

## Corrosion characteristics of vapour phase inhibitors for mild steel under different atmospheric condition

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### Abstract

Mild steel, due to its high mechanical strength, is used as main raw material in fabrication of equipment, chief material of construction and as weapons in defense forces. During the storage and transportation conditions, mild steel come in contact with aggressive environment which leads to decrease in mechanical strength. Four different vapor phase corrosion inhibitor (VPCI) were tested for mild steel in different atmospheric conditions at 50<sup>0</sup>C by weight loss, Eschke test, salt spray method, SO<sub>2</sub> test and metallurgical research microscopy technique. All the four VPCIs show very good corrosion inhibition efficiency for mild steel. Triethylamine (TEA) showed the best result. The results obtained from corrosion experiments were supported by microscopy technique. It was observed that nitrogen bases like N- Ethylaniline (NEA) and Cetyl tri methyl ammonium bromide (CTMAB) were ineffective VPCIs and strong bases of aliphatic compounds like Triethylamine (TEA) and 1,3- Diamino propane (DAP) were effective VPCIs for mild steel.

**Keywords:** Mild steel, Atmospheric corrosion, Vapor phase corrosion inhibitor.

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## 1. Introduction

Atmospheric corrosion also known as vapor phase corrosion (VPC) is due to the individual and combined action of oxygen, moisture, and atmospheric pollutants. Additional contributors to VPC are rain, snow, dust, soot, ash, wind, and radiation (light, heat, etc.). The rate of VPC may be accelerated by both acids and bases, depending upon the metal.

Mild steel is the most common form of steel and because of its low cost it is chief material of construction. Mild steel have good strength, hard and can be bent, worked or can be welded into an endless variety of shapes for uses from vehicles (like cars and ships) to building materials. Because of its unique properties like, high strength, hard, very cheap and easy availability, it has wide range of applications in nut bolt, chains, hinges, knives, armour, pipes, magnets, military equipments etc.

Metal and their alloys are exposed to aggressive environment under atmospheric condition during the manufacture, processing, storage, or transportation and can accelerate the degradation of the metal, alloys and their products. In such cases, the corrosion prevention methods like water-displacing products (oil or grease), water-absorption products (silica gel) and dehumidification are not significant due to high labor, material cost for the application and removal of product and difficulty to calculate specific moisture. The vapor phase corrosion inhibitor (VPCI) play a significant role in minimizing corrosion to metals and their alloy in atmospheric condition by producing vapors with sufficient vapor pressure, and prevent the metal or alloys from corrosion by adsorption of their vapors onto the metal surface. The effective use of surfactants for VPCI depends upon environment and properties of metals as well as surfactants [1-5]. It has been shown for iron that when relative humidity is below 60 percent, no corrosion is expected, while above 75 to 80 percent, the degree of corrosion will be high [6]. Detrimental effects caused by photochemical reactions of sulphur dioxide and nitrogen oxides have been demonstrated by Stern [7].

Use of VPCI is an effective method to prevent atmospheric corrosion [8, 9]. The protection of metal is due to the inhibitors volatilizing into the atmosphere surrounding the metal parts and modifying the atmosphere [10]. The choice of a chemical compound as VPCIs depends upon on its vapor pressure and efficiency to prevent corrosion by forming a protective film. The vapor pressure of VPCI must posses some optimum values. If the vapor pressure of the VPCI is too low, e.g. in the order of  $10^{-6}$  Torr at room temperature, the protective vapor concentration will be established only slowly. This may result in insufficient corrosion protection during an initial time period. Further, if the space that houses both the stored equipment and VPCI is not sealed, sufficient inhibitor concentration may not be reached. Conversely, under similar conditions, if the vapor pressure of VPCI is too high (approx. 0.1 Torr at ambient conditions), its effectiveness will be limited to a short time period, as its consumption rate will be high.

Subramanian et. al [11] studied the most commonly used VPCI, derivatives of ammonium carbonate and ammonium nitrite on copper, mild steel and zinc in sulphur dioxide ( $\text{SO}_2$ ) environment. Due to their easily availability and their better percentage corrosion inhibition efficiency (PCIE) they have been used in industry for several decades. However, the disadvantages of using these derivatives are their toxic nature to the environment. Thus,

replacing them with new environmental friendly inhibitors is desirable. Saurbier *et. al* [12] suggested toluyl alanine as an effective temporary inhibitor of steel in wet atmosphere. Vuorinew [13] reported a series of morpholine-mannich based derivatives as volatile corrosion inhibitors. Polymeric corrosion inhibitors such as polyacrylic and polyamino-benzoquinone etc. are widely used and they have a lower toxicity than their monomers [14, 15]. Many kinds of morpholine oligomer (MPO) as VPI for the temporary protection of box shaped hatch covers and rudder blades of large ships at Hudong Shipyard have been studied by Zhang *et al.* [16]. Quraishi *et al.* [17] studied the inhibiting properties of five organic vapor phase inhibitors namely, derivatives of imidazoline maleate, orthophosphate, nitrobenzoate, phthalate, cinnamate on mild steel, brass and copper. They also studied some organic volatile corrosion inhibitors mostly derivative of diaminohexane such as diaminohexane cinnamate, nitrobenzoate, phthalate, orthophosphate and maleate on aluminium, zinc and mild steel [18]. Study of some salts of benzoic hydrazide benzoate (BHB), benzoic hydrazide salicylate (BHS) and benzoic hydrazide nitrobenzoate (BHN) as corrosion inhibitors of mild steel [19-21], brass and copper was studied by weight loss method [22]. Persiantsava examined derivatives of benzene with  $\beta$ -naphthol as a VPCI in a sulphur dioxide and chloride atmosphere [23]. Subrumanian *et al.*, [24] studied the corrosion inhibition behaviour of morpholine and its three derivatives salts- morpholine carbonate, borates, and phosphates salts. Of these morpholine and its carbonates salt exhibited 90 and 85% corrosion inhibition efficiency (CIE) respectively while the other salts gave less than 40% corrosion inhibition efficiency.

In the present study, the inhibiting properties of four organic VPCIs named as Triethyl amine (TEA), 1,3- Diamino propane (DAP), N- Ethylaniline (NEA) and Cetyl tri methyl ammonium bromide (CTMAB) were studied on mild steel by weight loss technique at 85% of relative humidity and 50<sup>0</sup>C temperature, salt spray method in a medium of 3.0% sodium chloride, SO<sub>2</sub> test, Eschke test and research metallurgical microscopy technique for the surface study of corroded metal specimen.

## 2. Experimental

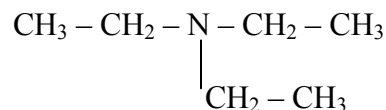
Name and structure of four VPCI for mild steel are take in Table No. 1. These VPCIs were selected due to their easily availability, suitable vapor pressure, less toxic nature, high durability and cost effective nature.

Mild steel (ASTM-283) used for the investigation was in the form of sheet (0.025 cm thick) and had the following 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).

The mild steel coupons of dimensions 3.5 cm × 1.5 cm × 0.025 cm were used for different corrosion tests. Metal specimens were mechanically polished successively with the help of emery papers of grades 100, 200, 300, 400 and 600 micron and then thoroughly cleaned with plenty of triple distilled water (conductivity less than  $1 \times 10^{-6}$  ohm<sup>-1</sup> cm<sup>-1</sup>) and then with acetone. The specimens were dried with hot air blower and stored in desiccators over silica gel. Duplicate in some case triplicate experiment were performed to check the reproducibility of data.

Table 1. Names and structures of four VPCIs.

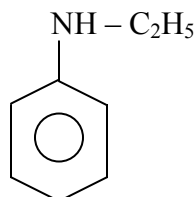
(i) Triethyl amine or N,N-Diethyl ethanamine (TEA) :



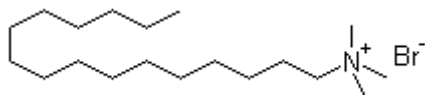
(ii) 1,3-Diamino propane or Propan-1,3-diamine (DAP) :



(iii) N-Ethylaniline (NEA) :



(iv) Cetyl trimethyl ammonium bromide or N,N,N-Trimethyl hexa deca ammonium bromide (CTMAB) :



## 2.1 Vapor pressure determination test

A standard Knudsen method [25] was used to determine the vapor pressure of all the four VPCIs. 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 air thermostat maintained at the constant temperature of 50°C for 10 days. Change in the weight of VPCIs was observed by the single pan analytical balance (0.01mg accuracy). Vapor pressure of all the four investigated VPCIs was determined by equation (1) and has been take in Table No. 2.

$$P = \frac{W}{At} \left[ \frac{2\pi RT}{M} \right]^{\frac{1}{2}} \quad \dots(1)$$

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

Table 2. Vapour pressure of all the four VPCIs

S. No.	Inhibitors	Vapour pressure (mmHg)
1.	TEA	$437.39 \times 10^{-2}$
2.	DAP	$178.92 \times 10^{-2}$
3.	NEA	$94.45 \times 10^{-2}$
4.	CTMAB	$40.93 \times 10^{-2}$

## 2.2 Weight Loss Technique

Weight loss experiments were carried out in an electronically controlled air thermostat (perfectly insulated) maintained at a constant temperature of  $50^{\circ}\text{C}$  with in an accuracy of  $\pm 0.1^{\circ}\text{C}$ . Four inhibitors named as TEA, DAP, NEA and CTMAB were placed separately in different isolated chambers in the air thermostat.

After recording the initial weights of mild steel specimens on a Mettler Toledo, Japan AB 135-S/FACT, single pan analytical balance, (with a precision of 0.01 mg), they were kept in different isolated chambers (perfectly insulated from each other) of air thermostat having fixed amount of VPCI at a constant temperature of  $50^{\circ}\text{C}$  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 digitally controlled humidity chamber maintained at 85% humidity at a constant temperature of  $50^{\circ}\text{C}$  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 (CR) in mils per year (mpy) and percentage corrosion inhibition efficiency (PCIE) were calculated using the equations (2) and (3) respectively [26].

$$\text{Corrosion rate (mpy)} = \frac{534 \times W}{D A T} \quad \dots(2)$$

Where,  $W$  = Weight loss (mg),  $D$  = Density of mild steel ( $\text{gm}/\text{cm}^3$ ),  $A$  = Area of specimen (sq. inch),  $T$  = Exposure time (hours).

$$\text{PCIE} = \frac{CR_{\text{Blank}} - CR_{\text{inhibitor}}}{CR_{\text{Blank}}} \times 100 \quad \dots(3)$$

Where,  $CR_{\text{Blank}}$  = corrosion rate in blank and  $CR_{\text{inhibitor}}$  = corrosion rate in presence of inhibitor.



### 2.3 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 50<sup>0</sup>C for duration of 10 days along with blank specimens. After exposing the specimens for 10 days, the specimens were taken out from the salt spray 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 (mpy) and PCIE were calculated using the equations (2) and (3), respectively.

### 2.4 Eschke Test

Eschke test was carried out on the pre weighed mechanically polished mild steel coupons as prescribed in the literature [27]. Kraft papers of suitable size were dipped in the VPCI for 30 second 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 transferred into the humidity chamber maintained at 85% relative humidity maintained at a constant temperature of 50<sup>0</sup>C for first 12 hours and 25<sup>0</sup>C for next 12 hours, alternately for 10 days. This temperature cycle was maintained in two sets because of formation and condensation of the vapors of VPCI on mild steel surface regularly. 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 (mpy) and PCIE were calculated using the equations (2) and (3), respectively.

### 2.5 Sulphur dioxide test

SO<sub>2</sub> test was carried out on the mild steel coupons of same dimension as in weight loss study. SO<sub>2</sub> gas was produced by dissolving 0.04 g of sodium thiosulphate in 30 mL aqueous solution of 1.0% NH<sub>4</sub>Cl and 1.0% Na<sub>2</sub>SO<sub>4</sub> solution and 0.5 mL of 1.0N H<sub>2</sub>SO<sub>4</sub> was added to the round bottom single neck flask. Definite amount of VPCIs were taken in a petridis and the flask, which is the source of SO<sub>2</sub>, were placed in the isolated chambers of air thermostat. Initially pre weighed and mechanically polished mild steel coupons were placed in air thermostat maintained at a constant temperature of 50<sup>0</sup>C for duration of 10 days. After exposing the specimens to acidic SO<sub>2</sub> gas for 10 days, the specimens were taken out from the air thermostat and treated in the same manner as in Salt spray method and Eschke test. Corrosion rate (mpy) and PCIE were calculated using the equations (2) and (3), respectively.

### 2.6 Metallurgical research microscopy technique

This technique is employed for the surface study of mild steel coupons to know about nature and type of corrosion using metallurgical research microscopy technique (CXR II from Laomed, Mumbai, India). The micrographs of the corroded specimens were taken after

exposure of 10 days. Micrographs of the blank mild steel coupons were also taken for the comparative study of metal specimen.

### 3. Results and Discussion

#### 3.1 Weight loss technique

The values of weight loss, corrosion rate and PCIE for all the four VPCIs were take in Table No. 3. Comparative chart of corrosion rate of all the four investigated VPCIs with the CR of blank specimen was take in Fig. No. 1. The corrosion rate is found to be almost negligible in the coupons of mild steel which were treated with TEA. PCIE of all the four investigated VPCIs are take in Fig. No. 2. It is clear from Table 3 that, TEA exhibit highest PCIE i.e. 92.74 for the mild steel under the atmospheric conditions at 50<sup>0</sup>C temperature and CTMAB shows minimum i.e. 44.70. PCIE follows the order as TEA > DAP > NEA > CTMAB.

Table 3. Weight loss (mg), CR (mpy) and PCIE of all the four VPCIs for mild steel at 50<sup>0</sup>C and 85% relative humidity after 10 days of exposure.

S. No.	Name of VPCI	Weight loss ( $\times 10^{-1}$ mg)	CR (mpy)	PCIE
1.	Blank	148	5.10	-
2.	TEA	11	0.37	92.74
3.	DAP	34	1.17	77.05
4.	NEA	44	1.51	70.39
5.	CTMAB	82	2.82	44.70

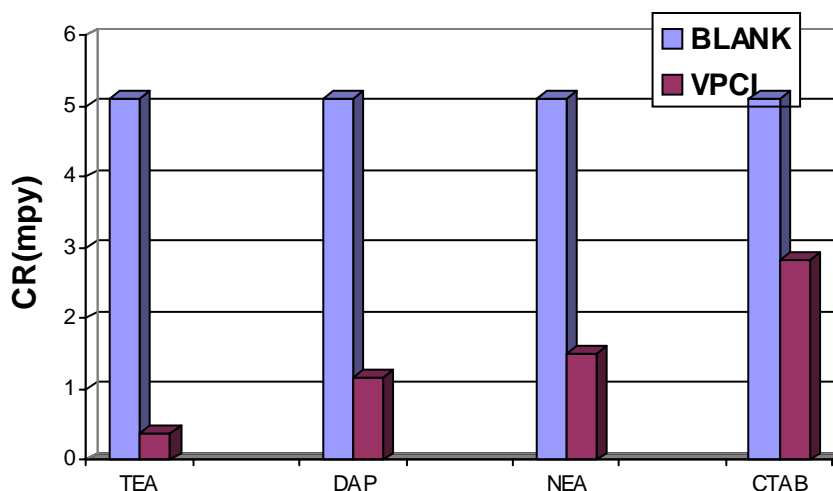


Fig. 1. Corrosion rate of mild steel coupons treated with VPCIs with respect to blank coupons obtained from weight loss technique.

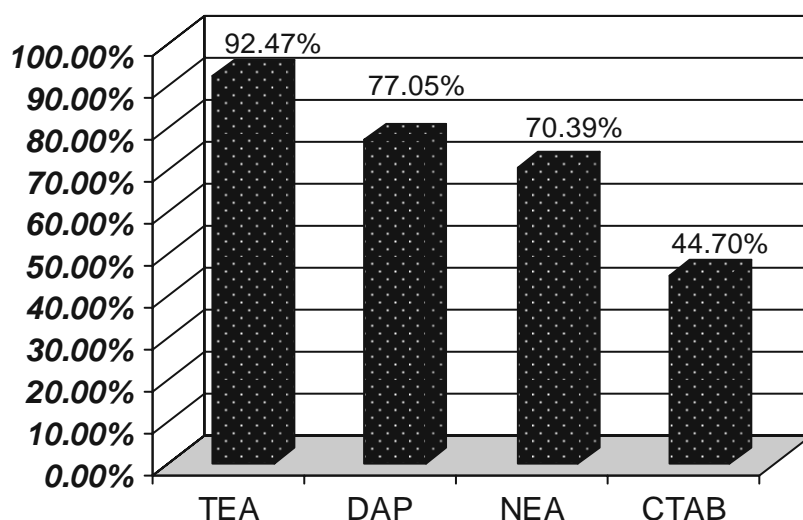


Fig. 2. PCIE of all the four VPCIs obtained from weight loss techniques for mild steel.

### 3.2 Salt Spray Method

Weight loss (mg), corrosion rate (mpy) and PCIE of all the four investigated VPCIs at a temperature of 50°C by salt spray method have taken in Fig. No. 3. As chloride ions are very aggressive from corrosion point of view, so a high corrosion rate was observed in salt spray method in comparison to weight loss method. All the four investigated VPCIs shows good corrosion inhibition efficiency even in this aggressive environment and at a high temperature of 50°C. The PCIE follows the same order as in weight loss method i.e. TEA > DAP > NEA > CTMAB.

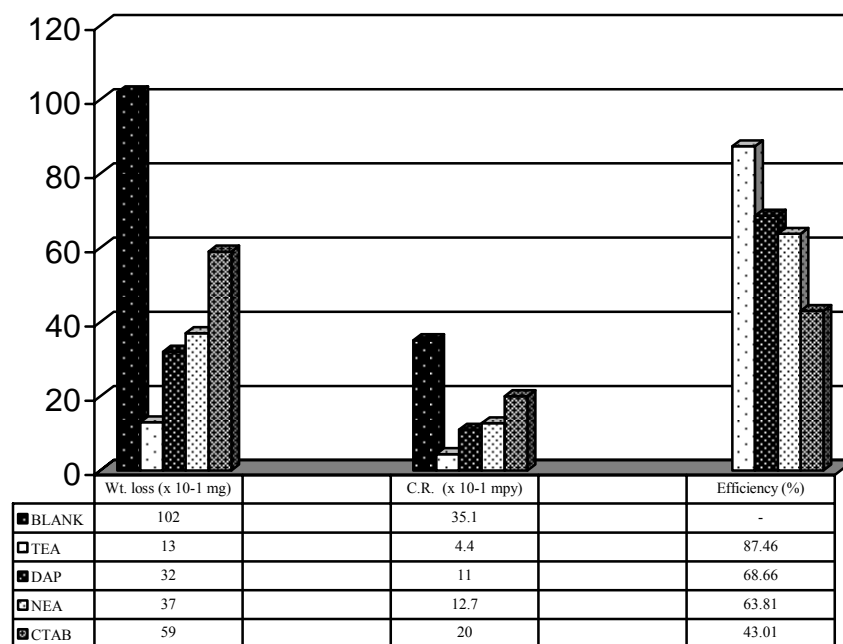


Fig. 3. Weight loss (mg), CR (mpy) and PCIE of all the four VPCIs obtained from salt spray method for Mild steel.



### 3.3 Eschke Test

Weight loss, CR and PCIE data of all the four VPCIs at 50°C after 10 days of exposure by Eschke test have been taken in Fig. No. 4. It is clear from the Fig. No. 4 that TEA shows 95.45% corrosion inhibition efficiency for mild steel. The PCIE follows the same order as in weight loss method and salt spray method i.e. TEA > DAP > NEA > CTMAB. Results of visual examinations of the mild steel coupons by Salt spray, Eschke test and SO<sub>2</sub> test were taken in Table No. 4.

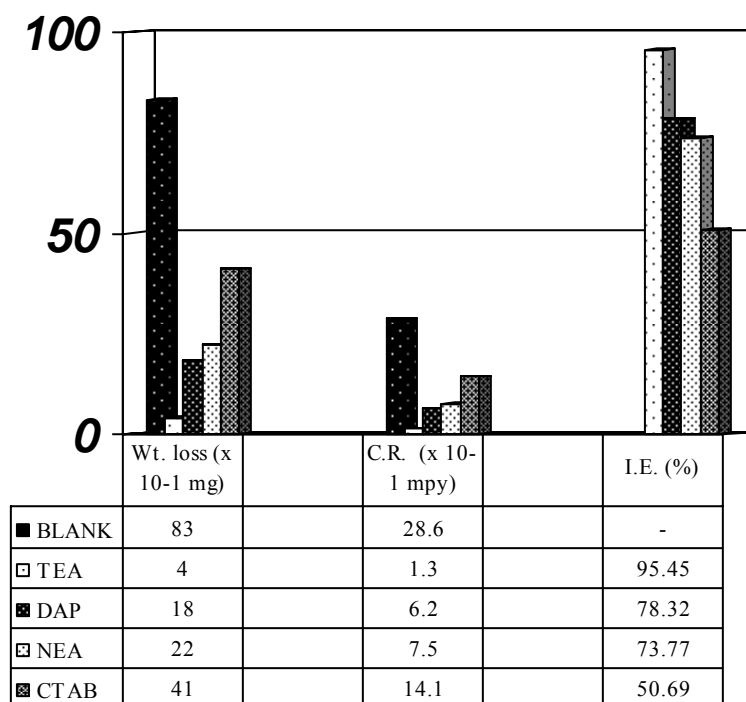


Fig. 4. Weight loss (mg), CR (mpy) and PCIE of all the four VPCIs obtained from Eschke test for mild steel.

Table. 4. Visual observations of surface of mild steel in presence and absence of VPCIs from different tests performed at 50°C.

VPCI	Salt Spray Method	Eschke Test	SO <sub>2</sub> Test
Blank	Pitting type of corrosion	Uniform corrosion	Pitting corrosion
TEA	Smooth surface	Smooth surface	Smooth surface
	No corrosion product	No corrosion product	No corrosion product
DAP	Slightly corroded	almost clean surface	Slightly corroded
NEA	Slightly corroded	almost clean surface	Few corrosion product seen
CTAB	3-4 spots of corrosion	Few corrosion product seen	4-5 spots of corrosion seen

### 3.4 SO<sub>2</sub> Test

Weight loss, CR and PCIE data of all the four VPCIs obtained from SO<sub>2</sub> test have been taken in Fig. No.5. Due to the acidic nature of sulphur dioxide gas, observed CR was very high in comparison to Eschke test. All the four VPCIs show good corrosion inhibition efficiency. The PCIE follows the same order as in weight loss method, Eschke test and salt spray method i.e. TEA > DAP > NEA > CTMAB. Results of visual examinations of the mild steel coupons by salt spray, Eschke test and SO<sub>2</sub> test were taken in Table No. 4.

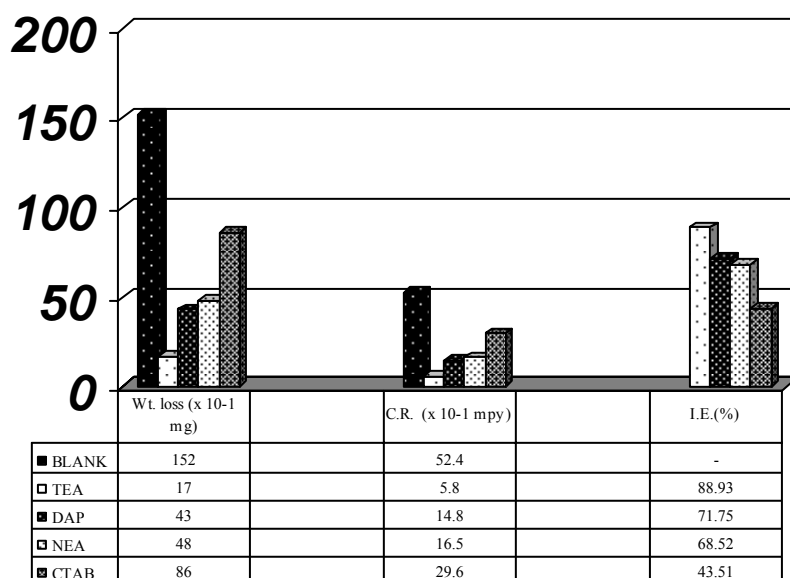


Fig. 5. Weight loss (mg), CR (mpy) and PCIE of all the four VPCIs obtained from SO<sub>2</sub> test for mild steel.

### 3.5 Metallurgical microscopy technique

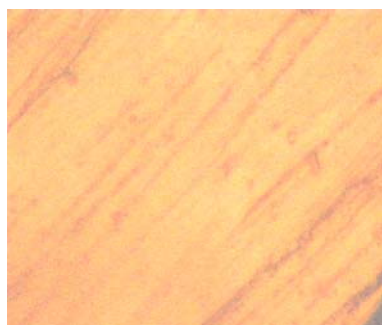
Metallurgical micrograph of mild steel coupons treated with different VPCIs by weight loss method after exposure of 10 days at 50°C have been taken in Fig. No. 6. Pits are clearly visible in the micrograph of blank sample showing pitting types of corrosion in absence of VPCI. The surface of mild steel coupon treated with TEA is very smooth and clear which confirms the high PCIE shown by TEA against the atmospheric corrosion. There is uniform type of corrosion on mild steel coupons treated with DAP and NEA.



(a) Blank mild steel coupon



(b) Blank mild steel coupon



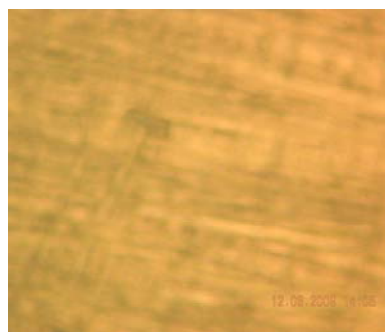
(c) Mild steel coupon treated with TEA



(d) Mild steel coupon treated with DAP



(e) Mild steel coupon treated with NEA



(f) Mild steel coupon treated with CTAB

Fig. 6. Metallurgical micrographs of mild steel coupons in presence and absence of different VPCIs.

#### 4. Mechanisms of Inhibition

Inhibitive action of VPCIs involves the vaporization of the VPCIs in non dissociated molecular form, followed by the adsorption of the vapors of VPCIs on the metal surface due to the presence of lone pairs of electrons on hetero atoms of inhibitor molecule. VPCI functions by forming a bond on the metal surface and by forming a barrier layer to aggressive ions. On contact with the metal surface, the vapors of the VPCI are condensed and are hydrolyzed by moisture to release protective ions. A VPCI must be capable of forming a protecting layer that limits penetration of the corroding species [28, 29]. The VPCIs investigated in present study inhibited corrosion of mild steel in one way or other:

- By saturating the space with their vapors and reducing the relative humidity below critical value.
- By alkalizing the medium to a pH value at which the rate of corrosion become significantly low.
- By reducing the corrosion current density to a minimum value by rendering the metal surface hydrophobic which prevented the reaction of metal with environment.

The presence of more number of lone pairs in the inhibitor enhances their inhibition efficiency but presence of unsaturation and bulky alkyl groups near lone pair carrier atom retard their action due the resonance stabilization and steric hindrance, respectively.

Very high PCIE shown by TEA may be due to the following reasons:

- 1) By saturating the space with their vapors (due to high vapor pressure) and reducing the relative humidity below critical value.
- 2) Due to presence of three electron releasing alkyl groups on nitrogen atom, which increases electron density on nitrogen atom and hence stronger adsorption to metal.

Low PCIE shown by NEA and CTMAB may be due to their low vapor pressure and resonance stabilization of lone pair of electrons on nitrogen atom by benzene ring in NEA and steric hindrance in CTMAB due to the presence of four alkyl group on nitrogen atom.

## 5. Conclusion

From the results of weight loss, salt spray, Eschke test and sulphur dioxide test, the following conclusion can be drawn.

1. All the four investigated VPCIs show good corrosion inhibition efficiency toward mild steel in different corrosive environment like very high relative humidity, 3.0% sodium chloride, acidic conditions (sulphur dioxide gas) and at a very high temperature i.e. 50°C.
2. Out of four investigated VPCIs, TEA shows best corrosion inhibition efficiency in different corrosive environment.
3. VPCI saturate the space with their vapors and reducing the relative humidity below critical value and also alkalize the medium to a higher pH value at which the rate of corrosion become significantly low.
4. Percentage corrosion inhibition efficiency was found to be in the order TEA > DAP > NEA > CTMAB in all the four corrosion experiments.
5. It was observed that nitrogen base CTMAB were ineffective (PCIE Approx. 45.0%) VPCI and strong bases of aliphatic compounds like TEA, DAP and NEA were effective (PCIE 70-95%) VPCIs for mild steel.
6. Results obtained from weight loss technique, Eschke test, SO<sub>2</sub> test, salt spray method are in good agreement with each other inspite of different corrosive environment and are further supported by surface study carried out by metallurgical microscopy technique.

## 6. Acknowledgment

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**Figure Captions:**

Fig. 1. Corrosion rate of mild steel coupons treated with VPCIs with respect to blank coupons obtained from weigh loss technique.

Fig. 2. PCIE of all the four VPCIs obtained from weight loss techniques for mild steel.

Fig. 3. Weight loss (mg), CR (mpy) and PCIE of all the four VPCIs obtained from salt spray method for Mild steel.

Fig. 4. Weight loss (mg), CR (mpy) and PCIE of all the four VPCIs obtained from Eschke test for mild steel.

Fig. 5. Weight loss (mg), CR (mpy) and PCIE of all the four VPCIs obtained from SO<sub>2</sub> test for mild steel.

Fig. 6. Metallurgical micrographs of mild steel coupons in presence and absence of different VPCIs.



## References:

1. 'Prediction of Corrosion Inhibition using Surfactants', M. L. Free, W. Klang, D. Y. Ryu, *Corrosion*, **60**, pp 837-844, 2004.
2. 'Corrosion Inhibition', I. L. Rozenfeld, McGraw Hill Inc, New York, 1982.
3. 'Organic inhibitors of Corrosion of metals', Y. L. Kuznestor, Plenum Press, New York p 70, 1996.
4. 'Principles and preventions of corrosion', D. A. Jones, 2<sup>nd</sup> ed., Prentice Hall, Upper Saddle River N J, p 503, 1996.
5. 'Corrosion Inhibition', J. L. Bregmann, Macmillan Co., New York, 1963.
6. I. L. Rosenfeld, *Proc. of the first International congress on metallic corrosion*, Butterworth, London, p 243, 1962.
7. 'Air Pollution', A. C. Stern., Academic Press, New York, p 149, 1968.
8. 'An overview: vapor phase corrosion inhibitors', A. Subrumanian, M. Natsen, V. S. Murlitharan, K. Balakrishan and T. Vasudevan, *Corrosion*, **56**, pp 144-155, 2000.
9. 'Corrosion Inhibitors Principles and Applications', V. C. Sastri, John Wiley & Sons, New York, p 787, 1998.
10. K. S. Rajgopalan and G. Ramaseshan, *J. Sci. Ind. Res.*, **19A**, pp 275-280, 1960.
11. 'Morpholine and its derivatives as Vapor Phase Corrosion Inhibitors for Mild Steel', A. Subrumanian, R. Gopalakrishan, C. S. Bhupati, K. Balakrishan, T. Vasudevan, M. Natesan, and N. S. Rengaswamy, *Bull. Electrochem*, **14**, pp 289-294, 1998.
12. K. Saurbier, V. Mandrof, G. W. Hchultze, J. Geke, J. Penninger and H. Robmeler, *Corros. Sci*, **33**, pp 1351-1359, 1992.
13. 'Derivatives of Cyclohexylamine and Morpholine as Volatile Corrosion Inhibitors', E. K. Vuarinew, P. Ngoben, G. H. Vander Klashorst, W. De Skinner and W. S. Ernst, *Br. Corros. J.*, **29**, pp 120-126, 1994.
14. I. Sekine, M. Sambongih, H. Hogiuda, T. Oshibe, M. Yuasa, T. Imohama, Y. Shibata and T. Wake, *J. Electrochem. Soc*, **139**, p 167, 1992.
15. 'Polyamino-benzoquinone polymers- A new class of corrosion inhibitors for mild Steel' S. Muralitharan, S. Pitchumani, S. Ravicahneran and S. V. K. Iyur, *J.*

- Electrochem. Soc.*, **142**, 1 pp 1478-1483, 1995.
16. 'Oligomeric Volatile Corrosion Inhibitors for Shipyard Installations', D. Q. Zhang and L. X. Gao, *Mater. Perform.*, **42**, pp 40-47, 2003.
  17. 'Synthesis and evaluation of some organic vapor phase corrosion inhibitors', M. A. Quraishi and D. Jamal, *Ind. J. Chem. Tech.* **11**, pp 459-464, 2004.
  18. 'Development and testing of all organic volatile corrosion inhibitors', M. A. Quraishi and D. Jamal, *Corrosion*, **58**, pp 387-391, 2002.
  19. 'Progress in Organic Coating', T. Tuken, Yazici and B. Erbil, **50**, p 115, 2004.
  20. M. Starostina, A. Smorodin, L. Galor, *Material Perform.*, **38**, p 52, 2000.
  21. 'Corrosion and its Control', S. Rajendran, B. V. Apparao and N. Palaniswamy, *Proc. of International Conference on Corrosion*, Mumbai, 1997.
  22. 'Prevention of Metallic Corrosion by Some Salts of Benzoic Hydrazide under Vapor Phase Conditions', M. A. Quraishi, V. Bhardawaj and D. Jamal, *Ind. J. Chem. Tech.*, **12**, pp 93-97, 2005.
  23. 'Chemistry Review in Corrosion', V. P. Persiantsava, Soviet Scientific Reviews of Moscow, OSSR, **8**, 2 p 64, 1987.
  24. A. Subrumanian, M. Natesan, K. Balakrishnan, and T. Vasudevan, *Bull. Electrochem*, **15**, p 54, 1999.
  25. 'Physical Chemistry through Problems' S. K. Dogra, S. Dogra, Wiley Eastern Limited, New Delhi, p. 231, 1986.
  26. 'An Introduction to Metallic Corrosion and its Prevention' R. Narayan, 1<sup>st</sup> ed, Oxford and IBH, 1983.
  27. 'Test methods for Vapor Corrosion Inhibitors', A. Furman, C. Chandler, *Proc. 9<sup>th</sup> Eur. Sym. Corros. Inhib.*, Ann. Univ., **11** p. 465, 2000.
  28. S. A. Baligim, *Compets Rendus de 2eme Europeen Symposium Sur Les Inhibiteurs de Corrosion*, Ann. Univ. Ferrara, N.S, 1996.
  29. I. L. Rosenfeld, V. P. Persiantseva, M. N. Polteva, *Inhibitors*, National Association of Corrosion Engineers, pp 606-609, 1972.