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Effect of Cleaning Detergents on the Corrosion Resistance of AISI 420 Stainless Steel during Surgical Instrument Reprocessing

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ABSTRACT: Objective To evaluate the resistance to localized corrosion of AISI 420 martensitic stainless steel used in surgical instruments when exposed to different cleaning detergent solutions. **Methods** An experimental laboratory study was conducted using AISI 420 stainless steel specimens. Corrosion behavior was evaluated by cyclic potentiodynamic polarization, in accordance with ASTM G61-86 (2024). Tests were performed in three solutions: alkaline detergent, enzymatic detergent, and disinfectant detergent, prepared in distilled-deionized water. Electrochemical measurements were carried out in a three-electrode cell with a saturated Ag/AgCl/KCl reference electrode at 40 ℃, simulating automated washer-disinfector conditions. Surface morphology after testing was analyzed using scanning electron microscopy. **Results** Higher resistance to localized corrosion was observed in alkaline conditions. The alkaline detergent showed stable passivation, absence of pitting potential, and high transpassive potential (E_{transp}=1.200 V±0.016). The disinfectant detergent also demonstrated relatively high corrosion resistance, with elevated crevice potential ($E_{crevice}$= 1.056 V±0.078), although localized attack was observed under crevice conditions. In contrast, the enzymatic detergent, with near-neutral pH, exhibited lower corrosion resistance, characterized by a defined pitting potential (E_{pit}=0.835 V±0.049) and positive hysteresis. Surface analysis confirmed the presence of pitting and crevice corrosion in enzymatic and disinfectant solutions. These findings highlight the importance of detergent selection in preserving surgical instrument integrity and preventing corrosion during reprocessing.

KEY WORDS: Stainless steel; Corrosion; Surgical instruments; Detergents; Central sterile supply department; Cyclic potentiodynamic polarization

1 Introduction

Surgical instruments are commonly manufactured from iron (Fe)-based metal alloys containing at least 10.5% chromium (Cr), known as stainless steels. This minimum chromium content enables the formation of a protective passive layer on the material surface, reducing the surface's reactivity and enhancing corrosion resistance[1].

According to the American Iron and Steel Institute, stainless steels are classified into different groups based on their microstructure and chemical composition[2-3].

Among these, the AISI 400 series is widely used in the manufacturing of surgical instruments due to its favorable mechanical properties[2-3].

AISI 420 martensitic stainless steel, containing approximately 12% chromium and 0.35% carbon, ex-

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hibits a martensitic microstructure characterized by high hardness and mechanical strength[3-4].

These characteristics make it suitable to produce surgical instruments such as bone rongeurs, forceps, chisels, curettes, scissors, retractors, and scalpels[3-4].

Corrosion is defined as the deterioration of metallic materials resulting from electrochemical or chemical interactions with the surrounding environment, which may also be influenced by mechanical stresses[5-15].

Among the various forms of corrosion, pitting corrosion is considered one of the most aggressive types of localized attack in passive metals such as stainless steels, often leading to structural failure during clinical use[7-9].

Pitting corrosion is characterized by the formation of localized cavities of variable depth, which can compromise the structural integrity of the material[5,8].

This phenomenon is strongly associated with acidic environments and the presence of chloride ions, commonly found in physiological fluids as well as in the water used during cleaning and sterilization processes in Central Sterile Supply Departments (CSSDs)[8,12].

In this context, the cleaning process plays a critical role in preserving the integrity of surgical instruments. The type of detergent used, especially its pH, may significantly influence corrosion behavior and contribute to the prevention of premature degradation[11,13].

Therefore, this study aims to analyze the resistance to pitting corrosion of AISI 420 martensitic stainless steel used in surgical instruments when exposed to solutions containing three commonly used types of detergents: alkaline, enzymatic, and disinfectant.

2 Experimental sections

2.1 Materials

This experimental study was conducted at the Electrochemistry and Corrosion Laboratory, Department of Chemical Engineering, Polytechnic School, University of São Paulo.

Laminated AISI 420 martensitic stainless-steel sheets were used as specimens, with dimensions of 3.0 cm×5.0 cm and a thickness of 2.0 mm, presenting a matte surface finish.

The chemical composition specifications of AISI 420 stainless steel used in this study are presented in Table 1, according to ASTM F899-20[3].

2.2 Methods

All electrochemical tests were conducted in accordance with ASTM G61-86 (2024), which standardizes cyclic potentiodynamic polarization (CPP) measurements for the evaluation of localized corrosion susceptibility[14].

The electrochemical tests were performed using a three-electrode cell (Fig. 1) positioned inside a Faraday cage (Fig. 2) to minimize external electromagnetic interference.

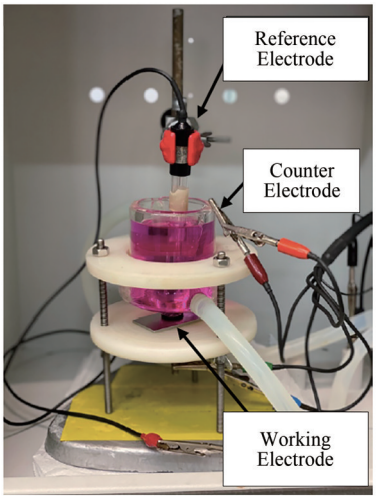


Fig. 1 Electrochemical cell used in this study

The electrochemical system was connected to a potentiostat (Gamry, Reference 600), as illustrated in Fig. 2.

The cyclic potentiodynamic polarization (CPP) technique was employed to evaluate susceptibility to localized corrosion[14,16].

Table 1 Chemical composition specification of AISI 420 stainless steel (mass %) used in this study.

Stainless steel	Carbon (C)	Manganese (Mn)	Phosphorus (P)	Sulfur (S)	Silicon (Si)	Chromium (Cr)	Nickel (Ni)
AISI 420	0. 16~0. 25	1. 00 max.	0. 04 max.	0. 030 max.	1. 00 max.	12. 00~14. 00	1. 00 max.

Source: ASTM F899-20[3].

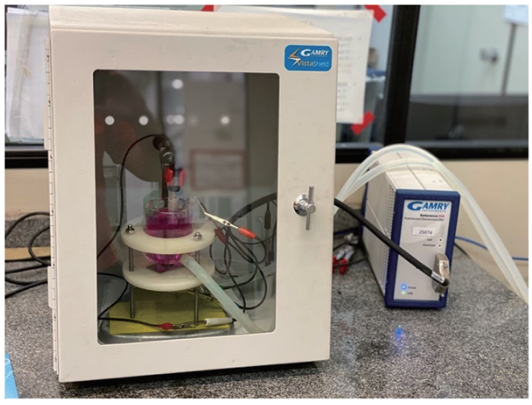


Fig. 2 Electrochemical cell inside the Faraday cage and potentiostat used in this study

The polarization curve was initiated at the open-circuit potential (OCP). As the anodic potential increased, the material could enter an active corrosion region (not observed in this study), followed by a decrease in current density associated with passive film formation occurring at the primary passive potential (Flade potential)[14-15].

According to ASTM G61-86 (2024), the stabilization time required to achieve a steady OCP was 3,600 s. As anodic polarization progressed, the current density increased sharply at a critical potential, which may be associated either with oxygen evolution due to water decomposition or with passive film breakdown leading to localized corrosion.

The region related to oxygen evolution is defined as the transpassive region, and the corresponding potential is referred to as the transpassive potential (E_{transp})[14,16].

The potential scan rate adopted in this study was 0.16 mV/s, and the threshold current density for reversing the scan direction (from anodic to cathodic) was set at 3 mA/cm², in accordance with ASTM G61-86 (2024)[14].

The interpretation of CPP curves depends on the material and electrolyte conditions, requiring careful analysis[15,18].

All tests were performed in duplicate. In cases of non-reproducibility, additional tests were conducted until consistent results were obtained.

Variability may occur due to crevice formation beneath the rubber O-ring during cell assembly.

One representative polarization curve was selected for graphical representation.

All experiments were carried out in a three-electrode electrochemical system at a controlled temperature of 40°C, simulating cleaning conditions in automated washer-disinfectors used for surgical instruments.

The working electrode consisted of AISI 420 stainless steel, the reference electrode was Ag/AgCl/KCl (saturated), and a platinum foil (7 cm² exposed area) was used as the counter electrode.

The pH of the solutions was measured before and after the tests using a pH meter (Gehaka®, Model PG1800).

The electrolyte solutions for the experimental groups were prepared as follows:

A) **Alkaline detergent group**: 1 mL of alkaline detergent diluted in 1 L of distilled-deionized water.

B) **Enzymatic detergent group**: 1 mL of enzymatic detergent diluted in 1 L of distilled-deionized water

C) **Disinfectant detergent group**: 10 mL of disinfectant detergent diluted in 990 mL of distilled-deionized water

At the end of the CPP tests, the specimen surfaces were documented using a digital camera and further characterized by scanning electron microscopy (SEM) to analyze surface topography.

SEM images and energy-dispersive X-ray spectroscopy (EDS) analyses were obtained using a Tescan Vega 3 microscope equipped with an Oxford Instruments® EDS system (PentaFET Precision®).

2.3 Statistical Analysis

Descriptive statistics were used to summarize electrochemical parameters, including mean values and standard deviations.

No inferential statistical tests were performed due to the experimental and exploratory nature of the study and the limited number of replicates (n=3).

A formal design of experiments (DoE) approach was not applied, as the study aimed to comparatively evaluate the influence of different detergent types on electrochemical behavior.

The independent variable was the type of deter-

gent, while the response variables included pitting potential (Epit), passive current density, and other electrochemical parameters derived from cyclic potentiodynamic polarization curves.

3 Results

The corrosion resistance of AISI 420 martensitic stainless steel in alkaline detergent solution, evaluated by cyclic potentiodynamic polarization (CPP), is shown in Fig. 3.

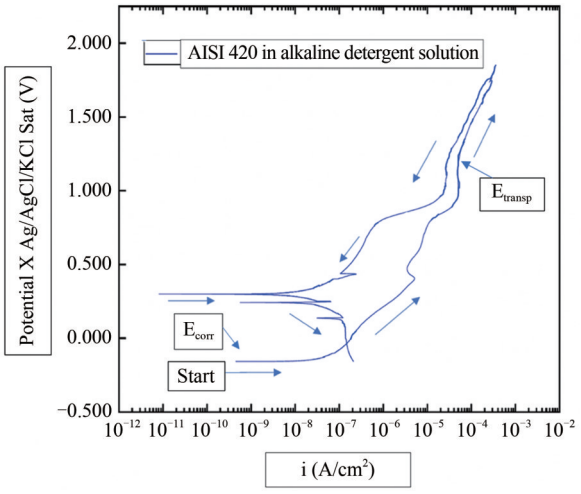


Fig. 3 Cyclic potentiodynamic polarization curve for AISI 420 martensitic stainless steel in alkaline detergent solution

According to the polarization curves (Fig 3), the mean corrosion potential (E_{corr}) was −0.128 V (SD=0.040 V vs Ag/AgCl/KCl sat). As anodic polarization progressed, a stable passive region with low current density was observed.

At higher potentials, a sharp increase in anodic current density occurred, associated with oxygen evolution (transpassive region), rather than passive film breakdown.

No pitting potential (E_{pit}) was identified. The reverse scan exhibited lower current densities than the forward scan, characterizing negative hysteresis, which indicates the absence of pitting corrosion.

The mean transpassive potential (E_{transp}) was 1.200 V (SD=0.016 V vs Ag/AgCl/KCl sat). Surface analysis after polarization (Fig. 4A and Fig. 4B) did not reveal evidence of localized corrosion.

No localized corrosion features were observed (Fig. 4A and Fig. 4B), confirming the high corrosion resistance of AISI 420 stainless steel under alkaline conditions.

The pH values measured before and after testing were 11.00 and 11.20, respectively, indicating minimal variation.

The corrosion behavior in the enzymatic detergent solution is presented in Fig. 5.

The mean corrosion potential (E_{corr}) was 0.067 V (SD=0.024 V vs Ag/AgCl/KCl sat), and the mean pitting potential (E_{pit}) was 0.835 V (SD=0.049 V vs Ag/AgCl/KCl sat).

The polarization curves exhibited positive hysteresis, indicating susceptibility to localized corrosion.

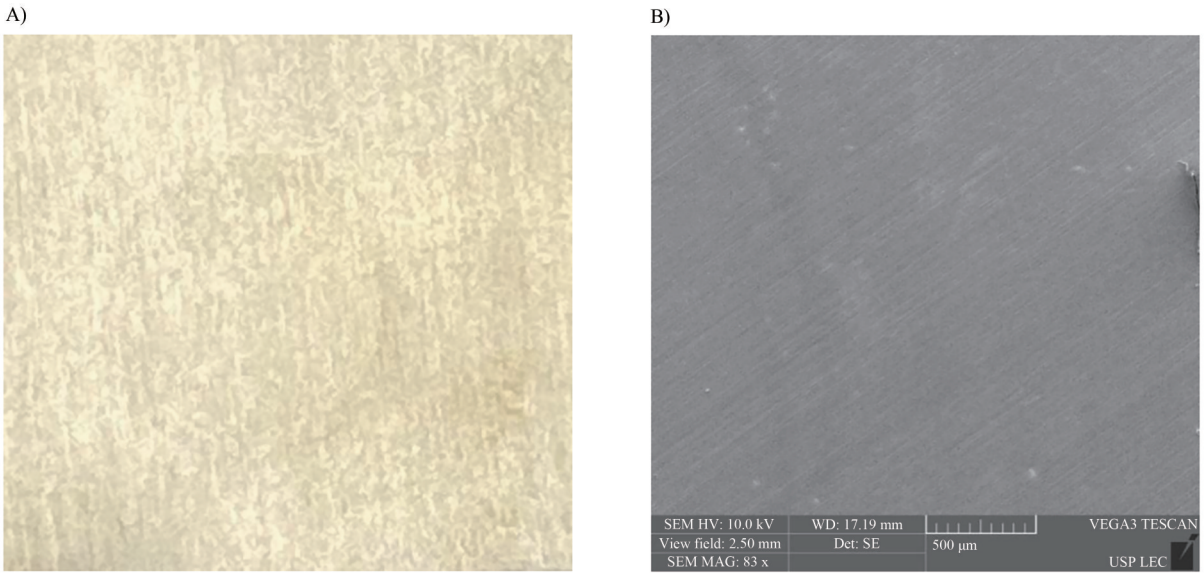


Fig. 4 Digital camera (A) and SEM (B) images of AISI 420 stainless steel after cyclic potentiodynamic polarization (CPP) testing in an alkaline detergent solution

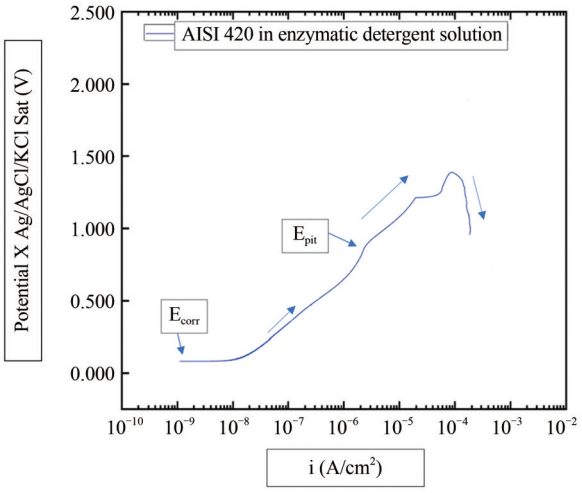


Fig. 5 Cyclic potentiodynamic polarization curve for AISI 420 martensitic stainless steel in enzymatic detergent solution

Higher current densities were observed during the reverse scan, suggesting pit propagation and limited repassivation. Surface analyses (Fig. 6A–C) confirmed the presence of pitting corrosion.

Crevice formation beneath the O-ring was also observed (Fig. 6A and Fig. 6B), which may have influenced the measured E_{pit} values.

The range of the solution pH is 6.93 to 7.05, which remains near neutral conditions. The CPP results for the disinfectant detergent solution are shown in Fig. 7.

The mean corrosion potential (E_{corr}) was 0.001 V (SD=0.011 V vs Ag/AgCl/KCl sat). The mean crevice potential ($E_{crevice}$) was 1.056 V (SD=0.078 V vs Ag/AgCl/KCl sat).

The polarization curves exhibited positive hysteresis, indicating localized corrosion under crevice

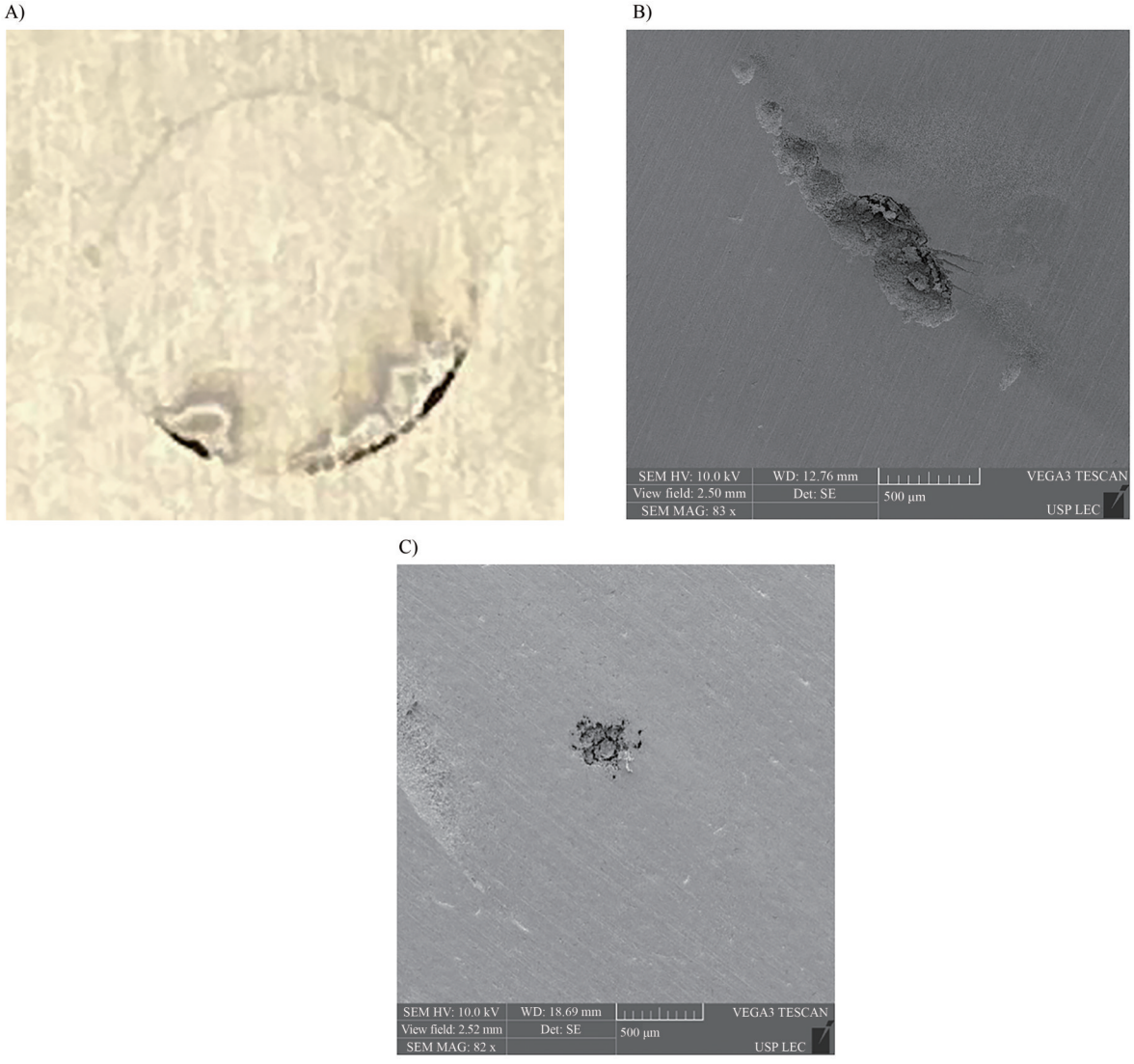


Fig. 6 Digital image (A) and SEM images (B, C) of AISI 420 stainless steel surface after cyclic potentiodynamic polarization (CPP) testing in an enzymatic detergent solution

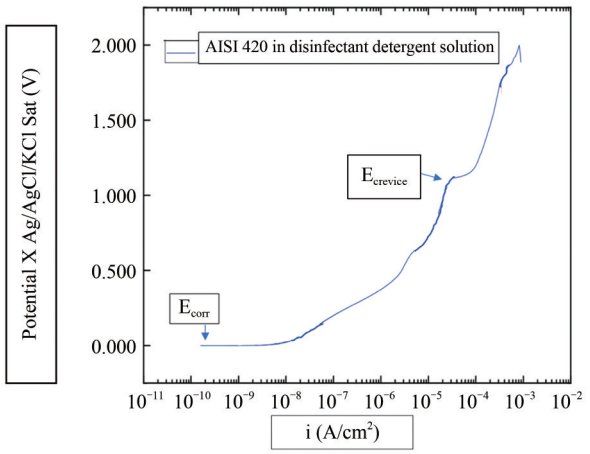


Fig. 7 Cyclic potentiodynamic polarization curve for AISI 420 martensitic stainless steel in disinfectant detergent solution

conditions.

Surface analysis after testing (Fig. 8A and Fig. 8B) confirmed the presence of crevice corrosion, particularly in regions associated with the O-ring.

The measured pH values ranged from 10.19 to 10.40, with minimal variation.

The electrochemical parameters obtained from CPP tests are summarized in Table 2, allowing direct comparison of corrosion behavior across the evaluated cleaning solutions.

Distinct corrosion responses were observed depending on the detergent type and pH conditions.

The alkaline solution exhibited stable passivation with no evidence of localized corrosion, whereas the enzymatic and disinfectant solutions showed susceptibility to pitting and crevice corrosion, respectively.

These differences highlight the influence of chemical composition and solution characteristics on the corrosion resistance of AISI 420 stainless steel.

The implications of these findings, particularly in relation to cleaning processes in Central Sterile Supply Departments (CSSDs), are further discussed in the following section.

4 Discussion

Alkaline detergents showed a protective effect

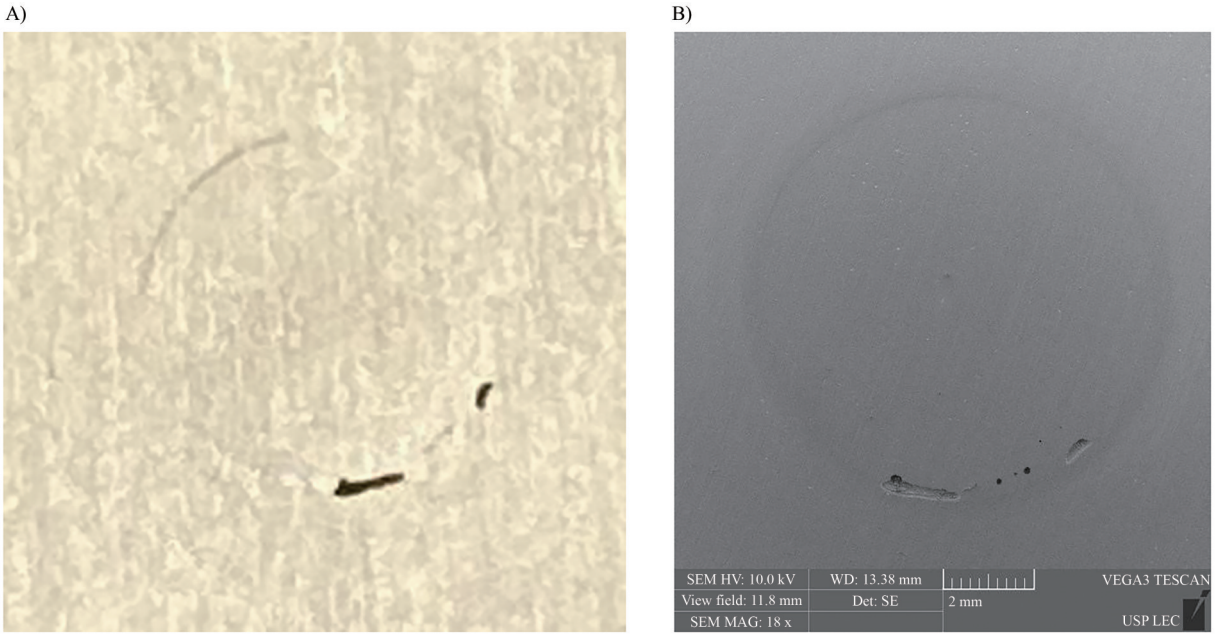


Fig. 8 Digital camera (A) and SEM (B) images of AISI 420 stainless steel after cyclic potentiodynamic polarization testing in a disinfectant detergent solution

Table 2 Summary of electrochemical parameters obtained from CPP tests

Solution	E_{corr} (V)	E_{pit} (V)	E_{transp} (V)	$E_{crevice}$ (V)
Alkaline detergent	−0. 128±0. 040	—	1. 200±0. 016	—
Enzymatic detergent	0. 067±0. 024	0. 835±0. 049	—	—
Disinfectant detergent	0. 001±0. 011	—	—	1. 056±0. 078

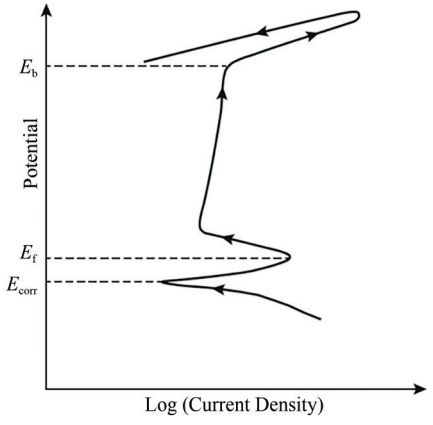
Note: (—) indicates that the parameter was not identified under the experimental conditions. All potentials are expressed in volts (V) versus Ag/AgCl/KCl (saturated) reference electrode.

against corrosion of AISI 420 stainless steel, which may be attributed to their high pH values (pH≈ 11~12).

Although previous literature suggests that highly alkaline detergents may damage the passive layer and promote corrosion[18], the results obtained in the present study demonstrated the opposite effect, indicating enhanced corrosion resistance under alkaline conditions.

Cyclic potentiodynamic polarization (CPP) analysis provides important insights into corrosion behavior, particularly through the interpretation of hysteresis in polarization curves[16-17]. As illustrated in Fig. 9 and Fig. 10, two types of hysteresis can be identified: negative and positive.

Negative hysteresis (Fig. 9), observed when the current density in the reverse scan is lower than that of the forward scan at the same potential, indicates stable passivation and effective repassivation of the metal surface.

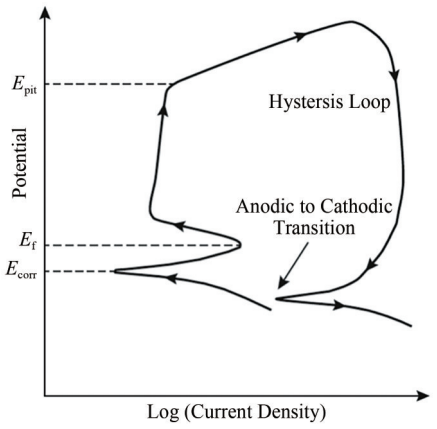


Source: Adapted from [16].

Fig. 9 Schematic representation of a cyclic potentiodynamic polarization (CPP) curve showing negative hysteresis and oxygen evolution at E_b

In contrast, positive hysteresis is characterized by higher current densities in the reverse scan and is associated with passive film breakdown and localized corrosion, such as pitting or crevice corrosion.

The results were interpreted based on electrochemical behavior and the reproducibility of polarization curves, in accordance with the ASTM G61-86 (2024) standard for cyclic potentiodynamic polarization measurements for the evaluation of localized corrosion susceptibility in iron-, nickel-, or cobalt-based alloys.



Source: Adapted from [16].

Fig. 10 Schematic representation of a cyclic potentiodynamic polarization (CPP) curve showing positive hysteresis and pitting corrosion at E_{pit}

Although electrochemical testing conditions may differ from clinical reprocessing environments, the use of cyclic potentiodynamic polarization in accordance with ASTM G61-86 (2024) provides a standardized and widely accepted approach for assessing susceptibility to localized corrosion.

This method enables controlled evaluation of pitting and crevice corrosion, which are critical for understanding material performance under simulated conditions.

Therefore, despite the simplifications inherent to laboratory studies, the methodology adopted in this study provides reliable and reproducible data for the comparative analysis of the effects of different detergents on the corrosion resistance of AISI 420 stainless steel used in surgical instruments.

In the present study, the CPP curves obtained in alkaline detergent solution (Fig. 3) exhibited negative hysteresis, confirming the absence of pitting corrosion and indicating a stable passive film.

In this medium, no pitting potential (Epit) was observed, and the transpassive potential reached high values (Etransp=1.200 V vs Ag/AgCl/KCl sat), indicating excellent corrosion resistance.

The disinfectant detergent, which also presented alkaline pH conditions (pH≈10~12), showed relatively high resistance to corrosion, with elevated crevice potential values (Ecrevice=1.056 V vs Ag/AgCl/KCl sat).

However, unlike the alkaline detergent, the polarization curves exhibited positive hysteresis (Fig. 7), indicating localized corrosion under crevice conditions, as confirmed by SEM analysis (Fig. 8).

Regarding the applicability of the findings, the use of laminated AISI 420 stainless steel specimens represents a controlled model for investigating corrosion behavior.

Although surgical instruments present more complex geometries and surface finishes, AISI 420 stainless steel is widely used in their manufacturing, as specified by international and national standards such as ASTM F899-20, which define its application in surgical instruments.

Therefore, the material selected in this study can be considered representative of clinically relevant substrates.

The results obtained provide meaningful insights into the inherent corrosion behavior of AISI 420 stainless steel, supporting the extrapolation of findings to surgical instruments subjected to routine reprocessing in clinical settings.

AISI 420 stainless steel is known to be susceptible to crevice corrosion under specific conditions [10], which is consistent with the observations in this study.

The presence of crevices, particularly in regions associated with the O-ring, likely contributed to localized attack, even in less aggressive environments.

In contrast, the enzymatic detergent, which presented near-neutral pH conditions (pH≈7), showed lower corrosion resistance, with a measurable pitting potential (E_{pit}=0.835 V vs Ag/AgCl/KCl sat) and clear evidence of positive hysteresis (Fig. 5).

This behavior indicates susceptibility to localized corrosion, which was confirmed by SEM analysis showing the presence of pits on the material surface (Fig. 6).

The relationship between pH and corrosion resistance is well established, as alkaline environments tend to stabilize the passive film of stainless steels, promoting passivation and reducing corrosion rates[13,19]. In electrochemical terms, higher values of E_{pit} or $E_{crevice}$ are associated with greater resistance to localized corrosion.

Previous studies have also reported corrosion issues associated with enzymatic detergents used in surgical instrument reprocessing.

Rodrigues et al. [19] observed pitting corrosion in AISI 420 stainless steel instruments exposed to enzymatic detergents, with variation in E_{pit} values attributed to differences in chemical composition and the presence of aggressive ions, such as chlorides.

Additionally, Xu et al.[13] demonstrated that repeated cleaning cycles using alkaline detergents may improve corrosion resistance by promoting chromium enrichment in the passive film.

From a practical perspective, the selection of cleaning detergents plays a critical role in preserving the integrity of surgical instruments, minimizing corrosion-related damage, and ensuring patient safety in Central Sterile Supply Departments (CSSDs)[20-21].

The present findings indicate that alkaline detergents may represent an effective strategy to reduce the risk of localized corrosion in AISI 420 stainless steel.

However, detergent selection should not be based solely on corrosion performance, and attention must be given to formulation characteristics, including surfactants, additives, and chemical stability, as well as to proper reprocessing protocols[20-21].

Detergents are designed to reduce surface tension and facilitate the removal of organic matter through the action of wetting and emulsifying agents[20-21].

On the other hand, inadequate detergent performance may contribute to the fixation of organic residues or insufficient cleaning, potentially compromising subsequent sterilization processes[20-21].

Therefore, the selection of cleaning detergents should consider both cleaning efficacy and their impact on material integrity.

In addition, factors such as rinsing ability, corrosiveness, cytotoxicity, foam formation, residual odor, and environmental impact should also be considered.

The adoption of objective parameters to guide these decisions is essential, as reliance solely on cost or marketing information may lead to suboptimal

choices.

Establishing standardized evaluation criteria within institutions may enhance decision-making processes and contribute to improved patient safety and instrument preservation.

In the context of the present findings, this broader perspective reinforces the importance of selecting detergents that not only ensure adequate cleaning but also minimize corrosion risks, supporting a comprehensive and evidence-based approach to detergent selection in CSSDs.

Beyond chemical aspects, institutional policies related to the procurement of surgical instruments should prioritize quality standards over cost considerations, ensuring that materials comply with specifications necessary to withstand repeated cleaning and sterilization cycles.

Overall, the findings of this study demonstrate that AISI 420 martensitic stainless steel exhibits greater resistance to localized corrosion in alkaline detergent solutions compared to enzymatic formulations.

While both alkaline and disinfectant detergents showed relatively high corrosion resistance, localized corrosion phenomena such as pitting and crevice corrosion were observed in enzymatic and disinfectant environments, respectively.

From a practical perspective, the use of alkaline detergents may represent an effective strategy to enhance the durability of surgical instruments and improve safety in CSSDs.

4.1 Implications for practice, education, and research

The findings of this study highlight the importance of selecting detergents that not only ensure effective cleaning but also preserve the integrity of surgical instruments.

The protective effect observed for alkaline detergents suggests their potential to reduce corrosion and enhance patient safety in CSSDs.

From an educational perspective, these results reinforce the need for training healthcare professionals on the relationship between cleaning agents and material durability.

Future research should investigate the long-term effects of repeated cleaning cycles, variations in detergent composition, and their impact on different grades of stainless steel used in surgical instruments.

4.2 Strengths and limitations

This study presents important strengths, including the use of standardized electrochemical methods (ASTM G61-86)[14] and the simulation of cleaning conditions relevant to CSSDs, particularly regarding temperature and detergent exposure.

The combined use of cyclic potentiodynamic polarization and surface characterization techniques (SEM/EDS) provided a comprehensive evaluation of corrosion behavior.

However, there still exist some limitations that should be considered. The study was conducted under controlled laboratory conditions, which may not fully reproduce the complexity of clinical reprocessing environments.

Additionally, factors such as water quality, detergent formulation variability, and the cumulative effects of repeated cleaning cycles were not assessed.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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