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Simulation of Corrosion Rates in Refinery Boiler Compartments

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Abstract This work presents the simulation of corrosion rates in the refinery boiler compartments. The study made use of proven mathematical model to predict corrosion rates of the boiler internal tube walls by generating data through computer program excel to ascertain metal losses from the various boiler compartments. The simulation made use of the boiler's past corrosion history to forecast possible metal losses for over a period of time. The simulation was tested using four compartments; bank tubes, vapourizing tube bank, furnace internal and rear wall tubes and the lower steam drum. The results showed that replacement of bank tubes is about forty years, vapourizing tube bank is between eight and ten years, furnace internal and rear wall tube is eighteen years and lower steam drum is twelve years. The effort in simulation has produced basis for monitoring corrosion in real time life of the boiler, and the sudden change in the corrosion rates and condition can be detected and dealt with in timely fashion. Application of the simulation rates will help plant personnel in timely maintenance and management in forestalling unforeseen breakdown of the refinery boiler.

Keywords Corrosion attack, simulation calculations, corrosion of metals, simulation data, boiler tube internal walls, refinery boiler, boiler compartments

Introduction

Petroleum refineries are known to be very complex processing plants. It is composed, of various units and each unit invariably involves heating by steam and cooling by water. As a result, water extremely is a very valuable resource for refineries and it is used in large volumes. Severe corrosions have been identified in process plants where water vapour and acid gases condense to form acid solutions. Gases often found in the production process are oxygen, carbon dioxide, hydrogen sulphide etc. which are corrosive agents.

The boiler is also a process unit in the petroleum refining plant and it is highly affected by severe corrosion attacks [1]. This is as a result of the generation of hot steam and large volumes of condensate water that passes through the unit system daily. The boiler is a, very important equipment in the process engineering unit of the refinery and it functions in the generation of steam for the turbine, so that power is generated [2]. The boiler, need to be protected from attack of corrosion in such a way as to minimize the rate of material degeneration and disintegration.

Metals exposed to extremely high temperature, especially in gaseous environments, as in the case of the boiler internal walls are prone to corrosion attack [3]. Material disintegration (corrosion), have been a long time problem in process plants and internal furnace walls of boiler tubes. In the presence of deposits, boiler internal wall corrosion sets in as a result of low excess oxygen level which leads to high concentrations of carbon (ii) oxide around the boiler tube walls [4]. Corrosion in the boiler results in deposits and contributes to metal loss and damage [5], leakages, cracks, tube failures, and control management of corrosion under high temperature gases includes forecasting of sound metal losses under different conditions of operation [6].

Corrosion attack is a very significant problem in chemical processing plants such as the petroleum refinery. Major equipment such as valves, condensers, heat exchangers, and key components of the boiler can be highly degraded [7], by corrosion attack. Such can reduce the performance and reliability of the equipment and in severe cases can lead to unexpected failure, breakdown and ultimately shutdown. Corrosion attack on equipment is the most serious mechanism for aging of such equipment [8].

The protection of equipment from corrosion attack may be very necessary and critical in the chemical process industry, especially boilers [9], and these equipment can suffer considerable corrosion once the conditions for the metal protection are not present at any given period. The application of high technology in the management of corrosion in high-temperature gases environment is very critical in boiler situation. Thus the application of predictions of sound metal losses for a wide range of conditions [10], is very important in the operation of the boiler which is a very vital equipment in the refinery.

During the process of equipment design, the process of design/operation and the maintenance of the plant are influenced by the expected lifetime of the equipment under harsh conditions, such as, corrosive environment, corrosive gases, and very high-temperature situations. In refinery boilers, areas of extreme corrosion activity tend to be fairly localized, but these locations can alter as a result of changes in the configurations of the burner and the turbulence within the boiler compartments [11].

The purpose of this paper is basically to use the past corrosion history of the refinery boiler to simulate corrosion for a long period. Through the use of proved mathematical model by Edori *et al* [7], the rate of metal loss will be extrapolated and the corrosion rate over a period will then be ascertained in order to advise plant personnel on the proper use of the boiler. The aim of this work is to make sure that the simulation of the rate of metal loss (corrosion) will help to determine at what time any internal component part of the boiler will be replaced or protective coating added.

Materials and Methods

Metal losses for a period of four years as a result of corrosion attack were recorded as it was obtained from ultrasonic thickness scanning of the internal part of the refinery boiler tubes of the different components or compartments. A material balance equation was then formulated and was subjected to mathematical analysis through the use of first order differential equation to arrive at the formula $C_R=C_{RO}e^{kct}$ [7]. A graph was drawn to determine the slope of the various parts of the refinery boiler as a result of the corrosion attack. The slope of each compartment is taken as the corrosion rate constant of that compartment. The corrosion rate constant is symbolized as K_c. The corrosion rate constant for bank tubes is 0.076, for vapourizing tube bank is 0.25, for furnace internal and rear wall tube (internal wall tubes) is 0.16 and for the lower steam drum (continuous intermittent blow line) is 0.35. The initial corrosion rate is the corrosion rate of the first year. The initial corrosion rate is designated as C_{RO}. The initial corrosion rate for bank tubes is 0.075mm, for vapourizing tube bank is 0.26mm, for furnace internal and rear wall tube (internal wall tubes) is 0.15mm and for the lower steam drum (continuous intermittent blow line) is 0.33mm.

A computer program is then drawn to ascertain the usefulness of the model equation in predicting the possible loss of metal (corrosion) for a period of time (t) in years. The computer program uses an algorithm where all corrosion rate calculations are performed. It made use of the past corrosion history of the boiler to perform simulation calculations. The computer simulation program uses excel to predict metal losses from the refinery boiler compartments by extrapolation of the past corrosion history, but does not predict how the rates will be affected by changes in boiler operation. When once the input data of the corrosion rates, corrosion rate constants (K_c) are put in, a new sets of data are produced for that particular compartment.

The simulation model was then tested using four compartments;[bank tubes, vapourizing tube bank, furnace internal and rear wall tubes(internal wall tubes) and the lower steam drum(continuous intermittent blow line)].

Results and Discussion

Application of simulation to the corrosion of the various boiler compartments will help to ascertain the reliability and the acceptability of the corrosion rate in application to the maintenance of the refinery boiler compartments.

In the bank tubes, simulation results were generated for sixty years as shown in table 1. The bank tube is 2.9mm thick and the corrosion rate is observed to be between 0.025mm to 0.075mm/year in this compartment. From the result, the highest corrosion rate in any part of this compartment is 0.075mm/year. The simulation reveals that it will take a period of about forty seven years for the tubes to wear or corrode to about 2.7mm metal loss. When the metal loss has gone up to about 1.8mm, that is for a period of forty years there is the possibility of tube rupture and leakage, hence tube replacement or additional paneling to forestall tube rupture.

Table 1: Simulation of corrosion rates for bank tubes

Time (Years)	$K_c t$	e^{Kct}	$C_{RO}\, e^{Kct}$
1	0.076	1.07896257	0.080922193
2	0.152	1.16416024	0.087312018
3	0.228	1.25608533	0.094206399
4	0.304	1.35526906	0.101645179
5	0.380	1.46228459	0.109671344
6	0.456	1.57775034	0.118331276
7	0.532	1.70233357	0.127675018
8	0.608	1.83675421	0.137756566
9	0.684	1.98178906	0.148534179
10	0.760	2.13827622	0.160370717
11	0.836	2.30712002	0.173034001
12	0.912	2.48929615	0.186697211
13	0.988	2.68585738	0.210439304
14	1.064	2.89793960	0.217345470
15	1.140	3.12676837	0.234507627
16	1.216	3.37366604	0.253024953
17	1.292	3.64005940	0.273004455
18	1.368	3.92748786	0.294561589
19	1.444	4.23761241	0.317820931
20	1.520	4.57222520	0.342916890
21	1.596	4.93325987	0.369994490
22	1.672	5.32280276	0.399210207
23	1.748	5.74310497	0.430732873
24	1.824	6.19659532	0.464744649
25	1.900	6.68589444	0.501442083
26	1.976	7.21382988	0.541037241
27	2.052	7.78345245	0.583758934
28	2.128	8.39805390	0.629854042
29	2.204	9.06118585	0.679588939
30	2.280	9.77668041	0.733251031
31	2.356	10.5486723	0.791150420
32	2.432	11.3816226	0.853621693
33	2.508	12.2803448	0.921025860
34	2.584	13.2500324	0.993752432
35	2.660	14.2962891	1.072221682
36	2.736	15.4251609	1.156887067
37	2.812	16.6431713	1.248237847
38	2.888	17.9573589	1.346801921
39	2.964	19.3753182	1.453148867
40	3.040	20.9052432	1.567893243
41	3.116	22.5559751	1.691698129
42	3.192	24.3370529	1.825278968

43	3.268	26.2587693	1.969407694
44	3.344	28.3322293	2.124917195
45	3.420	30.5694150	2.292706127
46	3.496	32.9832547	2.473744104
47	3.572	35.5876974	2.669077306
48	3.648	38.3977936	2.879834521
49	3.724	41.4297822	3.107233668
50	3.800	44.7011845	3.352588837
51	3.876	48.2309051	3.167317882
52	3.952	52.0393415	3.902950613
53	4.048	56.1485019	4.211137640
54	4.104	60.5821321	4.543659909
55	4.180	65.3658532	4.902438991
56	4.256	70.5273092	5.289548193
57	4.332	76.0963271	5.707224535
58	4.408	82.1050890	6.157881675
59	4.484	88.5883182	6.644123864
60	4.560	95.5834798	7.168760987

The vapourizing tube bank is 4.5mm thick, and the corrosion rate in this compartment, is 0.29mm/year. Simulation results from this compartment showed that in twelve years if corrosion continues at the same rate without change in the operation conditions, then the whole compartment would have been totally corroded. Metal loss in this compartment is high as a result of high temperature associated with it. The results in table 2, clearly revealed that this compartment will not last for even twelve years with metal loss of 5.2mm. Hence at 1.9mm to3.2mm metal loss, that is between eight and ten years there should be a change of this compartment.

Table 2: Simulation of corrosion rates for vapourizing tube bank

Time (Years)	**K_ct**	**e^{Kct}**	**$C_R = C_{RO}$ e^{Kct}**
1	0.25	1.284025417	0.333846608
2	0.50	1.648721271	0.428667530
3	0.75	2.117000017	0.550420004
4	1.00	2.718281828	0.706753275
5	1.25	3.490342957	0.907489169
6	1.50	4.481689070	1.165239158
7	1.75	5.754602676	1.496196696
8	2.00	7.389056099	1.921154586
9	2.25	9.487735836	2.466811317
10	2.50	12.18249396	3.167448430
11	2.75	15.64263188	4.067084290
12	3.00	20.08553692	5.222239600
13	3.25	25.79033992	6.705488378
14	3.50	33.11545196	8.610017509
15	3.75	42.52108200	11.05548132
16	4.00	54.59815003	14.19551901
17	4.25	70.10541235	18.22740721
18	4.50	90.01713130	23.40445414
19	4.75	115.5942845	30.05191398
20	5.00	148.4131591	38.58742137

Simulation results for corrosion rates, for furnace internal and rear wall tubes was done using the internal wall tube as a case study as seen in table 3. The simulation covered a period of thirty years. As observed by Farrell *et al* [12]; that the tubing of the furnace wall is generally about 6.5mm thick (with additional 9mm replacement tube paneling), this may be allowed to corrode to about 2.5mm beyond which the tube may be at risk of rupture.

Hence in this work, the furnace wall tube can be allowed for period of eighteen years before replacement or additional paneling since the tube has corroded up to 2.67mm.

Table 3: Simulation of corrosion rates for furnace internal and rear wall tubes (internal wall tubes)

Time (Years)	K_ct	e^{Kct}	$C_R=C_{RO}e^{Kct}$
1	0.16	1.173510871	0.176026631
2	0.32	1.377127764	0.206569165
3	0.48	1.616074402	0.242411160
4	0.64	1.896480879	0.284472132
5	0.80	2.225540928	0.333831139
6	0.96	2.611696473	0.391754471
7	1.12	3.064854203	0.459728130
8	1.28	3.596639726	0.539495959
9	1.44	4.220695817	0.633104373
10	1.60	4.953032424	0.742954864
11	1.76	5.812437394	0.871865609
12	1.92	6.820958469	1.023143770
13	2.08	8.004468914	1.200670337
14	2.24	9.393331287	1.408999693
15	2.40	11.02317638	1.653476457
16	2.56	12.93581732	1.940372597
17	2.72	15.18032224	2.277048337
18	2.88	17.81427318	2.672140977
19	3.04	20.90524324	3.135786485
20	3.20	24.53253020	3.679879530
21	3.36	28.78919088	4.318378632
22	3.52	33.78442846	5.067664270
23	3.68	39.64639407	5.946959111
24	3.84	46.52547444	6.978821166
25	4.00	54.59815003	8.189722505
26	4.16	64.07152260	9.610728390
27	4.32	75.18862829	11.27829424
28	4.48	88.23467268	13.23520090
29	4.64	103.5443476	15.53165214
30	4.80	121.5104175	18.22656263

Simulation results for lower steam drum (continuous intermittent blow line), is shown in table 4. The thickness of the line is about 44mm and the corrosion rate is 0.35mm/year. The rate of metal loss in this compartment is very high as a result of the high temperature associated with it. As a result of the high corrosion rate simulation results were only given for fifteen years. From the result it will take only fourteen years period for the carbon steel material used in construction to be totally degraded or corroded; therefore when the metal loss is up to 22mm, that is a period of twelve years there is supposed to be a replacement or additional paneling for the several lines that make up the steam drum.

Table 4: Simulation of corrosion rates for the lower steam drum (continuous intermittent blowline)

Time (Years)	K_Ct	e^{Kct}	$C_R=C_{RO}e^{Kct}$
1	0.35	1.41906755	0.468292291
2	0.70	2.01375271	0.664538393
3	1.05	2.85765112	0.943024869
4	1.40	4.05519997	1.338215989
5	1.75	5.75460268	1.899018883
6	2.10	8.16616991	2.694836071
7	2.45	11.5883467	3.824154417

8	2.80	16.4446468	5.426733434
9	3.15	23.3360646	7.700901312
10	3.50	33.1154520	10.92809915
11	3.85	46.9930632	15.50771087
12	4.20	66.6863310	22.00648924
13	4.55	94.6324083	31.22869474
14	4.90	134.289780	44.31562730
15	5.25	190.566268	62.88686859

Corrosion is a phenomenon that is complex and its multifaceted nature affects the deterioration of metals adversely through oxidation processes [13], hence the operating conditions should be kept under steady state in order to monitor the rate of metal loss and wall thickness of the boiler tubes effectively. Great loss of metal in the petroleum industry has been related to corrosion as a result of the operational conditions of the plants involved.

Since, the corrosion of metals is a major problem in the refining process, there need to be a mathematical projection of the rates at which these degradation and deterioration, occurs. This is done through the simulation of the rates in order to forestall uncertain shutdowns of the process plants, for it is well known that corrosion causes plant breakdowns and shutdowns, and also causes reduction in efficiency and gives rise to high cost of maintenance [14]. The contact of the water and other chemicals in the system results in acidic solutions and hence industrial processes that involve boilers causes plant dissolution and corrosion [15].

The simulation results have revealed that, compartments of high corrosion activity tend to vary due to changes in mill and burner configurations and also because of turbulence within the boiler. This is corroborated by Petersen [16], that uneven distribution of temperature in the boiler affects the performance of the boiler tubes. The rate of metal loss can also affect the profile of the various boiler compartments tubes. Simulation predictions are made based on metal loss survey or scanning of likely boiler tubes of the different compartments. If the loss of metal could predict the remaining wall thickness and it is found to be less than allowed minimum, then protective coatings should be added or total change of the tubes that has been affected [11].

The boiler wall is made of carbon steel or low-alloy, it can suffer considerable degradation (corrosion) when exposed to the boiler high temperature and harsh internal environment [17] and under oxidizing conditions the rate of corrosion (metal loss) can be very low (< 0.1mm/yr), but under highly reducing conditions, rates may greatly increase to values as high as 9mm/yr. The application of the simulation rates to the various boiler compartment tubes actually reveal the different rates of metal loss in the different compartment tubes.

This work has revealed through the simulation data that, the model can be used to predict the corrosion rates of the various boiler compartments and the usefulness of it in plant management by plant personnel. Also, in this simulation model, each time a new boiler compartment data are entered, the corrosion of the tubes are revealed, since the algorithm focuses on the corrosion rate data. This software program could be used as a leading for corrosion ratesfor refinery boilers. With this program, corrosion tendencies ofthe various boiler compartments tubes can be easily predicted and therefore avoid costly unexpected shutdowns and maintenance of the boiler [18].

With the simulation of the boiler's corrosion rates, non-expert could have access to expert knowledge if the expert is not available. Problems that are well understood can be easily solved by anyone who has access to the expert system. Each time new corrosion rate data from the boiler compartments are entered, a new set of values are obtained. This invariably makes it easier for refinery plant maintenance and management in order to forestall unforeseen breakdown of equipment due to corrosion attack and leakages.

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