## Objective

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## Outcomes

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### 1.1 Food Legislation
- International regulations
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- Risk Management
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- Security in the plants and manufacturing process
- Due Diligence
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- Showing how Due Diligence has been practised
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- Consumer Complaints Related to Product Safety

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MODULE ONE

**Objective:** Define Food Safety Legislation and how it applies to the beverage industry

**Outcomes**

- Define Food Safety Legislation at international level and how it is applied in your plant.
- Explain the importance of Due Diligence within the Food Safety Legislation when a Consumer Product complaint is recorded at your plant.
- Define and apply HACCP to identify and analyse a problem in the plant.

### 1.1 Food Legislation

**International Regulations**

The World Health Organisation (WHO)/Food and Agriculture Organisation (FAO) Codex Alimentarius Commission states “People have the right to expect the food they eat to be safe and suitable for human consumption”. This implies that the consumer is not expected to check for foreign objects, chemical or biological contamination before consuming the product. The product should be safe by default.

The World Trade Organisation (WTO) Sanitary and Phytosanitary (SPS) Agreement states “Members have the right to take SPS measures for the protection of human life”. Countries who are members of WTO are allowed to legislate for the purpose of protecting their citizens. In the case of the developed world, they will have to help the developing nations to comply.

The international food safety legislations have been tied to HACCP to bring focus on preventative measures. HACCP was adopted by WHO in 1969 as part of the Food Standard Programme. Food Hygiene principles or food industry GMP (Good Manufacturing Practice - see addendum) is also part of this programme. The 1993 EU (European Union) Directive on Food Hygiene initiated the momentum around the World on promulgation of food safety regulations that are in line with HACCP principles. This EU Directive required EU member countries to have HACCP type legislation in place by 1995. Because of the size of the European market, most countries outside Europe had to follow suit in order not to lose out. In the United States, FSIS (Food Safety Inspection Services) of US Department of Agriculture guides the implementation of HACCP in identified food related industries. The UK Food Safety Act of 1990 hinged around companies who manufacture or handle food to be able to demonstrate due diligence. In South Africa, the HACCP legislation NR 495 was promulgated as part of the Foodstuffs, Cosmetic and Disinfectant Act.

HACCP is intended to be a system that manages or controls food safety hazards but it is important for manufacturers or food handlers to design out these hazards. This means that the location, premises, equipment and practices should be established in such a manner that hazards are not introduced e.g. locating premises in an area prone to floods or using equipment not designed for cleanability will result in unmanageable hazards. Because of this requirement, HACCP legislation includes the application of good hygiene principles as an ‘infrastructure’ for HACCP systems.

**Company Policies and Procedures**

The company policy on food safety should be developed and aligned with the organisation’s vision, mission statement and values. The policy should be consumer focused. It should spell out the product safety system that will be used and how it will be regularly reviewed for continuous improvement as well as to guarantee effectiveness.
Other product safety policies and procedures must be integrated with quality assurance measures such as documentation and record keeping, corrective and preventative action, management reviews and consumer satisfaction.

Risk Management

Food safety measures must be part of risk management procedures of an organisation. The failure to produce safe and suitable food products will affect the brands, which in turn will reduce revenues and result in losses. When this occurs, the company value is negatively affected and shareholders’ worth is reduced. Turnbull’s requirements on risk management or Cadburys and King’s reports on Corporate Governance require that Board members should do everything possible to protect shareholders’ funds. A functional food safety management system reduces the risk of losses that might be incurred due to product recalls, litigation or civil law suits. Above all, the integrity of brands must be protected.

Risk assessment of all potential hazards should be conducted to establish the risk level as low, medium or high. Appropriate control measures should be instituted where risk is too high and measures of designing out the hazard should be considered.

HACCP

HACCP stands for Hazard Analysis and Critical Control Point. This a food safety management system which was developed by NASA in the late 60’s to ensure the safety of food that was going to be consumed by Astronauts during the space mission. The HACCP system was later adopted by WHO as part of the Food Standard Program. Since then, HACCP has been legislated in many countries as a consumer safety system to demonstrate due diligence.

HACCP system is implemented by applying six internationally recognised principles, which identifies hazards in every process step in the following manner:

- determine critical control points;
- establish critical limits for control points;
- establish critical control point monitoring procedure;
- establish documentation and record keeping procedure;
- establish HACCP review system.

The implementation of HACCP system is a team effort. The failure or success of the HACCP system will therefore rely on the composition of the team that did the HACCP study (with respect to expertise in product, process, technology, etc. and the quality of facilitation). A HACCP facilitator should be appropriately trained in GMP and HACCP system and the implementation thereof. A HACCP system should be deployed and managed according to company policies and reviewed regularly for continuous improvement and effectiveness.

Security in the Plants and in the Manufacturing Process

The food and beverage industry is sometimes faced with tampering of product with the intention to injure or render consumers sick. This may be done by employees of the company, external persons or extortionists.

HACCP is a product safety management system which focuses on the hazards associated with the production processes. HACCP is not intended for product tampering or preventing malicious damage to product after production. However, some of the HACCP principles can be adapted to identify potential modes of tampering with the product. A risk analysis should be conducted. The focus on potential tampering can be internal and/or external. The security measures put in place should cater for both. Special security measures are put in place to guard against internal tampering, which include structural redesigns in manufacturing processes to eliminate potential areas of tampering. External or market place intervention will require using packaging that is
Due Diligence

Due diligence is a method of defence used by business to demonstrate that they took all reasonable and humanly possible steps to prevent an offence from happening. From the food safety point of view, due diligence defence will relate to manufacture, sale or distribution of unsuitable and unsafe food, incorrect labelling or description of food, inappropriate consumer related information about product storage and preparation and non-compliance with food safety standards.

Contamination Prevention

Contamination of food can render it unsafe and unsuitable for human consumption.

Preventing contamination in a food product is the key to consumer safety. The prevention of contamination requires focus on all components of production; raw materials quality assurance, plant location, plant hygiene, the design and layout, process control, plant maintenance, waste management and pest control. To prevent contamination, a systematic approach is required.

Most of the prominent cases of reported contamination or food safety incidents in beverage products have been linked to raw materials.

The HACCP system focuses on preventing contamination by adopting a systematic approach to food safety management. Contamination of beverage products comes in three forms:

1. chemical contamination due to cleaning product residues or formation of carcinogenic compounds due to the presence of nitrate reducing bacteria;
2. physical contamination due to broken glass or other solid objects;
3. microbiologically, such as the presence of pathogenic bacteria. In the case of beer, due to its composition, pathogens cannot grow in it so the only concerns are spoilage micro-organisms.

Showing how Due Diligence has been Practised

Due Diligence requires a company to demonstrate that they are doing everything possible to safeguard the safety of consumers. The adoption of a food safety system like HACCP helps in due diligence defence.

Case Study of Due Diligence

There are some high profile cases of product contamination (Table 1.1) that have resulted in huge financial losses due to product withdrawals and recalls. When these cases occur, they may result in losses in revenues, profit warnings and subsequent collapse in share price.

These cases help to emphasise the importance of implementing the HACCP programme across the entire manufacturing value chain from material suppliers to sales outlets.
### Table 1.1 Examples of Cases of Product Contamination

<table>
<thead>
<tr>
<th>Incident</th>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Industrial Case 1</strong></td>
<td>Bass Breweries recalled beer due to contamination by glycol. The incident occurred during World Cup in France 1998. This resulted in a profit warning and collapse of the share price. The loss was estimated at $20m.</td>
</tr>
<tr>
<td><strong>Industrial Case 2</strong></td>
<td>Budweiser recalled beer packaged with twist-off caps from ten European countries after receiving a complaint on the glass. The cost of recall was not disclosed.</td>
</tr>
</tbody>
</table>

### 1.2 HACCP Plan

#### HACCP Team

The purpose of having a HACCP team is to ensure that the HACCP studies are conducted by a competent multidisciplinary team. The team should comprise technology, process and product experts as well as quality assurance and microbiology experts. Heading the team is the HACCP facilitator who reports to the executive representative on product safety matters (Fig. 1.1). Since HACCP is legislated in many countries, team members should be officially appointed by the most senior person on site *i.e.* General Manager, CEO or Managing Director. The responsibilities of the team members should be clearly defined and their duties included in agreed performance measures.

![HACCP Organogram](image-url)

**Fig. 1.1 HACCP Organogram**

#### HACCP Scope and Product Description

HACCP study will start and end at a certain point. It is preferable to scope the HACCP study in a manner that will allow the team to conduct the HACCP study in areas where they have control *e.g.* from manufacturing (brewing, packaging) to distribution warehouse.

The product is described fully by including physical and chemical properties and any characteristic that will affect the consumer safety.
Identify Product Use

The use of the product is identified to gauge the consumer safety risk associated with the target market. For instance when the product is used by infants or elderly, the risk would be high.

Process Flow Diagram (PFD)

The process flow diagram (Fig. 1.2) is used to describe how the product is made. A good PFD will include inputs, sub-processes, process and by-products. This may appear too detailed but when HACCP is integrated with a system like ISO 9000 and 14000, it works very well. The following PFD is shown as an example.

![Process Flow Diagram](image)

**Fig. 1.2 Process Flow Diagram**

On-site Investigation of PFD

It is important for the HACCP team to walk the plant and verify the process flow diagram. Once verified it should be signed off by a relevant responsible person as the true reflection of the process flow. The signing-off should be treated as a control document to cater for process modifications that may happen in future.

Identification of Hazards

Hazard identification is the step in a HACCP study that is the most important and its effectiveness relies on the composition of the HACCP team. Any under representation of disciplines will show by missing some of the hazards that are critical for consumer safety. The hazard identification process involves the identification of all hazards that may affect consumer safety in every process step. For HACCP purposes hazards identified should be limited to those that may affect consumer safety, otherwise the process loses focus. Hazards that may come with the raw materials should be handled within the raw materials quality assurance system. The raw materials specifications must comply with food grade requirements as indicated elsewhere. Food Chemical Codex 4th Edition is a good source of information of food grade specifications. It is an internationally accepted document put together by Codex Alimentarius Commission (Food Code Commission), which is a Joint Committee of WHO and FAO. Sometimes the Joint Committee of Food Additives
(JECFA) specifications are used. Individual countries sometimes prefer to use specifications from their own local regulating body like USFDA in the USA or relevant EU Directives in Europe. In South Africa, regulations from Foodstuffs, Cosmetics and Disinfectants Act are used as well. These regulations, codes or directives will cover food grade specifications of every material: water, additives, ingredients, colourants, water treatment chemicals, flavourants, grease/oil/lubricants including hoses. There are also codes governing the use of cleaning and sanitising chemicals.

In other words, raw materials quality assurance is very important for food safety with respect to specifications and supplier surveillance considerations.

**Determination of CCP’s**

Once hazards have been identified, critical control points (CCP) are determined using a decision tree (Fig. 1.3). The definition of a critical control point is a process step or procedure where significant control can be exerted to prevent or eliminate a food safety hazard or reduce it to levels specified in the relevant industry standards.

The decision tree goes through four questions, which should be answered to determine whether the hazard identified has a critical control point. If the hazard has no critical control point, the process step or procedure should be modified to either control the hazard or design out the hazard. A hazard can have more than one CCP. If the decision tree is not used properly, an organisation may end up with too many CCPs, which can be difficult to manage or have too few CCPs, which will compromise consumer safety. Below is an example of the decision tree.

![CCP Decision Tree](image)

**Fig. 1.3 CCP Decision Tree**

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Targeting Levels and Critical Levels

The targeting or critical level is the minimum or maximum level that the control parameter is set at in order to control the hazard, e.g. say 600°C is the critical temperature that needs to be achieved in order to kill a certain pathogenic micro-organism in a specified process step; then 600°C is the critical level of temperature. These levels should be established and validated to ensure that the CCP is effective in reducing the hazard to levels specified in the relevant industry standards.

CCP Monitoring Procedures

The CCP should be monitored appropriately to ensure effective control of the identified hazards. The monitoring procedure should spell out what is being monitored at what critical level, to control what hazard, what is the frequency of monitoring and who is responsible for monitoring the CCP. The record keeping of the CCP monitoring should be described. As part of monitoring procedures, verification procedures should be in place to ensure that CCP monitoring is always working.

Corrective/Deviation Action

Corrective or deviation action procedure describes what will be done to the product or process if there was an incident of exceeding the critical limit of the CCP. This is normally linked to the company correction/preventive action system. Records of deviation or corrective actions should be kept as per company record keeping procedure.

HACCP Review

Regular review of HACCP system will ensure that the system is effective in providing consumer safety and that the system is continuously improved. The regular review of the system is done through internal audits, management reviews and HACCP certification programme. HACCP plan review triggers should be in place to ensure that the HACCP system is updated whenever necessary. These HACCP review triggers include, change in product formulation, change in raw materials, plant modification, increase in specific consumer complaints related to safety and change in food safety legislation.

Documentation

To maintain the HACCP system will require a proper document control and record keeping system. HACCP document control procedures should be integrated with the procedure used for ISO or any other quality assurance system. Record keeping procedures should comply with legal requirements with respect to duration.

Consumer Complaints Related to Product Safety

The consumer complaint system for the HACCP purposes should allow the separation of quality related complaints from the safety related complaints. The complaints should be analysed for trends to be able to take appropriate corrective action.
Addendum: Application of Food Hygiene Principles

Introduction

The production of safe food suitable for consumption relies on management following the basic rules of food hygiene. The location, the design of plant facilities and maintenance thereof, the behaviour of personnel and product information must render the food product unsuitable for consumption i.e. the basic structures and systems must not be to the detriment of the safety of food product.

The WHO/FAO Codex Alimentarius International Code of Practice on Food Hygiene has been used in writing this document. This assessment document is meant to evaluate the degree of compliance to food hygiene standards of food and beverage companies requiring an answer of either YES or NO per element. For organisations embarking on HACCP, the food hygiene programme is the prerequisite for implementing HACCP.

Definitions

For the purpose of this document, the following expressions have the meaning stated below:

- **Adequate**: sufficient to accomplish the intended purpose
- **Cleaning**: the removal of soil, food residue, dirt, grease or other objectionable matter
- **Contaminant**: any biological or chemical agent, foreign matter or other substances not intentionally added to food, which may compromise food safety or suitability
- **Disinfection**: the reduction of the number of micro-organisms by means of chemical agents and/or physical methods to a level that does not compromise food safety or suitability
- **Production Plant**: any building or area in which food product is manufactured and the surroundings under the control of the same management
- **Food Hygiene**: all conditions and measures necessary to ensure the safety and suitability of food at all stages of the food chain
- **Food Safety**: assurance that food will not cause harm to the consumer when it is prepared and/or eaten according to its intended use
- **Food suitability**: assurance that food is acceptable for human consumption according to its intended use
- **HACCP**: a system, which identifies, evaluates and controls hazards, which are significant for food safety
- **Pest**: any animal capable of directly or indirectly contaminating food
- **Potable Water**: water that complies with or exceeds WHO guidelines on drinking water
- **Safe**: containing no substance likely to cause harm to the consumer
Good Manufacturing Practice (GMP) Assessment

a) Raw Materials Quality Assurance System

**Objective:** To ensure that raw materials quality (manufacturing, packaging and utilities) does not pose a threat to product safety and suitability from their production to receipt.

<table>
<thead>
<tr>
<th>Important Elements</th>
<th>Yes/No</th>
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<tbody>
<tr>
<td>Raw materials production plant is not located in areas prone to pest infestation and environmental hazards affecting food safety and suitability</td>
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</tr>
<tr>
<td>Raw materials specifications and transportation requirements minimise or eliminate food safety related hazards.</td>
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<tr>
<td>There are systems in place to ensure consistency of raw materials quality</td>
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</tr>
<tr>
<td>The production process of raw materials minimises risk to possible contamination and control measures are in place to control this risk</td>
<td></td>
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<tr>
<td>On site raw material receipts and storage facilities minimise or eliminate the possibility of contamination</td>
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<td>Comments:</td>
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b) Production Plant Design and Facilities

**Objectives:** Plant design and facilities must allow appropriate maintenance; good hygiene practices and materials of construction where there is the possibility of contact with food, must be of food grade standards.

**Sub-section 1**

<table>
<thead>
<tr>
<th>Important Elements</th>
<th>Yes/No</th>
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<tbody>
<tr>
<td>The production plant is located in an area prone to pest infestation or environmental hazards.</td>
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<tr>
<td>Equipment location permits adequate maintenance and cleaning, facilitates good hygiene practices and monitoring.</td>
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<tr>
<td>Design and layout of premises and rooms permit good hygiene practices including protection from the possibility of cross contamination.</td>
<td></td>
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<tr>
<td>Internal structures and fittings are made from materials which are non-toxic and permit good hygiene practices.</td>
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<tr>
<td>Floors allow cleaning and adequate drainage.</td>
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<tr>
<td>Ceilings and overhead fixtures minimise build-up of dirt, condensation and shredding of particles.</td>
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<tr>
<td>Windows are of appropriate design to minimise build-up of dirt and entry of insects.</td>
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<tr>
<td>Doors can be easily cleaned and disinfected.</td>
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<td>Comments:</td>
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**Sub-section 2**

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<tr>
<th>Important Elements</th>
<th>Yes/No</th>
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<tr>
<td>Equipment coming into contact with food can easily be cleaned, disinfected and maintained and of food grade standard.</td>
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<tr>
<td>Equipment allows monitoring of harmful and undesirable micro-organisms and their toxins can be eliminated or reduced to acceptable levels.</td>
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<tr>
<td>Equipment allows effective monitoring of critical control points.</td>
<td></td>
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<tr>
<td>Equipment allows effective monitoring of temperature and other conditions necessary for food safety.</td>
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<tr>
<td>Containers of non-food or dangerous substances are identifiable and suitably constructed and locked away to prevent food contamination.</td>
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</table>
MODULE 1  Objective: *Define Food Safety Legislation and how it applies to the beverage industry*

### Sub-section 3

<table>
<thead>
<tr>
<th>Important Elements</th>
<th>Yes/No</th>
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<tbody>
<tr>
<td>Quality of water used in production areas meet or exceed WHO requirements.</td>
<td></td>
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<tr>
<td>Non-potable water systems are easily identifiable.</td>
<td></td>
</tr>
<tr>
<td>Drainage and waste disposal systems are effective in removing waste.</td>
<td></td>
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<tr>
<td>CIP systems and facilities for cleaning utensils and equipment are suitably designed and effective.</td>
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<tr>
<td>Personnel ablution facilities are appropriately designed and maintained.</td>
<td></td>
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<tr>
<td>Personnel change-room facilities are clean and well maintained.</td>
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<tr>
<td>Handwashing facilities are hygienically designed and have adequate supply of hot and cold water.</td>
<td></td>
</tr>
<tr>
<td>Adequate facilities of heating, cooking, cooling, refrigerating and freezing the product are available.</td>
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<td>Comments:</td>
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### Sub-section 4

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<thead>
<tr>
<th>Important Elements</th>
<th>Yes/No</th>
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<tbody>
<tr>
<td>Natural or mechanical ventilation minimises airborne contamination.</td>
<td></td>
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<tr>
<td>Natural or mechanical ventilation adequately controls ambient temperature, odours and humidity.</td>
<td></td>
</tr>
<tr>
<td>Natural or artificial lighting is adequate.</td>
<td></td>
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<tr>
<td>Lights are protected to eliminate physical hazards from breakage.</td>
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</tr>
<tr>
<td>Appropriately designed and constructed storage facilities for ingredients and non-food chemicals are provided.</td>
<td></td>
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<tr>
<td>Storage facilities for non-food or hazardous chemicals are secured.</td>
<td></td>
</tr>
<tr>
<td>Storage areas are adequately cleaned and maintained.</td>
<td></td>
</tr>
<tr>
<td>Storage facilities are designed and constructed to avoid pest access and harbourage.</td>
<td></td>
</tr>
<tr>
<td>Storage facilities allow effective control of temperature and humidity.</td>
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<td>Comments:</td>
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c) **Control of Production Operation**

*Objective:* Design requirements and specifications of raw materials, product composition, processing, distribution and preparation must not render the product unsafe and unsuitable for human consumption. Monitoring systems implemented must be monitored and reviewed for effectiveness.

### Sub-section 1

<table>
<thead>
<tr>
<th>Important Elements</th>
<th>Yes/No</th>
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</thead>
<tbody>
<tr>
<td>Food hazards are controlled by identifying steps in the operation which are critical to food safety</td>
<td></td>
</tr>
<tr>
<td>Effective control measures are implemented for these steps.</td>
<td></td>
</tr>
<tr>
<td>Control measures are monitored for effectiveness.</td>
<td></td>
</tr>
<tr>
<td>Control measures are reviewed periodically based on pre-determined triggers.</td>
<td></td>
</tr>
<tr>
<td>Effective time and temperature control systems are in place to minimise food-borne illness or food spoilage.</td>
<td></td>
</tr>
<tr>
<td>Time and temperature devices are regularly tested for accuracy.</td>
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<td>Comments:</td>
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**Sub-section 2**

<table>
<thead>
<tr>
<th>Important Elements</th>
<th>Yes/No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical, physical, biological and controls specifications are based on sound scientific principles.</td>
<td></td>
</tr>
<tr>
<td>Validated monitoring procedures, analytical methods and critical limits are used.</td>
<td></td>
</tr>
<tr>
<td>Microbiological cross-contamination is prevented by separating raw, unprocessed materials from finished products.</td>
<td></td>
</tr>
<tr>
<td>High risk areas are accessed via change facilities where clean protective clothing, including footwear, are worn and hands washed.</td>
<td></td>
</tr>
<tr>
<td>Systems are in place to prevent contamination by foreign objects and unwanted chemicals.</td>
<td></td>
</tr>
<tr>
<td>Only raw materials meeting specification are used.</td>
<td></td>
</tr>
<tr>
<td>Packaging design and materials provide adequate protection for product and minimise contamination.</td>
<td></td>
</tr>
<tr>
<td>Re-usable packaging is durable and easy to clean and disinfect.</td>
<td></td>
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<tr>
<td>Comments:</td>
<td></td>
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**Sub-section 3**

<table>
<thead>
<tr>
<th>Important Elements</th>
<th>Yes/No</th>
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</thead>
<tbody>
<tr>
<td>Only potable water is used in food handling, processing and water as ingredient.</td>
<td></td>
</tr>
<tr>
<td>Ice is made only from potable water.</td>
<td></td>
</tr>
<tr>
<td>Steam is made from potable water and boiler water treatment chemicals are food grade.</td>
<td></td>
</tr>
<tr>
<td>Management have enough knowledge of food hygiene principles.</td>
<td></td>
</tr>
<tr>
<td>Proper documentation procedure exists.</td>
<td></td>
</tr>
<tr>
<td>Production and distribution records are kept for a period longer than the shelf-life of the product.</td>
<td></td>
</tr>
<tr>
<td>Effective product recall procedure is in place.</td>
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<td>Comments:</td>
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</table>

d) Plant Maintenance and Sanitation

**Objective:** To establish effective systems to ensure that adequate cleaning, maintenance, pest control and waste management are in place and that there are proper management systems to monitor the effectiveness thereof.

**Sub-section 1**

<table>
<thead>
<tr>
<th>Important Element</th>
<th>Yes/No</th>
</tr>
</thead>
<tbody>
<tr>
<td>The plant and the equipment are kept in a good state of repair.</td>
<td></td>
</tr>
<tr>
<td>Equipment functions as intended, particularly the monitoring of CCPs.</td>
<td></td>
</tr>
<tr>
<td>Building maintenance is effective to prevent contamination of product by flaking paint, debris and metal shards.</td>
<td></td>
</tr>
<tr>
<td>Plant and equipment maintenance allow effective cleaning of dirt and product residue to minimise contamination.</td>
<td></td>
</tr>
<tr>
<td>Factors important for effective cleaning are understood by operators and management.</td>
<td></td>
</tr>
<tr>
<td>Sanitation programmes are effective and sanitisers used are approved for use in food industry</td>
<td></td>
</tr>
<tr>
<td>Comments:</td>
<td></td>
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</tbody>
</table>
Sub-section 2

<table>
<thead>
<tr>
<th>Important Elements</th>
<th>Yes/No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good hygiene practices are employed to avoid creating an environment conducive to</td>
<td></td>
</tr>
<tr>
<td>pest.</td>
<td></td>
</tr>
<tr>
<td>Buildings are in good repair to prevent pest access and eliminate potential breeding</td>
<td></td>
</tr>
<tr>
<td>sites.</td>
<td></td>
</tr>
<tr>
<td>Holes, drains are kept sealed.</td>
<td></td>
</tr>
<tr>
<td>Open windows, doors and ventilation systems are screened.</td>
<td></td>
</tr>
<tr>
<td>Potential food sources are stored in pest-proof containers and are stacked away from</td>
<td></td>
</tr>
<tr>
<td>ground and away from walls.</td>
<td></td>
</tr>
<tr>
<td>Pest control system used is appropriate for food establishments.</td>
<td></td>
</tr>
<tr>
<td>Waste removal and storage is effective.</td>
<td></td>
</tr>
</tbody>
</table>

Comments:

e) Personal Hygiene

Objectives: To ensure that those coming into contact with food are not likely to contaminate product by maintaining an appropriate degree of personal cleanliness; behaving and operating in an appropriate manner.

<table>
<thead>
<tr>
<th>Important Elements</th>
<th>Yes/No</th>
</tr>
</thead>
<tbody>
<tr>
<td>People known or suspected to be suffering from or to be carrier of, a disease or illness transmitted through food are barred from entering food handling areas.</td>
<td></td>
</tr>
<tr>
<td>Employee conditions detrimental to food safety are reported to management e.g. jaundice, diarrhea, vomiting, fever, infected skin lesions, etc.</td>
<td></td>
</tr>
<tr>
<td>Operators or food handlers maintain high degree of personal cleanliness and wear protective clothing where appropriate.</td>
<td></td>
</tr>
<tr>
<td>Employees always wash their hands before food handling, after using toilet and after handling raw food or contaminated material.</td>
<td></td>
</tr>
<tr>
<td>Food handlers do not engage in behaviour that will affect food safety e.g. smoking, spitting, chewing or eating, sneezing or coughing.</td>
<td></td>
</tr>
<tr>
<td>Personal affects like watches and jewellery are not worn or brought to food handling areas.</td>
<td></td>
</tr>
<tr>
<td>Visitors and contractors coming into processing areas wear appropriate protective clothing and adhere to stipulated personal hygiene provision.</td>
<td></td>
</tr>
</tbody>
</table>

Comments:

f) Transportation

Objective: To provide measures necessary to protect product from contamination and damage and to provide an environment which effectively controls the growth of pathogenic and spoilage micro-organisms or the production of toxins in food.

<table>
<thead>
<tr>
<th>Important Elements</th>
<th>Yes/No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation systems are designed not to contaminate food.</td>
<td></td>
</tr>
<tr>
<td>Transportation facilities can be effectively cleaned and sanitised.</td>
<td></td>
</tr>
<tr>
<td>Transportation facilities allow effective separation of different foods or food from non-food items.</td>
<td></td>
</tr>
<tr>
<td>Transportation systems permit effective maintenance of temperature, humidity and other conditions that prevent microbial growth.</td>
<td></td>
</tr>
<tr>
<td>Transportation systems can be effectively maintained and the hygiene status can be monitored at all times.</td>
<td></td>
</tr>
</tbody>
</table>

Comments:
MODULE 1  Objective: Define Food Safety Legislation and how it applies to the beverage industry

**g) Product Information and Consumer Awareness**

**Objective:** Appropriate information should be provided to ensure proper handling storage and preparation of food: batch or lot to be easily identifiable.

<table>
<thead>
<tr>
<th>Important Element</th>
<th>Yes/No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product is clearly identified by lot or batch code or number.</td>
<td></td>
</tr>
<tr>
<td>Adequate product information is provided for proper storage, handling and preparation.</td>
<td></td>
</tr>
<tr>
<td>Labelling is clear and easy to read.</td>
<td></td>
</tr>
<tr>
<td>Consumer education is provided where necessary.</td>
<td></td>
</tr>
</tbody>
</table>

**Comments:**

**h) Personnel Training**

**Objective:** People engaged in food operation should be trained in food hygiene up to a level appropriate for operation.

<table>
<thead>
<tr>
<th>Important Elements</th>
<th>Yes/No</th>
</tr>
</thead>
<tbody>
<tr>
<td>All personnel are aware of their role and responsibility in protecting food from contamination or deterioration.</td>
<td></td>
</tr>
<tr>
<td>Food handlers have knowledge and skills to handle food hygienically.</td>
<td></td>
</tr>
<tr>
<td>Training needs analyses are conducted to determine the appropriate hygiene training programme for individuals involved in food handling.</td>
<td></td>
</tr>
<tr>
<td>The effectiveness of training programmes are assessed.</td>
<td></td>
</tr>
<tr>
<td>Training programmes are routinely reviewed for continuous improvement.</td>
<td></td>
</tr>
</tbody>
</table>

**Comments:**
INDEX : MODULE TWO

<table>
<thead>
<tr>
<th>Objective/s</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

| Outcomes | 1 |

2.1 Stainless steel, the material of choice
   - Passivity = corrosion resistance
   - Corrosion resistance
   - Classification of stainless steel
   - Grades of stainless steel
   - Composition
   - Associated properties and applications
   - Conventional (CrNi) austenitic stainless steels
   - Duplex stainless steels
   - Utility ferritic stainless steels
   - Availability
   - Local availability
   - International availability
   - Life cycle costing (LCC)
   - Industry and technical support

2.2 Corrosion resistance of stainless steel
   - What is corrosion
   - Severity of corrosion - 3 factors
   - Mechanisms of corrosion
   - General Corrosion
   - Galvanic Corrosion
   - Abrasion and Erosion Corrosion
   - Intergranular Corrosion
   - Pitting Corrosion
   - Crevice Corrosion
   - Microbiologically Influenced Corrosion (MIC)
   - Stress Corrosion Cracking
   - Material of construction vs. design/process conditions
   - Addendum: Examples of corrosion failures
   - Insulation
   - Underlying principles

2.3 Fabrication of stainless steel – Preservation and restoration of passivity
   - Mechanical damage and contamination
   - Storage
   - Handling
   - Cutting and forming
   - Fabrication
   - Welding
   - Restoration of passivity
   - Cleaning
   - Pickling
   - Passivating

2.4 Surface finishes on stainless steel related characteristics and properties
   - Designated surface finishes on flat product
   - The surface finish of different product forms
   - Electro-polishing
   - Other materials for process
MODULE TWO

Objective: Demonstrate an understanding as to why stainless steel is the material of choice in a hygienic environment

Outcomes

- Describe the reasons why stainless steel is the material of choice in the food and beverage industry.
- Explain the corrosion resistance of stainless steel.
- Describe the factors that must be considered during the fabrication of stainless steel to preserve and restore the passivity (corrosion resistance).
- Describe the different surface finishes on stainless steel and identify the related characteristics and properties.

2.1 Stainless Steel, the Material of Choice

Passivity = Corrosion Resistance

A steel is only stainless if it contains more than approximately 11% chromium (Cr). This results in the built-in natural resistance to corrosion termed passivity, i.e. a state in which a metal or alloy loses its chemical reactivity and becomes inert to many corrosive solutions (Fig 2.1).

![Fig. 2.1 Schematic illustration of the formation of the passive film on the surface of stainless steel](image)

The Cr content of stainless steels renders them passive due to the formation of a Cr rich oxide film (termed the passive film) on its surface. This passive film is

- extremely thin (=3-5x10^-6 mm thick)
- uniform and continuous
- stable and tenacious
- smooth
- self-repairing.

Corrosion Resistance

The corrosion resistance of stainless steel is totally dependent on and directly related to the integrity and the properties of the passive film, which are affected as follows.

- The alloy content
  - Chromium is the primary alloying element that renders stainless steel ‘stainless’. As stated above, a minimum of ~11%Cr (free and un-combined in the microstructure) is required. At this level a continuous passive film forms on the surface. Higher levels of chromium (up to ~26%Cr in wrought stainless steel and ~30% in cast stainless steel) result in superior corrosion resistance. However, with respect to each specific grade of stainless steel, it must
be appreciated that it is not possible to simply increase the chromium content to attain a superior corrosion resistance as this would adversely affect the related secondary properties.

- Secondary alloying elements that have a positive influence in increasing the corrosion resistance (in general, in specific corrosive environments and/or to specific corrosion mechanisms) include nickel (Ni), molybdenum (Mo), copper (Cu), and titanium (Ti).

- The process whereby the passive film developed

- Naturally by self-repairing, *i.e.* spontaneously (Note: not instantaneously) on a newly created surface of stainless steel by reaction with oxygen in the air or dissolved in solutions. For this natural self-repairing to take place the surface must be
  - clean, uncontaminated by and free of metallic particles, salts, dust, debris, polishing and/or adhesive residues, oil film, grease, paint, crayon marks, etc.;
  - chemically unaffected, *i.e.* oxidised (scaled) due to exposure at elevated and/or high temperature in an oxidising atmosphere.

Experience has shown that such self-repaired passive film has a lower resistance to discoloration, staining and possibly the initiation of corrosion.

- Chemical treatment by the use of acid solutions based on nitric acid (HNO₃), viz. pickling and/or passivating. These processes are covered in Section 2.3. The integrity and the properties of the passive film and hence the corrosion resistance, are superior to those that result from a natural self-repairing process.

- Electro-polishing: this process develops a passive film with the best integrity and corrosion resistance (covered in Section 2.3).

Stemming from the corrosion resistance are the inter-related properties of hygiene, cleanability, product purity and associated factors.

- Hygiene – a surface that is clean, sanitary, aseptic, free of germs/bacteria, sterile, healthy. Associated factors being a surface that is
  - tolerant of both high and low temperatures and resistant to thermal shock;
  - unaffected (not roughened, pitted) by a wide variety of liquids encountered both in production (*e.g.* acids, juices, spices, salts) and also by the cleaning and sterilising solutions employed;
  - non-porous and non-absorbent, thus prevents growth of germs and bacteria and their carry-over from batch to batch.

- Cleanability - an expression of the ease, simplicity and rate of cleaning the surface and the degree to which residues, germs and bacteria are removed. Associated factors being
  - CIP solutions applied through spray balls or spray jets and the subsequent easy and complete removal of the cleaning solutions;
  - rapid cleaning with little time loss between the processing of successive batches thereby attaining 100% removal (provided efficient contact of the cleaning solution with the surface occurs).

- Product purity: the associated factors being
  - non-porous and non-absorbent surface prevents tainting due to the retention of odours and flavours;
  - no discoloration of the product due to corrosion.

**Classification of Stainless Steel**

Stainless steel is not a single material, but a 'FAMILY' of different grades of stainless steels.

- All grades can be logically grouped within five classifications (and related sub-classifications) as schematically illustrated in **Fig. 2.2**. The stainless steels within any classification have similar properties.
  - Four classifications are named according to the inherent crystal structure (*i.e.* the atomic arrangement of the constituent elements) that results from the composition and the thermal treatment.
    - These classifications are the MARTENSITIC, FERRITIC and DUPLEX stainless steels.
The fifth classification is named from the heat treatment required to develop the properties - this classification is the PRECIPITATION HARDENABLE stainless steels.

- The stainless steels within any classification have similar properties.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRECIPITATION HARDENABLE</td>
<td>PRECIPITATION HARDENABLE stainless steels</td>
</tr>
<tr>
<td>AUSTENITIC Stainless Steels</td>
<td>AUSTENITIC Stainless Steels</td>
</tr>
<tr>
<td>FERRITIC Stainless Steels</td>
<td>FERRITIC Stainless Steels</td>
</tr>
<tr>
<td>MARTENSITI Stainless Steels</td>
<td>MARTENSITI Stainless Steels</td>
</tr>
<tr>
<td>DUPE Stainless Steels</td>
<td>DUPE Stainless Steels</td>
</tr>
</tbody>
</table>

Grades of Stainless Steel

There are many individual grades of stainless steel. Each is identified by a grade number (or a grade designation) in the different International and National Specifications (or Standards), e.g. USA - ASTM; Great Britain - BSI; Germany - DIN; France - AFNOR; Japan - JIS.

- Some countries adopt the National Specifications of other countries, e.g. the South African stainless steel industry has traditionally made use of the American Specifications.

The American Society for Testing and Materials (ASTM) Specifications

- The grades of stainless steel contained therein have historically been identified according to AISI (American Iron and Steel Institute), viz. the familiar 200 Series, 300 Series and 400 Series.
  - 200 Series include the CrMnNi (chromium/manganese/nickel) austenitic stainless steels, e.g. Grade 201;
  - 300 Series include the CrNi (chromium/nickel) austenitic stainless steels, e.g. Grades 304(L), 316(L), 321;
  - 400 Series include the ‘plain chromium’ stainless steels, both martensitic and ferritic stainless steels, e.g. Grade 420 and Grade 430 respectively.

- Newly developed grades could not be logically accommodated in these AISI Series and therefore the UNS (Unified Numbering System) for grade identification was evolved. The UNS grade identification consists of a letter followed by five numerals:
  - the letter denotes either a steel or an alloy type, e.g. Sxxxxx is a stainless steel grade, Nxxxxx is a stainless alloy or a nickel alloy grade;
  - for stainless steels the first three numbers are often the same as the previous 200, 300 or 400 Series Number (if this existed) and the last two numbers are used for the different grades of the same basic type, e.g. S30400=304; S30403=304L; S30409=304H; S30415= no previous grade; S30451=304N; S30452=XM-21; S30453=304LN.
The New European EN Standard

Historically each country in Europe had their own National Standard and Specifications that applied to stainless steel and other materials. Consequently, a huge number of individual grade identifications existed that, although similar with respect to composition, were not exactly equivalent.

National Standards and Specifications have been replaced by the new European EN Standards. Exactly the same Standard is used by all countries (e.g. by Great Britain as BS EN xxxx; by Germany as DIN EN xxxxx; by France as AFNOR EN xxxx, etc), the only difference being the language in which these Standards are written.

- Grade identification is according to either a grade number or a grade designation (e.g. 1.4301 or X5CrNi 18-10 respectively).
  - The grade numbers and grade designations in these new EN Standards appear to be the same as the old DIN Werkstoff numbers and Kunzname.
  - However there may be differences in the composition and/or properties. Therefore, care must be taken not to confuse the two nor to make unconsidered substitution.

Composition

Each grade of stainless steel has a unique composition as stipulated by the specification, i.e. the elements contained and the amount of each such element (often referred to by the term alloy content).

- The composition is the primary determinant of the properties associated with each classification and each grade therein.
- The elements contained and their relative amounts have a major influence and seemingly small differences can have a great effect.
  - The chemical composition is therefore carefully controlled to achieve not only the corrosion resistance but also the desired associated properties that include, for example, strength, hardness, formability, weldability, machinability. To attain one such property may require that another property has to some extent be sacrificed.

The more important alloying elements in stainless steel and their effects, are summarised below.

- **Chromium (Cr):** chromium is the primary alloying element of stainless steel and its effect has already been outlined in Corrosion Resistance above.
- **Carbon (C):** carbon has a high affinity for Cr and will form chromium carbides which can be very deleterious to corrosion resistance. Therefore, in most stainless steels C is kept to a low level, typically 0.08% max or to a lower level of 0.03% max in the low-carbon ‘L’ grades and other stainless steels which are utilised for the manufacture of welded fabricated components in thicker section. However, in the martensitic stainless steels C is the alloying element specifically added (in amounts varying from 0.15% to 1.2%). This renders these steels amenable to heat treatment by quenching and tempering to develop high strength and hardness.
- **Nickel (Ni):** nickel, when added to stainless steel in sufficient quantity, develops and stabilises the austenitic crystal structure, hence the austenitic stainless steels as typified by Grade 304 [1.4301] (18%cr 8-10%Ni). Lower levels of Ni, insufficient to develop a fully austenitic crystal structure, result in a duplex (mixed) crystal structure of ferrite and austenite of the duplex stainless steels.
- **Molybdenum (Mo):** molybdenum enhances the properties (passivity) of the passive film and thereby renders those stainless steels that contain it more corrosion resistant, e.g. to reducing acids and to localised corrosion such as Pitting Corrosion. Higher levels of Mo enable more aggressive corrosion conditions to be handled.
- **Manganese (Mn):** the normal content of Mn in stainless steels is typically 0.75% to 1.0%. It is similar to Ni in that it has the ability to promote the formation of the austenitic crystal structure, e.g. in the 200 Series Mn partly replaces Ni. However, Mn is only half as powerful as Ni in this respect and typically 2%Mn is needed to replace 1% Ni.
Objective: Demonstrate an understanding as to why stainless steel is the material of choice in a hygienic environment

- Nitrogen (N): nitrogen is an alloying element which strongly develops and stabilises the austenitic crystal structure. Because of the pneumatic (gaseous) refining processes used in the manufacture of stainless steel, N is a ‘natural’ alloying element and has beneficial effects except in martensitic and ferritic stainless steels. It improves the resistance to Pitting Corrosion and the strength. In the duplex stainless steels it increases the austenite fraction of the crystal structure and thereby the weldability.

- Titanium (Ti) and Niobium + Tantalum (Nb+Ta): these are stabilising elements, so termed because they are strong carbide formers. They will thus preferentially form carbides and thereby prevent sensitisation, i.e. the formation of grain boundary chromium carbide precipitates adjacent to the weld due to the high temperatures attained within this region. Sensitisation renders the stainless steel prone to Intergranular Corrosion (sometimes termed ‘weld decay’).

The following table is included in order to give an appreciation of the composition of different grades of stainless steels.

### TABLE 2.1
Nominal Composition of Some of the More Common Grades of Stainless Steel.

Similar Grades (on Basis of Composition only) from the ASTM and EN Standards are Grouped Together

<table>
<thead>
<tr>
<th>Grade Number</th>
<th>UNS Number</th>
<th>Grade Designation</th>
<th>%C</th>
<th>%Cr</th>
<th>%Ni</th>
<th>%Mo</th>
<th>%N</th>
<th>%Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>201</td>
<td>S20100</td>
<td></td>
<td>0.15</td>
<td>16.0-18.0</td>
<td>3.5-5.5</td>
<td>0.25</td>
<td>5.5-7.5 Mn</td>
<td></td>
</tr>
<tr>
<td>1.4372</td>
<td>X12CrMnNiN 17-7-5</td>
<td></td>
<td>0.15</td>
<td>16.0-18.0</td>
<td>3.5-5.5</td>
<td>0.05-0.25</td>
<td>5.5-7.5 Mn</td>
<td></td>
</tr>
<tr>
<td>201L</td>
<td>S20100</td>
<td></td>
<td>0.03</td>
<td>16.0-18.0</td>
<td>3.5-5.5</td>
<td>0.25</td>
<td>5.5-7.5 Mn</td>
<td></td>
</tr>
<tr>
<td>1.4371</td>
<td>X2CrMnN 17-7-5</td>
<td></td>
<td>0.03</td>
<td>16.0-17.0</td>
<td>3.5-5.5</td>
<td>0.15-0.20</td>
<td>6.0-8.0 Mn</td>
<td></td>
</tr>
<tr>
<td>202</td>
<td>S20200</td>
<td></td>
<td>0.15</td>
<td>17.0-19.0</td>
<td>4.0-6.0</td>
<td>0.25</td>
<td>7.5-10.0 Mn</td>
<td></td>
</tr>
<tr>
<td>1.4373</td>
<td>X12CrMnN 18-9-5</td>
<td></td>
<td>0.15</td>
<td>17.0-19.0</td>
<td>4.0-6.0</td>
<td>0.05-0.25</td>
<td>7.5-10.5 Mn</td>
<td></td>
</tr>
<tr>
<td>301</td>
<td>S30100</td>
<td></td>
<td>0.15</td>
<td>16.0-18.0</td>
<td>6.0-8.0</td>
<td>0.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4310</td>
<td>X10CrNi 18-8</td>
<td></td>
<td>0.05-0.15</td>
<td>16.0-19.0</td>
<td>6.0-9.5</td>
<td>0.80</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>1.4318</td>
<td>X2CrNi 18-7</td>
<td></td>
<td>0.03</td>
<td>16.5-18.5</td>
<td>6.0-8.0</td>
<td>0.10-0.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>303</td>
<td>S30300</td>
<td></td>
<td>0.15</td>
<td>17.0-19.0</td>
<td>8.0-10.0</td>
<td>&gt;0.15 S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4305</td>
<td>X8CrNiS 18-9</td>
<td></td>
<td>0.10</td>
<td>17.0-19.0</td>
<td>8.0-10.0</td>
<td>0.11</td>
<td>0.15-0.35 S</td>
<td></td>
</tr>
<tr>
<td>303Se</td>
<td>S30323</td>
<td></td>
<td>0.15</td>
<td>17.0-19.0</td>
<td>8.0-10.0</td>
<td></td>
<td>0.08 S &amp; &gt;0.15 Se</td>
<td></td>
</tr>
<tr>
<td>304</td>
<td>S30400</td>
<td></td>
<td>0.08</td>
<td>18.0-20.0</td>
<td>8.0-10.5</td>
<td>0.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4301</td>
<td>X5CrNi 18-10</td>
<td></td>
<td>0.07</td>
<td>17.0-19.5</td>
<td>8.0-10.5</td>
<td>0.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>304L</td>
<td>S30403</td>
<td></td>
<td>0.03</td>
<td>18.0-20.0</td>
<td>10.0-12.0</td>
<td>0.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4306</td>
<td>X2CrNi 19-11</td>
<td></td>
<td>0.03</td>
<td>18.0-20.0</td>
<td>10.0-12.0</td>
<td>0.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>304LH</td>
<td>S30453</td>
<td></td>
<td>0.03</td>
<td>18.0-20.0</td>
<td>8.0-12.0</td>
<td>0.10-0.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4311</td>
<td>X2CrNi 18-10</td>
<td></td>
<td>0.03</td>
<td>17.0-19.5</td>
<td>8.5-11.5</td>
<td>0.12-0.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>304H</td>
<td>S30409</td>
<td></td>
<td>0.04-0.10</td>
<td>18.0-20.0</td>
<td>8.0-10.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4948</td>
<td>X6CrNi 18-10</td>
<td></td>
<td>0.04-0.08</td>
<td>17.0-19.0</td>
<td>8.0-11.0</td>
<td>0.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>305</td>
<td>S30500</td>
<td></td>
<td>0.12</td>
<td>17.0-19.0</td>
<td>10.5-13.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4303</td>
<td>X4CrNi 18-12</td>
<td></td>
<td>0.06</td>
<td>17.0-19.0</td>
<td>11.0-13.0</td>
<td>0.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>309</td>
<td>S30900</td>
<td></td>
<td>0.20</td>
<td>22.0-24.0</td>
<td>12.0-15.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4828</td>
<td>X15CrNiS 20-12</td>
<td></td>
<td>0.20</td>
<td>19.0-21.0</td>
<td>11.0-13.0</td>
<td>0.11</td>
<td>1.5-2.0 Si</td>
<td></td>
</tr>
<tr>
<td>309S</td>
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### Austenitic Stainless Steels and Austenitic Stainless Alloys cont’d.

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Typical similar proprietary grades:
- Incoloy 825 ~ Nicrofer 4221
- Nicrofer 3127LC ~ Sanicro 28
- 904L ~ Cronifer 1925LC ~ 2RK65 ~ Uranus B6
- 3CR12™ 0.03 11.0-12.0 1.5 0.03 0.6 Ti
- 1.4864  X2CrNi 12 0.03 10.5-12.5 0.3-1.0 0.03 0.6 Ti
- 1.4512  X2CrTi 12 0.03 10.5-12.5 0.3-1.0 0.03 0.6 Ti

### Ferritic Stainless Steels

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<th>Cr</th>
<th>Mn</th>
<th>Si</th>
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| 3CR12™  | X2CRNi 12 | 0.03 | 11.0-12.0 | 1.5 0.03 0.6 Ti
| 1.4003   | X2CRNi 12 | 0.03 | 10.5-12.5 | 0.3-1.0 0.03 0.6 Ti
| 1.4512   | X2CrTi 12 | 0.03 | 10.5-12.5 | 0.3-1.0 0.03 0.6 Ti
| 430      | X6Cr 17 | 0.08 | 16.0-18.0 | 0.75 |
| 1.4016   | X6Cr 17 | 0.08 | 16.0-18.0 | 0.75 |
| 1.4509   | X2CrTiNb 18 | 0.03 | 17.5-18.5 | 0.045 0.10-0.60 Ti & (0.3+3x%C)-1.0 Nb
| 439      | S43035 | 0.07 | 17.0-19.0 | 0.50 0.04 (0.2+4x[C%]+[N]) -1.1 Ti & 0.15 Al
| 1.4510   | X3CrTi 17 | 0.05 | 16.0-18.0 | 0.05 0.10-0.60 Ti & (0.3+3x%C)-1.0 Nb
| 444      | S44000 | 0.025 | 17.5-19.5 | 1.0 1.8-2.5 0.035 (0.2+4x[C%]+[N]) -0.8 Ti
| 1.4521   | X20MoTi 18-2 | 0.025 | 17.0-20.0 | 1.8-2.5 0.03 (0.15+8x[C%]+[N]) -0.8 Ti

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Module 2: Objective: Demonstrate an understanding as to why stainless steel is the material of choice in a hygienic environment

Martensitic Stainless Steels

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<tr>
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(All Free Machining properties)

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Duplex Stainless Steels

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Typical similar proprietary grades: SAF2304 ~ 2304

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Typical similar proprietary grades: SAF2507 ~ 2507 ~ Uranus 45N

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Typical similar proprietary grades: Ferralium 255-3SF ~ Uranus 52N

Precipitation Hardenable (PH) Stainless Steels

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Typical similar proprietary grade: 17-4PH

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Typical similar proprietary grade: 17-7PH

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Typical similar proprietary grade: PH 15-7Mo

Associated Properties and Applications

Stainless steels have an extensive variety of associated properties which results in their application in a diversity of industries. For any application the full spectrum of the desired properties must be considered.

In the beverage and food industries the desired properties include:

- corrosion resistance and the associated properties of hygiene, cleanability and product purity;
- strength that will enable components to be manufactured that will:
  - be of an acceptable mass to size ratio;
  - be able to contain the required process pressure;
  - have the required temperature associated properties, e.g. strength at elevated and high temperatures, unaffected by temperature fluctuations (often rapid), tough (i.e. not brittle) at sub-zero and cryogenic temperatures;
  - have good formability - formability is a qualitative expression of the capability of a material to be plasticly deformed without fracture, e.g. to be formed by bending, pressing or deep drawing into the required shape;
  - have good (even excellent) weldability - weldability is a qualitative term that implies the ability of a material to be joined by standard welding processes so that the resultant mechanical, physical and chemical properties of the weld zone (i.e. both the weld metal and the adjacent heat affected zone within the parent material) are at least equivalent to the parent metal. In the design of welded components a weldability factor is used to impose a prescribed lower stress value than that as specified in the material specification. Good weldability enables
Objective: Demonstrate an understanding as to why stainless steel is the material of choice in a hygienic environment

- the fabrication of complex items of plant and equipment (e.g. pressure and process vessels, heat exchangers);
- joints to be effected without associated laps and crevices;
- maintenance, repairs or alterations to be carried out in situ (if necessary);
- be resistant to accidental mechanical damage;
- be able to be restored to a fully corrosion resistant condition should impairment of the corrosion resistance occur by accident or during repair.

The conventional austenitic stainless steels fulfil to an excellent degree all such desired properties and are thus utilised to the greatest extent, specifically Grades 304/304L (1.4301/1.4306) and to a lesser extent, Grades 316/316L (1.4401/1.4404), if a higher corrosion resistance is required.

- Duplex stainless steels fulfil a necessary role in applications where process conditions involve high chloride concentrations and thus require a high resistance to chloride induced mechanisms of corrosion, viz. pitting corrosion and stress corrosion cracking.

- Utility ferritic stainless steels are not suitable for components or equipment in direct contact with food or beverage being processed. However, they are definitely worthy of consideration in peripheral applications where lower levels of maintenance are of benefit (e.g. ducting, stairways and walkways, pipe racks and supports, cable trays, gullies and drains).

Conventional (CrNi) Austenitic Stainless Steels

Nickel (Ni) promotes the formation of an austenitic crystal structure and if sufficient Ni is contained a wholly austenitic crystal structure results. The stainless steels in this classification have both excellent corrosion resistance and associated secondary properties and account for the greatest usage of stainless steel.

**Basic Composition:**
- 18%Cr + 8-12%Ni
- 2-3%Mo in some grades for increased corrosion resistance
- low carbon (<0.08%C) in the straight grades
- extra low carbon (<0.03%C) in the L grades
- Ti in the stabilised grades

The L and stabilised grades are used to prevent the possibility of a mechanism of corrosion (viz Intergranular Corrosion), occurring next to the weld in thicker welded fabrications in some corrosive solutions.

**Common Grades:**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>304</td>
<td>304L</td>
<td>321</td>
</tr>
<tr>
<td>[1.4301]</td>
<td>[1.4306]</td>
<td>[1.4541]</td>
</tr>
<tr>
<td>and the grades that contain Mo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>316</td>
<td>316L</td>
<td>316Ti</td>
</tr>
<tr>
<td>[1.4401]</td>
<td>[1.4404]</td>
<td>[1.4571]</td>
</tr>
</tbody>
</table>

**Basic Properties:**
- very good to excellent corrosion resistance;
- excellent hygienic properties and cleanability and therefore associated excellent product purity;
- excellent formability and weldability and therefore associated excellent fabricability;
- moderate strength (in the annealed condition);
- can be strengthened and hardened by cold work, not by heat treatment;
- excellent mechanical properties at cryogenic (i.e. very low) temperatures;
- good high temperature properties;
- non-magnetic.
**Objective:** Demonstrate an understanding as to why stainless steel is the material of choice in a hygienic environment

**Common Uses:**
- in thicknesses of 0.5mm or less to over 200mm; articles and components weighing but a few grams to over 100 tonnes - from the mundane teaspoon to super-critical nuclear plant;
- hollow-ware, tableware, cutlery, sinks (both domestic and commercial);
- hospital and medical equipment;
- pharmaceutical;
- architectural (e.g. street furniture, facades, shop fronts, signs, balustrades, cladding, roofing);
- builders’ hardware, masonry ties and anchors;
- reinforcing bar for concrete;
- food and beverage processing (e.g. abattoirs, dairy, beer, wine, soft drinks), and preparation (e.g. hotel, restaurant and fast food equipment);
- transport (e.g. rail cars, tankers, ISO liquibulk “tanktainers”);
- boat and yacht hardware, fittings and rigging;
- cryogenic equipment (e.g. manufacture, storage and transport of liquid gases);
- pollution control and water treatment;
- at elevated and high temperatures;
- for plant and equipment in petrochemical, chemical, mineral extraction, pulp and paper, nuclear and other industries (e.g. as tanks, process and pressure vessels, heat exchangers, pipe-work).

**Forms Commonly Available:**
- plate, sheet, coil, strip, bar, pipe and tube, forgings;
- castings (as similar cast grades);
- product forms (flanges, fittings, fasteners, wire, rope, hollow bar, etc.).

**Duplex Stainless Steels**

These stainless steels contain insufficient Ni to develop a fully austenitic crystal structure and therefore consist of a mixed ferritic-austenitic (i.e. duplex) crystal structure. Until the early 1980’s the crystal structure consisted of approximately 70% ferrite and 30% austenite. The associated weldability was, at best, moderate. N, a powerful austenite former, was then included in the composition (sometimes referred to as the Second Generation Duplex Stainless Steels). This resulted in a crystal structure of approximately 50% ferrite and 50% austenite and a greatly improved weldability.

**Basic Composition:**
- higher Cr and lower Ni (i.e. compared to the Conventional Austenitic Stainless Steels)
- most contain Mo
- extra low C (<0,03%C)
- N as an austenite former.

**Nominal Composition of Typical Grades:**
Originally these stainless steels were developed as proprietary grades. The preferred and therefore more often used grades are now incorporated in different national specifications, for example:
- 23%Cr 4%Ni 0.4%Mo 0.15%N [1.4362]
- 22%Cr 5%Ni 3.0%Mo 0.18%N [1.4462]
- 25%Cr 7%Ni 3.5%Mo 0.30%N [1.4410]

**Basic Properties:**
- excellent corrosion resistance: the higher Cr+Mo and N improve the resistance to Pitting Corrosion and Crevice Corrosion;
- a high resistance to Stress Corrosion Cracking due to the duplex ferritic-austenitic crystal structure;
- strength =25% higher than the conventional austenitic stainless steels;
- good formability;
- very good weldability.
Objective: **Demonstrate an understanding as to why stainless steel is the material of choice in a hygienic environment**

**Common Uses:**
- as welded process plant and equipment, heat exchanger tubing and panels
  - in the chemical and petrochemical industries for resistance to corrosive solutions that are likely to cause Pitting Corrosion and/or Stress Corrosion Cracking;
  - in marine and off-shore oil applications;
  - to handle chloride brine solutions.

**Forms Commonly Available:**
- plate, sheet, pipe and tube.

**Utility Ferritic Stainless Steels**

The initial breakthrough discovery of 3CR12™ in the early 1980’s has led to the development of these stainless steels. Their good weldability is the significant property that differentiates them from all other plain chromium stainless steels. They contain the minimum amount of Cr to render them ‘stainless’ - i.e. preferably considered as corrosion resisting as opposed to corrosion resistant. Their main use has been as a cost effective material to replace uncoated and coated plain carbon steels in applications where these steels have inadequate corrosion resistance due to the environmental or operational conditions.

**Basic Composition:**
- plain chromium stainless steels, 11-12%Cr
- extra low C & N (both <0.03%)

**Common Grades:**
- 3CR12™ [1.4003].

**Basic Properties:**
- good weldability (in thicknesses of up to ≈20mm);
- corrosion ‘resisting’ (will stain and discolour but suffer minimal metal loss even in polluted industrial and marine environments);
- good corrosion-abrasion resistance.

**Common Uses:**
- in ‘rough and tough’ applications (for example in materials handling: e.g. ore cars, railway coal wagons, truck bodies, chutes, launders);
- tanks, silos, hoppers, bins;
- pollution control, dust and fume extraction, ventilation ducting, chimney stacks;
- to replace coated steel in applications in which either the coating is damaged/destroyed by the operational conditions or maintenance is difficult/costly; (e.g. walkways, stairways and ladders, high level lighting masts, electrification masts, portals and transmission towers, bus and coach frames).

**Potential Uses:**
- as production of these stainless steels as a range of ‘long products’ becomes more common, it is considered that there is a significant potential for their use;
  - in structural steel work (i.e. as angles, channels and beams);
  - as reinforcing bar for concrete.

**Forms Commonly Available:**
- plate, sheet and coil in thicker gauges
- welded tube, fabricated large diameter pipe
- bar and sections (limited size range, but increasing).
Availability

Although a material may be an excellent choice from a theoretical point of view it must further have, in the broadest sense, an associated availability for it to be a practical and useful choice. Stainless steel has such an associated ‘availability’. It is available in all product forms in a range of sizes and mass and in different grades, that enable the manufacture of items of plant, equipment and related components, viz.

- flat product such as plate, sheet, coil and strip:
  - process and pressure vessels, tanks and tankers, heat exchangers, filters, hoppers, conveyors, etc.
- long products as bar (round, flat, square, hexagon) and sections (angles, channels, beams):
  - shafts, spindles, bolts and nuts and other fasteners, etc.
  - pipe racks, cable trays, stairways and walkways, etc.
- forgings:
  - flanges, rings, tube plates, larger shafts and spindles, etc.
- castings:
  - pumps, valves, tube and pipe fittings, etc.
- pipe and tube (both welded and seamless):
  - tube and piping systems, shell and tube heat exchanger bundles, hand railing, etc.

Availability is further dependent on the existence of
- fabricators with the facilities and capabilities to manufacture the required items of plant, equipment and related components;
- suppliers of services, equipment and products, e.g. stockholding and distribution; profile cutting of blanks and shapes (plasma, laser, water jet); polishing and polishing consumables; welding equipment and consumables (electrodes and gases).

Local Availability

The South African Stainless Steel Industry has developed into a broad-based sophisticated industry.

- With respect to the different product forms:
  - stainless steel flat product is manufactured by Columbus Stainless, the only producer of such product in Africa. A limited range of long product is produced by Iscor;
  - there are several foundries and forge shops capable of producing a wide range of castings and forgings respectively;
  - further, there are several manufacturers of welded pipe and tube.
- The availability of the broad range of required plant, equipment and components made from the respective product forms are well catered for by the fabrication/conversion sector of the industry. Many individual companies exist in this sector which has the necessary facilities and proven capability. As such, this sector of industry is able to supply on a cost competitive basis, consumer, architectural and engineering products ranging from simple to high-tech critical plant and equipment as required by the chemical and petro-chemical industries.

The above is but a brief outline of the availability that exists within the local Stainless Steel Industry. For a full review, it is advised that reference should be made to THE STAINLESS STEEL BUYERS GUIDE as published by SASSDA and/or SASSDA’s Internet www.sassda.co.za.

International Availability

Whereas there is an excellent local availability, import supply must in some cases and for different reasons, take place. For example

- product forms not produced or produced only in a limited range of sizes such as
  - classifications or grades stainless steel, e.g. duplex stainless steels (except as castings);
  - seamless pipe and tube and larger sizes of welded pipe and tube;
  - long product as bar and sections (limited range only);
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Objective: Demonstrate an understanding as to why stainless steel is the material of choice in a hygienic environment

- ‘mass production’ items not produced because of low economies of scale related to local demand such as
  - some bolts, nuts and other fasteners;
  - some small size stopcocks and valves.

With respect to many such imports, local ex-stock availability will often exist from the stockists and distributors where a regular demand has been historically shown to exist.

International availability may be resorted to at times when the loading on the local fabrication/conversion sector of the industry is such that unrealistically long delivery times prevail.

If for some reason it is not available locally, it will undoubtedly be available internationally.

Life Cycle Costing (LCC)

Stainless steel is not a low cost material. Based on ‘first off installed price’ plant and equipment manufactured from stainless steel is often perceived and in fact may well prove, to be more expensive than that manufactured from other materials.

However, the ‘first off installed price’ is not a truly valid base for comparison or for decision making purposes.

- It is far more meaningful to apply the principle of Life Cycle Costing. This takes into account all the estimated costs incurred (or saved) over the expected life cycle (i.e. future years of operation) of the plant or equipment manufactured from different materials.
  - The estimated costs should be as rational and justifiable as possible based on best applicable knowledge and experience.
- For each material, the starting point is the ‘first off installed price’. Thereafter, either in tabular or graphical format, the estimated costs are entered, at the time that they will occur, to give both a progressive cost with elapsed time and a total cost at the end of the life cycle (i.e. expected years of operation).
- Costs that should be estimated and entered include, amongst others
  - costs of scheduled maintenance (for each such maintenance, inflated if necessary);
  - costs of unscheduled shutdown for repair/maintenance (which may be reasonably expected, based on historical experience);
  - cost of replacement of plant, equipment and components (either partial or complete) that will be necessary during the expected life cycle;
    - costs associated with lost production during any of the foregoing;
  - cost differences resulting from differences in production rates/volumes attained with the different materials;
  - costs incurred by the necessity to discard ‘off-spec’ product;
  - obtainable value for plant and equipment, either sold as scrap or in working condition at the end of the life cycle.

The merit of LCC is recognised in all end-use sectors. In those instances where LCC indicated a preferred choice of high cost material with an associated high ‘first off installed price’ it has, in the vast majority of cases, been proven as justified.

Industry and Technical Support

Southern Africa Stainless Steel Development Association (SASSDA) was formed in 1964. It offers members and the SA Stainless Steel Industry a wide range of services including education and training, skills upgrading, technical advice and information, industry and market support.

Further, SASSDA maintains strong links both nationally and internationally, viz.

- Columbus Stainless (being the primary producer) and technical institutions such as The South African Institute of Welding (SAIW), The South African Bureau of Standards (SABS), Mintek.
The Nickel Development Institute (NiDI), The International Chromium Development Association (ICDA) and works closely with other Stainless Steel Development Associations.

2.2 Corrosion Resistance of Stainless Steel

Although the corrosion resistance of the different classifications and grades of stainless steel does vary it is, in general terms, a highly corrosion resistant material. This has led to a perception that it is indestructible, immune to corrosive attack and thus a universal cure for all corrosion problems. However, this is not the case. Stainless steel can and does, suffer from corrosion. Regrettfully, in many instances, this is because of inappropriate events or conditions which amount to misuse or abuse.

An understanding of the basic mechanisms of corrosion and how/why stainless steel resists or is affected by these mechanisms, will assist in the application of stainless steel under conditions that will enhance its performance.

What is Corrosion

There are two forms of corrosion
- aqueous/wet corrosion
- gaseous and dry corrosion (which takes place at high temperatures, usually >500°-550°C).

Only Aqueous Corrosion will be covered in this module.

Aqueous/wet corrosion is the attack, destruction or wasting away of the metal only when it is in contact with or immersed in, a corrosive solution (electrolyte). The attack is as a result of aggressive substances/ions dissolved in the corrosive solution (usually water).
- The chloride ion (Cl\(^-\)) is one such ion, being both common and very aggressive towards stainless steel.
- A film of moisture or condensate, a damp film of dust, wet or damp insulation can also constitute the corrosive solution if such aggressive substances are contained therein.

Severity and Extent – 3 factors

The severity and extent of the corrosion depends on
1. the concentration of the aggressive substances dissolved in the corrosive solution;
2. the temperature of the corrosive solution;
3. the presence and nature of contaminants and trace elements within the corrosive solution.

The Concentration
This is generally known and controlled and care should be taken to avoid conditions that would change the concentration as this may result in unexpected, severe or localised attack, such as
- condensation and evaporation, especially if repeated cycles thereof;
- concentration in crevices.

The Temperature
This is usually known and uniform and care must be taken to prevent and to appreciate the effect of higher localised temperatures. A typical example of such a condition is that prevailing under heat transfer, e.g. solar heaters, heating coils (Fig 2.3):
- a thin layer or film of super-heated corrosive solution exists at the metal surface through which the heat is transferred;
- the temperature of this film must be taken into account as it causes far more aggressive conditions than those related to the average bulk temperature. The corrosion rate will therefore be far greater.
 MODULE 2  

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Fig. 2.3 Schematic illustration of superheated layer occurring at the metal surface under conditions of heat transfer

The Presence and Nature of Contaminants
Because all aqueous corrosion is electro-chemical there is always an equilibrium between the reactions at the metal surface and those within the corrosive solution. Trace amounts of contaminants can affect this balance and therefore aggravate and increase or counteract and lower, the severity and rate of corrosion.

Mechanisms of Corrosion

There are several mechanisms of corrosion. Each occurs because of different reasons and develops/progresses in a different manner.

The more common mechanisms of aqueous/wet corrosion are

- General Corrosion
- Galvanic Corrosion
  - Abrasion and Erosion Corrosion
  - Intergranular Corrosion
- Pitting Corrosion
- Crevice (Shielded) Corrosion
- Microbiologically Influenced Corrosion
- Stress Corrosion Cracking (SCC).

These different mechanisms of corrosion are sometimes thought to affect only stainless steel. This is not the case. Carbon steels, low alloy steels, other metals and alloys undergo similar forms of corrosive attack.

*In general terms, the mechanisms of corrosion as indicated by this symbol are considered to be those more pertinent to the conditions and events that prevail in the food and beverage industry. These will be covered in greater detail below.

General Corrosion

In General Corrosion the attack is uniform over the entire surface. It is the least dangerous form of corrosion because the rate of corrosion is measurable and predictable. Thus, a corrosion allowance can be included when designing for a required life or safety factor.

Stainless steels exhibit very low General Corrosion rates in many highly aggressive corrosive environments. The corrosion rate depends on the stability of the passive film which in turn is a function of the properties of both the stainless steel and the corrosive solution.

- The properties of the stainless steel are essentially dependent on its chemical composition in particular those alloying elements which enhance the passivity as previously outlined.
- The properties of the corrosive solution are also dependent on its composition in particular
  - if the species contained are either aggressive and breakdown the passive film (and may also cause other corrosion mechanisms to occur) or have the effect of enhancing the passivity;
  - whether it is oxidising (protective) or reducing (destructive) in nature.
Under some conditions, the surface may exhibit signs of discoloration or incipient staining ('rusting'). It is very seldom that this indicates corrosion at rates similar to those of plain carbon (mild) steel. If left untreated a minimal amount of metal loss will usually occur. In most cases a simple cleaning process will remove the discoloration or staining and restore the surface appearance. However, the cause should always be investigated, especially if severe dark staining is evident as this is an indication that passivity has broken down.

Rates of General Corrosion are measured and reported in different units:
as loss of mass grams/square meter/hour \((g/m^2/hr)\)
as loss of thickness millimetres/year \((mm/yr)\) or mils\((0,001'')\) year \(\text{mpy}\).
The approximate inter-relationship of these units is:\- 1 \(g/m^2/hr\)=1,1 \(mm/yr\)=43 \(\text{mpy}\).

The suitability or severity of attack within a specific corrosive environment is indicated in different ways (Table 2.2 and Fig. 2.4).

### Table 2.2

<table>
<thead>
<tr>
<th>Corrosion Rate</th>
<th>Suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0,1 mm/yr (≤5 mpy)</td>
<td>• Highly resistant</td>
</tr>
</tbody>
</table>
| 0,1-1,0 mm/yr (5-50 mpy) | • Metastable passivity  
|                        |   • Transition zone from highly resistant to severe corrosion  
|                        |   • Consider with care                           |
| >1,0 mm/yr (>50 mpy) | • Severe corrosion  
|                        |   • Generally not suitable                      |

**Fig. 2.4 Schematic illustration of an Isocorrosion Diagram showing corrosion rates over a range of temperature/concentration**

However, it must be remembered that the reported general corrosion rates are often determined under laboratory conditions using chemically pure solutions. Thus the effect of contaminants and trace elements that are usually present in actual applications are not taken into account. Reported corrosion rates must therefore be used as guidelines only. Full account should be taken of:

- service conditions and variations that could occur;
• uniformity of and variations to the corrosive solution with respect to the concentration, the temperature and the presence of contaminants;
• the state of the surface and the maintenance of passivity.

**Galvanic Corrosion**

Galvanic Corrosion occurs when two different metals are in electrical contact and immersed in the same corrosive solution (**Fig 2.5**).

![Schematic illustration of Galvanic Corrosion and the required conditions and results](image)

**Fig. 2.5 Schematic illustration of Galvanic Corrosion and the required conditions and results**

Metals and alloys may be ranked according to how active (anodic) or noble (cathodic) they are when coupled to or in contact with each other in any specific corrosive solution. This is termed a galvanic series. The galvanic series in sea water is that most often referred to (**Table 2.3**). Note: the ‘nobility’ of the passive stainless steels.

Passive stainless steel seldom suffers an increase in corrosion rate by Galvanic Corrosion due to its high nobility ranking. The danger of an increased corrosion rate of any more active metal coupled to or in contact with stainless steel, should always be considered.
Objective: Demonstrate an understanding as to why stainless steel is the material of choice in a hygienic environment

Table 2.3
Galvanic Series of Commercial Metals and Alloys in Sea Water (abridged: for indicative purposes only)

<table>
<thead>
<tr>
<th>NOBLE</th>
<th>Cathodic</th>
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<tbody>
<tr>
<td>Gold</td>
<td>Graphite</td>
</tr>
<tr>
<td></td>
<td>Titanium</td>
</tr>
<tr>
<td></td>
<td>Stainless steels PASSIVE</td>
</tr>
<tr>
<td></td>
<td>Plain Cr &amp; Ni containing</td>
</tr>
<tr>
<td></td>
<td>Most Ni based alloys</td>
</tr>
<tr>
<td></td>
<td>Most Cu based alloys</td>
</tr>
<tr>
<td></td>
<td>Tin</td>
</tr>
<tr>
<td></td>
<td>Stainless steels ACTIVE</td>
</tr>
<tr>
<td></td>
<td>Steel &amp; cast iron</td>
</tr>
<tr>
<td></td>
<td>Most Al alloys</td>
</tr>
<tr>
<td></td>
<td>Cadmium</td>
</tr>
<tr>
<td></td>
<td>Pure Al</td>
</tr>
<tr>
<td>Anodic</td>
<td>Zinc</td>
</tr>
<tr>
<td>ACTIVE</td>
<td>Magnesium</td>
</tr>
</tbody>
</table>

It is important to appreciate that different conditions on the surface of the same stainless steel sheet/plate within a fabricated component can also give rise to the occurrence of Galvanic Corrosion, for example:

- mechanical damage (e.g. grind marks, scratches, weld spatter) impairs the passivity and renders such areas anodic to the surrounding passive cathodic surface;
- if the deposited weld metal is of inferior corrosion resistance (e.g. incorrect composition), this will render the weld anodic to the surrounding cathodic parent plate;
- the heat impaired passive film (high temperature oxide) on and near a weld is of inferior corrosion resistance. This area, if not re-passivated, will suffer corrosion and become anodic to the surrounding cathodic parent plate material.

The unfavourable area ratio of small anode<>large cathode which is usual in such cases, adversely promotes and accelerates corrosion.

The galvanic effect is a factor within some other mechanisms of corrosion, as detailed in the following sections.

**Abrasion and Erosion Corrosion**

These are mechanically assisted mechanisms of corrosion.

- Abrasion Corrosion is due to abrasive particles sliding or flowing under low stress conditions (i.e. no impact) over the metal surface under damp/wet conditions, e.g. in materials handling as in chutes and in discharge from ore cars.
- Erosion Corrosion occurs at relatively high velocities by the action of particles contained in a slurry flowing over the metal surface or turbulence within liquid and gas streams, causing impingement on the metal surface, e.g. in mixing and agitator tanks, in pipes, on turbine blades and pump impellers.

The mechanical damage caused by the abrasion or erosion results in the removal of the products of corrosion (which are often loose and friable) from the metal surface. A new virgin surface is thus exposed to the corrosive attack. Both abrasion/erosion and corrosion act in synergy. The resultant rate of metal loss is higher than the total of each if acting alone.

In general terms, stainless steel has a high resistance to these forms of corrosion due to the stable and tenacious passive film present on the surface and its ability to re-passivate.
Intergranular Corrosion

Intergranular Corrosion takes place at and proceeds along the grain boundaries. The body of the grain is unaffected. The grains can literally be dissolved out of the metal.

Intergranular Corrosion of stainless steel is primarily due to the high affinity that carbon (C) has for chromium (Cr). If a certain set of conditions exists these elements will combine to form complex Cr carbide (Cr$_{23}$C$_6$) precipitates. The formation of these Cr$_{23}$C$_6$ precipitates takes place preferentially at the grain boundaries. A small amount of C locks up a relatively large amount of Cr and thus depletes the grain boundary area in Cr, i.e. the steel has been sensitised. Such Cr depleted grain boundaries have both a lower corrosion resistance and passivating capacity. They will therefore suffer preferential attack that is accelerated by the galvanic effect; a small corroding anodic area (viz. the grain boundary) and larger non-corroding cathodic area (viz. the body of the grain).

High temperatures in the range of ≈450°-850°C are necessary for the formation of the Cr$_{23}$C$_6$ precipitates:
- they will not form at lower temperatures;
- they also do not form at higher temperatures and if present, will begin to dissolve albeit slowly, until higher temperatures of 1050°±30°C are attained.

The C content of the stainless steel and the exposure time within the high temperature range are inter-related factors which also influence sensitisation (see The Prevention of Intergranular Corrosion).

Intergranular Corrosion of stainless steel is most often related to the fabrication by welding of thicker material (i.e. thicker than ≈2 mm). A narrow section within the heat affected zone (HAZ) will have attained and resided at a temperature within the sensitisation temperature range for a sufficient time to allow sensitisation to occur. Intergranular corrosion can therefore occur through this narrow section. This is termed weld decay (Fig 2.6)

![Fig. 2.6 Schematic illustration of sensitisation within the HAZ; with associated precipitation of chrome carbide and chromium depletion of the grain boundaries](image-url)
The Prevention of Intergranular Corrosion

- Fully annealed stainless steel should always be used for fabrication of components.
- Use the stabilised grades of austenitic stainless steel, *i.e.* those which contain the alloying elements of either titanium (Ti) or niobium + tantalum (Nb+Ta). These elements have a higher affinity for C than does Cr. They therefore combine with and lock up the C as Ti or Nb+Ta carbides that are uniformly distributed throughout the matrix of the steel (*i.e.* not formed at the grain boundaries). Thus there is insufficient free C to combine with and deplete the Cr at the grain boundaries.
- Use the low carbon (L) grades of austenitic stainless steel, *i.e.* those which contain <0,03%C (*e.g.* 304L, [1.4306]). Such lower C contents radically increase the time necessary for sensitisation to take place and decrease the temperature range over which it occurs. This gives adequate protection against sensitisation during the welding of thicker (plate) material, for example:
  - 0,08%C will sensitise in approximately 1-2 minutes;
  - 0,03%C will sensitise only after approximately 90 minutes.
- Due and proper care must be taken during fabrication to prevent sensitisation. Contamination by carbon containing substance (*e.g.* oil, grease, paint, polishing or adhesive residues, shop soil, etc.) must be avoided or if present, completely removed:
  - in and/or from the weld area (and welding consumables);
  - on and/or from the surface of the component if it is to be subsequently heat treated.
- The correct welding consumables for the welding of low carbon and stabilised grades of stainless steel must be used.
- Indiscriminate heating of the stainless steel for bending and forming must not occur.

Pitting Corrosion

Pitting Corrosion is a dangerous, very localised form of corrosion that results in small holes or perforations. There is little or a negligible amount of measurable general metal loss.

Pitting Corrosion mostly occurs in corrosive solutions that contain the chloride (Cl\(^-\)) halide ion. It is very aggressive and under suitable conditions it can attack any localised weak points within the passive film and thereby destroy the passivity in a very small area. This results in micro-anodes (active stainless steel) in a large surrounding cathodic area (the passive stainless steel surface), *i.e.* an extremely unfavourable galvanic effect (*Fig. 2.7*).

![Fig. 2.7 Schematic illustration of the factors involved in pitting corrosion](image)

Once the corrosion process has initiated the small and mobile negatively charged Cl\(^-\) is easily attracted into the pit by the positive (+\(^{ve}\)) charge that exists therein. Hydrochloric acid (HCl) is formed which, being very aggressive, accelerates the corrosion at this location.

Pitting Corrosion can occur in both acidic and basic corrosive solutions.
- However, it is more likely to occur and is more severe, in acidic corrosive solutions (*i.e.* pH <7).
- It is less likely to occur in basic corrosive solutions and in some instances, can be prevented by high pH levels, *viz.* ≈±12.
Elevated temperatures both increase the likelihood for it to occur and accelerate the rate of attack.
It is more likely to occur under stagnant conditions, i.e. in deoxygenated corrosive solutions.

**The Prevention of Pitting Corrosion**

- Use stainless steels of higher alloy content that will increase their inherent passivity (see Pitting Resistance Equivalent).
- The passive film must be unimpaired, undamaged, uncontaminated and in its most passive condition (i.e. preferentially have been formed by chemical oxidation).
- The stainless steel must be free of any sensitisation.
- Good design is necessary
  - to avoid occluded areas where concentration of the Cl\(^-\) can occur;
  - to ensure adequate flow rates that, in turn, promote better oxygenation, remove Cl\(^-\) from incipient pits and prevent stagnant areas or locations of higher temperatures or concentration within the corrosive solution.

**Resistance to Pitting Corrosion**

- **Critical Pitting Temperature (CPT):** determined by standard test as the lowest temperature at which pitting occurs:
  - a higher reported CPT may be taken as an indication that a specific grade of stainless steel/alloy is more resistant to Pitting Corrosion than those having a lower CPT;
  - a reported CPT must not be taken as a ‘go/no go’ service temperature in any application, as conditions present in the specific corrosive solution can exert a major effect.
- **Pitting Resistance Equivalent (PRE):** the pitting resistance is related to the chromium (Cr), molybdenum (Mo) and nitrogen (N) content.
  - The influence of these alloys is formulated as the PRE = %Cr + 3,3x%Mo + 16x%N. Note the marked effect of Mo and N, for example
    - Grade 316 [1.4401] 0,03%C 17,2%Cr 10,5%Ni 2,2%Mo \(\rightarrow\) PRE=24,5
    - Grade N08904 [1.4539] 0,02%C 20%Cr 25%Ni 4,5%Mo \(\rightarrow\) PRE=34,85
    - Grade 2205 [1.4462] 0,02%C 22%Cr 5%Ni 3,4%Mo 0,15%N \(\rightarrow\) PRE=35,6.
  - PRE values must be taken as a qualitative ranking of different grades of stainless steels/alloys in terms of their resistance to Pitting Corrosion. They must not be taken as an absolute quantitative measure of the resistance to Pitting Corrosion in any corrosive solution or service environment.

**Crevice Corrosion**

Crevice Corrosion occurs in locations where the surface of the stainless steel is occluded or shielded thus creating an oxygen differential, for example
- under bolt heads or washers;
- in the threads of nuts/bolts or pipe fittings;
- in flanged joints if absorbent gaskets are used or if the joint is improperly tightened;
- under sediments or settled solids;
- under marine growth and biofilms.
Such locations result in stagnant conditions (particularly the lack of free availability/access of oxygen to the surface of the stainless steel) and concentration effects. These in turn lead to the impairment or breakdown of the passive film.

In many respects Crevice/Shielded Corrosion is similar to Pitting Corrosion. It mostly occurs in neutral and acidic Cl\(^-\) containing corrosive solutions. The small and very mobile Cl\(^-\) easily enters the crevice or shielded area and builds up in concentration. The resultant corrosive attack of the impaired passive film usually takes place over a limited area that gives rise to an unfavourable galvanic effect, viz. a small anode<>large cathode ratio (Fig 2.8).
Objective: Demonstrate an understanding as to why stainless steel is the material of choice in a hygienic environment

Prevention of Crevice Corrosion

- The design must be such to avoid
  - conditions whereby solids may settle out and result in sedimentation, for example
    - flat bottomed tanks and vessels;
    - square corners (round corners are preferable);
    - insufficient flow rates in pipe/tube;
  - lap joints e.g. bolted, riveted, spot and/or seam welded: if present these should, if possible, be sealed with an inert, impervious sealing compound.
- Outlets must be such that tanks and vessels can be completely drained.
  - Similarly, pipe-work must be installed so that it can be completely drained during stoppages or plant shutdown.
- Tanks and vessels should be installed on legs or skirts to avoid the crevice that would result if they simply rested on the floor: if installed on the floor, the crevice must be perfectly sealed with an inert, impervious sealing compound.
- In welded joints
  - use butt welds rather than lap welds;
  - use continuous rather than spaced welds;
  - welds must be free of any defect that constitutes a crevice (e.g. undercut, porosity).
- In flanged joints
  - use flanges having a sufficient number of bolt holes;
  - properly tighten the joint;
  - use gaskets of impervious material;
  - do not re-use compressible gaskets.
- Remove any residues from the surface that may prevent free access or availability of oxygen to the surface (e.g. lubricants, cutting fluids, crayon marks, etc.).
- In use
  - the surface must not be covered with an absorbent material;
  - the surface must be regularly cleaned to remove any spillage or settled debris.

Resistance to Crevice Corrosion

In general terms the resistance of a stainless steel/alloy to Crevice Corrosion may be assessed from its resistance to Pitting Corrosion (i.e. the CPT and PRE values).
Microbiologically Influenced Corrosion (MIC)

MIC is not a new nor different mechanism of corrosion. It is the influence of micro-organisms (more specifically bacteria) on other mechanisms of aqueous corrosion.

Micro-organisms exist as bacteria, algae or fungi. They have the ability to attach and grow on the surface of many different structural materials as a biofilm, ranging in nature from a thin slime to a heavy encrustation of hard-shelled fouling. The micro-environmental conditions that develop within and under the biofilm can significantly influence the initiation and the subsequent rate of corrosion.

Corrosion would not occur if no biofilm were present.

Bacteria

Bacteria are considered to be the more common cause of MIC in stainless steel. They can exist and survive under and be present in, a wide range of environmental conditions:

- at dissolved oxygen concentrations from zero to saturated as
  - obligate anaerobes, i.e. complete absence of oxygen;
  - facultative anaerobes, i.e. with or without the presence of dissolved oxygen;
  - micro aerophilic, i.e. dissolved oxygen present only in minute amounts;
  - obligate aerobes, i.e. there must be dissolved oxygen present;
- in acidic to alkaline solutions (pH 1-10);
- at pressures varying from high vacuum to >30mPa;
- at temperatures varying from >100 °C to 10 °C below freezing;
- at salinity levels from a few ppb to >30%;
- in all types of water, e.g. natural and treated fresh water, estuarine and sea water, industrial and waste water;
- in marshes, wet soils and clays;
- in crude oil, petroleum products and some organic solutions;
- in many other aqueous solutions;
- their general characteristics include:
  - small size (0,1-5µm) and high mobility;
  - the ability to multiply at extremely high rates (some bacteria can double in number approximately every 20 minutes resulting in colonies of ≈2 million within 7 hours).

As a result of their different metabolic processes some bacteria can
- excrete acids
  - either organic acids (e.g. formic acid);
  - or mineral acids, e.g. sulphuric acid (H\textsubscript{2}SO\textsubscript{4});
- facilitate oxidation or reduction, for example
  - oxidation of sulphur (S) to sulphate ion (SO\textsubscript{4}\textsuperscript{2-}) to sulphuric acid (H\textsubscript{2}SO\textsubscript{4}); metals to metal ions, e.g. iron (Fe) to ferrous ion (Fe\textsuperscript{2+}) to ferric ion (Fe\textsuperscript{3+});
  - reduction of sulphate ion (SO\textsubscript{4}\textsuperscript{2-}) to sulphide (S\textsuperscript{2-}) as effected by sulphate reducing bacteria (SRB).

The slime coating of a bacterial cell
- entraps the needed food species and can concentrate corrosive species;
- can protect the bacteria from biocides and changes in the environment;
- of most importance, enables the bacteria to anchor onto localised surface areas of the stainless steel where they will multiply to form a bacterial film (or colony).

The more common bacteria that influence the corrosion of stainless steel include
- Gallionella and Sphaerotilus, both of which are aerobic oxidising bacteria that can exist at pH7-10 and temperatures of 20~40 °C;
Stainless steel is the material of choice in a hygienic environment because:

- *Desulfovibrio* (the most common being *D. desulfuricans*) and *Desulfotomaculum* (the most common being *D. nigrificans*), both of which are anaerobic sulphate reducing bacteria (SRB) that can exist at pH 4-8 and temperatures of 10°-40°C.

**Influence on the Corrosion Process**

The bacterial film will create a ‘micro-crevice’ (i.e. similar to Crevice Corrosion). Corrosion can initiate, usually in the form of an incipient pit.

**Under Aerobic Conditions:**
- At the corroding anodic area metal ions will go into solution, e.g. Fe → Fe²⁺ (ferrous ions).
- The ability of the aerobic bacteria to facilitate oxidation will alter the Fe²⁺ to Fe³⁺ (ferric ions) and Mn²⁺, if present, to Mn³⁺ (manganic ions).
- The positive (+ve) charge existing at the anodic area and the presence of +ve metallic ions will attract into the film any negatively charged anions present in the surrounding bulk solution:
  - the chloride ion (Cl⁻) is one such ion. Even if present in low concentrations of the order of ≈50ppm, being both small and mobile it is able to permeate through the slime coating to result in high concentration levels within the film. It will then combine with the Fe³⁺ and Mn³⁺ to form ferric chloride (FeCl₃) and manganic chloride (MnCl₃), both of which are very aggressive pitting agents.
- The initial incipient corrosion is accelerated and typically develops as a bottle-shaped pit (a narrow pin hole at surface opening to a large, sub-surface cavity):
  - penetration through the wall thickness can occur within a relatively short time.
- Corrosion products (mainly ferrous hydroxide [Fe(OH)₂] having a typical reddish/orange colour) form a tubercle (tubular mound) over the bacterial film on the surface.

**Under Anaerobic Conditions:**
- As above, at the corroding anodic area metal ions will go into solution.
- However, because of the anaerobic conditions, oxygen will not be present in the surrounding bulk solution:
  - therefore, the usual cathodic reduction of oxygen to hydroxide ions (OH⁻) cannot take place; instead the cathodic reduction will be that of hydrogen ions (H⁺) to molecular hydrogen.
  - This will exist on the cathodic surfaces as a layer of hydrogen (H), which polarises (i.e. masks) the surface and thus slows down the corrosion rate.
- The anaerobic sulphate reducing bacteria (SRB) have the metabolic ability to effect the reduction of sulphate ions present in the bulk solution by utilising the H on the cathode surface to produce sulphide ions, viz. SO₄²⁻ + 8H ↔ [SRB] → S²⁻ + 4H₂O:
  - thus, the surface of the cathodic area is depolarised and the corrosion is no longer slowed down.
- Iron sulphide (FeS) and hydrogen sulphide (H₂S) are the resultant corrosion products.

**Prevention of MIC**

- Carry out prior tests to determine the presence and nature of the bacteria if there is any likelihood of them occurring.
- Avoid the creation of localities where the bacteria can anchor and multiply.
- In many failures attributable to MIC it has been found to be associated with:
  - slight fabrication deficiencies, e.g. minute weld defects;
  - rough or profiled surfaces, e.g. grind marks, threads on bolts and fittings;
  - passivity impaired or destroyed (especially high temperature scaling) and not subsequently restored by pickling and passivating.
- Increase the flow rate to prevent sedimentation and build-up where bacteria could anchor and multiply.
- Flush and completely drain the equipment and/or pipework immediately after plant shutdown: if possible allow surfaces to dry.
* Use a suitable biocide to kill the bacteria: some bacteria are very resistant and are not killed, for example, by the level of chlorination that is used to treat potable water.
* If necessary, make use of grades of stainless steels or stainless alloys of higher inherent corrosion resistance.

**Stress Corrosion Cracking**

Stress Corrosion Cracking (SCC) is a localised mechanism of corrosion. It occurs in certain corrosive solutions and results in failure due to the initiation of fine cracks. These subsequently propagate (i.e. develop and progress) through the metal under the combined action of corrosion and a tensile stress.

A significant feature of SCC is that it can occur under corrosive conditions and stress values which independently and/or successively applied would not cause SCC.

- The crack propagation:
  - discontinuous (intermittent);
  - of a brittle nature (i.e. a very slight or negligible amount of deformation takes place);
  - either transgranular (i.e. through the body of the grains) or intergranular (i.e. along the grain boundaries) or sometimes both in nature.

The initiation (start) of SCC may take a considerable time but once initiated, the crack propagation is usually rapid to result in final failure. SCC can be very difficult to detect and often only final failure serves to indicate that it has occurred.

SCC of stainless steel has been much researched over the past 40-50 years. However, it is still not possible to positively identify, describe and quantify the underlying factors and mechanisms that cause or prevent its occurrence.

The chloride ion (Cl\(^-\)), which is commonly present in many corrosive solutions, is the most usual primary contributing factor to the SCC of stainless steels/alloys. It is referred to as Chloride Induced Stress Corrosion Cracking (Cl.SCC). The following will therefore be limited to outlining the factors pertinent to Cl.SCC of stainless steels/alloys.

- Other corrosive solutions can cause SCC, e.g. those which contain sodium hydroxide (NaOH), hydrogen sulphide (H\(_2\)S) but under conditions (e.g. of temperature and concentration) which differ from those applicable to Cl.SCC.

**Cl.SCC**

There are many factors which contribute to the occurrence of Cl.SCC. These may be grouped into three main divisions of influence (*Fig. 2.9*), viz. those as applicable to

- the corrosive solution
- the stainless steel/alloy
- the stress.

Some factors are essentially inter-dependent (e.g. crystal structure<->composition), but all may be regarded as interactive.

Cl.SCC is likely to occur only when the combined effect of all the various factors is such as to result in co-existence (i.e. overlapping) of the divisions of influence. Therefore, the divisions of influence should be considered as dynamic. Variations (sometimes to only a small extent) in any one contributory factor can cause or prevent this co-existence and thus respectively result in the occurrence or non-occurrence of Cl.SCC. e.g. a lower temperature of the corrosive solution will effectively shrink the division of influence of the corrosive solution thus preventing co-existence and hence Cl.SCC (*Fig 2.9(b)*).
Objective: Demonstrate an understanding as to why stainless steel is the material of choice in a hygienic environment

**Fig. 2.9 Schematic illustration of the three divisions of influence applicable to chloride induced stress corrosion cracking [Cl.SCC]**

(a) co-existence: therefore a likelihood of Cl.SCC;
(b) no co-existence: a shrinking of the corrosive solution division of influence (e.g. due to a lower temperature) thus preventing Cl.SCC

**The Corrosive Solution**

The chloride ion (Cl\(^-\)) which causes Cl.SCC is termed the aggressive or insidious ion. In general, the higher the Cl\(^-\) concentration, the greater the likelihood for Cl.SCC to occur. However, Cl.SCC can sometimes take place in a corrosive solution considered to be of a mild nature, *i.e.* of low Cl\(^-\) concentration.

An elevated temperature of above 50°-60°C is usually required. However, this is not a threshold temperature below which it can be guaranteed that Cl.SCC will not take place. Higher temperatures increase the likelihood of Cl.SCC and shorten the time for it to occur.

The pH has an effect in that Cl.SCC is most likely to occur under neutral to acidic conditions (*i.e.* pH 3-8).

**The Stainless Steel/Alloy**

The chemical composition will affect both the crystal structure and the passivity. The crystal structure exerts a major effect. In actual practice it has been found that the austenitic crystal structure of the conventional austenitic stainless steels which contain ≈8-20%Ni (*e.g.* 304 and 304L, [1.4301 and 1.4306] and 316 and 316L, [1.4401 and 1.4404]) are the most susceptible.

- The ferritic crystal structure of ferritic stainless steels (*i.e.* with no or very low Ni contents) and the mixed ferritic+austenitic crystal structure of the duplex stainless steels (*i.e.* which have relatively low Ni contents) have a high resistance, but not in all instances an immunity, to Cl.SCC in many actual applications.
- In duplex stainless steels cracking, that may initiate and propagate in a grain of austenitic crystal structure, is arrested at the grain boundary where it meets with an adjacent grain of ferritic crystal structure.
- The stainless alloys having ≈25-42% Ni have a high resistance and those with a Ni content of >=42% Ni may be considered, in most corrosive applications, as immune to Cl.SCC.

Other factors applicable to the micro-structure can also exert an effect, *e.g.* sensitisation, alteration to and within the crystal structure resulting from cold work.

Higher levels of alloying elements that improve the passivity and increase the resistance to Pitting Corrosion, such as Cr and Mo are thought to extend the resistance to Cl.SCC into more aggressive corrosive solutions (*viz.* higher concentrations of Cl\(^-\) and at higher temperatures).
**The Stress**

A tensile stress must be present for Cl.SCC to occur. A low level of tensile stress reduces the risk of Cl.SCC and increases the time taken for it to initiate. This tensile stress

- can either be applied (i.e. due to the conditions that exist in the application) or residual (i.e. resulting from fabrication, e.g. welding, cold forming, machining, grinding, etc);
- can either be as a threshold stress (in the case of a smooth unaffected surface) or as a stress concentration factor (in the presence of any defect, pit or crack).

The level of tensile stress necessary to induce Cl.SCC is

- of a low magnitude (viz. much lower than that required to cause mechanical failure);
- typical of those associated with residual stresses which therefore are considered to be the element of most Cl.SCC failures (i.e. as opposed to applied stresses).

Cl.SCC will not occur under conditions of compressive stress.

**The Mechanism of Cl.SCC in Austenitic Stainless Steels**

There is no unanimously accepted mechanism whereby Cl.SCC takes place in 8-20%Ni austenitic stainless steels. The following outline must therefore be considered in this light, i.e. as a ‘proposed mechanism’ (**Fig. 2.10**).

![Fig. 2.10 Schematic illustration of the initiation and propagation of Cl.SCC in a conventional (8-10%Ni) austenitic stainless steel](image)

(a) incipient pit and mechanical failure by cracking at the base of the pit;
(b) several further cracks initiate and propagate from the initial crack;
(c) cracks continue to initiate and propagate in a highly divergent manner: original pit tends to become enlarged

Conditions that in some way render the passive film relatively unstable and thereby cause ‘embryonic, incipient pitting’ (i.e. only just beginning) may be considered as the initiation of Cl.SCC.

- Thereafter a complex interaction between chemical and electro-chemical effects occurs within the incipient pit:
  - unfavourable galvanic conditions will exist, viz. micro-anode (the incipient pit) in a very large cathode (the surrounding surface);
  - the nature of the corrosive solution present within the pit will be altered.
- Mechanical failure by cracking initiates at the base of the pit. The corrosive solution then enters the resultant crack, possibly assisted by the crack slightly opening due to the tensile stress.
- Accelerated corrosive attack, in a manner similar to that which occurred in the incipient pit, now takes place on the newly created active (non-passive) anodic surfaces of the crack wall. This is thought to result in the creation of very small discrete (separate) and localised stress concentration sites on the pit wall from which several further cracks initiate.
Objective: Demonstrate an understanding as to why stainless steel is the material of choice in a hygienic environment

Crack propagation is thus discontinuous and of a highly divergent, branched nature. In conventional austenitic stainless steels crack propagation is transgranular.

**Prevention of Cl.SCC**

The design is of extreme importance in that it should avoid
- highly stressed components
- areas of stress concentration
- fabricational factors which would cause high residual stress
- locations where concentration of the Cl⁻ can occur.

Similarly, in the fabrication of the component, care must be taken to avoid the creation of factors which could contribute to or cause Cl.SCC, for example
- sensitisation
- coarse grinding
- welding process parameters that
  - adversely affect the crystal structure or the balance of the crystal phases within both the weld metal and the HAZ;
  - result in high residual stress.
- Conditions which introduce Cl⁻ must be avoided, for example
  - leakage into the insulation through the outer cladding
  - use of insulating material that contains (or is contaminated with) Cl⁻:
    - if elevated temperatures exist, any Cl⁻ introduced into or contained in the wet/damp insulation will be concentrated by evaporation, thus an aggressive corrosive solution likely to cause Cl.SCC will develop.
- Preventative measures that can be employed under such conditions include
  - coating the stainless steel surface that will be in contact with the insulation with an anti-stress corrosion lacquer, *i.e.* a special paint;
  - wrapping, *i.e.* inserting a barrier aluminium foil or plastic film between the stainless steel and the insulation.
- Spillage of a corrosive solution which contains Cl⁻ which could be concentrated by evaporation; if such spillage occurs it must be frequently and thoroughly washed off.

Introduce compressive stresses in the surface layers by suitable blasting or peening techniques.

Use stainless steels and/or alloys that have a higher and increased resistance to Cl.SCC, *viz.* super ferritic stainless steels, duplex stainless steels, austenitic stainless alloys and (if necessary) nickel based alloys.

**Resistance to Cl.SCC**

The resistance of different stainless steels/alloys is assessed by severe and aggressive laboratory test conditions that are designed to cause Cl.SCC in a short time.

**U-Bend Testing in Boiling Chloride Solutions**

- Standard specimens of the stainless steel/alloy to be tested are bent into a U and tensioned by a bolt through the legs of the U. Three such specimens are placed in either 45% magnesium chloride (MgCl₂) at boiling point (150 °C) or 40% calcium chloride (CaCl₂) at 100 °C.
- The longest time during which none of the three specimens exhibit cracking is taken as a measure of the resistance to Cl.SCC and used to rank different stainless steels/alloys, *e.g.* the typical times for cracking to occur in the MgCl₂ and the CaCl₂ solutions are respectively 316, [1.4401] → 5 hours and 450 hours
  NiCrMoCu 25-20-5, [1.4539] → 70 hours and >1000 hours.
Stress Level to Induce Cl.SCC

Various test methods are employed whereby the level of stress required to cause Cl.SCC in a specific time is determined.

One such test involves dripping a dilute Cl⁻ solution onto an electrically heated specimen that is held at a fixed constant temperature. Evaporation of the solution concentrates the Cl⁻ resulting in severe conditions conducive to causing Cl.SCC. The highest stress level for which no cracking occurred is taken as a measure of the resistance to Cl.SCC and used to rank different stainless steels/alloys.

- The stress level is reported as an intensity %, i.e. \((R/R_{p0.2})\)%, where \(R\)=Applied Stress and \(R_{p0.2}\)=Specified proof stress at the temperature of the test (\(T\)°C), e.g. the nominal stress intensity levels for different stainless steels are:
  - 316, [1.4401] <10%
  - CrNiMo 22-5-3, [1.4462] ≈40%
  - CrNiMo 25-7-4, [1.4410] ≈65%.

Materials of Construction vs. Design/Process Conditions

The interface of MATERIALS OF CONSTRUCTION ↔ DESIGN AND PROCESS CONDITIONS are inseparably linked and should always be considered together.

Particularly with respect to corrosion, minor modifications of the design and process conditions can often have a major effect on the selection of the materials of construction.

In operation, control of the operating conditions is equally important. Excursions outside the limits of the process conditions used as the basis for the selection of the material of construction or similarly, the use of inappropriate conditions in associated procedures can result in the rapid onset and propagation of unexpected corrosion.

Routine inspection is necessary to ensure that conditions and events that are likely to induce corrosion have neither developed nor are occurring. Rectification, done as soon as possible, will prevent a potentially serious situation developing.

Similarly, when maintenance is required, all work must be conducted so as to avoid creating a condition conducive to the initiation of corrosion.

An appreciation, understanding and application of the factors as outlined in the preceding text will enable stainless steel to be properly selected, fabricated, operated and maintained to its maximum capability.
Notes

The following terms used in or applicable to the subjects covered in the preceding text are defined/explained hereunder:

**Ion:** An atom or group of atoms which, by the gain or loss of one or more electrons, acquire/s an electrical charge, for example
- sodium chloride (NaCl) will result in sodium and chloride ions, *viz.* Na⁺ *(cation)* and Cl⁻ *(anion)*
- sulphuric acid (H₂SO₄) will result in hydrogen and sulphate ions, *viz.* H⁺ *(cation)* and SO₄²⁻ *(anion)*.

**Electrolyte:** a solution of a substance in a liquid (usually water), whereby the ions (both +ve cations and -ve anions) will conduct an electric current through the solution. A corrosive solution is often referred to as a corrosive electrolyte or simply an electrolyte.

**Anions:** in the electrolyte will flow towards and accumulate at (around) the anodic area.

**Cathodic area:** the area on the metal surface that is not undergoing corrosion.

**Cations:** in the electrolyte will flow towards and accumulate at (around) the cathodic area.

**Electrochemical:** aqueous corrosion is said to be electro-chemical because when the metal corrodes there is a co-existing flow of electricity (by electrons flowing through the metal) between the anodic areas and cathodic areas on the metal surface:
- at anodic area metal ions go into solution 4Fe → 4Fe²⁺ + 4e⁻
- the electrons flow through metal to the cathodic area where, typically, the reduction of oxygen occurs O₂ + 2H₂ + 4e⁻ → 4OH⁻
Addendum: Examples of Corrosion Failures

Underlying Factors

Examples of corrosion failures that initiated from both the internal and external surfaces and which had a significant impact on the hygienic condition of plant and equipment are given below. The underlying principles, events and causes are outlined.

It is important to appreciate that the corrosion failures are not due to the unsuitability of the metal but rather because of the introduction of inappropriate, aggressive environmental conditions.

<table>
<thead>
<tr>
<th>Corrosion Mechanism</th>
<th>Underlying Cause</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloride Induced Stress Corrosion:</td>
<td>Accumulated scale build-up resulted in the formation of a biofilm which</td>
<td>Total failure of tanks.</td>
</tr>
<tr>
<td>cracking (Cl.SCC) of stainless steel</td>
<td>concentrated chlorides present in the surrounding bulk solution: this then</td>
<td>It is not possible to repair stress corrosion cracks.</td>
</tr>
<tr>
<td>hot water tanks.</td>
<td>initiated the SCC.</td>
<td>Scale and the biofilm would also harbour bacteria.</td>
</tr>
<tr>
<td>Pitting Corrosion: vessels, heat</td>
<td>Pitting initiated due to the inappropriate use of descaling and sanitising</td>
<td>Surface pits harbour infection and bacteria.</td>
</tr>
<tr>
<td>exchangers, pipes and filters.</td>
<td>chemical having high free chlorine levels (&gt;50ppm)</td>
<td>Difficult to clean.</td>
</tr>
<tr>
<td>Localised Corrosion of</td>
<td>Sulphur dioxide (SO₂) in sugar solution. In vapour space this is absorbed</td>
<td>Localised attack of surface under condensates resulting in rough,</td>
</tr>
<tr>
<td>stainless steel product storage</td>
<td>in condensates forming sulphurous and/or sulphuric acids.</td>
<td>shallow pits.</td>
</tr>
<tr>
<td>vessel.</td>
<td></td>
<td>Pits harbour bacteria – difficult to clean.</td>
</tr>
<tr>
<td>Microbiologically Influenced</td>
<td>Stainless steel pipes were not drained. The water contained sulphur reducing</td>
<td>Shallow saucer shaped pits formed. Potentially these could penetrate</td>
</tr>
<tr>
<td>Corrosion (MIC).</td>
<td>bacteria (SRB). Refer MIC in main text above.</td>
<td>the wall thickness of the pipe to cause a major (irreparable) failure.</td>
</tr>
<tr>
<td>Outside Surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloride Induced Stress Corrosion:</td>
<td>Chlorides were present in the insulation. Due to poor initial specifications,</td>
<td>Stress corrosion cracks propagate through the stainless steel plate or</td>
</tr>
<tr>
<td>cracking (Cl.SCC) of stainless steel</td>
<td>insulation not properly installed, insulation not restored/repaired after</td>
<td>the welded heating/cooling jacket.</td>
</tr>
<tr>
<td>heating jackets coils and bundles.</td>
<td>maintenance, ingress of water into the insulation jacket.</td>
<td>Steam or ammonia breaks through to process side.</td>
</tr>
<tr>
<td>Stress Assisted Corrosion:</td>
<td>Chlorides present in the insulation due to poor initial specification,</td>
<td>Product contamination and/or risk to personnel.</td>
</tr>
<tr>
<td>cracking of epoxy lined plain carbon</td>
<td>installation and repair of insulation.</td>
<td></td>
</tr>
<tr>
<td>(mild) steel process vessels.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pitting Corrosion of stainless</td>
<td>Pitting due to inappropriate use of chlorine containing sterilants being used</td>
<td>Surface pits harbour infection and bacteria.</td>
</tr>
<tr>
<td>steel process piping, heat</td>
<td>in the process environments. Concentration by the evaporative effect after each</td>
<td>Difficult to clean.</td>
</tr>
<tr>
<td>exchangers and vessels.</td>
<td>application.</td>
<td>Pits can progress to result in perforation of the metal with little</td>
</tr>
<tr>
<td></td>
<td></td>
<td>associated general metal loss.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Usually unnoticed - pits can be very small and/or plant is not</td>
</tr>
<tr>
<td></td>
<td></td>
<td>regularly inspected.</td>
</tr>
<tr>
<td>Crevice Corrosion of stainless</td>
<td>Chlorides were present in the water used to dilute the glycol. The configuration</td>
<td>Crevice corrosion in the weld joint. The glycol solution leaked out</td>
</tr>
<tr>
<td>steel piping system containing</td>
<td>of the weld joint between the wall of the vessel and the cooling coil created</td>
<td>resulting in a system failure.</td>
</tr>
<tr>
<td>glycol.</td>
<td>a crevice.</td>
<td>Repair was possible but very costly.</td>
</tr>
</tbody>
</table>

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Insulation

Underlying Principles

Insulation of hot and cold process plants is required to maintain safe working conditions and keep the product at the required temperature. In the last 20 years serious failures caused by Stress Corrosion Cracking (SCC) in food and beverage process equipment have given rise to a greater awareness of the specifications required in the design, fabrication and maintenance of the plant. The key aspects which are now considered to address the failures are the following.

- Specifications of the insulation material from the manufacturers (foam, glass wool). Chloride present in the traditional materials range from 5 to 1000ppm chlorides. A maximum of 15ppm is considered critical in this material.
- Specifications of the application of insulation systems onto the vessels or pipe surfaces are as important as the material itself. No additional chlorides must be allowed to contaminate the insulation during its application to the surfaces. A drop of perspiration from the installation crew gives a concentration of 1000ppm chlorides or 1g/m$^2$ that severely accelerates corrosion of the metal surface.
- Design of the installation system must include an external coating (cladding) that prevents any moisture from entering the insulation throughout the life of the plant. Moisture in the insulation will leach out the chlorides in the insulation, concentrating them onto the surface of the vessel or the pipe.
- A barrier coating of anti-stress corrosion paint or lacquer must be applied directly onto the metal surface. On top of this a sacrificial layer (aluminum foil) is placed to protect the vessel or pipe surface if any defects exist in the barrier coating. The insulation material of the correct thickness is then applied, followed by a coating onto which is applied a totally enclosed and welded stainless steel cladding. Failure to follow these strict specifications will result in early corrosion of the equipment that will prove both costly and hazardous.
- On insulation systems used on cold vessel and piping, a vapour barrier is also fitted under the outside cladding to ensure that no moisture enters the insulation. This can cause ice build-up on the cooling jackets and physically destroy the insulation making it useless for its function.
- As corrosion starts on the metal surface in the areas of maximum stress, special care must be taken where welding has taken place or where the material has undergone stress through forming or bending and has not been stress relieved.

Both Figs. 2.11 and 2.12 explain the importance of a sound insulation system and the importance of maintaining these specifications throughout the life of the plant. Re-insulation of repaired or damaged areas is possible to prevent the entire vessel or piping from failure.
**Objective:** Demonstrate an understanding as to why stainless steel is the material of choice in a hygienic environment

**Fig. 2.11 Details of insulation**

Examples of good and poor insulation details are shown in Figs. 2.13 and 2.14. A fitting (Fig. 2.14) has been welded onto a hot vessel without placing a shroud around it to prevent water ingress into the insulation. This is found to be the most common fault.

**Fig. 2.12 Insulation integrity**

Stress Corrosion Cracking (SCC) has been experienced in stainless steel plants in all food and beverage industries where plants have not followed the specifications indicated above.
Examples of serious product spoilage and plant failures are recorded in the brewing, dairy, soft drinks and yeast industries in South Africa and around the world.

Examples of some of these incidents are shown below.

- **Fig. 2.15**: the SCC crack under the sensor (↑) started from the outside of the shell. Cause: chlorides in insulation. Age of vessel 10 years.
- **Fig. 2.16**: SCC cracks seen from insulation side; caused by chlorides in insulation. Age of vessel 10 years.
- **Fig. 2.17**: top is the insulation side where SCC started; bottom is product side.
- **Fig. 2.18**: the stress corrosion prevention coating, applied on vessel under insulation, contained excessive chlorides causing SCC. Age of vessel 6 weeks. Vessel replaced.
- **Fig. 2.19**: 40% surface corroded; cause: chlorine sterilisers used in cellars. Age of piping 6 years.
- **Fig. 2.20**: crevice corrosion of welds on fermenters’ cooling coils caused excessive glycol leaking. Root cause: chlorides in water used for diluting the glycol. Age of vessels 10 years.

### 2.3 Fabrication of Stainless Steel – Preservation and Restoration of Passivity

This chapter addresses the avoidance of damage (impairment) of the surface of stainless steel during fabrication. However, similar factors apply to the operation and maintenance of stainless steel plant and equipment. The text outlines the cause and effect and the suggested Dos(✓) and Don’ts(✗).
Mechanical Damage and Contamination

During fabrication the aim must be to preserve and maintain the integrity of this passive film and further to prevent any conditions that would otherwise adversely affect the corrosion resistance. In this respect there are two factors common to most stages of fabrication that must be considered:

- mechanical damage to the surface;
- contamination of the surface.

Further, in some instances the passivity will be unavoidably impaired or destroyed.

If any of the above has occurred the affected surface area must be suitably treated to fully restore the passivity (corrosion resistance).

Refer Restoration of Passivity.

Mechanical Damage

This is the impairment or removal of the passive film by mechanical means.

- It can either be avoidable (e.g. scratches and gouges) or unavoidable (e.g. the creation of a new surface by cutting or grinding).
- The passive film will spontaneously (Note: not instantaneously) repair itself if damaged or reform on a newly created surface, provided free and unimpeded access to oxygen is available (e.g. the oxygen in the air).

However, experience has shown that such a self-passivated surface has a lower resistance to discoloration, staining and possibly the initiation of corrosion. Therefore, it is highly advisable that passivity should be fully restored by suitable treatment.

Contamination

Contamination of the surface is caused by many different substances.

The most common form of contamination is the so-termed ‘ferrous contamination’, i.e. by substances that contain iron. This is caused in various ways as outlined in the text of the following sections.

- Corrosion of this ferrous contamination will occur on exposure to the environment and result in rust staining, i.e. typical of that which forms on the surface of carbon (mild) steel. The staining will vary from light to heavy and dark, depending on the degree of contamination that has taken place.
- In addition, the passivity can be impaired insofar as it would be more likely for corrosion to occur.
- Ferrous contamination should therefore be avoided. If it has taken place the affected surface area must be suitably treated to fully restore the passivity.

The cause and effect of other common forms of contamination are outlined in the text of the following sections.

Storage

Contamination

Storage by laying the sheets/plates on the floor will inevitably result in contamination by whatever debris is present (e.g. oil and hydraulic fluid that has leaked from trucks and forklifts, grease, carbonaceous and ferrous dust; shop floor litter).

Welding on a surface contaminated with any substance that contains carbon (C) (e.g. hydraulic fluid, oil, grease, carbonaceous dust) will cause carbon pick-up in the weld metal and thereby
Objective: Demonstrate an understanding as to why stainless steel is the material of choice in a hygienic environment

Seriously impair the corrosion resistance (viz. Intergranular Corrosion). Whereas rectification is possible, it requires that the component be heat treated at high temperatures, which is both difficult and often totally impracticable.

Store sheet and plate off the floor, preferably in horizontal or vertical racks. To avoid ferrous contamination, contact between the stainless steel and the carbon (mild) steel racks must be prevented:
- either by the use of hard wood bearers;
- or by covering such contact areas with stainless steel (off-cuts or scrap pieces can be used for this purpose).

Do not store carbon steel above stainless steel in vertical racks. Any loose friable debris (e.g. mill-scale) which falls off the carbon steel will cause ferrous contamination on the surface of the stainless steel in the rack below.

Remove oil, grease and hydraulic fluid with a water borne or dispersible degreaser, followed by thorough rinsing with clean water and drying.

Do not use solvents for this purpose as this will simply spread the contaminants in a thinner layer over a larger surface area.

In damp or humid environments dust that has settled on the surface can:
- cause incipient rust staining if it contains any ferrous substances (e.g. mill-scale, iron or steel particles);
- absorb aggressive salts (e.g. from marine or industrial atmospheres): continued alternate absorption and evaporation of such contaminated moisture within the dust layer results in an increase of the concentration of these aggressive salts. The dust layer can thus become a very aggressive corrosive medium (poultice) that will stain or discolour the surface and in serious cases, lead to the initiation of corrosion.

Prevent dust from entering the storage area, particularly ferrous dust that results from the abrasive cutting or grinding of carbon (mild) steel in adjacent work-areas (termed fly-over).

Use heavy paper or plastic sheets to cover the stainless steel in dusty environments.

Mechanical Damage

Mechanical damage to the surface can occur during storage (e.g. scratches).

Thin gauge cold rolled sheets, which have a superior surface finish to that of plate, are the more likely to be affected.

Separate sheets (and possibly the thinner gauges of plate) during storage by sheets of paper: preferably store thinner gauge sheets in crates.

Handling

Mechanical Damage

Scratches and gouges can easily occur during handling. Some degree of contamination of the scratches/gouges could also take place. This aggravates the damage and increases the likelihood of initiating corrosion. Examples of events that will cause such damage include:
- if handling equipment (e.g. the forks of a forklift) is haphazardly forced inbetween plates;
- if chain slings slip, which they tend to do, thus damaging the surface.

Carefully separate heavy plates and chock with wooden blocks so that handling equipment can easily be inserted between the plates without damaging the surface.

Keep plates and sheets laid out for use off the floor. Separate them with wooden planks to prevent surface damage, to facilitate subsequent handling and to prevent contamination.

Do not use chain slings: slings of heavy duty synthetic material are preferable.
Contamination

Ferrous contamination arises mainly from the surfaces of equipment that have previously been in contact with carbon (mild) steel. The loose scale that flakes off the surface of such steel will usually be present.

- It is preferable to dedicate equipment for use with stainless steel only (e.g. the synthetic slings).
- Clean all handling equipment employed to handle both stainless steel and plain carbon (mild) before use with stainless steel. It is therefore advisable to plan and schedule the handling of stainless steel.

Cutting and Forming

Mechanical Damage

Cutting:
Both mechanical and thermal cutting are considered as mechanical damage because a new surface is created.

Mechanical Cutting:
- Suitably treat mechanically cut edges that will be exposed to the environment in the end-use application to restore the passivity. It is not usually necessary to treat mechanically cut edges if they are to be welded.

Thermal Cutting:
Thermal cut edges and the adjacent surfaces will be oxidised (scaled) due to their exposure at high temperatures. Such surfaces will not naturally self-passivate.
- Suitably treat thermally cut edges to fully restore the passivity if they are to be exposed to the environment in the end-use application.
- Lightly dress thermally cut edges that are to be welded to remove the oxidation (scale).
- Thermally cut edges in which the chemical composition of the sub-surface layers has been altered must, in all instances, be mechanically dressed to a depth of $\approx 2\text{mm}$ to remove the affected material.

Forming:
In forming, the localised contact area of the tooling on the surface or the relative movement between the stainless steel and the tooling, will deform, scratch or gouge the surface and thereby impair the passive film.
- Prevent damage by either inserting heavy paper between the stainless steel and the tooling or by covering the stainless steel with a plastic film or by using lubricants.

Contamination

Cutting and forming equipment is often used for both carbon (mild) steel and stainless steel. Therefore, the likelihood for ferrous contamination of the stainless steel exists.
- The source of contamination is usually not from the tooling which is generally made of hardened tool and die steels. It normally stems from the carbon (mild) steel previously cut or formed, viz. the loose and friable scale that easily flakes off the surface or minute chips, slivers and swarf.
  - In the case of cutting and forming, the contamination may be aggravated due to these particles being forced into the relatively soft surface of the stainless steel to a depth vastly greater than the thickness of the passive film. Hence the rust staining will not simply be superficial as and more seriously, localised spots of weakness in the passive film will exist, resulting in sites where corrosion could initiate.
- Thoroughly clean cutting and forming equipment before use with stainless steel (e.g. plate rolls, spinning and knuckling rolls, press-brake tooling, guillotine table and the feet of guillotine clamps, any clamping surface, etc.).
In addition, contact of the stainless steel with such surfaces can be prevented by covering them with heavy Kraft paper. Alternatively cover the stainless steel with a plastic film.

As in handling, plan and schedule the cutting and forming of stainless steel.

**Fabrication**

**Contamination**

General ferrous contamination on the surface results from
- the stainless steel coming into contact with carbon (mild) steel and/or other ferrous contaminated surfaces;
- air-borne ferrous dust generated by the grinding or abrasive cutting of carbon (mild) steel, either in adjacent work-areas (i.e. fly-over) or in the stainless steel work-area. This dust will settle either on the surface of the stainless steel or on working surfaces and thus become an additional source of further contamination.

More localised ferrous contamination of the surface will result from the grinding or abrasive cutting of carbon (mild) steel in proximity to the stainless steel.
- The particles within the stream can be at a high temperature when they strike the surface of the stainless steel and thus burn through the passive film and fuse onto the surface.
- Each fused particle will cause a localised spot of weakness in the passive film resulting in a significant loss of corrosion resistance.

Note: It should be appreciated that the particles in a stream resulting from the grinding of stainless steel will be at a sufficiently high temperature to cause oxidation of their surface. Therefore they will not be corrosion resistant. Such particles are thus a similar form of ferrous contamination.

Surfaces (e.g. worktops) with which stainless steel will come into contact should be of a material that would not cause contamination and that will be free of contaminating debris. It is preferable that worktops should be of stainless steel (or covered with thin gauge stainless steel sheet). Alternatively, cover worktops (and other surfaces) with heavy Kraft paper.

The ideal is for the fabrication of stainless steel to take place in a separate shop. However, if this is not possible, set aside a specific area for stainless steel only. Erect vertical sheeting or screening to prevent (or reduce to a minimum) the fly-over of ferrous contamination originating from the adjacent carbon (mild) steel fabrication area.

Do not grind or abrasively cut carbon (mild) steel in the stainless steel work areas.

Especially, do not grind or abrasively cut carbon (mild) steel in proximity of stainless steel.

Cover the stainless steel if grinding or abrasively cutting of any metal has to be performed in the proximity. Use heavy paper (or other material) that will resist the high temperature particles burning through and impinging/fusing onto the surface of the stainless steel.

It is often necessary to use temporary attachments (e.g. lugs, tangs, braces) to maintain the required shape or to hold pieces in position during fabrication.
- Tack welding carbon (mild) steel temporary attachments to stainless steel causes contamination associated with each tack. This is both localised and can penetrate to a significant depth due to the dilution of the molten weld metal by the carbon (mild) steel.
- Likewise, contamination will result if the attachments and/or the welding consumables, used to effect the tack welds, are of an inferior grade of stainless steel to that being fabricated.
- Corrosion will initiate in these localised areas and progress rapidly through the stainless steel to or beyond the depth of the original contamination.
- Such contamination is extremely difficult to rectify.
  - Even if completely ground out and repair welded, a localised area with potentially inferior corrosion resistance will always result.
- All temporary attachments must therefore be
  - of the same (or superior) grade of stainless steel as that being fabricated;
  - welded (tacked) in place using the correct welding consumable, i.e. the same as that required for the grade of stainless steel being fabricated.
It is usually necessary to grind some areas either during or after fabrication. Note: the factors outlined below also apply to polishing, wire brushing, etc.

- Contamination of the ground surface can occur if the abrasives employed
  - contain iron;
  - have been contaminated
    - either by use on carbon (mild) steel (or any other metal)
    - or have come into contact with a contaminated surface (e.g. putting the grinder down on the shop floor);
- grinding of a contaminated surface will smear the contamination over and into the total ground surface;
- a contaminated ground surface seriously impairs the passivity: dark staining will develop and corrosion is more likely to initiate;
- ✓ all abrasives must be iron free;
- ✓ dedicate all grinding and polishing tools (and the abrasives fitted thereto) for use on stainless steel only;
- ✓ avoid contaminating the abrasives in use;
- × do not grind a contaminated surface.

Contamination of the surface can also result from other sources, e.g. inks and crayons used for marking or identification purposes, residues from adhesive tape, etc. Such contaminants usually result in discoloration or staining. In some instances they can cause the breakdown of the passive film in service and thus initiate corrosion. Further, if present, they can affect the processes used for the restoration of passivity.
- ✓ Remove all such contaminants from the surface by suitable means.

**Mechanical Damage**

- In the welding of temporary attachments, the welding is localised and therefore results in high heat input with resultant stresses concentrated in a very small area.
  - This constitutes a form of mechanical damage which may lead to corrosion in some corrosive solutions.
- The removal of a temporary attachment by simply knocking it off with a hammer will tear out the tack welds that attach it to the fabrication.
  - This results in small rough craters of inferior passivity where corrosion is more likely to initiate.
  - Both the repair and/or the restoration of the passivity of such craters is difficult, time consuming and costly.
- ✓ Formulate and implement procedures to minimise the effect of the localised welding.
- ✓ Remove all temporary attachments by carefully grinding them off the fabrication.

Weld spatter can either fuse to the surface creating a tiny crevice and/or burn through the passive film and create a tiny crater.

- The passivity is impaired in these small areas and the droplets of spatter will be oxidised (scaled).
  - Staining of the droplets and the surrounding surface will result and the initiation of corrosion is likely.
    - Weld spatter is therefore also a form of contamination.
- Attempting to remove the spatter fused onto the surface by grinding will smear the oxidised (scaled) droplets over and into a larger surface area and thus compound the problem.

Prevent spatter by optimising the welding process parameters.
- ✓ Make use of spatter prevention pastes that prevent the spatter fusing to the surface. After welding it is a simple matter to brush off the loosely adhering spatter and wash the paste off the surface.
- ✓ Remove fused spatter with care, preferably by chipping or wire brushing (stiff, short, stainless steel bristles). Then gently dress the ‘burn through’ spots by grinding.
Grinding will create a new surface and is therefore a form of mechanical damage.

* Use of inappropriate technique for localised and spot grinding can result in a rough surface that is often also overheated (heat tinted). If heat tints have resulted from over heating (burning), these are high temperature oxides and this surface will not self-passivate nor is it corrosion resistant.

**Do not use coarse abrasives.**

✓ Take care during grinding to avoid over-heating and developing the associated heat tints.

- Abrasive discs and flapper wheels are less likely to cause overheating compared to grinding wheels and belt grinders.

**Do not grind unnecessarily and/or indiscriminately.**

**Welding**

**Localised Damage**

The usual cause of this type of damage in electrical fusion welding is either striking an arc outside the weld-prep or arcing.

- Arc strikes are commonly a result of difficulty in igniting the electrode. Thus the expedient of tapping or scratching the electrode tip on or across the surface is adopted.
- Arcing at the surface of the metal being welded will occur if inadequate contact exists within the electrical circuit at this location.
- Both arc strikes and arcing result in random localised spots of high heat intensity, the harmful effects of which can penetrate to a significant depth below the surface.
  - Repair and rectification to match the properties of the parent material is difficult. Moreover, because of the small size and random locality of the damage, the repair and rectification is often overlooked.

✓ Prevention is vastly more preferable than cure - avoid arc strikes and arcing.

✓ If it is necessary, ignite electrodes on a separate striker pad.

- Ensure that the striker pads are well connected in the electrical circuit.
- Similarly, ensure good connection of the component being welded in the electrical circuit. If connection depends simply on contact with the worktop, arcing can occur at the points of contact.

**Passivity of the Weld Zone**

During welding the metal within the weld zone (i.e. both the weld metal and the adjacent parent metal) will be heated to within a range of high temperatures.

- Oxidation (scaling) of the surface will take place unless oxygen is completely excluded by perfect shielding with an inert gas.
  - The oxide (scale) formed will vary depending on the temperature attained by the metal surface, viz. a dark and heavy scale on the weld and parent metal just next to it, progressively decreasing to minor heat tints at distances further from the weld deposit. The inside (back) surface is also affected by a weld deposited on the outside only, *e.g.* cooling coils welded onto the outside surface.

- Oxidised (scaled) surfaces are not passive nor will the passive film form thereon. Corrosion will therefore readily initiate.

Under perfect shielded conditions (*e.g.* as in the gas shielded arc welding processes or by inert gas purging) oxidation (scaling) will be prevented and the passivity is therefore unaffected.

✓ High quality shielding/purge gas must be employed

- *e.g.* of very low oxygen content.

✓ The shielding/purge must be undisturbed

- *e.g.* use screens if welding under draughty conditions.

✓ The metal surface must be shielded until the temperature thereof drops to below ≈500°C

- *e.g.* employ a purge dam to follow immediately behind the torch.
Use purge dams to protect back surfaces or surfaces that will be inaccessible for subsequent treatment
- *e.g.* the internal surface of pipe.

Subsequently properly treat all surfaces that exhibit high temperature oxidation (even minor heat tints) to restore the full passivity. It is recommended that if the end-use is to be of a critical nature and/or be in a highly aggressive environment, the surfaces that have been under shielded inert conditions should also be treated.

Refer **Restoration of Passivity** that follows.

**Restoration of Passivity**

After the completion of the fabrication operations and processes it is vital to ensure that the passivity of the stainless steel is nothing less than perfect.

- All surfaces that have been affected or impaired in any way (either in localised areas or the total surface) must be suitably treated.
  - The effort, time and cost required to fully restore the passivity will be greatly reduced by the disciplined implementation of the relevant Dos (✓) and Don’ts (✗) as outlined in previous sections.

The treatments required to fully restore the passivity include
- cleaning
- pickling
- passivating.

**Cleaning**

Cleaning is performed to remove general contaminants (*i.e.* other than ferrous contamination) from the surface.

- Examples of such contaminants include dust; abrasive and adhesive residues; films of polishing lubricants, oils and grease; cutting fluids; substances used for marking and identification purposes; *etc.*
- If present they could
  - affect or impede the pickling and passivating treatments: some contaminants react with pickling and passivating acids to cause very corrosive conditions;
  - affect or impede the spontaneous self-passivation process;
  - cause discoloration or staining of the surface;
  - increase the likelihood of the initiation of corrosion.

**The Cleaning Process**

It is preferable to use water borne (or water soluble) pastes or solutions that will be easily and totally removed from the surface by subsequent water washing.

- The use of solvents should, in general, be avoided as they tend to simply spread the contaminants in a thinner layer over a wider surface area.

**Pickling**

Pickling is performed to produce a new unaffected surface on which the passive film can develop; either by a subsequent passivating treatment or by self-passivation. It is a chemical treatment using an aggressive acid mixture to dissolve the impaired surface and/or the contamination.

In the fabrication of stainless steels and stainless alloys the most common reason for pickling is to remove the oxide (scale) that has formed on the surface by exposure to oxygen (as in the air) whilst heated to high temperatures.
Typically welding and thermal cutting (if not inert gas shielded) will produce a heavy dark black scale on the weld (or the cut edge) and adjacent surfaces.

Heat tints (even those of the palest straw colour) are also high temperature oxides, e.g. those that occur
- at a greater distance from the weld or on back surfaces;
- in grind marks and polishing lines: these are sometimes difficult to detect with the naked eye.

High temperature oxidation (scaling) destroys the passive film and the oxide formed is totally different to the passive film with respect to its
- chemical composition: it will typically consist of oxides of Fe, Cr, Mn, Si;
- thickness: it will be much thicker than the passive film;
- structure: it is cracked and porous.

Moreover, due to the amount of chromium combined with oxygen in the high temperature oxides (i.e. the chromium oxides), a chromium depleted sub-surface layer will exist.

An oxidised (scaled) surface
- will not self-passivate;
- is not corrosion resistant. The chromium depleted sub-surface layer is considered to be the main reason for the inferior corrosion resistance.

Other reasons for pickling are to remove
- ferrous contamination that is on and more especially, that which has been forced into the surface;
- discoloration and staining that has developed on the surface; whereas this may also be accomplished by passivating, it is quicker and has the added assurance of completeness if it is done by pickling.

**The Pickling Process**

The Acid Mixture
Pickling is done using a mixture of hydrofluoric acid (HF) and nitric acid (HNO₃) in water (or in an inert water-soluble gel or paste. Note: acid mixtures that contain hydrochloric acid (HCl) should not be used as they cause pitting of the surface being pickled.

- The concentration varies, 1-4 parts/100 HF and 10-20 parts/100 HNO₃ the balance being water (or inert gel/paste).
- The aggressivity of the acid mixture is dependent on the relative HF:HNO₃ ratio and not simply the total acid concentration.
  - If too aggressive, the pickling time will be short and there is a danger of over-pickling (i.e. etching and dissolution of the exposed unaffected base metal).
  - If too mild, the pickling times will have to be extended to obtain a complete and effective pickle and the danger of under-pickling exists.

Pickling Solutions, Gels or Pastes
Pickling can be done by using solutions, gels or pastes.

Pickling solutions may be simply swabbed onto the surface. However, it is difficult to maintain uniform wetting of the complete surface for the required time. Therefore it is best

- that the fabrication or component be completely immersed (for large fabrications or components large tanks will be required – sometimes not possible or feasible); or
- that the pickling solution be uniformly and constantly sprayed onto the surface. This will generally require specialised plant and equipment and it is therefore better suited to the treatment of the inside surfaces of tanks/vessels.

- Solutions should preferably be warm when used (=35°C).
If used at normal ambient temperatures, the aggressiveness of the pickling solution and/or the pickling time may have to be increased. This is particularly the case during the colder winter periods. At the lower temperatures (\(\leq 15^\circ C\)) pickling is less efficient and tends to be patchy.

Gels and pastes are also based on HF+HNO\(_3\) contained in an inert substance. They have the advantage that they will remain in contact on vertical and overhead surfaces (i.e. termed thixotropic).

Gels are of thinner consistency and are normally sprayed onto the surface and used for the treatment of relatively large surface areas.

- Pastes are of thicker consistency and used for the treatment of localised smaller surface areas (e.g. the weld zone). Application is by use of a spreader or acid resistant brush.
- The formulation of both gels and pastes is such to be effective at normal ambient temperatures. Therefore do not apply them to warm surfaces, e.g. fabrications that have been standing outside in the full sun.

**Pickling Time**

- The pickling time should be approximately 30 ±10 minutes.
- Too short a time will result in incomplete pickling.
- Avoid longer times than necessary as over-pickling (etching and dissolution) will take place.
- If the total surface is to be pickled, pre-treatment (partial pickling) of specific locations is advisable (e.g. the weld zone) to avoid the over-pickling of the larger, less affected surface.
- Do not allow pickling solutions, gels and pastes to dry out on the surface.

**Water Washing**

- Thorough and complete water washing (preferably with warm water) to remove all traces of acids and pickling residues must immediately follow pickling.
- If the water is repeatedly used, the concentration of the dissolved metallic salts resulting from pickling will increase;
  - cold, the metallic salts may not be totally dissolved.
In both cases the metallic salts present will tend to develop coloured films or hues on the surface once it dries. Such films are not deleterious with respect to the corrosion resistance but may be unacceptable to some end-users.
- It is advisable that at least two stages of water washing be employed.
- Always use fresh uncontaminated water for the final wash.
- Completely drain tanks and vessels after washing.

**Passivating**

Passivating is performed to enhance the development and integrity of the passive film on the surface in as short a time as possible.

- It is an acid treatment that uses an oxidising acid.
- The necessity to passivate a pickled surface is a somewhat contentious factor. However, both experience and tests have shown that passivating is beneficial, particularly if the conditions of service approach the maximum order of severity with respect to the grade of stainless steel being used.
- For improved passivity and corrosion resistance all new surfaces created by mechanical means should, at least, be cleaned and passivated.
- A secondary but equally important effect of passivating is that any free/loose ferrous contamination present on the surface is dissolved.
If rust staining has resulted from ferrous contamination or if discoloration or incipient staining has already developed on a new surface, it is preferable that such surfaces be lightly pickled before being passivated.

**The Passivating Process**

*Acid used:* nitric acid (HNO₃) is used which, being an oxidising acid, best develops the Cr rich oxide passive film.
- HNO₃ is the only acid used for passivating stainless steel.
- The concentration used is usually between 12-25 parts/100. Higher concentrations of up to 35 parts/100 can be used with no injurious effects.
- Some dulling of the surface may occur and thus affect the surface appearance of a cold rolled, bright annealed, polished or machined surface. The use of the higher concentrations of HNO₃ and the addition of an inhibitor to the passivating solution (sodium dichromate [Na₂Cr₂O₇·2H₂O]) will assist in minimising or preventing the dulling.

**Passivating Solutions, Gels Or Pastes And Passivating Time**

Passivating can be done using solutions, gels or pastes. All aspects pertaining to their use are essentially the same as those given in Pickling. The two minor differences are
- application of passivating gels/pastes to warm surfaces is not injurious;
- no harm results from extended contact time.

**Water Washing**

Aspects pertaining to this subject are again essentially the same as those given in Pickling.

### 2.4 Surface Finishes on Stainless Steel Related Characteristics and Properties

**Designated Surface Finishes on Flat Product**

The designated surface finishes to which stainless steel flat products (viz. plate, coil, sheet and strip) are supplied, are designated by a system of numbers as laid down by the American Iron and Steel Institute (AISI) Committee of Stainless Steel Producers and in the new European EN Standards. These systems of numbers are broadly described in Table 2.4 relative to the finishing operations employed.

- The thicker gauges of stainless steel (i.e. plate) are hot rolled. This is carried out at high temperatures (in the range =1250° -925° C) and will always result in a scaled (oxidised) surface.
- Thinner gauges (i.e. coil, sheet and strip) are cold rolled. This is carried out without heating the stainless steel.
- Stainless steel flat product (with the exception of ‘temper rolled’ thin gauge material) is supplied in the annealed, i.e. fully softened, condition.
  - Annealing is a high temperature heat treatment process and unless carried out in a very closely controlled inert atmosphere, will result in a scaled (oxidised) surface.
- All scaled surfaces, whether resulting from hot rolling or annealing, must be properly treated (e.g. pickled and passivated) in order to develop the passivity of the surface.
### Table 2.4
Descriptive Summary of Surface Finish Designations
(The adjacent surface finishes are essentially similar)

<table>
<thead>
<tr>
<th>AMERICAN STANDARD</th>
<th>EUROPEAN STANDARD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hot rolled finishes typically related to plate</strong></td>
<td></td>
</tr>
<tr>
<td><strong>No.0:</strong> Material is hot rolled then annealed. (Finish is also sometimes referred to as ‘hot rolled annealed’[HRA]). The scaled (oxidised) surface is not removed by pickling and passivating. Therefore confined to applications such as materials handling in which the surface will be abraded, certain high temperature uses.</td>
<td><strong>1C:</strong> Material hot rolled, heat treated[annealed]. The surface is scaled (oxidised). Suitable for parts which will be machined or for certain heat resisting applications</td>
</tr>
<tr>
<td><strong>No.1:</strong> Material is hot rolled, annealed, pickled and passivated. A dull slightly rough (orange peel) surface. Some grinding marks may be visible where local spot dressing has been performed. Suitable for industrial corrosion resisting applications.</td>
<td><strong>1D:</strong> Material hot rolled, heat treated, pickled. Surface is free of scale. It is permissible for some grinding marks to be present. Usually standard for most stainless steel grades to insure good corrosion resistance</td>
</tr>
<tr>
<td><strong>Cold rolled finishes typically related to coil, sheet and strip.</strong></td>
<td></td>
</tr>
<tr>
<td><strong>The starting material for subsequent cold rolling is No.1/1D</strong></td>
<td></td>
</tr>
<tr>
<td><strong>No.2D:</strong> Material having a No1 finish is cold rolled. The resultant work hardening is removed by annealing, followed by pickling and passivating. A uniform dull matt finish, superior to a No1 finish Suitable for industrial applications. Very suitable for severe deep drawing as the surface (which may be subsequently polished) retains the lubricant during the drawing operation.</td>
<td><strong>2D:</strong> Material having a 1D finish is cold rolled, followed by heat treatment and pickling. Finish for good ductility, but not as smooth as 2B and/or 2R</td>
</tr>
<tr>
<td><strong>No.2B:</strong> Material having a No.2D finish is given a subsequent light skin pass cold rolling between polished rolls. It is smoother/brighter than a No.2D finish and is semi-reflective. It is the most common surface finish to which coil, sheet and strip is supplied.</td>
<td><strong>2B:</strong> Material having a 2D finish is subsequently skin passed. Smoother than 2D. The most common finish for most cold rolled grades of stainless steel.</td>
</tr>
<tr>
<td><strong>No.2BA:</strong> (Also referred to as BRIGHT ANNEALED [BA]). The No.1 finish starting material is cold rolled using highly polished rolls in contact with the steel surface. This smooths and brightens the surface. The smoothness and reflectiveness of the surface improves as the steel is rolled to the thinner gauges. The annealing process is effected in a very closely controlled inert atmosphere. No scaling (oxidation) of the surface takes place, and there is no need for subsequent pickling and passivating. The surface quality imparted by the cold rolling is thus preserved. The surface has a high degree of reflectiveness. Used for some architectural applications and consumer or consumer durable components.</td>
<td><strong>2R:</strong> Cold rolled and bright annealed. Smooth, bright and reflective. Smoother than 2B.</td>
</tr>
</tbody>
</table>

↑↑↑ The above surface finishes all result from mill operations.
↓↓↓ The following finishes are all mechanically produced polished finishes. Typically applied to only one side of the coil, sheet or strip. As well as being standard designated mill finishes they are also applied to stainless steel articles and components.
**Objective:** Demonstrate an understanding as to why stainless steel is the material of choice in a hygienic environment

| No.3: | This is a ground, unidirectional uniform finish obtained by using 80-100 grit abrasive. It is a good intermediate or starting finish for use in such instances when the surface will require further polishing operations to produce a finer finish after fabrication. |
| No.4: | This is a ground, unidirectional uniform finish obtained by using 150 grit abrasive. It is not highly reflective, but is a good, general purpose, finish on components or surfaces that will suffer from fairly rough handling or contact in service. |
| No.6: | This covers finishes that are produced using rotating cloth or fibre mops which are loaded with abrasive pastes. The finish is of a non-directional texture of varying reflectiveness dependent on the fineness of the abrasive used, the uniformity and finish of the starting surface. |
| No.7: | This is a buffed finish having a high degree of reflectiveness. It is produced by progressively using finer and finer abrasives and finishing with a buffing compound (rouge). Some fine scratches (grit lines) may remain from the original starting surface. |
| No.8: | This is a buffed finish produced in an equivalent manner to a No.7 finish. The final buffing is done using an extremely fine buffing compound to give a blemish free surface with a high degree of image clarity. |

| 2G: * | This is a ground, unidirectional finish. The grade of the abrasive grit or the surface roughness can be specified. |
| 2J: * | Brushed or dull polished. Unidirectional texture, not very reflective. Grade of brush or surface roughness can be specified. |
| 2K: * | Satin polish. Additional specific requirement to the 2J finish in order to achieve adequate corrosion resistance for marine and external architectural applications. Transverse $R_a < 0.5 \mu m$ with clean cut surface finish. |
| 2P: * | Bright polished non-directional reflective finish having a high degree of image clarity. The process or the surface roughness can be specified. |

**Surface Roughness Associated with Designated Surface Finishes**

Surface roughness (as $R_a$ values) of the designated surface finishes and various abrasive grit size are given in literature. These can be confusing and sometimes even misleading. This is illustrated in the Table 2.5 drawn up from five different references.

- Only two of these references give the $R_a$ value for the designated surface finishes which result from mill operations (No.1, No.2D and No.2B) and the correlation is good.
- However, the $R_a$ values given for the different abrasive grit sizes vary to a significant degree.

| Table 2.5 | Surface Finish/Grit Size vs. $R_a$ Values in $\mu m$ |
|---|---|---|---|---|---|
| | Ref #1 | Ref #2 | Ref #3 | Ref #4 | Ref #5 |
| No.1 | 3.75-6.25 | 3.75-6.25 | | | |
| No.2D | 0.375-1.0 | 0.375-1.0 | | | |
| No 2B | 0.125-0.5 | 0.1-0.8 | | | |
| No.2BA | 0.05-0.125 | 0.05-0.125 | | | |
| 60 grit | 3.56 max | 6.4 max | 1.8-3.2 | 2.0 | |
| No.3 (80-100 grit) | 1.0-2.0 | | | | |
| 120 grit | 1.14 max | 3.2 max | 0.8-1.7 | | |
| 180-240 grit | 0.2-1.5 | 0.64 max | 2.2 max | 0.4-1.1 | |
| 240 grit | 0.2-0.5 | 0.38-1.6 | 0.18-0.6 | | |
| 320 grit | 0.15-0.38 | 0.25-0.81 | 0.15-0.36 | | |

- Because of the wide variation in $R_a$ values it is not possible to equate a designated surface finish or grit size to a specific surface roughness $R_a$ value (more particularly so with respect to the mechanically produced surface finishes).
- Therefore neither a designated surface finish nor grit size should be the basis of specification for a desired surface roughness.

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Factors Affecting Surface Roughness of Mechanically Polished Surfaces

The surface roughness attained in abrasive mechanical polishing is dependent on several factors that include:

- the abrasive used
  - its type, shape, how quickly it wears or blunts;
- wheel vs. belt polishing;
- hand vs. machine polishing;
  - particularly with respect to the contact pressure and the consistency thereof;
- the grade of stainless steel being polished;
- the polishing lubricants being used;
- the increments in the sizes of the abrasives used in the successive stages of polishing.

The Effects of Mechanical Polishing

Mechanical polishing will totally remove the extremely thin passive film from the surface of the stainless steel.

The secondary effects are:

- residues will be present on the polished surface: these may consist of some or all of the following
  - bonding agents used in the wheel or to bind the abrasive onto the belt;
  - polishing lubricants;
  - particles of grit or buffing compounds;
  - metallic chips or slivers;
  - such residues must be removed from the surface because they
    - could taint or discolor the initial batches of product;
    - could be toxic;
    - would impede the development of passivity
      - by natural self-passivation because they act as a barrier to the oxygen of the environment;
      - by chemical methods because they similarly act as a barrier and also may form aggressive corrosive conditions with the acids used for pickling and passivating;
  - mechanically polished surfaces are often protected by a plastic film on the surface in order to prevent damage to the surface during fabrication and installation: this film should only be removed at the last possible moment;
    - but the surface cannot naturally self-passivate because the film is a total barrier to the availability of oxygen to the surface;
    - further, when the film is removed
      - any of the residues mentioned above will be on the surface having been held in place by the film;
      - the film adhesive will be present on the surface;
    Note: some film materials and film adhesives will tend to become brittle with time, especially if exposed to elevated temperatures and/or direct sunlight and thus be very difficult to remove.
  - All mechanically produced surfaces should, at least, be cleaned to remove any of the above surface contaminants.

- Mechanical polishing generates high temperatures within the surface layers.
  - Because stainless steels are poor conductors of heat, oxidation of the surface can occur at the elevated temperatures attained on the surface. This can be only as the palest of straw coloured heat tint that is difficult to detect without optical assistance.
    - Such oxidised (heat tinted) surfaces are not passive (corrosion resistant) and cannot self-passivate.
  - All such effected surfaces must be pickled or pickled and passivated, to restore the passivity of the surface.
The Surface Finish of Different Product Forms

Round and Square bar: normally machined and will therefore have a surface finish consistent with the machining operation employed.
  - As a minimum requirement all traces of the cutting fluid should be removed.
  - Additionally, passivating or pickling and passivating should be used to attain the level of passivity required by the conditions of the application.

Flat Bar: normally will have a surface finish similar to a No.1 finish as described above for flat product. Mechanical polishing may be carried out if required and if so, the effects of mechanical polishing as outlined above must be borne in mind.

Pipe and Tube:
  - **Seamless pipe and tube**
    - The initial production process is hot extrusion at high temperature. The pipe/tube is then annealed, pickled and passivated.
    - If necessary, subsequent cold drawing, reducing or sinking processes are employed to attain the required sizes (outside diameter and wall thickness). Several such cold working processes may be required and thus several inter-stage annealing heat treatments may be necessary. A final annealing heat treatment is always given.
    - The surface finish of both the outside and inside surface is similar to a No.1 finish as described above for flat product.
  - **Welded pipe and tube**
    - This is produced from coil (either hot or cold rolled dependent on thickness) slit to the width equal to the circumference of the tube.
    - After the pipe/tube is produced a subsequent annealing heat treatment may be given (if required by the specification to which the pipe/tube is produced). This annealing can be done in an air atmosphere or an inert atmosphere (total or inside bore only).
    - The surface finish is thus dependent on
      - the surface finish of the original coil (*i.e. whether hot or cold rolled*);
      - whether or not annealing is carried out and the atmosphere employed. If an inert atmosphere is not employed the pipe/tube is pickled and passivated after annealing.
    - The surface finish of either or both the inside and outside surface will be similar to
      - a No.1 finish, as described above for flat product, if the original coil was hot rolled;
      - a No.2D or 2B finish as described above for flat product if the original coil was cold rolled.
    - Mechanical polishing (usually of the outside surface only) may be carried out if required and if so, the effects of mechanical polishing as outlined above must be borne in mind.
  - **Castings**
    - Castings are produced by the solidification of molten metal in a cavity of the required shape in a mould. Different methods are used to make the moulds essentially dependent on the size of the casting and also to a degree on the required quantity of the specific casting.
    - In general no modification of the cast surface is affected due to the normal complex shape (geometry) of the casting.
    - The surface finish is thus dependent on the surface texture and finish of the mould cavity.
      - In increasing order the surface finish improves sand moulds → shell moulds → investment (lost wax) moulds.

**Electro-Polishing**

Electro-polishing is a process whereby the surface of the stainless steel is anodically (electrolytically) dissolved in an acidic electrolyte (*Fig. 2.21*).
MODULE 2  
Objective: Demonstrate an understanding as to why stainless steel is the material of choice in a hygienic environment

The article (surface) to be polished is made on the anode, i.e. connected to the +ve terminal of a DC rectifier, the inert cathode is connected to the –ve terminal.

Both the anode and the cathode are immersed in the electrolyte.

When the current is switched on (applied)
- the anode (the article/surface being polished) is electrolytically dissolved, i.e. metal ions ($M^{n+}$) will be released from the surface of the anode into the electrolyte;
- sulphate anions ($SO_4^{2-}$) will be attracted to the +ve and react to produce oxygen gas:
  \[ SO_4^{2-} + H_2O \rightarrow H_2SO_4 + O_2; \]
- hydrogen cations ($H^+$) will be attracted to the –ve cathode and become hydrogen gas (H).

The anode is dissolved and a general smoothing of the surface occurs. However, scratches or gouges will not be removed.

A blanket of oxygen is formed at the surface of the anode (the article/surface being polished).

When the current is switched off the now active (i.e. devoid of a passive film) surface of the stainless steel anode absorbs oxygen from the accumulated surrounding blanket to develop a highly superior passive film.

The major property and benefit of electro-polishing is that of superior passivity (corrosion resistance).

In the ASM (American Society of Metals) Metals Handbook it is stated, “electro-polishing passivates stainless steel to a greater extent than any other passivating treatment”.

Further properties and benefits which result from the electro-polishing of stainless steel include
- excellent hygiene and cleanability of the surface, particularly with respect to the ability for the surface to be sterilised;
- a smoother surface:
  - although scratches and gouges are not removed, burrs are removed from the edges of components or perforations produced by punching;
  - depending on the original surface finish, good light and heat reflectivity with fair specular (i.e. mirror-like) reflectance;
  - a surface of lower friction;
  - a lesser tendency for galling and seizing to occur if there is relative movement between the surfaces;
  - less pick-up or snagging of fine solids, particles or fibres;
- removal of stressed surface layers;

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Other materials are used in addition to stainless steel:
- the ability to polish very complex shapes, small and intricate components (e.g. coil springs) and the inside surface of a hollow component of small diameter (e.g. the ID of pipe/tube);
- the ability to polish the inside surface of even large tanks and vessels.

These properties and benefits of an electro-polished surface on stainless steel lead to its use for many and varied applications. Illustrative examples are
- beverage, dairy and food processing plant and equipment;
- pharmaceutical plant and equipment;
- medical instruments and implants;
- components used in the manufacture of fine textiles and papers;
- heat and light reflectors;
- screws and fasteners;
- components used in aerospace, missiles and rockets;
- the de-burring and/or polishing of complex components;
- removal of radioactive surface layers in the nuclear industry.

Other Materials for Process (Table 2.6)

Other materials are used in addition to stainless steel:
- hot vessels: stainless steel, copper, mild steel clad with stainless steel;
- cold vessels: stainless steel, aluminium, mild steel glass coated, mild steel epoxy coated, copper lined wood;
- process piping: stainless steel, copper, glass;
- heat exchangers only in stainless steel.

The surface finishes of all the materials in contact with the product must satisfy the hygiene requirements of a food and beverage plant environment.

<table>
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<tr>
<th>Material</th>
<th>Cleaning Method</th>
<th>Fabrication</th>
<th>Modification, Maintenance and Repair</th>
<th>Other Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless steel</td>
<td>Suitable for automated cleaning - CIP</td>
<td>Resources and skills freely available</td>
<td>In situ repair possible. skills available</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>Suitable for automated cleaning. Special treatment required after CIP</td>
<td>Resources and skills have been lost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mild steel - clad with stainless steel</td>
<td>Suitable for automated cleaning - CIP</td>
<td>Resources and skills are available</td>
<td>In situ repair possible but relatively difficult</td>
<td></td>
</tr>
<tr>
<td>Mild steel - epoxy coated</td>
<td>Suitable for automated cleaning - CIP</td>
<td>Difficult to apply in location of restricted access. Special care to be taken when applying coating.</td>
<td>Special care to be taken when repairing surfaces in situ.</td>
<td>Difficult to detect small defects. Corrosion of mild steel under coating causes delamination</td>
</tr>
<tr>
<td>Mild steel - coated with glass</td>
<td>Suitable for automated cleaning - CIP</td>
<td>Vessel dimensions restricted to size of oven.</td>
<td>Cannot be done in situ. Damaged surface repaired with compatible coating.</td>
<td></td>
</tr>
<tr>
<td>Aluminium</td>
<td>Corroded by alkali CIP solution. Requires acid cleaning solutions</td>
<td>Resources and skills freely available</td>
<td>In situ repair possible but relatively difficult</td>
<td></td>
</tr>
<tr>
<td>Glass piping</td>
<td>Suitable for automated cleaning – CIP</td>
<td>Resources and skills freely available</td>
<td>Replace items when damaged</td>
<td></td>
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Module Three

Objective: Identify the principles applied to plant design and methods of cleaning the surfaces to maintain appropriate levels of hygiene

Outcomes

- Define the key principles applied in the design of process plant that impact on hygiene.
- Identify the key factors that ensure appropriate hygiene in the plants.
- Identify the key factors in the design of effective cleaning techniques.

3.1 Process Environments

Underlying Principles

In the food and beverage industries the process is defined by the raw materials that have to be converted to the finished product for human consumption. The processing techniques and hygiene requirements have to be developed over time to ensure a reliable and efficient manufacturing operation that has to conform to the required Food and Safety regulations and Good Manufacturing Practices. This also applies to all relevant suppliers of materials and services.

The key principles applied to the manufacturing processes are as follows:

- fabrication of plant and equipment to meet the design specifications and fabrication codes of practice;
- plant and equipment must be maintained to industry standards to reduce the risk of failure, safety incidents and product contamination;
- quality control of all materials, processes, product and services are aligned to company and acceptable industry standards;
- management of hazards in the manufacturing and distribution chains meets national and international standards;
- materials used in the fabrication of equipment have to withstand all process and cleaning conditions without impairing the product. Corrosion of the equipment must be prevented;
- due to different environmental temperatures, the implication of microbiological spoilage of the product or attack of the surface material is possible. All precautions must be taken to understand both the nature of the micro-organisms and how these can be eliminated;
- all surfaces of the equipment have to be accessible for inspection and cleaning either by automatic cleaning systems (CIP) or by hand, as required;
- all heating and cooling media used in the process must be safe for the product being manufactured and for the operators and maintenance personnel that work in the plant;
- training of all operational personnel and stakeholders to ensure that they all meet the required competency standards in the specific functional areas.

The key aspects of the process plant that impact on hygiene are the following.

Layout

- Plant to produce food or beverage must be located in an environmentally acceptable location.
- Plant to produce food or beverage must be designed within a building envelope that allows for the maintenance of the appropriate hygiene standards. This envelope can include externally installed equipment that remains within the process environment.
- Materials used in the construction of the plant and in the production of the final product must be approved by the appropriate bodies.
- Storage of materials used in the production process must be kept separately from the process equipment to allow for the appropriate hygienic standards.

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**Process Plant**

All equipment used for the production of food and beverage must be designed and fabricated to the appropriate hygiene standards e.g. EHEDG (European Hygienic Engineering & Design Group).

**Vessels**

- Vessels must be designed and fabricated to meet the required hygiene and fabrication codes:
  - EHEDG classification of equipment defines the hygiene standard as ‘being free from relevant micro-organisms after cleaning’;
  - Classification 1 is for equipment that can achieve the standard without dismantling after cleaning in place CIP;
  - Classification 2 is for equipment that can achieve the standard after dismantling and cleaning.
- Vessels must allow for regular cleaning using processes and inspection techniques specified by the manufacturer of the consumable product.
- The key factors that are considered in design, fabrication and operation of vessels are:
  - dimension of the vessel must allow for cleaning either mechanically or manually;
  - good access around and into the vessel allows for safe inspection or manual cleaning;
  - correct design and position of the spray device in the vessel will allow for the entire surface to be freed of soil and maintained at the appropriate level of hygiene;

*Fig. 3.1* shows biofilm build-up on the surface of the bottom cone of a vessel where cleaning has been ineffective. Part of the surface has been manually cleaned with caustic and the biofilm has been removed and part has been cleaned with acid and the biofilm has remained.

- Correct design and positioning of manways, inspection lights, temperature probes, pressure and level sensors, sample valves, cooling/heating zones, agitators and inlet and outlet pipes will allow for appropriate cleaning.
- Bottom of vessels must slope 1% towards the outlet to ensure effective draining.
- Internal surface of the vessel and its fittings must allow for effective cleaning:
  - rough internal surfaces form sites on which scale and biofilm forms very rapidly (after one cleaning cycle), making it difficult to clean;
  - the following SEM photographs show surfaces of different materials. The relative roughness or smoothness will determine how easy or difficult it is to clean;
- See *Fig. 3.2* 10mm No. 1 finish; *Fig. 3.3* 1mm 2B finish; *Fig. 3.4* 10mm 220 grit; *Fig 3.5* Stainless steel polished to 220 grit finish with yeast cells superimposed; *Fig. 3.6* Electro polished stainless steel with yeast cells superimposed; *Fig. 3.7* Epoxy coated carbon steel with yeast cells superimposed.
The stainless steel plate used for vessel fabrication must be of the appropriate roughness and not damaged during fabrication. Welded areas do not normally require special preparation for thin sheets but must be free of grease and dirt prior to installation. With thick plates, both sides of the vessel are welded and the internal bead protrudes from the surface. This must be ground back flush with the parent metal. The welded areas can be polished to 150 grit finish.

Vessels with coated linings can be manufactured with surfaces as smooth as the electro-polished stainless steel surface. **Figs. 3.6 and 3.7** show the two surfaces. However, even on such smooth surfaces biofilms will build up. Coated surfaces tend to have a dark finish that makes visual detection of biofilm more difficult compared to the bright surface of stainless steel. Reputed manufacturers have developed successful procedures to apply coatings that range from 500 to 1000µm thick. These are applied to a carbon steel vessel shell (or to pipes). The key factors that are required for a successful application of a coating are as follows:

- correct selection of a coating material that is approved for use in the food and beverage industry and that can withstand the required process and cleaning conditions;
- preparation of the base metal surface to give the required anchor profile that assures the bonding of the coating onto the metal;
- automatic or manual application of the coating over the entire surface has to be carried out to exacting specifications;
- prevention of any contamination of the metal surface and the applied coating during its application;
- strict QC procedures are applied throughout the entire fabrication process and after the vessels are installed;
- incorrect application of the coatings will result in pin holes in the coating that break through exposing the bare metal to the product. This results in serious hygiene and contamination problems. In extreme cases, delamination of the coating will result. **Fig. 3.8** shows an example of air bubbles entrapped in the coating that result in pin holes and **Fig. 3.9** shows a coating that has delaminated exposing large areas of the vessel to the bare metal: the dark area is coating and the background area floor tiles.
heating surfaces have a superheated zone immediately under the heating medium where scale and biofilm burn onto the surface. This area is very difficult to clean and the scale and biofilm must be eliminated quickly as they will corrode the stainless steel surface and at the same time prevent the correct heat transfer required for the process. Effective cleaning and frequent inspection are required on all heating surfaces;
- cooling (sub-zero) surfaces, when operational, may retain a curtain of ice after the vessel is emptied. Care must be taken to eliminate the ice before the cleaning process starts as the temperature of the cleaning fluid will be lowered and lose its effectiveness. Ice may also fall on the internal fittings and damage them, as well as be hazardous to inspection personnel in the vessel.

Scheduled inspections of all surfaces are important to maintain an appropriate hygiene level and detect damage and corrosion of the surface and the internal fittings. Inspection of spray devices is very important to ensure that the holes in the spray balls or rotating jet heads are clear.

Vessels that are correctly designed and installed ensure that the entire environment outside and inside is conducive to achieving the required level of hygiene. Figs. 3.10, 3.11 and 3.12 show examples of vessels installed, in a good environment, in the hot and cold areas of a brewery.
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**Piping**

**Materials**

Stainless steel is used extensively for all process piping. The grades of stainless steel used are:
- AISI 304 piping;
- AISI 316 piping for more corrosive processes;
- AISI 405 used only for nuts and pipe unions that make dismantling easier for threaded parts as two identical grades tend to bind.

**Manufacture**

Pipes are supplied to the following requirements:
- welded, simple or spiral: spiral welded pipes have weld seams inside the pipe and are pickled and passivated;
- longitudinal welded pipe: mandrel flattens the internal weld in the bead rolling process;
- unpolished 2B finish or polished finish on the outside;
- polished finish to 3-A Sanitary Standard (e.g. US Dairy Industry). Pipes can be electro-polish finished inside and outside;
- bore size: 10 to 300mm ID;
- maximum working pressure: 10kg/cm²;
- hydrostatic pressure tested by manufacturer 25kg/cm²;
- internal surface roughness (0.42 to 2.4µm Ra) influences the cleanability of the pipe as demonstrated by the following experimental setup **Fig. 3.13**. The rougher surface required three times more cleaning time to achieve a similar level of organisms on the surface (biofilm).

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**Fig. 3.13** Cleanability of pipe relative to roughness finish of internal surface

- Biofilm accumulates on the internal surface of piping after one complete cycle (process and cleaning in place). If the biofilm is not removed through effective CIP, it will accumulate to such an extent that it will impact seriously on the hygiene level of the plant. **Figs. 3.14 and 3.15** show accumulated biofilm that is not removed by the standard CIP process.

**Fig. 3.14** Biofilm on fitting in a piping system  
**Fig. 3.15** Biofilm on process piping

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**Dimensioning**

Dimensioning of stainless steel piping is based on the flow speed within the pipe expressed in meters/second (m/s). The range is from 0.5 to 3.0 but over 2m/s vibration, water hammer and pressure – transport power has to be considered in the overall design of the piping system. Dimensions of pipes most commonly used in the beverage industry and the corresponding flow speed of detergents is shown in **Table 3.1**.

<table>
<thead>
<tr>
<th>Product</th>
<th>50 mm ID m/s</th>
<th>80 mm ID m/s</th>
<th>100 mm ID m/s</th>
<th>125 mm ID m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Detergent</strong></td>
<td>2.5 – 3.0</td>
<td>2.5</td>
<td>2.0 – 2.5</td>
<td>1.0 – 2.0</td>
</tr>
</tbody>
</table>

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Supports and Anchors

The issue of supports and anchors applies to all piping, but more so to stainless steel pipes as they are thinner than other materials. If this aspect is not addressed at the design and construction phase, piping will distort making them difficult to clean and it may also cause a safety hazard.

- **General considerations**
  - loading on piping and supports and anchor points:
    - stress on axial and circumferential directions due to pressure, weight, thermal conditions are considered in the design of the supports and anchors;
  - support and anchor methods: these methods are classified from various standpoints:
    - vertical; horizontal and anchoring in axial direction;
  - flexibility of the supports and anchors are classified as follows:
    - rigidity and flexibility to allow for displacement and vibration;
  - supports and anchoring are classified by normal load pressure and not under normal load pressure:
    - supports and anchoring are classified by the number of pipes they carry: simple and multiple pipes.
- **Spacing between supports**
  - Table 3.2 shows the loading, spacing and the gradients for each size of pipe. Gradients are required to allow for complete draining of the pipes. This being an important requirement for hygiene in the piping system.

<table>
<thead>
<tr>
<th>Nominal bore mm</th>
<th>Evenly distributed loads (kg/m)</th>
<th>Spacing between supports (m)</th>
<th>Required piping gradient</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 - 75</td>
<td>4.3 – 8.92</td>
<td>3</td>
<td>1 750</td>
</tr>
<tr>
<td>80 - 100</td>
<td>12.12 – 17.57</td>
<td>4</td>
<td>1 1000</td>
</tr>
<tr>
<td>125 - 150</td>
<td>24.12 – 35 -24</td>
<td>5</td>
<td>1 1250</td>
</tr>
<tr>
<td>200 - 300</td>
<td>54.72 – 105.82</td>
<td>6</td>
<td>1 1500</td>
</tr>
</tbody>
</table>

- Table 3.3 shows the spacing for vertical pipes.

<table>
<thead>
<tr>
<th>Nominal bore mm</th>
<th>Flexible structure (m)</th>
<th>Rigid structure (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>1.5</td>
<td>1.1</td>
</tr>
<tr>
<td>80</td>
<td>2.1</td>
<td>1.5</td>
</tr>
<tr>
<td>100</td>
<td>2.3</td>
<td>1.7</td>
</tr>
<tr>
<td>200</td>
<td>3.2</td>
<td>2.3</td>
</tr>
</tbody>
</table>

- **Expansion and contraction of pipes**
  - Table 3.4 shows the expansion per 10m length of pipe (mm/10m) (set to 0 at 0°C)

<table>
<thead>
<tr>
<th>Temp °C</th>
<th>-10</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS pipe AISI 304</td>
<td>-1.6</td>
<td>0</td>
<td>1.7</td>
<td>3.3</td>
<td>5</td>
<td>6.7</td>
<td>8.4</td>
<td>10</td>
<td>11.7</td>
<td>13.4</td>
<td>15</td>
<td>16.7</td>
</tr>
</tbody>
</table>

Expansion and contraction of pipes without effective support and anchoring can cause damage to the piping system making it difficult to drain, which is required for hygienic pipe systems.

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**Water Hammer**

Water hammer is a phenomenon whereby pipe wall and connected equipment are subjected to water impact when the pump that is part of the piping system is stopped or when the valves are shut off suddenly. The pressure waves travel back and forth in the closed portion of the piping system causing plant failure in extreme cases. Water hammer has the following impact on a piping system and on the hygiene and safety of the plant:
- automatic double seated valves in the system lift and can allow contamination of the product through the valve seals: some valves are designed to avoid impact of water hammer;
- in-line measuring equipment can be damaged through the shock waves;
- pipe supports break off their anchor causing pipes to drop making drainage difficult or impossible;
- pipes can split causing safety hazards;
- pump seals can leak.

To prevent water hammer the following precautions must be taken:
- ensure opening and closing of all automatic and manual valves is gradual;
- keep fluid speed in the pipes to the minimum;
- sequence pump starts and pump opening in a gradual mode;
- install air chambers where possible to absorb the impact of pressure;
- install an automatic pressure control valve on the system.

**Pipe Junctions**

**Welding**

- Welding is the most reliable kind of pipe junction because the strength of the weld is near to the base metal.
- Welding can be done manually or automatically but the manual technique requires a higher degree of skill.
- Hygiene security is assured through the prevention of the most common welding defects that create microbiological problems. The following list identifies these defects.
  - **Misalignment:** two edges of stainless steel are not aligned correctly introducing a step in the wall or bore.
  - **Cracking:** cracks that penetrate the product contact surface can lodge soil or microbes. This is caused by having too wide a gap during the joint preparation.
  - **Porosity and inclusion:** presence of porosity in the weld at the surface or excessive inclusion can trap soil or microbes.
  - **Incorrect penetration:** weld metal should exactly fill the joint and remain flush with the surface. Under penetration leaves a crevice at the joints which causes pockets of soil, scale or microbes that are difficult to clean.
  - **Lack of side wall fusion:** welded metal must be carefully fused to the parent metal to avoid crevices that create corrosion and hygiene problems.
  - **Lack of gas shield:** when welds are completed from one side only, (e.g. pipe work welds), the reverse surface must be shielded with inert gas. Failure to do so results in roughened weld and heat affected zone (HAZ). Both of these failures cause hygienic problems and potential corrosion problems. **Fig. 3.16** shows an example of weld defects detailed above.
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**Fig. 3.16 Examples of weld defects**

- **Flange Junctions**: flanges must be welded to the pipe applying the same quality requirements as for the pipe junctions above. Lap joints are not recommended as they require more skill and equipment than for welding. Dead spots that impact on hygiene are also found in lap joints that are poorly applied. The joints in the flanges must be flush with the inner bore of the pipe.

- **Joints and Seals (Elastomers):**
  - Joints should be avoided where possible. Where detachable joints (or flanges) are necessary they should be sealed by elastomers (gaskets) to ensure that the metal to metal contact and the inner bore of the pipe do not allow ingress of product or crevices where soil and biofilm may accumulate causing difficulties with cleaning.
  - Elastomers must be selected and installed to ensure hygienic characteristics are not compromised. This applies to aseptic equipment where bacteria tightness is required. Where variations in temperature range from pasteurisation (65°C) or sterilisation (100°C) to subzero conditions, materials such as polytetrafluoroethylene, with a thermal expansion co-efficient 5 times that of steel, may change shape as a result of heating.
  - Over compression of elastomers may lead to their destruction by becoming brittle and fail to provide an effective seal. Protrusions of elastomers caused by over compression will create pockets of soil and biofilm.
  - Under compression of elastomers may lead to crevices and fail to provide an effective seal. Even if leaking is not visible, micro-organisms will enter through the joints.
  - Misalignment of elastomers can also cause pockets of soil and biofilm that impede cleaning and draining.
  - Ring seals invariably leave crevices that are impossible to clean-in-place. Because of the different thermal expansion co-efficient of seals and stainless steel (seals greater by 15 over stainless steel), seals will expand during heating and trap the microbes during the hot cleaning. After cooling, the surviving microbes will contaminate the product. O rings must be mounted in a way that ensures that the area of steel covered by the rubber at the product side is not influenced by the thermal expansion. Metal to metal joints must not be used in hygienic plants *(Fig. 3.17).*
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Identify the principles applied to plant design and methods of cleaning the surfaces to maintain appropriate levels of hygiene

Heat damage on o-ring gasket

Heat damage on O ring gaskets

- Reducers: Pipe reducers must be installed to ensure correct drainage and flow in the pipe line systems. The following guidelines must be followed:
  - concentric reducers to be installed in vertical pipes;
  - eccentric reducers with flat plane on the bottom to facilitate drainage;
  - eccentric reducers with flat plane to the top to eliminate air pockets;
  - on centrifugal pumps use eccentric reducers on the inlets with the flat plane up to eliminate air pockets;
  - on centrifugal pumps outlets for the discharge, use concentric reducer for vertical discharge and eccentric reducer with the flat plane down for horizontal discharge.

Pumps

The choice of pumps is based on the following criteria:
- design to accommodate the required pressure, capacity and temperature requirements of the process and cleaning regimes;
- design and fabrication must be approved for use in the food and beverage industry e.g. EHEDG;
- materials of construction and all components must withstand the process and cleaning environments.

Types of Pumps

- Centrifugal pumps: These have the advantage that they are of simple and cheap construction and are therefore used extensively. By changing impeller, the rotation velocity and the total pressure head, the same type of pump can be used for a wide range of applications. At high rotations beer is subjected to strong mechanical impact which can cause cavitation, resulting in damage to beer quality. Fig. 3.18 shows the items in a pump and those that need to be inspected to ensure hygienic standards are not compromised e.g. impeller, O rings.
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Different constructions in centrifugal pumps, e.g. **Fig. 3.18 a)**, are available offering hygienic conditions for delicate food and beverage products.

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**Fig. 3.18 b) LKH adjustable range pump**

By having a fully adjustable pump casing, the drainability of the pump can be achieved, as shown in *Fig. 3.18 b)*.

The mechanical balanced, external shaft seal construction is a hygienic solution available in centrifugal pumps. The life of the seal is increased by having a smaller seal diameter. The seal faces are clearly visible externally, making leakage easily identifiable.

**Fig. 3.18 c) Mechanical balanced shaft seal**

The mechanical balanced shaft seal is constructed so as to avoid accidental opening of the seal, because of fluid pressure. The external design places the seal spring on the non-wetted side of the seal, as shown in *Fig. 3.18 c)*.

CIP return pumps are operating in a liquid/gas condition as fully flooded inlet pipes are not always easy to achieve. The liquid ring pump is a proven solution for the CIP return pump as it is not affected by the presence of gas and is self-priming, as shown in *Fig. 3.18 d)*.
**MR Principle**

- A: Impeller.
- B: Deepest part of groove.
- C: Start of groove.
- D: Inlet.
- E: End of groove.
- F: Outlet.

**Fig. 3.18 d) MR principle**

- *Rotary Positive Displacement Pump*: gear, lobe or screw pumps are more complicated than centrifugal pumps and are more difficult to clean. These pumps have a bypass installed that can give rise to hygienic problems if not installed correctly as shown in **Fig. 3.19**.
- Hygienic considerations for pump installations are as follows:
  - easily dismountable for inspection;
  - moving parts regularly inspected for soil accumulation, damage to casing, impeller and O-rings.

**Fig. 3.19  Lobe pump installation**

**Fittings and Instruments**

- The fittings and instruments that are welded to sockets on a vessel or piping system must follow the welding requirements shown above. Failure to weld the fittings attachments will result in dead legs where soils and microbes will accumulate and make cleaning difficult. **Fig. 3.20** shows an example of how the installation should/should not be done.
VALVES

Design of process valves must comply with food and beverage requirements, e.g. EHEDG.
- Manufacture of wetted parts that are in contact with the process and cleaning fluids are always constructed from stainless steel grade AISI 304 or 316.
- In most cases the entire valve is manufactured from stainless steel except for the seals and O-rings.
- The surface on the valves results from the casting or machining finish but high polished finishes are done to meet other specifications.
- The hygienic aspects of automated valves are based on their ability to be cleaned-in-place where the entire surface is subjected to the cleaning factors: mechanical forces that impinge on the surface to remove the soil, temperature, time and the chemical concentration of the detergent.
- In the design of some automated valves, the actuator lifts the seals so that they can be cleaned at the same time as other functions of the valve are allowing product to pass through the main valve body.
- Manually operated valves (butterfly, ball, diaphragm and needle valves) allow for the cleaning of the entire surface in contact with the product.

Figs. 3.21 and 3.22 show the hygienic design of some features of automated valves.
Fig. 3.22 a) Mixproof valves

Fig. 3.22 a) shows a balanced seat mixproof valve that eliminates the risk of forcing open the valve by water hammer.

Fig. 3.22 b) Alfa Laval membrane sample valve

Fig. 3.22 b) shows an example of a membrane sample valve in a sanitary installation on a vessel or pipe wall.

Heat Exchangers

The two types of heat exchangers most commonly used in the food and beverage industry are shell and tube and plate heat exchangers.

- Shell and tube heat exchangers: can be used in the boiling of wort or heating of CIP fluids. They are also used for cooling beer during transfers between fermentation and storage and at the filter plants. In these heat exchange processes, steam (or HTHW) or ammonia are used as the heating or cooling media respectively.
During the boiling operation, organic and inorganic scale and biofilm accumulate at the superheated zone of the tubes. At this area the soil is hardened making it more difficult to take off during the cleaning cycle. Frequent inspections of the heating and cooling surfaces are important to assess if the cleaning regime is eliminating the hardened soil. If not, special cleaning must be carried out to prevent product contamination and possible corrosion of the stainless steel surface. Soil build-up on these surfaces also reduce the heat transfer required for the purpose for which the heat exchanger was installed. Fig. 3.23 shows the tubular heat exchanger with clean tubes resulting from effective cleaning regimes.

![Fig. 3.23 Tubular heat exchanger](image)

- **Plate Heat Exchangers (PHE)**

  PHE are used extensively throughout the food and beverage industry. Whatever configuration is used in the plates to heat or cool the product, there will always be a scale or biofilm build-up on both sides of the heat transfer zones on the plates. This encrustation is not easy to clean off due to the extensive surface of the plates and their design. The four factors of cleaning come into play during the cleaning process: mechanical turbulence and forces to free the soil off the surface, the temperatures to increase the efficiency of the chemicals at specific concentrations and the time required to complete the cycle.

  The type of soil will dictate the type of chemical to be used on the soil and to ensure the stability of the stainless steel plate and the gasket material.

  Visual inspection must be carried out to ensure that the cleaning process is effective over the entire surface and that corrosion has not started anywhere on the plates.

  In cases where the contamination of the plates is high, the direction of flow is reversed (back flush) by a suitable pipe configuration with appropriate valves.

  In cases where the contamination of the plates will damage them, manual cleaning is recommended. This procedure requires careful removal of individual plates, one at a time, to prevent changing the plates from the original configuration required for the heat exchange process. (See Figs. 3.24, 3.24 a and 3.24 b.)

  Should heat exchange surface corrode or fracture, the product and/or the cooling/heating medium can be contaminated depending what side the higher pressure is. The heating or cooling media traditionally used in the brewing industry are:

  - heating media: steam or high temperature hot water (HTHW);
  - cooling media: ammonia as direct cooling of process vessels and heat exchangers, glycol solutions, alcohol solutions, brine solutions and chilled water at 1 °C.
Although all media must be approved for use in the Food and Beverage industry, the operating pressures are such that they may also cause hazards to operating personnel and cause serious effluent spills in the case of plant failure.

**Fig. 3.24** Plate heat exchanger  
**Fig. 3.24 a)** Plate heat exchanger – main components

**Fig. 3.24 b)** Plate with gasket
Agitators

Agitators fixed to the top, side or bottom of vessels must allow for effective elimination of soil from the blades during the cleaning process. At the point of fixture to the vessel, the shaft must be sealed not to allow product out of the vessel and any grease into the vessel from a gearbox, should there be one to drive the agitator. **Fig. 3.25** shows an example of a hygienically designed agitator.

![Fig. 3.25 Alfa Laval Scandi Brew agitator for yeast vessels](image)

3.2 Practical Considerations

The process of producing beer is taken as the example throughout this module to demonstrate the practical consideration, given the demanding requirements on plant design, detailed biochemical and biological processes, as well as the extensive international manufacturing infrastructure of this industry. Added to this is the world-wide acceptance of beer as a beverage with a long tradition, now manufactured and consumed extensively in all parts of the world.

The standards set for the brewing and sale of beer can be considered as a reference to most food and beverage industries.

**Fig. 3.26 a)** and **Fig. 3.26 b)** define the manufacturing chain of beer production.
Identify the principles applied to plant design and methods of cleaning the surfaces to maintain appropriate levels of hygiene.

**Fig. 3.26 a) Hot and Cold Processes**

**Fig. 3.26 b) Packaged Product Processes**
Process Plant

The main hygienic factors that are considered in the hot and cold processes and in the packaged product processes, are as follows. In each section of the process, the main scale, soil or biofilm build-ups are noted, as well as the regular cleaning processes.

<table>
<thead>
<tr>
<th>Hot Process Areas</th>
<th>Scale, Soil or Biofilm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mills</td>
<td>Solids from milling leave excess quantities of soil on the crushing rollers and the rest of the milling system. CIP spraying of the milling installation after each cycle.</td>
</tr>
<tr>
<td>Hot brewhouse vessels Including spent grains and trub vessels</td>
<td>Solids from the brewing process adhere to the sides of the vessels, agitators and fittings. Water spray after each cycle and CIP of vessels once weekly.</td>
</tr>
<tr>
<td>Piping in brewhouse</td>
<td>These are large diameter pipes up to 400mm ID. Solids adhere to the surfaces. These are flushed between each cycle and CIP by soaking once weekly.</td>
</tr>
<tr>
<td>Heat exchangers – wort boiling and heating surfaces of mash vessels. PHE for wort cooling</td>
<td>Tubular heat exchangers for wort boiling and heating surfaces on other vessels. PHE for wort cooling. Heavy scale and biofilm build-up, requiring once or twice weekly CIP.</td>
</tr>
<tr>
<td>Hot and cold water vessels</td>
<td>Scale build-up on hot water vessels. CIP of vessels once a month.</td>
</tr>
<tr>
<td>Hops, salts and sugar vessels</td>
<td>Residue at top and sides of vessels. CIP once weekly.</td>
</tr>
<tr>
<td>CIP vessels: hot and cold</td>
<td>Residue at top and sides of vessels. Scale on hot vessels Ad hoc CIP</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cold Process Areas</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fermenting, storage, yeast, filter &amp; bright beer tanks</td>
<td>Soil from yeast, protein and foam. Biofilm in inaccessible areas. CIP after each cycle.</td>
</tr>
<tr>
<td>Piping system; process and utilities</td>
<td>Diameters from 40 to 125mm. Process pipes flushed with water after each cycle and CIP once weekly. Ad hoc CIP on utility pipes (CO₂, air)</td>
</tr>
<tr>
<td>Mixing vessels with agitators</td>
<td>Solids residue on sides and on agitator blades. Flushed with water after each cycle, CIP once weekly.</td>
</tr>
<tr>
<td>Heat exchangers; plate type and tubular for cooling wort, yeast, beer.</td>
<td>Solids and biofilm on process side. Scale on cooling medium side. Flushed with water after each use. CIP once a week</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Packaging Process Area</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Filling machines</td>
<td>Foam in filling bowl. Beer on outside of filler and on seamer/crowner. Hot water flushes every day. Regular CIP once or twice weekly.</td>
</tr>
<tr>
<td>Pasteurisers; bottle or can</td>
<td>Soil and biofilm from broken bottles and leaking cans. Cleaning out of broken bottles from pasteurisers, recycling of water. Recycling plant forms heavy biofilm; chemical treatment is carried out</td>
</tr>
<tr>
<td>Tanker service for product transport</td>
<td>Foam on the surface. CIP after each cycle.</td>
</tr>
<tr>
<td>Keg filling</td>
<td>Detergent washes to eliminate old beer residue and steaming before filling.</td>
</tr>
<tr>
<td>Keg dispensing</td>
<td>Biofilm on dispensing system at bars that have thin gauge piping and cooler. Detergent and sanitising of entire dispensing system every day.</td>
</tr>
</tbody>
</table>
3.3 Hygiene Factors

Underlying Principles

The underlying principles that determine the need for a cleaning system are as follows:
- define the factors affecting performance of cleaning systems;
- determine the composition of the soils, scale or biofilm accumulating on the surfaces of the plant;
- identify the microbiology and chemistry of cleaning.

Factors Affecting Performance of Cleaning Systems

The underlying principles of a balanced cleaning system are based on the following:
- mechanical force for a determined time period;
- chemical composition at a determined temperature;
- the synergistic effect of the above factors.

The balanced application of these factors will determine both the design and effectiveness of the cleaning system. As each of the factors influence cost of the initial plant (vessels, pumps, piping, heat exchangers instrumentation and the area occupied by the cleaning station with upgraded building finishes), as well as the running costs (chemicals, water, heat, effluent, power, spares), the optimum balance must be achieved to obtain the required levels of hygiene.

The four factors have to be optimised during the operation of the cleaning system, as inefficiencies will become evident as soon as one or two of them falls below their effectiveness level. For example, a CIP system to clean process pipes in the cellar area with low temperatures will not be effective, even though the flow, time and chemical concentration are within the specification.
The four factors are inter-related and inter-dependent to ensure an effective cleaning of surfaces (Fig. 3.28).

**Fig. 3.28  Factors that effect cleaning**

The following four factors impacting on the cleaning efficiency are influenced by conditions that are also important to consider.

- **Mechanical Factor:**
  - quantity of the soil to be removed from the surface
  - flow rates
  - turbulence
  - shear stress
  - pressures and pressure drops
  - water hammer prevention (lifts seats on valves allowing CIP into product line)
  - efficiency of flow and pressure measuring instruments.

- **Chemical Factor:**
  - quantity and quality of the soil to be removed from the surface
  - initial concentration as measured and efficiency of conductivity meter
  - topping up in the circuit
  - presence of solids in solution
  - dilution in circuit
  - neutralisation *e.g.* CO$_2$ by caustic
  - return of CIP liquid to holding vessel or drain in multi-use system.

- **Temperature:**
  - initial temperature as measured
  - controlling in the circuit
  - cooling in the circuit *e.g.* pass over cold surface of process plant
  - return of CIP liquid to holding vessel or drain in multi-use system
  - efficiency of temperature control.

- **Time:**
  - time for complete process
  - time to wash out or rinse the previous chemical or product
  - time for chemical to react on surface soil
  - time to drain the detergent in the bottom of the vessel
  - time to sequence CIP and CIR pumps
  - time to sequence opening and closing of automated valves
  - efficiency of time control.

In the selection of the correct equipment to be included in the cleaning system, the following principles must be considered.

- A ‘multi use CIP system’ requires that the capacity of the vessels in the CIP plant must be sized to hold the required quantity of the chemicals and water for reuse and recirculation.
- The number of vessels is determined by the type of chemicals to be used *e.g.* caustic hot and or cold, acid, sterilant.
- The level of instrumentation is defined by what parameters are required to be monitored *e.g.* temperature, flow, pressure, level and conductivity.
The flow characteristics of the CIP for vessel and piping systems is determined by the principles of fluid dynamics as follows:

- Flow rates required to clean surfaces of vessels range from 1000 to 3510 litres per hour per meter of vessel circumference for spray balls;
- The force from the spray ball or rotating spray cleaners on the vessel surface is only totally effective at the point of contact; point of impingement. The fluid then runs down the side of the vessel wall by gravity to clean the rest of the surface. There are two schools of thought on whether flooding of all the surface with fluid from low pressure spray balls is more or less effective than rotating high pressure jets that work on the principle of maximum impingement of fluid directed at the targeted surface as it completes a rotation every 6 to 12 times a CIP cycle. There is no conclusive evidence that one system is superior to the other given all the factors that contribute to an effective cleaning system;
- The force of the fluid through pipelines determines the effectiveness of the cleaning of the surface. Turbulent flows, defined in Reynolds Number Re, have a direct relation to the shear stress on the side of the pipe and this determines the mechanical force on the surface that helps to remove the soil or scale;
- Other factors that will influence the flow-cleaning effectiveness are the pressure drop across the pipe lengths, the number of bends, fittings, roughness of the internal surface of the pipe and the pipe diameter. To optimise all these factors, a detailed hydraulics study is required of the entire piping system. Table 3.6 shows the recommended flow rates for CIP through pipe sizes normally encountered in a beverage plant.

<table>
<thead>
<tr>
<th>Table 3.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe Dimensions for Detergent Flows in a Beverage Plant</td>
</tr>
<tr>
<td>Product</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>Detergent</td>
</tr>
</tbody>
</table>

Composition of the Soils, Scale or Biofilm Accumulating on the Surfaces of the Plant

Soils and Scaling Composition and why they Build up in the Process Environment

There are two types of soil in a brewery or beverage plant:
- Organic which include organic polymers like carbohydrates, proteins, organic acids, tannins, hop oils, etc.
- Inorganic which includes metal ions like magnesium, calcium, potassium, sodium, etc., anions like sulphates, phosphates, silicates, carbonates, oxalates, etc.

It is very important to know the soil composition in order to be able to determine what type of detergent will be most appropriate to remove it.

When scale is formed in a vessel or pipe, it will reflect the composition ratio of material used in production *i.e.* if the ratio of organic to inorganic is $X$ in materials used in production, this ratio should only change if there is conversion in the processing, biological or chemical. If a conversion is taking place in different areas of the plant, these ratios should be known.

For scale to build up there should be some movement of molecules, polymers and particles. This movement should be slow enough to allow adherence to the surface of a vessel or pipe. The movement can be provided by mechanical means like stirring or by heating. Molecules, polymers or particles are sometimes charged which will result into polar or ionic interaction. Soils tend to build on a surface in layers. It has been observed especially in thick scales where layers are observed to be in different colours.
Biofilms

Microbes have the propensity to form their own niches or micro-environments by creating biofilms. Biofilms can be defined as organised microbial systems consisting of layers of microbial cells associated with surfaces (Microbiology 5th edition, Prescott L M., Harley J P., Klein D A McGraw Hill 2002 – Chapter 28). These biofilms can be simple to complex ecosystems with each different type of organism providing for the needs of the others in a co-dependant fashion. From a cleaning and sanitising point these biofilms are detrimental to the cleaning process in that they harvest and protect the inner layers of cells from the cleaning and sanitising agents.

Biofilms tend to adhere tightly to surfaces via the co-development of organic and inorganic scales that are bound and held together by materials such as gums and polysaccharides secreted by the microbial members of the biofilm. Once biofilms become established they can be extremely difficult to remove. Typical sites for biofilm formation are inside pipe lines where there is low turbulence, shadow areas of tanks and any surface that remains in contact with a source of nutrients for an extended time period. Thus once a biofilm has established itself it tends to become self-perpetuating in that the initial inadequate cleaning process that allowed for the film to develop becomes even less efficient at removing it and the film becomes deeper and larger and more firmly anchored to the production surface.

Surface roughness is critical in allowing these films to have an initial binding surface. The smoother the surface the more difficult it becomes for organisms to attach.

Dental plaque is an excellent example of a biofilm.

In industrial situations biofilms can reduce the flow in pipes, be responsible for sensor failures and valve failures. In addition they can harbour microbes that are responsible for corrosion and as such can become the sites of pinhole corrosion of metal surfaces leading to pipe and vessel failures. Thus biofilm control has become big business.

Microbiology of Cleaning

Why Microbiology Impacts on Levels of Hygiene

The required degree of cleanliness required for a processing plant is defined by the potential impact of the soil (soil and/or microbes) on the resultant product. This is largely determined by the type of product being produced in that particular plant.

Products that are sensitive to spoilage require higher degrees of cleanliness (hygiene) than those that are not as susceptible; therefore knowledge of the products propensity to spoil is essential in determining an appropriate cleaning solution. This may or may not include a sanitising/sterilisation step.

- Sterilisation is defined as the elimination of all forms of life including microbial spores, typically this is most effectively achieved with live steam at a minimum temperature of 120°C for a contact time of at least 20 minutes and typically is found in the pharmaceutical manufacturing environment.
- Hygienic conditions are defined as a degree of cleanliness that eliminates all vegetative forms of life, typically found to be suitable for most aspects of beer brewing and other beverage plants.
- Clean conditions are defined as those suitable for the removal of all soils but not all vegetative cells. Thus the higher the required degree of cleanliness the more robust the cleaning process has to be and the more important it becomes to ensure that the plant is designed for efficient cleaning.

Control of microbiological growth thus becomes the objective of any cleaning and sanitising programme. Growth control can be effected by:

- limiting microbial growth via the removal of nutrients (cleaning);
Objective: Identify the principles applied to plant design and methods of cleaning the surfaces to maintain appropriate levels of hygiene

- via the removal of protective materials and films in the forms of scales and biofilms;
- by removing all viable microbes via either total removal (sterilisation) or removal of vegetative cells only (application of bactericidal agents to kill microbes or via the application of agents that prevent growth – bacteriostatic).

Typically control measures follow the cycles of:
- decontamination (or cleaning);
- disinfection (via chemical and/or physical agents) to prevent growth or eliminate viable microbes;
- sterilisation to prevent the growth of any surviving organism in product, thus eliminating spoilage.

What Kills Micro-organisms

Heat sterilisation for all micro-organisms: there is a maximum permissible temperature for growth and survival and exceeding this will result in death (macro-molecules lose their structure and cease to function). This is a combination of time and temperature.

Radiation sterilisation: all forms of electro-magnetic radiation are effective in controlling microbial growth as each acts through a specific mechanism e.g. UV leads to denaturation of genetic material. Ionising radiation produces electrons, hydroxyl radicals and hydride radicals –these high energy unstable compounds react with cellular material leading to its ionisation and resultant loss of function (Xrays are the most common form of ionising radiation).

Which Micro-organisms are Detrimental to Hygiene

Those that have the potential to grow in the product being processed at that stage of the process.

Cleaning Chemicals and Materials

Safety Requirements

Cleaning of tanks and pipe lines require the use of harsh chemicals which are strong acids and strong bases. Sometimes, oxidising compounds are used. Safety precautions, as required by Occupational Health and Safety legislations (ISO 18000), have to be considered when using these chemicals. Components of these chemicals may have short or long-term affect on the health of the employees. Some components can affect the health of the consumer at parts per million levels. The safety of environment has to be considered as well, which means that the products used have to comply with environmental legislation with respect to handling of spillage.

Every material used must be accompanied by Material Safety Data Sheet (MSDS). A MSDS should disclose the following:
- manufacturer’s details
- product identification
- composition information on ingredient
- hazards identification
- safety first measures
- fire fighting measures
- accidental release measures
- handling and storage
- exposure control and personal protection
- physical and chemical properties
- stability and reactivity
- toxicological information
- ecological information.
The MSDS is meant to give enough data about the product that assist the user to make an informed technical decision. A user will only know about this safety information if the information provided is read and the supplier is questioned to get clarity. There is still a culture of not going through the MSDS document before the product is used.

**Detergent and Sanitiser Chemistry**

A detergent is a blend of chemicals, which is put together to solubilise soil and remove it from the surface and ensure that it does not re-deposit itself back on the cleaned surface. Sanitisers are formulated to kill microbes and bring micro-organism load to an acceptable level.

**Properties**

Detergent is made of the base of acids or alkalis, therefore the chemical properties are acidic or basic. The sanitisers, especially those for traditional non-rinse application, are acidic when peracetic acid or hydrogen peroxide is used as sanitiser. When halogens like chlorine are used as sanitiser, the base material is made of alkali for stability.

Alkaline detergents tend to work better for two reasons:
- organic soil tends to be ‘acidic’ in nature, organic acids, polyphenols, etc.;
- basic detergents can hydrolyse organic polymer chains, which add to the easy removal of soil as smaller molecules.

**Ingredients**

Formulated detergents used in the beverage industry comprise:
- base material, which is either alkali or acidic
- surface active molecules as wetting agents
- chelating agents or sequestrates
- flocculating agents (sometimes).

The sequestrants or chelating agents are added in order to soften water by grabbing metal ions like calcium and magnesium. The presence of these metal ions tends to bond dirt together by providing multiple charges for multi-site attachment. The surface-active molecules act as wetting agents that assist with penetration of dirt otherwise water clings to itself due to the bipolar nature of the water molecule. During cleaning of organic soil, like proteins, surface-active molecules are created out of hydrolysed proteins hence foaming is observed during cleaning. Flocculating agents are sometimes added to facilitate the easy removal of dirt by pulling dirt together into lumps, which are easily flushed away.

**Ingredients of Caustic or Alkali Detergents**

Caustic detergents are made of caustic soda (sodium hydroxide) as the main ingredient with sodium gluconate/heptonate or amino tris(methylene phosphonic acid) as chelating agents. Other agents like EDTA, NTA, sodium polyphosphates, zeolites are sometimes used. Caustic or alkali detergent can be chlorinated. The choice of chelating agents or sequestrants depends on the pH of the working solution. Their effectiveness is pH dependant.

Caustic detergents are not suited for the cleaning of aluminium tanks. To clean surfaces where caustic is not allowed, alkali detergents are used. These detergents use sodium metasilicates as a base. Sometimes soda ash or phosphates salts are used as alkali source with builder (sequestering) properties.

Dealing with stubborn dirt found in paraflows (heat exchangers), chlorinated caustics or chlorinated alkalis are used. The amount of available chlorine of the working solution should not exceed 200ppm to protect stainless steel from pitting.
Sometimes, wetting agents are added to caustic or alkali detergent to improve penetration and rinsability of caustic.

**Ingredients of Acid Detergents**

In the beverage industry, acid detergents are used for descaling. The scale is made of metal salts of oxalates, phosphates, carbonates, silicates, etc. The acid detergent should be able to penetrate for which a strong acid component is required. To facilitate the peeling of scale molecules, a component of acid is required that will attach itself to metal ions and act as a sequestrant. Acid detergents are predominantly made of a blend of phosphoric acid and nitric acid to a 1.2:1 ratio.

Nitric acid is a strong acid, which is good for penetrating the scale and phosphoric acid has sequestering properties for easy removal of scale. Acids with a higher level of nitric acid than phosphoric acid are recommended for passivation of stainless steel.

Adding wetting agents and flocculants in acid detergent improves penetration and removal of scale especially when the scale is not only inorganic soil.

**Ingredients of Sanitisers**

There are different types of sanitisers for use in different areas of the plant and they are formulated differently to minimise the negative effects that they might have on the finished product.

- **Sanitisers Recommended for Non-Rinse Application**
  These are peracetic and hydrogen peroxide based sanitisers. They are made from the blending of acetic acid and hydrogen peroxide in the presence of a stabilising agent such as 1-hydroxyethylidene-1, 1-diphosphonic acid (Dequest 2010). When used, the breakdown products will be oxygen and water for hydrogen peroxide and acetic acid and oxygen for peracetic acid. These types of sanitisers break down in the presence of metal ions. Because peracetic acid based sanitisers are oxidising they tend to affect flavour stability of beer if not rinsed. Apart from being used in vessel sanitation, they are also used in sanitisers baths and in environmental sanitisers formulation.

- **Sanitisers Recommended for Sanitiser Baths**
  Iodophors are used in sanitiser baths because their presence can be easily be detected with brownish red colour. Iodophors combine elemental iodine with surface-active compound. Acid is added to ensure that the usage concentration is at lower pH. Iodophors can taint the product when not handled properly. Where a fear of tainting exists, peroxide/peracetic acid based sanitisers are used in sanitiser baths.

- **Environmental Sanitisers**
  Environmental sanitisers are used in sanitising floors, walls, external surfaces of tanks and pipes and cleaning of drains. For these sanitisers to work effectively on surfaces, they must be able to cling to the surface to allow for extended contact time. When rinsed off the walls, they must be easily removed. Because the risk of contact with the product is low, there is a wider choice of ingredients that can be used.

  Quaternary ammonium compound (QAC) sanitisers work by surface action. The QAC formulations contain non-ionic surfactants like ethoxylated fatty alcohols to boost foaming properties of the product. In order that micro-organisms do not develop a resistance to sanitisers, different types should be used over specific periods of time.

  Gluteraldehydes are commercially available as acidic solutions and they are activated before use by making them alkaline. They have a wide spectrum activity against different micro-organisms. For sanitising purposes, a 2% solution is recommended.
Biguanides and Chlorhexidines have widespread bactericidal properties. For the product to foam, non-ionic surfactants are added. Because of their cationic nature, anionic compounds deactivate these sanitisers. They are also not compatible with phosphate, borate, chloride, carbonates ions because they form salts, which are insoluble. This will make active ingredients unavailable.

- **Sanitiser for Drains**
  The most popular sanitiser for drains is sodium hypochlorite solution that has been diluted to release about 5% available chlorine during use. These must be kept separate from stainless steel equipment, as the free chlorine settles on the moist surface causing pitting corrosion.

- **Sanitiser used in Different Areas of Processing**
  Chlorine dioxide has gained popularity as an effective safe to use sanitiser. It is effective at low concentration and it is not affected by pH. Chlorine dioxide is effective against a wide spectrum of micro-organisms. It is effective in removing biofilms. Chlorine dioxide does not chlorinate, therefore there is no risk of forming trihalomethanes (THM) when coming across organics. Chlorine dioxide works by free radical electrophilic abstraction rather than oxidative substitution or addition like chlorine. The breakdown products are chlorite and chloride.

Chlorine dioxide is used for disinfection in many areas, water disinfection, post or final rinse sanitiser, biocide for cooling tower and pasteurisers.

**Summary**

![Hygiene factors summary](image)

**3.4 Cleaning Techniques**

**Manual**

In manual cleaning, the normal steps of cleaning are followed i.e. pre-rinsing by removing as much loose dirt as possible followed by use of detergent at the correct concentration and scrubbers. The scrubbing material should not scratch the surface being cleaned. Therefore scrubbers or steel wools should be avoided. The surface that has been cleaned should be rinsed thoroughly with potable water.
High Pressure Cleaning

High pressure cleaning combines high pressure, high temperature and detergent. This cleaning technique allows effective cleaning of surfaces that are difficult to access, e.g. top of pipes and ceilings. Cleaning at high pressure (high hydraulics) and high temperature will minimise the detergent usage. The use of a high pressure gun at appropriate pressure will ensure that even stubborn soil is removed.

Foam Cleaning

In foam cleaning, the working solution is diluted with air. Strong detergent solutions can be used. Because of dilution with air, small quantities of water are used. The generated foam adheres to dirt, emulsifying and loosening it. The foam is removed by rinsing with water.

Cleaning In Place (CIP)

Cleaning-in-place (CIP) systems allow vessels, piping, valves and other equipment to be cleaned without dismantling all or part of the items. Surfaces are exposed to controlled conditions where detergents act on the surfaces to eliminate soil and to sanitise.

Spray Systems

To demonstrate the two principles of cleaning vessels, the following shows how the same size of vessel has been installed with the two different systems in two different plants:

- vessel size: 3000 hl working volume, 5.2 m diameter;
- service of vessel: fermenting beer, with similar soil on the entire surface
  - spray ball: capacity 350 hl/hour at 1.5 kg/cm²;
  - rotating spray cleaners: capacity 240 hl/hr at 6 kg/cm².

To understand the different equipment, the following are the details of the spray balls and the rotating jet spray.

Spray Balls

The choice of spray balls carried out for a research vessel followed the specifications required. Fig. 3.30 shows the flow rates for CIP spray balls used in different types of vessels at four operational plants. These were compared with theoretical flow rates cited in the literature and two different flow rates that were evaluated in the research programme.

![CIP Flow rates in vessels expressed in litre/hour/meter of circumference](image)
In this same research programme, the research vessel (600 litre and part of a training brewery) fermented a number of brews to study the type of soil and the effectiveness of two different CIP flow rates. **Figs. 3.31 and 3.32** show the type of soil (yeast ring) that accumulates at the top of all the vessels in the brewing process and what the top of the vessel looks like if the CIP is effective.

![Before CIP](image1) ![After CIP](image2)

**Fig. 3.31 FV before CIP**  **Fig. 3.32 FV after CIP**

The choice of spray balls or rotating spray cleaners is a key factor in the effective design and operation of a CIP system. There are a number of reputed manufacturers of this equipment but the chosen data is from GEA Tuchenhagen and Alfa Laval Tank Equipment A/S as they represent typical designs that could be selected to achieve the required outcomes.

The dimension of the vessel dictates the type of spray device required for an effective covering of the entire surface during the CIP cycle. Spray balls showers the entire surface all the time the pump is operational by directing the impact flow of the fluid on the area where most of the soil is located, e.g. at the yeast ring in the fermenting vessel example above. The fluid runs down the side of the walls of the vessel in a continuous curtain contributing to the effect of the chemical, timing and temperature to assure a clean surface.

The following shapes of vessels can be fitted with the fixed spray balls with multiple holes or for two, three or four jets. To cover the entire surface of the vessel, either one or multiple spray balls can be installed in one vessel to ensure that the spray diameter of each spray ball gives total cover of the vessel surface. The spray angle can be chosen to give from 90° to 360° cover.

Selection of spray balls should be done in consultation with the manufacturers. (See **Figs. 3.33 a) and b** and **Table 3.7**.)

![Spray Balls Diagrams](image3)

**Fig. 3.33 a) GEA Tuchenhagen spray balls as installed in vessels**

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Objective: Identify the principles applied to plant design and methods of cleaning the surfaces to maintain appropriate levels of hygiene

**Table 3.7**

<table>
<thead>
<tr>
<th>Type</th>
<th>Spray</th>
<th>Spraying</th>
<th>Spreading</th>
<th>Spray area</th>
<th>Spray area</th>
<th>Spray area</th>
<th>Spray area</th>
<th>Spray area</th>
<th>Spray area</th>
<th>Spray area</th>
</tr>
</thead>
</table>
| GEA   | Tuchenhagen | Data Sheet | for Selection of Spray Ball for Different Vessel Sizes

**Cleaning Technology - Sprayballs**

Sprühköpfe: Kranzberüttigung und Gewindemanschüttentypen: Sprayballs with pipe clip and threaded connection

Abmessungen: Diameter (mm) | Length (mm) | Height (mm) | Width (mm) | Flow rate (l/h) | Pressure (bar) | Weight (kg)

**Fig. 3.33 b) GEA Tuchenhagen vessel attachments for spray balls**

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Rotating Spray Cleaners

Rotating spray cleaners require a high pressure to direct the fluid onto the surface of the vessel that has an impact effect at the point of contact. The fluid flows down the rest of the surface cleaning on its way.

Rotating spray cleaners from two suppliers show the different applications when they are positioned on the floor of the vessel and when they are fixed at the top of the vessel. The rotating jets have a higher impact force on the surface exerting greater mechanical effect on the soil or scale, than the flooding low pressure system applied on fixed spray balls.

The jets on a rotating mechanism direct the fluid at one point a specified number of times for a complete cycle, at the end of which the entire surface will be covered.

Both GEA Tuchenhagen and Alfa Laval/Toftejorg rotating jet cleaners are shown below. (See Figs 3.34 a), b) and c).

The selection of rotating spray cleaners should be done in consultation with the manufacturers.

Fig. 3.34 a) GEA Tuchenhagen rotating jet cleaners placed on vessel floor

Fig. 3.34 b) GEA Tuchenhagen Orbital Cleaner TS – T4 and Orbital Cleaner M19
Fig. 3.34 c) GEA Tuchenhagen Orbital Cleaner RH19G

Fig. 3.34 d) Alfa Laval/Toftejorg Rotating Jet Heads

**Fig. 3.34 d)** shows examples of how different types of spray devices distribute liquid over the surface of vessels.
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**Application Guidelines**

<table>
<thead>
<tr>
<th>Area</th>
<th>Vessels</th>
<th>TZ-74 / TJ 20G</th>
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<tbody>
<tr>
<td>Brewhouse</td>
<td>Mesh vessel</td>
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<tr>
<td></td>
<td>Cereal cooker</td>
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<tr>
<td></td>
<td>Lauter tun</td>
<td>2 – 3</td>
</tr>
<tr>
<td></td>
<td>Wort kettle</td>
<td>2 – 4</td>
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<td>Whirl pool</td>
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<tr>
<td>Fermentation/</td>
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<tr>
<td></td>
<td>Horizontal</td>
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<tr>
<td>Yeast</td>
<td>Vertical or horizontal</td>
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</tr>
<tr>
<td>Bright Beer</td>
<td>Vertical, cylindrical</td>
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</tr>
</tbody>
</table>

*Sani Magnum rotary spray head alternative

**Fig. 3.34 e) Spray devices and application guidelines**

**Fig. 3.34 e) shows examples of Alfa Laval/Toftejorg devices as applied in brewing vessels.**

**Fig. 3.34 f) Alfa Laval/Toftejorg TZ-74 rotary jet head in operation**

**Fig. 3.34 g) Rotary jet head in brewkettle**

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 Maintenance of Spray Cleaning Devices

The blockage of holes in the spray balls and rotating spray jet cleaners must be avoided at all times as this seriously impairs their effectiveness. The devices must be inspected on a routine basis to ensure that they are clear of the debris and function correctly.

Rotating jet cleaners are sometimes fitted with a sensor to check that the system is rotating (see Rotacheck above). If the rotating jet cleaner is not functioning, the sensor will identify the condition and send a signal to the CIP control system to close down the plant.

Fig. 3.35 shows the hole of the spray ball blocked that caused ineffective cleaning of the surface at the top of the vessel.

CIP of Vessels and Piping

Vessels

The effectiveness of CIP over the entire surface of a vessel is determined by the flow of the fluid at its impinging area and as it flows down the walls of the vessel. However, the factors that assure an effective cleaning process are mechanical, chemical, time and temperature and these have to be optimised to ensure effective cleaning.

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The spray systems are most effective on those areas where the fluid impinges on the surface. Experience and research has shown that vessels have three zones with different levels of cleanability, *i.e.* absence of soil, biofilm and scale. This is shown diagrammatically in *Fig. 3.36.*

The top area surface, where there is greatest impingement, is always clean provided that the spray device holes are not blocked. The middle of the vessel tends to be less clean as the fluid flows down the side walls from the spray ball and the rotating jets are at their longest trajectory. In this area temperature probes are normally located. At the bottom of the vessel, whether conical or domed shape, there is clear evidence of biofilm and scale formation when using both types of cleaning device. In this area chemical effectiveness is at its lowest and the temperature may have been reduced by the cooling medium remaining in the cooling jackets that would cool the detergent as it flows down the wall. If the CO$_2$ has not been removed completely, caustic will be neutralised. Evidence has been seen of this in vessels that have completed the CIP cycle with caustic, demonstrated by a zero reading on the conductivity meter on the return line and by a distinct odour of CO$_2$ inside the tank.

*Fig. 3.36 Areas of cleanability of vessels*

Low level indicators at the bottom of the vessels have to be totally reliable at all times. This will allow for effective sequencing of the CIP return pump and the supply pump to ensure that the bursts of detergents do not accumulate at the bottom of the vessel making the chemical effect on the biofilm even less effective. These low level indicators also indicate that the CIP cycle has terminated and the vessel is empty of detergent ready for filling with product. Failures in these low
level indicators have caused numerous incidents of vessels being filled with product on top of detergent chemicals.

In the case of cleaning vessels with flow rates specified for spray devices, care must be taken that those flow rates are also effective for cleaning the outlet pipes of the vessel, especially as those detergents are cold and often low in concentration. Flow rates for vessel CIP are frequently not sufficiently high to achieve an effective cleaning of the outlet pipes. In the case of fully piped up and automated systems where inspection of the pipes and vessel is rarely practised, this problem requires careful consideration. Product pipes must be cleaned with hot detergents, separately from vessel cleaning. Fig. 3.37 shows the layout for CIP of hot and cold vessels.

**Fig. 3.37  Vessel CIP**

To optimise fluid flows for the CIP of vessels, the following factors must be considered:

- spray devices define the volume and pressure required for effective cleaning depending on its spray circle for the vessel in which it has been installed;
- supply CIP pumps will deliver the following flows:
  - spray balls example: 360 angle in a 5 meter diameter vessel: 350hl/h at 1,5 bar pressure. Burst of fluid shower the entire surface, normally recommended: with specific bursts of defined minutes on and off;
  - rotating jet cleaner example: 360 angle in a 5 meter diameter vessel; 240hl/h at 6 bar pressure. Continuous flow of fluid to get the rotating cycles to obtain 100% coverage over the total time for CIP;
- return CIP pump service:
  - low level probe senses flow and the pump starts;
  - low level probe senses no flow and the pump stops.

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There are some important considerations that need to be taken into account in the sequencing of the supply and return in CIP pumps.

- Avoid excessive back-up of fluid over the required level to cover the low level probe in the outlet pipe of the vessel.
- Ensure that the pipe has enough fluid to supply the required suction pressure on the return pump.
- Avoid vortexing of the pump when it has no suction pressure as it will cause cavitation of the pump and result in mechanical damage to the impeller and seal.

In a domed bottom vessel vortexing is often a problem. A vortex breaker has to be fitted manually at the vessel outlet, most often positioned next to the manway, before CIP starts. Once CIP is complete, the vortex breaker is removed. If the vessel is a fermenter or a storage tank where a thimble is fitted in the vessel outlet to hold back yeast or tank bottom, this can be done at the same time, once the vortex breaker is removed.

**Figs. 3.38, 3.39, 3.40 and 3.41** show a manual CIP system with the vortex breaker in position next to the thimble which is also cleaned at the same time as the rest of the vessel. The photos also show the effectiveness of a manual CIP system where all the mechanical and chemical factors are optimised at the design and operational phase.

![Manual CIP System](image)

The following represents three levels of CIP from a manual process, **Fig. 3.42**; semi-manual using pipe panels, **Fig. 3.43** and a fully automated system, **Fig. 3.44**.

![Manual CIP System](image)
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**Fig. 3.43** Semi automatic CIP system - the CIP of the vessel is done through the panels

**Fig. 3.44** Fully automated CIP system

The CIP of the vessel is done through a fully automated system. The CIP flows in the pipe behind the vessel and up to the spray device. The CIP return flows from the bottom of the vessel to the return pump. The CIP flows through the pipe directly under the vessel to ensure that the entire piping system is cleaned. The process piping is cleaned through a separate line with hot detergent.

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**Piping**

To ensure an effective cleaning of piping, all four factors must be optimised to ensure optimum hygienic conditions. The importance of flow characteristics has been discussed above under **Underlying Principles**.

**Hoses**

- Hoses should withstand cleaning by steaming and by hot alkaline and acid solutions without imparting any off flavour to the product or causing other problems. The hose should be unaffected by continuous immersion in 1% chloramine solution.
- As rubber hoses are used in connection with CIP systems, the risk of bursting has to be considered. New hoses must not be subjected to high internal pressure over 5kg/cm². If detergent is circulating at 3m/s a pressure of 5kg/cm² may be assumed.
- Two hose fastenings per end must be placed on the hoses to ensure that the coupling is secured on the hose and they are safe to use.
- Microbiological tests are done on the hoses by holding the two ends up and pouring 100ml of sterile water into one end of the hose. A person then ‘dances’ on the hose to release any biofilm from the internal surface. The water is then collected and plated as for any other micro sample. Each hose must be numbered and registered to record its life and the cleaning done.

**Multi Use CIP vs. Single Use CIP**

In the design of the CIP system, there is a choice of incorporating either a multi-use or single use system. In determining the choice of either of these two systems, the following factors need to be considered.

**Multi Use System:**
- high initial capital cost of the vessels, instrumentation, pumps, valves, piping and control system;
- relative inflexibility of the CIP chemicals;
- relative independence from the chemical suppliers;
- complex control system and instrumentation;
- high maintenance;
- control of chemicals requires complex instrumentation;
- high and variable effluent loads when discharging entire vessels with caustic, acid or sterilants;
- central location with high grade building finishes that are chemical resistant;
- recovery of detergent for re-use.

**Single Use System:**
- low initial capital costs: few to no vessels, short piping routes, simpler valving and instrumentation;
- relative dependence on chemical supplier;
- mobile unit;
- simple controls;
- medium maintenance;
- simple detergent controls;
- control of effluent discharges and smaller volumes;
- reduced area for CIP station;
- no recovery of detergent.

To compare the two systems, **Fig. 3.45** shows the two process flow diagrams. When deciding which of the two systems is most suitable, the economic and the logistical factors need to be considered side by side.
The following is an example of an economic calculation to justify the multi-use CIP system against a single use system.

**Basis Data**

<table>
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<th>Value</th>
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<tr>
<td>Pipe diameter</td>
<td>81mm ID</td>
</tr>
<tr>
<td>Length</td>
<td>50m</td>
</tr>
<tr>
<td>Product density</td>
<td>1,1kg/dm³</td>
</tr>
<tr>
<td>Product quantity in pipe length</td>
<td>283kg</td>
</tr>
<tr>
<td>Recovered product</td>
<td></td>
</tr>
<tr>
<td>• flushed out (lost to drain)</td>
<td>10%=28kg</td>
</tr>
<tr>
<td>• push out with pig</td>
<td>90%=255kg</td>
</tr>
<tr>
<td>Number of product push out</td>
<td>200/year (255-28=227x200=45400kg/year)</td>
</tr>
<tr>
<td>Operating costs</td>
<td></td>
</tr>
<tr>
<td>• spare pigs</td>
<td>16000 R(1) see note below</td>
</tr>
</tbody>
</table>

**Calculation**

- **Total investment**
  - Product recovery system: R250000
  - Piping & assembly: R150000
  - Control system: R100000
  - Total investment: R500000 (2)

- **Investment costs (8%)**
  - R 40000 (3)

- **Maintenance cost (3%)**
  - R 15000 (4)

- **Total cost 1 + 3 + 4**
  - R 71000 (5)

- **Cost saving on**
  - Recovered product: 45400 kg/a (6)
  - Product costs: R10/kg (7)
  - Savings 6 x 7: R454000 (9)
  - Profit 9 – 5: R383000 (10)

- **Write off time 2 divided 10**
  - 500000
  - 383000
  - = 1,3 years

**Note:** In the case of the above example, it is assumed that 90% of the detergent is recovered (by using a pig=rubber ball). This procedure is difficult to carry out in a fully automated plant as the pig will be blocked by valves or instruments. However the principle of recovery could be done by measuring how much detergent returns to the CIP vessel and how much is lost at the drains.

In the case of the single use system, the economic justification would be based on similar data inputs as shown above. The investment costs would be lower but the recovery costs would have a negative impact on the final calculation.

**Fig. 3.45** shows the PFD of the two systems.
Objective: Identify the principles applied to plant design and methods of cleaning the surfaces to maintain appropriate levels of hygiene

Fig. 3.45 CIP Processes

Summary

Fig. 3.46 summarises the key aspects of optimising a cleaning system.

Fig. 3.46 Optimising a cleaning system

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INDEX : MODULE FOUR

Objective

Outcomes

4.1 Environmental aspects of a process plant

4.2 Materials used for general cleaning

4.3 Cleaning agents

4.4 Control of environment
MODULE FOUR

Objective: Identify the environmental factors that contribute to plant hygiene

Outcomes

Hygiene of plant environment assured.

4.1 Environmental Aspects of a Process Plant

- All floors must be constructed from cement, tiles or suitable material that is durable and has a flat surface that will allow for regular cleaning and sanitation.
- Skirting of the wall to floor joints must be 100mm high and of the same material as the floor finish.
- Floors must have a 1 to 1.5% fall towards the drains to prevent ponding of water after hosing down.
- Floors of the process and packaging areas must be made from materials that resist acid and caustic at the concentrations found in the operational areas. Where areas are earmarked for storage of the concentrated forms of detergents and other materials, the floors and walls should be able to resist those materials.
- All drains in the process areas and packaging areas should have appropriate airlocks.
- Drain covers in the packaging areas should be constructed with baskets to retain glass.
- Walls in the process areas should be tiled to the ceiling or coated with a durable and washable coating. Ceilings should be painted with durable and washable coating. Where possible, anti-mould coatings should be used.
- Walkways and hand rails should be made of corrosive resistant material or coated with a suitable corrosion resistant material.
- Walls of the storage areas should be painted with a suitable durable coating.
- Natural ventilation or air-conditioning should supply sufficient air movement to prevent mould growth and eliminate odours.
- No protrusions should be allowed on walls and windows should have sills facing the outside. Any internal protrusion or beams should have a 30° fall to prevent dust from accumulating and to facilitate cleaning.
- All holes to the exterior should be covered by plastic mosquito netting.
- All process areas should be protected against entry of insects, vermin, dirt and dust.
- Hot and cold water points should be positioned strategically around the plant for hand cleaning and cleaning of equipment, walls and floors.
- All factory drainage systems should be dimensioned (size and falls) to allow for effective discharge of effluent with solids without having any blockages.
- Ablutions must be positioned away from the process area and be fitted with suitable lockers, showers, washbasins and other required sanitary fittings.

4.2 Materials Used for General Cleaning

- Suitable bins to hold all waste material should be positioned around the plant;
- brooms and brushes to sweep and clean the floor;
- squeegees to push excess water from the floors;
- drain pumps and pull through to clear blocked drains;
- sufficient hoses and hose points to clean all surfaces (walls, floors and equipment);
- special brushes for cleaning surfaces of the plant: care must be taken not to scratch inside and outside surfaces of stainless steel plant;
- personnel performing cleaning duties should be suitably clothed and protected.
4.3 Cleaning Agents

- Sufficient 70 °C water must be available on tap to facilitate cleaning in all process areas.
- A suitable detergent should be used for general cleaning of all surfaces: choices of the detergents need to take account of the fact that chlorine based chemicals are corrosive on stainless steel equipment. MSDS certificates must be available for all materials on site.

4.4 Control of Environment

- Physical inspection of all plant and buildings to assess the level of hygiene must be done on a routine basis.
- Microbiological surveys of the environment (walls, floors, equipment and the air) will indicate the effectiveness of the plant hygiene programme.
## INDEX : MODULE FIVE

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</table>

### 5.1 Different methods of inspection QC are compared

- Physical examination of the process and plant
- Physical inspection
- Chemical Inspection
- Surface measurement
- Sampling programme to determine hygiene levels

### 5.2 Analytical procedures

### 5.3 Non-destructive testing (NDT)

- Mechanical surface measurement
- Measuring equipment
- Vessel coating
- Dye penetrant testing

**Practical Implications**

- Ra and Sm measurements compared
- Use of RepliSet to assess the surface in conjunction with optical microscopy and AFM techniques
- ATP swab investigation of vessels in operational area and at the test vessel
- Appropriate surface roughness to ensure required hygiene standards

**Summary**
MODULE FIVE

Objective: Describe the methods to measure and inspect the surfaces

Outcomes

- Compare different methods to demonstrate if cleaning systems are operating correctly.
- Describe analytical procedures to measure the surface for levels of hygiene and residual cleaning chemicals.
- Describe non-destructive testing (NDT) methods to measure the surface for roughness and corrosion.

5.1 Different Methods of Inspection QC are Compared

Underlying Principles

This section looks at ways in which the levels of hygiene are measured. Fig. 5.1 shows the points in the manufacturing chain at which inspection of the plant and analytical methods are used to determine the hygienic condition of the process, plant, finished product and data related to customer complaints.

Fig. 5.1 Inspection and QC Process Flow

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Physical Examination of the Process and Plant

HACCP procedures have identified CCP’s in the process. These have to be inspected and controlled at specific intervals using the documented procedures.

When a process deviation or external customer complaint is reported, the required inspection is done of the process and plant to assess the root cause of the incident and put in place the correct action required. Feedback to the relevant in-house or external customer is carried out through formal reports that are logged manually or electronically.

Physical Inspection

Physical inspection carried out on routine plant walkabouts or on an ad hoc basis, must address the following aspects relating to plant hygiene.

◆ What elements in the process or plant are inspected visually, electronically, audibly or organoleptically:
  ▶ raw materials physical inspection, batch data from suppliers, storage area;
  ▶ process condition: step of the process, condition of the process;
  ▶ items of plant: monitoring devices (e.g. temperature, pressure, conductivity levels) functioning, condition of pumps, valves, heat exchangers, vessels and other relevant equipment;
  ▶ hygiene, safety, process deviations, operating performance, disposal of hazardous and non-hazardous materials: all these factors must be under control.

Chemical Inspection

Chemical testing is carried out on the following:

◆ deliveries of raw materials for infection and contaminants;
◆ deliveries of cleaning material, heating and cooling medium additives in bulk for MSDS certification and manufacturers batch numbers and QC certificate;
◆ concentration of CIP solutions: caustic, acid, sterilants and other, as required;
◆ residual chemicals in vessels, pipes and other relevant equipment;
◆ final product before dispatch to customer and samples from the trade or from Customer Complaints.

Surface Measurement

The following tests are performed on the surface to determine levels of hygiene:

◆ microbiological testing by taking samples from
  ▶ the surface or from solutions in contact with the surface (i.e. from vessels and pipes)
  ▶ the environment i.e. surface of floor and walls, air, rinse water;
◆ microscopic examination of samples of soil;
◆ surface roughness finish, presence of corrosion or metal fatigue cracks;
◆ surface integrity of coated process vessels.

Sampling Programme to Determine Hygiene Levels

The samples are taken at the following stages of the process.

◆ Raw materials:
  ▶ MSDS certificates for incoming cleaning chemicals and heating and cooling media additives e.g. boiler additives and glycol;
  ▶ batch ID of incoming relevant chemicals;
  ▶ samples of incoming cleaning chemicals:
    ▶ check for active ingredients: caustic, acid, sterilant
    ▶ stratification of chemicals in bulk vessel for incomplete mixing at producers factory;
  ▶ samples of packaging materials e.g. washed bottles, cans, kegs;
Objective: Describe the methods to measure and inspect the surfaces

- raw materials for presence of infestation;
- taint net samples e.g. water, liquid sugars, malt, filter aids and final product;
- batch ID of raw materials to allow for traceability in the production and distribution chain.

Process:
- product contamination by relevant chemicals;
- concentration and temperatures of cleaning chemicals in CIP tanks;
- physical appearance of cleaning chemicals in CIP tanks: presence of soil from process vessels;
- micro of rinse water and cleaning solutions in CIP tanks;
- pasteurisation units in packaged product;
- trade complaints micro.

Plant:
- vessels, piping, fillers (i.e. bottles, cans, kegs), finished product;
- welding quality of piping and water hammer: valves lifts and CIP enters product line;
- bottle washer baths caustic strength;
- pasteuriser water recovery plant: micro and chemical residue;
- EBI chipped bottle: breaks hermetic seal of finished product;
- keg beer dispensing plant micro;
- environmental micro samples: walls, floors, air, drains;
- CO$_2$ gas micro;
- compressed air micro;
- concentration of additives to boiler feed water and glycol additive corrosion inhibitors in cooling medium.

5.2 Analytical Procedures

The following analyses are performed to assess the level of hygiene in conjunction with the above sampling programme.

- Caustic or acid determinations on the following:
  - raw materials, incoming cleaning chemicals
  - bulk storage tanks
  - solution in CIP vessels
  - residual liquid after CIP of vessels, pipes, filters, fillers, keg dispensing plant
    - samples are taken from the different points and analysed in the laboratory by the approved method.

- Microbiological analyses on samples:
  - bacteria and wild yeast
    - samples are taken from the surface or from the rinse water. Sterile swabs are rubbed on the surface to be analysed and the swab placed in a solution of sterile saline water. Water samples are taken in a sterile bottle;
    - in the laboratory, 1ml of the sample is plated on a Petri dish or in a McConkey broth tube. The media added to the samples in the Petri dishes and in the McConkey tubes are specially formulated to show different types of micro-organisms. After incubation, from 48 hours to 5 days, the dishes are inspected for growth that will determine the level of contamination in the original sample;
  - ATP swabs and liquid samples:
    - ATP (Adenosine Triphosphate) has been extensively researched and applied in the food and beverage industry for rapid assessment of plant hygiene, product quality and process monitoring. Its application is now specified as the method of hygiene assessment in Hazard Analysis and Critical Control Point (HACCP) programmes;
    - the fundamentals of this measuring process consists of ATP being the basic energy currency of living organisms that is present in all microbial, plant and animal cells. Using an enzyme found in the North American firefly called Luciferase, together with its substitute D-Luciferin, it is possible to measure very small amounts of ATP by measuring the light produced in the reaction using a sensitive luminometer;
ATP-free swabs are pre-moistened with agents that help to lift the soil off the surface. After taking the sample with the swab, it is then pushed down into the tube, shaken and finally placed into the luminometer. Clean samples give low light levels and dirty samples give high levels of light. The measurement is made in RLU (Relative light units). The practical use of this procedure is very significant as the evaluation of the level of hygiene can be carried out immediately instead of waiting for the 3 to 5 day period normally required for standard microbiological analysis, where incubation of samples is required. The ATP process gives a general appraisal of hygiene levels that should be followed by more exacting analysis;

- microscopic analyses
- samples are taken form the surface and submitted to viewing under a microscope. It is possible to view the sample and determine if the soil is organic, inorganic or individual cells of bacteria or yeast. This is a very quick assessment that gives good information regarding the quality of the soil to be cleaned from any surface.

 Analyses of additives to boiler feed water and glycol and corrosion inhibitors to cooling medium are carried out according to standard procedures.

### 5.3 Non-Destructive Testing (NDT)

**Underlying Principles**

**Mechanical Surface Measurement**

**Roughness Parameters**

*Ra - (CLA, AA) Average Roughness*

The Ra or Average Roughness is the most widely accepted roughness parameter and accepted by international bodies such as ISO. The derivation of Ra is shown in Fig. 5.2. It can be seen that Ra is the average deviation of the profile from the mean line. Ra does not differentiate between peaks and valleys.

*Fig. 5.2 The derivation of Ra surface measurement*

*Fig. 5.3* shows three different profiles, each having the same Ra value and each profile having very different profile characters. Ra is unable to distinguish between the three profiles and the implication of this is important. The peaks and valleys are used for very specific purposes such as to characterise the bearing loads, lubrication, oil retention, wear resistance, painting and optical properties. The implication of these peaks and valleys influences the retention of soil on the surfaces.
Objective: Describe the methods to measure and inspect the surfaces

**Fig. 5.3** Graphical comparison of Ra values for different profiles

*Rz (DIN) (Rtm)* - Mean Peak-to-Valley Height

*Rmax (Rymax, Rma)* - Maximum Peak-to-Valley Height

To determine the parameters Rz (DIN) and Rmax, the filtered roughness profile roughness is divided into 5 equal lengths. The maximum peak-to-valley height (Z1) is determined within each cut-off length as shown in **Fig. 5.4**. Rz (DIN) is the average of the 5 peak-to-valley heights, while Rmax is the maximum peak-to-valley height within one cut-off. The use of these two parameters together is a valuable tool in monitoring the variations of surface finish in a production process.

**Fig. 5.4** Derivation of the parameters Rz (DIN) and Rmax

*Rz (ISO)* - Ten Point Height

*Ry* - Maximum Roughness Depth

These two parameters are analogous to the DIN parameters Rz (DIN) and Rmax. Rz (ISO) is the average distance between the 5 highest peaks and the 5 deepest valleys within the assessment length. Ry is the distance between the highest peak and the lowest valley. The disadvantage of Rz (ISO) is that it is possible to have a number of high peaks or valleys located close to each other.
Waviness Parameters

\( W_t \) - Total Waviness Depth

The parameter \( W_t \) is analogous to the roughness parameter \( R_y \). As shown in **Fig. 5.5**, \( W_t \) is the maximum peak to valley height of the leveled and filtered waviness profile. This parameter is used to monitor a production process where waviness and not roughness alone is critical of production variable.

![Fig. 5.5 Schematic drawing showing the derivation of the parameter Wt](image)

Total Profile Parameters

\( P_t \) - Total Profile Depth

\( P_t \) is the total peak-to-valley height or the unfiltered but leveled surface profile as shown in **Fig. 5.6**. \( P_t \) is equal to the total roughness height \( R_y \), plus the total waviness height, \( W_t \). \( P_t \) is useful in finding defects such as scratches or pits.

![Fig. 5.6 Schematic drawing showing the derivation of the parameter Pt](image)
MODULE 5  
Objective: Describe the methods to measure and inspect the surfaces

Spacing Parameters

NR (Pc) - Normalised Peak Count

The appearance of a surface is dependent on both the profile depth and the spacing between its peaks. Surfaces with the same Ra and Rz (DIN) can vary greatly in appearance. Because of this, the peak count, NR shown in Fig. 5.7, is often measured on surfaces where the appearance is critical. The number of peaks over the assessment length, Im, are counted and then normalised to give the number of peaks per 10mm. A comparison of profiles with the same Ra profile and with different NR peak counts is shown in Fig. 5.8. By measuring NR, the peak count and Rz (DIN), the mean peak-to-valley height, the appearance of the textured furnish can be closely monitored.

Fig. 5.7 Schematic drawing showing the derivation of the parameter NR

Fig. 5.8 Graphical comparison of parameter NR and Ra for different profiles

D Profile Peak Count

The parameter D is similar to the parameter NR in that it counts the profile peaks that exceed a pre-selected threshold. D is calculated over the entire assessment length and is not normalised to a standard length.

Sm Mean Peak Spacing

The mean spacing parameter is the average distance between the peaks counted in the D or NR calculation. The parameter Sm conveys the same data as the parameters D and NR in a different form.
Measuring Equipment

Two Dimensional Measurements

There are many methods of measuring the surface texture but the stylus method is the most widely accepted. The diamond stylus is traversed across the workpiece, much like a household record player. The vertical displacement of the stylus is converted into an electric signal. The signal is amplified before being converted into digital information that in turn is transformed through a computer into the different forms of numerical analysis.

The system consists of three sections; the stylus, the transducer and the skid. Fig. 5.9 shows the electron microscope photo of a diamond stylus tip R=5µm. The geometry and the maintenance of the stylus play a key role in the reliable measurement of the surface.

Fig. 5.9  Electron microscope photo of a diamond stylus tip R=5µm

The surface tester is comprised of a battery operated display-traverse unit and the pick-up. A drive motor traverses the pick-up across the surface to be measured. The unit contains the electronic circuits for computing and displaying the values as described in Mechanical Surface Measurement above. Fig. 5.10 shows the Surtronic 3 Display-traverse unit and pick-up in vertical use. The pick-up is a variable reluctance type transducer that is supported on the surface to be measured by a skid, a curved support projecting from the underside of the pick-up in the vicinity of the stylus.

Fig. 5.10  Photograph of a Surtronic 3 Display-traverse unit and pick-up, also in vertical use

Three Dimensional Microscopy

Two dimensional measurements are used for evaluation of surfaces in many industrial applications but it does not give the all important three dimensional perspectives that are required in the food and beverage industry, where the surface plays a critical role in the hygienic condition of the equipment. The three dimensional view of the surface is therefore presented. There are three forms of measurement that are reviewed: Optical Microscopy, Scanning Electron Microscopy.
(SEM) and Atomic Force Microscopy (AFM). All these techniques have been used in the food and beverage industry, including the brewing industry in Africa, to study the implication of surface conditions that are affected by biofilm and microscopic organisms that in one form or another have direct impacts on health and hygiene or corrosion.

**Optical Microscopy**

In the optical scan of the microscope, the polyvar optical system produces accurate images of extremely large object fields. Magnifications from 16 to 2000 are available to comply with DIN and ASTM standards.

An example of photographs (500 magnifications) of stainless steel surface on an optical microscope can be seen in *Fig. 5.11.*

![Fig. 5.11 Stainless Steel 120 grit polished surface: marker shows 100µm](image)

**Scanning Electron Microscopy (SEM)**

SEM has a resolution of up to 4.0nm and magnifications from 15 to 300,000. SEM has been used for evaluation of surfaces to detect micro-structures of surfaces and evidence of corrosion on stainless steel. Example of an SEM image is seen in *Fig. 5.12.* The depths of the pits or troughs on the surface are not measured in this procedure.

![Fig. 5.12 SEM microphotograph of stainless steel 220 grit polish finish with yeast cells superimposed at 1000 magnifications](image)

**Atomic Force Microscopy (AFM)**

The basic objective of the operation of the AFM is to measure the force (at the atomic level) between a sharp probing tip (which is attached to a cantilever tip) and a sample surface. Images are taken by scanning the sample relative to the probing tip and the measuring deflection of the cantilever as a function of later position.

Examples of the use of AFM to view the surface profile of stainless steel surfaces are shown in the following:

*Fig. 5.13* shows the irregularities of the surface of a 2B milled surface;
*Fig. 5.14* shows the relative smoothness of the surface that still has ridges where biofilm can grow;
Module 5

Objective: Describe the methods to measure and inspect the surfaces

Fig. 5.13 Stainless Steel, 2B milled finish  

Fig. 5.14 Stainless Steel, 240 grit polished finish

Fig. 5.15 shows a flat undulating surface where organisms and biofilm would find less sites to grow;  
Fig. 5.16 shows the structure of the biofilm on the surface of the vessel before cleaning. Once the surface is CIP’d the surface underneath is the same as Fig. 5.14 of 240 grit polished surface.

Fig. 5.15 Stainless Steel electro polished finish  

Fig. 5.16 Biofilm on top of fermenter before CIP

AFM can also be used to express roughness in the same terms as with the 2D Stylus instrument as above. The sample is prepared on the AFM and a computerised analysis function views the texture of the profile, as shown in Fig. 5.17 and then reports the different figures in tabular format as shown in Fig. 5.18 equivalent roughness. In the case of this example, the sample being shown is that of the replicated sample (see below) of a stainless steel surface.

Fig. 5.17 Image of replicating sample showing analysis of traces used to analyse the roughness measurements shown in Fig. 5.18

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Replicating the Surface Finishes

The replicating system developed by Struers called RepliSet, is based on applying a fast curing 2-pack silicone material applied to the surface and after 15 minutes, evaluating the replica sample under an optical microscope, SEM or AFM. The replicating sample can be used to measure a resolution up to 0.1\( \mu \)m. This technique has been used in defining the measurement methods for the research test rig.

This excellent reproduction of the surfaces makes the procedure valid as a NDT for surfaces over the entire life cycle of the equipment (Fig. 5.19). Samples of replica can be kept for a number of years for reference.

Fig. 5.19 RepliSet sample of stainless steel surface 240 grit finish, compared to optical photograph of the stainless steel material
**Camera and PC Measuring Surface of Vessels**

Weinzierl and Wasmuht of Steinecker Germany investigated the application of a camera mounted on top of a tank that supplies images of the inside of the tank that are displayed on a PC. During the cleaning of the tank, the images are automatically evaluated and the processes are correspondingly automated. When the image analysis shows no further dirt, a safety interval of a few minutes is observed and the cleaning procedure ends. Because the adjustment of the cleaning programme is dependent upon the actual circumstances present, the process could be shortened and the use of cleaning chemicals minimised.

**Vessel Coating**

The coating of process vessels has to be carried out under a very strict procedure, so that the epoxy coating is anchored onto the profile of the carbon steel vessel. The epoxy is heated and sprayed onto the surface in a uniform manner either automatically or manually, prior to polymerisation to give a taste-free and relatively chemical resistant surface. Special care is taken to ensure that no contamination of the surface is allowed during the coating application. This can occur in the following manner:

- contamination of the steel surface by the shot blasting material when the anchoring surface is prepared;
- contamination of the surface by any person entering the vessel during the lining process: perspiration from a person has 1000ppm of chlorides that can prevent the lining from adhering to the surface and cause pin holes;
- epoxy temperature must be kept at 70°C for 12 hours prior to coating and the steel substrate must be more than 10°C;
- spray equipment must be checked for correct operating parameters;
- all circumferential and longitudinal welds are stripe coated prior to coating the rest of the vessel;
- one or two coats of epoxy should be applied as specified to the required thickness e.g. 700µm;
- carbon steel to stainless steel interface areas should be prepared to ensure an adequate overlap of the epoxy lining.

The epoxy lining is tested for integrity to ensure that there are no pin holes that may give rise to delamination and eventually cause serious hygiene problems and contamination of the product with iron.

**Lining Integrity Tests (Holiday Detector)**

Lloyd MK 6b brass or copper brush probe (3–4mm flat faced) is placed on the surface of the lining, a current of 7KV is fed into the instrument and results will indicate if the instrument has detected a pin hole in the surface. This procedure is carried out after application of the lining, on receipt at the plant, after pressure testing and at regular intervals during the life of the vessel.

**Dye Penetrant Testing**

Liquid penetrant testing as a NDT method is used to detect surface breaking of non-porous materials. The liquid penetrant (mesityl oxide free) is applied to the surface and is drawn into the defect e.g. cracks or pinholes. Once a pre-set dwell time has passed, excess penetrant is removed and developer (e.g. chalk like suspension) is sprayed onto the surface. Visual inspection is then performed. The dye can be UV active so viewing under UV illumination also reveals cracks. The cracks arising from the following can be detected: stress corrosion cracking, heat affected zone defects, poor weld penetration, fatigue, intergranular corrosion.

Example of dye penetrant tests on a weld in a process vessel is shown in Fig. 5.20.
Practical Implications

A practical application of these testing techniques can be seen in the research done on vessel cleanability carried out since 2001 in the brewing industry in South Africa.

The research set out to establish the relative cleanability of certain stainless steel surface finishes in the brewing industry. In this investigation four different surfaces were applied to one 600 litre test vessel in a training brewery. Tests were carried out using two dimensional and three dimensional profilometry, replicating material and ATP swab tests to assess the presence of organic material. The tests were also used on vessels in the operational plants to assess the validity of the research findings.

The most important observations made are summarised by using graphic data compiled from the tests.

Surtronic stylus instrument was used to compare the expression of the roughness measurement with the visual appraisal of the surface. Ra is not considered a true reflection of the surface (the figures do not vary significantly between the different surfaces) but Rz (DIN) and Sm reflect the actual ‘look of the material’ more effectively, as the measurements differ more significantly over the range of surfaces. 2B finish is dull and electro-polished surface is ‘bright and shiny’. This is also shown on the AFM scans of these surfaces.

Ra and Sm Measurements Compared

Results were taken from readings from different levels of the surface of the test vessel during 4 weeks in 2001 and one set of samples in 2003 (Figs. 5.21).
Each of the surface finishes has had six readings, one at the start, four after each Brew & CIP in 2001 and the sixth on 15/4/2003. Each of these readings represents a different bar on the graph. The finishes are as follows: High Polish at the top ring, 2B, 240 & 120 Grit and Electro-polish at the top and middle of the vessel cylinder and Electro-polish at the cone.

There appears to be no significant change in the Ra measurements over 20 months.

Each of the surface finishes has had six readings, one at the start, four after each Brew & CIP in 2001 and the sixth on 15/4/2003. Each of these readings represents a different bar on the graph. The finishes are as follows: High Polish at the top ring, 2B, 240 & 120 Grit and Electro-polish at the top and middle of the vessel cylinder and Electro-polish at the cone.

There appears to be a slight increase in the Sm measurements over 20 months. This is not reflected in the Ra and Rz(DIN) measurements.

*Fig. 5.21 Comparison of Ra and Sm measurements*
Objective: Describe the methods to measure and inspect the surfaces

**AFM 2B surface**

**AFM Electro polished surface**

**AFM 240 grit polished surface**

**Fig. 5.22 Samples of AFM surfaces**

**Use of RepliSet to Assess the Surface in Conjunction with Optical Microscopy and AFM Techniques**

Surfaces from test and operational vessels were subjected to RepliSet samples and then viewed under the optical microscope (**Fig. 5.23**) and the AFM (**Fig. 5.22**).

**Fig. 5.23 Optical Photograph of RepliSet** taken from 220 grit surface
AtP Swab Investigation of Vessels in Operational Area and at the Test Vessel

The AtP swab results (Figs. 5.24 a, b and c) showed significant levels of organic material at the bottom of vessels as indicated in the section of Vessel Cleaning in Module Three.

![Diagram showing ATP swab results](image)

**Fig. 5.24 a) ATP swab test Plant A**

![Diagram showing ATP swab RLU values](image)

**Fig. 5.24 b) ATP swab test Plant B**
MODULE 5  
Objective: **Describe the methods to measure and inspect the surfaces**

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Stainless Steel surface finishes 
2B,120 & 240 grit and EP.

SAB TI ATP Swabs RLU

Temp probe upper

1000

Temp probe lower

100

240 EP

120 EP 240 2B

20.03.2003

Location on FV

Observations
• Upper surface area of vessel cylinder has low FTU
• Upper temperature probe has high FTU
• Lower surface area of vessel cylinder and cone show increase in FTU over upper area of cylinder.

Note 1. The results show the relevant difficulty of having a “clean” surface under the temperature probe.
Note 2. Lower cylinder and cone show lower hygiene levels, following same trend as 2 years ago when research started.

**Fig. 5.24 c) ATP swab test for Research Vessel**

**Appropriate Surface Roughness to Ensure Required Hygiene Standards**

The end users of equipment have to understand the importance of the surface roughness so that its impact on hygiene is appreciated.

To explain this, one can draw an analogy between the surface of equipment and the surface of the human skin (epidermis).

We understand that our skin is a membrane to the body:
➢ as we get older it changes and cracks;
➢ as we damage it through accidents or contamination, we allow infection into the body with possible serious consequences to our health;
➢ in order to maintain a hygienic state, we wash different parts of our body at different times of the day or night but the skin we have is the skin we wash.

If this analogy is used of the skin and its relative roughness (as measured), then there will be the following scenario in the process environment:
❑ the surface roughness of the equipment needs to be cleaned to maintain a ‘healthy process’;
❑ the surface roughness on the equipment changes over time due to mechanical or chemical attack: whatever the surface roughness is, it must be kept clean and must maintain its original state as best as possible to facilitate cleaning (and prevent corrosion).
❑ therefore, knowing the surface roughness allows end users to implement a cleaning process appropriate to their needs.
Summary

*Fig. 5.25* summarises the key aspects of inspection and measurement of the surface.

![Fishbone diagram of surface inspected and measured](image-url)