The search for higher output

The role of Continuous Distillation in spirit production

In Scotland during the 1820s, malt whisky was produced in direct-fired pot stills, typically with a capacity of about 2,250 litres. Grain whisky, produced from a mixture of malt and unmaltered cereal, was distilled in the Lowlands and sold as a cheaper product and also exported to England for further rectification. The Lowland distillers also used pot stills though these were of greater capacity than those of the malt distillers. Dissatisfaction in the Lowlands with this slow, batch and labour-intensive process led to the quest for improved methods of distillation and between 1826 and 1832 different types of continuous still were investigated. The aim was to increase a distillery's daily output.

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lthough the concept of the continuous still is simply a series of progressive distillations, the early continuous stills were complex pieces of plant. Even eighty years after their introduction, James Power, one of Dublin's famous distillers, described the continuous still, sometimes known as the Patent still, as a 'box of tricks'.

In 1826, Robert Stein patented the first continuous still and installed one in his distillery at Kilbagie in Central Scotland. Shortly afterwards he installed another at Cameronbridge Distillery for his cousin, John Haig, a well known name in whisky history. However, as you can see in Figure 1, the Stein still was extremely complicated; wash, dispersed as a fine mist, was mixed with steam and the increasingly enriched vapour passed through a series of chambers separated by cloth diaphragms. Only four Stein stills were operated and they were superseded by an altogether different design, which came from a rather unlikely source.

The Coffey Still

Aeneas Coffey was an Irishman born in Dublin in 1780 and after schooling he began a career in Customs and Excise. He was obviously bright and by 1819 had risen to the post of Inspector General of Irish Excise. However, five years later he left the Excise and bought the Dock Distillery in Dublin. Despite his lack of engineering training it was Coffey who designed and patented a superior continuous still in 1830 capable of processing almost 14,000 litres of wash per hour. When the Irish economy took a turn for the worse in the mid-1830s, Coffey moved his design business to London and promoted his Patent Still with great success. By 1860 there were twenty eight of his stills in use in Britain.

The success of the Coffey still was based upon its greater output, the use of steam instead of solid fuel, the consequent reduction in production costs and the fact that it made a stronger and blander spirit. The development of blended whisky in 1860 by Andrew Usher provided a further boost as this increased the demand for grain whisky dramatically. Continuously distilled grain whisky became the major component of blended whisky, which was established as an international drink by the turn of the nineteenth century.

The first version of the Coffey still (Figure 2) relied entirely on gravity with steam and wash in counter current flow. In later versions (Figure 3) pumps were introduced and the column was divided into two units. The early still structures were wooden with copper trays and pipework, and it is probably the use of wood which accounts for their rectangular shape – though copper eventually replaced wood as the material of construction.

The Coffey still, which became so popular, consisted of two columns, known as the analyser and the rectifier (theoretically they could be placed on top of each other but this would create a rather high structure). Such stills (Figure 4) continue in use today making grain whisky in Scotland.

The two feeds into the still are wash, currently a fermented wort of 8% ABV prepared from 10% malt and 90% wheat, entering the top of the rectifier and steam entering the base of the analyser. The stills are divided into a number of sections, separated by perforated trays and in each of these we have counter-current flows of liquid and vapour. Typically, the analyser would have about 28 and the rectifier about 40 trays.

The wash flows down the rectifier in a copper tube, which winds its way between the trays and moves from one section to another via bends protruding from the still.

As it descends the rectifier the wash temperature rises because it contacts hot vapour from the analyser, and by the time it reaches the bottom the temperature is about 94°C, the boiling point of an 8% alcohol/water mixture. It is then directed to the top of the analyser and flows out of the pipe on to the top tray. The liquid passes from tray to tray down the column via a series of weirs and pipes and as it crosses each tray it meets vapour forcing itself upwards through the perforations. Gradually the wash is stripped of its more volatile components as it descends and conversely the vapour becomes richer in alcohol and volatile congeners as it rises. Spent wash emerging from the base of the analyser will contain no more than 0.05% alcohol.

The alcohol-rich vapour at 30–40%ABV enters...
the bottom of the rectifier and rises through the trays heating the descending wash pipe. The vapour is progressively condensed as it rises, providing the downdown of liquid, and on each tray the conditions approach the equilibrium state for vapour and liquid at a particular temperature. This can be visualised as a series of batch distillations progressing up the rectifier with increasing concentrations of ethanol and the more volatile components at each higher tray. This is shown in Figure 5; when the vapour enters the liquid above it, which is at a slightly lower temperature, some of its less volatile components condense, so the vapour which passes through becomes richer in the more volatile components. Simultaneously, the release of the latent heat of this condensation causes the more volatile components in the liquid to vapourise, thus stripping the liquid as it descends from tray to tray.

As you may imagine, the vapour pressure in the still is critical for it must allow the vapour to bubble into the liquid through the tray perforations, while preventing the liquid from falling through them. So the design and operation of the perforated tray is a complex balance. Weeping through the perforations occurs when the vapour pressure is insufficient to maintain a level of liquid on the plate. Entrainment occurs with high vapour-flow rates when liquid can be carried upwards to the higher tray. The simplest system is the sieve tray, basically a plate containing a large number of round holes with diameters of about 1 mm. Sieves are cheap to make but are prone to liquid weepage at low vapour flows. Another option is the bubble cap tray; here the perforations have risers, which ensure that a level of liquid is maintained on the tray at all vapour-flow rates. The vapour passes up the risers, which are covered with a cap, and bubbles out under the cap into the liquid. The disadvantage of the bubble cap is that it is much more expensive and can become choked if solids are present in the liquid.

Within the rectifier it is the composition of the liquid on the trays which is important and this is determined by the tray temperature and the volatility of the congeners relative to ethanol; this latter property can vary depending upon the ethanol concentration. In Figure 6 we see that congeners like acetaldehyde are more volatile than ethanol at all concentrations and these will migrate to the top of the column. On the other hand, compounds like phenol are always less volatile and will be largely retained in the analyser. However, there are a number of compounds such as iso amyl alcohol which are more volatile than ethanol at low ethanol concentrations and less volatile at higher concentrations. These compounds will stabilise at a position in the column where their volatility matches that of ethanol.

The distribution of ethanol and the key congeners in the rectifier is shown in Figure 7. Here, the composition of spirit at about 94% ABV is at plate 30. This is not the highest alcoholic strength achieved but it avoids detectable concentrations of volatile sulphur compounds and acetaldehyde. The top vapour stream is condensed and the more volatile, unwanted compounds are allowed to escape to atmosphere while the recovered alcohol is returned to the rectifier to maintain the liquid levels in the top trays and bolster the downdown volume. A stream rich in iso amyl alcohol is collected from plate 6 and this stream is termed fusel oil. The fusel oil stream is redistilled in a packed column to separate the ethanol and the iso amyl alcohol, the ethanol being recycled. Butanol and propanol streams can also be collected separately. Modern installations of Coffey stills can run with outputs of 4,700litre/hr (litres of alcohol) for periods of up to twelve weeks and complexes like Cameronbridge Distillery can turn out 70mla per annum. The composition of new-make spirit collected from a Coffey still is very different from that emerging from batch distillation in pot stills. Firstly, of course, the strength is much higher at 94% ABV compared with 68%. But secondly the congener profile is considerably reduced. Table 1 shows some typical analyses adjusted to 63% ABV – the normal cask filling strength for malt whisky.

While Coffey stills continue to be used today there has been a move towards cylindrical columns fabricated from stainless-steel. These are cheaper to manufacture and have a longer life than copper stills. However, copper carries out an essential role in helping to remove unwanted sulphur compounds from spirit and this has to be acknowledged by the inclusion of sacrificial copper in stainless-steel distillation systems. A modern column still also employs a heat-exchanger to bring the entering wash close to boiling-point thereby dispensing with the need to heat the wash in a coil passing through the rectifier which was a feature of Coffey’s design. The loss of the liquid flow provided by condensation on this coil is overcome by recycling a proportion of the distillate as reflux to provide the downward flow of liquid, which interacts with the rising vapour.

The other change in processing which was introduced in the 1960s was the omission of the mash tun and consequently the separation of grains from wort. Greater yields are obtained as a result of the whole of the mash progressing through fermentation and into the still. The solids content of the wash, comprised of spent grains and yeast, makes it essential to use sieve trays in the analyser. However, as the solids do not reach the rectifier, bubble cap trays, referred to earlier, can be used there.

These remarks have so far been limited to distilling in Scotland but the situation in Ireland is very similar. Continuous distillation is used to produce Irish grain whiskey for blending, though pot stills have continued to be used with malt and barley mashers to create the distinct category of Irish pot still whiskey.

Continuous Distillation in North America
Scottish and Irish immigrants brought knowledge of whisky distilling with them to America and by the late eighteenth century had adapted the process to incorporate the indigenous cereals of corn and rye. By the mid nineteenth century the larger distilleries had turned to continuous distillation to increase efficiency and output and the commercial pot stills were phased out by 1900. With the exception of one recently-developed pot still
plant, all the major Bourbon and Tennessee whiskey distilleries use columns for distillation. However, there is a fundamental difference between requirements of continuous distillation in Scotland and USA. Grain whisky in Scotland comes from the still at high strength and with low levels of flavour congeners as it is used for blending with more characterful malt whiskies. On the other hand, Bourbon distillers require a flavourful spirit which they can simply mature and bottle. To achieve this they use a smaller single-column still (Figure 8) and collect the distillate at 56–60% ABV though the spirit strength is subsequently increased in a boiling vessel called a doubler. The doubler is a cylindrical tank with a steam coil near the bottom. The rate of entry of the distillate is controlled to maintain a constant level and the vapour is condensed to produce a distillate with increased strength. The older Bourbon columns are fabricated in copper while the modern ones are of stainless-steel with sacrificial copper included in the system. The distilling systems vary from plant to plant but as a generalisation the Bourbon distilleries have 16–20 trays in the analyser section and about 12 in the rectifying section. Clearly this is a very different situation to the stills making grain whisky in Scotland – where the rectifier would have about three times that number of trays. A comparison of congener levels with the two types of Scotch whisky spirit is included in Table 1.

Canadian whisky, some brandies, and some lighter rums and cachaca are produced in similar continuous distillation columns to those used in America. Canadian whisky distillate is collected at 55–80% ABV, brandy distillate at 70–80% ABV and rum distillate at levels as high as 95% ABV.

Continuous processing

It is one of the oddities of the global whisky industry that in the USA, where continuous stills dominate, they are, for the most part, operated for only twelve hours a day. While this is a consequence of the ratio of distillery capacity to current demand, it does rather defeat the main purpose of continuous distillation, namely to run the still for long periods. Conversely, in Scotland’s malt distilleries, where demand is high relative to capacity, the batch-operated pot stills are run twenty four hours a day – one could perhaps describe the systems as continuous batch in Scotland and batch continuous in USA. It might have been expected that continuous distillation would lead to totally continuous processing with continuous mashing and fermentation stages. This has not happened – though one grain distillery in Scotland persevered for a number of years with continuous mashing using conversion tubes. Continuous fermentation has never attracted much interest in the spirits industry probably because of the fact that the wort is not sterile and few new plants have been built in recent decades. On the other hand continuous distillation has been married with continuous distillation in modern fuel alcohol plants.

Neutral Spirit

These distillation systems all produce spirit with a noticeable flavour – indeed the Scotch whisky definition requires that grain whisky, as well as malt, should retain flavour and aroma stemming from the raw materials and the process. However, spirits like gin and vodka require a flavourless alcohol which is termed neutral spirit. Its production, generally from grain, molasses, or grapes presents the challenge of removing the low levels of congeners produced by the whisky type of column distillation.

To separate the remaining congeners with boiling-points close to ethanol, a technique called hydro-selection, or extractive distillation, has to be added to the process (Figure 9). This utilises the fact that the unwanted compounds tend to be much less soluble in hot water than ethanol. In an extractive distillation column the steam from the previous rectifier is fed into the column about two thirds of the way up; hot water enters at the top and steam at the bottom. The components which are less water-soluble rise to the top of the column and are drawn off. The water-soluble components are driven down the column and withdrawn from the base at about 15% ABV. This weak solution is then subjected to further rectification and a product with a strength just over 96% alcohol is produced with only traces of impurities (usually methanol, diacetyl and 2,3 pentane dione). The requirements to meet the EU definition for neutral spirit are shown in Table 2. The specifications for neutral spirit used in premium gin and vodkas are much tighter than the EU definition – particularly so for methanol.

If it is necessary to bring about a reduction in methanol content, then a demethylation column is also included in the system (Figure 10, opposite page). This is designed to separate methanol from ethanol; the methanol is condensed from the top of the still and ethanol is collected from the bottom. Putting all this together, we get a system including extractive and demethylation columns in a five column distillation plant (Figure 11).

Anhydrous Ethanol

Plants such as these are capable of producing alcohol very low in congeners but still with about 4% water. It is no accident that this is the highest level of alcohol used in beverage production as it is impossible with simple distillation techniques to achieve further concentration. The reason for this is that ethanol water mixtures form an azeotrope or constant boiling mixture at a composition of 97.2% ABV. At this point the composition of the liquid is the same as the vapour it is producing and no further separation is possible by simple distillation.

However, anhydrous ethanol is required for a number of applications including fuel alcohol – and methods have had to be devised for removing the remaining 4% of water. The modern technique is the use of packed beds of synthetic zeolite, known as a molecular sieve which removes water from a vapour stream by trapping it in the precisely-sized pores of their lattice structure.

Conclusion

All this has come a long way from Aeneas Coffey in 1830: a man with no scientific training, who with great skill, and possibly the luck of the Irish, invented a most ingenious technique for separating alcohol from water, which has been widely used in industry and in our own has given a great deal of pleasure around the world.