Wine Corks*

By Dr. Murli Dharmadhikari

Although there is some historical evidence suggesting that cork was used as a stopper about 2,000 years ago, its use became more prevalent with the introduction of glass bottles in the 17th century. In recent years, other alternatives such as capsules and plastic stoppers have been introduced as closures for wine bottles. However, cork still remains the principal closure of choice for premium wines.

Cork is essentially a piece of bark from an oak tree known as cork oak, *Quercus suber.* The cork tree grows naturally in a region bordering the western Mediterranean Sea. The major cork producing countries include Portugal, Spain, France, and Italy in Europe; and Morocco, Algeria, and Tunisia in Africa. Several efforts have been made to grow this species in other parts of the world; but, so far, the results have not been encouraging. Worldwide production of cork is estimated to be 3,075,000 tons. Of this amount, Portugal produces the lion's share (about 55%).

Structure and Properties of Cork

The cork tissue is produced by a special layer of cells called "cork cambium." The cambium is a part of the outer bark of the (cork oak) tree, and is responsible for the production of a thick and uniform layer of cork cells.

The cork tissue consists of many layers of tiny cells. The average diameter of these cells is 0.03 mm and there are about 15 to 42 million cells per cubic centimeter. The individual cell has four to nine sides, and has a small amount of air entrapped in it. The cell wall is made up of wax, suberin, lignin, and other materials. The wax and suberin are complex polymers which make the cells impermeable to gasses and liquids.

The texture of cork tissue is relatively homogenous. Some inhomogeneity occurs due to the presence of thin walled cells with intercellular spaces. These cells are known an lenticels. A high quality cork has fewer lenticels.

The cork possesses many remarkable qualities which make it an ideal stopper for wine bottles. Some of the important qualities include: compressibility, resilience, impermeability to liquids, low density, little tendency to rot, and a high coefficient of friction.

Cork is highly compressible. It can be compressed without causing significant lateral expansion. It is also very resilient. After compression, the cork can return to 85% of its original volume in about 20 minutes, and about 95% of its volume after 24 hours. During corking, a cylindrical cork 38 to 40 mm long and 23 to 25 mm in diameter is inserted in a bottle with a bore size of about 18 mm. In this situation, the cork diameter is reduced by 25% (from 24 mm to 18 mm) and the cork volume is reduced by 40 to 50%. Due to its elastic nature, the cork exerts a pressure of 1.5 to 3 kg/cm^2 against the glass surface (in the neck of the bottle) and forms an excellent seal. The elastic property of the cork is due to the unique cell structure. As noted earlier, the tiny cork cells are filled with air and thus the tissue can be envisioned as layers of tiny air cushions grouped together. The cork is very light in density (0.12 to 0.25 g/cm^3) and a little over 50% of the cork volume is air. When the cork is squeezed (as during corking), the air inside the cells is compressed. The compressed air inside the tiny cells exert counter pressure which permits the cork tissue to expand and provide an effective seal. With prolonged compression, the gas inside the cells gradually permeates out and the resiliency of the cork is permanently lost; the cork is not as elastic as it was before compression. This phenomenon can be observed when a cork from an old bottle (10 to 15 years storage) is withdrawn.

The elastic property of the cork is influenced by its moisture content. The cork remains fairly elastic for insertion into the bottle within a moisture content range of 5 to 12%. But the moisture content is maintained around the 5 to 7% level in order to discourage microbial growth. Cork is practically impermeable to liquids. This is because the cork tissue is made of tightly packed cells; this leaves practically no room for liquid to pass. One millimeter thick cork tissue may have as much as 30 layers of cells. The waxy and suberous composition of the cell wall makes it even more difficult for liquid or gasses to pass.

It should be remembered that although the cork is not permeable to liquids, it is permeable to gasses and water vapor. This is attributed to the presence of extremely small channels (diameter of about 0.06 μm) in the cell walls, which permit the gasses to pass. These channels are not permeable to liquid unless an extremely high pressure differential exists. Because of the permeability to water vapor, the cork will dry if it is stored in low humidity conditions or is not in contact with the wine when in a bottle.

Another drawback of this characteristic feature (permeability to gasses) of the cork is that it can absorb volatile compounds present in the atmosphere. For example, compounds like guaiacol and acetic acid can be absorbed and thus adversely influence the sensory properties of the wine.

Another unique and highly desirable property of cork is its high coefficient of friction. This means that it does not slide easily on smooth surfaces such as glass. The cut surface of the cork consists of broken cells that act like suction cups when they are in contact with the glass. Due to this tendency, the cork adheres tightly to the glass surface (this is what makes it hard to remove the cork from the bottle), and also assumes the shape of the neck of the bottle. In spite of small irregularities in the neck of the bottle, the cork fits well and provides an effective seal.

Cork is a very durable stopper. When in contact with wine, it does not readily degrade. In most cases, very little wine penetrates into the cork and few cork constituents leak into the wine (this assumes good cork). Occasionally, vanillin/woody odors may be imparted to the wine, but overall, it doesn't affect the wine flavor.

Production of Wine Corks

As noted earlier, cork is produced from the bark of a cork oak tree. The cork tree is unique; in that, a careful removal of the bark does not harm the tree and secondly, after stripping the bark, a new bark is regenerated. Although the cork tree is a forest species, it does require some care and attention in order to produce high quality cork bark over a long period of time.

The stripping of the bark begins in summer, usually in July. After the bark is peeled off, the tree produces a reddish fluid which protects the mother bark. The fluid dries to a thin layer and by early autumn, new cork cells begin to form. The first stripping of the bark occurs when a young tree is about 15 to 30 years old and has attained a trunk diameter of 70 cm. The bark that is removed for the first time is known as virgin cork. Its structure is irregular, it is relatively hard (not supple), and is not useful for cork stopper production. This virgin cork is used for producing cork stopper production. This virgin cork is used for producing other cork-based materials.

After a period of about nine years from the first snipping, the bark is removed again. The cork bark removed for the second time is called second bark, and is still not considered good enough to produce cork stoppers. The cork bark that is removed in the third and subsequent strippings is called reproduction cork. Its texture is more uniform and it provides excellent material for producing cork stoppers. Usually the cork quality is considered best when a tree is about 50 years old. The tree will live and produce cork until it is 160 to 180 years old. But after about 100 years, the quality of the cork declines. The stripping of cork is done every nine years. This allows enough time for a tree to grow and produce good sized bark. Starting at 25 years, a tree will yield about 15 strippings.

The stripped bark, also called cork slabs or cork planks, is stacked in piles outdoors. This allows the cork slabs to season or cure. During this period, the sap from the bark dries off and the cork planks undergo weather-induced chemical changes. Following curing, the cork planks are subjected to a boiling process which cleans and disinfects them and also makes the cork planks softer and more flexible. This is important because it allows the semi-cylindrical cork planks to be made into flat slabs called cork board.

In the next step, the cork board is cut into strips. The width of the strip is slightly greater than the length of the cork. The strips are placed on their side and the cork is punched out perpendicular to that of the cork growth. This ensures that the lenticels are positioned on the side of the cork touching the glass when the cork is inserted in the bottle. This reduces the potential leakage of wine through the lenticels.

Cork punching requires great skill in order to maximize the quality and quantity of the corks produced. It is estimated that about 30% of the cork board is used in making cork stoppers. After punching, the corks are polished and the edges are trimmed, if needed. Corks with edges trimmed at 45° are called champerd corks. Some winemakers prefer champerd corks because champering makes it easier to insert the cork during corking. Corks used for fortified wines are made by gluing or binding the plastic top to the end of the cork. Such corks are referred to as T-corks.

After polishing, the corks are rinsed with water to remove dust and treated with a solution of calcium hypochlorite and oxalic acid, followed by a final rinse. The process bleaches and disinfects the cork surface. Since chlorine treatment can contribute to the formation of 2, 4, 6-trichloroanisol, a compound known for causing cork taint, an alternative treatment is preferred.

One such alternative method is to treat corks with peracetic acid. When corks are treated with peracetic acid, hydrogen peroxide and acetic acids are formed. The peroxide is reduced to water,and acetic acid is removed by rinsing or simply drying off. When properly done, the process if effective.

Instead of chemical treatments, some cork producers sterilize corks by exposing them to irradiation. The process is very effective in eliminating microorganisms such as molds and bacteria. Cobalt-60 isotope (radioactive cobalt) emits gamma rays which can penetrate deep into the cork. This achieves the destruction of harmful microbes both on the surface, as well as, inside the cork.

Following chemical sterilization, the corks are dried to bring the moisture content between 6 to 8%, and then graded. Based on the customer's request, the corks are branded and/or surface treated with silicon or paraffin. Coated corks are often used in high speed bottlings. Finally, the corks are packaged in plastic bags containing sulfur dioxide and stored at a temperature of 15 to 20°C and 50 to 70% humidity.

Agglomerate cork or composition cork is another kind of cork used sometimes by the wine industry. To make agglomerate cork, the cork board is ground into small granules which are then mixed with a glue and extruded in the shape of long cylinders or tubes. The long cork cylinders are cut into pieces of the desired length. It is important to note that the agglomerate cork has a low compressibility and is less elastic; therefore, the diameter of the agglomerate cork is slightly less, than the diameter of a natural (one piece) cork. Cork granules are usually made from the cork strips leftover after punching cork stoppers or other cork board pieces that cannot be used for making cork stoppers. This allows more efficient use of cork board, i.e., there is less waste of cork wood.

Champagne corks are a type of composition cork. They are larger than the corks used to stopper still table wines. The upper section of the cork is made of cork particles (like agglomerate cork) and the lower section has two cork disks glued to it. The lower end is in contact with the wine when the cork is inserted into the bottle. Champagne corks must be able to withstand high pressure (about six atmospheres). To achieve this, corks with larger diameters (31 mm instead of 24 mm) are used and they are compressed to a greater degree than table wine corks. For example, the regular corks when compressed are reduced in volume by 45 to 50%. In the case of champagne corks, the volume is reduced by 65%. This provides an effective seal and holds the wine in the bottle under high pressure. Large single piece corks are available for stoppering champagne bottles. To produce a larger diameter champagne cork, thick cork strips are required which would take a longer (more than a year) time to grow. This makes them expensive; consequently, composite corks are commonly used by the champagne industry.

Cork Faults and Quality Control

Cork Defects - A defective cork can cause problems such as leaking. formation of deposits or sediment, and equally important, the development of cork taints. To prevent these problems the vintner should recognize faulty corks and avoid using them. Cork defects can be serious; that is, they can cause leakage and/or make cork insertion difficult. These are defined as critical defects. Other flaws may not be as problematic. They may be related to the appearance of the cork rather than the function. Such defects are considered noncritical. Amon and Simpson (1986) suggested this definition of critical and noncritical defects in wine corks. Some of the critical defects described by them are given below.

1. **Green wood** - This is caused by immature cork cells. The flaw is considered critical if more than 50% of the cork length is made of green wood.

2. **Poor cork ends** - They are caused by holes, cracks, and/or fissures. If the hole or crack is over one-third the length of the cork, it is a serious flaw. The holes can also be caused by worms. Such corks should not be used.

3. **Holes** - The presence of any large holes (>2 mm) is considered a critical defect, especially if they are connected together over 50% of the cork length. The holes can be due to insect damage or a large number of lenticels.

4. **Belly spots or cuts** - These are surface depressions caused by the inner density of the cork or by poor cutting of the cork cylinder. The defect is critical when the spots occur over 50% of the cork's length.

5. **Woody corks** - This condition results when a cork is cut too close to the bark surface. If over 50% of the cork is woody, it is a serious flaw.

6. **Chips, breaks and cracks** - This kind of damage usually occurs during the processing of corks. A dry cork is also prone to chipping and cracking. Larger chipped areas or cracks on the cork surface is a serious defect.

7. **Poor or improper surface coating** - The cork surface is often coated with paraffin, waxes, silicon, and other polymer coatings. The purpose of surface treatment is to make dry corking and cork extraction easier, and also to improve impermeability. When the coating is done improperly, it can cause problems during corking or in forming an effective seal.

8. **Dimensions not in accordance with designated size** - Incorrect cutting can result in corks that are smaller than the intended size. The cork diameter should not be less than 1 mm of the specified value and the cork length should not be below 2 mm of the specified limit. It is obvious that the cork that is smaller than the recommended size will not provide an effective seal.

Other problems associated with corks are sediment and off odors. Cork dust can sometimes be a source of unsightly deposits. The dust is produced during processing and can be located in large lenticels. Usually coating the cork prevents the dust from getting into the wine, but poor coating can release the dust into the wine, which can later form a sediment. Sometimes the deposits can be due to the presence of chemicals used in cork treatment, for example, calcium oxilate.

Cork taint or must and moldy odors can sometimes be imparted to a wine by a defective cork. There are many compounds which are associated with corky (musty and moldy) odors. Most important of these compounds is 2, 4, 6-trichloroanisol. It is commonly believed that when the cork bark is treated with calcium hypochlorite, the chlorine reacts with phenols to form chlorophenols. By the activity of microorganisms (present in the cork), these chlorophenols are convened to 2, 4, 6-trichloroanisol. When this compound gets into the wine, it imparts an off odor. It should be noted that this compound can get into the wine from various other sources.

Ouality Assessment of Wine Corks

In order to minimize cork related problems, a sound quality control plan should be followed. As noted earlier, the corks are separated into various grades, based on quality, before they are offered for sale. Cork is a natural product and some variation does occur in the quality of corks belonging to the same grade. Due to the variation in cork quality, it is important for the buyer to ensure that the corks received are true to the grade purchased. A proper sampling and visual inspection of corks conforming to a specified grade is the first step in quality control.

Wineries can use various criteria for assessing cork quality. The important quality parameters include:

1. Examining physical characteristics.
2. Checking dimensions.
3. Testing moisture content.
4. Sensory evaluation.
5. Checking microbial status.

Some of the important physical characteristics used in cork quality are:

1. Presence of holes.
2. Chips and cracks.
3. Large connected lenticels.
4. Condition of cork ends.
5. Sponginess.
6. Presence of green wood or hard wood.
7. Spacing between growth rings.
8. Belly spots.
9. Condition of the coating and other treatments.
10. Cork dimensions.

The results of the visual inspection should be recorded so that they can be used either for accepting or rejecting lots.

Cork Dimensions

The dimensions of the cork should be appropriate for the size of bottle. It should take into consideration the style of wine and the anticipated aging period. The diameter of the cork affects the sealing force exerted by the cork against the glass surface. It is, therefore, critical that the cork diameter be very close to the specifications. A cork caliper should be used to measure the dimensions. The wineries set various tolerance limits for accepting variance in diameter and length of the cork. For example, a variance of 0.05 to 0.4 mm for cork diameter, and a variance of 0.5 to 1 mm for cork length is acceptable.

Moisture Content

Moisture content influences the elasticity and microbial status of the cork. Moisture content in the range of 5 to 7% is desirable. Low moisture cork becomes brittle and it crumbles easily. A high moisture level invites microbial growth. Various methods can be used to measure the moisture level in the cork. Among them, using a moisture meter is a simple and rapid method.

Sensory Evaluation

The cork should be assessed for the presence of off odors. Various tests have been described to check for undesirable cork aromas. One winery samples several corks and places each cork individually into a small jar. The jar is filled with wine and stoppered. One jar is filled with wine only and is used as the control. After about five hours at room temperature, the wine is decanted and evaluated for the presence of musty or other off odors.

Amerine et al., (1970) suggested another procedure for testing the corks for off taste and aroma. According to their method, five to ten corks are randomly selected, cut into small pieces, and mixed. Five grams of mixed pieces are placed in 100 ml of 15% ethanol, warmed to l00ºF, and allowed to sit in a warm place overnight. The following day, the sample is filtered and checked for a musty odor.

There are several other test procedures described in the literature to test for tainted corks. It may be desirable to compare the various tests and adopt one that is simple and gives the best results.

Testing Microbial Status

Several methods are available to check the microbial status of the cork. They include extracting, filtering, culturing, and identifying the organisms. To perform this test, one needs training in microbiology and a well-equipped laboratory.

In addition to the tests mentioned above, the corks may be subjected to some additional tests to check their quality. These include checking the cork for elasticity, checking the extraction force needed to remove the cork, checking wine travel or cork wetting, and examining the corks for compression and recovery.

Although using a large number of tests gives a greater assurance of quality, from a practical standpoint, examining corks for physical defects, sizing within specifications, moisture, and cork taint may yield satisfactory results.

Recommended Procedure for Bottling, Corking, and Wine Storage

Whenever one comes across a leaky wine bottle, the immediate reaction, in most cases, is to blame the faulty cork. This may be justified in some cases. However, it needs to be emphasized that there are many factors other than a defective cork that can contribute to the problem of leaky bottles. Some of these include: bottle, filling head, corking machine, the operator of the corker, storage, and shipping conditions.

In order to prevent the problem of leaky bottles and pushed out corks, attention must be paid to the entire process of bottle filling, corking, and storage. The following recommendations regarding bottling techniques should be helpful in minimizing the problems indicated above.

Bottles

The bottle should be of appropriate size and the inside surface of the neck should be smooth. It should have a proper taper. The dimension of the neck should be checked with a gauge. Most wine bottles are produced according to certain standards, with a bore (inner neck) diameter of 18.5 + .5 mm at the lip (mouth) and 21 mm, 4.5 cm below the mouth. In other words, the width (diameter) of the bore increases from 18 mm to 21 mm over the length of 4.5 cm from the mouth. Note that the sides of the bore are not parallel. This design helps in limiting the movement of the cork after it is inserted.

Corker

a. The corking machine should be cleaned and maintained according to the manufacturer's directions.

b. The corking jaws should be cleaned and checked for wear and tear. They should be properly positioned. For example, a 24 mm diameter cork **should not** be compressed to less than 16 mm. Avoid compressing the cork greater than 35 to 40% of the original diameter. The compressing jaws should be smooth and should not cause any cut or groove to the cork.

c. Align the centering bell and the seal of the bottle neck properly. Change the position of the centering cone when the bottle type is changed.

d. Adjust the plunger so that the cork is inserted to the proper depth. It should not be pushed more than 1 mm below the top surface of the bottle mouth. To ensure cork insertion to the proper depth, the moisture content of the cork should be uniform.

Cork Dimensions
The diameter and the length of the cork should be appropriate for the size of the bottle neck. (For example, for a bottle with a bore size of 17.5 to 18 mm, a cork having a diameter of 24 mm should be used.) When inserted into the bottle, the cork will be compressed by about 6 mm. At this compression, it will exert a pressure of about 1 to 1.5 kg/cm^2 against the glass surface, which is adequate to seal table wine.

For wines with dissolved $C0_2$ (≤1 g/L) residual sugar (sweet wines), the cork diameter should be about 7 to 8 mm larger than the bottle bore. Champagne corks, which are required to withstand high pressure, usually have an even larger diameter of 30 to 31 mm. This means that they are compressed by about 12 mm.

A cork with a smaller or larger than recommended diameter should not be used. The smaller diameter cork will not exert enough pressure to prove an effective seal. The larger diameter cork can get wrinkled and thus cause a poor seal. The cork length is also important for effective sealing. Corks are usually available in three lengths: 1.5" (35 mm), 1.75" (44 mm), and 2.0" (49 mm). Generally a longer cork will provide a greater surface contact area with the glass and thus give a good seal. However, a longer cork will leave a smaller headspace and produce greater head pressure. These points, along with the cork dimensions (diameter and length), compatibility with the bottle bore, style of the wine, and the period of aging should be considered when selecting corks.

Cork Moisture
The significance of cork moisture content has been mentioned earlier. An important point to consider here is that the moisture content of the cork should be maintained between 5 to 7%. Lower than 5% moisture makes the cork brittle and prone to crumbling. A dry cork is also hard to feed in easily. High moisture in the cork promotes mold growth. It also increases the cork's elasticity; consequently, the cork expands rapidly during corking. This leads to higher under-the-cork pressure and the risk of wine leakage.

The cork should be stored in a clean cool place away from chemical storage areas, at a temperature of 50 - 70ºF and 50 to 70% humidity. Remember the cork can absorb off odors and can impart them to the wine through contact.

Bottling
Insertion of the cork into the bottle compresses the air trapped below the cork and above the wine, and generates excess pressure in the headspace. If the bottle is laid on its side or upside down shortly after corking, the pressure in the headspace can force some wine out, thus causing a leak. To release excess pressure and minimize the risk of wine leakage, the bottle should be stored upright (off the cork) for several hours immediately after corking.

Wine should preferably be bottled at a temperature of 60 to 70°F. If the bottles are filled with cold wine, the fill level should be adjusted to allow for the expansion of wine volume with the rise in temperature. It is also important to keep the bottles upright until the wine reaches the expected storage temperature.

To prevent the problem of wine leakage, many winemakers use a vacuum corker, and/or sparge the headspace with carbon dioxide. When a vacuum corker is used, a partial vacuum or negative pressure is created in the headspace. The negative pressure gradually dissipates as the dissolved CO_2 from the wine fills the headspace. When CO_2 is injected before corking, the air from the headspace is displaced by CO_2. As the CO_2 is dissolved into the wine, the positive headspace pressure is reduced.

Other than the reduction in headspace pressure, there are other benefits to using a vacuum corker and/or sparging headspace with CO_2. These include the lowering of the oxygen level in the headspace, less reduction in the concentration of added sulfur dioxide, and above all, the bottles can be stored upside down (to keep the cork moist) shortly after corking.

Wine Storage and Shipping
The bottled wine should be stored in a cool dry place. The temperature of the storage should be between 15 to 20°C. Sometimes in a warehouse or during transit in the summer months, a substantial increase in temperature (30 to 35°C) can occur. The rise in temperature can result in excess head pressure and cause wine leakage. It should be pointed out that two factors contribute to high pressure with the increase in temperature. First, the expansion in the volume of the wine; and second, the expansion of gas in the

headspace. The problem is made worse since gas expands ten times more than the wine with the rise in temperature.

The Operator(s)
The employees working on the bottling line should be well trained in the job. They should be mechanically inclined to understand the working of the corking machine. They should also take pride in their work and be committed to quality.

References
1. Amerine, M.A. and M.A. Joslyn. 1970. Table wines: The technology of their production. University of California Press, Berkeley, CA.

2. Amon J.F. and R.F. Simpson. April, 1986. Wine corks: A review of the incidence of cork related problems and the means for their avoidance. The Aust Grpgrw & Wnmkr. #268:63-80.

3. Casey, J.A. April, 1989. Closures for wine bottles-A user's viewpoint. The Aust. Grpgrw & Wnmla. #304:99-108.

4. Gibson, L.J., K.E. Easterling, and M.P. Ashby.
1981. The structure and mechanics of cork. Proc. Royal Soc., London. A 377:99-117.

*Previously published in *Vineyard & Vintage View*, Mountain Grove, MO.