Smoothing the Way for High Purity Process Systems

The stainless steels are the preferred materials of construction for tanks, reactor vessels, valves, pumps and process piping where high purity systems are required. Water for Injection (WFI) and Purified Water (WPU) are essential to many processes in the pharmaceutical and biopharmaceutical industries and the established standards of purity are consistently and reliably met by stainless steel equipment and piping. The hygienic properties of the stainless steel alloys are important to the food, dairy and beverage industries, minimizing microbial contamination of the materials being processed. This concern for purity is reflected in the demand for smoothness for the interior surfaces (surfaces that are in contact with the fluids used) of the process
Equipment and process piping. It has been established that the treatment of the stainless steel alloy prior the service can be critically important. The surface smoothness can be maximized to reduce the likelihood of localized corrosion, particularly at the weld areas. Furthermore, the formation of a homogeneous, passive film at the metal surfaces enhances the long- term performance of the system, again providing resistance to corrosion.

How important is the smoothness of the interior surfaces?
The rate of corrosion of metals and metal alloys is dependent upon several factors, one being the real surface area in contact with the fluids being used in the process. Roughness increases the real surface area and therefore the rate of corrosion. Surface smoothness affords several other advantages to the process industries:

- providing the ability to clean and disinfect the system efficiently and reproducibly
- minimizing the sites available for microbial growth
- reducing turbulence in the fluid flow
- inhibiting erosion corrosion processes, i.e., the loss of surface material due to the velocity of the flow
- minimizing the adherence of particulate material to the metal or alloy surface

How are smooth surfaces obtained?
The metal or alloy surface may be smoothed by either mechanical or chemical treatments, or by electropolishing. There are eight basic stainless steel mill plate finishes available and several of these are produced by mechanical surface treatments, i.e., using abrasive compounds, grinding and buffing processes. For example, the Polished #3 finish is an intermediate finish obtained using a 50-80 grit compound as the abrasive. The Polished #4 finish is a stainless steel finish that is widely used for dairy equipment. This finish is obtained with a final polish using a 100150 grit. Although microscopically flat the resulting surface has grooves and cavities that tend to entrap and contain contaminants. Smoother surfaces, such as the Buffed #6 and Buffed #7 surfaces, require abrasion with 200 and 220 grit abrasives respectively and are finally buffed using a white chrome rouge. The #6 and #7 finishes have a high degree of reflectivity (mirror like) with a non-directional surface texture.

The heat treatments and processing of the stainless steels typically result in the formation of surface scale and discolorations that may have to be removed. This requires a chemical treatment, i.e., immersion in a “pickling bath” or the use of pickling pastes on the metal surface. The pickling bath may be a mixture of aqueous solutions of nitric and hydrofluoric acids or a solution of citric acid and the treatment of the stainless steel is carried out at temperatures ranging from 25 to 45˚ C. The length of time of this chemical treatment will depend upon the thickness and composition of the scale.

Electropolishing is a process by which metal is removed from the substrate by passage of an electric current, with the substrate immersed in an electrically conductive solution, usually an aqueous solution. The substrate being polished is polarized anodically and a counter electrode completes the circuit to allow the current to flow. Metal is removed at a rate that is proportional to the applied current and the amount of metal electrochemically dissolved is dependent upon the electrolyte, temperature, current density (which is itself dependent upon the real surface area) and time. Electropolishing is particularly suitable for components that are susceptible to mechanical damage and/or have complex geometries. The “art” of electropolishing is the ability of the technician to configure the counter electrode (or cathode) to optimize the polishing process in inaccessible areas, corners, and areas where the current density will be low. It is also important to know when, where and how to provide agitation to avoid flow marks, gassing streaks and other undesirable markings.

A different approach to electropolishing has recently been developed by Faraday Technology (Clayton, Ohio) and is based upon the use of programmed current pulses, in contrast to the direct current applied in the conventional method. The new approach offers several advantages:

- it is a flexible method and the frequency and amplitude of the pulses can be easily changed as the profile of the surface changes
- it can be used with neutral electrolytes to avoid compatibility issues between the work piece, process, and materials of construction
- the oxide layer formed on stainless steel alloys provides enhanced corrosion resistance
- the pulse technique rapidly polishes the surface and is capable of replacing two step polishing processes.

This new approach to electropolishing may be regarded as a direct replacement for the conventional approach and will therefore be similarly limited in terms of the size of the work piece.

Why the concern over surface scale?

The superior corrosion resistance of the stainless steels, relative to carbon steels or mild steels, does not mean that the alloys do not corrode. In fact the stainless steels are subject to several types of corrosion, including pitting, crevice, stress cracking, intergranular and general corrosion. Problems occur when microscopically small particles of foreign matter are left on the surface of the alloy. Debris from grinding operations, abrasives, polishing and buffing compounds, can contribute to corrosion of the stainless steel. For processes that demand high purity it is essential to remove this surface scale. The presence of particles of iron on the alloy surface results in the formation of “rouge,” a red-brown film of iron oxide. This film may be physically wiped from the surface of the alloy. However, if the iron particles in the surface are not completely removed, the oxide layer is quickly reformed. The presence of surface “rouge” is a major concern when high purity is required, e.g., in the production of Water for Injection (WFI) and Purified Water (WPU) in the pharmaceutical industry.

In addition, the chromium at the surface of the stainless steel alloy will react with atmospheric oxygen to form a passive film, which protects the steel substrate by inhibiting general corrosion. However, this film must be homogeneous and the presence of surface impurities compromises the integrity of the passive layer.

How is surface smoothness measured?
A detailed surface topography may be obtained using scanning electron microscopy (SEM), which is an ultra-high vacuum technique. Surface roughness is more conveniently measured using a profilometer and is expressed as the arithmetic mean of the departure of the peak heights and valley depths from the center line over several sampling lengths. This average is termed the Ra value and is given in microns. Low Ra values are indicative of the smoother surfaces. For example, the Ra values for the mill plate finishes #s 3,4,7 and 8 are respectively 140, 24-45, 8-20 and 6-15.

Which surface treatment is preferred by the process industries?
For high purity requirements electropolishing offers significant advantages over mechanical surface treatments and is more versatile than the chemical treatments. Use of electropolishing results in a surface that is very smooth, brightened, stress relieved, cleaned and deburred. It has also been shown that the electrolytes used in this process enhance the formation of the passive film at the metal or alloy surface. Mechanically polished surfaces contain scratches, strains, metal debris and embedded abrasive particles. Furthermore, the cold working that accompanies grinding and polishing operations penetrates into the bulk metal and decreases the tensile strength.

A&B Process Systems has designed, fabricated and installed stainless steel systems for the process industries for over thirty years. Supporting this capability, the company has dedicated resources for testing equipment and a team of QA/QC professionals to ensure that all aspects of compliance and certification are met. The measurement of the surface roughness using the surface profilometer is one of the several testing and inspection methods used by A&B, particularly when fabricating equipment designed to provide products of high purity.

The importance of surface finish to A&B Process Systems is illustrated by the series of samples that the company has frequently exhibited and is available to all customers. These samples show the different levels of smoothness that may be obtained with stainless steels and in weld areas. Upon request A&B Process Systems will provide their “Surface Finish Cross Reference Chart.” This chart conveniently displays the range of surface conditions that may be obtained, tabulating grit numbers, Ra and Rmax values for various USA finishes, together with the corresponding ISO Numbers, ASTM and Japanese standards.