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Reducing And Analysizing of Flow Accelerated Corrosion at Thermal Power Plant, Heat Recovery Steam Generators

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ABSTRACT
The purpose of this study is to Reducing and Analysing of Flow Accelerated Corrosion in Thermal Plant Heat Recovery Steam Generators. All these studies have been performed in a new and 16 year-old established Combined Cycle Power Plants in Turkey. Corrosion cases have been investigated due to Mechanical Outage Reports at Power Plant in 2011-2015. Flow Accelerated Corrosion study has been based on specific zone related with Economizer Low Pressure connection pipings. It was issued a performance report. Results and lessons learnt from these studies will be used as a preventive action manner in all similar Plants.
Keywords:Corrosion, Flow Accelerated Corrosion (FAC), Thermal Power Plant, Heat Recovery Steam Generator (HRSG)

I. INTRODUCTION

Combined Cycle Power Plant's uses Gas Turbines which supply the overall 2/3 of Plant's Power (Figure 1). Exit gases form the Gas Tubine is recyled and used in Heat Recovery Steam Generators (HRSG). Hence 1/3 of Plant's Power is coming from the usage of Heat Recovery Steam Generator's process. Low effeciency of the Power Plant processing mainly comes from HRSG. Other than these loses there are obviously certain processing loses which comes from wrong management of the overall process. These loses have to be minimized as low as possible with a ratio of maximum 5%. One of the main problem causing the low effecient Plant Process is coming from the Corrosion of Tubular Piping System. There are certian Outage Problems arrise while Corrosion defects totally effect the process. Wang [1] and Duan [2] reported thatsimulation program showing the estimate usefull life of these basic Carbon Stell pipes. If it can be managed and adopted to this formulation to our old, experienced Plant, it will definitely get real values Corrosion life of pipes as Compared with the Duan Simulation formula [2].

Definition of Corrosion

Inside and outside of the metallic pipe, there are some electrochemical reactions with the water, steam, earth, concrete ...etc (Figure 2). These reactions may occur some metallic breakages inside and outside the metallic surface. This is so called Corrossion[3] Metals are generally free electrons flowing in the outer shell of neutral atoms which have potential to give free electrons and form a current. This current is also the reason of corrosion.

"Corrosion damage" is simply described as follows:"A component of the metal particle due to corrosion or damage function of the whole system".

Erosion corrosion, is the corrosion of metal corrosion of preventive film on the effect of the refrigerant and consequently the exposure of bare metal corrosion. Such corrosion attack occurs mainly at the ends of the tubes and grow in size if there solid particles present in the cooler. Mostly tubes starts this from one side. The formation of the longitudinal rounded cavities is a typical sign. Accelerating factors; high speed, sufficient section of area, a sudden change in the flow direction, trapped air inside and solid particles [4-5-6].

The main aim of this study is to determine, analyse and reduce the Flow Accelerated Corrosion in Heat Recovery Steam Generators in Power Plants.

II. MATERIALS AND METHODS

2.1.Reduction of flow accelarated corrosion

This study was was performed at a 16 year–old Combined Cycle Power Plant. This study analysed some reports such as; Planned Mechanical Maintenance records, Occasional Posture reports, repair reports and spare part orders, Flow Accelarated Corrosion Data, location, process conditions, damaged materials, renewable material, and the process of damaged material life. In addition to actual sample parts that have been reached on and stored, they are held to analyze the damaged part with ultrasonic method. Carbon Steel metallic pipes especially from the 2'', and 4' over a total of 10 pieces including pipes with 1 or up to 3 rapture due to corrosion and analyzed in a way that shows exposure to rapture.Measurements are based on the points that , raptured points and with a maxium diameter zone 10 mm and closer.Rapture and closer limited zone thickness points have been measured with Ultrasonic Measuremet Method. The minimum and maxium values have recorded in these raptured pieces.As it is known Engineering Calculations in certain diameter design stress values depending on the process conditions at a pipe, pressure values and metallic properties, including with a number of formulations[2]it is possible to determine the critical thickness. However, this value is nearly raptured that expressed close to zero practical values are more important to us than formulas.

Thesestudies with the actual value obtained as rapture damaged will be based on a comparison of the critical shear thickness calculated in the simulation program. With a conclusion taken from here, measures for early rapture, plus both in terms of work safety and efficiency will be achieved.

2.2. Corrosion works based on flow references

Corrosion-based flow process was performed at a 16 year–old Natural Gas Conversion Power plant between 2011-2015 years. And thesestudy was based on to the sources that was about mechanical planned maintenance, fault records, outage records, accident reports, Consulting Reports .It was decided to find some solutions to the damaged pipes of the Heat Recovery Steam Generator (HRSG) and damaged parts of Waste Heat Boiler. Especially, these 2" (inch), and 4" (inches) pipes are designed and made a prototype with Carbon steel A106 Grade B.Samples have checked of damaged and controlled critical thickness of the pipes and it parts in our old CCGT . To analyze critical thickness in main pipes, you can refer to the following Figure 3-4-5shown in below.

2.3. Ultrasonic thickness measurement method

Thickness measuring device is a portable device. It is designed to measure the remaining wall thickness in pipes, tubes, and pressure after the corrosion and erosion [7]. Measurement is made in terms of mm or inch within the range of 0.1-0.01mm. Calibration of this device is adjustable and it measures with sound waves (Figure 6-7-8).

2.4 Critical thickness detection and simulation

The measurement results obtained by measuring the change in thickness of the feeder exposed to corrosion accelerated on flow and by studies of using statistical methods, the time of when to expose to breakdown of the remaining feeder pipe, which is subjected to corrosion accelerated flow, is estimated [1-2-8].

2.4.1. Pre-Assessment

This study; critical thickness study we guide modelling and calculation theory. At the same time it was choosen important researches. Assumptions used in this theory are listed as follows [1];

1. It is assumed that maximum measured attenuation (thinning) ratio is equal when material loss is circumferentially 360 degree. This is a quiet cautious assumption However, regional thinning in size is usually occur angularly smaller than 90 degree and axially under the 20 mm.
2. Attenuation (thinning) ratio and loads are evaluated independently.
3. Usage of seismic inertia bending moment, tests of supplier pipes pointing out that there is a fairly mild effect of the bending moment. That's why it is a quiet cautious approach.
4. Fracturing occur when material's Von Mises tension exceeded tensile strength specified standards of ASME 2007 [9], Duan [2] also base on this approach in his work. Actual tensile strength is greater than the value specified in the standard.
5. Damage is independent one from another in different nutrients.

2.4.2. Brief theory

Flow Accelarated Corrosion (FAC) locally results a decrease in the diameter of the pipe as a function of time. Periodically measurements can be performed to monitor the thickness. And assumption based on rapture of pipe can be estimated**.** Under certain conditions thickness of pipe may be evaulated as a function of time.This study has used the below formulas as shown in the following equations (Equations 1-2-3-4-5). These are Mean Radius, Time of Rapture, Collopse Pressure, Critical Thickness, Thickness as a function of time [1].

-Calculation of Mean Radius .

$$R = \frac{D_0 - h_0}{2} \quad \textbf{(1)}$$

R= Mean Radius (mm)
D_0 = Outer Diameter (mm)
h_0 = Original Thickness (mm)

At this formula R is Mean Radius and taken as a constant value. However Thickness is a variable with a function of time. Plant Pressure and Axial Stresses will be evaulated to identify the Rapture time of pipe[1].

- **Calculation of Rapture Time**

$$t_f = \frac{1}{h_i}\left[h_0 - \frac{\sqrt{(S_0\ h_0)^2 + \frac{3}{4}(pR)^2}}{S_t}\right] \quad (2)$$

t_f= Rapture Time (Efective Annual Time)
h_0 = Original Thickness (mm)
h_i = Reduction Rate (mm /Efective Annual Time)
R= Mean Radius (mm)
S_0= Initial Axial Stress (Mpa)
p = Plant Operating Pressure (MPa)
St= Tensile Strenght of the Pipe (MPa)

At the defination of S_t, it was described in ASME Standarts as Maxium Tensile Strenght of the Material. At Equatation (**2**) it was defined as Original Thickness (h_0) and Mean Radius (R) and others are variable.

2.4.3 Estimation of crital thickness value

Duan [2] reported that Plant Operating Pressureused for the nd determination of Crital Thickness Rapture Pressure and it's moment at the line .

- **Calculation of Engineering Plastic Collapse Pressure**

$$P_c = 2\,\frac{\sqrt{(S_0\ h_0)^2 + \frac{3}{4}(pR)^2}}{D_0} \quad (3)$$

P_c = Engineering Plastic Collapse Pressure (MPa)
h_0 = Original Thickness (mm)
R= Mean Radius (mm)
p = Plant Operating Pressure (MPa)
S_0= Initial Axial Strenght (MPa)
D_0= Outer Diameter (mm)

- **Calculation of Critical Rapture Thickness**

Critical Rapture Thicknessused the formulas as shown in the following equation 4.

$$h_c = \frac{P_c D_0}{2\,S_u} \quad (4)$$

h_c = Critical Rapture Thickness (mm)
P_c = Engineering Plastic Collapse Pressure (MPa)
S_u= Material's Max. Tensile Strenght (MPa)
D_0= Outer Diameter (mm)

At thisequatation h_c is lowest thickness value of pipe and P_c is the Engineering Plastic Collapse Pressure value and St is tensile Strenght of pipe [9]and finally D_o is the Outer Diameter.At Cetain Conditons Thickness of the Pipe is the function of processing time[1].

- **Calculation of Thickness on the bases of time .**

$$h_{(t)} = h_0 - h_i t \quad (5)$$

$h_{(t)}$= Thickness as a function of time (mm)
h_0 = Original Thickness (mm)
t = Time (Effective Annual time)
h_i= Reduction Ratio (mm/Effective Annual Time)

Rapture that may occur at pipe has been controlled by line streess in which this has been created by Plant Operating Pressure, axial stress[1].

III. RESULTS AND DISCUSSION

In the research, it was estimated a realistic approach to a Plant Plant life; as compared with the Wang and Duan Simulation Studies. A case study of a 16 year-old Plant samples have been compared with the formulated studies of Wang and Duanwith some above listed assumptions.

Ultrasonic Thickness Measurement of Actual Raptures of 2'' Pipes values were summarized in Table 1.

3.1. Geometric properties

Wall Thickness and Diameter properties were summarized in Table 2 according to ASTM standarts .

3.2. Tensile strenght

According toASME 2007 Standarts Material A106 Gr-B (in temparature range −30 ◦C ile 375 ◦C) Tensile Strenght value is shown in 415 Mpa (Table 3).

3.3. Reducing of thickness value

Reducing of Thickness is a variable. Duan has reportedthat elbows have crital role for the reduced pipe thickness values [2]. Especially angled elbows have secondary effective role in the reduction of thickness as shown as belowtable .These are shown inTable 4. These are statistical values of Wang's studies at the last decade .

3.4.Load

Normal Operating Bar varies between 10,3 and 13,5 Mpa were summarized inTable 5[1].

3.5. Sample calculation of 2'' Feeder Pipe

a. 2'' Pipe Feederused the formulas as shown in the following equation 1.

- **Calculation of** Mean Radius

$$R = \frac{D_0 - h_0}{2} \quad (1)$$

R= Mean Radius (mm)
D_0 Outer Diameter (mm)
h_0Original Thickness (mm)
Result ;

$$R = \frac{60,3 - 5,54}{2} = 27,38mm$$

- Solution of Rapture Time Calculationused the formulas as shown in the following equation 2.

$$t_f = \frac{1}{h_i}\left[h_0 - \frac{\sqrt{(S_0\ h_0)^2 + \frac{3}{4}(pR)^2}}{S_t}\right] \quad (2)$$

t_f= Rapture Time (Effective Time Annual)
h_0Original Thickness (mm)
h_i = Thickness Rate (mm/(Effective Time Annual)
R= Mean Radius (mm)
S_0= Initial Axial Strenght (MPa)
p = Plant Operating Pressure (MPa)
St= Material's Max. Tensile Strenght (MPa)

Result ;

$$t_f = \frac{1}{0,0906}\left[5.54 - \frac{\sqrt{(56,34x5,54)^2 + \frac{3}{4}(10,3x27,63)^2}}{415}\right]$$

$$t_f = 50,57\ AnnualPowerYear$$

-Calculation of Engineering Plastic Collapse Pressure used the formulas as shown in the following equation 3.

$$P_c = 2\,\frac{\sqrt{(S_0\ h_0)^2 + \frac{3}{4}(pR)^2}}{D_0} \quad (3)$$

P_c= Engineering Plastic Col.Pressure(MPa)
h_0Original Thickness (mm)
R= Mean Radius (mm)
p = Plant Operating Pressure (MPa)
S_0= Initial Axial Strenght (Mpa)
D_0= Outer Diameter (mm)

Result ;

$$P_c = 2\,\frac{\sqrt{(56,34x5,54)^2 + \frac{3}{4}(10,3x27,63)^2}}{60,8} = 13,08\ MPa$$

- Calculation of Critical Rapture Thickness used the formulas as shown in the following equation 4.

$$h_c = \frac{Pc\ \ D_0}{2\,S_t} \quad (4)$$

P_c= Engineering Plastic Collapse Pressure(MPa)
h_c= Critical Rapture Thickness (mm)
St= Material's Max. Tensile Strenght (MPa)
D_0= Outer Diameter (mm)

Result ;

$$h_c = \frac{13.08x60.3}{2x415} = 0,95\ mm$$

- Calculation of Thickness value as a function of time used the formulas as shown in the following equation 5.

$$h(t) = h_0 - h_i\ t \quad (5)$$

h= Thickness (mm)
h_0 = Original Thickness (mm)
t= Effective Time (Effective Time Annual)
h_i= Reducing Rate (mm/(Effective Time Annual)

Result ;

$$h(t) = 5,54 - 0,0906x50,57 = 0,95\ mm$$

Calculation of 2'' Pipe in different Years were summarized in Table 6.

IV. CONCLUSION

After having many raptures and repairs in our old Power Plant; Management decided to close our 16 years old Plant that will not be efficient enough to get satisfactory values. This period of 16 years definately shows us the life of the Power Plant is basicly related with the outage that comes from mainly raptures of pipes. Although; Duan and Wang have stated in their study that the Reduction rate of 2'' pipe has a value of 0,0906 mm/year and Standart Deviation value is 0,0198 mm/year ;our case study values and Duan&Wang Study does not comply each other. Forthis study new Plant have estimated new basic values that will certainly change our approach to the new plant efficiency. Based on the Assumptions of Wang ; this study has revised our calculations with new parameters.

Plant Basic Pipe Thickness : 5.54 mm (Table 2)
Actual Ave. Thickness of Raptured Pipes : 2,30 mm (Table 1)
Actual Ave. Total Corrosion of 2'' Pipe : 5,54 – 2,30 = 3,24 mm
Power Plant Effective Operating Life of 16 years ;

Thus Corrosion Rate is 3.24 mm / 16 Year = 0,2025 mm / year. Thus for 2'' pipes Wang has obtained a value (Table 4) 0,0906 mm/year however our actual value is almost 0,2025 mm/year . This difference shows us the difference between the estimated approach of Wang and Duan and our case study of 16 year-old Plant Sample.

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Figure 1. Flow Diagram of a basic Power Plant

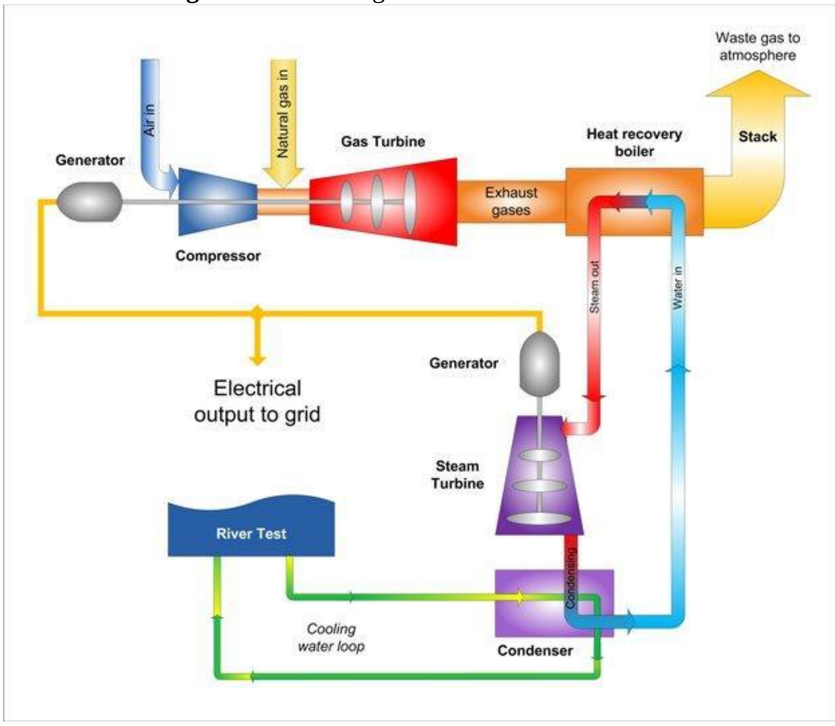

Figure 2. Corrosion directed by Turbulance Flow [5-6]

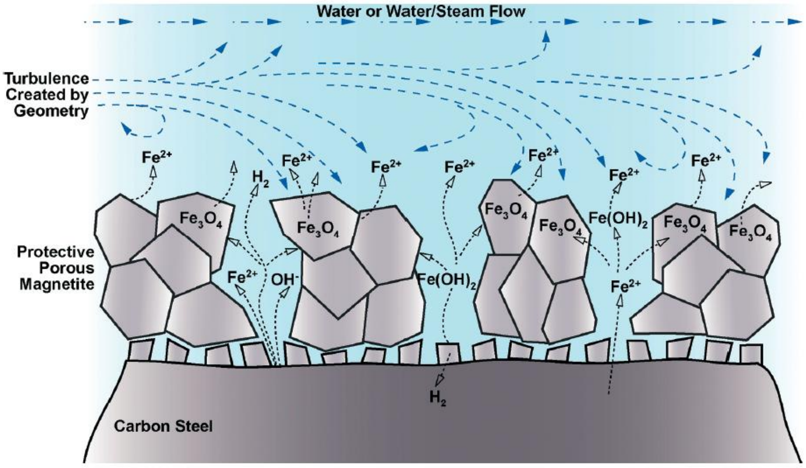

Figure 3. Old CCGT feeding pipe rupture [10]

Figure 4. Estimated Ultrasonic Measurements [10]

Figure 5. Corrosion takes place in Economizer Piping [10]

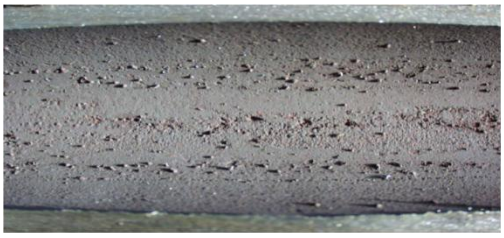

Figure 6. Ultrasonic Measurement

Figure 7. Raptured Pipe Thickness Measurement 1

Figure 8. Raptured Pipe Thickness Measurement 2

Figure 9. Rapture Experiment of Pressure Before and After [2]

Table 1. Ultrasonic Thickness Measurement of Actual Raptures of 2'' Pipes

Sample No	Measurement Values (mm)												
	1	2	3	4	5	6	7	8	9	10	Min.	Max.	Avg.
1	2,35	2,10	2,18	2,45	2,33	1,89	2,25	2,46	2,25	2,48	1,89	2,48	2,27
2	1,96	2,15	2,14	2,17	2,20	2,49	2,49	2,23	2,50	2,10	1,96	2,50	2,24
3	1,90	1,90	2,21	2,49	2,32	2,35	2,33	2,60	2,54	2,45	1,90	2,60	2,31
4	1,89	1,96	2,35	2,51	2,41	2,37	2,44	2,58	2,11	2,02	1,89	2,58	2,26
5	2,25	2,12	2,17	2,29	2,38	2,45	1,97	2,55	2,65	2,44	1,97	2,65	2,33
6	2,45	1,91	2,21	2,19	2,31	2,36	2,59	2,35	2,11	2,40	1,91	2,59	2,29

Table 2. Properties of nominal feeder pipes (ASTM Std)[9]

Diamètre nominal *Nominal size*	Diamètre extérieur *Outside diameter*		Epaisseur *Wall thickness*		Masse *Weight*		Identification		
							Specif. API	Epaisseur W.T. STD XS XXS	Schedule
Pouces *Inches*	Pouces *Inches*	mm	Pouces *Inches*	mm	*lb/ft*	kg/m			
2	2.375	60,3	0.218	5,54	5.02	7,48	5L	XS	80
4	4.500	114,3	0.438	11,13	19.00	28,32	5L		120

Table 3.ASTM A 106 Pipe Properties[9]

ASTM A 106-95

Seamless carbon steel pipe for high temperature service

CHEMICAL REQUIREMENTS IN %

Grade	C maxi (a)	Mn	S maxi	P maxi	Si mini	Cr maxi (b)	Cu maxi (b)	Mo maxi (b)	Ni maxi (b)	V maxi (b)
A	0.25	0.27 to 0.93	0.035	0.035	0.10	0.40	0.40	0.15	0.40	0.08
B	0.30	0.29 to 1.06	0.035	0.035	0.10	0.40	0.40	0.15	0.40	0.08
C	0.35	0.29 to 1.06	0.035	0.035	0.10	0.40	0.40	0.15	0.40	0.08

(a) For each reduction of 0.01 % below the specified carbon maximum, an increase of 0.06 % manganese above the specified maximum will be permitted, up to a maximum of 1.35 %
(b) These five elements combined shall not exceed 1 %.

TENSILE REQUIREMENTS

Grade	Minimum tensile strength		Minimum yield strength		Minimum elongation(1)	
					Longitudinal	Transverse
	ksi	MPa	ksi	MPa	in 2", per cent	
A	48.0	330	30.0	205	35	25.0
B	60.0	415	35.0	240	30	16.5
C	70.0	485	40.0	275	30	16.5

(1) Basic minimum elongation transverse strip tests, and for all small sizes tested in full section. For longitudinal strip tests the minimum elongation in 2" shall be : e = 625.000 $A^{0.2}/U^{0.9}$ (See ASTM).

Table 4. Reducing of Thickness[2]

Type	Diameter	Angle	Feeder Number	Average Reduction (mm/year)	Standart Deviation (mm/Year)
1	2''	90^o	48	0.0906	0.0198
2	4''	90^o	48	0.1706	0.0251

Table 5. Bending Stress Values [1]

Type	Diameter	Angle	Feeder Number	Bending Stress (Mpa)	Standart Deviation (MPa)
1	2''	90^o	48	56,34	8,04
2	4''	90^o	48	45,8	5,14

Table 6. For 2'' Pipe Table shows Thickness varies on annual bases

5 Year	**10 Year**	**20 Year**
h(5) = 5.54 – (5x0,0906)	h(10) = 5.54 – (10x0,0906)	h(20) = 5.54 – (20x0,0906)
5,087mm	4,634mm	3,728mm
30 Year	**40 Year**	**50 Year**
h(30) = 5.54 – (30x0,0906)	h(40) = 5.54-(40x0,0906)	h(50) = 5.54 – (50x0,0906)
2,822mm	1,916mm	1,01mm