Making Scotch: Engineering, Chemistry, and Education

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Abstract

During two successive summer hands-on whisky making classes at the Bruichladdich Distillery on Islay in Scotland, two types of samples were taken and analyzed using GC/MS. Samples were taken periodically during the two stages of distillation, and of whisky that had matured for different periods of time in different character casks. HYSYS\textsuperscript{®} engineering software was adapted to the batch distillation processes using the samples for parameterization and validation. The pot stills were modeled as having equivalent trays and internal reflux from condensation of the less volatile components on the copper walls of the stills. The maturation samples are being used to elucidate the physical and chemical interaction between the toasted, charred, and previous used barrels and the maturing whisky.

The effect of transforming the boiling phenomena in the wash still (1\textsuperscript{st} stage) from nucleate to film boiling to break the head was utilized. Phase separation was observed upon distillate condensation resulting in the transformation of the distillate in the spirits still (2\textsuperscript{nd} stage) from the first cut (foreshots) to the second cut (spirits cut i.e. product) indicated the decay of the concentration of ethyl acetate and acetal. The enhancement of flavor by phase separation caused by addition of water to whisky was also noted. The equilibration in a receiving tank of the wash still product (low wines) with the foreshots and tails (third cut) of the spirits still to form the feed for the next spirits still batch that enabled stable operating conditions was observed.

The students who participated in each summer’s class earned academic credit either for the required senior laboratory, or as a special topics course on either the undergraduate or graduate level. A team of four senior ChE students did a project in the required design class on potential usage of the CO\textsubscript{2} generated during fermentation.

Introduction

The University of Tennessee (UTK) Chemical Engineering Department and the Bruichladdich Distillery on Islay in Scotland cooperated in hands on whisky making classes during June 2003, and May 2004 and by the time of this conference will have had another class during May 2005. Hands on whisky making classes at Bruichladdich were conceived by Jim McEwan, have evolved to the Bruichladdich Single Malt Academy open to the public, and initiated with the UTK ChE department and the Colliers. Samples of the distillates in the wash and spirits pot stills, and from different age whiskies were taken by the UTK group, shipped back to the University, and analyzed at the Bush Brothers research laboratory in Knoxville. The UTK students earn academic credit for
their participation, with the amount of credit dependent upon whether or not the 
Bruichladdich course is coupled with a related project. The Bruichladdich/UTK course 
can be the basis for the required senior laboratory or for a thesis or dissertation project. 
The projects have been related to analysis of the samples, resulted in an M.S. thesis, a 
current PhD dissertation and a team senior design project that won first place in green 
engineering at the 2003 AIChE annual conference. The Bruichladdich/UTK course will 
involve students from other institution and from the UTK marketing MBA students. 

Differences between scotch single malt whisky and Kentucky bourbon and 
Tennessee whiskey result from the grains used, the processing and maturation processes. 
Scotch single malts are produced using only barley, whereas corn is the major constituent 
of American whiskies along with rye and barley [Jacques, 1999]. Scotch single malts are 
produced using batch pot stills; whereas most American whiskies are produced using 
continuous distillation, with Woodford Reserve bourbon being the exception, produced 
primarily using batch pot stills. Scotch blends are more similar to American whiskies 
since they are produced from other grains in continuous stills and blended with single 
malts. American whiskies must be matured in fresh, toasted and charred oak containers; 
whereas scotch whiskies must be matured in previously used American white oak 
whiskey casks (all referred to bourbon casks) or previously used wine or wine derivatives 
(Sherry, Port, Madeira) white or European oak casks. These primary effects and more 
subtle processing effects are discussed with the emphasis being on scotch single malts 
with comparisons to other whiskies.

**Whisky Production**

**Malting the Grains:** Soaking barley grains initiates germination for the start of 
the growth cycle. Rootlets and shoots appear as the enzymes are activated that break 
down the cell walls and enable conversion of the starch molecules to the lower forms of 
sugars that are more easily converted to alcohols. Starch is a polymer of glucose, and 
glucose is a monosaccharide, that is a carbohydrate that can not be reduced further by 
hydrolysis. The growth is arrested by stopping the malting cycle thereby preventing 
conversion of an excessive amount of the starch to sugars. In the normal growth cycle 
the sugars formed provide the energy for the barley growth; in whisky-making these 
sugars are converted during fermentation to alcohols and other components. Modern 
steeping of the barley occurs in large aerated tanks for 40 to 60 hours. Periods of water 
immersion are alternated with rest periods in which the barley is exposed to air. In the 
germination boxes the green malt from the steeping tanks will double in volume in up to 
six days and normally develops a wrinkled skin indicating lower nitrogen content, 
meaning less protein and more starch. Winter barley is usually used in Scotland for 
malting. Barley is also malted, but not peated, for American and Irish whiskies to 
generate the enzymes needed for conversion of starches to sugars.

**Floor Malting:** Floor malting is the traditional form of malting in which the 
barley is stored in a solid floor loft with a hole to accommodate dropping to the level 
below. The steeping tank for floor malting is filled to about one half meter deep in barley 
and then the barley is steeped over period of 36 hours not including resting periods. The 
steeping in the winter must be at 18°C or higher, and the traditional cycle is 12 hours of 
soaking (steeping), 12 hours of resting (drained), 12 hours of soaking, 12 hours of rest, 
and 12 hours of soaking. After steeping, a quarter meter of barley is placed on the 
malting floor for a seven-day cycle. During days one and two the barley is thrown every
six hours, during days three and four it is thrown every four hours, on day six the throwing is slackened off and the barley is allowed to rest for day seven.

*Kilning and Grinding:* Malting is followed by drying in a kiln in which peak smoke may be used for up to 24 hours and then another 24 hours of drying for a 48-hour total drying time. The kilns used have a wire mesh bottom and generally a pagoda style roof to keep the smoke in the kiln chamber. Kilning accomplishes the drying of the malted barley slowly enough that the enzymes are not damaged. Peat smoke in the early stages of kilning causes phenolics in the smoke to be absorbed by the moist barley. As the barley dries it is less absorbent and therefore peating, when done at dedicated malting facilities, usually does not typically occur for more than 4 to 6 hours. The extent of peating that is done is specified by each distillery and contributes to the unique character of each single malt. The dried malted barley is stored until near time for use, and then it is ground to grist which is desired to be about 15% husk, 67% middle cut, and 18% flour.

*Mashing:* Mashing extracts the sugars from the grist and is typically accomplished with four washes. The first wash has the grist and water conveyed in at 65°C for the first wash. The second wash is at 82°C and both the first and second wash products (wort) are transferred to the washbacks (fermenters). The third and fourth washes are to extract any residual sugars and occur at 88°C and 92°C respectively. The wash from the third is stored to become the water solution for the first wash of the next mash run and the fourth wash becomes the water solution for the second wash of the next mash run. The residual in the mash tun, i.e. draff, after the fourth wash is used for cattle feed. Only malted barley is used for single malts; in Scotland vat malts can be produced mixing single malts from different distilleries. Blends in Scotland typically involve barley, wheat and corn (maize) and may be distilled using a continuous process whereas single malts are produced using a batch process. In the United States bourbon, sour mash, sipping whiskey, etc. are produced using corn (usually at least half of the grain), barley and rye.

*Fermentation:* Fermentation of the wort from the mash tun is accomplished in washbacks, typically takes about 65 hours at about 23°C and result in about 36,000 liters of product (wash or beer) that is 6 to 7 v% (volume percent) ethanol (ethyl alcohol). Some distilleries in America culture their own yeast from a barley extract, whereas others in Scotland use brewers and distillers yeast. The initial portion of fermentation is in the aerobic phase (oxygen present) during which ethanol is not formed but for each molecule of glucose consumed by the yeast six molecules of CO₂ form. Since CO₂ is heavier than air and the washback has a quiescent gas layer above the wort, the CO₂ displaces the air and causes the fermentation to become anaerobic (oxygen absent). The anaerobic phase is referred to as the active phase of fermentation because two molecules of ethanol and two molecules of CO₂ are generated for each molecule of glucose. Both stages of glucose metabolism proceed through cyclic biochemical processes and the anaerobic process can also produce lactic acid, acetone, butanol, acetic acid, and other minor constituents. Vinegar is a 5 v% aqueous solution of acetic acid and can be produced by fermentation.

*Distillation:* Single malts are distilled in batch pot stills that have an “onion shape” resemblance although the specific shape varies from distillery to distillery. Most Scottish distilleries use two stages of pot stills, a first stage wash still, and a second stage spirits still, although there are some triple distilled scotch whiskies, most Irish whiskies
are triple distilled, and one American bourbon is produced using three pot stills. Scotch blends and many American whiskies are typically distilled in continuous stills that are designed based upon mole fractions since the vapor and liquid on each plate or equivalent plate have essentially the same enthalpy change. Pot stills on the other hand are operated based upon volume percent and benefit from the non-ideal character of the ethanol/water equilibrium giving a nearly flat vapor composition over a broad liquid phase composition as shown in Figure 1.

The feed (wash or beer) from the washbacks to the first stage of pot stills and to the continuous still, i.e. the wash or beer, contains about 6 to 7 v% ethanol, primarily water, a number of other minor constituents and yeast fragments. This feed has some of the characteristics of a beer in that it has a tendency to form a head when agitated and during the initial part of the distillation in the first stage. Therefore in operating the wash

![Figure 1: Ethanol/ Water Equilibria](image)

Figure 1: Ethanol/ Water Equilibria

still, care must be taken to avoid entraining yeast fragments by foam action into the distillate stream. This is typically done by carefully controlling the steam pressure and therefore the heat flux into the still. There are two stable modes of heat transfer that can be active in pot boiling, nucleate boiling and film boiling with a transition region between. The driving forces for nucleate and film boiling are nearly equal in the transition region causing the system to be unstable. In nucleate boiling bubbles of vapor are formed on the heating surface, rise through the liquid and can form a head thereby entraining the yeast fragments. Operator care is therefore needed to prevent continuous rising of bubbles. However, when the bubbles are large and oscillate up and down, indicating the approach of the transition region, the operator will make a dramatic step increase in steam pressure forcing the system into film boiling. In the film boiling region a film of vapor forms around and on the heating surfaces increasing the resistance to heat transfer and requirement for a higher temperature gradient between the heating surface and the liquid that is then boiling at the interface between the vapor and surrounding
liquid rather than on the heating surface. Film boiling tends to be more stable without a significant head formation thereby needing less care yet a higher steam pressure. With proper operation of the wash still, the yeast fragments become part of the pot ale (i.e. the bottom product that is discarded) and are not part of the feed for the second stage stills (spirits stills) therefore not as much care has to be taken in passing through the nucleate to film boiling stages in the spirit stills. Wash stills typically have sight glasses and opposing lights for observation of the bubble phenomena whereas spirit stills do not.

The start up of the first still is affected by the configuration of the heating elements and also by the composition of the feed. The few pot stills used for American bourbon were manufactured in Scotland and have opposing glass inspection windows in the first stage for observation of the start up. These windows are not needed, since this bourbon has corn as 72% of the grain and the surfactant character of the corn oil dramatically reduces the foaming character and makes the start up sufficiently quiet to not require the windows.

The two major components, water and ethanol, dominate the whisky (and whiskey) distillation process; therefore, the process is significantly influenced by the strongly non-ideal vapor liquid equilibria of ethanol and water. An azeotrope, (i.e. constant boiling point where the vapor and liquid have the same composition) occurs at 97.2 v% ethanol in water [Jacques, 1999]. The same chemical effects and the relative size of the ethanol and water molecules affect the relationship between the vapor phase in equilibrium with the boiling liquid phase. The condensate from each type still is strongly related to the vapor phase composition. Since ethanol is more volatile than water, the concentration of ethanol in the liquid phase drops during distillation. For the wash still the starting ethanol concentration in the liquid phase is about 7 v% and this is in equilibrium with a ethanol concentration in the vapor phase of 40 v%; whereas when the liquid phase ethanol concentration drops to 0.1 v% ethanol the vapor phase ethanol composition is 10 v% as shown in Figure 1. This difference enables distilling off most of the ethanol leaving very little in the pot ale and having a higher liquid concentration for the second stage of distillation. Furthermore, it indicates that the highest ethanol concentration condensate that could be achieved in the wash still with a 7 v% feed is only about 40 v% and that would only occur at the beginning of distillation. Therefore, a second stage is required to achieve higher ethanol concentrations.

The initial feed to the spirit stills is about 27 v% with about one half of that coming from the wash still with the remainder recycled from the previous spirit still runs. In the spirit stills, the advantage of the vapor liquid equilibria again influences the operation. The initial vapor phase composition in equilibrium with this starting liquid phase composition is at least 75 v% ethanol and as the ethanol is being depleted in the liquid phase the vapor phase composition decreases rather slowly. When the liquid phase composition has dropped to 20 v%, the vapor phase composition is 70 v%, and then it begins to drop more rapidly. When the liquid phase drops to 15 v% the vapor phase has dropped to 60 v%. The spirits cut, which becomes the product, is about one third of the distillate from the spirits still, and about one fifth of the initial charge to the spirit still. The composition of this cut benefits from the relative insensitivity of the vapor phase composition to the liquid phase composition and results in an average composition of about 70 v%.
The analysis of the samples shipped back to the University, indicates that the distillate ethanol concentration in both the wash and spirit stills agreed well with the results anticipated from the vapor liquid equilibria except for a small but potentially significant different in the first third. The ethanol concentration drops rather rapidly around the end of the spirits cut and through the feints or third cut. The first cut or foreshots will have a composition in the seventies percent range and that mixed with the third cut gives a solution that is 35 v % ethanol. These two cuts are recycled to become part of the charge for the next spirits still charge. The other part of the charge to the spirits still is the low wines from the wash still at 22.5 v % ethanol. The spent lees that are discharged as the bottoms from the spirit still are about 44% of the charge and have only 0.1 v% ethanol due to the vapor liquid equilibria relationships.

Although the ethanol concentration in the vapor phase during the foreshots and spirits cuts is relatively insensitive to the liquid phase concentration, this is not the case for at least two minor constituents. Our analysis of condensates during the different stages of spirits still distillation indicated that two minor components, ethyl acetate and acetal exhibit an exponential decay in concentration from above 0.2 v % at the beginning of boiling in the spirits still to about 0.05 v % at the transition from the foreshots to the spirits cut as shown in Figure 2. The dashed vertical lines denote the transition from foreshots to spirits cut and spirits to tails. The insert indicates the ethanol concentration. The concentrations of ethyl acetate and acetal continue to decrease to very low values during the spirits cut. Other minor components identified do not exhibit the sensitivity to time in the distillation as do acetal and ethyl acetate. Both components were identified in the wash still samples and again their concentration had a rapid decrease during distillation. Ethyl acetate is formed from ethanol and acetic acid and acetal is formed in an acidic environment from ethanol and ethyl aldehyde, all of which can be formed in fermentation. Furthermore, there could be additional equilibration reactions occurring in the low wines and feints receiving tank.

Both ethyl acetate and acetal have limited solubility in water although in the vapor phase they are completely miscible. As a result when the initial spirits still vapor is condensed to room temperature and below, and particularly when water is added, the ethyl acetate and acetal probably form a separate phase rich in their composition. The initial ethyl acetate and acetal concentrations in the foreshots could be the cause of the condensate appearing cloudy and bluish, whereas at the transition to the spirits cut the concentration of these two has probably decreased sufficiently so that phase separation does not occur. It may be worthwhile to consider minor changes in the washback environment or the low wines and feints receiver to lower the initial charge concentration for the wash and/or spirits stills of the ethyl acetate and acetal. The most significant change would be to raise the pH slightly; however yeast changes and temperature changes may also be effective.

The analysis of the distillate ethanol concentration in both type stills agreed well with the results anticipated from the vapor liquid equilibria. The ethanol concentration in the wash still distillate slowly decreased during the run and was fairly stable through the foreshots and spirits cuts in the spirit still. The percent ethanol that was measured using GC/MS in the foreshots was nearly the same as in the spirits cut. It could be that the higher ethyl acetate and acetal concentration in the foreshots affects the vapor liquid equilibria and also influences the density measurements made to determine the ethanol concentration.
Temperature measurements were made on the spirits still for both the boiling liquid and external locations above the liquid level. During the foreshots the boiling liquid temperature was 84 °C, the temperature above the liquid was 64 °C to 65 °C, and the condensate temperature was 15 °C. At the transition from foreshots to spirits cut the condensate density indicated an ethanol content of 72 v%. During the spirits cut the boiling liquid temperature increased gradually from 85 °C to 87 °C, and the top of the still external temperature increased from 67 °C to 70 °C. After five minutes into the tails cut, the external temperatures were equal at 70 °C and the boiling liquid was 85 °C.

Still Construction and Shape: The pressure profile in pot stills has an influence on the vaporization and condensation of the lower vapor pressure components. Reductions in pressure lower the boiling point of all components and increases in pressure enhance the condensation of these same components on the interior walls of the stills. The construction and shape of the stills should have a noticeable effect on the spirits produced. The copper construction enables excellent heat transfer through the still causing the less volatile, i.e. higher boiling, components to condense on the cooler sides of the still and return to the boiling liquid.

In the modeling of the stills using HYSYS engineering software, it was found that assuming that the stills were composed of eight equivalent stages and a reflux ratio of one fourth of the vapor phase was appropriate to fit the data [Rogers 2004]. As noted in the temperature profile data the external surface of the copper stills in the vapor phase region is significantly cooler than the boiling liquid and this temperature is not strongly dependent upon the height above the boiling liquid. The vapor condensate that forms on the still surfaces is enhanced in composition of the higher temperature boiling, i.e. less volatile component, compared to the vapor from which it condenses. This results in reflux of the less volatile components thereby enriching the vapor phase that reaches the condensers in a manner similar to that in a tray or packed column in which the rising
vapor phase is contacted with falling liquid phase. Therefore the condensate on the interior of the still should have a higher concentration of the lower vapor pressure or higher boiling components. The copper construction of the still enables the removal of sulfur compounds from the distillate by forming copper sulfates that precipitate out and are not carried over into the final spirits.

The height and degree of contraction of the stills affect the surface area for contact with and repeated enrichment of the rising vapor. Furthermore, the manner in which the stills contract can also have an influence. The Bruichladdich stills have a smooth transition from the pot to the neck. Stills that have a significant contraction and then expansion above the liquid level can induce a venturi effect in which the vapor is accelerated and then decelerated in its upward motion. If there is a constant mass flow rate through a venture, the fluid’s average velocity is increased due to the reduction in cross sectional area and the associated increase in kinetic energy causes a reduction in pressure, i.e. pressure volume energy is converted to kinetic energy in the contraction and then the pressure is recovered as the cross section increases. The decrease in pressure begins prior to the rapid contraction and if the boiling liquid level is near the significant contraction, the pressure is lowered and the boiling point of the components lowered. This in turn causes the lower vapor pressure components to be included in the vapor at a lower temperature but as the cross sectional area expands these components will be more prone to condensation on the interior surface of the still and a higher effective reflux ratio. As the liquid level recedes during a run the effect on the boiling is also decreased even though the pressure changes in the venturi section are not. Stills for which a bulge occurs above the boiling liquid have an opposite effect to the venture: increased pressure preceding the bulge and decreased in the bulge. The pressure profile will also be influenced by the general contraction effect in the onion shaped stills and this in turn will affect the condensation and reflux on the interior surface of the still.

**Maturation:** American white oak, or the similar European oaks, are used for casks since these oaks have tyloses that grow across the vesicles of the heart wood and act as membranes thereby dramatically decreasing the permeability of the casks. It has been estimated that a much higher volume loss occurs through the joints and ends than through the staves. Casks for American whiskies are cut to about 45° to the grain axis, whereas European wine casks are split along the grain. There are significant physical and chemical interactions between the casks and the whiskies during maturation. The new American casks are toasted at near 200 °C for a few minutes, and then set on fire for about a half minute by passing over an open gas flame. As a result of the toasting, wood components, such as lignin, are partially degraded and when these components interact with components in the whiskies, reactions occur creating various compounds such as vanillin (giving a vanilla flavor) [Jacques et al, 1999]. Furthermore the charring on the inside of the casks and ends creates what may function as an activated carbon layer, with significant splitting exposing the uncharred wood beneath.

The white spirits (i.e. fresh distillate) are harsh, bitter, transparent, and colorless, but the matured spirits are softer and have developed character and color. The maturation period and location also contribute to the character. Temperature changes, either seasonal or induced, can affect the spirits, causing a loss in volume, with a pressure increase during warmer periods and a vacuum in cooler times. The developing vapor phase can cause the barrels to breath during these temperature cycles. A faint salty flavor
can result from whisky matured in sea side locations. The rule of thumb in Scotland is that about 2% of the volume of a cask is lost per year with about 0.8% decrease in alcohol content per year. In America the volume also decreases but the alcohol content increases. The American whiskies aged in Kentucky and Tennessee experience larger temperature and humidity swings than the scotch single malts which may lead to more extensive drying of the outer layer of the casks in America. At some American distilleries programmed heating cycles are used whereby the warehouses may go through a series of imposed temperature changes in the winter from about 20 to 30 °C. As previously stated American whiskies are aged in new white oak casks, whereas the scotch single malts are aged in used oak casks. The effect of the previous contents of the casks used in Scotland can also add to the character of the single malt as noted by the recent trend at some distilleries to age in American white oak casks for perhaps ten years and then finish the aging by transferring to a cask that previously contained wine, madeira, sherry or port. At premium single malt distilleries the casks chosen by the master distiller for mixing prior to bottling can be a prescribed number of casks that previously contained American whiskies and those that previously contained sherry. When there are a significant number of cask levels in the warehouse, the mixing for bottling intentionally uses casks from different levels.

**Water and Cold Filtering Influences on Flavor:** The solubility of some of the flavor components in whisky is decreased by lowering the temperature and by a decrease in alcohol content. When water is carefully added to whisky, the intensity of flavor is enhanced probably because the careful addition causes a local dramatic change in concentration and the component not as soluble in the lower alcohol content solution forms a separate phase causing a higher vapor pressure of those components. The effect is probably not as intense in cold filtered whisky since lowering the temperature prior to filtration should have a similar effect on the flavor components and the lowered temperature induces a separate phase which is then filtered out. The fact that the cold filtered whisky can be bottled at a lower alcohol content and remain stable in the bottle, indicates that these components that are less soluble in lower alcohol content whisky have been removed. Without cold filtering the alcohol content after reduction for bottling is traditionally higher, e.g. 46 v%; if lower alcohol content were used these less soluble contents would gradually separate and cause the whisky to appear cloudy in the bottle.

**University Involvement and Student Projects:** Four UTK students (Jose Alfaro, Sam Morton, Ben Rogers, and Joy Watson,) and two UTK faculty members (Professors Billie Collier and John Collier) were the first group in June 2003 to participate in the Bruichladdich Single Malt Academy, and these two faculty members plus two more UTK students (Jason Campbell and Elijah Shekinah) graduated from the now formal Bruichladdich Single Malt Academy in May 2004. During the 2004 session, the UTK students and faculty, with a UTK alumnus (Tom Neal) and Bruichladdich personnel bottled 610 bottles of 32 year old whisky donated by Mr. Neal. Mr. Campbell and Mr. Shekinah satisfied the senior ChE lab by participation and analyzing the distillation samples shipped back from the 2004 group.

Mr. Rogers successfully defended his MS thesis in Chemical Engineering at UTK on the GC/MS analysis of samples taken by the UTK group in 2003 and subsequent HYSYS
modeling of the wash and spirits stills as related in the text of this report. Fortunately Bush Beans Inc. (through Dr. Phil Perkins) opened their research laboratory in Knoxville to our students for the GC/MS analysis and is continuing to encourage involvement. Sam Morton was also involved in the GC/MS analysis, has successfully defended his PhD dissertation on an unrelated topic, and is a faculty member in Chemical Engineering at Lafayette College in Pennsylvania. He was also the primary advisor (assisted by UTK Professors Pete Counce and John Collier) during the Fall Semester, 2003 at UTK of a team of four senior ChE students in the required design class on a project related to distillery operation [Campbell et al, 2003]. This student group (Jason Campbell, David McCollum Oleg Melnichenko, and Chris Tyree) considered usage of the CO₂ generated during fermentation. Their preliminary design indicated that conversion of the CO₂ to use in carbonated beverages would have a payback of the installation cost of $1.1 million in 2.2 years, conversion to dry ice would have a payback of the $0.9 million in 3.6 years, and that the other two options considered (algae growth and enhanced oil recovery) were not viable for Bruichladdich. A chemistry faculty member at Lincoln Memorial University in Tennessee (Roy Wilcox) is pursuing his PhD research in Materials Science and Engineering at UTK under the joint direction of Professors Tim Rials (UTK Forest Products Center Director) and John Collier on the chemical and physical interactions between the wood in the casks and whisky during maturation. Mr. Wilcox is analyzing the samples of matured whisky shipped back from the 2004 group at Bruichladdich. The profits from the sale of the whisky bottled by the 2004 UTK Bruichladdich team should also form an endowment for UTK students to participate in this and other international programs.

References: