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COMMON CORROSION PROBLEMS IN THE BREWERY SECTOR

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ABSTRACT

By means of several case histories, the paper describes some often observed corrosion problems at breweries both on the process and utility side, e.g. corrosion problems related to tank manufacturing, transport and on-site erection, welding of stainless steel pipes, CIP and disinfection procedures, glycol systems and carbon dioxide recovery systems.

Keywords: Breweries, Corrosion, Fatigue, Transport, Welding, CIP, Disinfection, Glycol, Carbon Dioxide

INTRODUCTION

It is the authors' experience that corrosion is a very common problem at many breweries and that this with surprisingly small variations concerns practically all brewery companies and all regions of the world. As a matter of fact, in the "food" production industry the brewery sector is probably the sector that suffers most severely from corrosion. It is the authors' assessment that the main reason for this is that the brewery sector is a conservative and extremely price-conscious industry which is reluctant to pay for what it considers to be unnecessary quality control of the "hardware". Moreover, in contrast to another very conservative and extremely price-conscious industry, such as the pharmaceutical sector, the breweries face less compulsory requirements for regular inspection and documentation of "good" quality. Consequently, this priority results in a tendency to buy cheap when designing and ordering new equipment, and to allocate insufficient funds to systematic maintenance of operating equipment. The case histories described in this paper are by no means an exhaustive description of all the corrosion problems that occur at breweries. However, the case histories were selected because they deal with corrosion problems that have been observed at many breweries.

CASE HISTORIES

Case # 1 Tank Manufacturing, Transport and On-site Erection

Tank manufacturing involves several sub-task issues, e.g. selection of dimension, design, steel type and grade, welding requirements, surface treatment and finish, NDT control. Moreover, many decisions have to be taken about packaging, transport, on-site erection and final cleaning etc. The preparation of requested documentation material including all the listed issues plus for instance the compulsory approval of equipment for pressure purposes can also be a rather comprehensive and time-consuming task.

For an experienced tank manufacturer, neither of the aforementioned sub-tasks should present challenges beyond the achievable. However, there are plenty of possibilities to commit errors. From experience three of the high-risks situations are a tank manufacturer hard pressed for time, transport from the tank manufacturer to the brewery and the use of an insufficient qualified sub-contractor for the on-site erection of the tank.

Figures 1-2 show a very annoying situation where a rolling defect was discovered in an AISI 316L tank. Unfortunately, the pictured rolling defect was just one of many identical defects in the coil from which the tank was made and none of the defects were observed until the protective plastic foil was removed just prior to completion of the tank. However, the authors are aware of more cases where such defects were detected at an even later stage, e.g. after the process equipment had been put into operation by the end-user.

Figures 3-4 show corrosion in an AISI 304 bright beer tank. Rust runs (stripes of reddish corrosion products) with a vast number of pits were present from the top of the tank and downwards. The distribution of rust runs and pits showed that the tank once in a horizontal position had suffered corrosion due to exposure to a corrosive fluid. Based on the history of the tank, it was evident that the corrosive fluid was seawater that had entered the tank when the tank was shipped as deck cargo. The extent and severity of corrosion was aggravated because the tank after shipping had been stored in a horizontal position at the brewery for quite some time before it was erected.

The great majority of the pits were of a shallow nature, typically 0.1-0.2 mm. Nevertheless, many pits were so deep that they could not be removed completely by grinding without thinning the material below the minimum required wall thickness. Consequently these pits had to be opened to the healthy material by milling with a "diamond miller" such that the depressions looked like semicircles/semiellipses. The depressions were repair welded, then a comprehensive amount of grinding work was needed to reestablish a smooth surface in accordance with the specification $Ra \leq 0.6$ µm. Figures 5-6 show the magnitude of the repair work.

Figure 7 shows severe pitting in an AISI 304 cold water tank caused by lack of final surface treatment of a weld between the tank shell and a flat iron used for attachment of the inlet pipe. Moreover, pitting was also observed in a heat tinted area on the tank shell as a result of lack of post-treatment after external welding of support for a rectangular hollow section. The tank was manufactured and transported to the brewery as a “high” quality product whereupon the on-site mounting of the tank at the brewery was performed by an insufficiently qualified sub-contractor. Unfortunately, this is a very common case history as in many projects the price-incentive is the all-important criterion for selection of local sub-contractors.

Case # 2 Welding of Stainless Steel Pipes

Pitting in the heat affected zones (HAZ) of stainless steel pipes as a consequence of welding with an inadequate supply of purging gas and/or a lack of appropriate final surface treatment (pickling) after welding (figure 8) is a corrosion problem that occurs in many sectors. However, the brewery sector is one of the sectors that suffers most severely from this corrosion problem quite simply because the decision-makers often prefer for economical reasons vaguely formulated requirements for welding quality and/or specify an insufficiently amount of NDT control to follow up on the quality of the delivered pipe systems. By comparison, it is the authors’ general opinion that the dairy sector suffers less corrosion problems in this area than the brewery sector because the dairy sector on average has stricter and more specific requirements to the welding quality and the amount of NDT control to be performed.

It is worth noting that from a technical point of view it is an easy task to avoid these corrosion problems, e.g. by stipulating a general welding quality corresponding to level B, EN 5817 plus some additional requirements such as no pores and straw yellow as the maximum heat tint level (see level C in figure 9). It is of course also necessary to specify - and in practice also undertake - a sufficiently amount of adequate NDT control, e.g. video endoscopy (figures 10-11). By use of such welding requirements (or comparable requirements such as ASME BPE-2005, AWS 18.2 etc.) and a very thorough NDT control (often 100% video endoscopy), the pharmaceutical sector has almost totally eliminated these corrosion problems.

Case # 3 CIP and Disinfection of Stainless Steel Equipment

At breweries, a cleaning in place (CIP) process usually involves several water flushes (pre-flush, intermediate flushes and a final flush) plus an alkaline and an acidic cycle. Generally, the alkaline cycle is performed with 0.5-2.0 % w/w sodium hydroxide (NaOH) at 60-80 ºC whereas the acidic cycle is performed with 1.0-2.0 % w/w phosphoric acid (H_3PO_4) or nitric acid (HNO_3) at ambient temperature. The cycle times may vary a lot. Generally 15-30 minutes for each cycle is the most prevalent practice but cycle times ranging from 10-100 minutes is not unusual.

Unless exceptionally harmful circumstances occur, the aforementioned CIP processes do not represent a corrosion risk for standard austenitic stainless steel grades such as AISI 304 and AISI 316. However, “common” examples of such circumstances are tank implosions caused by vacuum as a result of rapid thermal changes or rapid pump-out, pitting corrosion caused by residues of CIP acid trapped for extended periods on dirty surfaces etc. These so-called “exceptionally harmful circumstances” do in fact occur surprisingly often.

At breweries, disinfection is not an integrated part of the regular CIP system. While CIP of all process equipment is performed very often in accordance to the current production, disinfection is performed regularly with significantly longer intervals or as an ad hoc decision in case of microbiological problems. In the latter case, disinfection is usually limited to minor parts of the process equipment.

Generally, the disinfection process is undertaken by use of an oxidizing disinfectant, e.g. hypochlorite (OCl^-), chlorine dioxide (ClO_2), peracetic acid ($CH_3C(=O)OOH$), hydrogen peroxide (H_2O_2) etc. Depending on the actual disinfection parameters such as the choice of disinfectant, disinfectant concentration, quality of mixing water, temperature, contact time etc., the disinfection process can be everything from very corrosive to non-corrosive towards stainless steel. Nevertheless, it is the authors' experience that in order to carry out disinfection processes that satisfy the hygienic requirements it is more often than not necessary to enter a "dangerous" operating range where there is a strong thermodynamic driving force for corrosion initiation. In these cases we have to rely on a short disinfection time (contact time) and a subsequently very thorough water rinse in order not to cross the kinetic borderline for corrosion initiation.

Figures 12-13 show severe pitting in an AISI 304 buffer tank in an aseptic bottling line. The brewery had for quite a long time been fighting microbiological problems ("bad" CFU numbers) by use of several different disinfectants such as iodophor, per-acetic acid, hypochlorite etc. The tank had thousands of critical pits (deep and undercut). Thus, it was no surprise that the brewery at last realized it was fighting a losing battle and decided to replace the tank.

Case # 4 Failure Investigation of Cracks in Cooling Jackets in Yeast Storage Tanks

Six yeast storage tanks (YSTs) were put into operation immediately after they were delivered ten years ago. The cooling jackets were made from stainless steel type AISI 304. The YSTs, insulated with polyurethane foam, were placed outside in a humid climate where temperatures were up to 40 °C. The cooling medium in the cooling jackets was propylene glycol. The inlet and outlet temperatures were approximately –2 °C and +10 °C respectively.

It was reported that the cooling jackets in two of the six YSTs were leaking due to the presence of cracks in the knuckled areas of the dimples. Unfortunately, the leaks had been repair welded just prior to the on-site inspection of tanks (figure 14). However, a sample had been "spared" for metallurgical examinations; see the cut out-procedure described in table 1.

The failure investigation was undertaken by use of the following procedures and techniques:

1. Visual inspection and stereo microscopy
2. Scanning electron microscopy (SEM)
3. Light optical microscopy (LOM)

The received parts of the dimple plates (figure 15), which were colored with remaining residues from a dye penetrant test, were cleaned with a mild alkaline detergent in an ultrasonic bath. Neither the internal nor the external sides of the dimple plates suffered from corrosion attacks like pits or general corroding of surfaces. A test using a magnet revealed that the regions with the cracks, i.e. the knuckled areas of the dimples, were greatly strain hardened. The internal sides of the dimple plates were investigated using stereo microscopy and this revealed that there were some places, where two crack tips had not made contact with one another during their propagation.

A crack was opened so the surface of a fracture could be studied; see mark 3 on figure 15. Of those cracks that did not penetrate through the plate, about 95 % were initiated from the internal side and the remainder from the external side. In addition, many steps ("notches") were observed on the fractured surface. The many steps ("notches") on the fractured surface show that there have been many crack initiating sites.

Scanning electron microscopy was also utilized to study a fractured surface. In addition to the features seen in the stereo microscope, beach marks (“crack-arrest lines”) that propagated from the internal side were also observed (figure 16). At about half of the plate thickness, the cracks met each other. Thus a single crack has been created, so the crack finally broke through the plate over a long distance at the same time. At a greater magnification, these cracks were observed to be transcrystalline. At very high magnifications, striations showing fatigue were observed (figure 17). The curvature of the beach marks, the presence of striations on the fracture surface and the unbranched course of the cracks are all strong indications of fatigue initiated predominantly from the internal side.

The fracture surface of a crack tip was also investigated; see the circle marked at cut 1 on figure 15. If a ductile fracture was present, it may have indicated that the stress hardening had lowered the ductility unacceptably with respect to fatigue resistance. However, no signs of ductile rupture were seen.

In order to investigate the structure of the steel as well as the propagation of cracks, a microsection was prepared, see cut 2 on Figure 15. All cracks were unbranched and localized to the knuckled area of the dimple, where strain hardening was highest. The large crack from the internal side indicates that the damage has mainly been initiated from this side. The absence of parallel cracks on the internal side is due to the stress relieving effect of the rapidly growing large crack. Electrolytical etching of the microsection in chromic acid showed that the steel was rolled and had a normal austenitic structure (figure 18). All these observations substantiated that fatigue initiated from the non-corrosive environment at the internal side was the cause of failure.

Based on the clear result of the failure investigation, the brewery made a further damage investigation with focus on pressure pulsations. It turned out that the regulating of cooling medium to the cooling jackets of the six YSTs was controlled by use of six valves on six parallel pipelines coupled to one pump. The pump had insufficient capacity when cooling requirements were highest thus causing fluctuating pressure.

Case # 5 Investigation of Corrosion in Carbon Dioxide Recovery Plant

Figure 19 shows an overall sketch of the carbon dioxide recovery plant. In a few words, the plant consists of seven operating steps:

1. A foam trap that removes any foam carried over from the fermentation tanks. For water saving purposes the foam trap reuses the water from the water scrubber.
2. A water scrubber that removes all impurities from the CO_2 which are soluble in water. These are primarily alcohols but also to some extent aldehydes and other oxygenates.
3. A balloon that acts as a capacity controller for the compressor and allows the plant to operate at all capacities between 0 and 100 % without frequent start/stop of the compressor.
4. A CO_2 V-compressor that compresses the raw gas from atmospheric pressure to 15…20 bar in two stages. The compressor is a non lubricated compressor securing a total oil-free product.
5. An activated carbon filter that removes the remaining smelly substances such as acetates, aldehydes and sulphur components. The filter is regenerated by means of steam or hot air and double mounted to allow regeneration of one filter while the other is in operation.
6. A dehydrator that removes water down to less than 10 ppm. The dehydrator is regenerated by means of electric heating elements and waste gas from the CO_2 condenser and double mounted to allow regeneration of one vessel while the other is in operation.
7. A refrigeration unit that supplies the necessary cold(ness) to liquefy the CO_2. Basically, the refrigeration unit consists of a CO_2 condenser where the CO_2 is liquefied at a temperature of approximately –25 °C and a refrigerant compressor which sucks the refrigerant from the CO_2 condenser and compresses it to approximately 14 bar. The compressor is typically a two stage piston compressor (small plants) or a one or two stage screw compressor (large plants).

The investigation was performed because the brewery had reported several leaks in the stainless steel pipe arrangement (AISI 304) on the CO_2 compressor's gas side (figures 20-21).

The compressor was dismantled and it was seen that the gas side of the compressor suffered substantial uniform corrosion. Furthermore, the piston and the cylinder lining also showed signs of wear and mechanical damage (see figure 22). The valve casings were covered with corrosion products (figure 23).

Some of the leaking stainless steel pipe sections were cut out for further investigations. Thereafter the pipe sections were cut open lengthways whereupon the internal sides could be studied visually and using stereo microscopy (figure 24). Severe pitting corrosion initiated from the gas side was observed.

If process water (treated with chlorine dioxide at the actual brewery), despite the demister between the water scrubber and the CO_2 compressor, had entered the CO_2 compressor as aerosols, this could explain the observed corrosion scenario. Besides carbon dioxide, the fermentation gas contains hydrogen sulphide and various hydrocarbons but no chlorine. Energy dispersive X-ray fluorescence (XRF) analyses of the corrosion products on the pipe sections detected the presence of chlorine and sulphur. This proved that the process water, at least periodically, had entered the system.

In order to avoid this corrosion risk in the future, the brewery decided to install a local activated charcoal filter to treat the process water just before the inlet to the water scrubber.

SUMMARY

The cases demonstrate the advantages of "thinking" corrosion at an early stage in project management. Moreover, the cases demonstrate the advantages of undertaking a thorough failure investigation of damaged equipment in order to establish the cause of failure and thereby select the correct remedy. In this way, many prospective problems can be avoided, e.g. unforeseen downtime due to operating trouble or even breakdown. In addition, many unprofitable discussions can be avoided.

TABLE 1.
PROCEDURE FOR CUTTING OUT DIMPLE PLATE-SAMPLES FOR METALLURGICAL EXAMINATIONS

1	It is important that the cutting out of samples be made as cold and lenient as possible, e.g. by careful use of a small cutter or a hollow drill.
2	It is recommended to make a circular cut a good distance away from the dimple between the jacket and the tank bottom and subsequently – in one movement – break-off the sample.
3	Weld in a replacement dimple – preferably supplied by the tank manufacturer.

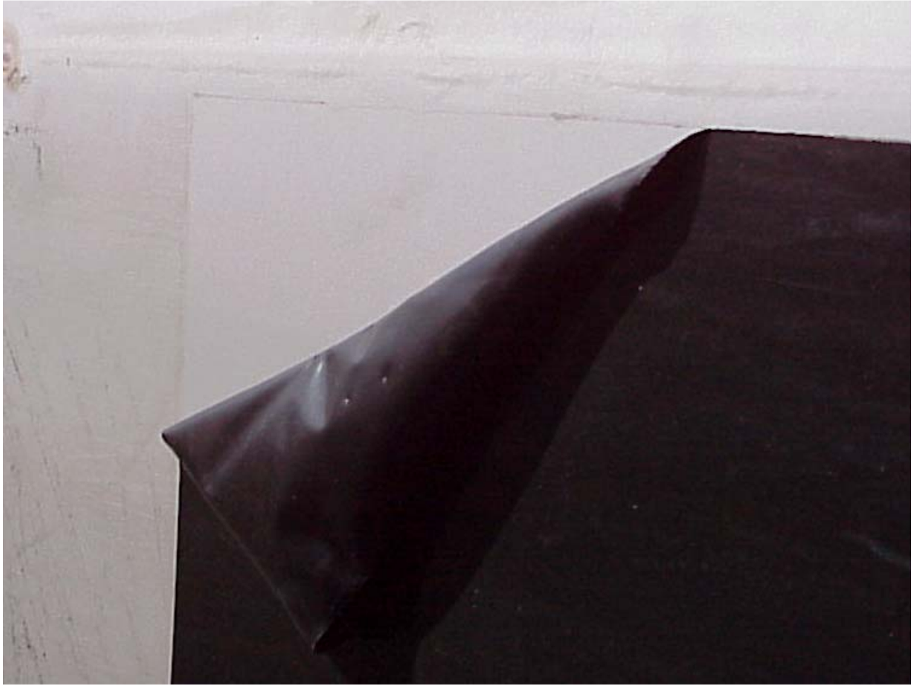

FIGURE 1 – Protective plastic foil on a stainless steel sheet.

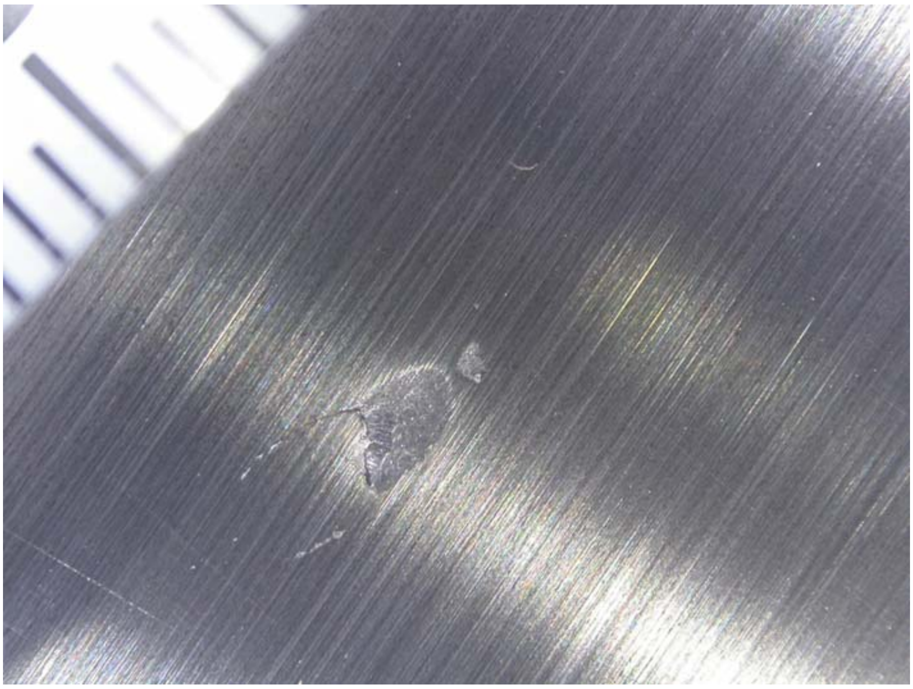

FIGURE 2 – A rolling defect in an AISI 316L sheet. Unfortunately, the pictured rolling defect was just one of many identical defects in the coil from which the tank was made. None of the defects were observed until the protective plastic foil was removed just prior to the completion of the tank.

FIGURE 3 – Rust runs with a vast number of pits were present from the top of the AISI 304 bright beer tank and downwards. The distribution of rust runs and pits showed that the tank once in a horizontal position had suffered corrosion due to exposure to a corrosive fluid (which later turned out to be seawater).

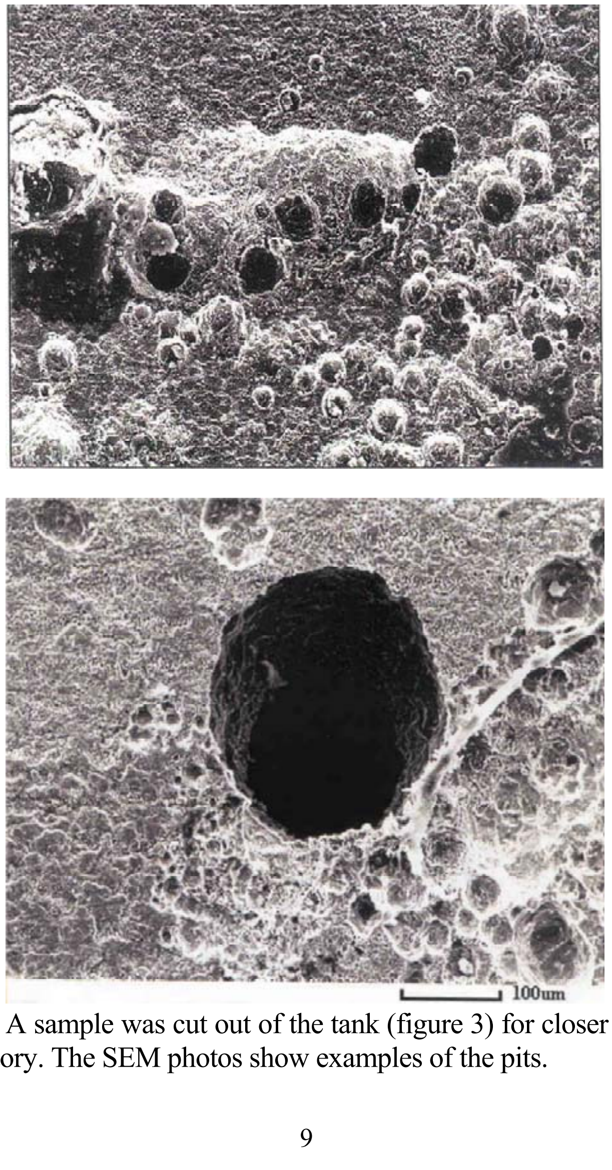

FIGURE 4 – A sample was cut out of the tank (figure 3) for closer investigation in the laboratory. The SEM photos show examples of the pits.

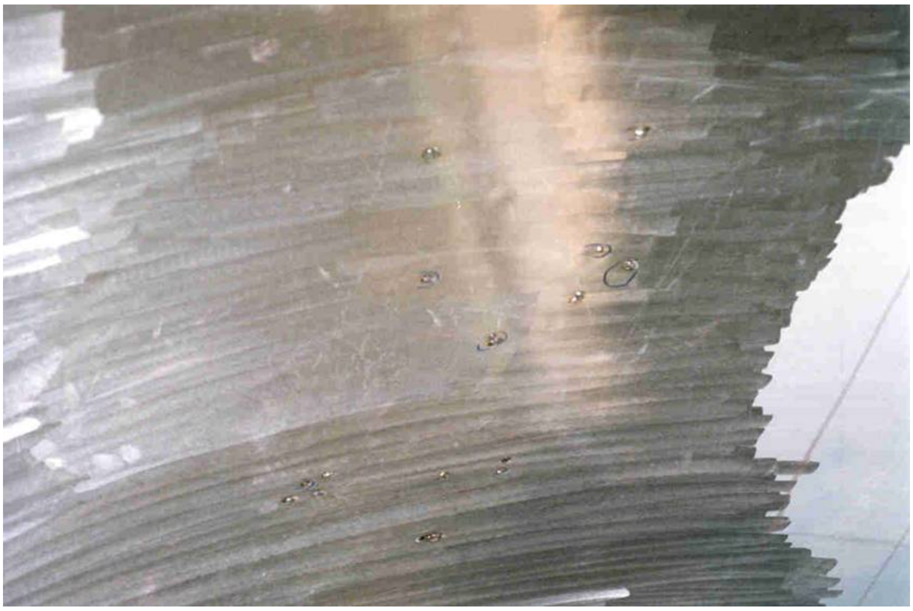

FIGURE 5 – Many pits were so deep that they could not be removed completely by grinding without thinning the material below the minimum required wall thickness. Consequently it was necessary to perform repair welding.

FIGURE 6 – Overview photo showing the magnitude of the repair work.

FIGURE 7 – Severe pitting in an AISI 304 cold water tank caused by lack of final surface treatment of the weld between the tank shell and the flat iron used for attachment of the inlet pipe. Moreover, pitting was also observed in a heat tinted area on the tank shell as a result of lack of post-treatment after external welding of support for a rectangular hollow section.

FIGURE 8 – Pitting in the HAZ of an AISI 316 tube characterized by heat tint. In this case where the root geometry is “reasonable”, pickling would have been an adequate surface treatment to re-establish the corrosion resistance.

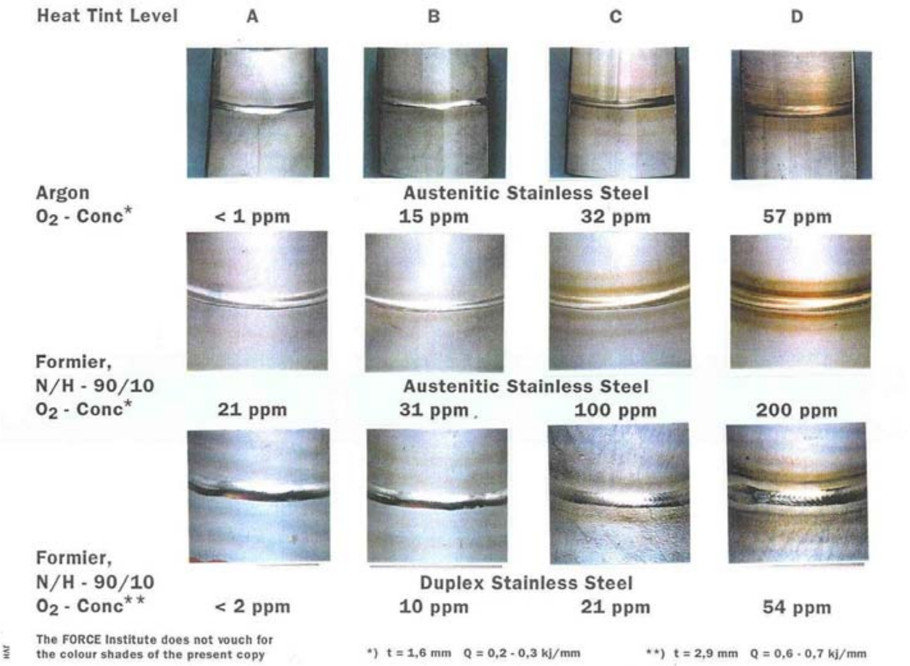

FIGURE 9 – Reference atlas for heat tint (FORCE report 94.34).

FIGURE 10 – Flexible video-endoscope.

FIGURE 11 – No heat tint, slight heat tint and heavy heat tint.

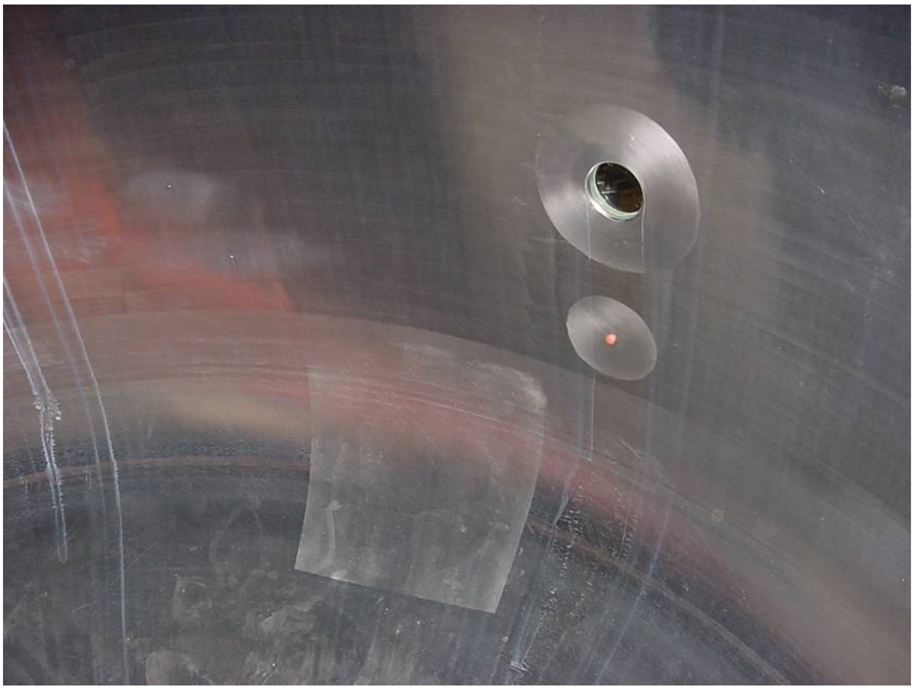

FIGURE 12 – Severe pitting in an AISI 304 buffer tank in an aseptic bottling line. The brewery had for quite a long time been fighting microbiological problems by use of several different disinfectants such as iodophor, per-acetic acid, hypochlorite etc.

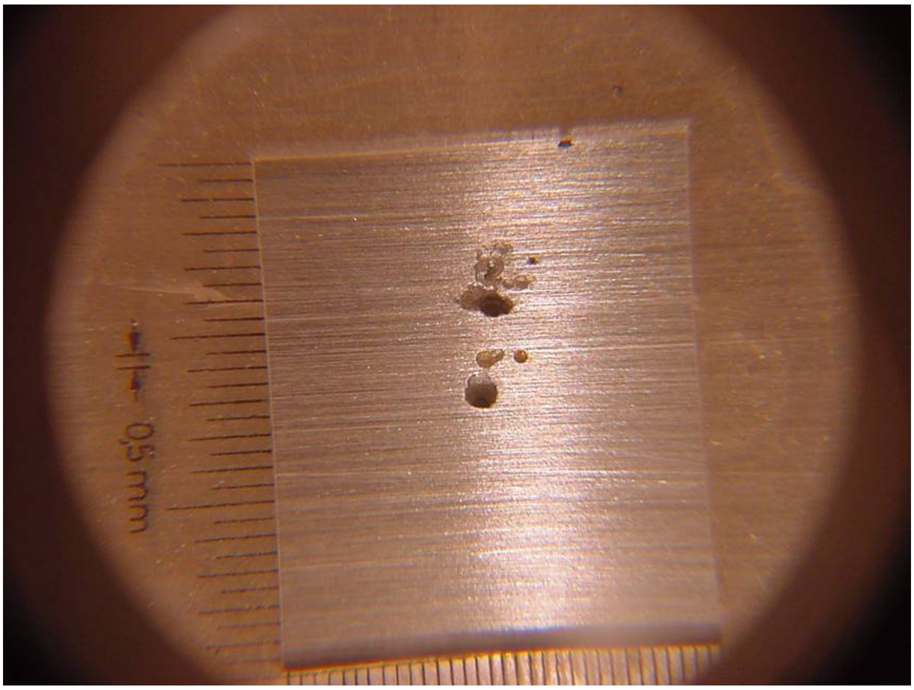

FIGURE 13 – The AISI 304 tank (figure 12) had thousands of critical pits (deep and undercut).

FIGURE 14 – Overview of the bottom of the yeast storage tank after removal of the insulating material. The great majority of the repair-welded dimples were observed in clusters. Unlike the original welds at the dimples between the jacket and the tank bottom, it seemed that the repair welding had been performed using filler material.

FIGURE 15 – Macrograph of damaged dimple plate with the internal side of cooling jacket uppermost. Crack was opened at position 3 so fractured surface could be studied. At cut 2, a microsection was taken. Magnification 2x.

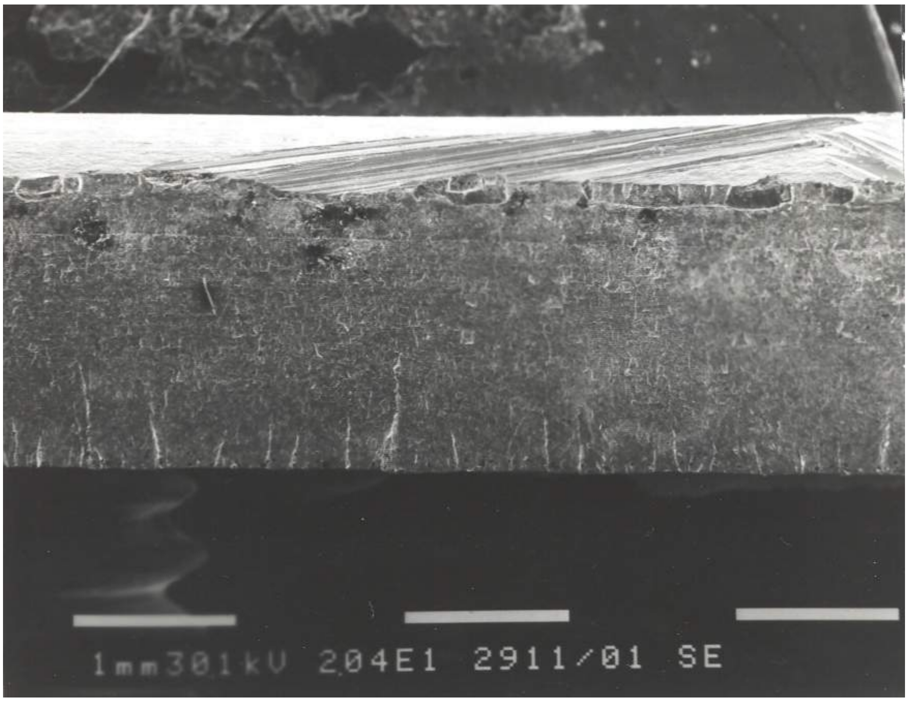

FIGURE 16 – SEM-micrograph of part of the fractured surface (see mark 3 on figure 15) with internal side of the cooling jacket at the bottom of the micrograph. Note the presence of beach marks and steps (“notches”). Magnification 20.4x.

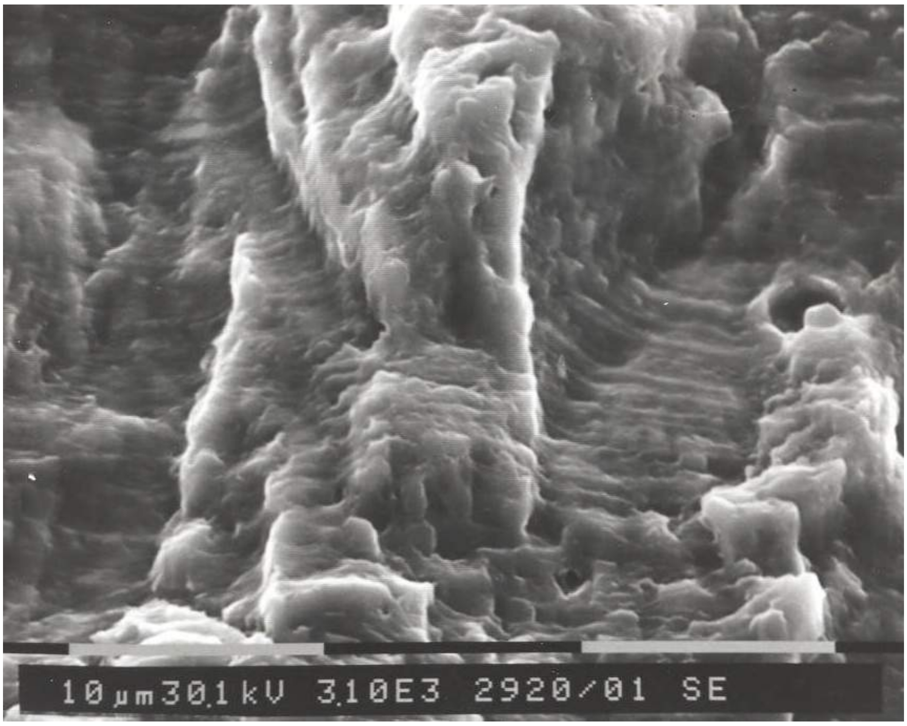

FIGURE 17 – SEM-micrograph at high magnification of fractured surface on figure 16. Note the presence of striations. Magnification 3100x.

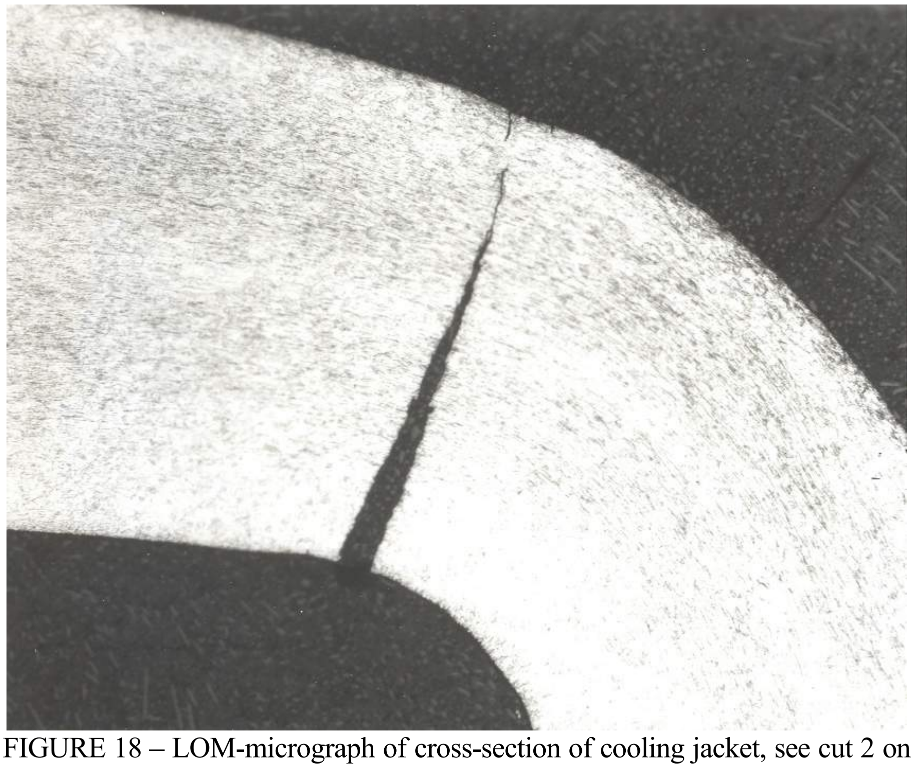

FIGURE 18 – LOM-micrograph of cross-section of cooling jacket, see cut 2 on figure 15. The cracks are localized to the knuckle area of the dimple. The large crack enters from the internal side of cooling jacket. Magnification 3100x.

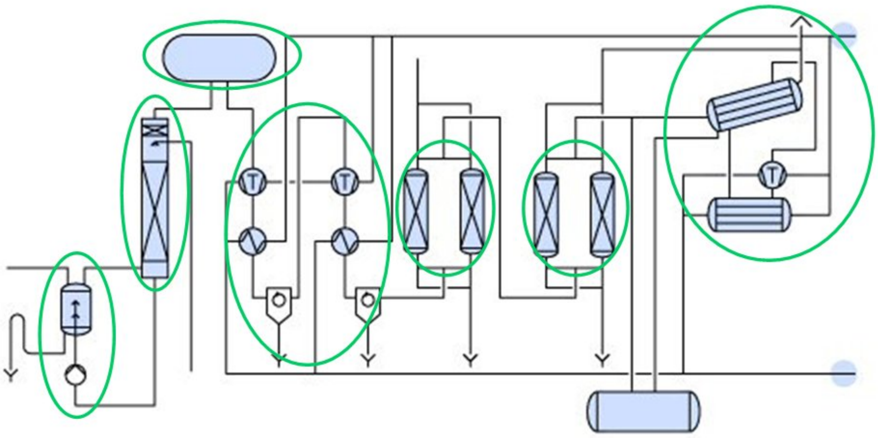

FIGURE 19 – The carbon dioxide recovery plant consists of seven operating steps; a foam trap, a water scrubber, a balloon, a CO_2 compressor, an activated carbon filter, a dehydrator and a refrigeration unit.

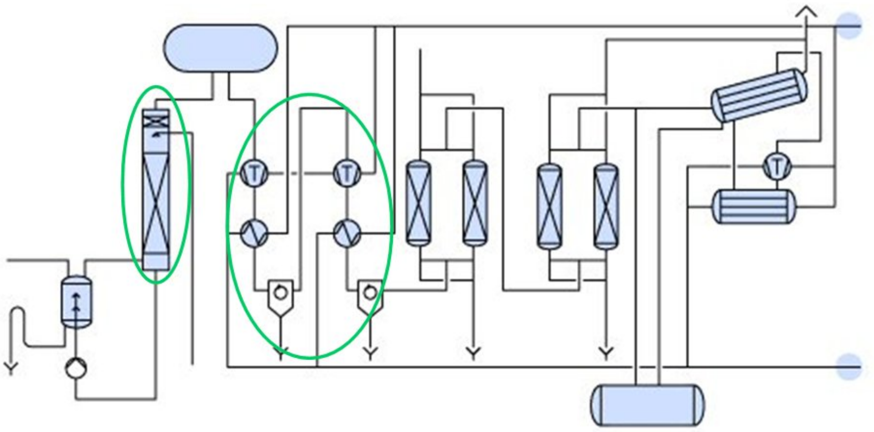

FIGURE 20 – The two circles mark the water scrubber (left) and the CO_2 compressor (right), i.e. the two operating steps in the carbon dioxide recovery that turned out to be of significant importance for the investigation.

FIGURE 21 – Overview photo of the CO_2 compressor that was subject for the investigation.

FIGURE 22 – The V-compressor was dismantled and it was seen that the gas side of the compressor suffered substantial uniform corrosion. Furthermore, the piston and the cylinder lining showed signs of wear and mechanical damage.

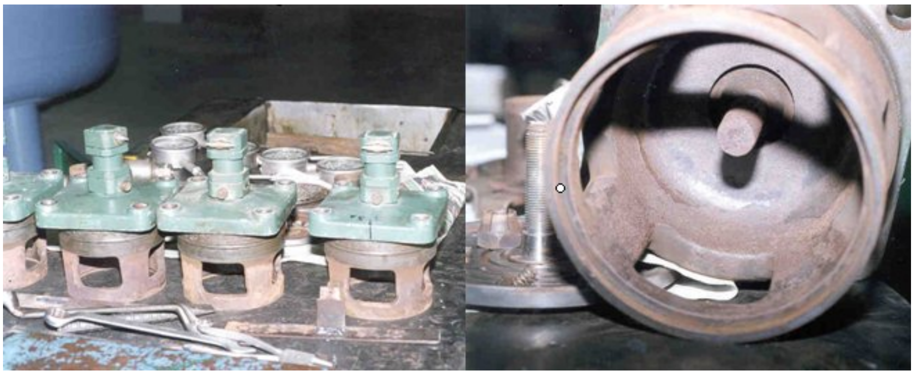

FIGURE 23 – Valve casings dismounted from the V-compressor. The valve casings were covered with corrosion products.

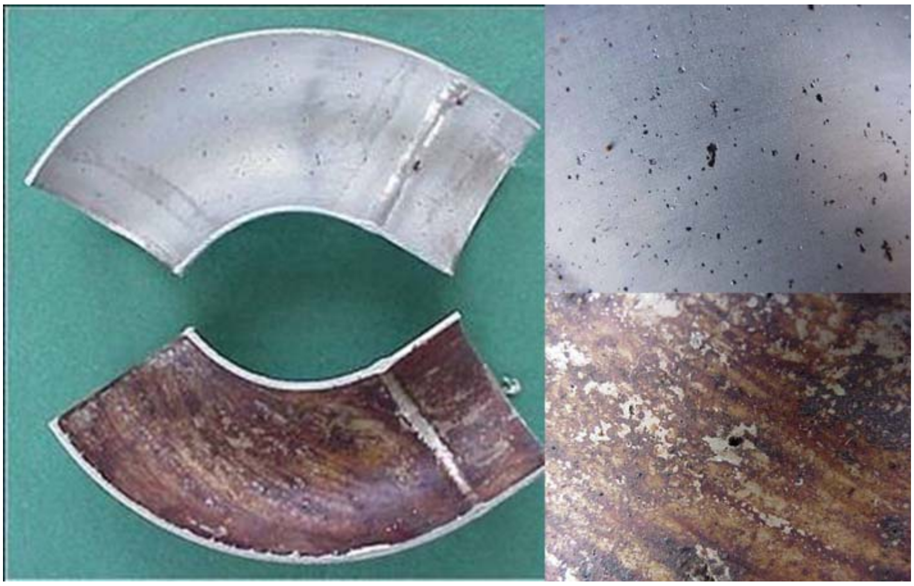

FIGURE 24 – The photos show the cut open piping (after cleaning at the top) between the 2nd stage separator and 2nd stage compressor. Severe pitting corrosion initiated from the gas side was observed.