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To
DSG/SSG Specialist Inspectors,
AFQ Inspectors

SAFETY IN THE ELECTROPOLISHING OF LARGE VESSELS

This SIM provides details of a fatal accident that occurred whilst electropolishing th interior of a vessel and the safety precautions that should be followed to prevent recurrence.

BACKGROUND

1 The surface of cold rolled metal has a microscopic roughness after fabrication or pressing. This greatly increases the surface area of the workpiece and also provides areas for contaminants to attach, which can cause process difficulties particularly in the food, chemical and pharmaceutical industries. Electropolishing micro-smoothes the metal's surface by removing a very small amount of metal from the peaks of the surface profile. As well as providing a bright reflective finish this treatment also helps to improve the metal's corrosion resistance and reduce friction. Metals that can be electropolished include mild steel, stainless steel, copper, aluminium and chrome cobalt alloys. Of these, stainless steel is most commonly treated in this way. Many precious metals used as jewellery items also receive this treatment.

THE ELECTROPOLISHING PROCESS

2 The electropolishing process is essentially the reverse of electroplating. The workpiece is submerged in a specially formulated solution called the electrolyte through which an electric current is passed. This causes the surface of the workpiece to slowly dissolve adding metal ions to the solution, which are then deposited in the bath as a fine slurry of metal salt. The quantity of metal removed from the workpiece is proportional to the size of current applied and its duration.

3 The workpiece is connected to the positive (anodic) terminal of a direct current (DC) electrical supply. The workpiece (the positive conductor) and the negative (cathodic) conductor are then submerged in the electrolyte creating an electric circuit between the two terminals. The direct current supply is usually provided by a device

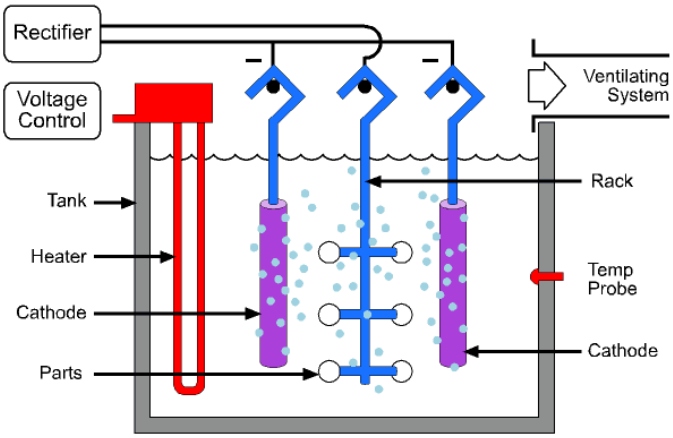

Figure 1: Typical Electropolishing Installation

called a rectifier, which converts an alternating current (AC) electrical supply to DC. Figure 1 illustrates a typical installation used to electropolish several parts at the same time. The exact composition of the electrolyte depends on the metal that is to be treated. However, typically a mixture of phosphoric acid, sulphuric acid and electrolyte additives will be used for ferrous metals.

4 Electropolishing in the UK is undertaken by a relatively small number of companies most of who are members of the British Stainless Steel Association (BSSA). The work can either be done in-house or on a subcontract basis, which can involve working on-site. Typically, the process involves treating small to medium sized workpieces immersed in open tanks of varying capacities. This can be carried out either manually or automatically. However, electropolishing can also be used to treat the internal surfaces of vessels too large to fit into a conventional electropolishing tank. In such cases the vessel itself acts as the electropolishing tank. This is a more hazardous process than immersion and requires a higher level of skill.

FATAL ACCIDENT

5 A fatal accident happened when a small, subcontracting company were electropolishing the interior of a 4,600 litre, stainless steel, process vessel. The vessel was 2 metres in diameter and had dished ends. It was the first time that the company had electropolished a vessel of this size most of their work involving electropolishing smaller items in immersion tanks.

6 The vessel was placed horizontally on rollers, and a large cathode array was assembled inside by suspending it from a central pole running the length of the vessel. Anode connections were attached to the outside of the vessel. Electrolyte consisting of a mixture of phosphoric acid, sulphuric acid and water was pumped into the vessel from the main processing tank until it was just over half full. The anodes and the cathode were both connected to a rectifier, which was set to approximately 2000 amps at 12 volts. Half the vessel was electropolished. It was then rotated through 180^{o} on rollers and the other half also treated. A pump was placed inside the vessel to empty the

electrolyte back into the main processing tank. The pump had been running for only a few seconds when an explosion occurred. As a result of the explosion one person died and another sustained chemical burns and partial loss of sight.

7 During electropolishing a small, but significant quantity of hydrogen is produced at the cathode and a smaller amount of oxygen is produced at the anode. An increase in the current used raises the temperature of the electrolyte resulting in an increase in the volume of hydrogen and oxygen generated (as shown in figure 2). Significant quantities of gas will also be produced if the gap between the anode and cathode is too large or if the electrolyte solution is too dilute.

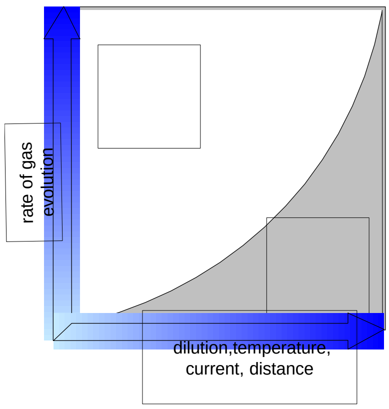

Figure 2: Gas evolution

8 During conventional electropolishing in open tanks the quantity of these gases produced, and the buoyancy of hydrogen when compared to the air present, means that an explosive concentration should not occur. However, when electropolishing takes place within the confines of a vessel, a potentially explosive concentration of hydrogen and oxygen in air can rapidly build up particularly if there is a lack of openings through which the gas can escape.

9 The vessel involved in the incident had only one unblocked opening. No steps were taken to prevent a build up of hydrogen or oxygen. The large volume of electrolyte used and the resulting need for a high current increased the volume of hydrogen and oxygen generated. The pump used to empty the vessel was not suitable for use in a flammable atmosphere.

SAFETY PRECAUTIONS

10 While there is an appreciation within the industry of the dangers of hydrogen generation, the full extent of this risk does not appear to have been recognised. Immediately after the accident there was evidence of some companies failing to adopt all the necessary safety precautions. The Engineering and Utilities Sector assisted the BSSA to circulate details of the incident and the required precautions to their members. However, when inspectors encounter this type of work either as part of an investigation or where it has been raised as a matter of concern (as described in OM 2002/2 *Addressing the HSC & FOD Priority Topics during inspection 2002/03*) they should verify, where appropriate that all necessary safe working practices are followed.

11 The Dangerous Substances and Explosive Atmospheres Regulations 2002 are due to come into force later this year and will apply to this type of work. They will make explicit the following safety precautions already required under existing legislation including the Management of Health and Safety at Work Regulations 1999 and the Health and Safety at Work etc Act 1974. Guidance on the Regulations will be contained within a forthcoming Approved Code of Practice.

12 Given the high risk nature of this type of work it is essential that a suitable and sufficient risk assessment is carried out. This should be completed prior to the work commencing and should be based specifically on the work that is planned. Written safe working procedures derived from the risk assessment should also be established. All relevant employees should be made fully aware of the hazards involved and fully trained in the safe working procedures. An adequate level of supervision should also be provided to ensure that the required precautions are followed.

13 The flammable range of hydrogen in air is 4-74%. To provide a suitable margin of safety the hydrogen content within vessels should be kept below 0.4%. The first step in achieving this should be to try and reduce the quantity of hydrogen and oxygen that is generated for example, by using the lowest current required. In the case of a large vessel this can be achieved by electropolishing the ends of the vessel before they are welded in place. This then enables the vessel to be electropolished horizontally using a small volume of electrolyte and hence a lower current. Powered rollers (which can be hired) continually rotating the vessel ensures the effective distribution of the electrolyte over the vessel's internal circumference. The vessel should rotate around a stationary cathode.

14 When a similar vessel to the one involved in the accident was electropolished using the above method, a current of 500 amps (25% of that used in the incident) and an electrolyte 125 mm deep were sufficient. Inspectors should note however, that even with these parameters a measurable quantity of hydrogen and oxygen was produced. When the mechanical exhaust ventilation in use was temporarily switched off, the concentration of these gases rapidly moved into the flammable range. The actual current used and the quantity of electrolyte required will vary according to circumstances and the required specification.

15 It is essential that air is either forcibly fed into the vessel or the hydrogen and air mixture is extracted. Ideally, both measures will be adopted for example by feeding air into the rear of the vessel whilst extracting from the front. The need for such action should be identified as part of the risk assessment before the work commences. This then enables the necessary equipment to be made available.

16 Where localised extraction is used the ventilation rates will need verification to ensure they are sufficient to maintain the volume of hydrogen below 0.4% (see para 13). This can be achieved for example by gas monitoring during the work using the power supply's maximum power input to simulate a worst case scenario. Alternatively, the amount of hydrogen that is produced for the maximum power input can be calculated and this figure then used to establish the required ventilation rates. As the ventilation is crucial to maintaining the volume of hydrogen below safe levels it should be interlocked

with the power supply. If the ventilation is either not switched on or if it goes off electrolysis will either be prevented or stopped. An alternative control measure is to use continuous gas monitoring to warn of unsafe levels of hydrogen.

17 The risk assessment should also identify all possible sources of ignition and how to safeguard against them. This should include consideration of hydrogen's very low ignition energy and the impact that any build up of oxygen may have. Possible ignition sources include electrical sparking from the internal cathode or any other piece of unprotected electrical equipment, eg lights, pumps, fans, etc, and static electrical discharges from synthetic textiles.

18 Any equipment used, including electrically operated fans, must be designed for use in a flammable atmosphere. In particular due to the explosive properties of hydrogen gas only certain types of protected electrical equipment should be used where hydrogen is likely to be present. The Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations 1996 come fully into force from 1 July 2003 and require that equipment and protective systems intended for use in explosive atmospheres meet specified health and safety requirements before being placed on the market or put into service. The regulations apply to both electrical and mechanical equipment and place duties principally upon suppliers of equipment. However, where a user either makes their own equipment to be used in an explosive atmosphere or imports such equipment from outside the European Union, they have to meet the requirements of the regulations as if they were the manufacturer. Under the Provision and Use of Work Equipment Regulations 1998 reg.10 employers also have a general duty to ensure that an item of work equipment to be used in an explosive atmosphere meets the 1996 Regulations.

19 Where reasonably practicable electrical equipment should not be used in a potentially flammable atmosphere. In the case of electric pumps this can be achieved by placing the motor associated with the pumping process outside the flammable atmosphere thereby removing the risk of ignition. If the pump or any other item of electrical equipment has to be located within the hazardous zone then it should be selected, installed and maintained in accordance with British Standard series (BS) EN 60079 *Electrical apparatus for explosive gas atmospheres*. Conformity with such a standard ensures that only suitable electrical equipment is used in zones where explosive or flammable atmospheres are found. Any other standard, which provides for an equivalent level of safety may alternatively be used.

20 As the electropolishing process involves the use of acids a suitable and sufficient assessment should be made of the associated risks to health and appropriate precautions established. In particular, suitable personal protective equipment (PPE) should be provided. As a minimum the PPE worn should be as detailed on the safety data sheet, typically this will consist of rubber or neoprene gauntlets, rubber apron and boots and chemical safety goggles or a full face shield. All PPE should be certified as suitable for use with the chemical components of the electrolyte. Contaminated PPE should be washed before reuse or storage. An emergency shower and suitable means of washing the eyes should also be provided. Emergency procedures should also be established to deal with any acid spills that may occur.

21 Entry inside the vessel is likely to be necessary, for example to assemble/disassemble the cathode. As there is the potential for harmful fumes to be present inside the vessel, any such access should comply with the requirements of the Confined Spaces Regulations 1997. See OC 288/7 for further details.

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