Sulphamic Acid Corrosion Inhibition: A review

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Abstract. Sulphamic acid solutions are frequently employed in industrial equipment cleaning, descaling, and other processes, such as acidizing low-temperature carbonate reservoirs. Several researchers have reported the inhibition of corrosion of different metals and alloys in sulphamic acid using inhibitors like tryptophan, olive leaf, azo dyes, chitosan, Juniperus, cystine, s-containing amino acids, etc. Sulphamic acid is soluble in water and is classified as a strong inorganic acid in solution. Still, its corrosiveness is significantly lower than other acids, such as sulphuric acid and hydrochloric acid. Sulphamic acid and inorganic acid cleaners based on sulphamic acid are used extensively in diversified cleaning applications. They are superior to other mineral acids due to lower corrosion rates and the absence of corrosive fumes evolution. For this reason, mild and stainless-steel cleaning employs sulphamic acid. Nevertheless, the application of sulphamic acid in industrial cleaning is only partially without its drawbacks, as the cleaning action usually leads to dissolution and loss of base metals. Industrial practice includes adding corrosion inhibitors to minimize equipment corrosion damage. The current review paper summarises recent research on sulphamic acid corrosion inhibition. It summarizes the various corrosion inhibitors employed to mitigate corrosion in various pieces of equipment made of metals or metal alloys exposed to sulphamic acid in different conditions. The researchers employed weight loss, electrochemical methods, and surface characterizations. In literature and practice, the usual concentration of sulphamic acid for cleaning is 5 – 10 wt. % at a temperature range of 55 – 65 ℃. The inhibition efficiencies observed varied from 84 – 97.3 %. The examinations include studies of the effects of temperature, concentration, immersion time, and stirring velocity.

INTRODUCTION

Utilizing corrosion inhibitors is crucial, especially when performing industrial cleaning procedures involving very corrosive and aggressive acidic solutions, such as acid descaling, pickling, cleaning, and oil well acidification (Bhatt et al., 2021; Verma et al., 2018). Corrosion is the physical degradation of pure metals, and their alloys caused by environmental, chemical, and/or electrochemical processes (Reza et al., 2021). Other factors contributing to corrosion are solution activity, surface contaminants,

temperature, and pressure (Hossain *et al.*, 2020). Mild steel is extensively used in energy, food, chemical, and oil industries machinery and construction materials due to its comparatively lower cost and outstanding mechanical qualities, such as toughness and durability, despite its proclivity to corrode in natural environments, particularly acid solutions (Jawad *et al.*, 2019; Miralrio and Vazquez, 2020). Corrosion is a global issue due to the rapid development of industrial technology and its widespread adoption due to globalization. Assets like vehicles, industrial machinery, railway bridges, and houses are all subject to structural damage due to corrosion. Industries have created a variety of corrosion prevention techniques to prevent this loss. Since they are inexpensive, highly adaptable, easy to use, and economical, corrosion inhibitors are among the techniques that have found acceptance and are widely utilized in a variety of industries (Hossain *et al.*, 2020). In various contexts, various types of material degradation have been addressed. Additionally, other novel strategies and techniques have been developed to combat these dangerous occurrences caused by well-known elements. These include sealants, protective coatings, defensive bushings, and cathodic/anodic protection. The use of corrosion inhibitors, however, was found to be the mildest and simplest method of averting the degradation of metals and alloys in corrosive conditions, according to the results of studies on anti-corrosion applications in the sectors above (Kadhim *et al.*, 2021). Compared to sulfuric and hydrochloric acids, sulphamic acid is one of the most stable and least corrosive acids, frequently used to clean ferrous alloys. This is especially true for cleaning mild and stainless steels, where there is little risk of chloride-

accelerated corrosion. As a result, this acid may occasionally be used to clean iron artifacts (Baymou *et al.*, 2018). This study reviews current literature regarding corrosion inhibition in Sulphamic acid medium.

Overview of Corrosion and Its Economic Relevance

Corrosion is the deterioration of metals and alloys caused by chemical or electrochemical contact with their surroundings. Wet and dry corrosion are two categories used to differentiate corrosion reactions based on the types of corrosive conditions. Corrosion can also be categorized into general, crevice, galvanic, pitting, intergranular, de-alloying, erosion, and environmentally induced fracture corrosion, depending on the morphology of metal degradation. There are several ways to prevent metal corrosion. They include cathodic and anodic protection, coating, alloying, the addition of inhibitors, and the recent trend of utilizing lasers. In addition, using laser by surface treatment of metal is thought to be a way to enhance the qualities of metals, such as their hardness, roughness, and corrosion resistance (Kadhim *et al.*, 2021). Around the world, corrosion results in significant economic losses. It has a significant impact on the production and transportation of oil and gas. Corrosion also causes expensive damage in the manufacturing, chemical, oil, and other industries, with processes involving metal applications. Most corrosion-related issues can be brought on by broken oil pipelines, corroded chemical leaks, and even fire when electrical materials and components are exposed to them. Numerous industries have recognized the expense of improper corrosion control. Corrosion control done right can result in cost savings. For this

reason, there has been much research on various corrosion inhibitors (Hossain *et al.*, 2020). According to Hossain *et al.* (2020), the market for corrosion inhibitors was valued at $7.2 billion globally in 2019 and is projected to grow by 3.6 % to $9.6 billion by 2026. This is corroborated by Reza *et al.* (2021).

**Corrosion Inhibition Fundamentals**

An inhibitor is a type of chemical additive that, when introduced to a corrosive media, reduces the rate of corrosion of the target metallic substrate without significantly altering the corrosive medium itself (Quraishi *et al.*, 2021). In general, the inhibitor's mechanism is one or more of the following,

i. The inhibitor generates a protective thin layer with an inhibitory effect or by combining with ions on the metal surface and chemically adhering to the metal's surface (chemisorption).

ii. The inhibitor causes the base metal to create a layer protected by oxide.

iii. The inhibitor reacts with a potentially corrosive element in an aqueous media, yielding a complicated product (Dariva and Galio, 2014).

In the industry, it is typical to utilize corrosion inhibitors to reduce the corrosion rate of metallic components in acidic environments (Fouda and Ibrahim, 2018). Applications for corrosion inhibitors include pulp and paper, water treatment facilities, metal and chemical processing, oil and gas extraction, and electricity generation, among other industries (Quraishi *et al.*, 2021). Corrosion inhibitors provide many benefits, including ease of use, rapid response, low cost, high efficiency and the ability to be applied without altering the procedure or machinery (Hossain *et al.*, 2020). Since they are widely used to reduce metallic deterioration during operations and the

possibility of material failure, which can also result in the abrupt shutdown of industrial operations and subsequent expenditures, corrosion inhibitors are of significant practical importance. By forming a bond and barrier layer on the metal surface, corrosion inhibitors prevent the deterioration of metals and lower acid usage in the case of cleaning solutions. (Kadhim *et al.*, 2021).

$$Org_{(sol)} + aH2O_{(ads)} \rightarrow Org_{(ads)} + aH2O_{(sol)} \quad (1)$$
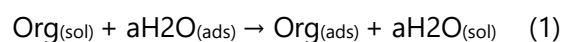
There are various models that demonstrate the mechanism of the inhibitor's action. In the most well-accepted model, shown in Eq. (1), the inhibitor molecule is adsorbed on the metal surface; generally, adsorption ensures that absorbed water molecules are removed from the metal surface (Kadhim *et al.*, 2021).

$$Org_{(sol)} + aH_2O_{(ads)} \rightarrow Org_{(ads)} + aH_2O_{(sol)} \quad (1)$$

An inhibition chain diagram to depict the sequence of inhibition action is shown in Figure 1.

Addition of inhibitor to corrosive medium
↓
Adsorption of inhibitor on metal surface
↓
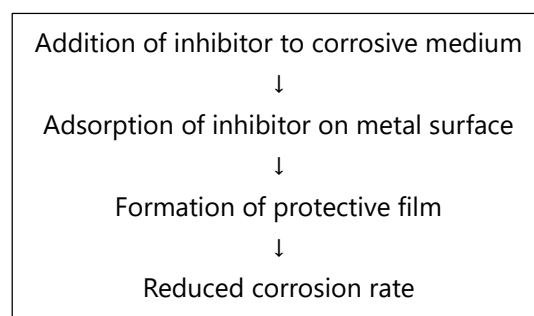Formation of protective film
↓
Reduced corrosion rate

Fig. 1: Inhibition chain diagram

In corrosion inhibition, the first step in the inhibition process is the adsorption of the inhibitor molecule on the metal surface (Elabbasy & Fouda, 2019; Motamedi et al., 2011). According to the International Adsorption Society, adsorption is the preferential distribution of a chemical

substance from the liquid or gaseous phases onto a solid substrate's surface (Adejo & Ekwenchi, 2014). Encyclopedia Britannica defines adsorption as the capacity of solids to draw gaseous molecules or solutions with which they are in contact to their surfaces (Adejo & Ekwenchi, 2014). The study of the adsorption of corrosion inhibitors on the metal surface usually provides a complementary description of the corrosion inhibition process to the techniques of weight loss and potentiodynamic polarisation. Adsorption isotherms are commonly used to demonstrate the adsorption of inhibitor molecules on metal surfaces. Adsorption isotherms describe the relationship between amounts of substance absorbed to the metal surface and its concentration in the gaseous or solution phases at a given temperature. An adsorption isotherm measures the amount of inhibitor adsorbed on the surface of the metal as a function of the pressure or concentration at a given temperature. The isotherm, therefore, gives insight into the mechanism of adsorption of the corrosion inhibitor on the metal surface leading to inhibition. Adsorption isotherms commonly employed in corrosion inhibition studies includes Langmuir, Temkin, Flory-Huggins and Frumkin isotherms (Agboola et al., 2019). The plot of the concentration versus a function of the surface coverage yields a linear relationship where the slope is unity for any isotherm that fits the adsorption mechanism of the reaction. The model best fits the experimental value is then chosen as the appropriate one. Langmuir isotherm assumes that the adsorption takes place on a homogeneous surface, with the adsorbed molecule forming a monolayer, covering specific sites on the metal surface. The following mathematical equation expresses the Langmuir isotherm in Eq. (2)

$$\frac{c}{\emptyset} = \frac{1}{k} + C \qquad (2)$$

C is the inhibitor concentration, $\emptyset$ is the degree of surface coverage by the inhibitor and k is the adsorption equilibrium constant.

The plot of c/$\emptyset$ versus C yields a linear relationship where the slope is unity and constant 1/k.

Freundlich isotherm model applies to and describes the adsorption characteristics of heterogeneous surfaces and is not limited to monolayer formation. The Eq. (3) gives the linear form

$$log\emptyset = logK_f + \frac{1}{n} logC_e \qquad (3)$$

C is the inhibitor concentration, $\emptyset$ is the degree of surface coverage by the inhibitor, and K_f gives an approximate indication of the adsorption capacity.

Temkin isotherm measures the affinity of an inhibitor to the material or surface it adheres. The mathematical relationship in Eq. (4) gives Temkin isotherm.

$$\emptyset = -\frac{2.303logK}{2a} - \frac{2.303logC}{2a} \qquad (4)$$

C is the inhibitor concentration, $\emptyset$ is the degree of surface coverage by inhibitor, k is the adsorption equilibrium constant, and a is the attractive parameter. A plot of $\emptyset$ against log C gives a linear relationship with $\frac{2.303}{2a}$ and $-\frac{2.303logC}{2a}$ as the slope and intercept, respectively. A negative value of 'a' proves the existence of repulsion in the adsorption layer.

The expression in Eq. 5 gives the Frumkin adsorption isotherm.

$$log(c * \frac{\emptyset}{1-\emptyset}) = 2.303 \log k + 2 \propto \emptyset \quad (5)$$

C is the inhibitor concentration, $\emptyset$ is the degree of surface coverage by inhibitor, and k adsorption equilibrium constant, and $\propto$ is the lateral interaction term that describes the interaction in the adsorbed layer.

The plot of $\log \left(c * \frac{\emptyset}{1-\emptyset}\right)$ versus 2α should give a linear relationship where 2α and $2.303\log k$ are the slope and intercept. A positive value of α is an indication that there is an attraction between the inhibitor and mild steel (Gomes, 2015).

The mathematical expression in Eq. (6) gives the Florry-Higgins isotherm is given by the

$$\log\left(\frac{\emptyset}{C}\right) = \log k + x\log(1-\emptyset) \qquad (6)$$

C is the inhibitor concentration, $\emptyset$ is the degree of surface coverage by inhibitor and k adsorption equilibrium constant and x is the size parameter.

A plot of $\log\left(\frac{\emptyset}{C}\right)$ against $\log(1-\emptyset)$ should give a linear relationship x and log k are the slope and intercept, respectively. If x is positive, then the adsorbed species is positive because it can displace water molecules from the surface of mild steel (Gomes, 2015).

For equipment made of carbon steel, typical acids used for cleaning operations include hydrochloric acid (HCl), formic acid (HCOOH), and Sulphamic acid (NH_2HSO_3), while formic acid (HCOOH), nitric acid (HNO_3), and Sulphamic acid (NH_2HSO_3) for equipment made from stainless steel. Usually, corrosion inhibitors should be applied in conjunction with these acids in acid cleaning operations.

Classification of Corrosion Inhibitors

In recent years, many publications have reported the use of inhibitors derived from natural extracts, ionic liquids, biological polymers, drugs, amino acids, and so on (Quraishi *et al.*, 2021).

Corrosion inhibitors are either natural or synthetic and can be categorized by:

i. The mode of action is either anodic, cathodic or a mixture of both and adsorption action.

ii. As oxidants or not oxidants

iii. The chemical nature is either organic or inorganic (Dariva and Galio, 2014).

Depending on the prevention mechanism, corrosion inhibitors can be divided into three categories: cathodic, anodic, or mixed-type inhibitors. By preventing reactions like oxygen reduction and hydrogen evolution at the cathode, cathodic corrosion inhibitors drive the corrosion potential downward. Using chitosan-polyethylene glycol (Cht-PEG) to mitigate the corrosion of mild steel in 1M sulphamic acid, Chauhan *et al.* (2018) explained that it is a slightly cathodic-type inhibitor. Chitosan-polyethylene glycol (CS-PEG) also acted as a slightly cathodic type inhibitor in the mitigation of mild steel corrosion in 1 M HCl by Srivasta *et al.* (2018). Anodic corrosion inhibitors passivate the reactive sites on the metal surface by interacting with them, which increases the corrosion potential values. For example, a mixture of *Tamarindus indiaca* (TAM) extract and zinc nitrate used to mitigate the corrosion of mild steel in 3.5% NaCl showed dominant anodic depression in the polarisation spectrum (Akbarzadeh et al., 2019). Mixed-type inhibitors are those that are neither cathodic nor anodic. Pais and Rao's (2021) examination of glycogen as an inhibitor for zinc corrosion in sulphamic acid showed glycogen as a mixed-type inhibitor with 71.2% efficiency. Through physisorption, chemisorption, or film formation, these inhibitors may shield the metal surface (Miralrio and Vazquez, 2020). Physisorption is driven by the electrostatic contact between inhibitor molecules and the metal surface, while chemisorption results through donor-acceptor interactions between free electron pairs in the inhibitor and unoccupied orbitals

on the metal surface. Finally, the metal surface is shielded from corrosive attacks by film formation, creating a physical barrier between it and the corrosive media (Miralrio and Vazquez, 2020).

Factors that Influence Corrosion Inhibitor Efficiency

The effectiveness of organic molecules at inhibiting corrosion is directly correlated with their capacity to bind to metal surfaces, the type of acid, system geometry, its concentration, agitation of the mixture, temperature, velocity, the type of metallic elements involved, and the presence of dissolved particles (Rajeev *et al.*, 2012). The factors above influence the selection of efficient acid corrosion inhibitors. In some cases, the combined inhibitory effect of two or more inhibitory chemicals (organic or inorganic) in a corrosive environment is more potent than the effect of the individual substances. This is a synergistic inhibitory effect (Dariva and Galio, 2014, Rajeev *et al.* 2012). The following variables have been found to affect how effectively a corrosion inhibitor works.

i. **Concentration of inhibitor:** It has been generally reported that the inhibition efficiency rises as inhibitor concentration rises and tends to peak at a certain concentration (Rajeev *et al.*, 2012). With an increase in inhibitor concentration, the corrosion rate slows down. This could be because as concentration increases, more inhibitor molecules bind to the metal surface, covering the corroded metal surface more thoroughly and protecting it from more corrosive attacks by the electrolyte solution.

ii. **Exposure time:** The inhibitors' protectiveness has been found to generally decline with exposure time (Abdel-Fatah and Hesham, 2012; Rehim *et al.*, 2011). This is because metal dissolution increases with exposure time when inhibitors are present. The possibility of the inhibitor molecules partially desorbing from the metal surface during an extended exposure period may account for this observation.

iii. **Temperature:** As the temperature rises, corrosion rates rise linearly (Miralrio and Vazquez, 2020). The metal dissolution reaction is intricate and results in pre-adsorbed inhibitor molecules desorbing from the surface of the metal, some inhibitors undergoing decomposition and rearrangement, the rate of heterogeneous reaction increasing at an uninhibited metal surface and rapid etching causing changes to the active area of the metal surface (Miralrio and Vazquez, 2020; Rajeev, 2012). In addition, activation energy is a direct function of temperature. At higher temperatures, increased activation energy results in the attaining of the activated complex that serves as the limiting factor to corrosion reaction, thereby leading to increased corrosion rates (Miralrio and Vazquez, 2020).

iv. **Impact of inhibitor structure:** The structural characteristics of the organic inhibitors have a substantial impact on the adsorption phenomena and, consequently, the level of inhibition (Rajeev *et al.*, 2012). The heteroatoms (nitrogen, sulphur, oxygen, and even selenium and phosphorous) found in the inhibitor molecule typically help it to adsorb on the metal surface. The development of an adsorptive bond is caused by the electron active center in the organic molecule, which causes a Lewis acid-base reaction in which the inhibitor serves as an electron donor and the metal as an acceptor. The electron density and polarizability of the reaction centre

significantly impact on the adsorption bond strength. Many researchers have discovered that when molecular weight and dipole moment rise, so does the adsorption of surface-active chemical molecules (Rajeev *et al.*, 2012).

Inhibitors Characterization Techniques

It is essential to characterize inhibitors employed in corrosive environments, and numerous experimental techniques have been utilized to do this (Miralrio and Vazquez, 2020). The weight loss method is the most traditional and reliable way of measuring corrosion (Hossain *et al.*, 2020; Reza *et al.*, 2021). The surface characterization is frequently addressed using spectroscopic and microscopy techniques. A scanning electron microscope (SEM) can be used to compare the surface of the metal in the presence or absence of a corrosion inhibitor, and it also yields additional morphological data (Miralrio and Vazquez, 2020). It is also a crucial technique for characterization of corrosion since it enables simultaneous assessment of surface kinetic properties, electrochemical properties, and chemical reactivity. SEM may be used to investigate localized corrosion that happens at specific locations by identifying the spots where corrosion prefers to occur in addition to information on the concentration of active species for corrosion (Dwivedi *et al.*, 2017). Similarly to this, the atomic force microscope (AFM) is an effective tool for analyzing the surface microstructure for topography imaging and comparisons (Miralrio and Vazquez, 2020; Motamedi *et al.*, 2013). The force necessary to pierce a surface film can be measured using AFM. This understanding of the penetrating force might help in designing surface films for certain applications by correlating it with the film's durability under specified mechanical loading (Dwivedi *et al.*, 2017). To determine oxidation states, stoichiometry, and electronic states, X-ray photoelectron spectroscopy (XPS) is frequently utilized. XPS is viewed as a quantitative spectroscopic method that provides information on the elemental composition, in parts per thousand level, based on the elemental electronic and chemical state of the surface under study (Dwivedi *et al.*, 2017, Miralrio and Vazquez 2020). The ability to examine the surface chemistry of a solid-liquid interface is known as grazing-angle X-ray diffraction spectroscopy (GI-XRD) (Dwivedi *et al.* 2017). Fourier transform infrared spectroscopy (FT-IR) is typically used for complementary characterizations to learn more about the functional groups and vibrational modes of corrosion inhibitors and to create the distinct fingerprints of molecules based on their absorption and transmission. FTIR can be used to determine the quantity and quality of individual components in samples (mixtures). FTIR is widely used nowadays because it has numerous benefits such as exact measurement, quick data gathering, non-destructive, high sensitivity, no external calibration, and so on (Dwivedi *et al.*, 2017, Miralrio and Vazquez 2020). Raman spectroscopy, which may assess the surface features of single or multiple layers, has established itself as a key instrument for corrosion investigations. Raman spectroscopy exposes structural information about the interface between a corrosion inhibitor and a metal by providing information about surface bonding (vibrational information) (Dwivedi *et al.*, 2017). Reza *et al.*, (2021) underline the advantages of using electrochemical analysis in research. This method can measure a low corrosion rate and only needs a short testing

period. Examples of this method include potentiodynamic polarisation (PDP), electrochemical frequency modulation (EFM), electrochemical impedance spectroscopy (EIS), and so on. They added that three-cell systems are typically used for electrochemical experiments. Reza *et al.*, (2021) mentioned using PDP to assess a metal's susceptibility to localized corrosion, such as pitting and crevice corrosion, and to characterize kinetic interactions on the metal surface. The measurement and analysis of the current generated by a changing voltage in a working electrode is the basis of polarisation testing (Miralrio and Vazquez, 2020). Electrochemical impedance spectroscopy (EIS) is another frequently employed method to examine anti-corrosion effectiveness in comparatively brief testing intervals. This method is employed to establish a system's impedance regarding the frequency of a variable potential. Nyquist plots are the most frequently used graphical representations of the findings of EIS analysis, which is based on models with equivalent electrical circuits. EIS provides more details, such as the system's mechanism and various resistance levels (Fouda and Ibrahim, 2018; Miralrio and Vazquez, 2020). Given that the adsorption process is interfacial, this approach is also beneficial for revealing information about the electrochemical interfaces. The lack of a scan rate is a benefit of adopting EIS. Consequently, it is appropriate for testing situations with low conductivity (Reza *et al.*, 2021). A potentiostat combines two sinusoidal potential signals and applies them to a corrosion sample in the electrochemical method known as the EFM. The causality elements, which work as an internal review of the EFM measurement's validity, are the EFM's greatest strength (Abdel-Fatah *et al.*, 2016; Fouda *et al.*, 2014). EFM employs a tiny signal
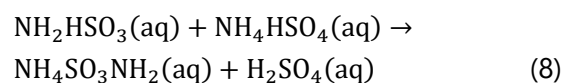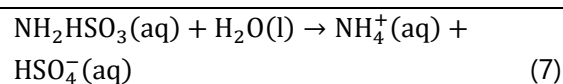
AC technique for non-destructive corrosion measurement, similar to EIS.

Contrary to EIS, two sine waves are simultaneously applied to the cell (Fouda *et al.*, 2014). Converting time-domain data to frequency domain and measuring the resulting current, the applied fundamental frequencies, their harmonics, and intermodulation frequencies are all monitored in this frequency domain. The large peaks are utilized to directly determine the values of causality factors, Tafel constants, corrosion rate, and corrosion current density using the necessary mathematical manipulation (Abdel-Fatah and Hesham, 2012; Rehim, 2011). By establishing the link between electrochemical potential and produced currents on charged electrodes, a technique known as linear polarisation resistance (LPR) is utilized to calculate the corrosion rate. The weight loss method (WL), based on the mass lost by corrosion and directly monitored to determine the corrosion rate, is less sophisticated and time-consuming. The inhibitory efficiency of a compound can be determined by measuring certain characteristics both in its presence and absence, such as the corrosion current density acquired by PDP (Miralrio and Vazquez, 2020).

Sulphamic Acid: Properties and Application

Sulphamic acid (NH_2HSO_3) is odorless white crystalline solid commercially accessible because it is non-hygroscopic and non-volatile, allowing for long-term storage in the laboratory. It shows significant ionization and the synthesis of extremely acidic aqueous solutions, and it dissolves just minimally in water and formamide (Chopra *et al.*, 2021). Sulphamic acid in aqueous solution does not produce corrosive fumes, but it

dissolves hard scales and produces soluble compounds with most industrial residues. In aqueous solutions, it functions as a potent acid, but compared to other acids, its corrosion rates are noticeably lower (Rehim *et al.*, 2014; Fouda *et al.*, 2017; Motamedi *et al.*, 2013). However, the solubility of sulphamic acid in other fluids, like acetone, ethanol, methanol, and hydrocarbons, is essentially nonexistent. It is ideal for various applications because of its exceptional physical characteristics and stability (Chopra *et al.*, 2021). Due to its exceptional ability to dissolve deposits and tough scales, Sulphamic acid (NH2HSO3, amido sulfuric acid) is employed as an industrial cleaning agent. In addition, when applied on mild steel, it prevents pitting or stress corrosion cracking brought on by chloride. An effective cleaning will only be achieved at moderately low concentrations, whereas corrosion will occur at very high concentrations. Sulphamic acid is effective at temperatures above 308 K. Due to these characteristics, inorganic acids like sulfuric, Sulphamic and hydrochloric acids are regularly used in a range of industrial and domestic applications (Fouda *et al.*, 2014) which include acid descaling, cleaning and pickling such as heat exchangers, cooling water systems, multistage flash evaporators (MSF) and saltwater desalination plants (Abdallah *et al.*, 2018; Fouda *et al.*, 2017; Morad, 2008; Motamedi *et al.*, 2011). While Sulphamic acid exhibits strong acidic behavior in aqueous solutions, it is substantially less corrosive than hydrochloric and sulfuric acids. Because it hydrolyzes very slowly at room temperature, NH2HSO3, in solid form, is infinitely stable (Motamedi *et al.*, 2013) instead, it forms ammonium hydrogen sulfate and ammonium sulfamate, as shown in equations 7 and 8:

$$NH_2HSO_3(aq) + H_2O(l) \rightarrow NH_4^+(aq) + HSO_4^-(aq) \qquad (7)$$

$$NH_2HSO_3(aq) + NH_4HSO_4(aq) \rightarrow NH_4SO_3NH_2(aq) + H_2SO_4(aq) \qquad (8)$$

Due to its much lower corrosion rates and lack of corrosive vapors, Sulphamic acid is superior to other mineral acids. Sulphamic acid is used to clean stainless steel and mild steel because of its exceptional qualities as a potent cleaning agent. Combined with most oxide deposits, it tends to break tough scales and produce soluble chemicals. Chemical cleaning has been demonstrated to be secure without pitting corrosion and stress corrosion cracking caused by chloride (Abdel-Fatah and Hesham, 2012). Sulphamic acid is a recognized cleaning agent for removing oxide scale buildups in steam-generating tubes (Abdel-Fatah and Hesham, 2012). Sulphamic acid is also used to clean cooling and heating systems, as well as the related heat exchangers. Sulphamic acid is frequently used in sugar production to remove scales because it doesn't encourage pitting corrosion, is non-toxic, and readily dissolves tough scales (Gupta *et al.*, 2018). It is used to clean austenitic stainless steels without chlorides, carbon steel, copper, and admiralty brass when this equipment is suitably inhibited. Using it on zinc, cast iron, aluminium, or 410 stainless steel is not advisable. It works well when used on a calcium carbonate scale and is effective on calcium phosphate or silica scales (Abdel-Fatah and Hesham, 2012).

Sulphamic Acid Corrosion Inhibition

Sulphamic acid solutions are frequently employed in industrial equipment for acid cleaning, descaling, and other processes. The importance of corrosion inhibitors for metals

in Sulphamic acid has grown due to extensive use (Fouda and Ibrahim, 2018). A corrosion inhibitor must be added to the Sulphamic acid solution to preserve the metal's surface and lessen its corrosivity throughout the cleaning and pickling operation. By adhering to a metallic surface and creating a barrier film, inhibitors frequently shield metals from deterioration (Motamedi *et al.*, 2013). Several researchers have reported the inhibition of corrosion of different metals and alloys in Sulphamic acid using different inhibitors like tryptophan (Abdel-Fatah *et al.*, 2013; Abdel-Fatah *et al.*, 2016), olive leaf (Elabbasy and Fouda, 2019), azo dyes (Jeyaraj *et al.*, 2005), chitosan (Gupta *et al.*, 2018), Juniperus (Fouda and Ibrahim, 2018), cystine (Abdel-Fatah and Hesham, 2012), s-containing amino acids (Abdel-Fatah *et al.*, 2013) etc. A review of publications shows that, Sulphamic acid has been extensively explored as a corrosive medium. (Fouda and Ibrahim, 2018) investigated the corrosion behavior of mild steel in 5% NH_2HSO_3 both with and without aqueous Juniperus extract. It was observed that temperature and concentration had an impact on inhibitor effectiveness. (Pais and Rao, 2021) examined the inhibitive ability of glycogen to prevent zinc corrosion caused by NH_2HSO_3 utilizing surface studies and electrochemical techniques. At 323 K, a maximal inhibition efficiency of 72% was recorded with a glycogen content of 0.05 g/L. Glycogen was reported to conduct chemisorption and to obey the Langmuir adsorption isotherm. A study by Abdel-Fatah and Hesham (2012) explored using a Sulphamic acid-base formulation on modified steel instead of the conventional corrosive HNO_3 and HF. EIS and weight loss methods were utilized to examine the impact of the inhibitor and NH_2HSO_3 on metal loss. Abdel-Fatah *et al.* (2013) studied how

Tryptophan's adsorption and corrosion inhibitive properties affected low alloy steels in acidic media (NH_2HSO_3 and HCl). Tryptophan functioned well in both acid mediums but performed best in hydrochloric acid (HCl). While inhibitor efficiency declined as time and temperature increased, it increased with an increase in the concentration of the inhibitor. Elabbasy and Fouda (2019) studied the role of olive leaf as a carbon steel inhibitor in a 10% NH_2HSO_3 solution. The corrosion mechanism was discovered to be physisorption. As olive leaf concentration was increased, IE % also increased. Gupta *et al.* (2018) investigated the effectiveness of using chitosan alone and chitosan and KI as mild steel inhibitors in 1 M NH_2HSO_3. At a concentration of 200 ppm, chitosan alone exhibited an inhibitory efficiency of 73.8 %; however, the IE % increased to 90 when KI was added. In a 5 % NH_2HSO_3 medium, Abdallah *et al.* (2018) examined the synthesis and evaluation of PPDs as carbon steel corrosion inhibitors. They discovered that PPDs function as mixed-type inhibitors. Using EFM, EIS, and PDP techniques, Fouda *et al.* (2014) investigated oxazole derivatives as 316L stainless steel inhibitors in NH_2HSO_3. It was reported that the chemicals function as mixed-type inhibitors. The highest IE rate was discovered to be 91 % at 0.0002 M. Motamedi *et al.* (2011) used the EIS method to investigate the electrochemical behavior of mild steel in NH_2HSO_3 with a Gemini cationic surfactant and its monomeric equivalent. AFM was used to analyze the morphology of the steel samples. As the concentration of the surfactants rose, so did the inhibition efficiency for both substances. In addition to examining the impact of molybdenum and chromium content on corrosion behavior, Abdel-Fatah *et al.* (2012) conducted

experiments on the inhibitive behavior of tryptophan when low alloy steels were immersed in 0.6 M NH_2HSO_3 at various temperatures. With rising temperatures, it was observed that the corrosion rate gave higher values. It was discovered that tryptophan can reduce corrosion. In order to better understand how Type 316L stainless steel behaves when exposed to NH_2HSO_3 solution, Kish *et al.* (2009) evaluated the use of a commercial inhibitor. Jeyaraj *et al.* (2005) investigated how mild steel corrosion in 10 % NH_2HSO_3 was inhibited by azo dyes. At the ideal concentration of 0.00001 M, the maximum IE of 80.4 % was attained. To investigate the impact of the five S-containing amino acids (S-benzyl cysteine, cysteine, N-acetylcysteine, cystine, and methionine) as corrosion inhibitors of mild steel in 5% NH_2HSO_3, Morad (2008) employed EIS and PDP curves. It was discovered that the effects of the amino acids on the mild steel corrosion potential in NH_2HSO_3 solutions were comparable to those of the amino acids in H_2SO_4 and H_3PO_4 solutions. N-acetylcysteine was the most effective inhibitor, followed by cysteine, S-benzyl cysteine, cystine, and methionine. Measurements from the EIS and PDP also supported this. In NH_2HSO_3, *Myrtus communis* extract was tested suppressing corrosion and activating thermodynamic processes (Fouda *et al.*, 2017). *Myrtus communis* is a mixed-type inhibitor, according to PDP. The fact that the value of IE rose as the temperature increased suggests a physical adsorption mechanism. Cysteine was examined by Rehim *et al.* (2011) as an inhibitor of low alloy steel corrosion in NH_2HSO_3 solutions. The corrosion inhibition efficacy of cysteine was found to be about 84 %, making it a potent inhibitor. The inhibitor concentration, the temperature of

the solution, and the rate of solution stirring were all factors that directly affected inhibition efficiency. With increasing inhibitor concentration, inhibition efficiency rises but declines with increasing solution temperature and stirring. The electrochemical behavior of white cast iron in NH_2HSO_3 using hexadecyltrimethylammonium bromide (CTAB) as a corrosion inhibitor was studied (Baymou *et al.*, 2018). They also assessed how well CTAB and NH_2HSO_3 worked together. The inhibition efficiency was 95% at 10^{-3} M CTAB and NH_2HSO_3 concentrations ranged from 0.2 to 1 M. In Sulphamic acid solutions, CTAB was discovered to be a mixed-type iron corrosion inhibitor. Both physisorption and chemisorption are adsorption techniques used to adsorb this compound. Table 1 is a compilation of various published papers in which Sulphamic acid was employed. When inhibitor concentration increased, there was a general trend toward higher inhibitor efficiency values, which was supported by Abdallah *et al.* (2018), Abdel-Fatah *et al.* (2016), Elabbasy and Fouda (2019), Fouda and Ibrahim (2018). However, with immersion time and temperature as process parameters, inhibitor efficiency decreased when temperature and immersion time rose. This is supported by studies in which amino acids were used as inhibitors (Abdel-Fatah and Hesham, 2012; Rehim, 2011). Additionally, when introducing stirring velocity or speed, inhibitor efficiency decreased with increasing stirring velocity. It was discovered that static conditions favor inhibitor effectiveness than agitated environments (Abdel-Fatah and Hesham, 2012; Rehim, 2011).

Table 1: Summary of some reports

S/No	Inhibitor	Metal	Medium	Temperature	Characterization techniques used	Nature of inhibitor(s)	Adsorption isotherm	Essential points	References
1.	MBI (2-mercaptobenzimidazole)	9Cr-1Mo ferritic steel	10 % NH_2HSO_3	Room temperature	WL, EIS, LRS	Mixed type		IE >90 % at room temperature. Optimal composition for efficient cleaning was found to be 10 % + 2 mM MBI	Upadhyay et al. (2020)
2.	Tryptophan	Low alloy steel	0.6 M NH_2HSO_3	25, 40, 50 & 60 °C	WL, EIS, EFM		Temkin isotherm	IE = 88.79 % at 25 °C. Values of IE percent increased with increasing inhibitor concentrations but dropped with rising temperatures.	Abdel-Fatah et al. (2016)
3.	Olive leaf	C-steel	10 % NH_2HSO_3	298, 303, 318 & 328 K	WL, SEM, EIS, PDP, Tafel, EFM	Mixed type	Langmuir isotherm	IE% values increased as the inhibitor concentration increased. The IE% reported from all electrochemical and chemical tests was consistent.	Elabbasy and Fouda (2019)
4.	Commercial organic inhibitor containing diethyl thiourea.	Type 316L Stainless Steel	10 wt. % NH_2HSO_3	65 °C	PDP, WL, XPS	Mixed type			Kish et al. (2009)
5.	Gemini (12-4-12) and monomeric (DTAB) surfactants	Mild steel	1 M NH_2HSO_3	20 °C	EIS, AFM	Mixed type	Langmuir & Flory-Huggins isotherm	Gemini cationic surfactant can be used to protect mild steel from acids.	Motamedi et al. (2011)
6.	Tryptophan	Low Cr-Mo Steels	0.6 M NH_2HSO_3	25, 40 & 60 °C	WL, EIS, EFM			With rising temperature, the corrosion rate showed higher values.	Abdel-Fatah et al. (2012)
7.	Azo dyes	Mild steel	10 % NH_2HSO_3	30 °C	WL, OCP,	Mixed type		Both inhibitors appear to limit mild steel corrosion by physically obstructing the metal surface and inhibiting both the anodic and cathodic processes involved in corrosion.	Jeyaraj et al. (2005)
8.	Chitosan and KI	Mild steel	1 M NH_2HSO_3	308 K	SEM, AFM, PDP, EIS	Mixed type	Langmuir isotherm	With chitosan alone, IE% OF 73.8 at 200 ppm. Chitosan + KI (5 ppm) achieved IE% > 90 %	Gupta et al. (2018)
9.	Pyridopyrimidinone derivatives	Carbon steel	5 % NH_2HSO_3	25 °C	EIS, PDP, EFM	Mixed type	Langmuir isotherm	As the concentration of PPDs rises, so does their inhibitory	Abdallah et al. (2018)

S/No	Inhibitor	Metal	Medium	Temperature	Characterization techniques used	Nature of inhibitor(s)	Adsorption isotherm	Essential points	References
								effect.	
10.	S-containing amino acids	Mild steel	5 % NH_2HSO_3	40 °C	EIS, PDP		Langmuir & Temkin isotherm	N-acetylcysteine (97.3 %) > cysteine (94.3 %) > S-benzyl cysteine (92.7 %) > cystine (91.7 %) > methionine (86.5 %)	Morad (2008)
11.	Juniperus	Mild steel	5 % NH_2HSO_3	25 – 40 °C	WL, PDP, EFM, EIS, EDX, SEM	Mixed type	Langmuir isotherm	IE % increased with increasing inhibitor concentration.	Fouda and Ibrahim (2018)
12.	*Myrtus* communis	Mild steel	5 % NH_2HSO_3	25, 30, 35, 40 °C	WL, EIS, EFM, PDP	Mixed type	Langmuir isotherm	Weight loss yields an IE that is comparable to EFM, EIS, and PDP.	Fouda *et al.* (2017)
13.	Oxazole derivatives	316L stainless steel	0.6 M NH_2HSO_3	25 – 55 °C	PDP, EIS, EFM	Mixed type		IE = 91 % @ 0.0002 M	Fouda et al. (2014)
14.	Tryptophan	Low alloy steel	0.6 M HCl & 0.6 M NH_2HSO_3	25, 40, 50, 60 °C	EIS, WL, EFM	Mixed type	Temkin isotherm	Tryptophan behaved better in HCl with IE% = 93.83 than NH_2HSO_3 with IE% = 92.11.	Abdel-Fatah *et al.* (2013)
15.	Cystine	Low alloy steel	0.5 M NH_2HSO_3	25, 35, 45, 55 °C	EIS, EFM		Temkin isotherm	IE% = 84 %. The inhibition performance under stirring conditions is lower than the IE under stationary conditions.	Rehim *et al.* (2011)
16.	Glycogen	Zinc	0.25 M NH_2HSO_3	303, 308, 313, 318, 323 K	SEM, EDX, AFM, EIS, PDP	Mixed type	Langmuir isotherm	IE% = 71.2 for 0.05 g/L glycogen at 323 K	Pais and Rao (2021)
17.	Hexadecyltrimethyl ammonium bromide (CTAB)	Cast iron	0.2 – 1 M NH_2HSO_3	22 °C	EIS, XRD, PDP, EMIS, SEM, ICP-OES	Mixed type	Langmuir isotherm	95 % IE at 10^{-3} M.	Baymou *et al.* (2018)
18.	Tyrosine	Low chromium steel	7 wet % NH_2HSO_3	30, 40, 50, 60 °C	EFM, EIS		Temkin isotherm	At 30 °C, IE = 85.69 %. Inhibition efficiency was higher in static conditions than stirred conditions.	Abdel-Fatah and Hesham (2012)

Problems Associated with Sulphamic Acid Corrosion Inhibition

Sulphamic acid decomposes sodium nitrite in an exchange reaction that reduces the salt and is accompanied by nitrogen gas evolution. Before trying to re-passivate a cleansed system with sodium nitrite, it is important to remove all sulphamic acid from the system because it can convert nitrile to nitrogen. Therefore, Sulphamic acid and sodium nitrite should not be brought together. Strong alkalis, cyanides, hypochlorous acid, chlorine, hypochlorites, sulfides, and hypochlorites are incompatible with Sulphamic acid, and the dangerous byproducts of its decomposition are sulfur oxides and ammonia. Sulphamic acid hydrolyzes to generate sulfuric acid at temperatures higher than 1800 °F, so Sulphamic acid is not advised for usage in those environments (Rajeev *et al.*, 2021). Sulphamic acid also requires more cleaning time than hydrochloric acid (Reza *et al.*, 2021).

CONCLUSIONS AND PERSPECTIVES

The study of various types of corrosion inhibitors on metal surfaces in sulphamic acid media is currently at the cutting edge of science, and this article provides a comprehensive summary of that research. This review includes significant investigations on corrosion prevention in Sulphamic acid medium for petroleum, desalination, acid descaling, cleaning, and pickling applications. Sulphamic acid solutions are more ecologically friendly for cleaning metallic surfaces and less hazardous electrolytes. On the other hand, Sulphamic acid-based electrolytes erode metal and metallic structures similarly to typical acidic solutions. It has numerous additional benefits, such as being appropriate for use with alloy steels and austenitic stainless steels, in addition to its strength as a potent solvent for iron oxides and a variety of water-formed scales. Sulphamic acid typically has a weight-based concentration of 5–10% at temperatures between 55 and 65 °C and flow rates between 1,200 and 4,500 l/min. According to the NRF-005-PEMEX-2009 standard, the most crucial challenge is extracting or isolating the main component with inhibition efficiency potential greater than 90%. Novel organic compounds can be isolated and studied to produce large quantities required for the industry. Another important challenge is that the requirements of the selection of compounds today must also include eco-friendliness and benignity. In recent times, the use of toxic chemicals has been minimized because of global interest in environmental safety as well its impact on human health and ecological balance. On this note, greener materials are gradually replacing inorganic inhibitors and certain hazardous organic compounds despite the effectiveness of these compounds. The interest in this class of greener compounds has continued to grow since the last decade as naturally occurring, and some synthetic biopolymers and their products with good inhibition efficiency meet the environmental requirement for application with reduced pollution risk. Effective organic corrosion inhibitors should contain heteroatoms (nitrogen, oxygen, sulfur, and phosphorous) with lone electron pairs and moiety with pi electron (aromatic rings and multiple bonds) that can interact with the free d orbital of the metal, favouring the adsorption process.

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