Warm Hydrocarbon Gas Flare Burners - Corrosion Analysis

P. N. Atamuo, *Member IAENG*, Gbasouzor Austin Ikechukwu, *Member IAENG*, G. M. Onyegbuchule and A. U. Iwuoha

Abstract – **In Nigeria Oil/Gas industry, crude oil receiving stations have with them gas flaring facility to burn away the associated gas which follows the crude oil to the stations. Some of these gas flaring facilities are fabricated with stainless steel (SS), typically of the 400 series which from experience have yielded to corrosion earlier than calculated/estimated. Replacements with unscheduled costs have been made on these burners that failed due to scaling, flaking, pitting, material loss and smoking. A study is made here of the resistance of other grades of AISI SSs to determine their resistance to the corrosive flare environment and hence their effectiveness as burners in the flare stack for longer service life, thus minimize costs by lengthening the replacement time and prevent production shut-ins. In this service domain, the grades of SSs with higher quantities of chromium, nickel and silicon produced in the cast state as against the wrought state showed higher corrosion resistance and service stability. The alloying elements must be balanced to preserve the austenitic structure required for the high temperature service of the final product.**

***Keywords*: AISI (Types 312, 347, 410, 446) SSs, 4130 Carbon Steel, Corrosion, Environment, Scaling, Stainless Steel.**

I. INTRODUCTION

In Nigeria Oil/Gas industry, crude oil flow stations are usually integrated with a flare system to burn out the natural gas which accompanies the oil to the surface. The associated hydrocarbon gas is typically of the $C_{1\text{-}6s}$. This gas is flared because most times it is not utilized except in some cases of gas injection to the reservoir to assist pressure-dropping wells or back into aquifers for storage. Various flare system designs exist: horizontal, inclined, and vertical; all with a flare header and burner. The burners are of heat/corrosion -resistant stainless steel grade typically of the AISI 400 series. This grade of SS has shown remarked corrosion in service; and that have resulted in flow/flame distortions and burner collapse. Occasionally crude oil is burnt in these flare systems as a result of "carry-overs" due to operational surges. With the corrosion experienced, there became the need to analyze/find replacement burner materials to provide higher efficiency and longer service time.

P. N. Atamuo, MIAENG is the Dean, Faculty of Engineering, Anambra State University, P. M. B. 02 Uli, Nigeria

Gbasouzor Austin Ikechukwu, MIAENG is a Lecturer in the Department of Mechanical Engineering, Anambra State University, P. M. B. 02 Uli, Nigeria. e-mail: unconditionaldivineventure@yahoo.com
Phone: 2348034247458, 2348063896067, 2348028283035

G. M. Onyegbuchule
Department of Mechanical Engineering
Imo State University, Owerri, Nigeria

A. U. Iwuoha
Department of Mechanical Engineering
Imo State University, Owerri, Nigeria

II. THEORETICAL BACKGROUND

Stainless steels technically are called heat and corrosion resistant steels. This is so due to their higher resistance to corrosion and a higher resistance to scaling at high temperatures. The resistance is achieved by the formation of an invisible adherent chromium-rich oxide on the surface as a membrane. The oxide is formed in the presence of oxygen. In general, stainless steels are iron-based alloys containing at least 10.5% chromium. Other elements may be added to improve characteristics such as nickel, molybdenum, copper, titanium, silicon, niobium, selenium. Carbon is from less than 0.03% to more than 1.0% in certain grades.

The common groupings for stainless steels are: Martensitic, Ferritic, Austenitic, Duplex (Ferritic Austenitic), and Precipitation Hardening. Austenitic stainless steels are usually suitable for both cryogenic and high temperature service. (Parmar, R. S., 2007).

Effects of Alloying Elements on Steels

Nickel: This has the impart of increasing the strength and toughness of the steel. Generally it combines higher strength level and hardness with enhanced elastic limit, good ductility as well as high resistance to corrosion and creeping at elevated temperatures.

Chromium: Generally the addition of this element improves hardness, strength and elastic properties. The great purpose is that it serves to impart corrosion resistance to steel both at low and high temperatures. Steels combined with chromium and nickel are extensively used in the automobile and oil/gas industries.

Manganese: It improves the strength of the steel be it in the hot rolled or heat treated condition,

It is usually added in small amounts. The main uses of manganese steels are in machinery parts serving heavy wear operations as in gears and splines. These steels come in the cast state and are generally ground to finish.

Silicon: They are like nickel steels. Possess high elastic properties compared to ordinary carbon steels. Steels combined with silicon are employed in services requiring resistance to corrosion.

Tungsten: Inhibits the growth of grains; it increases the depth of hardening of quenched steel and stabilizes the property of hardness even when heated to become red hot. Tungsten combined steels are used in the machine tool industry as well as some aspects of the electrical industry.

Vanadium: Vanadium aids in obtaining a fine grain structure in the steel. Addition of small amount of vanadium (about 0.2%) achieves quite a high increase in tensile strength and elastic strength in low and medium grade carbon steels without appreciable reduction in ductility.

Molybdenum: A very small amount of molybdenum is added with chromium and manganese to form molybdenum steels. They possess extra high tensile strength and have anti-creep properties at high temperatures, thus the steel helps to stabilize chrome nickel steels at elevated temperatures.

Steels that must be resistant to creep at high temperatures must contain molybdenum, silicon and chromium. These impart on their resistance to oxidation and scaling at high temperatures.

The steels that are satisfactory up to 700 °C working temperatures are: C = 0.15% maximum, Mn = 0.5% maximum, Cr = 1.0 - 6%, Mo = 0.50%, Si =0.5 - 2.0%, Ni = 0%. These are useful particularly for the valves of internal combustion engines. For temperatures of up to 1000 °C, steels of composition: nickel = 22% and chromium = 26% are used. These fall in the stainless steel group with not so-good mechanical properties at high temperatures. For good resistance to creep at 650 ^{0}C, 20% molybdenum is added. (Davies, D. J. and Oelmann, L. A., 2000).

III. METHODOLOGY

A chemical composition analysis with Belec 2000 Analyser was performed to determine the elemental composition of the burner material and this was compared with the AISI grades. The governing flare stacks and burners design relations were considered and matched with the facility to determine service requirements level. A theoretical analysis of the requirements of materials suited for resistance to corrosion in such environment was performed and based on that, it was hypothesized that the material chosen was not suitable for the service and new ones were considered relying on the strength of the higher contents of Si, Cr and Ni to provide the desired results. Further, experimental tests based on pitting and "weight loss" were carried out to evaluate the corrosion resistance of the chosen materials in the operating environment. This was based on ASTM G46 and G48, The software "Statistics" was used to interpret/evaluate the results of the laboratory data. Both visual and metallurgical examinations were made on the corroded burners for any useful facts, for instance intergranular corrosion due to loss of alloying element.

Flare Service Description

Fig. 1: Flare stack operating with corroded burners

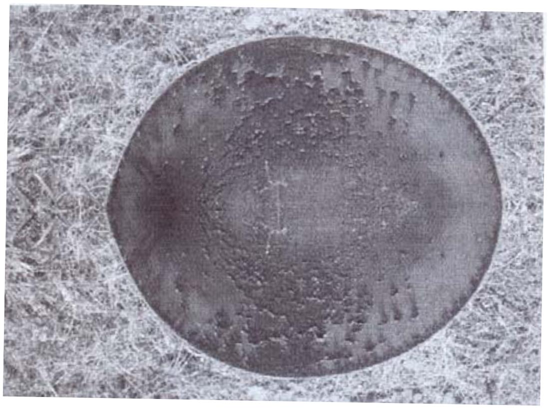

Fig. 2: Burner showing corroded internals

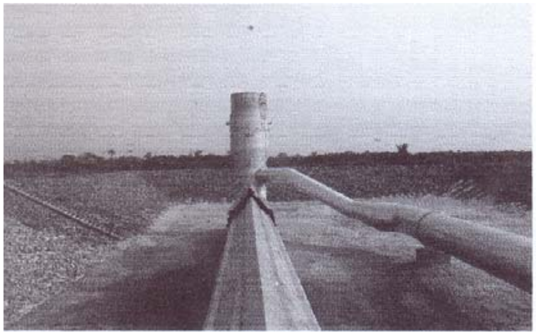

Fig. 3: Flare Stack with AISI 446 SS Burner ready for Service.

Fig. 4: Flare Stack with AISI 347 SS Burner in Service.

In-coming crude oil with associated gas are gathered into receiving tanks where the gas naturally settles above the oil and are channeled to the bulk flare header. Before the Hare stack is installed a liquid knock out vessel where any entrapped liquid is removed and pumped back to the tanks. The gas leaving the knock out vessel is directed to the flare stack where it is streamed into the stack header 950 cm above an air line. The air is made available by an air generating facility positioned away from the flare stack and moved by a blower into the 90 cm line connected to the base of the flare stack. The normal operating conditions of the burner are 4-6 Bars gauge (4-6 Barg) at 32-37 °C. Before reaching the flare burner, the gas and air nave formed a combustible mixture and thus freely burns at the burner. The flare header is fabricated from AISI type 4130 carbon steel while the burner is made with AISI type 410 stainless steel for corrosion resistance. The volume rate through the header and burner is 12.2 x 106 SCMD.

ISBN: 978-988-19252-9-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Flare stack is 80 cm ID x 4.5 m height with the burner jacketed in the stack. Both are located within a bund wall to trap any occasional crude oil spill due to "carry over." Any liquid carried over to the stack is sprayed and burnt.

Pitting Resistance Equivalent Number (PREN)

As a way of mathematical modeling, PREN was devised and has been found useful in providing a good approximation of the pitting resistance of stainless steels. PREN can be calculated as:

PREN = %Cr + 3.3 x %Mo +16 x %N

Treseder, 1983)

Usually once pitting has commenced in a material, it has the tendency to progress at the point though the remaining part of the material may remain intact. This makes it particularly serious. A number of laboratory tests are handy to evaluate the tendency of a particular steel to be attacked by pitting corrosion. One of the commonly used is the ASTM G48.

Examination of Corroded Flare Burners
The corroded flare burners were examined visually and metallurgically.

Visual Examination

- No signs of erosion were identified in the corroded burners. This suggests the material used was not unsuitable for the velocity regime (70m/s) of the existing flare gas/air mixture.
- Majority of the diffusers and vanes of the burners were broken off and some missing. This is an indication that material of lower yield strength was used for the bending and dynamic stresses generated in the service burners. (Clifford, 1998).
- There were large amounts of metal flakes and scales and thus general material loss of the burners. An indication of low resistance to corrosion damage due to low level of chromium for such service environment. (Fontena, and Stachle, eds. 2005).
- On the main body side of the burners, pitting corrosion as widespread and deep.

Metallurgical Examination

- A chemical composition analysis showed that the flare burner material was the same in composition with AISI Type 410 specified. (See Table III).

- Metallurgical examination of pitted regions showed the pits to be "narrow, deep" and "undercut". ISO 7539-1: 1987. This is further indication of very low material resistance to corrosion in the operating environment.
- Deep cracks were observed at the base of the weldments of the remaining diffusers and vanes, an indication of material overload i.e. material choice and weldments were lower in strength than required for the service load. (Cragnolino, G., Dunn, D. S. Sridher, N. 2006).
- The cracks equally suggest that the weldments may not have experienced the desirable post-weld heat treatment. (Parmar, R. S., 2007).
- The crack direction was observed towards the inner portion of the metal as against running along the surface.

IV. EXAMINATION RESULTS

See Table IV below.

Materials Recommended for the flare burners
Based on the results of the analysis, the following materials were recommended for the flare burners: **Material A:** AISI Type 312 SS; **Material B:** AISI Type 347 SS and **Material C:** AISI Type 446 SS. The recommendations were implemented. Replacement flare burners were produced with the recommended materials and were installed/put to use. The actual elemental composition of these grades of steel used for the production of the new replacement burners are listed in Table below alongside their AISI standards. Table VII lists the new burners service data after installation and use.

Data

[ ] Design condition [X] Test condition

Specific gravity of liquid, G:	1.0
Corrosion allowance:	0.0 mm
Tank diameter, D:	6.0 m
Total height of tank, H:	4.0 m
Number of courses:	3
Allowable stress for design, Sd:	-
Allowable stress for testing, St:	208 MPa
Height of bottom course, h1:	1,300mm
Nominal tank radius, r:	3,000mm

Calculations

Visual and Metallurgical Examinations of Weldments
Sections were cut from the unfailed weldments of the vessels and subjected to visual and metallurgical examinations.

Visual Examination

- Dye-penetrant examination of cut sections of the revealed cracks.
- The weldments revealed deep cuts. This is usually an effect of poor surface- grinding after welding.
- The unfailed sections of the base metal and we1dments showed pitting corrosion attack. See Figure 4. The depths of pits are environment. This is normal for the metal in the exposed environment.

Metallurgical Examination

- A chemical composition analysis (see Table VIII) showed that the material is not different from that specified (Mild Carbon Steel). This is inacceptable within the industry standards.
- Metallurgical examination of a section of the failed vessel identified fatigue cracks, which extended into the bulk of the material. This is traceable to the vibration load imposed by the adjacent pipeline escorting gas (gas excursion) to the flare stack.

ISBN: 978-988-19252-9-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Tensile Test

The tensile of the weld, including fusion zone of the specimen shall be greater than or equal to the specified minimum tensile strength of the vessel or pipe material but need not be greater than or equal to the actual tensile strength of the material (API 1104, 2000).

Nick-Break Test

The results of the Nick-Break test (exposed surfaces of each fractured specimen) showed evidence of lack of complete penetration and fusion in the weldments, there was gas pocket in excess of 1.6 mm in the weldment. The acceptance limit for gas pockets in the weldments is less than 1.6 mm (API 1104, 2000).

V. CONCLUSIONS

The following are the conclusions from the study and tests:

- The most stable SSs in the flare corrosive environment are the ones with higher quantities of nickel, chromium, silicon produced in the cast state as against the wrought state.
- The alloying elements must be balanced in quantities to preserve the austenitic structure of the final alloy material product.
- The inferiority suffered by ferritic stainless steel during welding can be mitigated by addition of a litt1e molybdenum element (generally in the range of 0.02 - 0.035).
- Further study is required for the situation where the flaring environment is further compounded by salty atmosphere, for instance off shores.
- Design errors were responsible for the premature failure of the settling tanks: 1) The choice of shell plate material thickness was inadequate to bear the service loads imposed on the vessels. 2) The welding procedure specification used did not produce the design mechanical properties required to withstand the service stress. The tensile tests and Nick Breaks tests results of the cut out weldment provide confirmations.
- The same plate thickness was used for all the courses of the shell -there should be different plate thickness for the different shell courses.
- The welding workmanship was responsible for the porosities and cracks detected in the weldments. These porosities and cracks served as spots of weakness, the weakness was exaggerated on exposure to the circumferential stresses in the vessels induced by the stored product.
- Visual examination of the weldments revealed deep cuts. This is usually an effect of poor surface- grinding after welding.
- The vessel was subjected to vibrations and the effects of fatigue were not considered in the design.
- The result of the chemical compositional analysis (shown in Table VIII) of the vessel material was not different from mild grade specified, i.e., mild carbon steel. Generally this grade is within the industry standard.

Table I: Flare Burners Physical Data (Average for the Four Units)

Position above ground	4.5 m above the ground.
Internal Diameter	80cm.
Flare Stack Material	AISI Type 4130 Carbon Steel.
Flare Burner Material	AISI Type 410 Stainless Steel.

Table II: Corroded Flare Burners Service Data

Unit	1	2	3	4
Service Time (Months)	48	54	40	58
Flare Gas	Warm Natural Gas	Warm Natural Gas	Warm Natural Gas	Warm Natural Gas
Normal Operating Temperature	33°C	37°C	32°C	35°C
Normal Operating Pressure	4-6 barg	4.5-5.5 barg	5-6 barg	4-6 barg
Gas Exit Velocity at Flare Burner	70 m/s	72 m/s	70 m/s	68 m/s
Environment	Free Atmosphere	Free Atmosphere	Free Atmosphere	Free Atmosphere
Duty Cycle	Continuous	Continuous	Continuous	Continuous
Duty History	2 shut downs of 48 hrs and 20 hrs. Otherwise continuous in service, experienced occasional liquid flaring due to "carry-overs".	3 shut downs of 48 hrs, 38 hrs and 30 hrs. Otherwise continuous in service, experienced occasional crude oil flaring due to "carry-overs".	Continuous in service, experienced occasional crude oil flaring due to "carry-overs".	4 shut downs of 64 hrs, 20 hrs, 20 hrs and 18 hrs. Otherwise continuous in service.

ISBN: 978-988-19252-9-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Table III: Chemical Composition of Flare Burner Material: AISI Type 410 Stainless Steel.

Element	Flare Burner Material (% by mass)	AISI Type 410 Material (% by mass)
Carbon	0.17	0.15
Silicon	1.35	1.50
Manganese	1.00	1.00
Sulphur	0.035	-
Nickel	1.00	1.00
Molybdenum	0.45	0.50
Phosphorus	-	-
Chromium	12	11.5-14
Iron	Remainder	remainder

Table IV: Results of Examination of Flare Burner Units 1 to 4.

Flare Burners: Units 1, 2, 3 and 4	Findings	Conclusion
Flare Burners: Units 1, 2, 3 and 4.	No signs of erosion were identified in the corroded burners.	The material used was not unsuitable for the velocity regime of the existing flare gas/air mixture.
Flare Burners: Units 1, 2, 3 and 4.	Majority of the diffusers and vanes of the burners were broken off and some missing.	Indication of lower yield strength of the material compared to stresses generated in the burners. (Clifford, M., A. (1998).
Flare Burners: Units 1, 2, 3 and 4.	Large amounts of metal flakes and scales and thus general material loss of the burners.	Low resistance to corrosion damage due to low level of chromium for such service. (Fontena, M. G. and Staehle, R. W. eds., 2005).
Flare Burners: Units 1, 2, 3 and 4.	Chemical composition analysis showed that the flare burner material was the same in composition with AISI Type 410 specified. (Specified Table III).	Inadequate amounts of Ni and Cr produced low corrosion resistance values and stability at the operating conditions.
Flare Burners: Units 1, 2, 3 and 4.	Metallurgical examination, of pitted regions showed pits to be "narrow, deep" and "undercut." ISO 7539-1: 1987.	Further indication of very low material resistance to corrosion in the operating environment.
Flare Burners: Units 1, 2, 3 and 4.	Deep cracks observed at the base of the weldments of the remaining diffusers and vanes.	Indication of material overload i.e. material choice and weldments were lower in strength than required for the service load. (Cragno1ino, G., Dunn, D. S. Sridher, N. 2006).
Flare Burners: Units 1, 2, 3 and 4.	The crack direction was observed towards the inner portion of the metal as against running along the surface.	Material of weak strength used in a higher stress operating envelop.

Table V: Chemical Composition of Recommended Flare Burner Materials:
AISI Types 312, 347 and 446 (Cast Grades) SS. Treseder. R S. (ed), (2000).

Element	Material A: Type 312		Material B: Type 347		Material C: Type 446	
	Flare Burner Material (% by mass)	AISI Type 312 Material (% by mass)	Flare Burner Material (% by mass)	AISI Type 347 Material (% by mass)	Flare Burner Material (% by mass)	AISI Type 446 Material (% by mass)
Carbon	0.30	0.30	0.09	0.08	0.55	0.50
Silicon	2.10	2.00	2.15	2.00	1.45	1.50
Manganese	1.50	1.50	1,45	1.50	1.10	1.00
Sulphur	-	-	-	-	0.025	-
Nickel	10.5	8-11	1.1	9-12	4.50	14.00
Molybdenum	-	-	-	-	-	-
Phosphorus	-	-	-	-	-	-
Chromium	28.5	26-30	19.5	18-21	28	26-30
Iron	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder

ISBN: 978-988-19252-9-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Table VI: Mechanical Properties* of the Stainless Steel (Cast Grades) Treseder, R.S. (ed.), (2000).

Stainless Steel Grade	Tensile Strength Mpa	Yield Strength Mpa	Elongation %	Hardness (Brinell)
AISI Type 410	483	310	25	147
AISI Type 312	669	434	18	190 '
AISI Type 347	531	262	39	149
AISI Type 446	669	448	18	210

Typical room temperature properties for solution annealed material

Table VII: Recommended Flare Burners Service Data. *Source: Facility Daily Operations logbook.*

Unit	1	2	3	4
Flare Burner Material	AISI312	AISI347	AISI 446	AISI 446
Service Time (Months)	66+	66+	48+	68+
Flare Gas	Warm Natural Gas	Warm Natural Gas	Warm Natural Gas	Warm Natural Gas
Normal Operating Temperature	33°C	37°C	32°C	35 °C
Normal Operating Pressure	4-6 barg	4.5-5.5 barg	5-6 barg	4-6 barg
Gas Exit Velocity at Flare Burner	70 m/s	72 m/s	70 m/s	68 m/s
Environment	Free Atmosphere	Free Atmosphere	Free Atmosphere	Free Atmosphere
Duty Cycle	Continuous	Continuous	Continuous	Continuous
Duty History	Continuous in service. Removed from service and inspected after 48 months: no pitting, scaling, flaking, material thinning observed. Returned to service and planned for inspection after another 48 months.	Continuous in service. Removed from service and inspected after 48 months: minor pitting observed, no scaling, flaking, material thinning observed; Returned to service and planned: (or another inspection after 48 months	Continuous in service. Removed and inspected after 40 months. No pitting, scaling, flaking, material thinning observed. Returned to service and planned for inspection after another 40 months.	Continuous in service. Removed and inspected after 48 months. No pitting, scaling, flaking, material thinning observed. Returned to service and planned for inspection after another 48 months.

Table VIII: Chemical Composition of Settling Vessel Material.

Element	Settling Vessel Material (% by mass)	Low Carbon Steel (% by mass)
Carbon	0.28	0.30
Silicon	0.20	0.30
Manganese	0.90	1.00
Sulphur	0.04	0.05
Phosphorus	-	0.05
Iron	remainder	remainder

ISBN: 978-988-19252-9-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

REFERENCES

[1] API Specification 12 D: Specifications for Field welded Tanks for Storage of Production Liquids, Washington D. C. 2007.
[2] API Standard 620: Recommended Rules for Design and Construction of Large Welded Low Pressure Storage Tanks, Washington D. C. 2007.
[3] API Standard 650: Welded Steel Tanks for Oil Storage. Ninth Edition, Addendum 1 -1994, Addendum 2 -1995, Addendum 3 -1996, Washington D. C., 2007.
[4] API Standard 653: Tank Inspection, Repair, Alteration and Reconstruction, Second Edition; Errata February 1996, Errata May 1996, Follow Up to Errata May 1996, Addendum 1 - December 1996, Washington D. C., 2007.
[5] ASME SEC IX: BPVC SECTION IX Qualification Standard for Welding and Brazing Procedures, Welders, Brazers and Welding and Brazing Operators Addenda -1995; Addenda
[6] ASME SEC VIII: Unfired Pressure Vessels, New York, 2008.
[7] ASNT RP SNT-TC-IA: Test Method for Surface Flaws in Tank Shells, Recommended Practice
[8] Avallone, E.A. and Baumeister III, T. (eds.), (1996). Marks Standard Handbook for Mechanical Engineers, 10th ed., McGraw-Hill, New York.
[9] Benham, P. P. and Warnock, F. V., Mechanics of Solids and Structures, S. I. Units, Pitman,
[10] Blodbett, Omer W., Design of Welded Structures, James F. Lincoln Arc Welding Foundation, BS 7777: Flat Bottomed, Vertical Cylindrical Tanks for Low Temperature Service.
[11] Cihal, V. (2002). Intersemiles Corrosion of Steels and Alloys, Elsevies Science Publishers, B. V. Cleveland, Ohio. 1970.
[12] Clifford, M., A. (1998). Practical Guide to Engineering Failure Investigation, 1st ed., Professional Engineering Publishing Limited, London.
[13] Cragnolino, G., Dunn, N. S. Sridher, N. (2006). Environmental Factors in the Stress Corrosion Cracking of Type 316 Stainless Steel in Chloride Solutions, NACE Corrosion Journal.
[14] Davies, D. J. and Oelmann, L. A., (2000). The Structure, Properties and Heat Treatment of Metals, Pitman, London.
[15] Fontena, M. G. and Staehle, R. W. eds., (2005). Advances in Corrosion Science and Technology, 3. Pg. 369, Pienum Press, New York, NY.
[16] Fuchs, R.O. and Stephens, R. I., Metal Fatigue in Engineering, John Wiley, London 1980.
[17] GPSA, 12th edition, (2004). Engineering Data Book, SI Version, Vols I and 2, Oklahoma.
[18] ISO 3651-2: 1998. Determination of Resistance to Intergranular Corrosion of Stainless Steels -
[19] ISO 7539-1: 1987. Corrosion of Metals and Alloys Stress Corrosion 'resting - Part 1: General Guidance on Testing Procedures.
[20] ISO 8044: 1999. Corrosion of Metals and Alloys, Basic Terms and Definitions.
[21] Jarman, R. T. and Turville C. M. (1983). Condensation of Flue Gas Vapours in Ducts and Chimers. Atmospheric Environments, Pg 1837, No 9, Vol 17.
[22] Kadry, S. (2008). Corrosion Analysis of Stainless Steel, European Journal of Scientific Research, Pg. 508-516, Vol 22, No.4.
[23] Khurmi, R. S., Strength of Materials, (Mechanics of Solids), S. I. Units, S. Chand and Company, New Delhi, 2008.
[24] Nash, W. A., Strength of Materials, S. I. (metric) edition, Schaum Outline Series, McGraw-Hill Books, New York, 2009.
[25] Parmar, R. S., (2007). Welding Engineering and Technology, Khanna Publishers, New Delhi.
[26] Pennwell, M. D., (ed.), (1999). Offshore Oil and Gas Journal, Vol 5, Issue 11, Pennwell Publishing Company, London.
[27] Rajput, R. K., Strength of Materials (Mechanics of Solids), S. T. Units, S. Chand and Company, New Delhi, 2008.
[28] Timoshenko, S. and Young, W., Elements of Strength of Materials, S. I. Units, MacMillan Press, London, 1991.
[29] Treseder, R. S,(1983). NACE Corrosion Engineer's Reference Book, National Association of Corrosion Engineers, Houston, Texas.
[30] Umezurike, C. (2001). Engineering Materials Design: Properties, Selection and Uses, 1st ed., Pam Unique Publishers, Port Harcourt.
[31] Yamanaka, K. and Kowaka, M. (1998). Corrosion Engineering Japan, 32, Pg. 23-31.
[32] Zick, L. P. and R.V. McGrath, R. V., Design of Large Diameter Cylindrical Shells, Proceedings-Division of Refining, American Petroleum Institute, Volume 48, pp. 1114-1140, New York, 1968.