the stills employed differ somewhat from those used in Scotland in that they are generally much
larger, the wash still occasionally being of a capacity of 20,000 gallons. The head of the still is shorter and in the still used for the distillation of low wines and feints the pipe connecting the head of the still with the worm is of considerable length and passes through a trough of water, the result being that a certain amount of rectification of the spirit vapor is effected on its way to the worm. This pipe is termed the "Lyne arm" and is connected with the body of the still by what is known as a "return pipe" through which is conveyed to the still for redistillation any liquid which has condensed in the pipe.

Three distillations appear to be universally practiced in Ireland for obtaining pot still whiskey and the method of collecting various fractions during a distillation is somewhat more complicated than with the Scotch process. Strong low wines and weak low wines, strong feints and weak feints, are collected and blended in various orders, and the practices in this connection probably differ in every Irish distillery. The whiskey fraction is usually run at a higher strength than in the Scotch process, viz; from 25–50 per cent o.p.

The addition of charcoal and also of soap in distillation is common both in Ireland and in Scotland, the soap being used to prevent frothing in the wash still and the charcoal in the low wines still to remove undesired constituents by absorption.

The differences between Scotch High and Lowland and Irish practices in pot distillation are readily seen from the flow diagrams (Fig. 24).

British Patent Still Whiskey.—General Statement.—It is claimed for patent still operation in preference to pot still operation that various economies are achieved as follows:

1. Economy of time:
   a. Operation is continuous and rate of distillation is greater. There is a continuous feed of wash and a continuous discharge of spent wash, as compared with shut downs to charge and discharge in pot still practice.
   b. Rectification and distillation are carried out as part of the one process, whereas in pot still practice rectification is only partially achieved in one distillation, and two or even three distillations are necessary for complete rectification.
WHISKEY MANUFACTURE

IRISH

Wash 20,000 gallons

Wash Still

Waste or fertilizer

Weak Low Wines 40,000 gal.

Strong Pot Ale

Low Wines

Spent fees to waste

SCOTCH LOWLAND

Wash 10,000 gallons

Wash Still

Waste of Pot Ale

Low Wines

Spent fees to 2000 gal.

Strong Wines

Waste or fertilizer

SCOTCH HIGHLAND

Wash 10,000 gallons

Wash Still

Low Wines 3000-5000 gal.

Low Wines 60-70% u.p.

Spent fees to waste 1500-2000 gal.

Stills

Middle Feints 12-20% o.p.

Middle Spirit 45-50% o.p.

Middle Feints 5-10% o.p.

Strong Foreshots & tailings 60-70% u.p.

Strong Feints 5-10% o.p.

Middle Feints 45-50% o.p.

Fig. 24
c. Only one condensation of the distillates is necessary, with cooling from a maximum temperature of 150° F. down to 60° or 70° F., as compared with pot still practice in which two or three condensations are necessary.
d. Operation can be carried on throughout the year.

2. Economy of operation:
a. Less cooling water required for condensing vapors to distillates.
b. Cold wash is used to condense vapors to distillate, and the latent and sensible heats of the vapors and of the distillate serve to preheat the wash and raise it almost to its boiling point. This results in large fuel savings for primary heating.

3. Efficiency of operation:
a. Pure grain alcohol for use in the arts can be made as well as alcohol for denaturing.
b. A highly rectified whiskey can be produced.
c. Distillate is 148 to 154% proof.
d. Strength of distillate can be practically constant despite wide variations in strength of wash.

4. Miscellaneous:
a. A greater variety of materials can be used and from practically all sources of supply so that advantage can be taken of temporary low prices.
b. Yeast can be made as a by-product.

On the other hand, the elimination of secondary products contained in the fermented wash is 95 per cent for the patent still as compared to only 90 per cent for the pot still. Hence many old time Irish and Scotch whiskey makers claim that it is the presence of some of these secondary products in the distillate which determines that their product is whiskey and not merely “neutral spirit”; i.e., flavorless, pure grain alcohol.

The Scotch and Irish pot distillers claim that over a period of many years they built up a world-wide reputation for a beverage called “whiskey” to obtain which it is necessary to distill a wash, obtained from certain raw materials, in a pot still according to certain methods developed by long years of practical research and experimentation. They claim that no patent still spirit, however dosed with flavors, can duplicate the quality and flavor of their product.
Preparation of Wort.—In harmony with greater efficiency in the distillation, patent still operators have introduced modifications in the method of saccharification of their cereal grains, usually by some application of the "acid-conversion" process. This process has as its object partial conversion of the starch of the grains into fermentable sugars by the use of acid rather than the diastase of malt and depends on the latter only for the final completion of the conversion.

The general principles underlying this operation have been discussed in Chapter I on Starch. In practice small amounts of either sulphuric or hydrochloric (muriatic) acid are added to the mixture of ground grain and water, heat is applied until the action has proceeded to a sufficient extent and then the acid is neutralized. The procedure consists in mixing in a tun about 36 gallons of water per cwt. of ground cereal or grist. About 1–1.5 pounds of 60° B. sulphuric acid (oil of vitriol) suitably diluted (by pouring the acid into the water—never the reverse) is added for each cwt. of grist. Agitation is applied, and steam injected so that the temperature rises gradually. Care must be taken that the heating is neither too high nor too prolonged. When the starch has been gelatinized and the whole converted to a thin liquid the action is stopped by neutralizing the acid. Ordinarily milk of lime (a suspension of slaked lime in water) is used to accomplish most of the neutralization and the rest effected to a very faint acid reaction by the gradual addition of powdered chalk. At the optimum condition of acidity cold water is added to cool the batch to about 145° F.

The batch is then discharged into the mash tun in which some malt at a temperature of 125°–130° F. has been previously prepared. The temperature of the whole mash after mixing should be about 138° F.

There are various modifications of this acid conversion process in which small amounts of malt are added at different stages to supplement the action of the acid. Three such variations are shown diagrammatically in Figure 25.

It will be noted from Figure 25 that the first modification represents the acid conversion process exactly as described pre-
FIG. 25.
viously. In the second modification a small portion of malt is added immediately to the ground cereal which is steeped in tepid water. Heat by steam injection is carefully applied so that the rate of temperature rise is very closely 1° F. per minute. The acid is only added when the batch has heated up to 165°-170° F. and the cooking is then continued as previously. In the third modification it is customary to use more water (50 gal. per cwt.) and less acid (½ lb. per cwt.). The cooking follows the usual procedure except that a small portion of malt is added to the acid mash as a final step before it is poured into the main malt mash. In each case three extractions on a sort of counter-current system are used as in the all malt process.

Fermentation.—While equipment in a patent still distillery may be both larger and more elaborate, the process of fermentation is practically identical with that described under pot still whiskey (p. 104).

Distillation.—The operation of a patent still in the British Isles is in all respects as described in Chapter VIII and on page 126 of this Chapter under American Practice. The wash or beer is fed continuously from a storage tank or well through a heater, in which it absorbs heat from the ascending spirit vapors, into a distilling column consisting of perforated plates. Steam is fed at the bottom of the still causing evaporation of alcohol from the wash. By regulation of:

1. Rate of beer inflow
2. Point of beer entry
3. Steam input
4. Amount of condensed vapor returned to column (reflux)
5. Point of reflux entry

a dynamic equilibrium is established within the still. That is, the temperature and concentration of liquid at each point of the still remain constant even though there is continuous counter-current flow of liquid and vapor past the plates. Hence, it becomes possible to discharge from the still bottom a spent slop containing less than 1 per cent of its original alcohol and to recover over 90 per cent of the alcohol as whiskey of 50-75 per cent o.p. and
of almost any desired content of the “congeneric substances” on which the flavor and odor depend.

Operation and Yield.—Netleton ("The Manufacture of Whiskey and Plain Spirit," Aberdeen, 1913) cites records of various distilling operations at pot and patent still distilleries from which the following have been abstracted for comparison:

Lowland Pot Still Distillery—All Malt

Equipment:
- 2 wash stills, each 6,200 gallons capacity
- 2 low wines stills, each 3,800 gallons capacity

Batch:
- 2,600 bushels of malt—835 cwt. malt

Wash:
- 54,100 gallons
- 4 consecutive mashings at 7 to 9 hour intervals

Yield:
- 5,104 British proof gallons or 6 1/10 gal. per cwt.

Small Lowland Pot Still Distillery—All Malt

Batch:
- 1,000 bushels of malt

Wash:
- 20,900 gallons

Yield:
- 1,979 British proof gallons or 6.16 gallons per cwt. (with a high class malt, skilfully manipulated, yield should be 7 to 7 3/4 gallons per cwt.)

Highland Pot Still Distillery—All Malt

Equipment:
- 1 wash still, 8,500 gallons capacity
- 1 low wines still, 4,500 gallons capacity

Batch:
- 1,800 bushels of malt—659 cwt.
Wash:
37,730 gallons
4 successive mashings at 7 hour intervals

Yield:
4,370 British proof gallons or 6\%\frac{1}{3} gallons per cwt.

PATENT STILL DISTILLERY

Batch:
6,080 bushels of corn and malt—3,052 cwt.
(5,168 bushels of corn)
(912 bushels of malt)

Wash:
216,500 gallons

Yield:
16,542 gallons of British proof spirit or 5.4 gallons per cwt.

Reduction in bulk, in one continuous operation, from 216,500 gallons of wash to 9,930 gallons of spirit, or of 100 gallons of wash to 4.5 gallons of spirit. The wash had an average spirit value of 7.8% of proof spirit and the spirit produced an average spirit value of 165.2% or 65.2% o.p. The relative quantities of spirit and feints in the collected distillates were in the ratio of 100 proof gallons of spirit to 2.7 proof gallons of feints (16,409.9 actual to 444.6 actual). In bulk, the ratio was 100 gallons of spirit to 5.7 gallons of feints.

PATENT STILL DISTILLERY

Batch:
10,500 bushels of corn and malt—5,089 cwt.
(3,000 bushels of malt)
(7,500 bushels of corn)

Wash:
500,000 gallons wort
50,000 gallons yeast washings

Yield:
31,068.1 proof gallons or 6.1 proof gallons per cwt.

Rate of distillation:
2 Coffey stills operating 32 hours; rate per hour—17,187 gallons

Reduction in bulk in one continuous distillation was 550,000 gallons (original wort, with yeast pressings, etc., recovered) reduced to 18,615
gallons of spirit and feints, or in the ratio of 100 wash to 3.38 spirit and feints. The wash had an average spirit value of 6.3 per cent proof spirit, and the spirit and feints one of 166.9 per cent proof (83.5 per cent by volume).

The relative quantities of spirit and feints collected as distillates were 31,045.3 and 826.2 proof gallons; or in a ratio of 100 spirit to 2.6 feints. The ratio of bulk was 100 spirit to 2.9 feints.

In considering yield figures it should always be borne in mind that yield does not wholly depend on efficiency of distillation. The quality of grain varies from year to year and though the distiller may pay more for his grain in one particular year it is quite possible that the yield per cwt. will be less than in the preceding year. This reduced yield is due to inferior grain and the rise in prices to economic factors.

**American Whiskey.**—*General Statement.*—While the practice of whiskey manufacture in the United States varies quite definitely from British practice, it is also divided within itself into two general schemes. The divergences from British practice are mainly in the method of preparing the grain before the actual mashing (saccharification of the starch); in the general custom of fermenting the whole mash rather than filtered wort; and in the almost universal employment of patent stills. Within itself American whiskey making may be classified as small scale and large scale. There are definite differences of procedure and not merely size of operation which distinguish the two groups.

**Preparation of Wort.**—Small Scale.—Not only is starch a highly resistant material, but in cereal grains it is present in such highly compressed masses that some variety of treatment is necessary to loosen and spread it thinner before it is possible to convert it to sugars with any degree of efficiency. In the British Isles this object is accomplished either by subjecting the entire batch of grain to the malting process or else by the use of one or another modification of the acid conversion process. In the United States, where mixed mash whiskey is made, the starch is "opened up" or "pastified" by boiling with water, with or without the addition of a small portion of malt. In "small scale" operation this cooking is done at atmospheric pressure. The grain is ground to grist,
a portion of dry or green malt grist is added, hot water is poured on in the ratio of 20 gallons per 56 lb. bushel of grist, and heat (steam) and agitation applied until the starch is "pastified." While the primary object of the process is "pastification," the addition of malt undoubtedly causes a slight amount of saccharification to occur simultaneously. It is usual to start the cooking at about 140° F. Live steam is then run into the open tank until the batch boils. Boiling continues for about one hour and then the batch is cooled to about 150° F. and the mashing commenced by the addition of a suitable quantity of malt. Generally, in a small distillery of this character, an open tank equipped with agitator, live steam, and cooling coils is employed for the starch pastification and the mashing is carried in the same vessel. Usually the malt, when introduced into the mashing vat, is at a temperature of 125°-130° F. so that the batch after mixing will have a temperature of about 140° F. The mash is held at this temperature for a half hour or so and then warmed to about 150° F. After being held at this temperature for about one and a half hours it is cooled to about 66° F. in the summer or 72° F. in the winter.

_Fermentation._—The batch is then ready to commence the fermentation. While it is possible to commence fermentation at a somewhat higher temperature than those stated, it is also dangerous as the reaction may overheat beyond control.

It has been suggested that the process just outlined may be modified in the interest of malt economy, as follows: The mixed mash is started at 135° F. and after thorough agitation, most of the wort is drained off and stored temporarily. In the while, the wet grain is again raised to boiling temperature and boiled for a short time. Cold liquor is then added to reduce the temperature to 140° F. and the stored wort pumped back and thoroughly mixed with the balance of the mash. The subsequent procedure is as above. This modified process was designed to permit a second pastification of such starch as was uncooked in the first operation and provides no advantage if the first cooking was sufficiently thorough.
Distillation.—Practically all American whiskey is distilled in patent stills by the process described in detail for large scale distillation.

**LARGE SCALE OPERATION**

The manufacture of whiskey on a large scale in the United States represents the application to this process of all the improvements in efficiency and economy of time and materials made available by modern Chemical Engineering knowledge. A distillery includes units for milling; yeast production; whiskey, spirits and gin manufacture; recovery of secondary constituents; blending; and reduction and recovery of slop. A diagrammatic layout is shown as a whole in Figure 26 and the separate parts in Figures 27-31.

**Milling.**—The first operation at the distillery is the preparation of the grain and malt. These are elevated to hoppers and passed over magnetic separators to remove tramp iron, etc., which might injure the crushers. The cereals are then fed to grinders of the type commonly used for flour milling, and reduced to meal. The separate meals are then elevated to receivers and hoppers by means of air conveyors, and fed to their respective storage bins.

**Cooking.**—Starch is completely pastified by cooking under pressure. In order to maintain semi-continuous operation this is accomplished in three cookers used cyclically at intervals of an hour. That is, cooking of each distinct batch consumes three hours, but each hour another cooker in rotation has completed its batch and commences with a fresh one. A scheme of this operation is shown in Figure 32, p. 125.

The charge is usually made up on the proportion of 15–20 gallons of water at 100° F. per bushel of grist. In the mash tun more water or “slop-back” is added until the ratio is about 40 gallons per bushel. It will be noted that economy of steam is obtained by using the high pressure steam from one cooker to pre-heat another. Similarly, the use of a barometric condenser serves to economize on cooling water. When the charge is properly
GRAIN STORAGE  MILLING

Fig. 27.—(Courtesy E. B. Badger & Sons Co.)
MASHING

YEASTING & FERMENTING

FIG. 28.—(Courtesy of E. B. Badger & Sons Co.)
Fig. 29.—(Courtesy E. B. Badger & Sons Co.)
BARRELING & BOTTLING

Fig. 31.—(Courtesy E. B. Badger & Sons Co.)
FIG. 32.—(Courtesy E. B. Badger & Sons Co.)
### Time Scale

<table>
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<tr>
<th>Time</th>
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<tr>
<td>0 Hour</td>
<td>Charge with grist and water. Steam bled from No. 2 cooker. Live steam at 50 lb. pressure.</td>
<td>1 Hour</td>
<td>Steam bled to No. 3 cooker. Steam bled to barometric condenser. Kept boiling until cooled to 150°F. 22&quot; vacuum.</td>
<td>2 Hour</td>
<td>Cold malt mash added. Kept at 145°F. for 1st 15 min. 150°F. for 2nd 15 min. Discharge to mash tun.</td>
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**Figure 33.—3-Hour Cooking Cycle in Large American Distillery.**