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Model of Corrosion Rates in Refinery Boiler Components (Bafflewall Tubes, Vapourizing Tube Bank and the Superheater Coils)

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ABSTRACT

This paper predicted the corrosion rates of three refinery boiler components namely: Baffle wall tubes, vapourizing tube bank and the superheater coils, using a mathematical model developed from the balance equation of the refinery boiler. The results obtained were then compared those already measured by Ultrasonic Thickness Scanning Technique (UTS). The essence is to determine if the prediction equation can be useful in predicting the life expectancy of the various boiler components. The prediction was done for a period of four years. Metal loss recorded for Baffle Wall Tubes was 0.10 mm to 1.10 mm from UTS, while the one from the model was 0.11 mm to 0.98 mm. Metal loss recorded for vapourizing tube bank was 0.06 mm to 1.00 mm from UTS and that from the model was 0.05 mm to 0.98 mm. Metal loss recorded for superheater coil was 0.026 mm to 0.67 mm. The percentage deviation calculated between the model and that from UTS showed a correlation between the rates observed by the different measurement tools. The introduction of the inhibitor model indicated that inhibitor application can greatly reduce the corrosion rates of the refinery boiler's components. The paper has also shown that the mathematical predictive model can be used to predict the corrosion rates of the internal boiler components as compared to the recorded readings of the Ultrasonic Thickness Scanning Technique.

INTRODUCTION

In the oil and gas production industries, there is the regular problem of internal corrosion or deterioration of carbon steel equipment and facilities, which are designed to last for a long time in the operations processes. In order to solve this problem, many corrosion control programs has been put in place and also many researches has been sponsored to put this problem under check the world over [1]. The refinery boiler is not an exception to this fact. A concerted effort is actuality made to reduce boiler tube failure events. Boiler tube disappointments has continued to be the one principal source of forced power outages in industries that use steam type generators for electrical services. Complete Elimination of boiler tube disappointments could amount to millions of dollars annually to the industry. If the major problems that leads to boiler tube operation failures (corrosion and sealing) could be reliably predicted a long time before the event, then a contingency plan could be put in place to forestall the shutdown or power outage problems [2]

Corrosion (deterioration), fouling and occasional failure of the heat-exchanger tubing of which the boiler walls is made of is the greatest obstacle to reducing boiler breakdown. Parts of high corrosive action tend to be fairly localized, although these locations can change as a result of variations in mill and burner patterns, and also because of flow within the boiler units [3]. Process units in the boiler are affected by severe corrosion occurrences that resulted from the hot steam and condensate water that passes through the system unit in large volumes daily.

The major function of the boiler, a known important equipment in the Engineering process department of the refinery, is for the generation of steam which runs the turbine so that electricity is generated. Therefore, the need arises for proper prevention of the boiler from corrosion attack so that the corrosion attack of the various boiler components can be minimize, so that the boiler can work optimally. Hence the development of this model to monitor the internal corrosion of the boiler compartments and to know the degree of metal loss at any given time.

It is a known fact that normally, predictions are prepared manually based on surveys of the thickness of equipment walls) of probable tube wall metal loss before the next major power outage. When the outcome of the prediction of the loss showed that the remaining wall thickness is below the minimum requirement, then tubes must be replaced or perhaps a protective coating device is added to enable longer lifespan [3]. Different attempts have been made put in place to provide a mathematical model or equations that can predict some of these corrosion processes, but in most cases, the practical value of these model equations when put to the real practical situations are not absolutely reliable. Other factors that affects corrosive disintegration of metals high heat fluxes and the deposition of unburned carbon [4].

Practically, the quality of corrosion models cannot be separated from the theory on which they were formulated, which are expressed in terms of mathematical equations and made known to us by user-interfaces.

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However, the basis on which any model, theoretical or empirical, can be trusted is through experimental verification or proofs. This verification generally comes in the form of data collected normally in a laboratory experiment and in some cases from data obtained from field work or real life situations [5]. This model is developed from ordinary differential equation, using material balance equation of the boiler to test the corrosion rates measured by Ultrasonic Thickness Scanning Technique (UTS) of three compartments, which are; Baffle wall tube, vapourizing tube bank and super heater coils to see if they correlate.

MATERIALS AND METHODS

Corrosion data was obtained from the refinery. The material balance equation was the starting point of the model equation. The material balance equation is as follows.

Corrosion rate = Inflow rate of Material into The System + Chemical generation rate of reaction within the system - Consumption rate of corrosion inhibitors - Rate of outflow materials from the system

The data obtained was subjected to modelling using ordinary differential equation to arrive at a result that is comparable to those of the data obtained. Two different equation were derived, one was modelled without a corrosion inhibitor, while the other was derived based on the addition of an inhibitor to the system. Percentage deviation of the models from the original data was also calculated to test the reliability of the models developed.

The detailed approach to arriving at the non-inhibitor model equation ($C_R = C_{RO} e^{K_C t}$)

and the inhibitor model equation($C_R = C_{RO} e \left[\frac{C_{inh}\,\theta}{1-\theta}\ t\right]$)

been derived in others works on boilers [6,7].

CORROSION RATE CONSTANT DETERMINATION

In order to obtain the slope (rate constant), a graph was drawn, for the corrosion in the four years data measured by the Ultrasonic Thickness Scanning Technique, for each of the boiler compartments in view. As slope [change in corrosion rate divided by change in time (years)] was obtained from the graph. Mathematically,$C_{R2} - C_{R_1} / t_2 - t_1$, gave the slope of the curve which was designated as K_C. The K_C values determined from the graph for the different components were: Baffle wall tube; 0.10 for lower level and 0.275 for higher level, vapourising tube bank; 0.05 for lower level and 0.26 for higher level and for the superheater coils: 0.025 for the lower level and 0.175 for the higher level.

RESULTS

The results presented below were gotten from Ultrasonic Thickness Scanning (UTS) technique of the boiler components, the predictive model equation and the inhibitor model equation. Percentage deviation was calculated between the UTS result and those from the predictive model equation to see if there was any correlation between them. The percentage deviation was calculated from the equation below:

$$\%\ Deviation = \frac{model\ data - UTS\ data}{UTS\ data} \times 100$$

The UTS reading in the Baffle wall tube showed metal loss of 0.4 mm to 1.10 mm in four years. Metal losses for the first, second and third year were between 0.1 mm to 0.325 mm, 0.2 mm to 0.55 mm and 0.3 mm to 0.825 mm respectively, while the predictive model equation results gave 0.15 mm to 0.98 mm metal loss in the fourth year. Metal loss recorded were between 0.11 mm to 0.36 mm, 0.12 mm to 0.48 mm and 0.13 mm to 0.79 mm for the first, second and third year respectively. Percentage deviations recorded were 10.78%, - 12.73%, - 4.24% and – 10.91% for the first, second, third and fourth year respectively. The inhibitor model equation gave metal loss of between 0.17 mm to 0.47 mm in four years. Metal losses in the first, second and third year were between 0.069 mm to 0.19 mm, 0.116 mm to 0.32 mm and 0.147 mm to 0.409 mm respectively, as can be seen in table 1.

In the vapourizing tube bank, UTS reading recorded metal loss of 0.2 mm to 1.0 mm in four years. In the first, second and third year metal losses recorded were 0.06 mm to 0.29 mm, 0.10 mm to 0.50 mm and 0.15 mm to 0.72 mm respectively. The predictive model equation gave metal loss of 0.16 mm to 0.98 mm in four years and 0.05 mm to 0.32 mm, 0.06 mm to 0.46 mm and 0.08 mm to 0.63 mm metal losses in the first, second and third year respectively. Percentage deviation recorded were; 10.34%, - 8.0%, - 12.5% and – 2%, for the first, second, third and fourth year respectively. In the inhibitor model equation metal loss recorded in four years amounts to between 0.085 mm to 0.427 mm. metal losses recorded in the first, second and third year were between; 0.034 mm to 0.172 mm, 0.058 mm to 0.29 mm and 0.074 mm to 0.371 mm respectively. This result is shown in table 2.

TABLE 1. Corrosion rate (metal loss) for Baffle wall tube.

No. of years	Rate from UTS mm/yr	Rate from model mm/yr	% Deviation	Rate from inhibitor model mm/yr
1	0.10 – 0.325	0.11 – 0.36	10.78	0.069 – 0.190
2	0.20 – 0.55	0.12 – 0.48	- 12.73	0.116 – 0.32
3	0.30 – 0.825	0.13 – 0.79	- 4.24	0.147 – 0.409
4	0.40 – 1.10	0.15 – 0.98	- 10.91	0.17 – 0.47

TABLE 2. Corrosion rate (metal loss) for vapourizing tube bank.

No. of years	Rate from UTS mm/yr	Rate from model mm/yr	% Deviation	Rate from inhibitor model mm/yr
1	0.06 – 0.29	0.05 – 0.32	10.34	0.034 – 0.172
2	0.10 – 0.50	0.06 – 0.46	- 8.00	0.058 – 0.29
3	0.15 – 0.72	0.08 – 0.63	-12.50	0.074 – 0.371
4	0.20 – 1.00	0.16 – 0.98	-2.00	0.085 – 0.427

TABLE 3. Corrosion rate (metal loss) for superheater coils.

No. of years	Rate from UTS mm/yr	Rate from model mm/yr	% Deviation	Rate from inhibitor model mm/yr
1	0.025 – 0.195	0.026 – 0.21	7.61	0.017 – 0.120
2	0.050 – 0.35	0.026 – 0.32	-8. 57	0.029 – 0.202
3	0.075 – 0.525	0.27 – 0.50	- 4. 76	0.037 – 0.259
4	0.10 – 0.70	0.028 -0.67	-4.29	0.043 – 0.298

The metal losses recorded by UTS for the superheater coil in four years is between 0.10 mm to 0.70 mm. first, second and third year metal losses recorded were between 0.025 mm to 0.195 mm, 0.050 mm to 0.35 mm and 0.075 mm to 0.525 mm respectively. The predictive model equation metal loss recorded in four years amount to between 0.028 mm to 0.67 mm. The metal losses recorded in the first, second and third year were; 0.026 mm to 0.21 mm, 0.026 mm to 0.32 mm and 0.27 mm to 0.50 mm respectively. The percentage deviation recorded for the first, second, third and fourth year were 7.61%, - 8.57% - 4.78% and – 4.29% respectively. The inhibitor model equation metal loss recorded in four years amounts to between ; 0.043 mm to 0.298 mm. Metal losses recorded in the first, second and third year were between; 0.017 mm to 0.12 mm, 0.029 mm to 0.202 mm and 0.037 mm to 0.259 mm respectively as can be seen in table 3.

DISCUSSION

Corrosion in boilers originates primarily from gases dissolved in the feed water. These gases are majorly oxygen and carbon dioxide and few other gases that may be found during release operations in the boiler compartments. The corrosion or disintegration rates of the various boiler units determined by the scanning technique (UTS) as recorded in this study were discussed and compared with those derived from the non-inhibitor mathematical model. The corrosion or disintegration rate was determined for a four year period. The essence of model development is to enable plant personnel to have a foreknowledge of the expected rate of metal deterioration or loss in the internal systems of the boiler components being investigated.

As was observed by Jaffer *et al*., [3], initial assessment of the numerical data determined by UTS revealed a reasonable connection to those of the predictive model. The figures obtained from the model equation is an indication that it can be used to measure the degree of internal corrosion rates of the numerous boiler compartments. In a paper published [8], predictions on the time taken for any equipment to deteriorate or get corroded is dependent strongly upon the corrosion rate predictions. The model equation developed in this study can be useful in the prediction of the corrosion or disintegration rates (metal loss) of the different boiler components or units. If the data obtained from this model is incorporated into the system, it will be very useful tool to compare with that of the traditional method of measuring with the UTS. Hence, the extent of corrosion penetration or damage can be predicted ahead of time, thus showing the usefulness or relevance of the model to plant personnel.

The inhibitors' effect on corrosion rates were also put into consideration in the different boiler components of the refinery using the inhibitor equation of the developed mathematical model. The model was based on the assumption that 75% was covered by corrosion inhibitors which are adsorbed unto the boiler components internal surfaces. The inhibitors therefore prevented electrochemical reactions or ion exchange from occurring on the underlying surface of the boiler components or units. The corrosion rate was found to have been decreased greatly by the inhibitor growth corrosion rate when compared with corrosion rates of those without inhibitors. The data obtained from the inhibitor model equation clearly revealed to us that corrosion inhibitor films formed on the surfaces or walls of the boiler components greatly reduced the rate of metal loss from the refinery boiler components to a noticeable level.

Data results from the various boiler components showed that corrosion or disintegration rates differed slightly from one component to the other. This was possibly due to the fact that the same process condition passed through all the different boiler components. The model was able to confirm that metal loss increased as the number of years increased. Hence, the model can be a useful tool in forecasting the life time of the different refinery boiler components and also the overall lifetime of the boiler. A comparative overview on the rate of corrosion determined through the predictive model equation and those determined by the Ultrasonic Thickness Scanning Technique will provide the plant personnel with reliable and qualitative information on the metal loss (corrosion rates) in the various boiler components. Hence, the time when a change or replacement of any is require due to rupture is readily at hand.

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