10.2 Example Problem 2

A fired crude heater experienced a temperature excursion for a short duration. The refinery needs to know how much additional damage occurred to the tubes to understand how the excursion impacts the remaining tube life. This information will be used to help determine if the heater will need to be re-tubed at an upcoming scheduled turn-around, or if the tubes are likely to last for another run. Evaluate the tube remaining life (typical past history plus known temperature excursion) and determine if they are fit for service for another run.

Heater Tube Data

- Material = $SA-335\ Grade\ P22\ Year\ 1998$
- Typical Conditions (j=1) = $210\ psig\ @1115\ ^{\circ}F$
- Outside Diameter = $8.625\ in$
- Fabricated Thickness = $0.322\ in$
- Future Corrosion Allowance (FCA) = $0.10\ in$
- Weld Joint Efficiency = 1.0
- Unsupported Length = $144\ in$
- Cylindrical Shell
- Past Operating Time (j=1) = $131400\ hours$
- Past Operating Time (j=2) = $336\ hours$
- Future Expected Time (j=1) = $43800\ hours$

Temperature Excursion Data

- Excursion Pressure: = $210\ psig$
- Excursion Temperature: = $1220\ ^{\circ}F$
- Excursion Duration: = $336\ hours$

Inspection Data

There are no visual signs of damage to the tube, no bulging, metal loss, or excessive scale was noted. UT thickness readings indicated light general metal loss within the original corrosion allowance. Looking through the inspection records, this is the first operational excursion into the creep range for this component. There are no weld seems in the fire box.

Perform a multiple condition Level 1 Assessment for the component in creep service per paragraph 10.4.2.2

Each component of the vessel must be analyzed separately. In this example, the tube bends are located outside the firebox, so only the cylindrical portion of the tubes will be analyzed. For the purposes of this example, assume the tubes are adequately supported and that circumferential pressure stress is the limiting design condition.

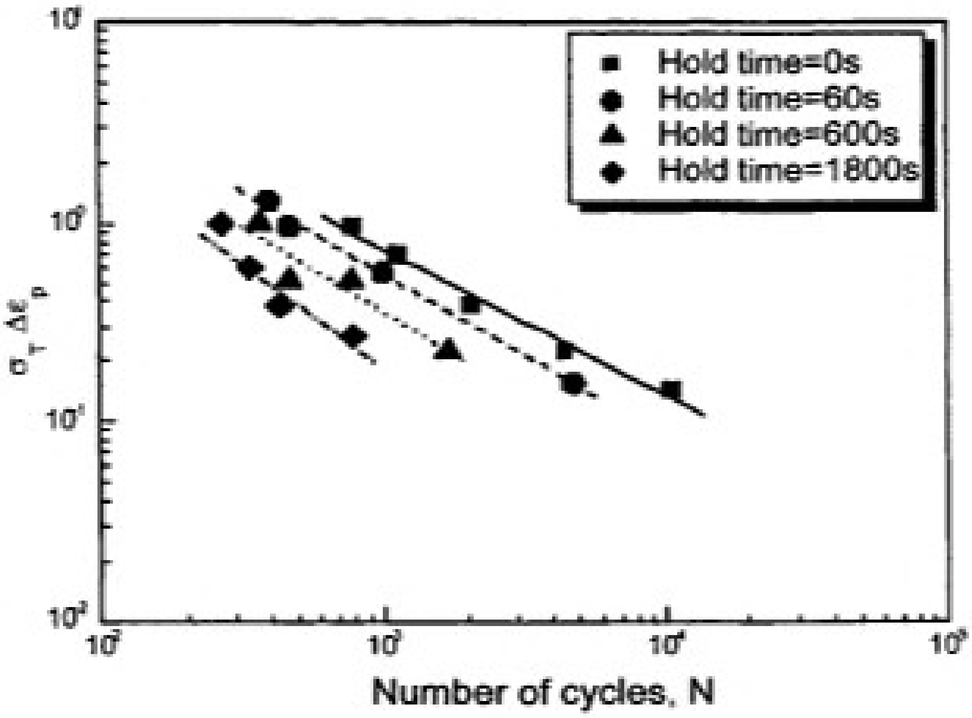

Fig. 9. The tensile hysteresis energy versus number of cycles to failure

CONCLUSION

In this study, with specimens extracted from aged boiler header in a power plant, the isothermal low cycle creep-fatigue tests are performed. The results are as follows.

1. At a given strain range, the fatigue life decreases with increasing hold time. There seems to be a saturation effect, no further reduction of the fatigue life above 600 s hold time is apparent by the long creep effects.

2. The tensile hysteresis energy approach for in-serviced material tests is introduced. This correlated to the number of cycles to failure by the relationship, $\sigma_T \Delta\varepsilon_p N_f^{\,\delta} = C$. Comparison of calculated values with experimental results shows good agreement.

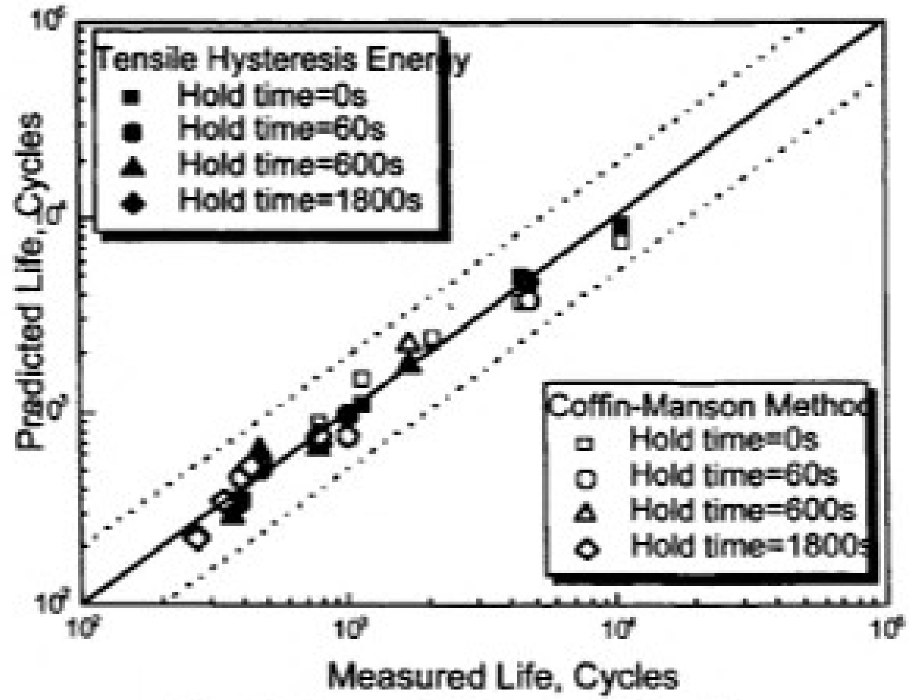

Fig. 10. Measured life versus predicted life

Temperature-Fatigue Interaction
L. Rémy and J. Petit (Eds.)

CREEP-FATIGUE LIFE PREDICTION OF AGED 13CrMo44 STEEL USING THE TENSILE PLASTIC STRAIN ENERGY

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Korea Electric Power Research Institute (KEPRI),
103-16,Daejeon, Korea

ABSTRACT

Low cycle creep-fatigue tests of 13CrMo44 steel used for boiler header of fossil power plant for 185,000 hr are conducted at 515°C with triangular and trapezoidal strains wave. Trapezoidal wave is considered about hold time for creep effects. The relationship between the tensile hysteresis energy and number of cycles to failure is examined to predict the low cycle creep-fatigue life of 13CrMo44 steel. The life, predicted by the tensile hysteresis energy method, is found to coincide with experimental results and analytical results obtained from models such as Coffin-Manson method.

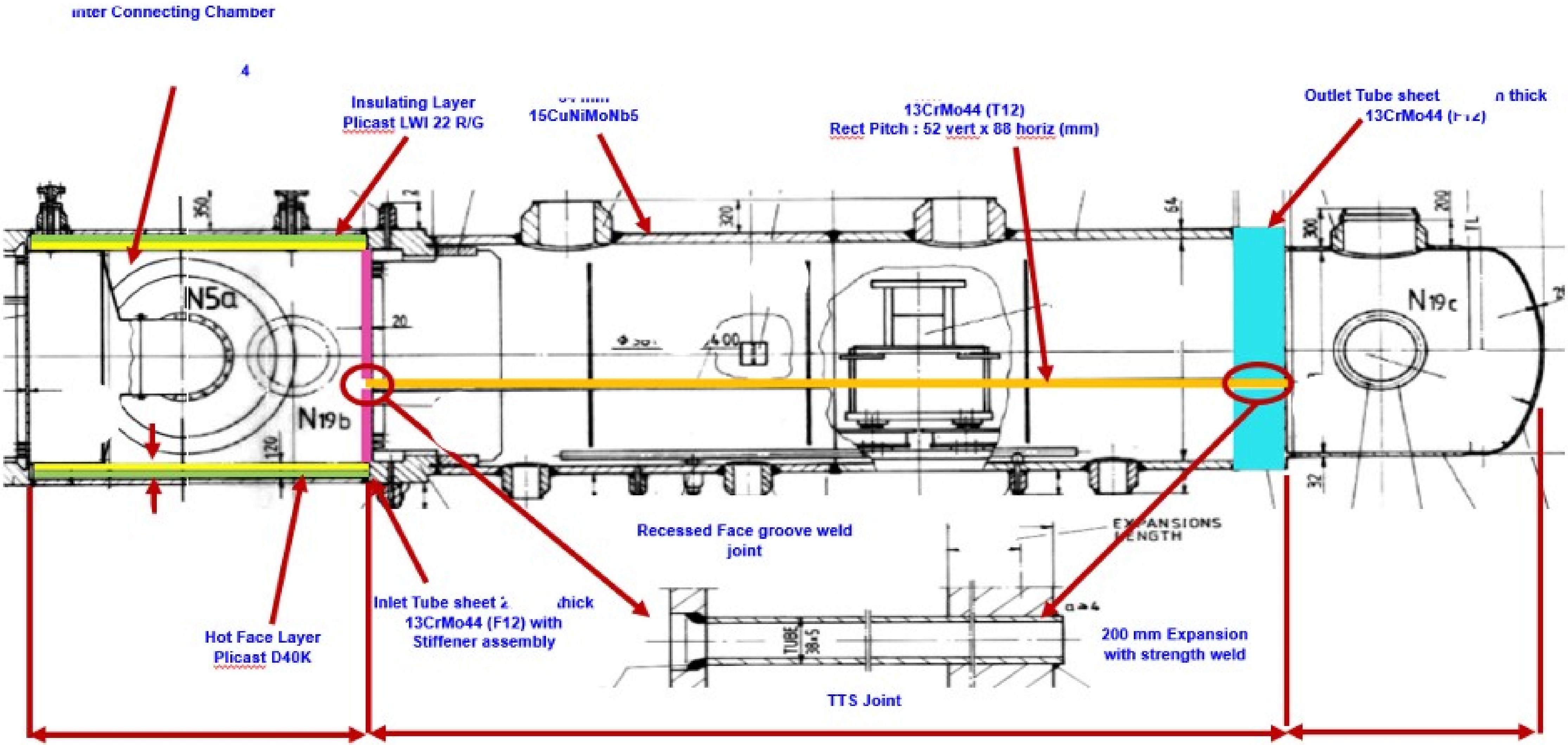
KEYWORDS

13CrMo44 steel, plastic strain energy, creep-fatigue interaction, tensile hysteresis energy, boiler header, life prediction.

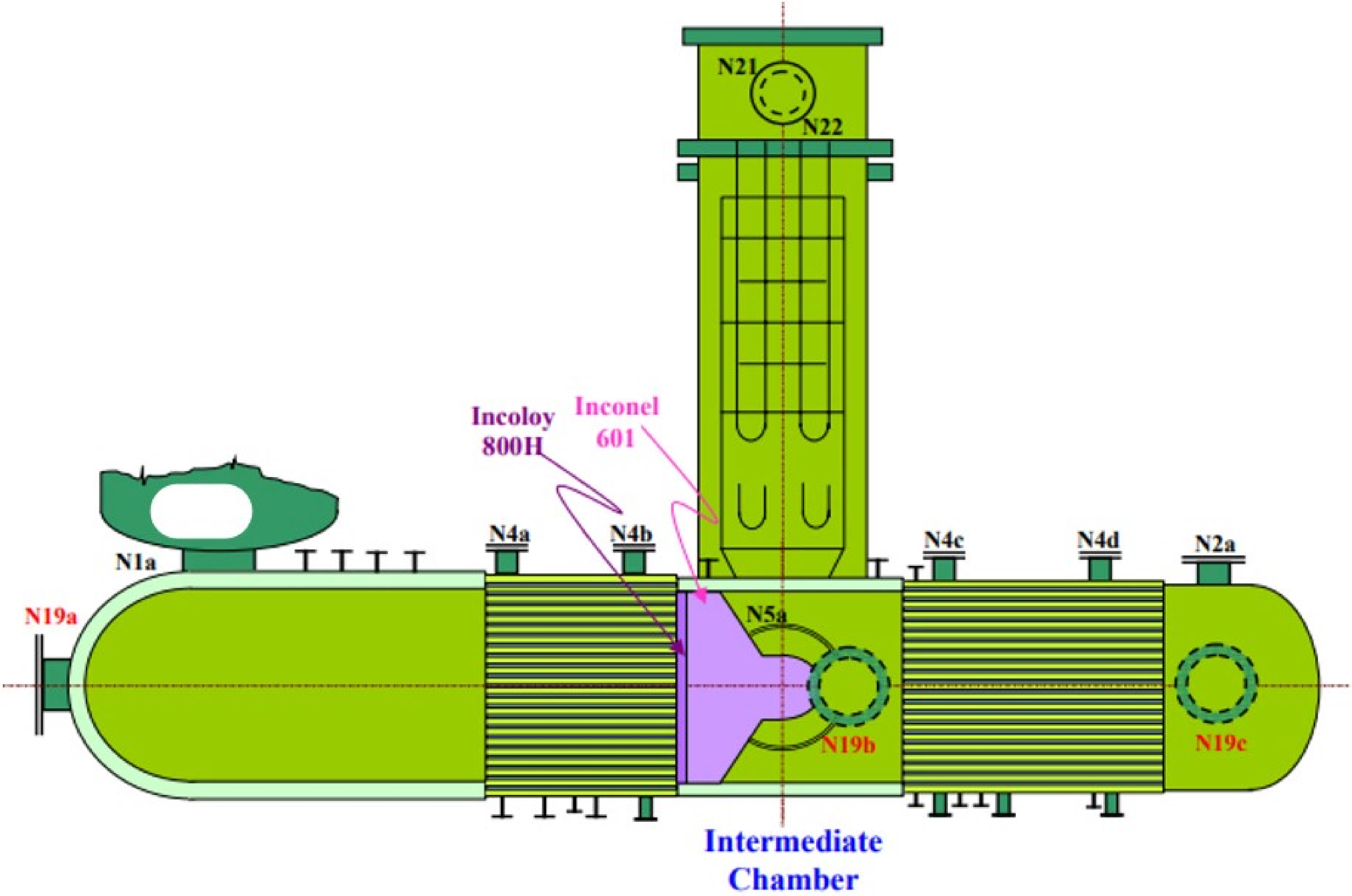
INTRODUCTION

The power plants use high temperature and high pressure for good thermal efficiency and these components of a power plant such as boiler header, steam pipe, turbine rotor and casing, etc. may undergo low cycle fatigue at high temperature. These critical components are subjected to transient loadings resulting from the large number of start-up and loading changes induced by the daily and seasonal variations in the electricity demand. Thus, most materials of components used in conditions of high temperature and high pressure suffer from thermal stresses as well as mechanical stresses. Although actual low cycle fatigue fracture is caused by thermal stresses due to the temperature changing, the behavior of materials is customarily investigated at constant temperature under mechanical loading.

Previously, most of the evaluation of low cycle fatigue life of materials has been done at uninterrupted (triangular) cycling. Correlation with actual service experience using this data is not encouraging. Therefore, introducing hold times makes a simulation closer to the actual service conditions. Since the fatigue damage is generally caused by the cyclic plastic strain, the plastic strain energy plays an important role in the damage process. Therefore, the idea of relating fatigue life to the plastic work during a load cycle has been proposed [1-5]. In this approach, plastic strain energy was proposed by Morrow. Ellyin proposed a fatigue failure criterion based on the strain energy density damage law. Ostergren proposed the net tensile hysteresis energy that can be used as the damage function. The objective of this paper is the investigation of the effect of hold time in the creep-fatigue tests and evaluate remaining life of the 185,000 hr, 439 start-up, aged 13CrMo44 steel by using the tensile hysteresis energy as the measure of creep-fatigue damage per cycle.



Inter Connecting Chamber
4
Insulating Layer
Plicast LWI 22 R/G
15CuNiMoNb5
13CrMo44 (T12)
Rect Pitch : 52 vert x 88 horiz (mm)
Outlet Tube sheet
N5a
N19b
N19c
Recessed Face groove weld
joint
EXPANSIONS
LENGTH
TUBE
Inlet Tube sheet
13CrMo44 (F12) with
Stiffener assembly
Hot Face Layer
Plicast D40K
200 mm Expansion
with strength weld
TTS Joint



N21
N22
Incoloy
800H
Inconel
601
N1a
N4a
N4b
N4c
N4d
N2a
N19a
N5a
N19b
N19c
Intermediate
Chamber

Waste Heat Boiler Related Literature References

AIChE Papers References

Sr No.	Relevant or Not Relevant	Year	Title	Description	Brief Summary	Construction details etc.	Installed Location and Designer
1	Not relevant. Vertical.	1969	Failure of a Primary Waste Heat Boiler	Fuilure of pressure shell due to refractory. Indications are that silica-based castable refractories lose insulating properties when used in reducing-atmospheres, and under the temperature pressure conditions in the steam-methane section of an ammonia plant.	Failure of pressure shell due to refractory. Indications are that silica-based castable refractories lose insulating properties when used in reducing-atmospheres, and under the temperature pressure conditions in the steam-methane section of an ammonia plant. Refractory type was changed to bubbled alumina.	Vertical	Terra Chemicals International Iowa.
2	Partially relevant w.r.t. BFW quality and dry-run out etc.	1976	Waste Boilers: Problems & Solutions	Discussion on different failures and possible remedial actions. A single failure of one of these units can easily result in a profit loss equal to the total cost of the boiler.	Discussion on different failures and possible remedial actions. A single failure of one of these units can easily result in a profit loss equal to the total cost of the boiler.		
3	Partially relevant	1979	Waste Heat Boiler - Failure and Modifications	Failures and subsequent repairs eventually resulted in the decision to replace these boilers with a new double compartment design.	Two waste heat boilers. Thick tubesheet 50 mm replaced with 20 mm thin tubesheet in modified design. Cooling issues of tubes with less flexibility in thick tubesheets. Stress concentration at weld root due to gap between tube and tubesheet at rolled portion increases in thick tubesheet design. Single compartment replaced with double compartment design. By reducing the tubes length the differential expansion is reduced to approximately half of its value with gradiant reduction in the tube sheet deflection.Tubes material was changed to 0.3 Mo in modified design. The use of tube and tube sheet material of 0. 3 Mo is intended to minimize welding stresses and improve the reparability and also permitted the use of full penetration weld without the need to stress relieving. The full penetration weld eliminated the chance for stress concentration as in rolled and face welded type.	Horizontal Single Compartment, Tube sheet material 13 Cr. Mo 44 (11/4 Cr. 1/2 Mo) Tubes material 13 Cr. Mo 44 Ferrules Incoloy 800 x 210 mm. long. 1.8 metre dia and 12.5 metre long. Designed according to DIN standards	Petrochemical Industries Kuwait
4	Not relevant. Vertical.	1985	Failure and Repair of the Shell of a Primary Waste Heat Boiler on a 1,100 ton/d Ammonia Plant	A primary waste heat boiler shell installed on a 1,100 ton/d Kellogg ammonia plant failed to operate. Inspection and repair procedures, results of failure analyses, and methods for avoiding future failures are outlined.	Analysis of the failure revealed anextensive surface cracking pattern on the OD surface of the waste heat boiler shell,extending downward to the center-line of the process gas outlet nozzle. The mechanism clearly involves localized corrosion, aggravated by periodic mechanical stress. The cracking involves a slow, step-like progression, and is not restricted to the water jacket portion of the shell. Thermally-Educed surface stresses due to liquid level fluctuation, local boiling, or splashing within the water jacket was initially accepted as the failure mechanism. However, such conditions of corrosion and surface stress were not obvious at the flange weld above the water jacket. To alleviate the corrosion problem, FERTRIN is considering: (l) coating the upper exposed area of the shell of the boilers during the next turnaround, and (2) the use of oxygen scavengers to reduce the corrosivity of the cooling water. In addition, the water jacket will be raised such that the water will cover the shell up to, and including, the flange weld.	Vertical Bayonet Type. A 516 Gr 70 shell	Fertilizers of Trinidad & Tobago Ltd., Point Lisas, Trinidad
5	Vertical. General discussion on TTS joint cracking.	1986	Improving Reliability of Waste Heat Recovery Units in Ammonia Syn Loops	Incidents of leaks experienced during operation of boiler feed water heaters/boilers in syngas loops led to good repair procedures and current design concepts.	It is evident that there is not one single mechanism causing failure of tube-to-tubesheet joints in WHRU's. Periodic upsets may induce stresses in the tube-to-tubesheet joints which can cause eventual fatigue of the joints. Hydrogen attack may be enhanced by metallurgical problems resulting from poor fabrication techniques and periodic temperature excursions. No design is absolutely foolproof. However, the present design and choices of metallurgy are considered adequate for these service conditions. The current metallurgy should offer satisfactory repairability in the event tube-to-tubesheet joints do crack. In addition, Kellogg is continuing to develop new designs which will eliminate more of these underlying problems.	Literature study	
6	Not relevant	1987	Failure and Repair of a Primary Waste Heat Boiler	Rupture occurred in the bottom dished head of the primary waste heat boiler in a 1500 T/d ammonia plant after two-year operation. Extensive in-situ metallography, mechanical testing, and nondestructive examinations were performed to determine the integrity of the bottom shell course and inlet nozzle.	Metallography and mechanical testing established that there was no deterioration in the property of the bottom head material even close to the failure. Decarburization was confined to the surface and the fine grain structure of the metal indicated there was no prolonged exposure to high temperatures. The absence of voids or fissures in the decarburized layer and good ultrasonic sound transmission discounted hydrogen attack. Failure of the bottom head was concluded to be as a result of localized refractory damage and short term high temperature stress rupture. The reason for refractory failure could not be determined as all evidence was destroyed in the rupture. The first shell course, gas inlet nozzle and bottom drain nozzle were in good physical, metallurgical and weldable condition and could be reused.	Vertical, irrelevant failure. The shell is made of ASTM A-516 Gr. 70 carbon steel internally lined with 97% bubbled alumina castable. The refractory is protected from erosion and collapse by 6mm thick stainless steel shroud sections that fit together with expansion joints.	Kellogg ammonia plant of P.T. Pupuk Kalimantan Timur located at Bontang, East Kalimantan, Indonesia
7	BFW quality is very important in operation of WHB	1988	Problems with a Process Gas Cooler	Poor boiler feed water quickly corrodes tubing in fire tube boiler with a high heat flux at the gas inlet, as evidenced in Duslo Sala's process gas cooler.	Higher contents of iron and copper and low pH-values lead to severe corrosion. Due to poor raw water quality and a failure in the water treatment plant the iron content of the boiler feed water rose up to a level more than 10 times higher as specified. In addition the ph-value dropped down from 9 to below 5 for some hours. These incidents occurred twice.	Horizontal, dual compartment, corrosion of tubes, 1973 16 tubes repaired, 1978 totally retubed, 1986, first compartment repaired. Gas side shells, tube sheets and tubes are fabricated from C-1/2 Mo-steel.	Ammonia plant of Duslo Sala in Czechoslovakia, which has a capacity of 1000 TPD, was commissioned in 1973
8	General discussion on tube-tubesheet joints improvement and utilization of thin tubesheets.	1988	Experience with a new Design of Reformer Waste Heat Boiler, Synthesis Steam Generator, and Steam Superheater	A new design of thin-tubesheet straight-tube reformer waste heat boiler, synloop steam generator, and steam superheater are discussed. Improvements in design increased the reliability of boilers.	The new Balcke-Durr design concept for the reformer waste heat boiler is unique and offers many advantages over other designs. A thin tubesheet can now be utilized without complex stiffening members. The hydraulic expansion process provides crevice free tubejoints and adds operating integrity to the tubejoint weld. In the event that a repair is necessary, the removal and replacement of a tube is a fairly simple operation since postweld heat treatment is not required. The first of these units has operated successfully in NSM's new plant for about one year.		
9	Vertical. Guidelines on protecting magnetite layer.	1989	Problems with the Magnetite Layer in Primary Waste Heat Boiler and Auxiliary Boiler	After 18 years of operation, the auxiliary and the first waste heat boiler downstream of the secondary reformer leaked due to corrosion. Since the last repairs of October 1988, no signs of tube failures were detected.	Steps taken to protect magnetite layer are discussed.		BASF, Germany
10	Not relevant	1990	Post-Weld Heat Treatment of a Repaired Synloop Waste Heat Boiler	Repair of leaking tube-tubesheet connections often requires post-weld heat treatment. This can create a problem, since the tubesheet is hindered in expansion by the exchanger head and shell. A local conductive heat treatment procedure can overcome this problem.	Experience of local heat treatment of TTS joints is discussed as PWHT of complete tubesheet can cause cracks in TTS joints.		DSM Fertilizers Netherlands. Kellogg Ammonia technology plant
11	Not relevant. Water tube vertical boiler.	1990	Use of Ceramic Thermal Barrier Coating in a Waste Heat Boiler	The cause of tube failures in the waste heat boiler has been eliminated by applying plasma sprayed zirconia to the area of the tubes exposed to the maximum thermal gradient	To avoid metal dusting on outside surface of tubes, plasma sprayed ceramic coating was applied.		Arcadian Memphis ammonia plant. Foster Wheeler design
12	Not relevant. Vertical.	1991	Failure of Waste Heat Boiler Downstream of Secondary Reformer	After 3 1/2 years of operation without any failure, waste heat boilers experienced failure of tubes. The causes of failure are analyzed. Remedial actions taken and features of safer design are described.	Discussion on improvement of design features.		Krishak Bharati India. Ammonia plants designed by Kellogg USA
13	Not relevant	1992	Timely Detection of Damaged Gas Distributor Avoided Failure of WHB	On routine inspection, the inlet gas distributor of a WHB was found damaged. Removal of the tube bundle revealed blisters on caps of 50 scabbard tubes. Microstructure studies showed that carburization and plastic deformation were due to overheating. The distributor was replaced and actions were taken to avoid recurrence of the problem.			Krishak Bharati India. Ammonia plants designed by Kellogg USA
14	Not relevant. Synthesis Section WHB.	1993	Failure of Synthesis Waste Heat Boiler by Rotating Ferrules	Following several problems in the early 1980s with the synthesis waste heat boiler in an ammonia plant, the design of the gas inlet for a spare boiler was slightly modified. After less than 3 years of operation, rotating ferrules caused damage to some of the tubes.			
15	Not relevant. Synthesis Section WHB.	1993	Repair of Waste Heat Boiler in Synloop of NH3-Plant	The failure of the heat protection shield caused a leak in a waste heat boiler in the synloop of NH3-Plant. For reconditioning of the on-site boiler, 71 boiler tubes were removed, repaired, and reinstalled.			
16	Not relevant. Synthesis Section WHB.	1994	Tube Failure in a Waste Heat Boiler Ammonia Synthesis Section	The detailed history of several tube failures in one of two connected high-pressure steam generating waste heat boilers is presented. The damage could be explained by lack of water circulation due to insufficient design of the connecting outlet steam pipelines.			
17	Not relevant. Case Studies 1 Methanol plant. 2 U-tube bundle. 3 Firetube 4 Refinery Vertical exchanger	1994	Failures in Waste Heat Boilers	Case histories of failures in waste heat boilers and the remedial actions taken to restore those boilers for continued service are provided. The failures were caused by various factors including design deficiencies, defects introduced during manufacturing or fabrication, service-related deterioration and/or upset operating conditions.			
18	Not relevant. Vertical.	1994	Ammonia Plant Waste Heat Replacement	Following several years of problems with a leaking fixed tubesheet waste heat boiler on the exit of the secondary reformer of an ammonia plant, the boiler was redesigned and replaced with a floating head type. This paper provides the background for the reasons for the replacement, the decisions leading to the final choice, and the decisions made during the selection and placement of the new boiler.	Refractory repair, internal bypass valve failed, TTS joint failed. Different replacement options considered and finally horizontal boiler replaced with vertical WHB.		Sherritt Canada. Designed by Kellogg.
19	Not relevant.	1994	Experience with Metal Dusting in Waste Heat Boilers	Metal dusting can occur in ammonia plants in process equipment between the secondary reformer outlet and the inlet of the high-temperature shift converter. The case history in a DSM ammonia plant is described, as well as the metallurgical and thermodynamic know-how about metal dusting. Experimental results with test coupons are given.	Metal dusting issues are discussed.		DSM Fertilizers Netherlands. Kellogg ammonia plant.
20	Partially relevant.	1996	Catastrophic Failure of Tubesheet in Fire Tube Reformed Gas Waste Heat Boiler	The reformed gas waste heat boiler failed after nine years in service due to prevalent high heat flux and departure from nucleate boiling. The interim repair, the failure analysis, and replacement of the front section of the boiler are described.	Front compartment replaced due to failure of tubesheet and one leaking tube.		Terra Courtright Canada. Equipment designed by Steinmuller.
21	Not relevant. Water tube boilers. Vertical.	1996	Remedial Actions to Reformer Waste Heat Boilers	Several repeated failures were experienced by reformer waste heat boilers in two similar ammonia plants. The failure analysis, the investigations carried out, and the remedial actions are described.	Not relevant. Watertube boilers . Vertical WHB tube failures discussed.		Asmidal Algeria. Kellogg designed plants.
22	Relevant	1996	Failure, Repair and Replacement of Waste Heat Boiler	Waste heat boiler failure, subsequent repairs to enhance the reliability of the unit, and design improvements made to the new WHB are addressed.	FFC Goth Machhi P-I WHB discussed	FFC	
23	Not relevant. Shell failures	1998	Ammonia Process Primary Waste Heat Boiler Shell Failure Experiences	Three cases of pressure shell failures during 20+years of operation are described. The results of the failure analysis following each event are also presented, as well as a description of the repair methods employed. Although the nature of the failures were not all similar, some common elements surfaced as a result of thefailure investigations.			Canadian Fertilizers Canada. Kelloog designed plants.
24	Not relevant. Synthesis Section WHB. Vertical.	1999	Two Case Studies: New Concept WHB and Repair of BFW Heater	In Case A, a new concept Synthesis Loop WHB is discussed: gas flow reversal to increase operating life of a corrosion damaged synloop waste heat hotter and a new type of gas tight ferrule WHB to face nitriding of low alloy parts exposed to temperature above 470°C. Case B presents an analysis of the causes, stress calculations and repair by hydraulic expansion of a BFW preheater suffering from cracks on a tube-tube sheet weld joint.			
25	Not relevant. Failure of line connecting secondary reformer and WHB.	2001	Fire in Secondary Reformer Outlet Line to Waste Heat Boiler	The failure of the pressure shell of the interconnecting pipe between the secondary reformer and primary waste heat boiler, resulting in a fire in Ammonia Unit I after 13 1/2 years of operation, is discussed. The fire incident resulted in a plant shutdown of 15 days. Analysis, repair work carried out to put the plant in service in minimum possible time, and the remedial measures taken are also described.			
26	Not relevant.	2001	Selection of Nickel-Base Alloys for Metal Dusting Resistance	The causes of "metal dusting", a potentially severe corrosion problem resulting from the steam reforming process, are examined. Long-term laboratory data is presented which shows how the consideration of alloy content can be effective in resisting metal dusting attack. A newly-developed alloy offers promising potential for metal dusting limited applications.	Metal dusting issues and selection/comparison of various alloys are discussed.		
27	Not relevant. Shell failure	2002	Burst Before Leak Failure of a HTS Effluent Waste Heat Boiler	Following an unplanned outage on the ammonia plant 2 in December 2001, a leak from the shell of the waste heat boiler (H201) was detected during start-up. After visual inspection a full wall crack of 1,2 meters was identified in the 32 mm thick shell of the waste heat boiler (after this named heat exchanger). In this paper the damage, the investigations, the metallurgical phenomenon and the repair of the heat exchanger are described.			DSM Agro. Kellog designed ammonia plant
28	Not relevant. Synloop WHB outlet line. Vertical.	2003	Syn-Loop Waste Heat Boiler Exit Line Failure	This paper will describe two failures that occurred two years apart on the same exit line of a Syn-loop waste heat boiler. The failures occurred at the weld joint between two different Chrome – Moly alloys at almost the identical location. At the time of the second failure the downstream inlet nozzle to the Syn-loop feed preheat exchanger also failed. This paper will provide the analyses from a metallurgical investigation, and pipe Finite Element Analysis and provide some insight into the problems encountered in making a sound repair at these weld joint locations.	Vertical U-tube WHB		
29	Vertical. Sleeves inserted to avoid tube shearing near bottom tubesheet.	2003	Failures of Secondary Waste Heat Boilers	In Ammonia Plants, the Secondary Waste Heat Boiler (102-C) are installed as a trim exchanger, along-with two Primary Waste Heat Boilers (101-CA/CB), for heat recovery from reformed gas. It is a vertical boiler with boiler feed water in shell side, and hot process gas in tube side. Its tubes started leaking frequently 3 to 4 years after commissioning, which some times resulted in plant stoppage. Various efforts, like BFW treatment, modifications in exchanger, inserting sleeves inside tubes, were made to reduce tube failures and to prolong service life of exchanger. By inserting sleeves in the tubes, the life of one of the 102-C's was prolonged by about two years and a plant stoppage was avoided.	The main cause of failure, seems to be sludge formation and its accumulation due to low circulation rate due to operation of the exchanger at much lower than design heat load. However following factors also would have played some role. 1. No IBD for initial 4 years. 2. Conventional treatment of dosing TSP till 1998. 3. Improper tube expansion at tube to tube sheet joint in case of 102-C (OA2-R) Sleeves inserted in the weakened tubes have helped to prolong the life of exchangers and avoided unplanned stoppages of plant for two years.		Krishak Bharati India. Ammonia plants designed by Kellogg USA
30	Not relevant. Design improvements discussed.	2003	Facing the Demand of Reformed Gas Boilers of Big Capacity	All the major process engineers design methanol and ammonia plants of higher and higher unit capacity. This has an impact on the size of the secondary reformer waste heat boiler, which, before reaching the limit on feasibility from the fabrication and transportation point of view, may have undesired negative effects on the reliability of the equipment. Innovative concepts have been studied in order to maintain an acceptable level of reliability in increasing diameters and lengths of the equipment. In this document it is shown that, with the adoption of the 'multi ferrule concept' and after increasing the circulation ratio by increasing the elevation of the drum, economic and reliable designs are available for boilers of unit capacity corresponding to 5000 MTPD of ammonia production.			Paper presented by FBM

31	Theoretical discussion on dynamic behaviour of WHBs	2004	Dynamic Behavior of the Waste Heat Boiler for Ammonia Plant	Non-stationary operating cases like start-up, shut-down or quick trip conditions which can be caused for example due to the loss of the boiler feed water lead to the additional stresses in the pressurized parts of the waste heat boiler. The paper describes the calculation of the pressure and temperature changes on the water side of the waste heat boiler for some transient operating cases. The temperature changes on the water and gas sides determine the temperature distribution as well as the time depended stress distribution in the pressurized parts of the waste heat boiler. The lifetime of the waste heat boiler can be affected.			
32	Not relevant. Water tube boiler.	2005	Waste Heat Boiler (101-C) Leakages & Possible Causes	Waste Heat Boiler 101-C is an essential part of Ammonia Plant in Kellogg design. Almost every plant is facing the problems of no flow, reverse flow and tube leakage. These problems are more significant on the plants where production capacity has been increased. In this article flow in the risers is considered. How flow is checked and a method is proposed to establish and maintain equal flow in both the risers.		DH	Dawood Hercules Lahore. Plant designed by Kellogg
33	Related to BFW quality issues	2005	Corrosion damage in Waste Heat Boilers; Major root causes and remediation	The crucial factor determining damages of high-pressure waste heat boilers in ammonia plants are fouling of the boiler tube surface with magnetite (Fe_3O_4) in combination with exceptionally high local heat fluxes. The main reasons for the magnetite fouling are: (i) Flow Accelerated Corrosion (FAC) in the preboiler / feed water system (ii) First Condensate Corrosion (FCC) in steam and condensate equipment (iii) Ineffective chemical cleaning and conditioning programs for the boilers The main goal of boiler water treatment programs should be to keep the boiler heat transfer surface free from deposits. Conventional chemical treatment programs are not always successful. Polyamine treatment can offer an alternative approach.	Due to extreme high local heat fluxes WHBs are very sensitive to corrosion damage. During operation fouling of heat transfer surfaces with corrosion products aggravates this situation. These corrosion products are mainly magnetite formed by Flow Accelerated Corrosion (FAC) and First Condensate Corrosion (FCC). The classic approach to keep the boiler water as free as possible from alkaline and acidic impurities (such as in power stations) generally is not feasible in ammonia plants. The main goal of boiler water treatment programs should be to keep the WHB heat transfer surface free from deposits. Conventional chemical treatment programs are not always successful. WHB polyamine treatment seems to offer an alternative approach to ammonia plants operators.	plant 1 (AFA-2) in 1971, plant 2 (AFA-3) in 1984, Betchel and Kelogg technology. AFA-2 WHB dual compartment, AFA-3 WHB Single compartment	
34	Relevant	2005	SECOND FAILURE OF REFORMED GAS WASTE HEAT BOILER	On 21st Augusts 2004, the Ammonia plant had to be emergency shut down due to instrument air failure. After the feed gas and process steam was stopped to Primary Reformer and also process air stopped to Secondary Reformer, the acid header vent was still venting a lot of saturated steam from the gas stream side. Therefore, it might be concluded that the Reformed Gas Waste Heat Boiler 1-E-108 failed. This was the second failure after three years; previously, on 9th May 2001 bulging was found at circumferential weld line of the inlet channel failed of waste heat boiler about 250 mm from the inlet of tube sheet. This paper reports the experience of repairing the second failure of this particular waste heat boiler.	The probable cause of second failure of reformed gas waste heat boiler was a crack in welding connection zone, which happened after operation stage during 3 years later. This occurred due to poor quality of PWHT during retubing, therefore the welding connection zone had metal structure that very easily cracked due to stress work and hydrogen rich environmental condition during operation	Design Borsig, Manufacture Kawasaki, second failure after three years. Tube repaied in october 2001 leaked in august 2004. Tubes failed due to inadequate PWHT in first repair.	PT. Pupuk Kalimantan Timur Indonesia. Equipment designed by Borsig. Manufactured by Kawasaji. Ammonia process licensor Haldor Topsoe.
35	Not relevant. Refinery.	2005	Failure of 110 bar WHB's due to poor quality boiler feed water	PetroSA, formerly known as Mossgas is a 36000 bpd Gas to liquid (GTL) plant situated at Mossel Bay in South Africa. This plant has been in operation since 1992 and the plant produces synthetic fuels from synthesis gas. The synthesis gas is produced by reforming natural gas in a three-train combined reforming plant utilizing both primary tubular steam reforming and oxygen-blown auto-thermal reforming. The front end of the plant layout incorporates a gas reforming unit, which was designed on the principle of the LURGI Combined Reforming process. The factory was shutdown in May 2003 for its 3 yearly T&I. After commissioning of the three Reformer trains all six Waste heat boilers developed boiler feed water leaks in excess of 60 tons per hour BFW of poor quality caused the failure of the WHB's tubes that resulted in a complete factory shutdown. This incident resulted in a comprehensive failure analysis. Several system improvements were considered and the modifications were implemented prior to the restarting of the three reformer trains.	Six WHBs developed boiler feed water leaks due to poor water quality management within 10 days of startup after TA. All six WHBs had to be replaced. By the end of next month while 4 ordered an replaced in next six months. Insulating magnetite layer resulted in overheating of tubes. The waste heat boiler is a special shell and tube exchanger.		Petro SA
36	Partially relevant.	2005	Failure of REFORMED GAS Boiler Tubes: A Learning in Harder Way	Tube failure in any boiler is a common phenomenon, the analysis of data and conclusions derived, some times may be so misleading, it prevents laying hands on simple mistakes or defects. A similar kind of situation was encountered by IGFL. From this experience it is learned, that however big a problem is, one should start from very basic fundamentals, rather than straightway thinking in a complicated way.	Tube failure incidents. BFW quality issues and malfunctioning of valves etc. are discussed.		Indo Gulf Fertilizers India
37	Not relevant. Synthesis loop WHB. Vertic	2006	Life Extension of Waste Heat Boilers in Ammonia Plants	Life extension measures can significantly increase the total lifetime of the equipment. If they are done correctly and in time, they "buy time" until replacement equipment is available and reduce the risk of unplanned outages. The described solutions are not only limited to case of failures, gas flow reversal or modification to hot/cold alternating tubing can be applied to prolong the total lifetime of the equipment.			
38	Not relevant. Refractory issues are discu	2006	Waste Heat Boiler (101C) Refractory Management	This paper shows the problems that Petrobras/ Fafen-SE faced with two waste heat boilers in relation to the lining design and refractory losses. The lining was found almost completely destroyed at the first turnaround after the revamping of the plant. It shows how plant personnel managed to run the plant safely in spite of the lack of refractory that caused the water in the water jacket to boil and the procedures that were adopted in order to keep the plant in operation until the turnaround. It also shows the details (region, extension, etc.) of the damage of the refractory and lining, the modifications performed in the equipment and the way we now monitor the refractory integrity.			
39	Not relevant. HTS catalyst recovery incidents discussed.	2007	Successful Recoveries from Major WHB Failures Experience	An all too common experience in the ammonia industry is the leaking of the waste heat boiler (WHB) located downstream of the autothermal reformer. A significant tube leak of the WHB usually results in a subsequent flow of boiler water into the High Temperature Shift (HTS) reactor, causing thermal shock to the catalyst bed, flooding the reactor, and preventing continued operation of the plant. In addition to the requisite WHB repairs, the change-out of the HTS catalyst is also sometimes required. Terra Industries has experienced two recent significant WHB failures at different manufacturing sites.			
40	Relevant	2007	Failure of Damaged Tubes of the Reformed Gas Waste Heat Boiler at Profertil	Profertil commissioned their 2050 MTPD Ammonia plant in January 2001. Since then the Reformed Gas Waste Heat Boiler has had repeated failures for various reasons. Tube plugging or partial tube replacement can be performed for equipment to remain operative in face of new failures but with low reliability owing to the structural state of remaining tubes and high load limitations. No additional information is available to predict future failures at the equipment, yet there is a high probability of failure repetition. As a final remark, it is essential to stress the need for highly safe and reliable utility service facilities because their impact on plant operations is huge and to ensure, at all times of plant life, a proper treatment of the alterations, no matter how small they are (MOC, Risk Analysis, HAZOP, etc.).	Evidence shows that pits on the tubes were caused by excessive oxygen content in water, worsened by the presence of dissolved copper, alikely source of cooper in the tube deposit. The root cause of the problem can be traced back to the lower water circulation in the area close to the tubesheet which generates a relative temperature increase of the metal in relation to other areas and the same vicious cycle is started – thickening of the magnetite layer – tube temperature increase.	thin stiffened tubesheet, full penetrtion fillet weld TTS, manufacturer BORSIG	Profertil Argentina
41	Not relevant. Watertube boilers . Vertical WHB tube failures discussed.	2008	A Waste Heat Boiler Replacement – From Bayonet to Fire-tube	The bayonet WHB 101-C after the secondary reformer that operated smoothly for 20 years faced frequent failures after the plant revamp. Chemical cleaning of the old BFW/steam system performed during the revamp was a disaster. The water chemistry control was improved to avoid corrosion. However, major cause of the failures was uneven/reverse circulation in one of the risers. A zigzag baffle was installed but, for a future plant revamp, the 101-C was replaced with a new fire-tube exchanger. The paper presents operational experiences of waste heat boilers, tube failure analyses, its rectification and details of exchangers' transformation in Kellogg designed ammonia plant, where space availability was a major constraint.		Kelogg Design, Vertical, 255 tubes,	DH Chemicals Lahore
42	Partially Relevant	2008	Replacement of Reformed Gas Waste Heat Boiler at Terra Courtright Ammonia Plant	The Reformed Gas Waste Heat Boiler (C110) at Terra Courtright facility, a Steinmueller designed equipment, was in service since 1985. During the 22 years, it had experienced one catastrophic failure, in 1995 after 9 years of service, which required replacement of the first section of the boiler. In the early years, several metal dusting related problems on non-pressure components were reported as well, mostly in the second section of the boiler, which were eventually solved by adopting different metallurgy. Subsequent to first compartment replacement in 1995, the boiler was in operation for the next 8 years without any signs of known failure. In 2003 and 2005, during the routine inspection of the boiler in turnarounds, it was observed that the outlet tube sheet of the first compartment developed numerous cracks in the ligament sections. This paper describes the type of failure observed on the tube sheet and the reasoning that went into the decision to replace the equipment in the year 2007. The paper also highlights the activities that were involved in the design, procurement, onsite assembly & fabrication and installation of the waste heat boiler.	During the 1995 replacement job the first section was re-designed by Steinmueller to reflect the 115% operating rate of the plant. The revised design of the first compartment had two different sizes of tubes. Complete replacement with single compartment design in 2007	Two compartments with intermediate chambers, before 1995 the first compartment had 559 tubes of 39 mm OD with 1,050 mm long ferrules with a shell OD of 1,994 mm. replaced with redesign in 1995. Tubesheet 1 Cr-1/2 Mo. Differential Elongation porblem for long tube lengths between tubes and shell. It is important to note that ASME Section VIII Division 2 code does not allow surface temperatures to exceed 482 ºC for 1 Cr – ½ Mo.	Terra Industries, Canada
43	Not Relevant. Synloop WHB.	2011	Ammonia Synthesis Loop Waste Heat Boiler Failure at GNFC	GNFC Ltd, Bharuch , India experienced two similar failures in the synthesis loop WHB. The failures occurred on two boilers of the same design but manufactured by different fabricators. This paper covers details of the failures of the weld joint, the inspection, and the repair procedure adopted. The failure analysis was carried out at different levels to reach to the root cause of the problem and also to address all the possible causes. Recommendations of Haldor Topsoe and a meticulous future action plan to avoid such failures are also described	The failures occurred on two boilers of the same design but manufactured by different fabricators. The failures were at the same weld locationand both happened within the first two tofour years of operation.The first failure was confirmed to be a PWHT problem. The in situ repair of the Borsig WHB worked well for more than 20 years and each inspection found no issues. The second failure gave indications of inadequate weld penetration, but poor PWHT or initial welddefect have not been ruled out. This FBM manufactured WHB was repaired at L&T and put back in service. It will be inspected every year during the annual turnaround to confirm its mechanical integrity. Efforts to find the root cause of this failure involved the help of M/s Haldor Topsoe, external experts and internal experts continues. A new WHB with different design has been ordered. Based on the failures at GNFC site and also failures of similar WHB at other sites, M/s Haldor Topsoe has recommended the PWHT of the new WHB to be done in single piece and in a furnace only. There should not be local heat treatment of any pieces.	Vertical, Borsig Design, Syn Loop	Gujarat Narmada Valley Fertilizers Company Ltd. (GNFC), located at Bharuch in Gujarat State in India
44	Partially Relevant	2012	Successful Management of a 102C Waste Heat Boiler Leak by close and effective collaboration between Operator and Water Treatment Supplier	This paper captures the growing importance of the need for plant Operators to engage Water Treatment Providers that understand all of the Operator's critical processes. Further, Water Treatment Providers should provide a range of supportive services that will meet the original service mandate while continuing to add value during non-routine operation.	To ensure protection of the internal 1500 psig (106.5 kg/cm2) boiler steam generation surfaces from caustic gouging or acidic attack at this particular Operator site, a "coordinated pH/phosphate" program, also referred to as a "coordinated phosphate" program (see Figure 2) was recommended. In summary, boiler leaks can be successfully managed while maintaining safe operational and production goals through careful monitoring and maintenance of water chemistry. In this example, clear communication and planning led to orderly management and measurement of the parameters that affected plant operation and water treatment control, resulting in extended operation and realization of the Operator's production business plan.	Kelogg Design, Leak after 30 years of vessel service. No mechanical Repair other than tube plugging mentioned. The vessel was operated for two more years after leakage until planned replacement.	
45	Not relevant. Vertical.	2012	Failure of Waste Heat Boiler in a Kellogg Designed Ammonia Plant	This failure pertains to a Kellogg designed Ammonia Plant of Indian Farmers Fertilizer Cooperative Ltd. (IFFCO) located at Phulpur, Allahabad, India. The twin Waste Heat Boilers (101-CA/CB) happen to be the most critical equipment of a Kellogg designed Ammonia Plant. These density operated, bayonet type exchangers having inner and outer tubes with water cooled pressure shell have been the subject of great anxiety in recent past due to problems associated with the rupturing of their tubes, no flow of water or reverse flow through risers etc., The repeated failure of these exchangers caused due to rupturing of tubes twice in 3 months (May - August 2011) had cast a shadow on the energy, productivity and performance of the otherwise excellently performing 30 year old plant. This article sheds light on the probable causes of failure, root cause analysis and more importantly, the threadbare analysis of the methodology adopted for rectification so that plant can be restored back on stream in the shortest possible span of time and recurrence can be avoided.	Watertube boiler. Vertical. Concentric two sets of tubes (inner tubes with both ends open and outer tubes with one end closed). The spare tube bundles which were installed after the 3rd failure had undergone repairs. The outer tubes, baffles, tie rods and spacers were procured as new under third party inspection and assembled together. They even passed the hydrotest of shell and tube side successfully. All above activities were performed in our presence but we were not witness to the most important aspects such as the removal of water from inside the tubes after hydrotest, subsequent drying of tubes by air and filling of nitrogen before dispatch. It seems that the above factors e.g. lack of care and attention to water removal, drying and nitrogen blanketing resulted in the formation of corrosion or rust deposits on the surface of tubes. These deposits got detached during service and fell at the bottom of outer tubes thereby blocking or reducing the specified gap between the bottom face of inner tubes and the bottom of outer tubes. The flow path was blocked leading to over-heating of tubes and ultimate rupture. Another factor, which is worth mentioning, is the exact location of the tubes of the boilers, which failed recently. In order to be more specific, if we see the location of ruptured tube as shown in Figure 5 and 7, we find that only peripheral tubes have ruptured subsequently damaging the nearby tubes. This indicates that there might have been some problem while inserting the tube bundle into the shell. There is a possibility of peripheral tubes being rubbed with the shroud and consequently being damaged. During insertion of tube bundle into the shell, the bundle got stuck-up in between & had to be pushed in forcibly as withdrawal at that stage would have distorted the shroud.	Vertical boilers.	Kellogg designed Ammonia Plant of Indian Farmers Fertilizer Cooperative Ltd. (IFFCO) located at Phulpur, Allahabad, India.
46	Not relevant. Watertube vertical.	2014	Lessons Learned from High Pressure Process Boiler Failure	After 13 months of service, a new 1500 psig (103 barg) secondary reformer effluent process boiler developed a severe leak. After stabilizing the plant, operators identified the nature of the issue. Precautions were taken during the shutdown that were successful in preventing catalyst damage in the secondary reformer and shift converters due to the leak of BFW into the process gas. The tube bundle was removed and replaced with a spare. The immediate cause of the failure was identified and a metallurgical analysis was performed on the failed and adjoining tubes. Possible contributing factors were considered. Metallurgical analysis results are consistent with the cause identified. Recommendations are shared on promptly recognizing this type of failure, shut down precautions, and prevention.	Watertube boiler.	Forced Circulation (not natural), Vertical, U tube. Tube Material Inconel 625	PCS Nitrogen Fertilizer LP operates a 2425 stpd (2200 mtpd) ammonia plant at Augusta, Georgia, USA
47	Not relevant. Syntheis loop. Vertical.	2015	Retubing experience of synthesis loop WHB No 1 and Failure of Incoloy WHB No. 2	Synthesis loop waste heat boiler no 1: This boiler was replaced in year 2009 after being in operation for 12 years. In 2005, modifications were made to the internals to reverse the flow which prolonged the life of the boiler. In 2010, re-tubing of the boiler was done so that a spare boiler is available for replacement in case of failure. Unexpected problems were faced during re-tubing which necessitated replacement of tubesheet increasing project cost and schedule. This paper describes the re-tubing experience and the improvements done during re-tubing. Synthesis waste heat boiler no 2: The new boiler installed in year 2009 had Incoloy 800 tubes. Chloride analyzers were installed and modifications were done in the process to prevent stress corrosion cracking. Despite control mechanisms being in place, the boiler failed within 5 years. This paper describes the construction features of the boiler and the causes that contributed to the failure.	WHB 1 : Tubes inspected at random using IRIS (Internal rotary inspection system) technique. Severe thinning of the tubes just after the fenule on steam side was the reason for the above leaks. The probable reasons for the failure attributed to corrosion under oxide layers build up which were partly formed during PWHT (Post weld heat treatment), but mainly deposited during operation by deposition of iron oxides from the water phase. Another contributing factor is low circulation rate on water side. (A similar phenomenon was noted also in the QAFCO-4 plant in 2006. After rerouting of steam condensate and optimization of water treatment these deposits were found completely removed in 2008 and 20 12 inspections. WHB 2 : Based on above experience, it is essential to carryout internal bore welding to eliminate crevices in the tube sheet to restrict chloride build-up. This is only possible if same materials are used for tube sheet and tubes to carryout internal bore welds. 2 1/4 Cr 1.0 Mo matenal (T22 / F22) is the preferred option with Inconel weld-overlay on the tube sheet.	Vertical. Good read.	

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Sr. No.	Year	Reference	Description
1	2010	0102 Page 31-35	20 incidents of failures discussed shortly . (8 out of 20 incidents AIChE paper references available)
2	2010	0304 Page 33	One incident of failure due to scale build-up. Details not found yet.
3	2010	1112 Page 23	Failure of WHB due to change in water treatment programme. Details not available yet
4	2011	0102 Page 7	News - 3 times plant shutdown in a year due to WHB leaks. Details not found yet
5	2011	1112 Page 15	Conference Review - Informed about failure of two WHB due to welding issues. AIChE paper reference available.
6	2012	0304 Page 15	Conference Review - KBR design WHB replaced in Agritech Lahore. Detals not found yet
7	2012	1112 Page 13	problems and repair methodology dicussed (AIChE paper reference available).
8	2013	0708 Page 17-18	WHB incidents and conclusions with references to AIChE papers. Full Article available
9	2015	1112 Page 16	Qafco tube replacement and WHB replacement experience. AiChE paper available. Synthesis loop.

World Fertilizer Magazine

Sr. No.	Year	Reference	Description
1	2018	10 Page 58	Pop a plug technique used in fertilizer plant located in Qatar. Full article available