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Study of Amine as Vapour Phase Corrosion Inhibitors for Mild Steel under different aggressive Atmospheric Conditions at high temperature

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Abstract - Mild Steel and their products are main raw material for a strong infrastructure for every country which is the main demand in the race of survival, stabilization, growth and competition for every country. Industrialization and modernization in now a days has made a strong demand of steel and their maintenance but atmospheric corrosion can aggressively accelerate the degradation of metals during their manufacturing, processing, storage and transportation. In these cases, traditional methods to prevent corrosion are not suitable which provides the scope of VPCIs in industries, defense and daily life. Three new vapour phase corrosion inhibitors (VPCI) Triethylamine (TEA), Ethylamine (EA) and N-Ethylaniline (NEA) were tested for mild steel in different atmospheric conditions at 50^{o}C by Weight Loss Technique, Eschke test, Salt Spray Method, Sulphur Dioxide (SO_2) Test and results of tests were supported by Metallurgical Research Microscopy Technique and SEM Technique.

Keywords: **Mild Steel, Weight loss technique, Eschke test, Salt spray method, Metallurgical research microscopy, SEM, Vapour phase corrosion inhibitors.**

I. INTRODUCTION

In spite of much advancement in the field of corrosion science and technology, the phenomenon of corrosion (mainly of Fe, Al, Cu, Zn, Mg and their alloys) remains a major concern to industries around the world. Though the serious consequences of corrosion can be controlled to a great extent by selection of highly corrosion resistant materials, the cost factor associated with the same, favors the use of cheap metallic materials along with efficient corrosion prevention methods in many industrial applications. Conventional atmospheric parameters that may lead to metal corrosion comprise of weathering factors such as temperature, moisture, rainfall, solar radiation, wind velocity etc. Air pollutants such as sulphur dioxide, hydrogen sulphide, oxides of nitrogen, chlorides have also been found to contribute to atmospheric corrosion. The complexity and diverse nature of the atmospheric pollutants make the prediction of the atmospheric corrosion difficult. The synergistic interaction of the variables must also be considered in the model for arriving at a definite solution. Corvo [1] and Moricelli et al. [2] studied the relationship between the chloride concentrations with the corrosion rate in the atmospheric conditions. Ericsson [3] showed that sodium chloride on a carbon steel surface can cause corrosion at relative humidity which has been considered too low to start SO_2 induced corrosion. He reported that the synergistic effect of sodium chloride and SO_2 at 90% relative humidity increased the corrosion rate of carbon steel by about 14 times than caused by sodium chloride alone. Blucher et al. [4] reported a laboratory study of the effect of CO_2 on the atmospheric corrosion of aluminum is reported. The samples were exposed to pure air with 95% relative humidity and the concentration of CO_2 was <1 and 350 ppm, respectively. Atmospheric corrosion of aluminum is about 10-20 times faster in CO_2 free humid air compared to air containing ambient levels of CO_2. Vuorinen et al. [5] and a list of authors have worked on the organic compounds as VPCIs. Due to presence of long chain hydrophobic part and the presence of atom having high electron density, organic compounds are the best selection for the compounds used as VPCIs. The organic substances studied as a VCPI for mild steel were morpholine and its derivatives [6], diamino hexane derivatives [7], octylamine [8], cyclohexylamine and dicyclo hexyl amine [9], amine carboxylates [10], ammonium caprylate [11], Benzoic hydrazide derivatives [12-13], Bis-piperidiniummethyl-urea [14], β–amino alcoholic compounds [15] etc. Apart from organic substances, natural compounds like wood bark oil [16] and thyme [17-18] have also been used as VCPIs. Cano et al. [19] recently have proposed the use of vapour phase corrosion inhibition mechanism to study the inhibition mechanism of dicyclo hexamine isonitrite and dicyclohexaminenitrite on carbon steel surfaces in polluted environments with acetic or formic acid vapours. Zubielewicz et al. [20] studied the electrochemical behaviour of mixed anodic inhibitors. Batis et al. [21] evaluated the performance the two primers, a natural rust converter and an organic primer coating containing VPCI against atmospheric corrosion of reinforcing steel. Lyublinski [22] studied the synergistic corrosion management systems designed to eliminate, manage, control and/or mitigate corrosion in containers, enclosures, cisterns and storage tanks utilized a combination of cathodic-based corrosion prevention system, soluble corrosion inhibitor, and VPCI. In continuation to our earlier study [23-27], in the present study, the inhibiting properties of three organic VPCIs named as triethylamine (TEA), ethylamine (EA) and N-ethylaniline (NEA) were investigated on mild steel by Weight Loss technique at 85 % of relative humidity and 50 °C temperature, Salt Spray method in a medium of 3.0

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% sodium chloride, Eschke test, SO2 test, Metallurgical research microscopy and SEM techniques.

II. MATERIALS AND METHODS

Many research papers, articles and reviews have been reported to the study of the techniques used to determine the effectiveness of the vapor phase corrosion inhibitors (VPCI) against the metallic corrosion. Previous studies have utilized Adsorption Isotherm Technique[28], Weight Loss Technique 29], Potentiodynamic Polarization Measurements[30], Electro dynamical Impedance Meseaurment[31], Audio radiography[32] and Capacitance Measurements [33] to monitor the presence of VPCI on surfaces of metal. Tormoen et al.[34] reported three new techniques, namely Surface-Enhanced Raman Spectroscopy, Scanning Kelvin Probe Microscopy and Contact Angle Analysis, to monitor the adsorption of VPCI on the metallic surface in real time. These techniques can be used to evaluate the ability of two VPCI to diffuse and adsorb on the surface of metal simultaneously.

A. *Chemicals* (Min. Assay 99.0%, Grade AR)

i. *Triethylamine (TEA)*
Source Spectrochem. Pvt. Ltd. Mumbai.
ii. *Ethylamine (EA)*
Source Qualigens Fine Chemicals Mumbai.
iii. *N-Ethylaniline (NEA)*
Source Spectrochem. Pvt. Ltd. Mumbai.
iv. *Ammonium Chloride*
Source Himedia Lab. Pvt. Ltd. Mumbai.
v. *Sodium Thiosulphate (Anhydrous)*
Source Himedia Lab. Pvt. Ltd. Mumbai.
vi. *Ehanol*
Source Changsu Yangyuan Chemical Ltd. China.
vii. *Acetone*
Source Himedia Lab. Pvt. Ltd. Mumbai.
viii. *Sodium Sulphate (Anhydrous)*
Source Himedia Lab. Pvt. Ltd. Mumbai.
ix. *Sodium Chloride*
Source Himedia Lab. Pvt. Ltd. Mumbai.

Along with them triply distilled water (conductivity < 1 x 10^{-6} $ohm^{-1}cm^{-1}$) and sulphuric acid were also used.

B. *Equipments*

i. ***Weighing Balance***
Single Pan Analytical Balance, Precision 0.01mg, Model AB 135-S/FACT, Source Mettler Toledo, Japan.
ii. *Humidity Chamber* Thermotech TIC-4000N Temperature Controller, Humidity controller with course and fine adjustments, AC Frequeny 50-60Hz, Max. Voltage 300V, Source Make-Associated Scientific Tech., New Delhi.
iii. *Salt Spray Chamber*
Thermotech TIC-4000N Temperature Controller, Pumping system Pt-100, AC Frequeny 50-60Hz, Max. Voltage 300V, Source Make-Associated Scientific Tech., New Delhi.
iv. *Air Thermostat*
Nine adjustable Chambered, Electrically controlled, Accuracy ± 0.1°C.
v. *Metallurgical Research Microscope*
CXR II from Laomed, Mumbai, India
vi. *Scanning Electron Microscope*
JEOL 5900LV scanning electron microscope

C. *Methods*

i. *Vapour Pressure Determination Test*

A standard Knudsen method was used to determine the vapour pressure of all the investigated vapour phase corrosion inhibitors (VPCIs). For this purpose, definite amount of exactly weighed VPCIs were placed in a single neck round bottom flask fitted with a rubber cork in the neck having a glass capillary of 1.0 mm diameter in the center of rubber cork. Then the flask was kept in electrically controlled air thermostat maintained at the constant temperature of 50°C for 10 days. Change in the weight of VPCIs was observed by analytical balance and then vapour pressure of the investigated VPCIs were determined by the weight loss of VPCI for the time of exposure by equation 1.

$$P = \left[\frac{W}{At} \left[\frac{2\pi R T}{M} \right]^{1/2} \right] \quad \text{---------- (1)}$$

Where, P = vapour pressure of the VPCI (mmHg), A = area of the orifice (m^2), t = time of exposure (sec.), W = weight loss of substance (kg), T = temperature (K), M = molecular mass of the inhibitor (kg) and R = gas constant (8.314 JK-1mol-1).

ii. *Weight Loss Test*

Mild steel (ASTM-283) used for the investigation was in the form of sheet (0.025 cm thick) and of chemical composition: C – 0.17, Si – 0.35, Mn – 0.42, S – 0.05, P – 0.20, Ni – 0.01, Cu – 0.01, Cr – 0.01 and Fe - balance (w/w). Coupons of mild steel of dimensions 3.5 cm × 1.5 cm × 0.025 cm were used for weight loss studies. All metal coupons were mechanically polished successively with the help of emery papers grading 100, 200, 300, 400 and 600µ and then thoroughly cleaned with plenty of triple distilled, ethanol and acetone. Coupons were dried with hot air blower and stored in desiccators over silica gel. After recording initial weights of mild steel coupons on analytical balance, they were kept in different isolated chambers of air thermostat having fixed amount of VPCI at a constant temperature of 50°C for 24 hours of exposure time. A uniform thin film of VPCI was adsorbed onto the metal coupons after 24 hours of exposure. Then these coupons were transferred to a

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digitally controlled humidity chamber maintained at 85% humidity at a constant temperature of 50°C for 10 days. Blank coupons were also kept in the humidity chamber for the same duration in the same corrosive environment. After exposing the specimens for 10 days, the specimens were taken out from the humidity chamber and washed initially under the running tap water. Loosely adhering corrosion products were removed with the help of rubber cork and the specimen was again washed thoroughly with triple distilled water and dried with hot air blower and then weighed again. Corrosion rate in mils per year (mpy) and percentage corrosion inhibition efficiency (PCIE) were calculated using the equations 2 and 3 respectively.

$$\text{Corrosion Rate (mpy)} = \frac{534\ X\ W}{DAT} \quad \text{---------- (2)}$$

Where, W = Weight loss (in mg), D = Density of mild steel (in g/cm^3), A = Area of specimen (in sq. inch), T = Exposure time (in hour).

$$\text{PCIE} = \frac{CRo - CR}{CRo}\ X\ 100 \quad \text{---------- (3)}$$

Where, CRo = weight loss in absence of inhibitor and CR = Weight loss in presence of inhibitor for 10 days, the specimens were treated in same manner as treated in weight loss test to remove corrosion products and then CR, and PCIE were calculated.

iii. Eschke Test

Eschke test was carried out on the pre weighed mechanically polished mild steel coupons as prescribed in the literature. Kraft papers of suitable size were dipped in the VPCI for 30 seconds and then dried to adsorb uniform layer of the inhibitor on the Kraft papers. Then mild steel coupons were wrapped in VPCI impregnated Kraft papers and then taken in the humidity chamber maintained at 85 % relative humidity maintained at a constant temperature of 50oC for first 12 hours and 25oC for next 12 hours, alternately for 10 days. This temperature cycle was maintained in two sets because of formation and condensation of the vapours of VPCI on mild steel surface regularly. After exposing the coupons for 10 days, the coupons were treated in same manner as treated in weight loss test to remove corrosion products and then CR and PCIE were calculated.

iv. Salt Spray Method

After exposing the pre weighed mild steel coupons to VPCI in air thermostat for 24 hours, they were transferred to salt spray chamber having 3.0 % sodium chloride solution maintained at constant temperature of 500C for duration of 10 days along with blank specimens. After exposing the coupons for 10 days in NaCl spray, coupons were treated in same manner as treated in weight loss test to remove corrosion products and then CR and PCIE were calculated

v. Sulphurdioxide Test

SO2 test was carried out on the mild steel coupons of same dimension as in weight loss test. SO2 gas was prepared by dissolving 0.04 g of sodium thiosulphate in 30 mL aqueous solution of 1.0 % NH4Cl and 1.0 % Na2SO4 solution and 0.5 mL of 1.0N H2SO4 was added to the flask. Initially pre weighed and mechanically polished mild steel coupons were placed in air thermostat maintained at a constant temperature of 50oC for duration of 10 days. Definite weight of VPCIs in a petridis and the flask, which is the source of SO2, were placed in the isolated chambers of air thermostat containing mild steel coupons. After exposing the specimens for 10 days, the specimens were treated in same manner as treated in weight loss test to remove corrosion products and then CR and PCIE were calculated.

vi. Metallurgical Research Microscopy Technique

This test was employed to know about nature and type of corrosion using metallurgical research microscope. To investigate the corrosion inhibition efficiency of investigated VPCIs, micrographs of the corroded coupons treated with investigated VPCI were subjected to porosity study and morphology of surface. By the obtained results a comparative study of that porosity and surface morphology was carried which provided the information about the number of pores, size of pores, percentage porosity and area covered by the pores on the surface of coupon after the four different corrosion experiments. Percentage porosity (PP) and total objects (TO) shows the roughness of surface. On the other hand maximum perimeter and maximum area object ratio (A/O) provide the information about the size and depth of the pores on the surface of mild steel. Micrographs of blank corroded coupons were taken after exposure of different aggressive environments for 10 days are shown in table 1 and results of metallurgical research microscopy of blank mild steel coupon after different corrosion tests are reported in table 2 from which it is clear that in weight loss test 9774 pores cover 8886066.4820 µ2 area due to uniform corrosion in humid environment by which 68.90% surface become porous. In this test, numbers of pores are very high but A/O ratio is not very high as compared to that of salt spray test. In salt spray test, percentage porosity (69.94%) is almost equal to that of weight loss test but the numbers of pores (13,380) and the porous area (10960879.5014 µ2) on the mild steel surface are high due to corrosive action of direct exposure of chloride ions on the surface of mild steel coupon. In this test, perimeter of pore (52323.4375 µ) and A/O ratio are high due to large size and high depth of pores respectively.

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Table 1. Micrographs of mild steel blank coupon in different corrosion tests

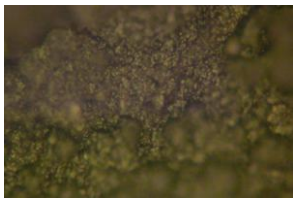
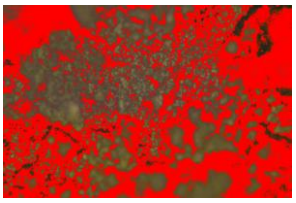
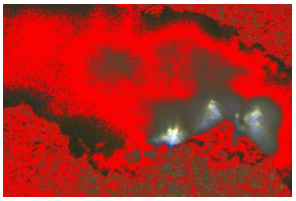
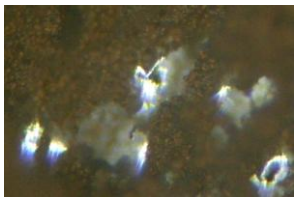
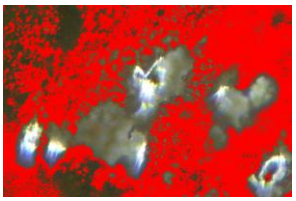
	
Micrograph of blank coupon in Weight loss test	
	
Micrograph of blank coupon in Salt spray test	
	
Micrograph of blank coupon in SO_2 test	
	
Micrograph of blank coupon in Eschke test	

Table 2. Total objects (TO), percentage porosity (PP), maximum perimeter (MP) of pore and maximum area (MA) covered by pore on blank mild steel coupon after different corrosion tests.

	TO	PP	MP(μ)	MA (μ^2)
Weight Loss Test	9774	68.9	55805.5407	8886066.4820
Salt Spray Test	13380	69.94	52323.4375	1096879.5014
SO_2 Test	3783	86.62	78541.5913	9770443.2133
Eschke Test	6448	69.11	20138.1682	4461322.7147

In SO_2 test, although the numbers of pores (3387) are very low as compared to other corrosion experiments yet the percentage porosity (86.52%) are highest in this test. In this test the size of pores (78541.5913 μ) and A/O ratio are very high due to high depth of the pores by the acidic action of SO_2 environment which provide evidence in favour of mechanism of pits formation on the surface of coupon by the acidic action of SO_2. In Eschke test, depth of pores is very low due to small size of pore of perimeter (20138.1682 μ) but total objects (6448) are high due to roughness of surface by the action of corrodents of environment.

vii. Scanning Electron Microscopy

Morphology of the selected samples was observed by scanning electron microscopy (SEM) using scanning electron microscope. This technique provides the evidences in support of the inhibition data of different VPCIs, type of corrosion in different environment and for the mechanism of inhibition. In this technique, the samples, after treating with the different tests, were studied at different resolutions on the different spots on the mild steel coupons for complete information about the inhibition mechanism. SEM of the blank mild steel coupons were also taken for the comparative study of metal specimens which are given in Fig 1.

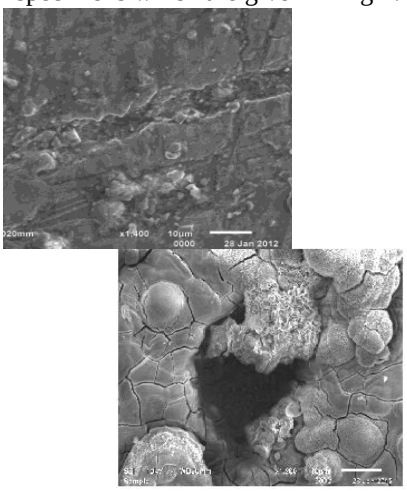


Fig 1. Scanning Electron Micrographs of Blank Coupons

SEM of the blank coupons clearly provides the evidence of the pitting and crevice corrosion in corroding environments.

III. RESULTS AND DISCUSSION

i. Vapour Pressure Determination Test

The values of the investigated vapour phase corrosion inhibitors are given in Table 3.

Table 3. Vapour Pressure of investigated VPCIs

S N.	VPCI	Vapour Pressure (mmHg)
1.	TEA	437.39×10^{-2}
2.	EA	86.97×10^{-2}
3.	NEA	9.44×10^{-2}

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Due to presence of sufficient vapour pressure, its vapours can easily adsorbed on the surface of metal coupon and form a barrier film for water vapours and corrosive aggressive contents of atmosphere around the metal coupons and protect the metal from corrosion by the formation of protective layer.

ii. Weight Loss Test

Values of CR and PCIE for investigated VPCIs obtained by weight loss technique at 50oC are summarized in Table 4. Corrosion rate of mild steel under the different investigated VPCIs are given in Fig.2 form which it is clear that the corrosion rate is negligible in the coupons of mild steel which were treated with TEA. Percentage Inhibition Efficiency of different investigated VPCIs are given in Fig.3 from which it is clear that all the investigated inhibitors work well against the corrosion on the mild steel under atmospheric conditions. In present investigation, TEA exhibit highest (92.74%) PCIE for the mild steel under atmospheric conditions at 50oC.

Table 4. Weight Loss Parameters obtained for investigated VPCIs at 50°C temperature and 85% Relative Humidity for 10 days for mild steel coupons.

S N.	VPCI	Wt. Loss ($x\ 10^{-1}$mg)	CR (mpy)	PCIE
1.	Blank	148	5.12	-
2.	TEA	11	0.37	92.74
3.	EA	52	1.80	64.76
4.	NEA	44	1.51	70.39

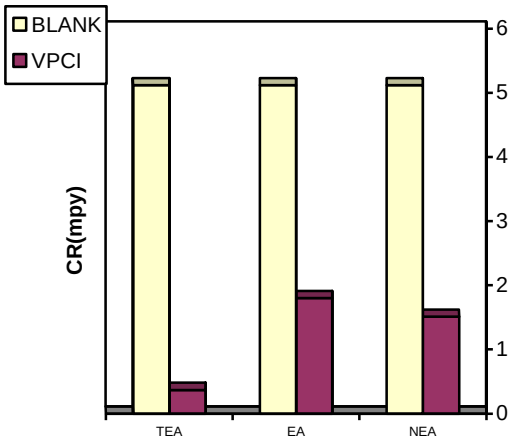

Fig 2. Corrosion Rate of Coupons treated with VPCI w.r.t blank coupons obtained from Weigh Loss Test.

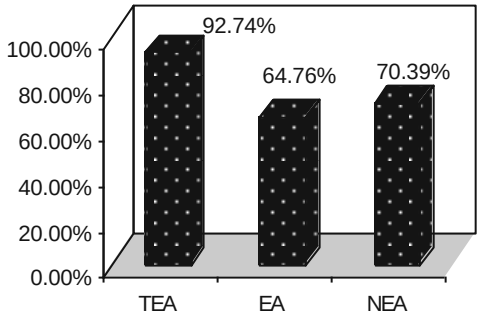

Fig 3.PCIE of Investigated VPCIs obtained from Weight Loss Test.

iii. Salt Spray Test

After 10 days duration of salt spray test, mild steel coupons were collected and weight loss of mild steel coupons treated with VPCIs were noted from which CR and PCIE were calculated for investigated VPCIs. From which performance of various investigated VPCIs were noted on atmospheric corrosion at 50°C through CR and PCIE as shown in Fig.4. It is clear from Fig.4 that in salt spray test, direct contact of chloride ions on mild steel coupons accelerates the rate of corrosion. So obtained corrosion rate were high as compared to the weight loss technique for the same duration. In this test all investigated VPCIs were worked very well against the corrosion.

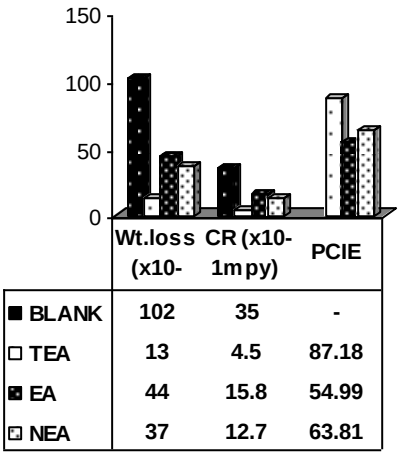

Fig 4. Wt. Loss of mild steel coupons, CR and PCIE of Investigated VPCIs obtained from Salt Spray Test.

iv. Escke Test

Weight loss of the mild steel coupons, corrosion rate and percentage inhibition efficiency of various VPCIs were calculated at 50°C for the duration of 10 days in Eschke Test and the data obtained is shown in Fig.5. It is clear from the Fig.5 that TEA perform very significant role against the corrosion at atmospheric conditions at high temperature. Visual observations of the mild steel coupons are also given in Table 5.

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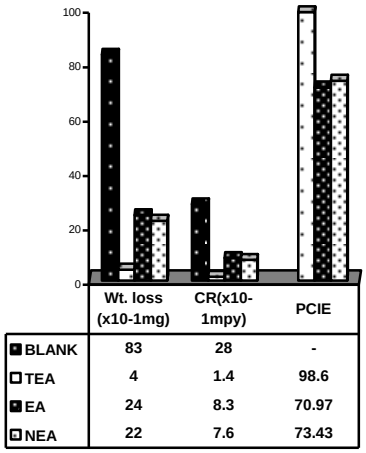
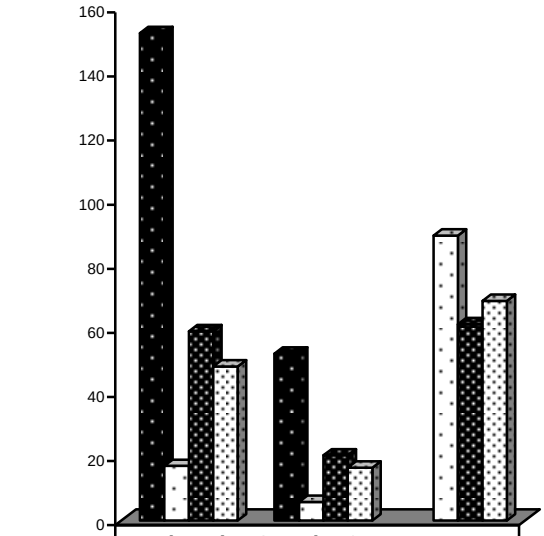


	Wt. loss (x10-1mg)	CR(x10-1mpy)	PCIE
BLANK	83	28	-
TEA	4	1.4	98.6
EA	24	8.3	70.97
NEA	22	7.6	73.43

Fig5. Wt. Loss of mild steel coupons, CR and PCIE of Investigated VPCIs obtained from Eschke Test.

v. Sulphurdioxide Test

Results obtained of SO_2 test are represented in Fig.6. It is seen that the value of CR is very high for the same duration in this test due to the acidic environment of SO_2. All investigated VPCIs play significant role to prevent the mild steel from the corrosion in acidic environment of SO_2 which is the part of the atmosphere near the industries. Visual observations of SO_2 test is also given in Table 5.



	Wt. loss (x 10-1 mg)	C.R. (x 10-1 mpy)	PCIE
BLANK	152	52	-
TEA	17	5.8	88.93
EA	59	20.3	61.26
NEA	48	16.5	68.52

Fig6. Wt. Loss of mild steel coupons, CR and PCIE of Investigated VPCIs obtained from SO_2 Test.

Table 5. Visual observations of mild steel coupons surface in presence and absence of VPCIs from various tests performed at 50°C for 10 days duration.

VPCI	Salt Spray Test	Eschke Test	SO_2 Test
Blank	Clear pits visible	Uniform corrosion	Pitting corrosion
TEA	Clean surface No corrosion	Clean surface No corrosion	Clean surface No corrosion
EA	Slightly tarnishing	Clean surface	Slightly tarnishing
NEA	Slightly tarnishing	clean surface	Slightly Tarnishing

vi. Metallurgical Research Microscopy

Metallurgical Research Microscopy of TEA

Results of metallurgical research microscopy and micrographs of mild steel coupons treated with TEA after different corrosion tests are reported in table 6 and table 7 respectively.

Table 6. Micrographs of mild steel coupons treated with TEA in different corrosion tests.

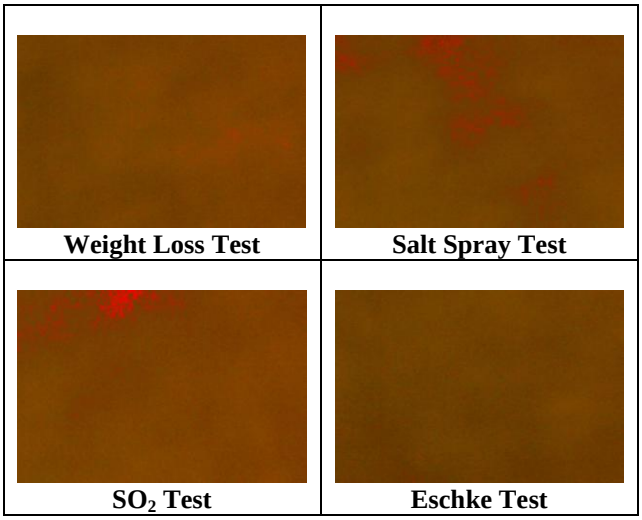


Table 7. Total objects (TO), percentage porosity (PP), maximum perimeter (MP) of pore and maximum area (MA) covered by pore on mild steel coupon after treated with TEA after different corrosion tests.

	TO	PP	MP(μ)	MA (μ^2)
Weight Loss Test	517	0.51	363.6449	983.3795
Salt Spray Test	1116	2.19	646.1372	1689.7507
SO_2 Test	998	1.94	960.5706	1232.6870
Eschke Test	386	0.06	127.8842	367.0360

In weight loss test, 517 pores cover 983.3795 μ^2 area due to uniform corrosion in humid environment by which

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negligible surface (0.51%) become porous. In salt spray test and SO_2 test percentage porosity (2.19% and 1.94) and numbers of pores (1116 and 998) are little bit a high as compared to weight loss test due to direct action of salt and ions on surface of coupon. In this test, perimeter of pore (646.1372 µ and 960.5706 µ) and A/O ratio are also very low due to action of TEA as VPCI which inhibit the rate of corrosion and formation of pits and crevice on the surface of mild steel coupon. In Eschke test, all the porosity parameters are very low which provide the evidence in favour of very efficient action of TEA as an excellent VPCI. First micrographs of all tests show that very clean surface without any corrosion products are obtained of mild steel coupon after the treatment of coupon with TEA.

Metallurgical Research Microscopy of EA

Results of metallurgical research microscopy and micrographs of mild steel coupons treated with EA after different corrosion tests are reported in table 8 and table 9 respectively.

Table 8. Micrographs of mild steel coupons treated with EA in different corrosion tests.

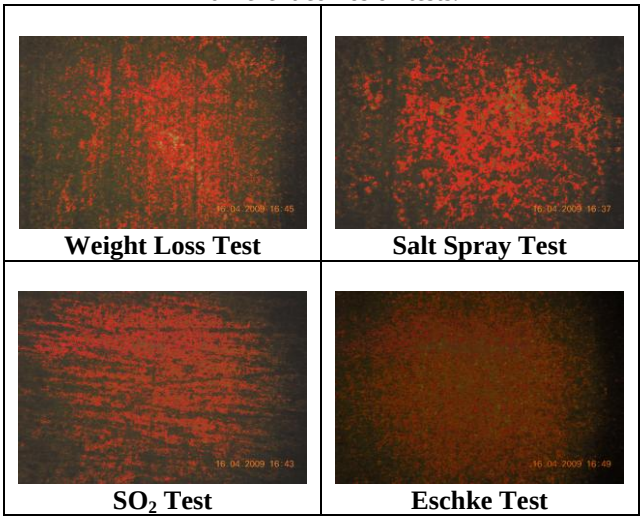

Table 9. Total objects (TO), percentage porosity (PP), maximum perimeter (MP) of pore and maximum area (MA) covered by pore on mild steel coupon after treated with EA after different corrosion tests.

	TO	PP	MP(µ)	MA (μ^2)
Weight Loss Test	2227	12.06	2777.1574	4963.9889
Salt Spray Test	3542	15.75	7129.0238	19591.9127
SO_2 Test	2288	12.24	1933.4041	4716.0665
Eschke Test	1926	8.17	227.0579	318.5596

By comparison of the data obtained by four different corrosion tests, it is clear that percentage porosity is significantly low in all tests due to good inhibition action of EA against the atmospheric corrosion. In weight loss test, 2277 pores cover 4963.9889 μ^2 area due to uniform corrosion in humid environment by which 12.06% surface become porous. In weight loss test A/O ratio is not very high as compared to salt spray test due to relatively low depth and large size of pore of perimeter 2777.1574 µ. In salt spray test, percentage porosity (15.75%) and numbers of pores (3542) are very high due to direct exposure of salt on surface of mils steel coupon. In this test, perimeter of pore (7129.0238 µ) and A/O ratio are very more than that of pores in weight loss test due to large size and high depth of pores respectively. In SO_2 test, numbers of pores (2288) and percentage porosity (12.24%) are relatively low as compared to salt spray test which is due to acid neutralizing action of EA. In this test, depth of pores is comparatively low due to small size of pore of perimeter 1933.4041 µ. First micrographs of all tests show that almost smooth surface without any corrosion products are obtained of mild steel coupon after the treatment of coupon with EA.

Metallurgical Research Microscopy of NEA

Results of metallurgical research microscopy and micrographs of mild steel coupons treated with NEA after different corrosion tests are reported in table 10 and table 11 respectively.

Table 10. Micrographs of mild steel coupons treated with NEA in different corrosion tests.

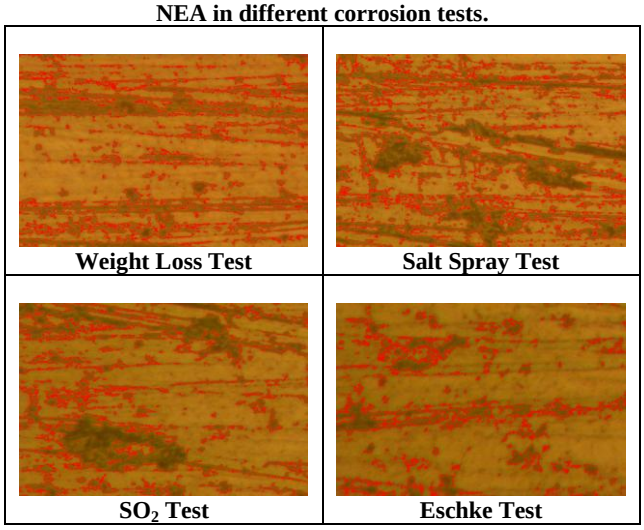

Table 11. Total objects (TO), percentage porosity (PP), maximum perimeter (MP) of pore and maximum area (MA) covered by pore on mild steel coupon after treated with NEA after different corrosion tests.

	TO	PP	MP(µ)	MA (μ^2)
Weight Loss Test	2288	10.89	5265.2042	13545.7064
Salt Spray Test	3726	14.95	7760.5237	19806.0942
SO_2 Test	3352	11.12	8264.5675	14704.9861
Eschke Test	2053	9.27	5201.8767	8552.6316

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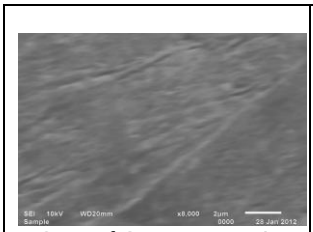
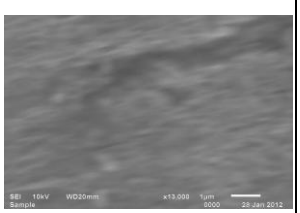
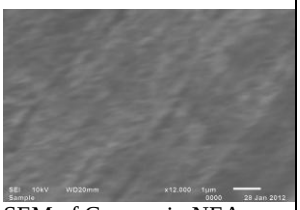
In weight loss test, 2288 pores cover 13545.7064 μ^2 area due to uniform corrosion in humid environment by which 10.89% surface become porous. In this test the size and depth of pores are high in the comparison of that of coupons treated with DAP inhibitor. In salt spray test, percentage porosity (14.95% and 11.12%) and numbers of pores (3726 and 3352) are some high due to direct spray of salt ions on surface of coupon. In these test, perimeter of pores (7760.5237 µ and 8264.5675 µ) are little bit high but A/O ratio are significantly low due to corrosion inhibition action of NEA which prevent the formation of pits on the surface of mild steel coupon by the action of chloride ion. In Eschke test, depth of pores is comparatively low due to small size of pore of perimeter (5201.8767 µ) but total objects (2053) are high due to roughness of surface by the action of corrodents of environment. In this inhibitor the size and depth of pores are high as compared to above inhibitor. First micrographs of all tests show that very smooth surface without any corrosion products are obtained of mild steel coupon after the treatment of coupon with NEA.

vii. Scanning Electron Microscopy

This technique gives the morphology study of mild steel coupons after treatment of different corrosion tests which provide the evidences in the support of inhibition data of investigated VPCIs, type of corrosion and for the mechanism of inhibition as shown in Table 12. In this test, samples were studied at different resolutions on the different spots on the mild steel coupons for complete information about the inhibition mechanism after treating with different tests. SEM of blank mild steel coupons were also taken for the comparative study of metal specimens which are given in Fig.1. Micrographs of the blank coupons clearly provide the evidence of the pitting and crevice corrosion in corroding environments.

Table 12. SEM image of mild steel coupons treated with TEA, EA and NEA after corrosion test.

 SEM of Coupon in TEA	• Shining Clean Surface • No Pitting Corrosion • No Corrosion Products • Good Corrosion Inhibition of TEA
 SEM of Coupon in EA	• No Pitting Corrosion • No Corrosion Products • Some Roughness on Surface • Little but low PCIE of EA
 SEM of Coupon in NEA	• Clean Surface • No Pitting Corrosion • No Corrosion Products • Good Corrosion Inhibition of NEA

IV. MECHANISM OF INHIBITION

The probable mechanism of inhibition action of investigated VPCIs contains the following features:

a) Presence of lone pair donar N atoms provide them specific active functional groups by which it can be easily adhere on the surface of mild steel.

b) Due to high vapour pressure it saturates the environment around the mild steel coupon and due to high vapour density than air its vapours retain on the surface of mild steel and excludes the corrosive contents.

c) Presence of three ethyl groups directly attached with the lone pair donar atom in TEA and one ethyl group in EA and in NEA enhance the basic strength of TEA molecule due to inductive effect by which it can easily neutralized the acidic environment around the mild steel.

d) Due to low molecular weight of the EA molecule and the high vapour pressure, the rate of condensation of the vapours is very high and the vapour density is very low. By this reason its PCIE is low.

e) Presence of lone pair donor N atoms and π-electrons of instauration of benzene ring make NEA as a good surfactant for mild steel provide the ability to adsorb on the surface of mild steel to protect it from corrosive environments.

f) Presence of alternative double bond and instauration near the lone pair donor atom make PCIE of inhibitor low due to resonating stabilization.

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