Suomen Soodakattilayhdistys ry

Soodakattilapäivä 1997

MARINA CONGRESS CENTER
HELSINKI 22.10.1997

Raportti 7/97

60V00928
Suomen Soodakattilayhdistys ry
Finnish Recovery Boiler Committee

SOODAKATTILAPÄIVÄ 1997
RECOVERY BOILER DAY 1997

AIKA ***TIME***	**22.10.1997 klo 9.30-**	
PAIKKA ***LOCATION***	**Marina Congress Center, Helsinki**	
OHJELMA ***PROGRAM***	09.30-10.00	Ilmoittautuminen ja aamukahvi *Registration and coffee*
	10.00-10.30	Tilaisuuden avaus, SKY:n tulevaisuuden tutkimushankkeet *Opening words* (Heikki Keskinen, UPM-Kymmene Pietersaari)
	10.30-10.45	Suojaussuositus *Recommendations for recovery boiler protection* (Tuomas Timonen, Laminating Papers Oy)
	10.45-11.00	Tauko *Break*
	11.00-11.45	Mustalipeän poltto-ominaisuudet III *Black Liquor Combustion Characteristics III* (Mikko Hupa, Åbo Akademi)
	11.45-12.45	Lounas *Lunch*

12.45-13.15	Terminen väsyminen *Thermal fatique* (Pekka Saarinen, Teknillinen Korkeakoulu)
13.15-13.45	Kahvi *Coffee*
13.45-14.30	Sodahuskommittén esitys *A review of the Swedish-Norwegian Recovery Boiler Committee* (Per Sellerholm, ÅF-IPK)
14.30-15.15	AF&PA:n esitys *A review of the AF&PA* (Thomas Grant, AF&PA)
15.15-15.30	Tauko *Break*
15.30-16.00	NO_x:n poisto soodakattilasta *NO_x removal from recovery boiler* (Kauko Janka, Kvaerner Pulping Oy)
16.00-16.30	Jatkuvatoiminen soodakattilan lentotuhkan analysointilaite *Recovery boiler dust analyzer* (Tarja Tamminen, Dekati Oy)
16.30-18.00	Tauko *Break*
18.00-19.00	Cocktail-tilaisuus (Ahlstrom Machinery Oy) *Coctail* (Katajanokan Kasino)
19.00-	Päivällinen *Dinner* (Katajanokan Kasino)

OSANOTTAJALUETTELO
LIST OF PARTICIPANTS

EVK/RPX Otaniemi 13.10.1997

60V00928
Suomen Soodakattilayhdistys ry
Finnish Recovery Boiler Committee

Soodakattilapäivä 1997
Recovery Boiler Day 1997

Yritys *Company*	**Osallistujat** *Participants*	**Kokous** *Meeting*	**Päivällinen** *Dinner*
LUENNOITSIJAT *LECTURERS*			
American Forest & Paper Association, NY, USA	Thomas J. Grant	x	x
Dekati Oy, Tampere	Tarja Tamminen	x	x
Kvaerner Pulping Oy, Tampere	Kauko Janka	x	x
Laminating Papers Oy, Kotka	Tuomas Timonen	x	x
TKK, Materiaalitekniikan lab.	Pekka Saarinen	x	x
UPM-Kymmene Oy, Pietarsaaren tehtaat	Heikki Keskinen	x	x
Åbo Akademi, Turku	Mikko Hupa	x	x
ÅF-IPK Ab, Stockholm	Per Sellerholm	x	x

Yritys *Company*	**Osallistuja** *Participants*	**Kokous** *Meeting*	**Päivällinen** *Dinner*
OSANOTTAJAT *PARTICIPANTS*			
Ahlstrom Machinery Oy, Varkaus	Lauri Hämäläinen	x	x
	Lasse Koivisto	x	x
	Lasse Mannola	x	x
	Mika Metsärinne	x	x
	Ari Nieminen	x	x
	Raimo Paju	x	x
	Kari Saviharju	x	x
Energia-Ekono Oy, Espoo	Juha Hakala	x	x
	Petri Nieminen	x	x
	Risto Paldanius	x	x
	Pertti Turunen	x	
Enocell Oy, Uimaharju	Ismo Orava	x	x
Enso Oy, Heinolan Flutingtehdas	Rainer Kokemäki	x	x
Enso Oy, Imatran tehdas	Tapani Hämäläinen	x	x
	Juha Kosonen	x	
Enso Fine Papers Oy, Oulun sellutehdas			
	Juha Parpala	x	x
	Reijo Hukkanen	x	x
Enso Fine Papers Oy, Varkauden sellutehdas			
	Lassi Kankala	x	x
	Veli-Antti Kortelainen	x	x
Enso Fine Papers Oy, Veitsiluodon sellutehdas			
	Aimo Laakko	x	
	Pentti Tolonen	x	
Horizon Pulp and Paper Ltd., Estonia			
	Heinrich Suik	x	x
Jaakko Pöyry Oy, Vantaa	Pekka Heikkinen	x	x
	Markku Lehtinen	x	x
	Gösta Wickström	x	x

Yritys *Company*	**Osallistuja** *Participants*	**Kokous** *Meeting*	**Päivällinen** *Dinner*
KCL, Espoo	Klaus Niemelä	x	x
	Kurt Sirén	x	x
	Jorma Torniainen	x	x
Keskeytysvakuutusyhtiö OTSO	Juhani Ingalsuo	x	x
	Bror-Erik Mattsson	x	x
	Jukka Örmälä	x	x
Kemijärven Sellu Oy, Kemijärvi	Antero Raassina	x	x
Kvaerner Pulping Oy, Tampere	Kari Haaga	x	x
	Jussi Orhanen	x	x
	Tuomo Ruohola	x	x
	Antero Salja	x	x
	Matti Salmela	x	x
Kvaerner Steamservice Oy, Tampere	Jari Ekholm	x	x
	Jouko Kylänpää	x	x
	Kaj Lindström	x	x
	Risto Seppänen	x	x
Laminating Papers Oy, Kotka	Matti Takala	x	x
Oy Metsä-Botnia Ab, Joutseno Pulp	Keijo Imeläinen	x	x
	Jukka Veitola	x	x
	Jorma Viinikainen	x	x
Oy Metsä-Botnia Ab, Kaskinen	Antero Heinävaara	x	x
Oy Metsä-Botnia Ab, Kemin sellutehdas			
	Pauli Harila	x	x
	Kauko Ylioinas	x	x
Oy Metsä-Botnia Ab, Äänekoski	Reijo Anttila	x	x
Oy Metsä-Rauma Ab, Rauma	Matti Alamaa	x	x
	Reijo Kiuru	x	x
Paperi ja Puu, Helsinki	Marja Korpivaara	x	
Pohjola-yhtiöt, Helsinki	Thomas Åström	x	x

Yritys *Company*	**Osallistuja** *Participants*	**Kokous** *Meeting*	**Päivällinen** *Dinner*
Oy Polyrec Ab, Siivikkala	Erik Uppstu	x	x
Sunila Oy, Sunila	Petri Lundén	x	x
TTKK, fysiikan laitos, Tampere	Juha Enroth	x	x
UPM-Kymmene Oy, Energia, Valkeakoski			
	Juha Kouki	x	x
UPM-Kymmene Oy, Kymi, Kuusankoski			
	Lasse Elojärvi	x	x
	Raine Rantanen	x	x
	Timo Suominen	x	x
UPM-Kymmene Oy, Pietarsaaren tehtaat			
	Sami Lehtola	x	x
	Carl Westman	x	x
	Lars-Martin Wikström	x	x
UPM-Kymmene Oy, Tervasaari	Olavi Aaltonen	x	x
Valmet Automation Oy, Tampere	Jukka Koskinen	x	x
	Jukka Puhakka	x	x
	Ari Setälä	x	x
Åbo Akademi, Turku	Mikael Forssén	x	x
	Maritta Kymäläinen	x	x
ÅF-IPK Ab, Espoo	Anja Klarin	x	x

Finnish Recovery Boiler Committee
RECOMMENDATIONS FOR RECOVERY BOILER PROTECTION 1997

FOREWORD

The Recommendations for Recovery Boiler Protection 1997 are based on the old recommendations published in 1988, which have been updated.

The Recommendations 1997 give boiler protection a broader aspect than before. For example, the chapters for Automation, Fire Protection and Testing chapters have been added to the Recommendations 1997.

The Recommendations 1997 are based on today´s knowledge and experiences.

Neither the Finnish Recovery Boiler Committee nor the writers shall be responsible for any errors in the Recommendations 1997. Neither the Finnish Recovery Boiler Committee nor the writers shall be responsible for any application of the Recommendations 1997 in practice and any expenses caused by them.

The Finnish Recovery Boiler Committee´s Material Subcommittee wants to thank the following persons for their assistance without which the Recommendations for Recovery Boiler Protection 1997 would not have been possible:

Kari Auvinen	Oy Metsä-Botnia Ab, Kaskinen Mill
Juha Hakala	Ekono Energy Ltd
Reijo Hukkanen	Enso Fine Papers Oy, Oulu Mills
Hannu Hänninen	Helsinki University of Technology
Esa Ilves	Otso Loss of Profits Insurance Company Ltd.
Rauno Karvinen	UPM-Kymmene Oy, Kymi
Jorma Kiimalainen	Tampereen Prosessi-insinöörit Oy
Lasse Koivisto	Ahlstrom Machinery Oy
Kari Korpiola	Technical Research Center of Finland
Sulo Lahdelma	University of Oulu
Lasse Lahti	Laminating Papers Ltd, Kotka Mills
Jukka Mikkonen	Enso Oy, Imatra Mills
Petri Nieminen	Ekono Energy Ltd
Risto Paldanius	Ekono Energy Ltd
Asmo Rantanen	Industrial Insurance Company Ltd.
Kalle Salmi	Kvaerner Pulping Oy
Tuomas Timonen	Laminating Papers Ltd, Kotka Mills

and
Automation Subcommittee

RECOMMENDATIONS FOR RECOVERY
BOILER PROTECTION 1997
Finnish Recovery Boiler Committee

EVK/RPX 7 October 1997

TABLE OF CONTENTS

1 INTRODUCTION

Juha Hakala, Ekono Energy Ltd.

Boiler plant safety is the responsibility of the whole personnel. This means that everyone working at the plant shall take care of the safety of the plant, his own and others' safety in all circumstances. The Recommendations for Recovery Boiler Protection 1997 help improve plant safety and the safe operation of the plant.

The Recommendations for Recovery Boiler Protection 1997 are indented for all personnel working at the plant and shall answer everyday questions arising at the plant. The publication has been written by specialists in chemical recovery boiler operation, research, inspection, manufacture and maintenance. The new version has been updated to meet today's conditions and needs better. A new meaning has been given to the concept boiler protection. The Recommendations for Recovery Boiler Protection 1997 are also suitable for training.

Fire Protection, Automation, Operator Guidelines, Water Treatment and Chemistry, Dissolver, Testing, Conditioning of Pumps and Fans are all new chapters in the Recommendations for Recovery Boiler Protection 1997. Chapter 8, Fire Protection, contains lots of standards, which are also the basis for the text. Chapter 9, Automation, gives guidelines for recovery boiler automation and designing and running safety systems. Chapter 9 also gives ideas of how to improve boiler and personnel safety with automation. Chapter 10, Operator Guidelines, lists things that should be written in operation, maintenance, safety and job training instructions. Chapters 11, Water Treatment and Chemistry, deals with boiler water sampling, control and quality. It also deals with some problem situations. Chapter 11, Dissolver, considers dissolvers from a safety point of view. It concentrates on the structure and operation of the dissolver. Chapter 15, Testing, provides example forms for testing. Chapter 16, Conditioning of Pumps and Fans, introduces about typical fan and pump failures and their causes.

The old Recommendations included the chapters for Materials, Coatings, Inspection and Water Wash. Now these subjects have been written by different writers. For example chapter 5, Coatings, has now a check-list for selecting and supplying coatings. Chapter 7, Inspections, contains a table which introduces all inspection methods used in different parts of the boiler.

LIQUOR-TO-LIQUOR DIFFERENCES IN COMBUSTION AND GASIFICATION PROCESSES: DUST COMPOSITION AND MELTING PROPERTIES

Soodakattilapäivä 1997
Recovery Boiler Day 1997
22.10.1997, Marina Congress Center
Helsinki

Mikko Hupa, Rainer Backman, Sonja Enestam, Mikael Forssén
Åbo Akademi University, Åbo, Finland

ABSTRACT

This work is a continuation of our advanced liquor characterization studies, in which we have tested a set of different mill liquors using novel laboratory tests and advanced chemical analyses to gain better predictions of the liquor behavior in combustion or gasification processes. The previous parts of the characterization work have dealt with pyrolysis behavior and char reactivity /1/, nitrogen oxide formation tendency /2/, and sodium release during pressurized gasification /3/. The work has been done in cooperation with Suomen Soodakattilayhdistys ry, Ahlstrom Machinery Oy, Kvaerner Pulping Oy and TEKES through the National Combustion and Gasification Research Programme, LIEKKI 2.

In this paper we focus on the behavior and properties of the inorganic residues (carry-over) and condensed dust (fume) formed during combustion of these liquors. We present data for 4 different mill liquor samples.

Based on (i) elemental analyses of the liquors, on (ii) analysis of the char residues obtained by single particle pyrolysis tests and (iii) advanced chemical model for the formation and conversions of the inorganic material in combustion, we estimate the composition of the droplet residues (carry-over particles) and condensed dust (fume particles) to be formed when these liquors are burned in typical recovery boiler conditions.

The liquors are characterized this way for two different recovery furnace conditions, for a "hot" furnace (high solids firing conditions) and for a "cold" furnace (normal solids). The main difference between these two conditions comes from the behavior of sulfur and chlorides at these two conditions. At the hot furnace conditions, all of the chlorides will be present in the fume and carry-over particles, at "cold" furnace conditions part of the chlorides will be released by the sulfur gases as gaseous HCl.

Besides particle compositions we also give estimates for the melting behavior of the carry-over and fume particles to be formed. The melting range estimates are based on the multicomponent multiphase melting equilibrium model recently developed at Åbo Akademi. With this model we can give the full melting curve (percentage of melt in the mixture vs. temperature) for any salt compositions typically found in recovery furnaces.

The results show that the sticky temperature (T_{15}) estimated for the liquors varies between 510 and 730°C for the carry-over particles and between 580 and 760°C for the fume particles at hot furnace conditions.

We also present dust data collected from boilers using these liquors. In all the boilers both ESP dust samples and short term superheater deposit samples were collected. The compositions of these samples are compared with the predicted compositions.

Figure 1 gives the composition for ESP dust samples collected from the boilers studied as compared with the fume composition as predicted based on the liquor characterization data only ("hot" furnace conditions).

Figure 2 gives the calculated melting behavior of probe deposits collected at four recovery boilers. The probe samples were collected on air cooled probes (450°C) before the superheaters, windward; before the superheaters, leeward; after the superheaters, windward and for the precipitator dust

Literature:

1. Whitty, K., Backman, R., Forssén, M., Hupa, M., Rainio, J., Sorvari, V., "Liquor-to-Liquor Differences in Combustion and Gasification Processes: Pyrolysis Behavior and Char Reactivity", Journal of Pulp and Paper Science 23 (3) (1997) J119-J128.

2. Forssén, M., Hupa, M., Hellström, P., "Liquor-to-liquor Differences in Combustion and Gasification Processes: Nitrogen Oxide Formation Tendency". Proceedings: TAPPI Engineering Conference, September 11-15, 1995, Dallas, TX, USA, pp. 825-832.

3. Sorvari, V., Backman, R., Hupa, M., Rainio. J., "Liquor-to-liquor differences: Sodium Release During Pressurized Pyrolysis of Black Liquor in a Grid Heater", Nordic Pulp and Paper Research Journal, (1996) No. 4, pp. 273-284.

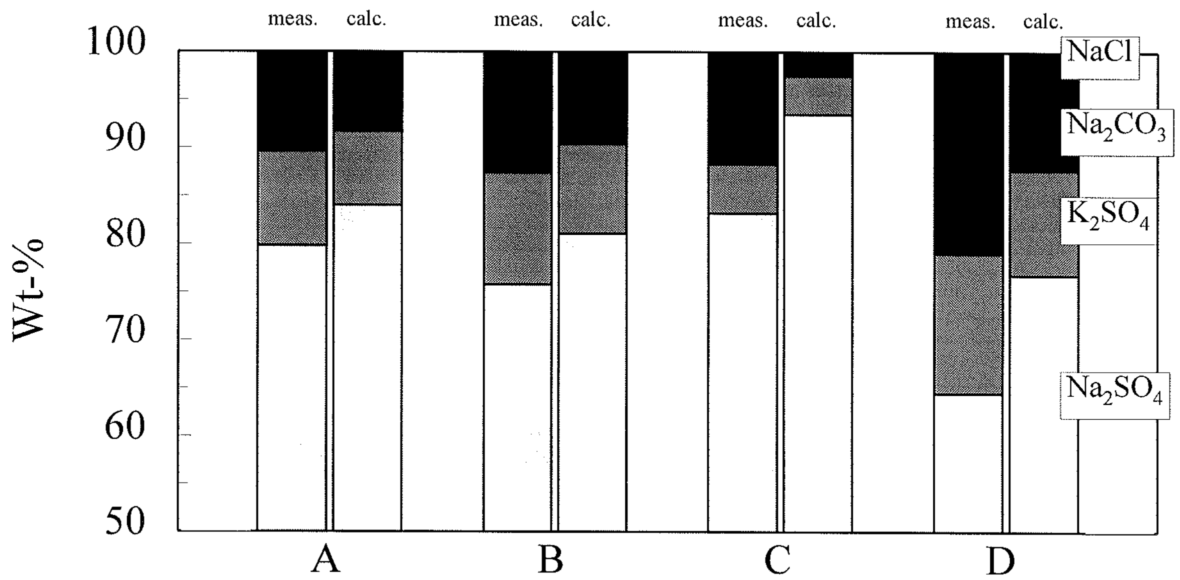


Figure 1. Composition of ESP-dust of four recovery boilers.

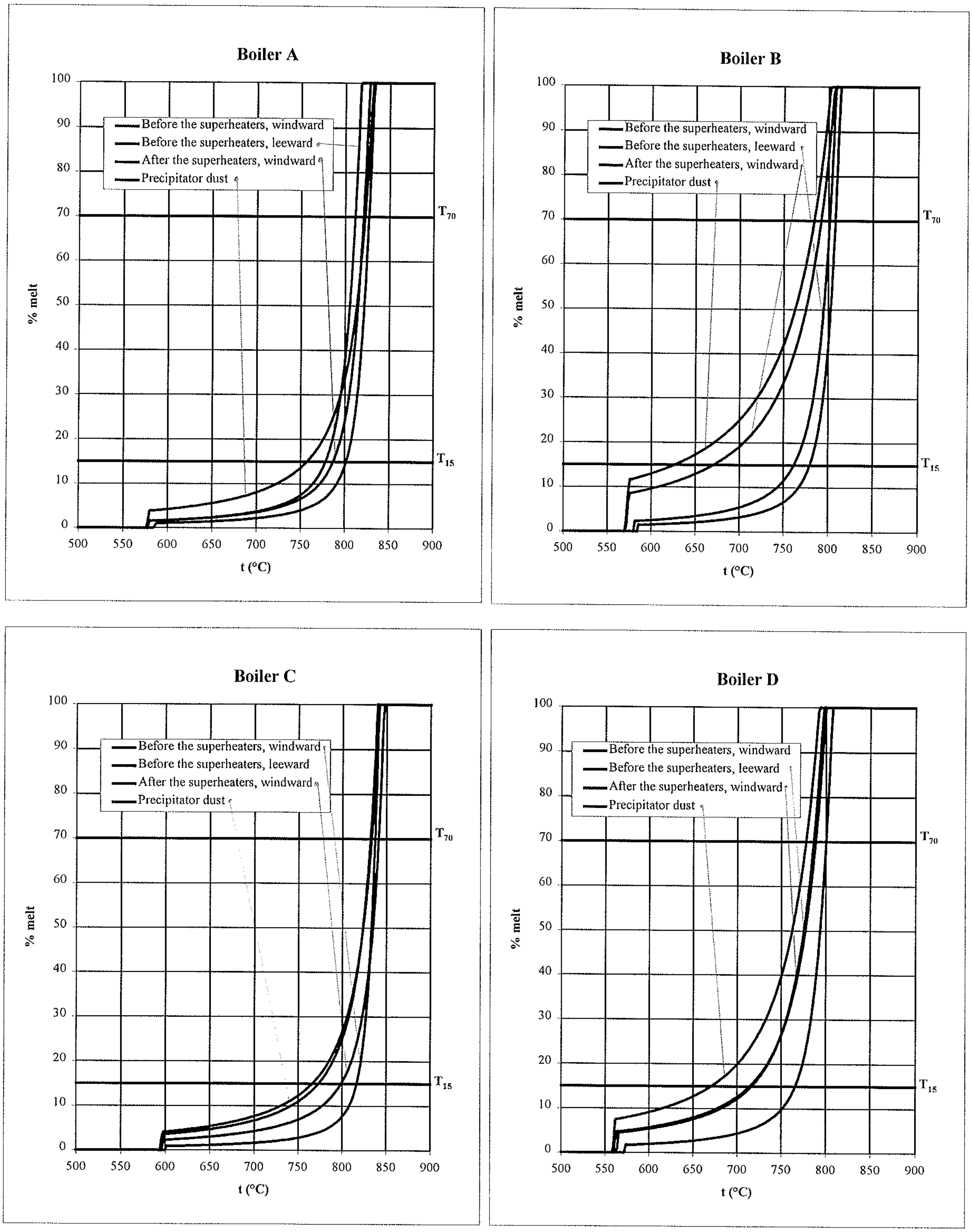


Figure 2. Calculated melting behavior of probe deposits collected at four recovery boilers. Samples before the superheaters, windward; before the superheaters, leeward; after the superheaters, windward and precipitator dust.

Soodakattilapäivä 1997

Marina Congress Center, Helsinki
22.10.1997

Terminen väsyminen soodakattilan compound-putkissa

Pekka Saarinen, Hannu Hänninen

Teknillinen Korkeakoulu, Konetekniikan osasto, Materiaalitekniikan laboratorio

SUMMARY

Thermal fatigue of recovery boiler composite tubes

1. Thermal fatigue test equipment

Thermal fatigue test equipment has been built in Laboratory of Engineering Materials in Helsinki University of Technology. Principle of the equipment is to heat specimens by induction heating and cool them by water spray and/or compressed air. Temperature of the specimen is measured by pyrometer. The composite tube test equipment is shown in Figure 2.

The composite tube is connected to the rotating axis of the test equipment (upper part in Figure 2) surrounded by a heating coil. At the bottom of the tube there is a steel pipe through which compressed air is blown into the composite tube to keep its internal surface temperature close to 300 °C. When the surface of the composite tube reaches its desired temperature, the tube is transferred to water spray cooling (aluminum container). After cooling the tube is transferred back to the heating phase.

2. Thermal fatigue tests

Thermal fatigue tests heve been made with Sandvik 3R12/4L7 and Sandvik San38/4L7 composite tubes. The tubes were exposed to steep temperature gradients which caused plastic strain and initiated cracks. The main purposes of the tests are to find out the crack initiation times in different temperature ranges (ΔT) and to study the growth of the cracks. The tubes were tested with various ranges of thermal cycling: 300-700 °C, 300-500 °C and 300-400 °C. Examination of the tubes after fatigue tests was done with optical and scanning electron microscopy (SEM).

With the temperature range 300-700 °C cracks were initiated after 300 cycles in both studied composite tubes. The cracks were observed after 500 cycles with the temperature range of 300-500 °C and after 2500 cycles with the temperature range of 300-400 °C in 3R12/4L7 composite tubes. In San38/4L7 composite tubes the cracks were seen after 1500 cycles with the temperature range of 300-500 °C and after 7500 cycles with the temperature range of 300-400 °C, respectively. The number of cycles needed to initiate cracks in composite tubes in different temperature ranges is shown in Figure 15. Cracks in both composite tubes are shown in Figures 3-8.

Both composite tubes were tested up to 2000 and 8000 cycles with the temperature range of 300-700 °C. The cracks in the cladding were about 0,5-0,6 mm deep in both tubes after 2000 cycles. After 8000 cycles the cracks had propagated through the cladding to the carbon steel in San38 tube and also along the cladding/carbon steel interface in 3R12 tube. In San38 composite tube one crack propagated through the wall of the tube. Cracks appeared also on the internal surface of both tubes after 8000 cycles with the high thermal cycle. Cracks in the cladding of composite tubes after 2000 and 8000 cycles with the high temperature range of 300-700 °C are shown in Figures 9-14.

In the beginning of the tests shear bands appeared first inside the grains. Shear bands grew steadily larger and formed finally cracks. The same initiation mechanism happened in all the composite tubes. The cracks propagated transgranularly in the cladding. Fatigue striations were sometimes seen on the fracture surfaces.

1. Terminen väsyminen

Erityisesti metallisilla ja keraamisilla materiaaleilla on terminen väsyminen säröilynä esiintyvä vaurioitumismekanismi. Tyypillisiä vauriokohteita ovat jarrurummut, turpiinien siivet, taontamuotit, kuumavalssit, polttomoottoreiden männät ja sylinterikannet, junan pyörät sekä uunirakenteet. Termistä väsymistä esiintyy myös yleisesti sooda- ja konventionaalisten kattilalaitosten sekä ydinvoimalaitosten putkistoissa ja venttiileissä.

1.1 Termisen väsymisen määritelmä

Terminen väsyminen on materiaalin vähittäistä vaurioitumista säröilemällä lämpötilavaihtelujen seurauksena. Kun lämpötilan muutoksista aiheutuvaa materiaalin luonnollista lämpölaajenemista tai -kutistumista rajoitetaan, syntyy termisiä jännityksiä, jotka toistuessaan voivat ydintää ja kasvattaa väsymissäröjä. Terminen väsyminen luokitellaan yleisimmin low-cycle-väsymiseksi, jolloin vauriot ilmenevät tyypillisesti ennen 10000 kuormitusjaksoa. Termisessä väsymisessä lämpötila muuttuu ajan funktiona, kun taas isotermisessä väsymisessä lämpötila pysyy vakiona. Korkealämpötilalaitteen käynnistyksen ja pysäytyksen yhteydessä esiintyy termistä väsymistä, kun vastaavasti laitteen värähtely vakiolämpötilassa voi aiheuttaa isotermistä väsymistä (Mäkinen, 1994).

1.2 Jännitykset termisessä väsymisessä

Lämpötilan vaihtelusta johtuvat termiset jännitykset jaetaan yleensä kahteen ryhmään:

- *Venymäkontrolloidut jännitykset* (strain-controlled stresses), kun materiaalin paikallinen laajeneminen tai kokoonpuristuminen estyy ympäröivän materiaalin vaikutuksesta.

- *Siirtymäkontrolloidut jännitykset* (displacement-controlled stresses), kun kappaleen kokonaislaajeneminen tai -kokoonpuristuminen rajoittuu ympäröivien kappaleiden vaikutuksesta.

Venymäkontrolloidut jännitykset voivat johtua materiaalissa olevasta lämpötilagradientista tai rakenteessa ilmenevästä anisotropiasta. Anisotropia johtuu esim. rakenteessa olevien eri faasien erilaisista lämpölaajenemiskertoimista. Rakenteet tulee suunnitella siten, että siirtymäkontrolloituja jännityksiä ei pääse edes syntymään (Kemppainen, 1997).

1.3 Termiseen väsymiseen vaikuttavia tekijöitä

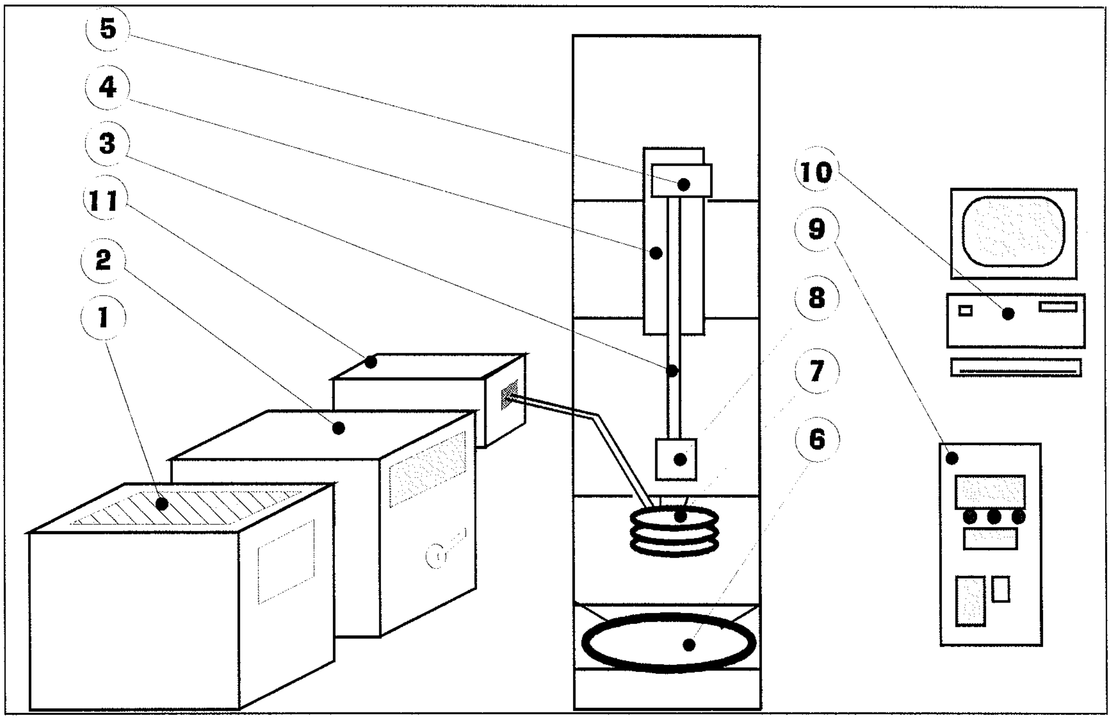
Useat eri tekijät vaikuttavat termisen väsymisen säröjen ydintymiseen ja kasvuun. Tärkeimpiä tekijöitä ovat lämpötila-aika-jakson parametrit (ΔT, maksimi lämpötila, kuumennus- ja jäähtymisnopeudet, pitoajat), erilaiset materiaaliominaisuudet (kovuus, sitkeys, lujuus yms.), fysikaaliset ominaisuudet (lämmönjohtavuus, lämpölaajenemiskerroin yms.), kappaleen pinnanlaatu, mikrorakenne (raekoko, karbidit yms.) sekä kappaleen muoto ja vallitseva ympäristö. Monet näistä parametreista ovat toisistaan riippuvaisia ja muuttuvat lämpötilan mukana (Bartsch ym., 1993).

Koska materiaalien korkean lämpötilan lujuusominaisuudet ovat usein huomattavasti huoneen lämpötilan arvoja alempia, on kuormitusjakson maksimilämpötila yksi tärkeimpiä tekijöitä termisen väsymisen kannalta. Myötörajan pienemmän arvon takia on venymän plastinen komponentti samalla jännitystasolla korotetussa lämpötilassa paljon suurempi kuin huoneen lämpötilassa.

Korkeissa lämpötiloissa, kun toipuminen/rekristallisaatio tai viruminen voivat laukaista jännityksiä, maksimilämpötilassa vietetyn ajan merkitys korostuu (Mäkinen, 1994).

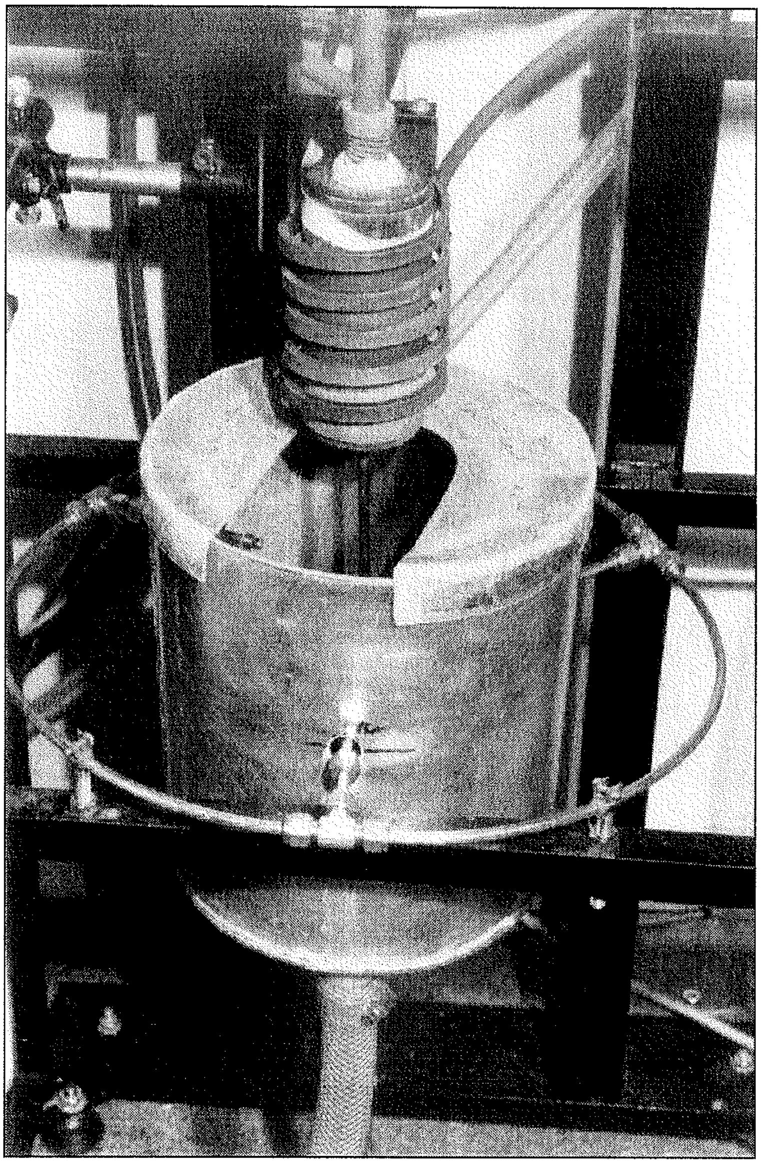
2. Termisen väsymisen koelaitteisto TKK:n Konetekniikan osaston materiaalitekniikan laboratoriossa

TKK:n Materiaalitekniikan laboratorioon on rakennettu 'Terminen väsyminen'-projektin yhteydessä termisen väsymisen testauslaitteisto. Koelaitteiston periaate on, että koekappale kuumennetaan induktiokelan sisällä ja jäähdytetään jäähdytysrenkaassa. Kuumennus tapahtuu induktion avulla ja jäähdytys joko puhaltamalla vettä tai ilmaa tai upottamalla kappale jäähdytysastiaan. Jäähdytysväliaineina voidaan käyttää muitakin kaasumaisia tai nestemäisiä aineita, jos niiden käytöstä ei aiheudu ympäristölle haittaa. Kappaleen liikutus tapahtuu servo-ohjatun paineilmasylinterin avulla. Kokeen aikana koekappaletta pyöritetään tasaisen kuumentumisen ja jäähtymisen varmistamiseksi. Koekappaleen lämpötilaa mitataan pyrometrin avulla. Periaatekuva koelaitteistosta on kuvassa 1.



Kuva 1. Periaatekuva koelaitteistosta osakomponentteineen: 1) induktiokuumentimen jäähdytysyksikkö, 2) induktiokuumentimen virtalähde, 3) koekappaleen pyöritysakseli, 4) siirtokelkka, 5) pyöritysmoottori, 6) jäähdytyskehä, 7) induktiokuumennuskela, 8) koekappale ja kiinnitin, 9) ohjausyksikkö, 10) ohjaustietokone, 11) induktiokuumentimen korkeataajuusyksikkö (Kemppainen, 1997).

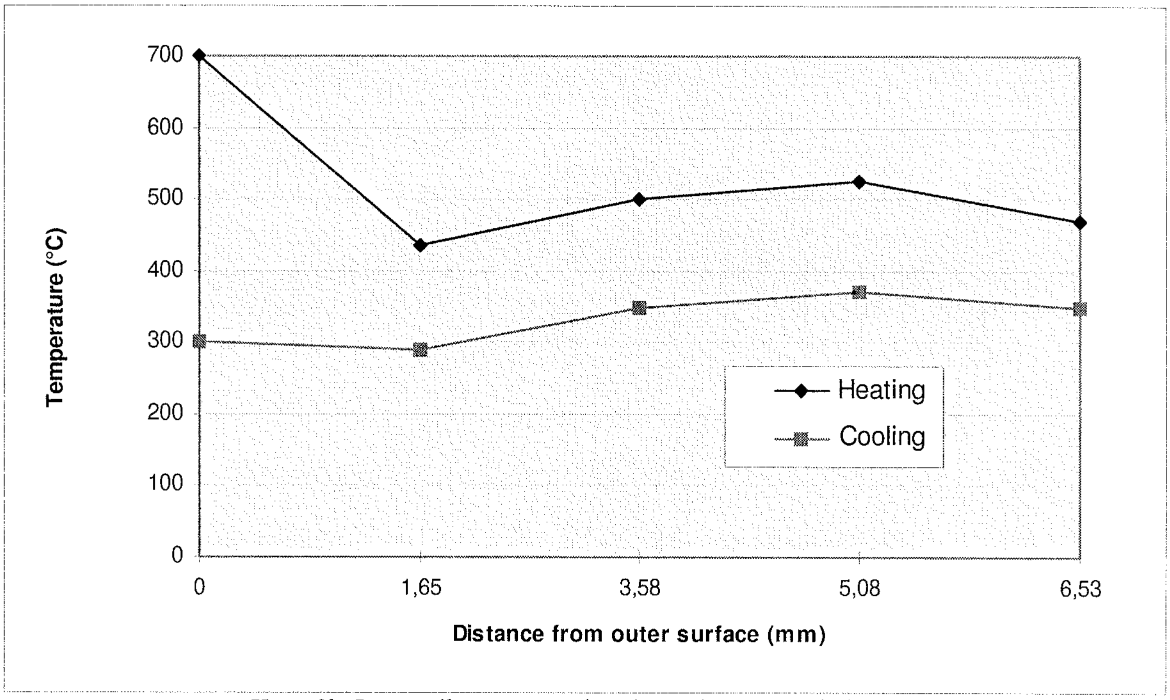
Soodakattilan compound-putken testausta varten rakennettiin putken kuumennukseen sopiva kuumennuskela sekä erillinen jäähdytysasema (Kuva 2a). Mitoituksen lähtökohtana oli niin pitkä compound-putki, että sen keskellä vallitsee samanlainen jännitystila kuin äärettömän pitkässä putkessa. Eli putken vapaat päät eivät vaikuta putken keskelle muodostuvaan jännitystilaan. Mallinnuksen tuloksena saatiin putken minimipituudeksi 120 mm.



Kuva 2a. Soodakattilan compound-putken termisen väsymisen koelaitteisto

Kuvan 2a yläreunassa nähdään koekappaleen pyöritysakseli, jonka päähän compound-putki on kiinnitetty. Putken ympärillä on elektrolyyttisesti puhdistetusta kuparista valmistettu kuumennuskela. Compound-putken alapäästä lähtee ohut teräsputki, jota käytetään paineilman puhaltamiseen putken sisään. Aluksi tehdyissä putken kuumennuskokeissa havaittiin, että induktio kuumentaa putken hiiliteräksistä sisäosaa huomattavasti voimakkaammin kuin austeniittista pinnoitetta. Sisäpinnan lämpötilan rajoittamiseksi oli paineilma ainoa käyttökelpoinen menetelmä. Jäähdytyksen ansiosta sisäpinnan lämpötila saatiin jäämään n. 300 °C:een. Kuvassa 2b on esitetty putken seinämästä mitattu lämpötilajakauma heti kuumennuksen ja jäähdytyksen päätyttyä.

Kun compound-putki on saavuttanut syklin maksimilämpötilan, se siirtyy paineilmasylinterin kuljettamana jäähdytysasemaan (alumiinisäiliö). Jäähdytyksessä putken ulkopinnalle suihkutetaan vettä kolmen suuttimen kautta. Yksi vesisuihku on suunnattu putken keskiosaan, yksi ylä- ja yksi alaosaan. Putken pyöriessä tulee koko ulkopinta tasaisesti jäähdytettyä. Jäähdytysvesi poistuu jäähdytysaseman alaosaan kiinnitetyn poistoputken kautta. Jäähdytysaseman kannessa olevan aukon kautta poistuu jäähdytyksessä muodostuva vesihöyry, joka kohdeimurin avulla imetään ja puhalletaan ilmanvaihtoventtiilin kautta ulos.



Kuva 2b. Lämpötilat compound-putken seinämän eri kohdissa.

3. Compound-putkille tehdyt termisen väsymisen kokeet ja niiden tulokset

Termisen väsymisen kokeisiin valittiin kaksi compound-putkea: Sandvikin 3R12/4L7 ja San38/4L7. Sandvik 3R12/4L7-putki on yleisimmin käytetty compound-putki ja San38/4L7 on vaativiin olosuhteisiin tarkoitettu compound-putki. Molemmissa on pinnoitteena austeniittinen ruostumaton teräs (3R12 ja San38) ja perusaineena niukkaseosteinen hiiliteräs (4L7). Pinnoitteen paksuus 3R12/4L7-putkessa on 1,65 mm ja San38/4L7-putkessa se on 1,82 mm. Molemmissa putkissa seinämän paksuus on 6,53 mm ja putken ulkohalkaisija on 63,5 mm. Compound-putkien ulkopinnalle kiillotettiin elektrolyyttisesti useita kohtia säröjen ydintymisen havaitsemiseksi.

3.1 Compound-putkille tehdyt kokeet

Compound-putkia testattiin kolmella eri lämpötila-alueella: 300-700 °C, 300-500 °C ja 300-400 °C. Putkea kuumennettiin induktiolla niin kauan, kunnes sen ulkopinta saavutti maksimilämpötilan. Tämän jälkeen putki siirtyi välittömästi jäähdytykseen. Jäähdytys päättyi ulkopinnan lämpötilan saavutettua minimiarvon. Putkea pyöritettiin kokeen aikana ja sisäpinnan paineilmajäähdytys oli päällä koko ajan.

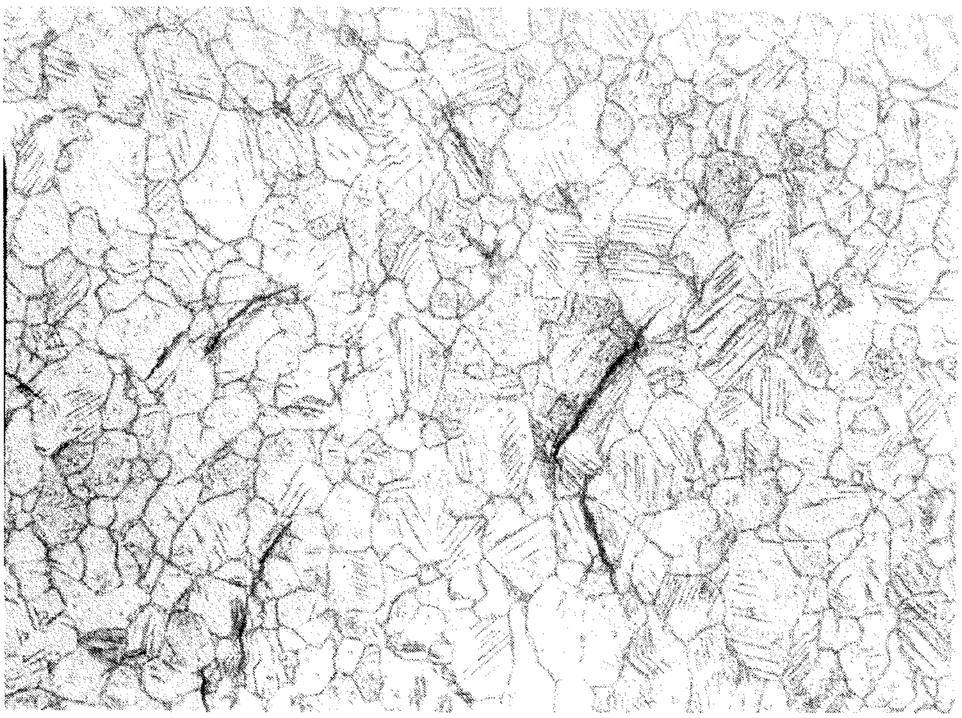
Molemmille putkimateriaaleille määritettiin säröjen ydintymisvaihe kaikilla kolmella lämpötila-alueella. Tämän lisäksi molemmilla compound-putkilla ajettiin suuret syklimäärät rankimmalla syklillä (300-700 °C). Tarkoituksena oli tutkia, miten säröt käyttäytyvät kohdatessaan pinnoitteen ja perusaineen rajapinnan. Lisäksi tutkittiin särön etenemistä pinnoitteessa sekä pinnoitteen ja perusaineen rajapinnassa mahdollisesti tapahtuneita ilmiöitä, mm. hiilenkatoa.

Säröjen ydintymistä ja kasvua tutkittiin pääasiassa optisella mikroskoopilla, mutta myös elektronimikroskoopilla (SEM). Säröjen murtopintoja tutkittiin SEM:llä. Ennen mikroskooppitarkasteluja tutkittavat pinnat puhdistettiin puhdistusaineella, joka poisti myös hapettumat.

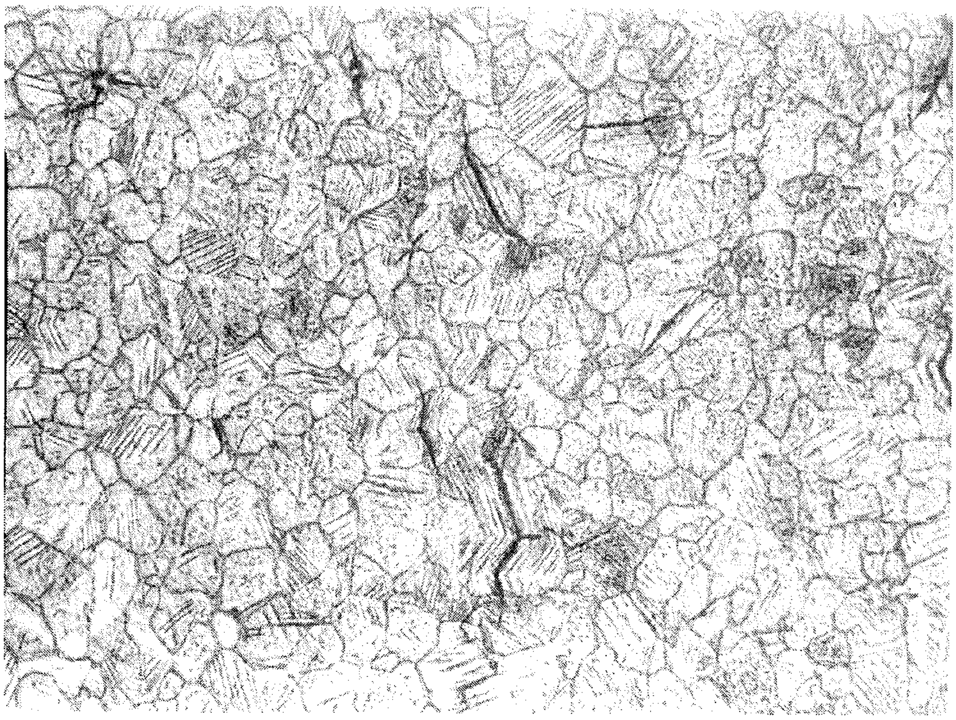
3.2 Kokeista saadut tulokset

Rankimmalla syklillä (300-700 °C) tehdyissä testeissä havaittiin molemmissa compound-putkissa säröjä ensimmäisen kerran n. 300 syklin jälkeen. Lämpötilasyklillä 300-500 °C havaittiin ensimmäiset säröt 3R12/4L7-putkessa 500 syklin jälkeen ja San38/4L7-putkessa 1500 syklin jälkeen. Lievimmällä syklillä (300-400 °C) havaittiin säröjä ensimmäisen kerran 3R12/4L7-putkessa 2500 syklin jälkeen ja San38/4L7-putkessa 7500 syklin jälkeen. Kuvassa 15 on esitetty säröjen ydintymiseen vaadittavat syklien määrät eri lämpötila-alueilla. Eri lämpötila-alueilla ydintyneitä säröjä nähdään kuvissa 3-8.

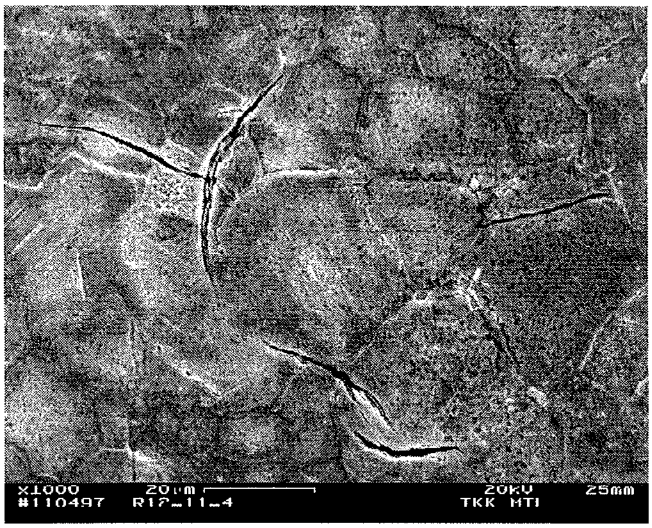
Compound-putkia väsytettiin rankimmalla syklillä (300-700 °C) 2000 ja 8000 sykliä. Molempien putkien ulkopinnalla oli 2000 syklin jälkeen lähes yhtenäinen säröverkko. Pinnoitteiden poikkileikkauksessa särökoot olivat n. 0,5-0,6 mm syvyyssuunnassa (Kuvat 9 ja 10). Pitkän testin (8000 sykliä) jälkeen havaittiin säröjen edenneen molemmissa compound-putkissa hiiliteräkseen (Kuvat 11 ja 12). 3R12/4L7-putkessa säröt etenivät osittain ruostumattoman pinnoitteen ja hiiliteräksen rajapinnassa irrottaen osan pinnoitteesta (Kuva 13). San38/4L7-putkessa oli yksi särö edennyt eräässä kohdassa koko seinämän läpi (Kuva 14). Lisäksi molempien putkien sisäpinnalla (hiiliteräksessä) oli pieniä säröjä 8000 syklin jälkeen.



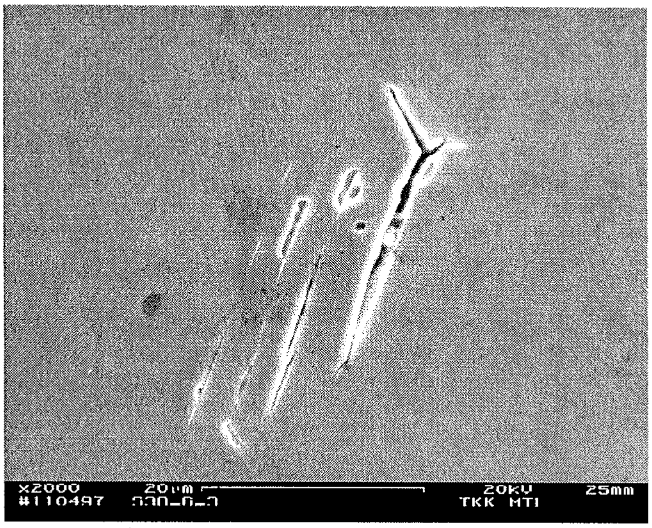
Kuva 3. Ydintyneitä säröjä 3R12/4L7-putken pinnalla (300-700 °C, 300 sykliä). 500x.



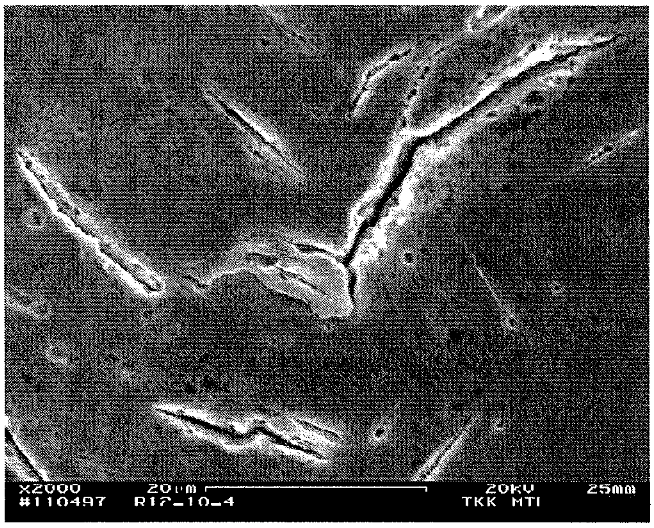
Kuva 4. Ydintyneitä säröjä San38/4L7-putken pinnalla (300-700 °C, 300 sykliä). 500x.



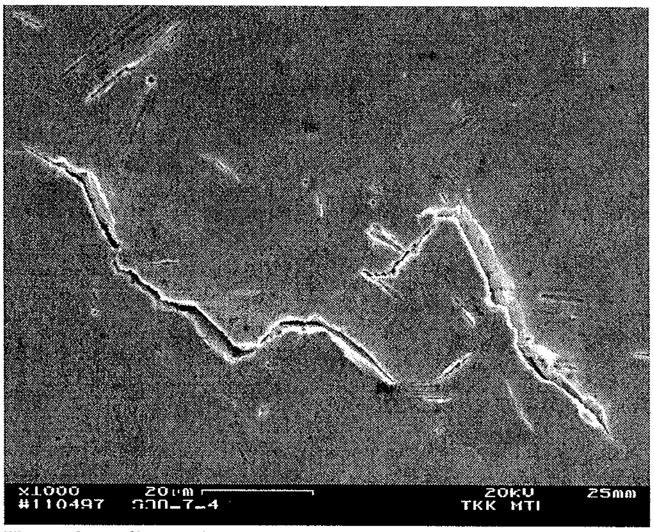
Kuva 5. Ydintyneitä säröjä 3R12/4L7-putken pinnalla (300-500 °C, 500 sykliä).



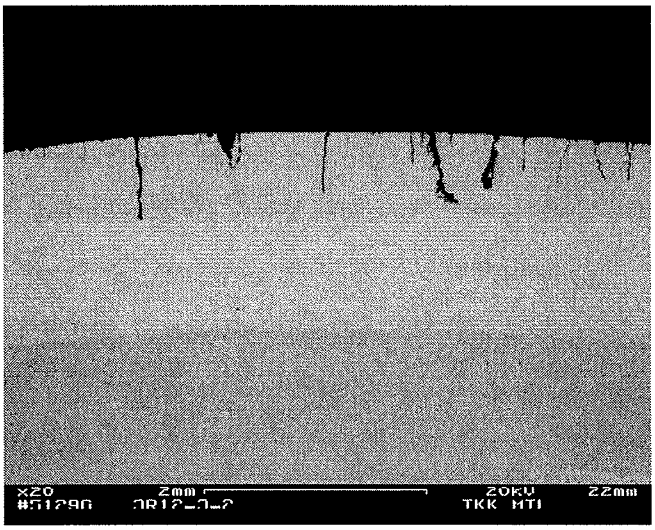
Kuva 6. Ydintyneitä säröjä San38/4L7-putken pinnalla (300-500 °C, 1500 sykliä).



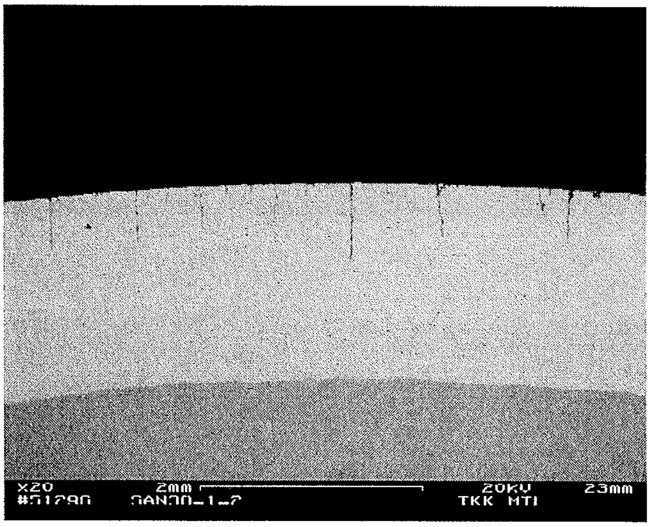
Kuva 7. Ydintyneitä säröjä 3R12/4L7-putken pinnalla (300-400 °C, 2500 sykliä).



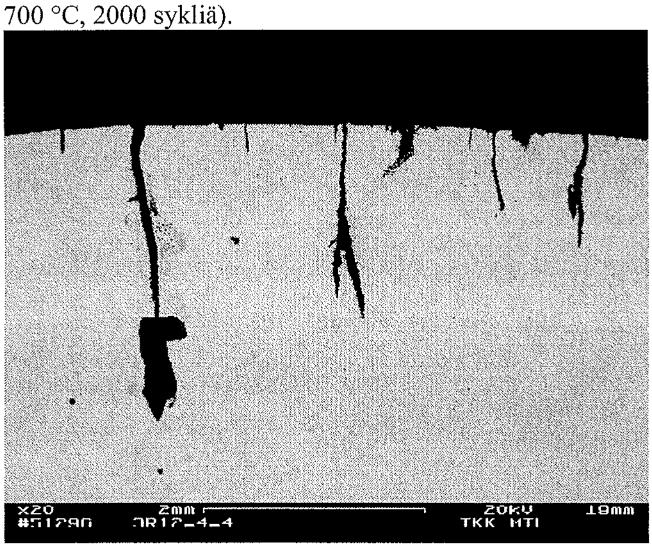
Kuva 8. Ydintyneitä säröjä 3R12/4L7-putken pinnalla (300-400 °C, 7500 sykliä).



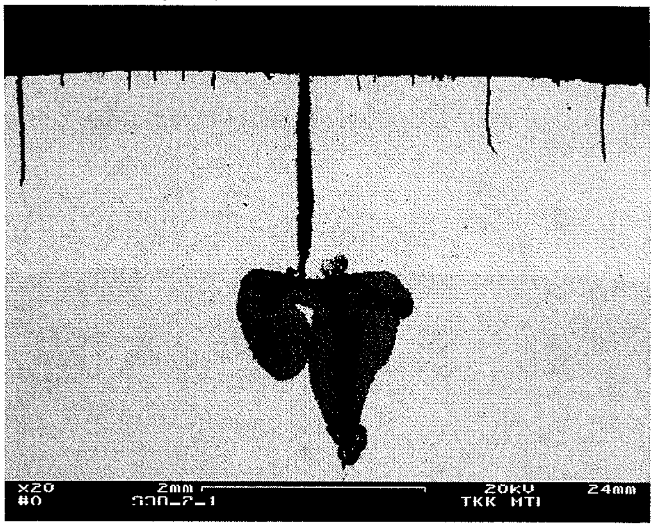
Kuva 9. Säröjä 3R12/4L7-putken pinnoitteessa (300-700 °C, 2000 sykliä).



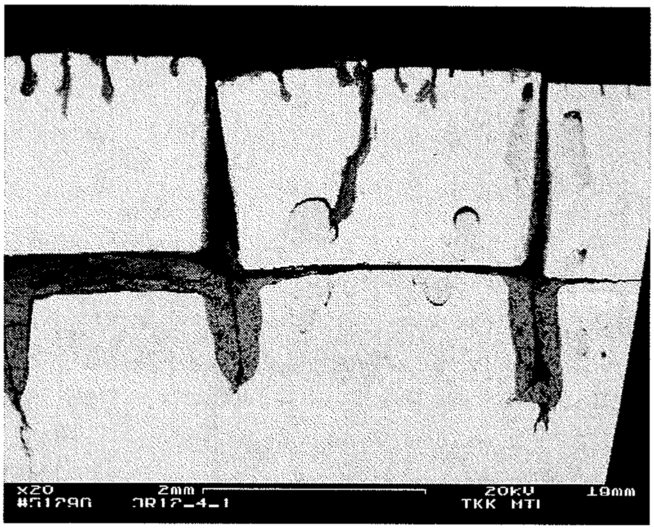
Kuva 10. Säröjä San38/4L7-putken pinnoitteessa (300-700 °C, 2000 sykliä).



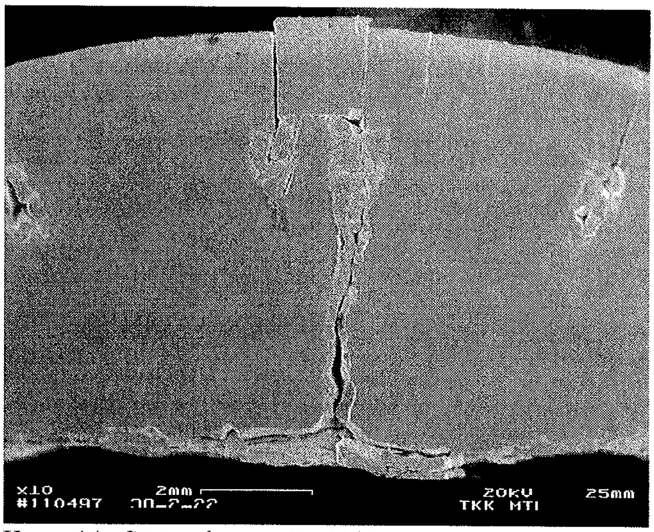
Kuva 11. Säröt etenevät hiiliteräkseen 3R12/4L7-putkessa (300-700 °C, 8000 sykliä).



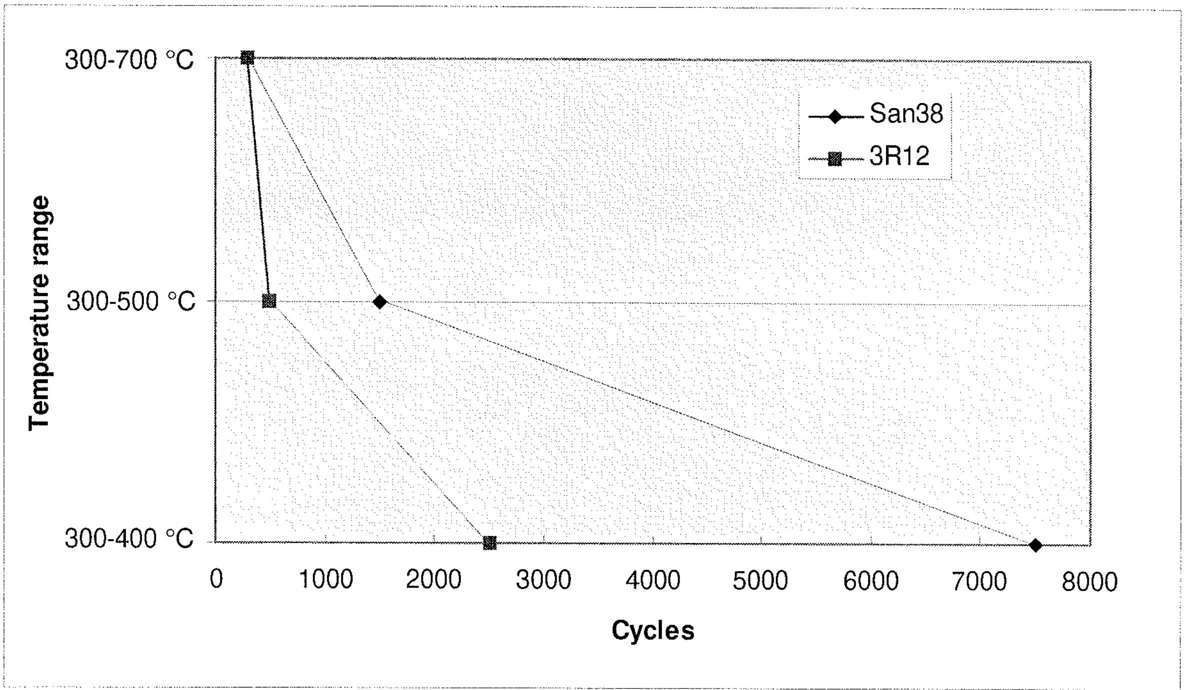
Kuva 12. Säröt etenevät hiiliteräkseen San38/4L7-putkessa (300-700 °C, 8000 sykliä).



Kuva 13. Säröt etenevät rajapintaa pitkin 3R12/4L7-putkessa (300-700 °C, 8000 sykliä).



Kuva 14. Särö edennyt San38/4L7-putken seinämän läpi (300-700 °C, 8000 sykliä).



Kuva 15. Säröjen ydintymiseen johtaneet syklimäärät eri lämpötila-alueilla.

Compound-putkien isoimmat säröt avattiin ja murtopinnat tutkittiin elektronimikroskoopilla. Molempien compound-putkien murtopinnoilla havaittiin väsymismurtumalle tyypillisiä väsymisjuovia. Väsymisjuovat olivat osittain oksidikerroksen peitossa ja kulkivat kohtisuoraan särön etenemissuuntaan nähden.

Säröjen havaittiin etenevän pinnoitteessa rakeiden läpi. Pitkän testin jälkeen (300-700 °C, 8000 sykliä) molempien compound-putkien sisäpinnalla havaittiin myös pieniä säröjä. Säröt muodostivat lähes yhtenäisen säröverkon. Sisäpinnan poikkileikkauksesta havaittiin, että 3R12/4L7-putkessa sisäpinnan säröt olivat edenneet hieman syvemmälle kuin San38/4L7-putkessa.

Syy 3R12/4L7-putken pinnoitteen irtoamiseen on todennäköisesti pinnoitteen ja perusaineen hyvin erilainen lämpölaajenemiskerroin. San38/4L7-putkessa pinnoitteen ja perusaineen lämpölaajenemiskertoimet ovat lähellä toisiaan, eikä pinnoitteen irtoamista tapahtunut. 3R12/4L7-putken pinnoitteen ja perusaineen rajapinnalla havaittiin karbidierkaumia pitkän testin jälkeen. Nämä ovat saattaneet edesauttaa pinnoitteen irtoamista (Saarinen ja Hänninen, 1997).

Pitkän testin (300-700 °C, 8000 sykliä) aikana havaittiin, että pinnoite isojen säröjen ympärillä kuumeni enemmän kuin pinnoite muualla putkessa. Syynä lämpötilan kohoamiseen on säröjen aiheuttama putken resistanssin kasvu. Säröt vaikuttavat pyörrevirtojen kulkuun, jolloin lämpötila nousee. Tämä saattaa olla syynä putkien poikkeuksellisen suuriin vaurioihin pitkän testin jälkeen (pinnoitteen irtoaminen, särön kasvu seinämän läpi).

4. Compound-putken mallinnus

Pinnoitteen jännityksiä laskettiin jatkuvaa putkea kuvaavalla pyörähdyssymmetrisellä tasomallilla, joka asetettiin reunaehdoilla ja vapausasteiden kytkennällä yksidimensioiseksi. Perusainetta ja pinnoitetta vastaavat paksuudet mallitettiin vastaavilla materiaaliarvoilla ja materiaalin käyttäytyminen oletettiin elastis-plastiseksi ilman syklistä lujittumista tai pehmenemistä. Laskennassa käytettiin lämpötilasta riippuvia materiaaliominaisuuksia. Laskennassa käytetyt compound-putket ja niiden dimensiot nähdään Taulukossa 1.

Taulukko 1. Laskennassa käytetyt compound-putket ja niiden dimensiot.

D_{ulko}/mm	Pinnoite		Perusaine	
	Materiaali	t/mm	Materiaali	t/mm
63,5	Sanicro 38	1,82	4L7	4,71
76,2	Sanicro 28	2,81	4L7	3,77
63,5	3R12	1,65	4L7	4,88
63,5	3RE28	1,68	HT8	4,85
42	FeCrAl	2	HT8	4

Putkille laskettiin ensin alkujännitystila huoneen lämpötilassa vertaamalla pinnoitteen ja perusaineen lämpölaajenemiskertoimia. Jos lämpölaajenemiskertoimet poikkesivat, alkujännitystä laskettiin olettamalla kerrokset jännityksettömiksi 1000 °C:ssa ja antamalla putken jäähtyä 20 °C:een, jolloin pinnoitteen suurempi kutistuminen johti (yleensä) myötörajan suuruiseen vetojännitykseen ulkopinnalla. FeCrAl:ssa, jonka lämpölaajenemiskerroin on hieman alle HT8:n (perusaine), jäähtyminen aiheutti n. 60 MPa vastaavan puristusjännitystilan pinnassa. Putken sisäiseksi paineeksi laskelmissa oletettiin 80 bar. Laskenta sisälsi seuraavat vaiheet:

1. Putken annettiin lämmetä käyttölämpötilaan 300 °C, jolloin jännitystila tasaantui.

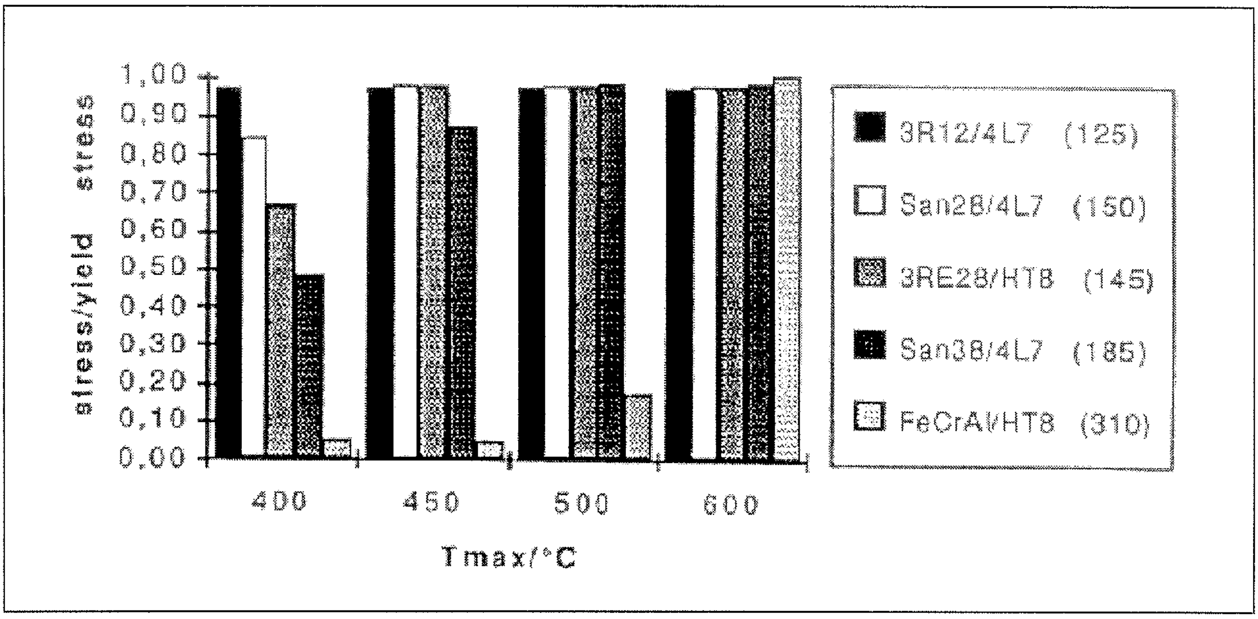
2. Ulkopinnan lämpötila annettiin nousta korotettuun arvoon 400, 450, 500 tai 600 °C, jolloin seinämän läpi muodostui lähes lineaarinen lämpötilajakauma.

3. Ulkopinnan lämpötila palautettiin takaisin käyttölämpötilaan, jolloin ulkopinnalle jäi vetojännitystila, mikäli syklin aikana tapahtui plastisoitumista.

4. Lasku huoneen lämpötilaan säilytti pinnoitteen vetojännitystilan.

Eri materiaaliyhdistelmillä laskettuja tuloksia verrattaessa todettiin, että riittävän suuri lämpötila-piikki ja paluu käyttölämpötilaan johti kaikilla materiaaliyhdistelmillä plastiseen venymään ja myötörajan suuruiseen jännitystilaan pinnalla. Austeniittisilla ruostumattomilla teräksillä kuten

3R12 (suuri α ja pieni σ_y) jo huippulämpötila 400 °C riitti tähän (Kuva 16); muilla materiaaleilla vaadittiin 450-600 °C huippulämpötila (Kahala, 1996).



Kuva 16. Pinnan jännitykset ($\sigma_y \approx \sigma_z$) käyttölämpötilassa (300 °C) häiriötilan T_{max} jälkeen. Suluissa myötöraja / MPa 300 °C:ssa.

5. Compound-putken termisen väsymisen koetuloksia kirjallisuudessa

Termisen väsymisen kokeita compound-putkilla on tehty jo 1970-luvulla. Egnell ja Tornblom (1973) raportoivat AISI 304/hiiliteräs-compound-putkien termisen väsymisen kokeista, jotka oli tehty lämpötilavälillä 200-500 °C. Putkea kuumennettiin induktiokuumentimella ja jäähdytettiin paineilmalla. Tällä menetelmällä pystyttiin tuottamaan 15-20 sykliä tunnissa. Laskennallisesti kappaleen väsymisiäksi saatiin n. 10000 sykliä, mutta compound-putki kesti säröilemättä 10000 sykliä. Tämä todettiin myös TKK:n kokeissa.

Wilson (1995) raportoi termoshokkikokeista, jotka tehtiin compound-tangoille. Tangoissa oli hiiliteräs perusaineena ja AISI 304L tai Sanicro 38 pinnoitteena. Kappaleet kuumennettiin 400-1000 °C:een ja sammutettiin veteen alle 100 °C:een. Testiä jatkettiin 1000 sykliä ja kappaleita tutkittiin 100 syklin välein. AISI 304L-teräksellä pinnoitetuissa tangoissa havaittiin säröjä 1000 syklin jälkeen, kun sammutus tapahtui 500 °C:sta. Sanicro 38 seoksella pinnoitetuissa tangoissa havaittiin vain muutamissa kappaleissa säröjä 1000 syklin jälkeen, kun sammutus tehtiin 700 °C:sta. Muut kappaleet selvisivät kokeista säröilemättä (Swindemann, 1996).

Linde ja Henderson (1995) raportoivat termisen väsymisen tuloksia kuormitetuissa Incoloy 825/hiiliteräs-compound-putkissa. Väsytyslämpötila-alue oli 300-600 °C. Testi oli järjestetty siten, että maksimi vetojännitys ja lämpötila vallitsivat aina samaan aikaan. Väsymissäröt ydintyivät hiiliteräkseen ja etenivät siitä kohti pinnoitetta. Muutama särö havaittiin myös pinnoitteessa. Raekoon vaikutusta tutkittiin samassa kokeessa ja havaittiin, että pienirakeisella Incoloy 825-pinnoitteella oli heikompi termisen väsymisen kestävyys kuin suurirakeisella (Linde ja Henderson, 1995).

Oak Ridge National laboratoriossa tehdyissä tutkimuksissa on havaittu mm. seuraavia compound-putken termisen väsymisen vaurioihin liittyviä asioita. Tyypillisesti säröt ydintyvät pinnoitteen ulkopintaan ja etenevät siitä kohti pinnoitteen ja perusaineen rajapintaa. Säröt, jotka kulkevat pinnoitteen läpi, joko pysähtyvät rajapinnassa tai jatkavat etenemistä rajapintaa pitkin. Hyvin usein havaitaan pistemäistä korroosiota siinä kohdassa, missä särö on pysähtynyt rajapintaan. Muutamissa tapauksissa säröt ovat edenneet hiiliteräkseen (Keiser ym. 1996).

6. Compound-putkien mallinnus Oak Ridge National laboratoriossa

Elementtimenetelmällä tehdyssä mallinnuksessa (FEM) oletetaan perinteisesti, että soodakattilan putkeen muodostuvat jännitykset ovat sisäisen paineen ja käytön aikana esiintyvien lämpötilojen aiheuttamia. Compound-putki käy kuitenkin läpi monia eri valmistusvaiheita, mm. pursotus ja kylmämuovaus, ennen hitsausta soodakattilaan. Jokainen näistä valmistusvaiheista aiheuttaa putkeen tietyn suuruisen jännityksen. Ennen asennusta soodakattilaan compound-putkessa on suuria sisäisiä jännityksiä, jotka ovat erityisesti hitsatulle rakenteelle haitallisia.

Oak Ridge National laboratoriossa soodakattilan compound-putken (304L/SA210) FEM-mallinnus aloitettiin simuloimalla putkien hitsausta. Simulointi suoritettiin siten, että ensin pala putkistoa hitsattiin toiselta puolelta, ja kun kappale oli jäähtynyt huoneen lämpötilaan simuloitiin hitsaus toiselta puolelta. Näin saatuja laskettuja jännityksiä käytettiin hyväksi soodakattilan putken kolmedimensioisessa mallinnuksessa.

Compound-putken termisessä mallinnuksessa määritettiin putken lämpötilajakauma kehän ja säteen suunnassa käyttöolosuhteissa ja häiriötapauksissa (lämpötilan kohoaminen, hot spot). Putken korkeimpaan kohtaan asennettuja termoelementtejä käytettiin putken pinnan lämpötilan arviointiin. Oletettiin, että termoelementin mittaama lämpötila vastasi kiinteän massan lämpötilaa 3,2 mm etäisyydellä putken pinnasta. Kun lisäksi oletettiin, että sulan massan lämpötila oli 800 °C ja että lämpötilajakauma massan (sula+kiinteä) läpi oli lineaarinen, pystyttiin varsin tarkkaan arvioimaan lämpötila compound-putken pinnalla. Näin saatua lämpötilajakaumaa käytettiin kolmidimensioisessa mallinnuksessa yhdessä jäännösjännitysten kanssa, kun analysoitiin compound-putken jännitystilaa lämpötilavaihteluiden aikana ja niiden jälkeen.

FEM-mallia käytettiin jännitysten ja venymien laskentaan mm. seuraavissa tapauksissa:

1. Compound-putken kuumennus käyttölämpötilaan ja takaisin huoneen lämpötilaan.
2. Kaksi peräkkäistä "lämpötilapiikkiä" (hot spot) samassa kohdassa.
3. Höyrykuplan muodostus hot spot:n aikana.

Käyttölämpötilassa vallitsee puristusjännitys, joka voi ylittää myötörajan AISI 304L-tyyppisessä pinnoitteessa. Käyttölämpötilasta huoneen lämpötilaan (yksi kuumennuskerta) jäähdytetyssä compound-putken pinnoitteessa vallitsee vetojännitys, joka on huomattavasti alkuperäistä jännitystä suurempi.

Menetelmällä laskettiin lisäksi putken lämpötila, jossa puristusjännitys muuttuu vetojännitykseksi. Laskennassa oletettiin paineen ja lämpötilan putoavan lineaarisesti käyttöolosuhteita vastaavista arvoista niihin lukemiin, jotka vallitsevat laitoksen ollessa alasajettuna. Tuloksena saatiin, että lämpötilan laskiessa 270 °C:een muuttuu puristusjännitys vedoksi, ja lämpötilassa 220 °C ylittää vetojännitys myötörajan AISI 304L-tyyppisessä pinnoitteessa.

Käytön aikana esiintyvä lämpötilapiikki aiheuttaa pinnoitteeseen voimakkaan puristusjännityksen, joka ylittää myötörajan. Lämpötilan palautuessa normaalikäyttölämpötilaan, vaihtuu pinnoitteen jännitys vedoksi. Toisen lämpötilapiikin jälkeen on pinnoitteessa vielä suurempi vetojännitys kuin aiemmin. Pinnoitteen plastinen venymä kumuloituu lämpötilapiikkien johdosta ja saattaa olla jopa yli 2 %.

Höyrykuplan muodostus putken sisäpuolella kohottaa perusaineen (hiiliteräs) lämpötilaa ja pienentää lämpötilagradienttia. Perusaine lämpölaajenee ja pinnoitteen puristusjännitys muuttuu vedoksi. Höyrykuplan kadottua pinnoitteeseen jää vetojännitys (Keiser ym. 1996).

Kirjallisuusviitteet

Bartsch, K., Hänninen, H., Nieminen, M., 1993. "Thermal fatigue, a litterature review". TKK, Julkaisu MTR 3/93, Espoo. 90 s.

Egnell, L., Tornblom, H., 1973. "Thermal Fatigue in Composite Tubes", paper C238/73 in Joint International Conference on Creep and Fatigue in Elevated Temperature Applications, Institute of Mechanical Engineers, London.

Kahala, Timo, 1996. "Suomen Soodakattilayhdistys ry, Soodakattilaputken terminen väsyminen, 2. väliraportti". TKK, Espoo. 10 s.

Keiser, J. R., Taljat B., Wang X-L., Swindemann, R., W., Maziasz, P. J., Thomas, R. L., Payzant, E. L. 1997. "Analysis of cracking of coextruded recovery boiler floor tubes". Oak Ridge National Laboratory, Oak Ridge, Tennessee. 16 s.

Kemppainen, Mika, 1997. "Termisen väsymisen testausjärjestelmän suunnittelu ja toteutus". Diplomityö. TKK, Espoo. 121 s.

Linde, L., Henderson, P., J., 1995. "Thermal-Mechanical Fatigue of a Composite Steel" paper presented at the International Symposium on Fatigue under Thermal and Mechanical Loading, Petten, May 22-24.

Mäkinen, Hanna-Leena, 1994. "Terminen väsyminen, koelaitteiston vaatimukset ja suunnittelu". Diplomityö. TKK, Espoo. 113 s.

Saarinen, P., Hänninen, H. 1997. "Thermal fatigue of recovery boiler composite tube, 3. Progress report". TKK, Espoo. 19 s.

Swindeman, R., W., 1996. "A Review of Thermal/Mechanical Fatigue in Composite Tube Materials". Oak Ridge National Laboratory, Oak Ridge, Tennessee. 30 s.

RECOVERY BOILER DAY IN HELSINKI, OCT. 22, 1997
REPORT FROM SWEDEN AND NORWAY

A REPORT FROM THE SWEDISH -NORWEGIAN RECOVERY BOILER COMMITTEE

Per Sellerholm, ÅF-IPK AB, Sweden
(Secretary in the Swedish-Norwegian Recovery Boiler Committee)

ABSTRACT

The following report from the Swedish-Norwegian Recovery Boiler Committee includes a brief review of the Committee's history and organization, incidents (in particular the Östrand explosion) and the methods used to evaluate these incidents, education of recovery boiler operators, what the European Union has meant to our work, our co-operation with the Finnish recovery boiler committee, research work that is supported by the Committee, and finally describe our ongoing work within the area of safety.

The Swedish Recovery Boiler Committee has existed since 1965. Initially, the main purpose of the committee was to come up with recommendations on how to handle a water leakage into a recovery boiler furnace. As a result of this, the name of the Committee was the Emergency Shutdown Procedures Committee. In 1972 the name changed to its current name, "Sodahuskommittén". The reason for this name change was the increased need to look at other safety issues associated with recovery boilers and their surroundings.

A smelt-water explosion occurred in February 1997. This is the first smelt-water explosion that has occurred in Sweden or Norway since 1985. This explosion is described in more detail in the report. The education of recovery boiler operators is ongoing. Close to 500 operators have either been or are in the process of being certified. The committee is also involved with the ongoing compilation of the new European Union boiler code together with the Finnish committee. A co-operation with the Finnish recovery boiler committee started in 1997 and will hopefully help both committees to reach their future goals. The only research-program that is currently ongoing is the black liquor gasification research program. The results of this research-program will be presented this fall. The Swedish-Norwegian Recovery Boiler Committee is also doing a revision of its safety recommendations. One especially interesting recommendation that will be published during the fall is the recommendation concerning 'Guidelines for destruction of high concentration low volume non condensable gases (HCLV) in the recovery boiler'.

RECOVERY BOILER DAY IN HELSINKI, OCT. 22, 1997
REPORT FROM SWEDEN AND NORWAY

A REPORT FROM THE SWEDISH -NORWEGIAN RECOVERY BOILER COMMITTEE

Per Sellerholm, ÅF-IPK AB, Sweden
(Secretary in the Swedish-Norwegian Recovery Boiler Committee)

This report will include a brief review of the Committee's history and organization, incidents (especially the Östrand explosion) and the way we evaluate these incidents, education of recovery boiler operators, what the European Union has meant to our work, the co-operation with the Finnish recovery boiler committee, research work that is supported by the committee, and finally our ongoing work on safety recommendations.

The Swedish-Norwegian Recovery Boiler Committee represents 23 mills in Sweden and two mills in Norway. The total number of recovery boilers in Sweden and Norway is 34, two of these are located in Norway. The average age of these recovery boilers is approximate 25 years. However, several boilers have been modernized in some way, for example new furnace, new steam drum, new superheater etc. The newest recovery boiler was brought on line in June of last year. This recovery boiler has been widely discussed due to its octagonal shaped lower furnace.

ORGANIZATION

The Swedish Recovery Boiler Committee has existed since 1965. Initially, the main purpose of the Committee was to come up with recommendations on how to handle a water leakage into a recovery boiler furnace. As a result of this, the name of the Committee was the Emergency Shutdown Procedures Committee. In 1972 the name changed to its current name, "Sodahuskommittén". The reason for this name change was the increased need to look at other safety issues associated with recovery boilers and their surroundings. The Committee is now an independent non-profit organization with the Steam Boiler Association's Research Foundation as the principal. The Steam Boiler Association's Research Foundation is also the major owner of the ÅF-Group, which has approximately 1,800 employees and is one of the largest technical consultants in Sweden. The Steam Boiler Association's Research Foundation is responsible for the Committee's administrative duties. The secretary of the committee is from ÅF-IPK, which is a subsidiary of the ÅF-Group and specializes in the pulp and paper industry.

RECOVERY BOILER DAY IN HELSINKI, OCT. 22, 1997
REPORT FROM SWEDEN AND NORWAY

The annual budget for the Swedish Recovery Boiler Committee's work is 2 million Swedish kronor. Almost 90% of the budget comes from member fees. The member fees are based on the annual production of pulp according to government regulations that are set for each mill. This year the fee is 20 öre per ADt pulp. As part of their membership the members get documentation on what has happened concerning recovery boiler incidents, recommendations on how to operate recovery boilers and their auxiliary equipment in a safe manner, and receive up-to-date information on other recovery boiler activities, for example, information from this meeting. The members in the Committee include all recovery boiler owners in Sweden and Norway, ÅF-IPK, the Swedish Papermakers Union, one recovery boiler manufacturer - Kvaerner, the Swedish Board for Occupational Health and Safety, and two certified pressure vessel inspection companies - SAQ and ÅF-Kontroll. ÅF-Kontroll is a subsidiary of the ÅF-Group. Each year there are four ordinary board meetings with the annual board meeting in April. At the annual board meeting we set the budget and activities for the coming year and elect the members of the board. The committee has several sub-committees. Of these sub-committees two are permanent and the others are formed as required. The two permanent sub-committees are the "incident" sub-committee and the "recommendations" sub-committee. We also have several tasks which are handled by either one or two persons. The "incident" sub-committee has a meeting before every ordinary main committee meeting. The members in the "incident" sub-committee are chosen from the board. The "recommendations" sub-committee has several meetings during the year as required. One very important task for the "incident" sub-committee group is to regularly publish short information pamphlets that include information regarding educating, and if I may say so, interesting incidents. As the name indicates the "recommendations" sub-committee is responsible for publishing recommendations after they have been accepted by the main committee board.

A difference between the Finnish committee and the Swedish-Norwegian committee is that the annually Swedish recovery boiler conference in Stockholm in November is not arranged by the Committee. It has been arranged by the ÅF-Group since the start 1943 and is now arranged by one of the subsidiary companies in the ÅF-Group, ÅF-IPK. However, the Committee is responsible for one annual conference and that is the recovery boiler operator meeting (Sodapanneträffen) that is generally held in May. This conference is arranged by the Committee and one host mill. The host mill changes every year. The number of participants is around 100. The 1998 recovery boiler operator meeting will be hosted by SCA Packaging Munksund, Piteå.

INCIDENTS

There have been very few incidents during 1996 and so far also during 1997. The total number of incidents for 1996 was 14. These included: five economizer incidents, two furnace incidents, three boiler bank incidents, two smelt spout incidents, one superheater incident, and one incident with water leakage on the outside of the furnace. As of August 1997 the total number of incidents was seven. We had not had any severe incidents in Sweden or Norway for quite a long time, however we had one in February of this year which I will describe in more detail later on. Due to this, if I may say ”lack of incidents” up until the explosion that occurred in February, we had noticed, especially among people that do not operate these boilers on a daily basis, that a feeling that recovery boilers are a safe piece of equipment (false or not) has grow more and more. I am not implying that this is a general feeling, however, we have noticed a tendency in this direction. The Committee has decided that for more ”interesting” incidents the staff in charge at the site of the incident will be invited to a Committee meeting to report on the incident. Not only to describe the incident from a technical point of view but also from a human point of view, i.e. how people reacted and behaved before, during and after the incident. By doing these interviews the Committee will hopefully be able to get a more detailed picture of what actually happened, and then use this information to adjust applicable recommendations and guidelines.

One example of an incident where we did such an interview was a water leakage in the lower furnace of a recovery boiler that occurred in the spring of 1996. The staff started to suspect a water leakage almost a week before the decision to start the shutdown procedures was taken. The incident that made them ”push the button” was seeing water come out from one of the smelt spouts. During this week, not only did several signs indicate a water leakage, but the behavior of the staff could have resulted in severe personal injuries if an explosion had occurred. It is of course always easier to say what should have been done after the fact. However, getting the full picture of an incident of this type may prevent a similar incident at another mill.

Another incident where we afterwards also did a similar interview was the earlier mentioned Östrand incident that occurred in February.

Tuesday February 25th at 11:45 pm the Östrand mill experienced an external power failure that lasted for 3 minutes. The internal power supply did not come online immediately due to difficulties in restarting the transformer equipment. As a result several disturbances in the operation of the recovery boiler occurred. While the operation of the recovery boiler stopped one of the feed water pumps continued to operate. This feed water pump is a steam operated turbine pump and the steam is taken from the steam system of the mill.

This together with a loss of instrument air pressure, resulted in the feed water valve being locked in an open position such that the feed water flow to the boiler continued after the liquor firing had stopped. It should be mentioned that the feed water flow from the turbine pump decreased as the steam system pressure of the mill decreased.

At around 1:00 am February 26th the liquor guns were removed and at the same time a small steam pop was noticed in the furnace. The draft into the boiler continued to be quite strong even after this steam pop. Two people, one electrician that tried to get the internal power supply system to work and one boiler operator that was on the ground floor, observed at around 1:10 am a soft rumble from the recovery boiler. At first it was noticed that some ash had blown out from the upper part of the boiler and some smelt from the lower part. Also a greyish sticky mass was coming from the liquor gun openings. These observations resulted in that the recovery boiler building alarm was initiated. It must be clarified that the explosion never was taken for or identified as an explosion. After the alarm was on the superintendent, that had arrived to the scene, made a visual inspection of the boiler. He saw that the recovery boiler had several deformations and also water coming out from a couple of the smelt spouts. At this time the recovery boiler building was abandoned.

On the inspection of the recovery boiler the day after, deformations were noticed on the boiler walls, the walls of the boiler bank and the air channel walls. When looking in through the manholes a hissing and pulsating sound was heard. The boiler had still a pressure of one bar. When entering the boiler the day after, after a water wash, it was seen that a tube in the primary superheater no. 3 was broken. The tube was replaced and the boiler was pressurized to check for other possible leaks. No other leaks were observed. The boiler was out of operation for 23 days before black liquor could be fired again.

The computerized information system worked until 1:00 am, i.e. approximately 10 minutes before the explosion. Therefore, it is possible to study the operation of the boiler on trend curves up until the explosion occurred. The steam operated turbine feed water pump was in operation when the power failure happened. It continued operating as long as there was any pressure in the steam system of the mill, which slowly faded away. The internal power supply system had problems in restarting after the external power came back. As a result the recovery boiler operation stopped except for the feed water turbine pump. As I mentioned earlier the pressure of the pressurized-air system was lost at the same time and as a consequence the feed water valve stayed in an open position, just as it was designed to do. So what we had was a recovery boiler that was being filled with feed water even after the boiler had stopped. This resulted in water filling the steam drum and then going from the steam drum and into the superheater.

Due to the fact that the steam flow from the boiler decreased, as the liquor firing stopped, the temperature of the superheater material increased. And when the primary superheater was cooled down in such a quick way by the entering water the flash welding in this specific tube burst. There are no signs that the water should have entered the secondary superheater. The flash welding burst probably around a quarter past midnight. From that time until just before the explosion approximately 100 ton of water entered into the furnace through the open superheater tube. Because of the heat in the furnace only around 50 to 60 m^3 of the water reached the bed.

There are several important things to learn from this incident:

- If the steam driven feed water turbine pump is operating you must have the level indicator of the steam drum under full control.
- If the liquor firing has stopped the feed water pumps should be stopped as soon as possible. Manually if necessary.
- If you have to stop the feed water flow to the boiler it is not enough to close the control valve due to the small leaks found in control valves. The pump must be either stopped or a second shut-off valve has to be closed.
- It has to be clarified what happens with instrumentation-air pressure for the recovery boiler if the mills instrumentation pressurized-air system loses pressure.
- Recovery boilers with this old type of welding as the flash welding is should try to get these welds checked.

the operators responsibilities can increase, and as a result of this a certain level of recovery boiler supervisors have almost become redundant in the mill organization. The next step for several mills is to adjust their organization according to these more qualified operators. As you well know the Nordic people are not famous for being talkative and chatty. But at the annual conference for recovery boiler operators, organized by the Committee and a host mill, we saw a change in the operators behavior after they had taken part in the recovery boiler courses. Now the operators are aware that they know a lot regarding recovery boiler operation and the discussions at these conferences are becoming more and more intense. The operators are prepared to stand up and say what they think about almost everything.

During the last recovery boiler operators meeting at the Mörrum mill one subject for discussion was just "mill organization". It is very likely that this organization topic will also be discussed at the recovery boiler operators meeting next year in Piteå.

The next phase in educating recovery boiler operators is to come up with an even higher level of courses. The work with the continuing education of recovery boiler operators has started this year and hopefully we will have something to present next year. One suggestion for a continuation course is to discuss the subject of the economical aspects of recovery boiler operation, new technical solutions etc. A major difference as compared to the existing recovery boiler operator education program is that after these continuation courses the operators will not be required to write a test to pass the examination.

THE EUROPEAN UNION

In 1996 the Committee became involved with the ongoing compilation of the new European Union boiler code which is going to be applied within the European Union, which you are well aware of. This code will only be applied to new plants, and is expected to be implemented within the next few years. In charge of creating the boiler code is the technical committee TC 269. The boiler code consists of different areas, for example, materials, design rules, workmanship, inspection, safety equipment and installations, firing and firing equipment, feed water recommendations, and parts of the flue gas cleaning equipment. The Swedish-Norwegian Committee has, together with the Finnish committee, Ahlström and Kvaerner proposed several additional rules to apply to recovery boilers in sulphate pulp mills. The Committee's proposed additions to the code have been based on our own recommendations. We have also tried to examine these general rules and to determine if there are any proposed codes which might be difficult to implement on Swedish recovery boilers. The work with these codes will continue for several years. We will continue to follow this work such that we will not end up having European codes that are in conflict with our own recommendations. The work on the European codes has also resulted in information being exchanged with the Finnish recovery boiler committee and meetings between the persons from both committees responsible for the CEN work.

CO-OPERATION WITH THE FINNISH RB COMMITTEE

In the beginning of this year a first meeting was arranged in Helsinki between our two committees. At this meeting we presented to each other how our committees worked, future ambitions, and both the strong and weak sides of our committees. It was decided at this meeting that the CEN work should be carried out in a close co-operation, which will hopefully benefit both committees. In respective board meetings, after this meeting, both committees received the go-ahead to start this co-operation. The next time we met was in Kemi in June. At this meeting publications and material from both committees was exchanged or agreed to. At our board meeting in August we had Juha Hakala, the secretary in the Finnish recovery boiler committee, as a guest. If members from the Finnish recovery boiler committee would like to participate in our future board meetings they are more than welcome. Representatives from the committees will try to meet twice a year and in that way try to establish good communication with one another.

I think that both committees are aware that a co-operation, where we exchange information and material, and where we can work together to reach common goals is necessary today. As both Finland and Sweden now are members of the European Union it is important that we try as much as possible to join forces and increase our strength with regards to safety issues, regulations etc.

RESEARCH

The main goals of the Swedish-Norwegian Committee has always included the follow up of incidents and to compile safety recommendations, however they have not included the support of research projects. The Finnish Committee, on the other hand, has made a great effort to support and lead research in the recovery boiler field in Finland. The only research project that we have supported lately is the ongoing black liquor gasification project lead by Björn Warnqvist, ÅF-IPK, which will be reported at a symposium next week, October 28th and the other is an investigation regarding the corrosion in the recovery boiler furnace and superheater made by Fredrik Bruno, ÅF-IPK. We have also acted as a discussion partner for the recovery boiler CFD project where the Swedish part has been handled by the Swedish Pulp and Paper Research Institute.

The black liquor gasification project was funded not only by the Committee but also directly by in the project participating mills and manufacturers. The total budget for this project was slightly less than ten million Swedish kronor.

RECOMMENDATIONS

Safety recommendations have always been the main goal of the Committee. Around four years ago we started a revision of all of our recommendations. There were also some areas that needed to be added as new recommendations. At the moment there are 35 recommendations but we have several new recommendations in the progress. The recommendations are divided into six different areas: Technical terms and expressions, Construction and equipment, Operation and operation disturbances, Inspection and maintenance, Education of personnel, and Safety regulations.

One recommendation that is under revision is the recommendation for emergency shutdown procedures. The reason for updating this important recommendation is new information from BLRBAC and that we have to adjust it due to age. It is not expected that it will change significantly.

Of the new recommendations I believe that two could be of interest to this group. They are guidelines for the design of the smelt dissolving tank and guidelines for the destruction of high concentration low volume non condensable gases in a recovery boiler (HCLV). The reason for us calling the instructions of burning HCLV gases for guidelines and not recommendations is that we, the committee, do not recommend destruction of HCLV gases in the recovery boiler. However, if a mill insists on doing so they should as a minimum follow these guidelines so as to decrease the safety hazard when handling HCLV gases. Up until now we have not recommended burning HCLV gases in the recovery boiler and have not said how to do so. However, Swedish mills have been influenced by Finnish mills in their way of handling HCLV gases. As you are aware there are a couple of Finnish mills that burns HCLV gases and as we have heard also are successful in doing so. One HCLV gas burning system has already been installed at a Swedish mill and several other mills plan to follow in their footsteps. As a result, we have put a lot of effort into developing this guideline such that it could be published in September, 1997.

The main work on revising and editing our recommendations will continue another two to three years. However, the work with the recommendations will always be something we have to work with along with other daily committee business. For this reason we have created a special subgroup that is in charge of updating and developing these recommendations. The Committee believes that it is important to spread information regarding safe handling of the recovery boiler and have therefore decided to let other recovery boiler committees and recovery boiler vendors to buy our recommendations for the publication cost. Unfortunately, our recommendations are currently in Swedish, however, we hope that in co-operation with vendors and other committees that in the future translated versions of these recommendations will be available. For example one non-member recovery boiler vendor that has bought our recommendations is Ahlström Machinery.

REVIEW OF THE AMERICAN FOREST & PAPER ASSOCIATION RECOVERY BOILER PROGRAM

By
Thomas J. Grant
American Forest & Paper Association
New York, New York

October 22, 1997
Finnish Recovery Boiler Committee
Helsinki, Finland

REVIEW OF THE AMERICAN FOREST & PAPER ASSOCIATION RECOVERY BOILER PROGRAM

Abstract

The AF&PA Recovery Boiler Program continues to strive for the safe and reliable operation of recovery boilers. Training, maintenance and supervision are required to accomplish this task, The AF&PA Program has developed an industry-wide safety audit program, updated its reference manuals, its training program and its guidelines for the safe operation of recovery boilers. The subcommittees continue sponsoring seminars, overseeing research projects, reviewing their guidelines, and coordinating efforts with BLRBAC and TAPPI.

On behalf of the American Forest & Paper Association's Recovery Boiler Program, I bring greetings to the Finnish Recovery Boiler Committee and my friends here, especially Tuomas Timenen. It is indeed a pleasure to be here in your country again. I must thank the Committee and Risto Paldanius for inviting me to present a review on the recovery boiler activities in the U.S.

To give you a little background of the AF&PA, it was formed in 1993 when the American Paper Institute (API) merged with the National Forest Products Association (NFPA) and the American Forest Council (AFC). API was made up of pulp, paper and paperboard manufacturers, NFPA's membership was from the sawmills and lumber mill owners, and AFC were the forest landowners. Now we have the forest owners and producers, and membership is approximately 700 companies - from small sawmill operators to large companies producing pulp, paper and lumber for building homes. The main function of the trade association is lobbying for the industry's interests and concerns for regulations affecting the daily operations of the companies.

The AF&PA Recovery Boiler Program was formed in 1974 for the purpose of bringing together all U.S. companies operating recovery boilers, to improve procedures and guidelines for the safe operation of recovery boilers. Currently, 41 companies operate 216 boilers in 130 mills in the United States. (34 of the 36 AF&PA member companies participate in the Program.) When we look at chart 1, we can see almost a 40 year history of recovery boiler explosions in the U.S. in five year spans, along with the days of outage, since the 1958 period. The companies decided collectively to reduce those explosions by combined efforts of exchanging techniques and practices for improving safety and efficiency of the recovery boilers. Looking at charts 2 and 3, one can see the impact the AF&PA Program had in helping reduce these upsets. We did not have an explosion from early 1993 until mid-1996 and none since that time. As you can see we were averaging better than 3 explosions a year in the 1970's and 1980's

The companies realized at that time, and at present, that the recovery boiler continues to be the largest single investment in a pulp mill - often exceeding $100 million. Over 40% of all the energy used in the U.S. pulp and paper industry is produced from the black liquor. The combustion of the black liquor is equivalent to about 200 million barrels of oil and at today's prices, is valued at over $4 billion.

The goal of the Program continues to be to improve the operation, maintenance, safety and efficiency of recovery boilers. Three subcommittees were established - and continue in existence today - to handle various areas in achieving the Program's goal. These three subcommittees are as follows:

- Research and Development
- Operation and Maintenance
- Organization and Training.

Membership in each subcommittee consists of company representatives who are involved in day-by-day concerns of their respective areas related to recovery boilers. A list of publications produced by the committees is shown in <u>Chart 4</u>.

While it is clear that a great deal of progress has been made, the subcommittees and members realize that there are still things that we do not know about operating recovery boilers, in addition to other things to be done to reduce serious operator errors. Training programs, operational safety seminars and maintenance guidelines reflect the greater awareness of the human factor in achieving the specified objectives of the AF&PA Recovery Boiler Program and the safe and reliable operations of recovery boilers.

The Operation and Maintenance Subcommittee realized in the early years of the Program that there was need to publish information that could be useful to the operators. The Subcommittee developed the Recovery Boiler Reference Manuals, and has since updated and revised them to include the most up-to-date practices and procedures. Volume I consists of "Inspection and Nondestructive Testing." Volume II includes "Maintenance and Repair Analysis, and Repair Guidelines and Practices," Volume III provides "Operational Effects and the Case History Descriptions." This subcommittee also wrote the publication for safety audit guidelines which was developed as a comprehensive and generic system of auditing so that each mill may regularly evaluate the overall safety and reliability of the boiler operations. The subcommittee also produced guidelines and checklists for new boilers. The subcommittee developed these guidelines and checklists, based on past and current boiler failures and associated operating problems and through discussions with industry operating personnel, equipment manufacturers, and construction personnel. This document is not intended to serve as a complete boiler specification but can serve as a checklist of major topics and items to be resolved by the manufacturer and the user during boiler specification and proposal discussions.

To further improve the safe operation of the boilers, the subcommittee sponsored a seminar in 1985 for boiler superintendents which pointed out the need for training, maintenance and other concerns of operation. Since that time, we have sponsored three operational safety seminars a year for operators, superintendents and maintenance personnel which have proven most successful. In 1996, we had 150 attend the seminars and in 1997, we had 145 attend. These seminars are considered most helpful and informative by providing both formal and informal open forums for the discussion of problems and situations in the safe and reliable operation of recovery boilers. We also coordinated with the Black Liquor Recovery Boiler Advisory Committee (BLRBAC) to sponsor seminars for maintenance and operation of boilers. In 1994, we had 285 attend a Maintenance Seminar. With the increased concern of cracking and/or corrosion of tubes in the lower furnace, the Subcommittee sponsored a seminar with BLRBAC last year which was attended by over 300 people from all sides, operators, manufacturers and suppliers of the recovery boiler equipment. The purpose of this seminar was to further enhance the development and knowledge of those people involved in corrosion control of recovery boilers. It stressed the need for corrosion prevention. Although there were different perspectives on what is causing this problem, it made the operators aware of the need and methods for a solution. I will talk a little further on corrosion when I get to the R&D Subcommittee. The next joint seminar planned is for young and/or new engineers to the recovery boiler operations. The objective is to make them more aware of the unique situations in this area.

The Organization and Training Subcommittee has been most active in producing a major training program of lessons and audio visual tapes for operators. That program has recently been put aside for a more modern and comprehensive program which includes up-to-date practices and procedures.

The James River Company developed a very comprehensive training program in 1988 and in 1993 gave it to the industry through AF&PA. After reviewing it, the Organization and Training Subcommittee revised and updated the program so that it would be generic. It was developed to provide training for personnel involved in operating recovery boilers and designed to cover all processes for the safe and efficient operation of recovery boilers. The intend was for the use by operators, supervisors, technical support personnel and anyone else who needs to understand the workings of the recovery process. It is organized into nine modules with specific areas of operation - as we can see from chart 5. For each module, there is a Technical Manual for use of the "students" and an Instructor Guide for aiding the instructors in presenting the material. The information is meant to be generically applicable to all operating Tomlinson-type kraft black liquor recovery boilers, regardless of age or manufacturer. There are nearly 1,300 pages of text and hundreds of illustrations and diagrams in the Technical Manual and almost 1,400 pages of text, 315 overhead transparencies, and 380 handout sheets modified for classroom use.

The Recovery Boiler Tutor was also developed by this subcommittee through the J. H. Jansen Company. The RBT is a computerized recovery boiler simulator and tutor designed to teach safe and efficient operation for black liquor recovery boilers. It allows operators to control a dynamic interactive model of a kraft recovery boiler and provides a combination of artificial intelligence and process simulation on a personal computer for operator training. The RBT was developed to help improve operator's confidence and competence, particularly during problem situations. Operators may simulate operating problems, upset conditions and emergency situations, and then take appropriate action to resolve them. It acts as a "coach" explaining the full range of operation variables answering questions and providing advice - nearly 100 U.S, Canadian and Brazilian mills have installed the RBT.

The Research and Development Subcommittee has done its share of work for the Program with its many research projects over the years and by publishing a book to bring together disparate pieces of research into a single integrated, coherent portrayal of the recovery boiler research. From this, the subcommittee developed a training module for those who wish to use the material in whole or in units to convey the principles of recovery boiler operation to operators, superintendents, managers, engineers and students. More recently, as part of its ongoing effort to transfer the wealth of information on recovery boilers to the practitioner in the field, the Subcommittee published another textbook, "**KRAFT RECOVERY BOILERS**." It is primarily intended for people who work every day in pulp and paper mills as a reference textbook on recovery boilers. The target audience is made up of the engineering, technical, and supervisory staff at mills, but the book contains enough breadth and depth to satisfy the non-specialist designer, consultant, student, and researcher. Strong emphasis was placed on producing a book with a lot of the typical values, practical examples, and clear diagrams of equipment and processes.

The Expert Advisory System is another project that the subcommittee has developed with Stone & Webster Engineering. This is a multiple alarm situation system for recovery boiler operations. The system consists of an artificial intelligence system that embodies the experience and judgmental decision-making capabilities of recognized human experts in the safe operation of recovery boilers. This system provides guidance to operators in situations involving multiple alarms from the control system, complex problems in the mill and unusual circumstances which normally require independent judgment and experience. The system has been installed in several mills, in addition to a test-site mill and has produced very good reports in detecting leaks. Companies have been advised to look at the possible use of various leak detection systems in their mills so that there is at least on system in place.

The R&D Subcommittee is in a multiple phase research project with the ultimate goal to develop effective field corrosion monitoring methods and procedures for testing for corrosion in the lower furnace. An extensive database is being developed aimed at three promising technologies: electrical resistance, electrochemical probe, and thin layer activation technology. The Technical Advisory Group is working closely with the Institute of Paper Science and Technology (IPST) and the Pulp and Paper Research Institute of Canada (PPRICAN) in moving toward the next stage in developing a real time probe for monitoring corrosion

The subcommittee also monitors recovery boiler explosions and incidents in the recovery boilers through the services of Dr. Dave Clay. (Formerly Dr. Tom Grace handled this until his retirement earlier this year.) We also work closely with BLRBAC in this area as well as in the development of guidelines for the safe operation of the boilers.

Another major project involving the R&D Subcommittee was the recently completed kraft recovery modeling study at the University of British Columbia, the Institute of Paper Science and Technology with the guidance and support of Dr. Grace, Abo Akademi, major boiler manufacturers and other noted researchers. The purpose of the project was to develop modeling capability for kraft recovery boilers that can be used to extend recovery boiler design or operating variables. Such a model could serve as a basis for changes in recovery boiler designs and operating practices leading to improved safety and reliability, greater capacity utilization, more effective emission control and greater energy efficiency. Reports show great strides were made. Final reports on the codes that can be used in modeling have not been published at the time of this writing but are expected to be available later this year.

The Subcommittee is looking into a study for bed cooling following an Emergency Shutdown Procedure (ESP). This study is just about to begin. Companies have been advised to discontinue using a spray mist system for bed cooling.

I hope this presentation of the AF&PA Recovery Boiler Program has given you a better idea of what we are doing and our efforts to meet the objective of operating recovery boiler more safely and efficiently. The U.S. pulp and paper industry is working toward another record year of production - not necessarily a record year of income.

At our annual meetings and conference held in this past February, we had manufacturers present their perspectives on the latest design/operating breakthroughs. In addition, the attendees learned of the strides made in black liquor gasification technologies' areas and the features of four active developments and the process each uses - Chemrec, Noell/Bechtel, ABB and MTCI. It was pointed out that some of the factors motivating gasification are: need to affordable incremental capacity; increasing dependence on electrical power; changing environmental regulations; reduced capital cost and aging recovery boilers, to name a few.

Objectives of the microstructural study in the Advanced Material research at Oak Ridge involve the characterization of microstructure of composite tubes, measurement as to how composition and properties vary by manufacturer, size, cladding composition, location within the tube as well as fabrication history. The study also involves residual stress measurements, and modeling studies. Some of the participants in the study visited Sweden and Finland last year to discuss the status of programs on recovery boiler composite tube degradation and to promote mutual exchanges of experiences and information.

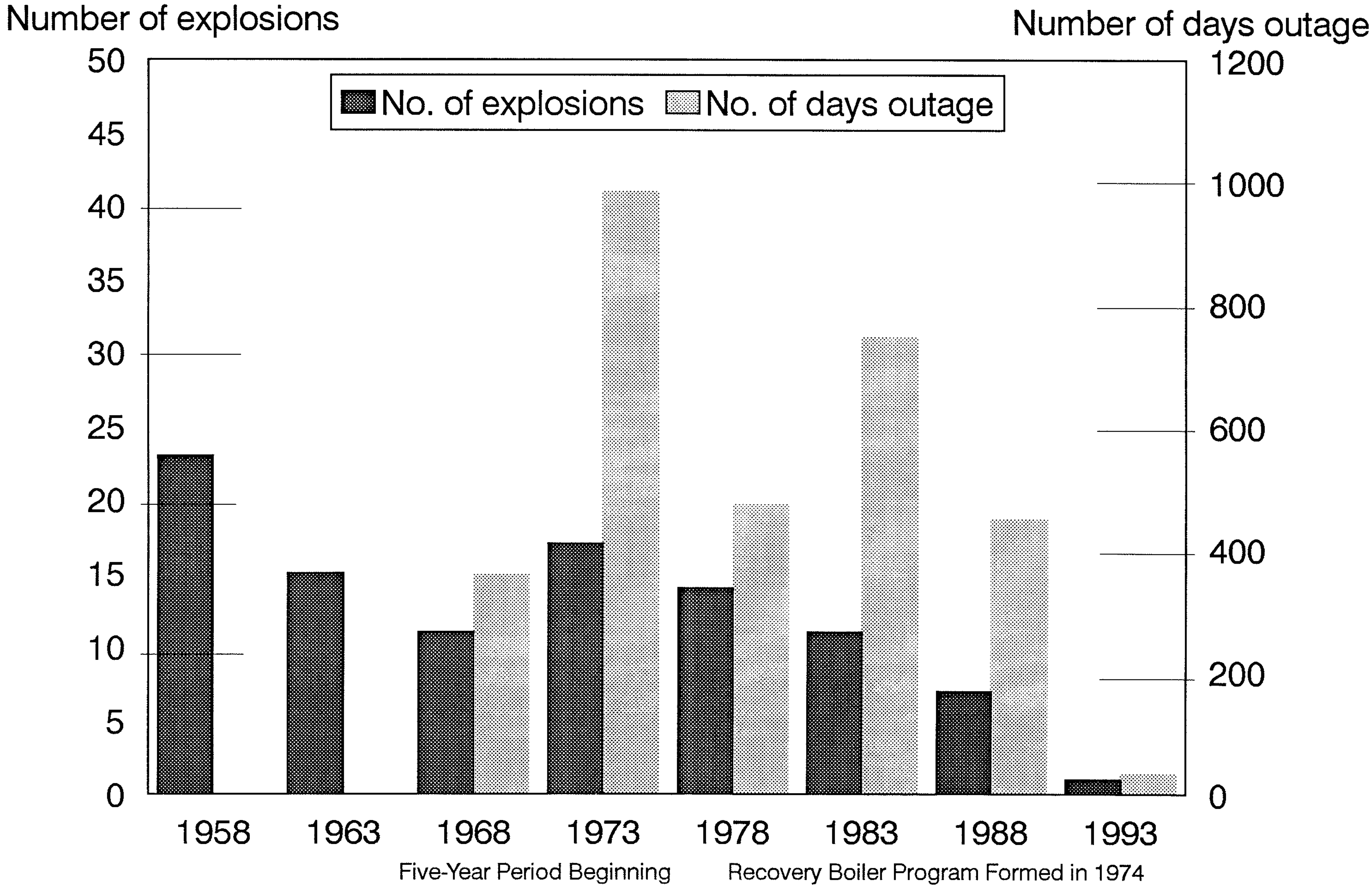
Our next annual meetings and conference will be held in February 1998 and we will have presentations on the progress of the gasification projects; the Advanced Materials research at Oak Ridge, in addition to vendor's views on the optimization of recovery boiler operational techniques.

Thank you very much for your attention and inviting me.

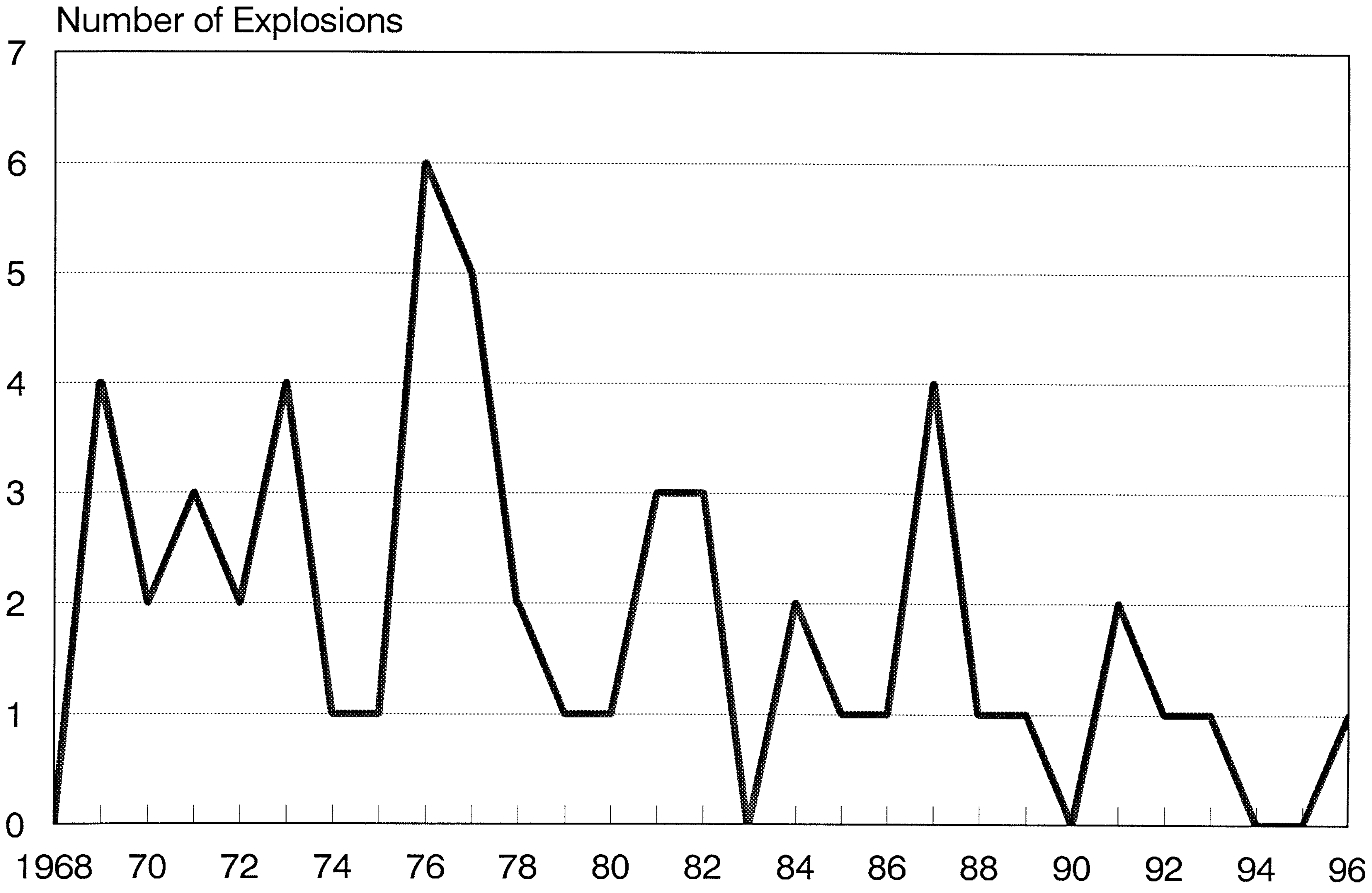
speech.5

RECOVERY BOILER EXPLOSIONS/OUTAGES

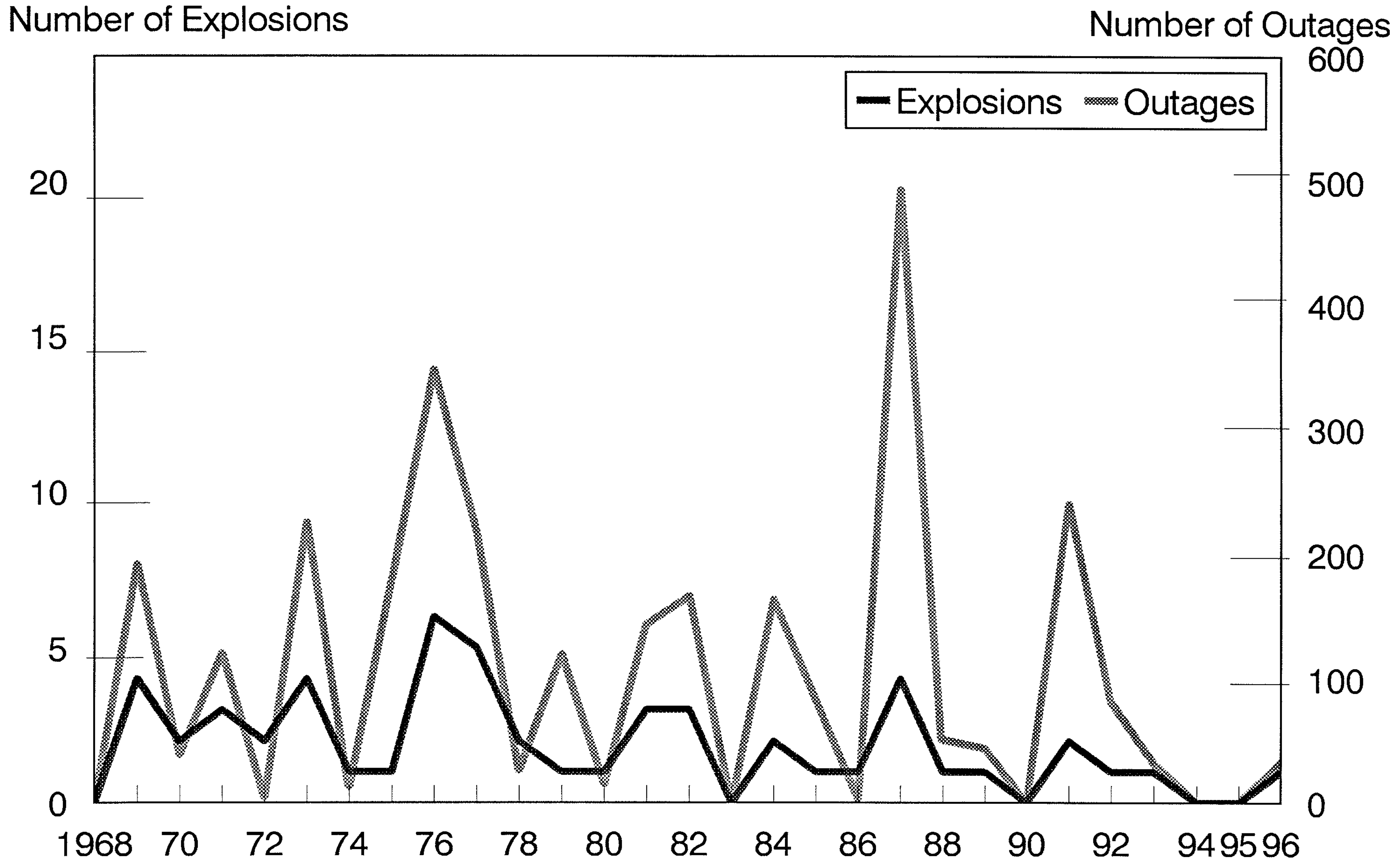
1958 - 1997



U.S. RECOVERY BOILER EXPLOSIONS



NUMBER OF EXPLOSIONS OF RECOVERY BOILERS
& NUMBER OF DAYS OF OUTAGES (U.S. only)



AF&PA RECOVERY BOILER PUBLICATIONS

RECOVERY BOILER TRAINING PROGRAM - Incorporates the latest technology - generically applicable to all recovery boilers. Includes 9 modules for Technical Guide of 1,300 pages of text and hundreds of illustrations and diagrams, and 9 modules for Instructor Guides consisting of detailed instructions - 1,400 pages of text, 313 overhead transparencies and 378 handout sheets for classroom use.

RECOVERY BOILER REFERENCE MANUAL - Three volumes of reference material for corporate engineers, boiler operators, supervisors as well as all others involved in inspections and repairs of recovery boilers.

Volume I	- Chapter I	- Inspections
	- Chapter II	- Nondestructive Testing
Volume II	- Chapter III	- Maintenance and Repair Analysis
	- Chapter IV	- Repair Guidelines and Practices
Volume III	- Chapter V	- Operational Effects
	- Chapter VI	- Case History Descriptions

RECOVERY BOILER SAFETY AUDIT GUIDELINES - Developed by AF&PA Operations and Maintenance Subcommittee based on a general consensus of current procedures employed in pulp mills. The purpose of the recovery boiler audit program is to reduce the risk of explosions by evaluating the overall safety and reliability of black liquor recovery boiler operations.

GUIDELINES AND CHECKLIST FOR SPECIFICATION AND CONSTRUCTION OF NEW BLACK LIQUOR RECOVERY BOILERS - Developed by AF&PA Operations and Maintenance Subcommittee to improve existing procedures and lead to a safer, more reliable recovery boiler. It is not intended to serve as a complete boiler specification but can serve as a checklist of major topics and items to be resolved by the manufacturer and the user during boiler specification and proposal discussions.

RECOVERY BOILER TUTOR (RBT) - A computerized recovery boiler simulator and tutor, designed to teach safe and efficient operation of black liquor recovery boilers. Allows operators to control a dynamic interactive model of a kraft recovery boiler. It can be customized to the specifications of any B&W or CE recovery boiler with direct contact evaporators or direct fired units.

"KRAFT RECOVERY BOILERS" - A new comprehensive recovery boiler textbook by the AF&PA and written by seven recovery boiler experts. The book was edited Dr. Terry Adams with contributions from Drs. Jim Frederick, Tom Grace, Mikko Hupa, Honghi Tran, Andy Jones and Kristiina Iisa. It covers all aspects of recovery boilers including: black liquor properties, combustion chemistry, black liquor and char bed burning, air and liquor systems, plugging, corrosion, design, safety and control. The book may be ordered through TAPPI Press, P. O. Box 102556, Atlanta, GA 30368-0556.

AMERICAN
FOREST &
PAPER
ASSOCIATION

Recovery Boiler Program
Measurement Technology Program

AF&PA RECOVERY BOILER PROGRAM

MODULE I
PULP & PAPER MILL PROCESS OVERVIEW AND OPERATING SAFETY INFORMATION

MODULE II
RECOVERY BOILER SYSTEM INFORMATION

MODULE III
RECOVERY BOILER WATER AND STEAM SYSTEMS

MODULE IV
COMBUSTION AIR/FLUE GAS SYSTEMS

MODULE V
AUXILIARY FUEL SYSTEMS

MODULE VI
COMBUSTION OF BLACK LIQUOR IN A RECOVERY BOILER

MODULE VII
SMELT DISSOLVING TANK SYSTEM

MODULE VIII
GENERAL OPERATING PRACTICES
INTRODUCTION TO INSTRUMENTATION

MODULE IX
EMERGENCY SHUTDOWN PROCEDURE AND INTRODUCTION TO BOILER INSPECTION

pro.5

893 McLean Avenue, Yonkers, New York 10704
Phone : 914-776-6697 Fax: 914-776-6698

SOODAKATTILAN NO_X-PÄÄSTÖJEN VÄHENTÄMISMAHDOLLISUUDET: KENTTÄKOKEIDEN VERTAILUA

K. Janka, A. Tamminen , T. Ruohola ja P. Siiskonen

Kvaerner Pulping Oy
Kelloportinkatu 1D
FIN-33101 Tampere,

ABSTRACT

Different kind of NO_x reduction methods applied to recovery boilers are compared. The methods are: air staging, SNCR, and the newly developed NO_x-scrubber. Results from various boilers indicates that air staging may yield 30% reduction. This can be achieved with practically no additional operating cost. Both SNCR and NO_x-scrubber can yield 60% reduction. In certain cases the investment cost of the NO_x-scrubber may be very low. The operating costs are typically reasonable. The scrubber method does not affect boiler operation and it can be easily combined with other NO_x reduction methods.

JOHDANTO

Soodakattilan NO_x-päästöt ovat alhaisia tyypillisiin voimakattilapäästöihin verrattuna. Syinä päästötason alhaisuuteen on polttoaineen vähäinen typpipitoisuus sekä tulipesän edulliset olosuhteet. Tulipesä on riittävän kylmä, jotta - ainakaan merkittäviä määriä - ilman molekylaaritypestä syntyvää nk. termistä NO_x:ia ei muodostu. Lisäksi suhteellisen pitkä kaasujen viipymäaika pelkistävässä vyöhykkeessä on edullinen NO_x-reduktion kannalta.

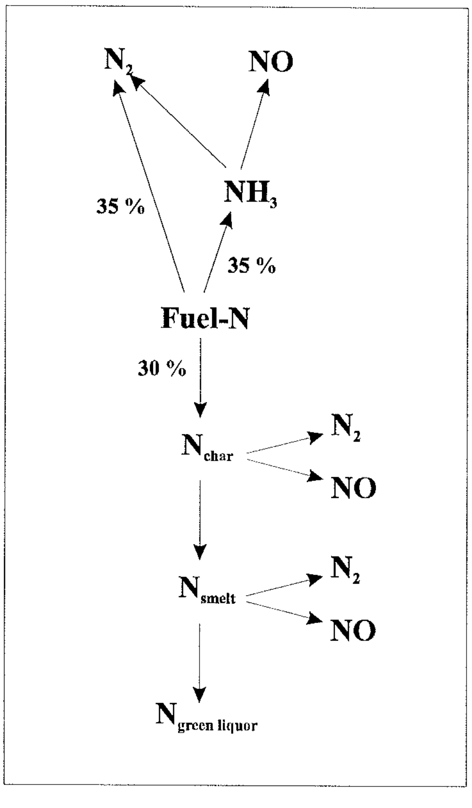
Huolimatta alhaisesta NO_x-pitoisuuksista, soodakattilan NO_x-rajat ovat kiristyneet. Syynä on soodakattiloiden suurista savukaasumääristä johtuva päästöjen paikallinen merkitys. Onkin yleisesti näkyvissä, että soodakattiloissa on sovellettava erilaisia NO_x-päästöjen alentamismenetelmiä.

Voimakattiloille yleisimmin sovellettavat NO_x-reduktiomenetelmät ovat: 1) erilaiset polttotekniset menetelmät, 2) selektiivinen katalyyttinen reduktio (SCR) sekä 3) selektiivinen, ei katalyyttinen reduktio (SNCR). SCR on näistä tehokkain. Soodakattiloille sen ei ole kuitenkaan katsottu soveltuvan, koska suuren alkalipölymäärän pelätään sekä tukkivan katalyyttikennot mekaanisesti että huonontavan katalyytin aktiivisuutta kemiallisesti. Lisäksi soodakattilan suuren savukaasumäärän edellyttämä katalyytilaitos on kallis.

Tässä esityksessä verrataan kenttäkokeiden tuloksia erilaisista soodakattiloille sovelletuista NO_x-reduktiomenetelmistä. Tarkasteltavat menetelmät ovat: ilmavaiheistus, SNCR-menetelmä ja äskettäin kehitetty NO_x-pesuri.

SOODAKATTILAN NO_x -MUODOSTUS

Kuten yllä mainittiin, soodakattilan tulipesän suhteellisen alhaisesta lämpötilasta johtuen polttoaine-NO_x:in oletetaan dominoivan NO_x-muodostusta. Mustalipeän typpipitoisuudet ovat tyypillisesti välillä 0,05 - 0,2 %. Åbo Akademi on tutkinut mustalipeäpisaran typpiyhdisteiden vapautumista tulipesäolosuhteita jäljittelevässä laboratoriouunissa. (Forssen et al. /1/). Kuva 1 esittää tulosta typpiyhdisteiden kulkureiteistä. Typpiyhdisteet vapautuvat pääasiassa ammoniakkina. Kokeiden mukaan n. 1/3 typestä joutuu NO_x-muodossa savukaasuihin, 1/3 muuntuu elementaaritypeksi N_2 ja loppu 1/3 jatkaa koksin mukana liuotussäiliöön. Lisätty viipymäaika ja suurempi lämpötila lisää tulipesään vapautuneen ammoniakin määrää.



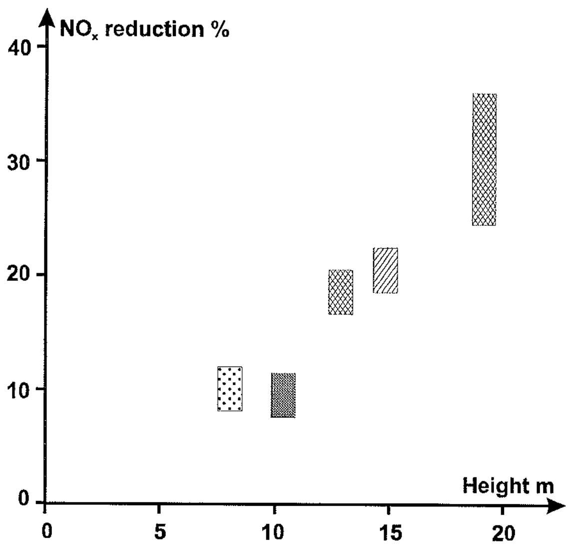
Kuva 1. Mustalipeän laboratoriopolttokokeissa havaitut mustalipeän typen kulkureitit (Forssen et al.)

Åbo Akademissa (Kilpinen et al. /2/) on niin ikään laskennallisesti tutkittu ilmanvaiheistuksen vaikutusta saavutettavaan NOx-tasoon. Laskennassa on oletettu, että NOx-muodostumiseen vaikuttavat reaktiot ovat kaasufaasissa tapahtuvia homogeenireaktioita, ja kussakin vaiheessa tuotava ilma sekoittuu tulipesän kaasuihin välittömästi. Laskelmat osoittavat, että syöttö 6 vaiheessa tuottaa lähes 50% pienemmän NOx-pitoisuuden kuin vertailukohtana ollut 3 vaiheinen syöttö. Lisäksi tuloksena on saatu, että alhainen lämpötila on edullinen NOx-reduktion kannalta. Eri tilanteiden erot ovat kuitenkin melko pieniä, verrattuna tyypillisiin voimakattiloilla saavutettaviin tuloksiin. Vaiheistuksen todellista merkitystä arvioitaessa, on vielä otettava huomioon että todellisessa soodakattilan tulipesässä tapahtuu jossakin määrin hitaasta sekoittumisesta johtuvaa jatkuvaa ilman vaiheistumista.

ILMAN VAIHEISTUS

Julkisesti raportoituja ilmavaiheistuskokeita NO_x-tason pudottamiseksi on tehty pohjoismaisilla soodakattiloilla v. 1991 lähtien. Periaatteena on viedä viimeinen osuus palamisilmaa tulipesän yläosaan neljänneltä (kvartiääri-) tasolta, jolloin tulipesän olosuhteet säilyvät pelkistävinä lähes koko tulipesän alueella. Kvaerner Pulping:lla on patentti ilman vaiheistuksen soveltamisesta soodakattilan NO_x-päästön alentamiseen /3/.

Vaiheistuksen teho NO_x-reduktioon riippuu, siitä paljonko viiveaikaa pelkistävässä vyöhykkeessä lisätään sekä siitä, kuinka pelkistävänä tämä pelkistysvyöhyke pidetään. Saavutettava viiveaika riippuu ylimmän ilmatason sijainnista, seka tietysti kattilan kuormasta. Ilmasuhteet puolestaan määräävät pelkistys/hapetustilan. Kuva 2 esittää yhteenvetoa eri kattiloilla saavutetuista NO_x-reduktiotuloksista, kun kvartiääri-ilmatason korkeus vaihtelee kattilakohtaisesti /4/. Kahden alimman korkeustason tapauksessa kvartiaari-ilma on syötetty kuormapolttimista. Riippuvuus korkeustasosta (viipymäajasta redusoivasssa vyöhykkeessä) on selvä.



Kuva 2. Kvartiäärirekisterin korkeussijainnin vaikutus NO_x-reduktioon. Korkeus on mitattu lipeäruiskujen tasolta /4/.

Yleinen käyttökokemuksiin pohjautuva käsitys on, että soodakattilankattilan kuormalla selvä vaikutus savukaasujen NO_x-pitoisuuteen. Kuorman alentaminen vähentää NO_x-pitoisuutta. Erääseen suureen nykyaikaiseen kattilaan asennettiin kvartiääri-ilmatasot 12 m ja 20 m korkeudelle lipeäruiskuihin nähden /5/. Muutoksen jälkeen ajettiin koeajot eri ilmasuhteilla ja kuormilla, siten että muuten noudatettiin mahdollisimman yhtenevää ajotapaa. Muutokset ilmanjaossa tehtiin muuttamalla tertiääri- ja kvartiääri-ilmojen suhdetta. Alimmilla kuormilla jouduttiin lisäksi hieman lisäämään alailmojen osuutta stabiilin ajon saavuttamiseksi. Kaikissa tapauksissa ilmasuhde pidettiin niin suurena, etta merkittäviä CO-päästöjä ei esiintynyt. Tulokset on esitetty taulukossa 1 /5/. NO_x-pitoisuudet on sovitettu kahden muuttujan lineaariseen funktioon (1) /5/, jossa muuttujina ovat suhteellinen kvartiääri-ilman syöttö ja suhteellinen kuorma.

$$C_{NOx} = C_0 + B \times q + A \times l \qquad (1)$$

missä:

C_{NOx}	=	NO_x -pitoisuus
q	=	suhteellinen kvartiäärisyöttö (verrattuna kokonaissyöttöön)
l	=	suhteellinen kuorma (vs. nimellinen maksimi),
C_0, B, A	=	sovitettavia vakioita

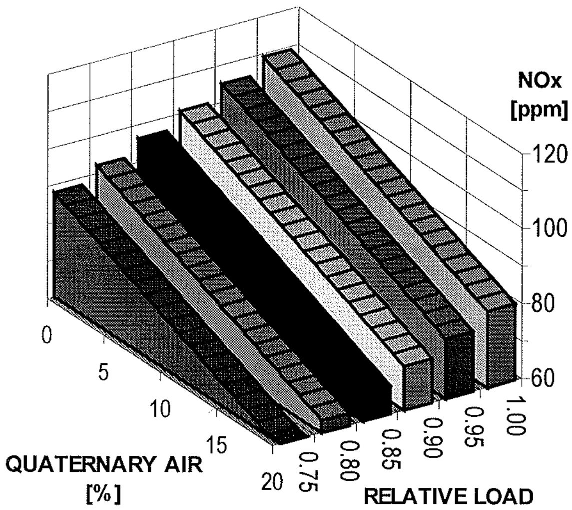
Taulukossa esiintyy 6. Sarakkeella parhaan sovituksen tuottavat NO_x-arvot, jotka on saatu vakioiden arvoilla: C_0 = 23.7 ppm , B = -143.8 ppm, A = 85.5 ppm.

Taulukko 1.

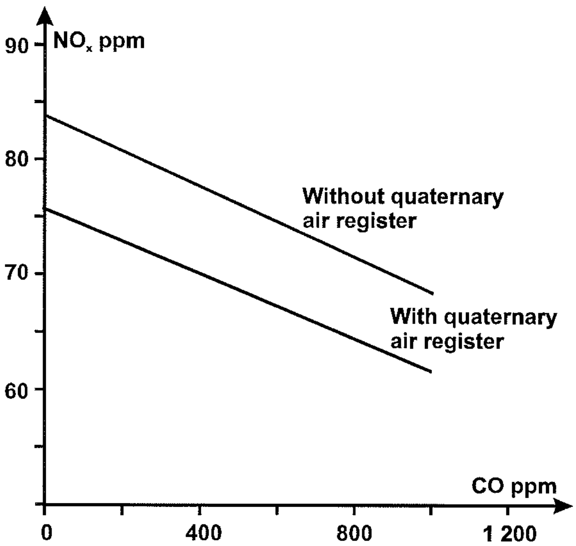
tertiar Air	quater. air	steam gener. kg/s	Relative load	NO_x [ppm] (3% O2) meas.	Fitted	differ.
25 %	0 %	108	0.90	100	100.6	0.6
22 %	0 %	97	0.81	95	92.8	-2.2
16 %	10 %	108	0.90	88	86.2	-1.8
10 %	14 %	114	0.95	85	84.8	-0.2
19 %	0 %	90	0.75	85	87.8	2.8
7 %	17 %	108	0.90	78	76.2	-1.8
6 %	20 %	120	1.00	78	80.4	2.4
5 %	20 %	100	0.83	66	66.2	0.2

Kuva 3 esittää sovitteen (1) mukaista NO_x-tason riippuvuutta kvartiääri-ilman määrästä ja kattilan kuormasta. Havaitaan, että 20% kvartiääri-ilma tuo n. 30% reduktion, ja kuorman pudotus 100% arvosta 75% arvoon n 20% reduktion. Vaikkakin tämä riippuvuus perustuu yhden kattilan ajoon, yhdellä lipeällä ja yhdellä ajotavalla, antaa se kuvan siitä, kuinka kuorma ja tertiääri-ilman määrä vaikuttaa NO_x-arvoihin. Sen sijaan sovitefunktion (1) vakioiden arvoja ei voida luonnollisestikaan yleistää.

Kokemukseen nojautuva yleinen käsitys on, että savukaasujen CO-pitoisuudet korreloivat NO_x-päästöjen kanssa määrätyllä kattilalla, niin että NO_x-päästöt vähenevät CO-päästöjen kasvaessa. Kuva 4 /4/ esittää mitattua riippuvuutta eräälle kattilalle kahdessa tapauksessa: kvartiääri-ilma käytössä ja pois käytöstä.



Kuva 3. Savukaasuujen NO_x-pitoisuuden riippuvuus kvartiääri-ilman määrästä ja kattilan kuormasta /5/.



Kuva 4. NO_x-päästöt CO-päästön funktiona kun kvartiääri-ilma on käytössä ja pois käytöstä /4/.

SNCR -MENETELMÄ

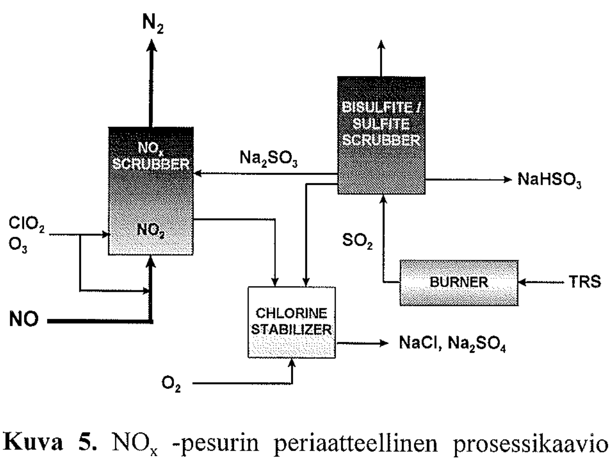
SNCR (Selective Non Catalytic Reduction) perustuu sellaisen kemikaalin käyttöön, joka reagoi NO:n ja/tai NO_2:n kanssa tulipesässä, niin että tuloksena syntyy molekylaarityppeä N_2. Kemikaaleina voidaan käyttää ammoniakkia NH_3 tai ureaa $(NH_2)_2CO$ /6/. Reagenssi syötetään tulipesään paikkaan, jossa on optimilämpötila. Mikäli lämpötila nousee liian korkeaksi, reduktioteho laskee, mikäli se laskee liian alhaiseksi, osa ammoniakista jää reagoimatta aiheuttaen ammoniakkipäästön.

Savukaasuissa ammoniakki voi reagoida lentotuhkan ja kerrostumien kanssa. Tuloksena syntyy mahdollisia tukkeutuma ja korroosio-ongelmia aiheuttavia ammoniumsuoloja.

Soodakattilakokeissa on saavutettu n. 60% NO_x-reduktio urean ja lämpötilaikkunaa leventävän lisäaineen käytölle perustuvassa $NO_xOUT^{®}$ prosessissa. Kokeissa savukaasujen ammoniakkipäästö pysyi 10 ppm tason alapuolella.

NO_x -PESURI

Kvaerner Chemetics:in kehittämä NO_x-pesuri perustuu NO:n hapettamiseen paremmin liukoiseksi NO_2:ksi, ja hapetusvaiheen jälkeen syntyneen NO_2:en pelkistymiseen molekylaaritypeksi N_2 /5/. Kuva 5 /5/ esittää prosessin periaatetta. Hapetuskemikaali syötetään pesuriliuokseen tai savukaasuihin ennen pesuria. Klooridioksidi ClO_2 toimii tehokkaana hapettimena. Toinen vaihtoehto on otsoni. Pelkistyskemikaalina käytetään natriumhydroksidiliuoksessa olevaa natriumsulfiittia Na_2SO_3. Hapettimen valinnan sanelee käytännössä tehtaan muu kemikaalitarve. Klooridioksidivalkaisua käyttävässä tehtaassa on klooridioksidi luonnollinen ratkaisu, ja vastaavasti otsonivalkaisun tapauksessa otsoni. Sen käyttö ei ole kuitenkaan aivan yhtä taloudellista kuin klooridioksidin.

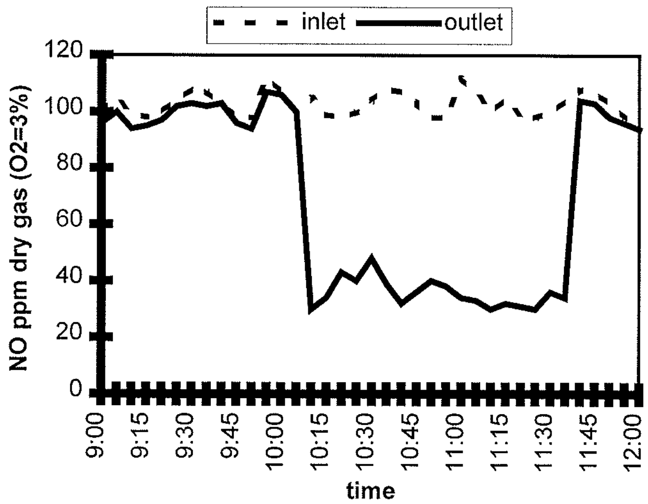


Kuva 5. NO_x -pesurin periaatteellinen prosessikaavio /5/.

Pilot-kokeet ovat osoittaneet täytekappalepesurin toimivan venturipesuria paremmin. Korrodoivan klooridioksidin käyttö edellyttää korroosiokestoisten (esim. lujitemuovi) rakenteiden käyttöä. Kehitetty NO_x-pesuriteknologia suojattu patenttihakemuksilla /7/ eri maissa.

NO_x-pesurin suorituskyky on demonstroitu pilot- ja täydessä mittakaavassa. Kuva 6 esittää täyden mittakaavan pesurikokeessa saatua tulosta. NO_x-poistotehokkuudeksi saatiin 66% määriteltyinä eroina kahden tilanteen välillä: ClO_2 syöttö päällä ja pois.

NO_x-pesurin investointikulut riippuvat ratkaisevasti siitä, millainen savukaasupesuri ja väkevien hajukaasujen käsittelyjärjestelmä tehtaalla on. Mikäli tehtaalla on lujitemuovinen savukaasupesuri ja natriumsulfiittia tuottava hajukaasujen käsittelyjärjestelmä, ovat investointikulut minimaaliset. Käyttökulut riippuvat tehtaan sisäisestä ClO_2:n tuotantokuluista ja ovat tyypillisesti verrattavissa SNCR järjestelmän reagenssikuluihin.



Kuva 6. Klooridioksidin syötön vaikutus pesurista poisuvan kaasun NO_x-pitoisuuteen /5/.

YHTEENVETO

Ilmanvaiheistus on taloudellinen ja ongelmaton menetelmä NO_x-päästöjen pienentämiseksi, mikäli sillä saavutettava n. 30% pudotus on riittävä. Varsinaisia käyttökuluja ei sillä ole. Investointikulu on pieni, etenkin uuden kattilan tapuksessa.

SNCR-menetelmä tarjoaa tehokkaamman menetelmän aina 60% vähennykseen asti. Reagenssin varastointi, syöttö- ja säätöjärjestelmä vaatii kuitenkin huomattavat investointikulut. Reagenssin kulutus aiheuttaa pääasialliset käyttökulut. Tarkkoja kustannuksia ei ole kuitenkaan missään julkaistu. Menetelmä on ilmeisen kriittinen ammoniakkisyöttösuuttimien asennukselle ja kattilan ajolle reaktion kapeasta lämpötilaikkunasta johtuen. Ammoniakkipäästöjen pitäminen riittävän alhaisena on tärkeää, paitsi päästörajoista johtuen, myös ammoniumsuoloista syntyvien mahdollisten kattilan käytettävyysongelmien takia.

NO_x-pesuri on monessa tapauksessa kilpailukykyinen vaihtoehto, kun tarvitaan sellaista NO_x-poistotehoa, johon ilmanvaiheistuksella ei voi päästä. Tietyissä tapauksissa sen investointikulut voivat olla erittäin pienet. Merkittävä etu on, että sillä ei ole mitään vaikutusta kattilan käyttöön tai käytettävyyteen. Se voidaan helposti myös yhdistää muiden NO_x-poistomenetelmien kanssa.

VIITTEET:

1. Forssen, M., Hupa, M., Hellström P. and Martin, D., "NO Release During Black Liquor Char Combustion and Gasification ", *Proceedings of the 1995 International Chemical Recovery Conference, Toronto, Canada, 24-27 April.* B231-B239 (1995).

2. Kilpinen, P. et al. "Nitrogen Chemistryi in Black Liquor Combustion ", Year Book part 2 of LIEKKI2-Research Program 1996, ed.. Hupa, M. and Matinlinna, J., Åbo 1996, 767 - 801.

3. Pat. SE 468171, US 5454908

4. Larsson, A. and Olausson. L., "A Fourth Air Register - Lower NO_x", Proceedings of *"Soodahuskonferenssen 1992" , Stocholm, Sweden, November, 26., 1992,* (1992).

5. Janka, K., Ruohola, T., Siiskonen, P. and Tamminen, A. , "Comparison of recovery boiler field experiments on NO_x reduction methods", *Proceedings of the TAPPI Engineering Conference, Nashville, TN, October 5-9, 1997.* (1997).

6. Lövblad, R., Moberg, G., Olausson, L. And Boström, C., "NO_x Reduction from a Recovery Boiler by Injection of an Enhanced Urea Solution (NOxOUT® Process)", *Proceedings of the TAPPI Environmental Conference, San Antonio, Texas, April 7-10, 1991.* (1991).

7. Pat. app. FI 944344, US 08/510,815

On-line Recovery Boiler Dust Analyzer (RBD-Analyzer)

Tarja Tamminen *
Juha Enroth **
Jan Landkammer*
Juha Tikkanen*
Jorma Keskinen **

* Dekati Ltd. Papinkatu 14-16, FIN-33200 Tampere, FINLAND
** Tampere University of Technology, Department of Physics, Box. 692, FIN- 33101 Tampere, FINLAND

ABSTRACT

Fouling and plugging of the recovery boilers have recently been under intensive research work. It has been found out that some non-process elements, such as potassium and chlorine, effect the melting behaviour of the flue gas dust. They also tend to enrich into the fly ash when using more closed cycles in pulp mills. An on-line dust analyzer has been developed for better process control of recycled dust and even for prediction of boiler fouling. The instrument is named Recovery Boiler Dust Analyzer (RBD-analyzer). The schematic picture of the analyzer is shown in Fig.1.

The analyzer prototype has been tested in kraft recovery boiler conditions in a Finnish pulp mill during 1997. The sampling point was upstream from an electrostatic precipitator (ESP) where the flue gas temperature was +160 °C. An example of measured time variation of total dust concentration and potassium and chlorine contents of the dust is shown in Fig. 2. Fluctuations in total dust concentration caused by soot blowing can be seen (Fig.3). Comparison measurements have been done in parallel with standard off-line techniques and laboratory analyses. Results of preliminary comparisons have been collected to Table 1, Table 2 and Table 3.

The basic concept of the sampling probe operation and analyzer construction has been validated in the measurements this far. Preliminary comparison results show reasonable agreement between RBD-analyzer and standard sampling methods, but further comparison is clearly necessary for assessing the new instrument in different conditions.

Possible applications of the instrument include arrangement of better process control of recycled dust by measurement of the dust on-line and simultaneously before and after ESP. Real time information of the concentration of non-process elements is valuable when predicting fouling and plugging conditions of a boiler. The analyzer can be used also in other parts of the chemical cycle of a pulp mill to measure non-process elements and their behavior and possible enrichment.

Sooda-analysaattori (RBD-Analyzer)

Johdanto

Soodakattilan likaantumisongelmia ja siihen vaikuttavia tekijöitä on tutkittu viime vuosina voimakkaasti myös Suomessa mm. Liekki 2-ohjelman piirissä. Tällä hetkellä tiedetään, että tiettyjen alkuaineiden, kuten kaliumin ja kloorin esiintyminen lentotuhkassa laskee tuhkan sulamislämpötilaa ja voi lisätä tuhkan takertumista kattilan keittoputkipinnoille ja muihin savukaasukanavan kylmenpiin osiin. Sellutehtaiden kemikaali- ja vesikiertojen sulkeutuminen tulee lisäämään kaliumin ja kloorin rikastumista kemikaalikierrossa soodakattilan lentotuhkaan, mikä voi lisätä kattilan tukkeutumisherkkyyttä ja myös korroosiota. Toisaalta kiertojen sulkeutuminen luo paineita kehittää ja ottaa käyttöön ns. vierasaineiden poistoprosesseja, joissa hallitusti poistetaan kierrosta mm. kaliumia ja klooria.

Sooda-analysaattori (Recovery Boiler Dust Analyzer) on kehitetty soodakattilan pölyn määrän ja koostumuksen on-line monitorointiin. Analysaattori mittaa jatkuvatoimisesti savukaasun Na-, K- ja Cl-pitoisuutta laskien kokonaispölypitoisuuden (g/Nm^3) ja vierasaineiden massaosuudet lentotuhkassa (K, Cl wt %).

Analysaattorin toimintaperiaate

Savukaasunäyte imetään isokineettisesti savukaasukanavasta sondiin, jossa savukaasun sisältämä pöly liuotetaan ionivaihdettuun veteen. Savukaasunäytteen vesiliukoiset suolat liukenevat näytteenottolinjassa täydellisesti veteen ennen analysaattoria. Kaasu-vesiseoksesta erotetaan analysaattorissa kaasu ja sen määrä mitataan. Näytevesi johdetaan ioniselektiivisille elektrodeille (ISE), joiden avulla määritetään natrium-, kalium- ja kloridi-ionien konsentraatiot näytevirtauksessa.

Laitteessa on oma sisäinen PC, joka laskee halutut suureet analyysituloksista. Analysaattori antaa tuloksiksi savukaasun kokonaispölypitoisuuden (mg/Nm^3), joka on natriumpitoisuuden funktio sekä pölyn kaliumin ja kloorin massaosuudet painoprosentteina (wt %). Analysaattori voidaan asentaa kiinteästi soodakattilalaitokselle, jolloin se liitetään laitoksen prosessivalvonnan tiedonkeruujärjestelmään (virta- tai jänniteviestit).

Laite on varsin nopea, mikä mahdollistaa nopean reagoinnin prosessiolosuhteiden muuttuessa. Laiteen toiminta on automatisoitu vaatien huoltoa keskimäärin kahden viikon välein. Huoltoväli riippuu kalibrointi- ja referenssiliuosten kulutuksesta. Huoltoväliä on mahdollista kasvattaa, jos laitteen toimintaa jaksotetaan.

Erikoisrakenteensa ansiosta näytteenottosondi pystyy toimimaan tukkeutumatta vaikeissa soodakattilaolosuhteissa pitkiä aikoja. Sondin toiminta on varmistettu myös tukkeutumien varalta automaattisella puhdistuksella.

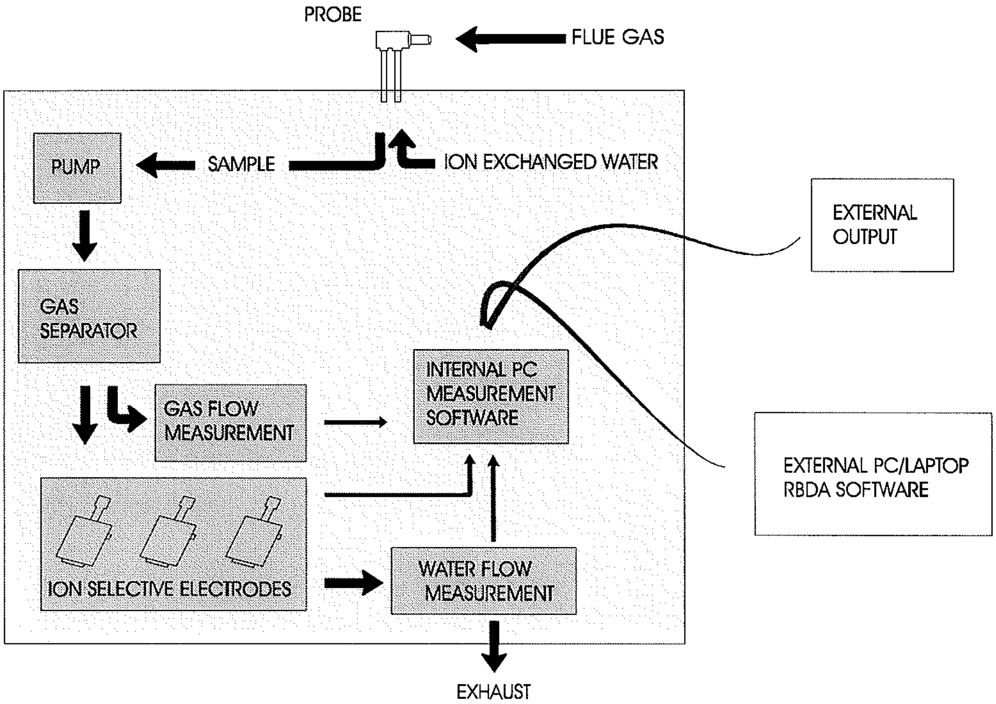


Figure 1. Schematic picture of recovery boiler dust analyzer.

Mittaukset soodakattilalla – laitteen validointi

RBD-analysaattorin prototyyppiä on testattu Metsä-Botnian Kaskisten tehtaalla useaan otteeseen kesän –97 aikana. Mittaukset tehtiin savukaasukanavasta ennen sähkösuodatinta, jossa savukaasun lämpötila on noin 160 °C. Kuvassa 2. on esimerkki analysaattorin antamasta datasta ajan funktiona. Pitkän aikavälin mittauksissa on kokonaispölypitoisuuksissa havaittavissa kattilan keittopintojen ja ekonomaiserin nuohoimien aiheuttamat nuohouspiikit (Kuva 3.).

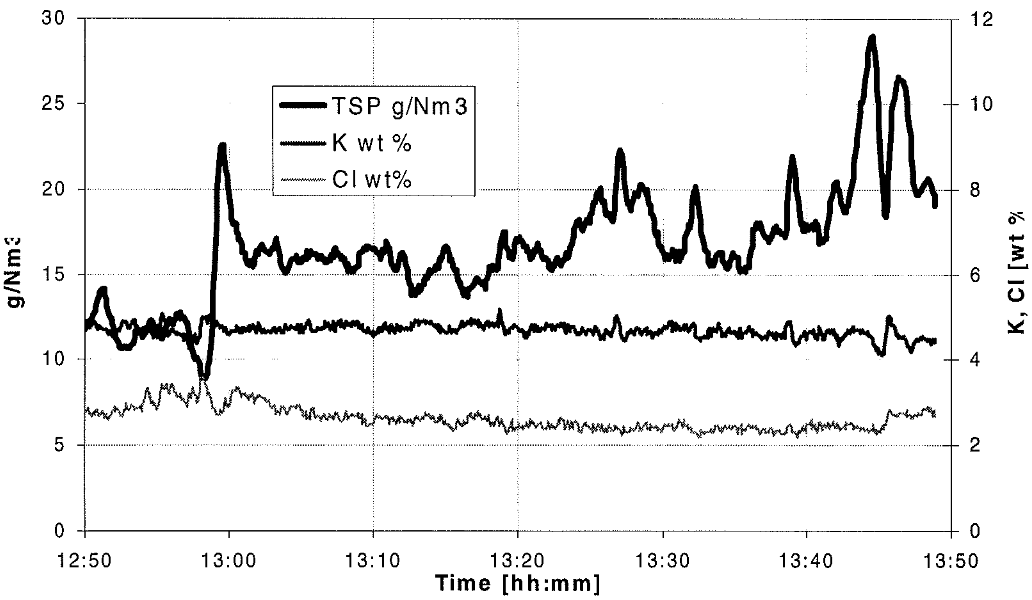


Figure 2. An example of total dust concentration (TSP) and potassium and chlorine concentrations in dust from recovery boiler flue gas measured with RBD-analyzer.

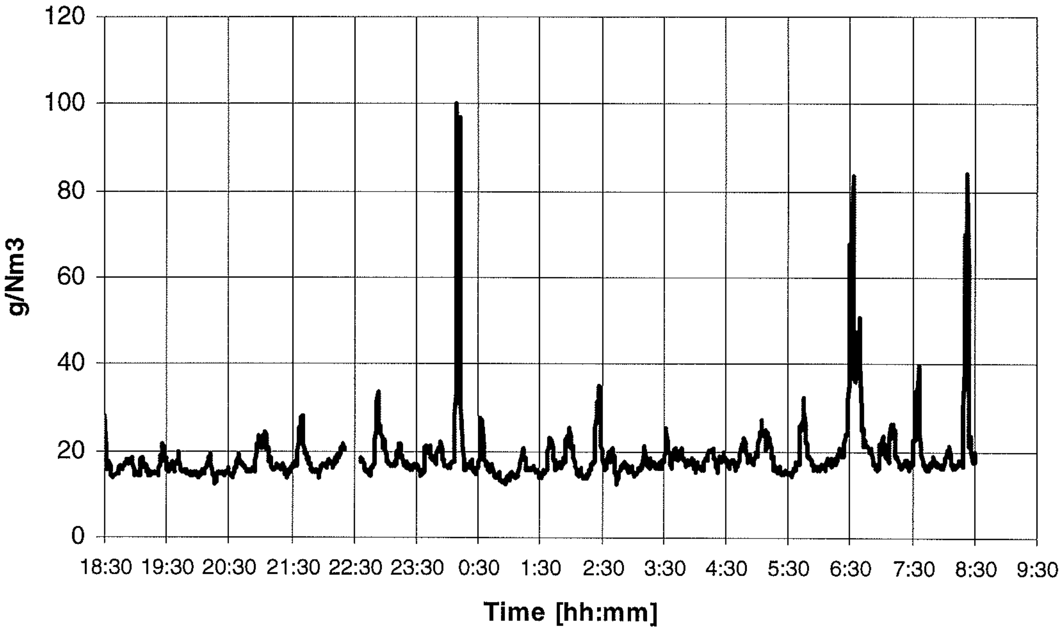


Figure 3. Total dust concentration (g/Nm^3) upstream from an ESP measured with RBD-analyzer over night (6:30 pm – 8:30 am). Average TSP concentration over the whole period was 18.9 g/Nm^3.

Samanaikaisesti analysaattorin tehtyjen mittausten kanssa otettiin rinnakkaisia kokonaispölynäytteitä off-line menetelmällä standardia SFS 3866 soveltaen. RBD-analysaattorilla mitattu kokonaispölypitoisuus korreloi hyvin standardimittausten kanssa. Vertailumittausten tulokset on esitetty taulukossa 1.

Table 1. Comparison of on-line and off-line measurements of total dust concentration before ESP.

	On-line RBD-analyzer Total dust conc. (g/Nm^3)	Standard off-line sampling method (SFS 3866) Total dust conc. (g/Nm^3)
21/05/97 17:02-17:12	20	20
22/05/97 9:32-9:38	25	21
14/06/97 10:47-10:56	20	20
14/06/97 13:40-13:45	23	21

Kaliumin ja kloorin massaosuustulosten varmistamiseksi sähkösuodintuhkasta otettiin näytteitä mittauspäivien aikana ja ne analysoitettiin laboratoriossa[1]. RBD-analysaattorilla määritettyjä kaliumin ja kloorin massaosuuksia lentotuhkassa verrattiin laboratoriotuloksiin. Taulukossa 2. esitetyistä tuloksista voidaan havaita poikkeamia laboratorioanalyysien ja RBD-analysaattorin antamien tulosten välillä.

[1] Keskuslaboratorio Oy KCL / Outokumpu Research Oy, Pori

Tämä johtuu pääasiassa ensimmäisen prototyypin näytevirtauksen lämpötilan vaeltamisesta kanavan ja ulkoilman lämpötilan mukana sekä kaasuvirtauksen mittauksen epätarkkuudesta. Nämä ongelmat on korjattu uudessa laiteversiossa. RBD-analysaattorin mittaaman kloorin massaosuuden poikkeamaa laboratorioanalyysistä lisää savukaasun sisältämä kloorivety (HCl), joka liukenee analysaattorin ionivaihdettuun veteen nostaen kokonaiskloridipitoisuutta.

Table 2. Comparison of ESP dust composition analyzed with the RBD analyzer and standard laboratory analyses.

	RBD-analyzer	Laboratory analyses	
14/06/97			
K wt %	4,7	4,7	4,8
Cl wt %	2,6	2,1	2,1
03/09/97			
K wt %	4,6	3,5	
Cl wt %	1,6	2,0	
04/09/97			
K wt %	4,9	3,6	
Cl wt %	3,2	2,4	
05/09/97			
K wt %	4,5	4,0	
Cl wt %	3,1	2,3	

Mittausten aikana havaittiin myös, että tehtaan ionivaihdettu vesi, jota käytetään analysaattorin näytelinjassa, sisälsi sellaisia määriä natriumia ja kloridia, että ns. nollakorjaus on paikallaan. 0-veden pitoisuudet vähennetään automaattisesti analyysituloksista ennen tulosten laskentaa. 0-korjaus voidaan myös välttää, jos kalibrointiliuokset tehdään tehtaan veteen. Tällöin tehdasveden tulisi olla tasalaatuista.

Tehdasmittauksissa RBD-analysaattorin näytelinjasta otettiin myös vesinäytteitä, jotka analysoitettiin laboratoriossa[2]. Tuloksia verrattiin laitteen antamaan keskimääräiseen pitoisuuteen näytteenkeräysaikana. Tulokset on esitetty taulukossa 3. Nämä mittaukset osoittavat, että analysaattorin näyttämä korreloi laboratoriotuloksiin natriumpitoisuuden osalta ± 3 %:n tarkkuudella. Kaliumin ja kloridin korrelaatio laboratoriotuloksiin nähden oli hieman heikompi. Yleensä analysaattorin antamat kaliumin ja kloridin pitoisuudet olivat suurempia kuin laboratorioanalyysien tulokset, ollen suurimmillaan noin + 20 %:a. Nämä erot saadaan jatkossa pienenemään laitteen kalibrointimenetelmän ja lämpötilakontrollin automatisoinnilla.

[2] Keskuslaboratorio Oy KCL / Outokumpu Research Oy, Pori
Menetelmät: K – FAAS-menetelmä; Cl – potentiometrinen $AgNO_3$-titraus

Table 3. Comparison of RBD-analyzer readings and results from laboratory analyses. Laboratory water samples were taken from the overflow of the analyzer.

	RBD-analyzer	Laboratory analyses
14.6.1997 13:10-13:30		
Na g/l	355	374
K g/l	51	55,8
Cl g/l	40	35,4
3.9.1997 14:43-14:50		
Na g/l	322	325
K g/l	45,4	41
Cl g/l	39,6	44
3.9.1997 17:15-17:20		
Na g/l	407,4	395
K g/l	56,3	46
Cl g/l	45,5	48
3.9.1997 0-water		
Na g/l	45	45
K g/l	4	3,5
Cl g/l	26	21
5.9.1997 10:09-10:14		
Na g/l	408,6	405
K g/l	54,8	54
Cl g/l	62,7	53

Johtopäätökset ja tulevaisuuden haasteet

Analysaattorin ja näytteenottosondin toimivuus vaikeissa soodakattilaolosuhteissa on todennettu pääpiirteittäin kesän 1997 mittauksissa. Alustavat vertailumittaukset osoittavat laitteen näyttämän kohtuullista korrelaatiota standardimittausten ja laboratorioanalyysien kanssa. Kokonaispölymittausten osalta korrelaatiota voidaan pitää jopa erinomaisena. Kaliumin ja kloorin osalta laite kaipaa vielä viimeistelyä.

Ennen vuoden loppua analysaattori on tarkoitus modifioida siten, että savukaasun kokonaispölypitoisuus on mahdollista mitata jatkuvatoimisesti ja reaaliajassa sähkösuotimen jälkeen. Myös kierrosta poistuvan kloorin määrä (HCl-pitoisuus savukaasussa) sähkösuotimen jälkeen on mahdollista mitata tällä analysaattorilla.

RBD-analysaattori parantaa soodakattilan prosessikontrollia kiertävän pölyn ja hiukkasemissioiden osalta. Jatkossa analysaattorin avulla pyritään ennustamaan myös mahdollista kattilan likaantumiskäyttäytymistä. Tulevaisuudessa laitteella on käyttöä vierasaineiden poistoprosessien reaaliaikaisessa monitoroinnissa.

Laitteen kehitystyössä Dekati Oy on siinä vaiheessa, että tavoitteena on laitteen pitkäaikainen testaus soodakattilaolosuhteissa. Tavoitteena on myös löytää korrelaatio analysaattorin näyttämän ja kattilan likaantumiskäyttäytymisen välille, jolloin mahdolliseen tukkeutumistilanteeseen voidaan puuttua hyvissä ajoin.

Yhteistyökumppanit

Laitteen tuotekehitystyö Dekati Oy:ssa aloitettiin vuoden 96 lokakuussa. Pohjana kehitystyölle oli Tampella Powerin 1980-luvulla soodakattilan kehitystyön tueksi kehittämä soodakattilan kokonaispölypitoisuuden reaaliaikainen analysaattori.

Tampereen teknillisen korkeakoulun fysiikan laitoksella on yhteishanke Dekati Oy:n kanssa Liekki 2-tutkimusohjelmassa. Hankeessa " Soodakattilan pölyn koostumuksen reaaliaikainen monitorointi", TTKK verifioi sooda-analysaattorin toimintaa.

Metsä-Botnian Kaskisten tehtailla analysaattorin prototyyppiä on testattu useaan otteeseen todellisissa kattilaolosuhteissa.

Kesäkuussa –97 tehdyt mittaukset toteutettiin osana suurempaa mittauskokonaisuutta, jolloin Liekki 2-tutkimusohjelman kolmen erilaisen hankkeen (ÅA, TTK ja TTKK) mittaukset toteutettiin samanaikaisesti Metsä-Botnian Kaskisten tehtailla.

REVIEW OF THE
AMERICAN FOREST & PAPER ASSOCIATION
RECOVERY BOILER PROGRAM

By
Thomas J. Grant
American Forest & Paper Association
New York, New York

October 22, 1997
Finnish Recovery Boiler Committee
Helsinki, Finland

REVIEW OF THE
AMERICAN FOREST & PAPER ASSOCIATION
RECOVERY BOILER PROGRAM

Abstract

The AF&PA Recovery Boiler Program continues to strive for the safe and reliable operation of recovery boilers. Training, maintenance and supervision are required to accomplish this task, The AF&PA Program has developed an industry-wide safety audit program, updated its reference manuals, its training program and its guidelines for the safe operation of recovery boilers. The subcommittees continue sponsoring seminars, overseeing research projects, reviewing their guidelines, and coordinating efforts with BLRBAC and TAPPI.

On behalf of the American Forest & Paper Association's Recovery Boiler Program, I bring greetings to the Finnish Recovery Boiler Committee and my friends here, especially Tuomas Timenen. It is indeed a pleasure to be here in your country again. I must thank the Committee and Risto Paldanius for inviting me to present a review on the recovery boiler activities in the U.S.

To give you a little background of the AF&PA, it was formed in 1993 when the American Paper Institute (API) merged with the National Forest Products Association (NFPA) and the American Forest Council (AFC). API was made up of pulp, paper and paperboard manufacturers, NFPA's membership was from the sawmills and lumber mill owners, and AFC were the forest landowners. Now we have the forest owners and producers, and membership is approximately 700 companies - from small sawmill operators to large companies producing pulp, paper and lumber for building homes. The main function of the trade association is lobbying for the industry's interests and concerns for regulations affecting the daily operations of the companies.

The AF&PA Recovery Boiler Program was formed in 1974 for the purpose of bringing together all U.S. companies operating recovery boilers, to improve procedures and guidelines for the safe operation of recovery boilers. Currently, 41 companies operate 216 boilers in 130 mills in the United States. (34 of the 36 AF&PA member companies participate in the Program.) When we look at chart 1, we can see almost a 40 year history of recovery boiler explosions in the U.S. in five year spans, along with the days of outage, since the 1958 period. The companies decided collectively to reduce those explosions by combined efforts of exchanging techniques and practices for improving safety and efficiency of the recovery boilers. Looking at charts 2 and 3, one can see the impact the AF&PA Program had in helping reduce these upsets. We did not have an explosion from early 1993 until mid-1996 and none since that time. As you can see we were averaging better than 3 explosions a year in the 1970's and 1980's

The companies realized at that time, and at present, that the recovery boiler continues to be the largest single investment in a pulp mill - often exceeding $100 million. Over 40% of all the energy used in the U.S. pulp and paper industry is produced from the black liquor. The combustion of the black liquor is equivalent to about 200 million barrels of oil and at today's prices, is valued at over $4 billion.

The goal of the Program continues to be to improve the operation, maintenance, safety and efficiency of recovery boilers. Three subcommittees were established - and continue in existence today - to handle various areas in achieving the Program's goal. These three subcommittees are as follows:

- Research and Development
- Operation and Maintenance
- Organization and Training.

Membership in each subcommittee consists of company representatives who are involved in day-by-day concerns of their respective areas related to recovery boilers. A list of publications produced by the committees is shown in Chart 4.

While it is clear that a great deal of progress has been made, the subcommittees and members realize that there are still things that we do not know about operating recovery boilers, in addition to other things to be done to reduce serious operator errors. Training programs, operational safety seminars and maintenance guidelines reflect the greater awareness of the human factor in achieving the specified objectives of the AF&PA Recovery Boiler Program and the safe and reliable operations of recovery boilers.

The Operation and Maintenance Subcommittee realized in the early years of the Program that there was need to publish information that could be useful to the operators. The Subcommittee developed the Recovery Boiler Reference Manuals, and has since updated and revised them to include the most up-to-date practices and procedures. Volume I consists of "Inspection and Nondestructive Testing." Volume II includes "Maintenance and Repair Analysis, and Repair Guidelines and Practices," Volume III provides "Operational Effects and the Case History Descriptions." This subcommittee also wrote the publication for safety audit guidelines which was developed as a comprehensive and generic system of auditing so that each mill may regularly evaluate the overall safety and reliability of the boiler operations. The subcommittee also produced guidelines and checklists for new boilers. The subcommittee developed these guidelines and checklists, based on past and current boiler failures and associated operating problems and through discussions with industry operating personnel, equipment manufacturers, and construction personnel. This document is not intended to serve as a complete boiler specification but can serve as a checklist of major topics and items to be resolved by the manufacturer and the user during boiler specification and proposal discussions.

To further improve the safe operation of the boilers, the subcommittee sponsored a seminar in 1985 for boiler superintendents which pointed out the need for training, maintenance and other concerns of operation. Since that time, we have sponsored three operational safety seminars a year for operators, superintendents and maintenance personnel which have proven most successful. In 1996, we had 150 attend the seminars and in 1997, we had 145 attend. These seminars are considered most helpful and informative by providing both formal and informal open forums for the discussion of problems and situations in the safe and reliable operation of recovery boilers. We also coordinated with the Black Liquor Recovery Boiler Advisory Committee (BLRBAC) to sponsor seminars for maintenance and operation of boilers. In 1994, we had 285 attend a Maintenance Seminar. With the increased concern of cracking and/or corrosion of tubes in the lower furnace, the Subcommittee sponsored a seminar with BLRBAC last year which was attended by over 300 people from all sides, operators, manufacturers and suppliers of the recovery boiler equipment. The purpose of this seminar was to further enhance the development and knowledge of those people involved in corrosion control of recovery boilers. It stressed the need for corrosion prevention. Although there were different perspectives on what is causing this problem, it made the operators aware of the need and methods for a solution. I will talk a little further on corrosion when I get to the R&D Subcommittee. The next joint seminar planned is for young and/or new engineers to the recovery boiler operations. The objective is to make them more aware of the unique situations in this area.

The Organization and Training Subcommittee has been most active in producing a major training program of lessons and audio visual tapes for operators. That program has recently been put aside for a more modern and comprehensive program which includes up-to-date practices and procedures.

The James River Company developed a very comprehensive training program in 1988 and in 1993 gave it to the industry through AF&PA. After reviewing it, the Organization and Training Subcommittee revised and updated the program so that it would be generic. It was developed to provide training for personnel involved in operating recovery boilers and designed to cover all processes for the safe and efficient operation of recovery boilers. The intend was for the use by operators, supervisors, technical support personnel and anyone else who needs to understand the workings of the recovery process. It is organized into nine modules with specific areas of operation - as we can see from chart 5. For each module, there is a Technical Manual for use of the "students" and an Instructor Guide for aiding the instructors in presenting the material. The information is meant to be generically applicable to all operating Tomlinson-type kraft black liquor recovery boilers, regardless of age or manufacturer. There are nearly 1,300 pages of text and hundreds of illustrations and diagrams in the Technical Manual and almost 1,400 pages of text, 315 overhead transparencies, and 380 handout sheets modified for classroom use.

The Recovery Boiler Tutor was also developed by this subcommittee through the J. H. Jansen Company. The RBT is a computerized recovery boiler simulator and tutor designed to teach safe and efficient operation for black liquor recovery boilers. It allows operators to control a dynamic interactive model of a kraft recovery boiler and provides a combination of artificial intelligence and process simulation on a personal computer for operator training. The RBT was developed to help improve operator's confidence and competence, particularly during problem situations. Operators may simulate operating problems, upset conditions and emergency situations, and then take appropriate action to resolve them. It acts as a "coach" explaining the full range of operation variables answering questions and providing advice - nearly 100 U.S, Canadian and Brazilian mills have installed the RBT.

The Research and Development Subcommittee has done its share of work for the Program with its many research projects over the years and by publishing a book to bring together disparate pieces of research into a single integrated, coherent portrayal of the recovery boiler research. From this, the subcommittee developed a training module for those who wish to use the material in whole or in units to convey the principles of recovery boiler operation to operators, superintendents, managers, engineers and students. More recently, as part of its ongoing effort to transfer the wealth of information on recovery boilers to the practitioner in the field, the Subcommittee published another textbook, "**KRAFT RECOVERY BOILERS**." It is primarily intended for people who work every day in pulp and paper mills as a reference textbook on recovery boilers. The target audience is made up of the engineering, technical, and supervisory staff at mills, but the book contains enough breadth and depth to satisfy the non-specialist designer, consultant, student, and researcher. Strong emphasis was placed on producing a book with a lot of the typical values, practical examples, and clear diagrams of equipment and processes.

The Expert Advisory System is another project that the subcommittee has developed with Stone & Webster Engineering. This is a multiple alarm situation system for recovery boiler operations. The system consists of an artificial intelligence system that embodies the experience and judgmental decision-making capabilities of recognized human experts in the safe operation of recovery boilers. This system provides guidance to operators in situations involving multiple alarms from the control system, complex problems in the mill and unusual circumstances which normally require independent judgment and experience. The system has been installed in several mills, in addition to a test-site mill and has produced very good reports in detecting leaks. Companies have been advised to look at the possible use of various leak detection systems in their mills so that there is at least on system in place.

The R&D Subcommittee is in a multiple phase research project with the ultimate goal to develop effective field corrosion monitoring methods and procedures for testing for corrosion in the lower furnace. An extensive database is being developed aimed at three promising technologies: electrical resistance, electrochemical probe, and thin layer activation technology. The Technical Advisory Group is working closely with the Institute of Paper Science and Technology (IPST) and the Pulp and Paper Research Institute of Canada (PPRICAN) in moving toward the next stage in developing a real time probe for monitoring corrosion

The subcommittee also monitors recovery boiler explosions and incidents in the recovery boilers through the services of Dr. Dave Clay. (Formerly Dr. Tom Grace handled this until his retirement earlier this year.) We also work closely with BLRBAC in this area as well as in the development of guidelines for the safe operation of the boilers.

Another major project involving the R&D Subcommittee was the recently completed kraft recovery modeling study at the University of British Columbia, the Institute of Paper Science and Technology with the guidance and support of Dr. Grace, Abo Akademi, major boiler manufacturers and other noted researchers. The purpose of the project was to develop modeling capability for kraft recovery boilers that can be used to extend recovery boiler design or operating variables. Such a model could serve as a basis for changes in recovery boiler designs and operating practices leading to improved safety and reliability, greater capacity utilization, more effective emission control and greater energy efficiency. Reports show great strides were made. Final reports on the codes that can be used in modeling have not been published at the time of this writing but are expected to be available later this year.

The Subcommittee is looking into a study for bed cooling following an Emergency Shutdown Procedure (ESP). This study is just about to begin. Companies have been advised to discontinue using a spray mist system for bed cooling.

I hope this presentation of the AF&PA Recovery Boiler Program has given you a better idea of what we are doing and our efforts to meet the objective of operating recovery boiler more safely and efficiently. The U.S. pulp and paper industry is working toward another record year of production - not necessarily a record year of income.

At our annual meetings and conference held in this past February, we had manufacturers present their perspectives on the latest design/operating breakthroughs. In addition, the attendees learned of the strides made in black liquor gasification technologies' areas and the features of four active developments and the process each uses - Chemrec, Noell/Bechtel, ABB and MTCI. It was pointed out that some of the factors motivating gasification are: need to affordable incremental capacity; increasing dependence on electrical power; changing environmental regulations; reduced capital cost and aging recovery boilers, to name a few.

Objectives of the microstructural study in the Advanced Material research at Oak Ridge involve the characterization of microstructure of composite tubes, measurement as to how composition and properties vary by manufacturer, size, cladding composition, location within the tube as well as fabrication history. The study also involves residual stress measurements, and modeling studies. Some of the participants in the study visited Sweden and Finland last year to discuss the status of programs on recovery boiler composite tube degradation and to promote mutual exchanges of experiences and information.

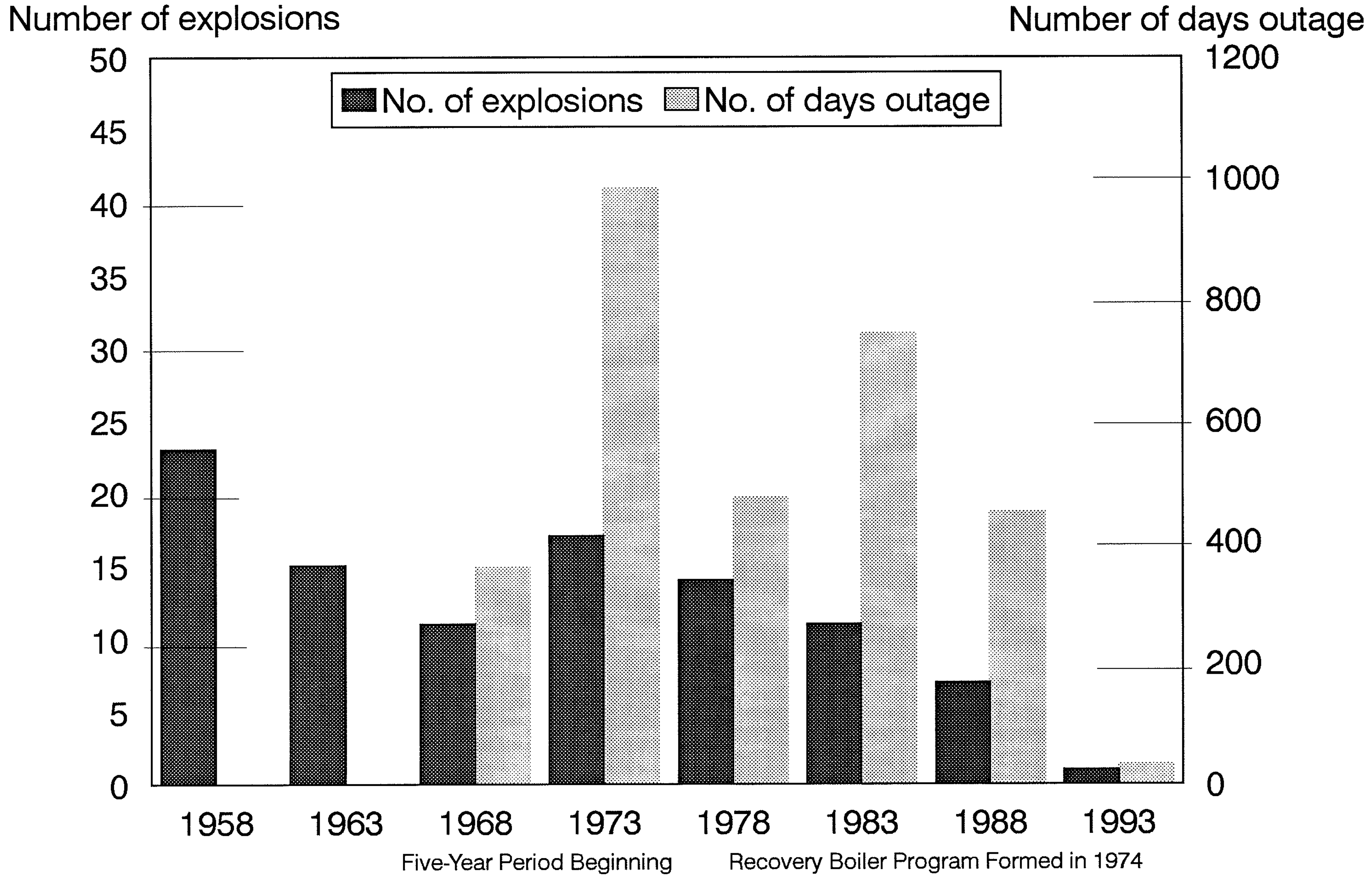
Our next annual meetings and conference will be held in February 1998 and we will have presentations on the progress of the gasification projects; the Advanced Materials research at Oak Ridge, in addition to vendor's views on the optimization of recovery boiler operational techniques.

Thank you very much for your attention and inviting me.

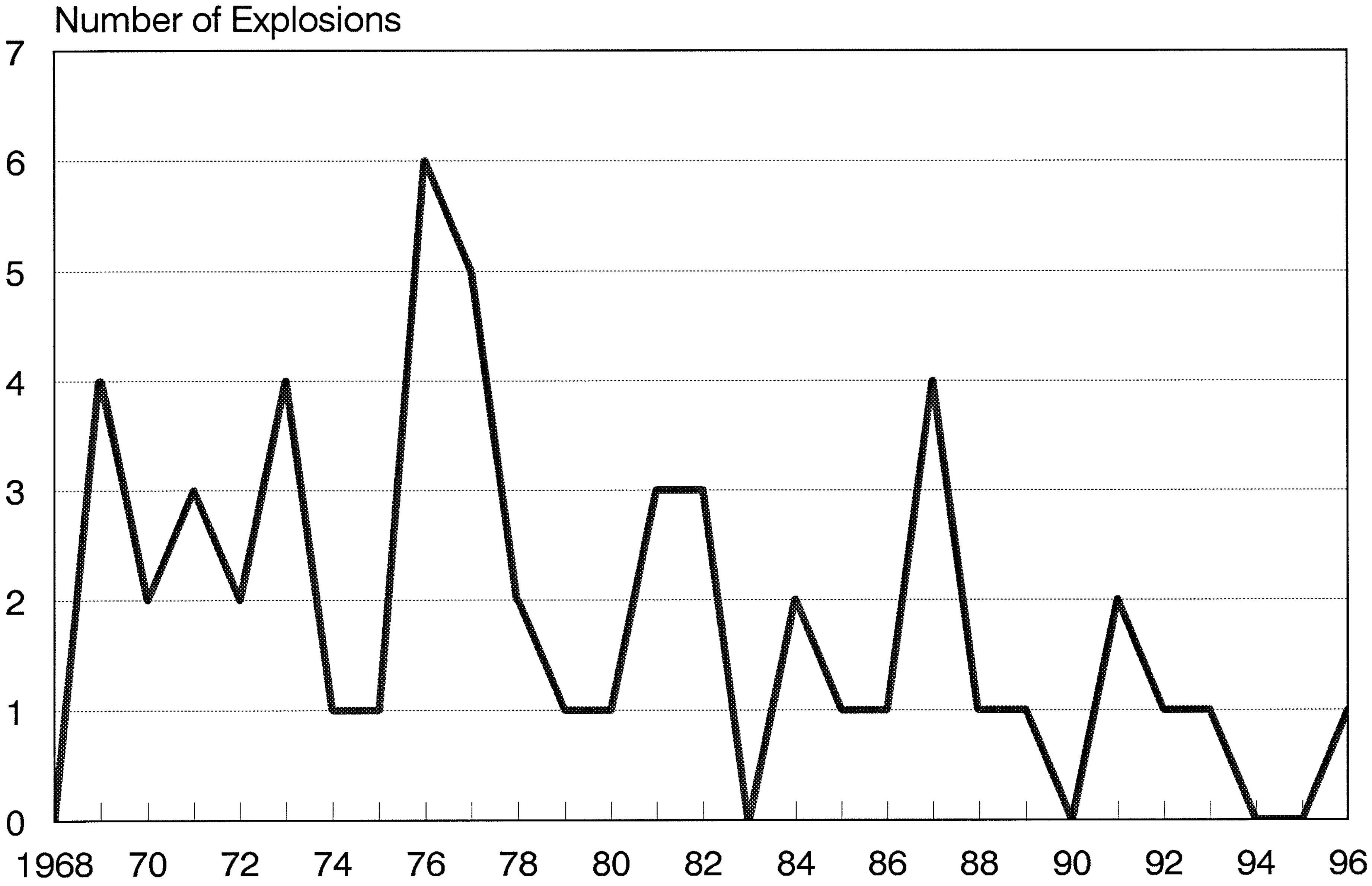
speech.5

RECOVERY BOILER EXPLOSIONS/OUTAGES

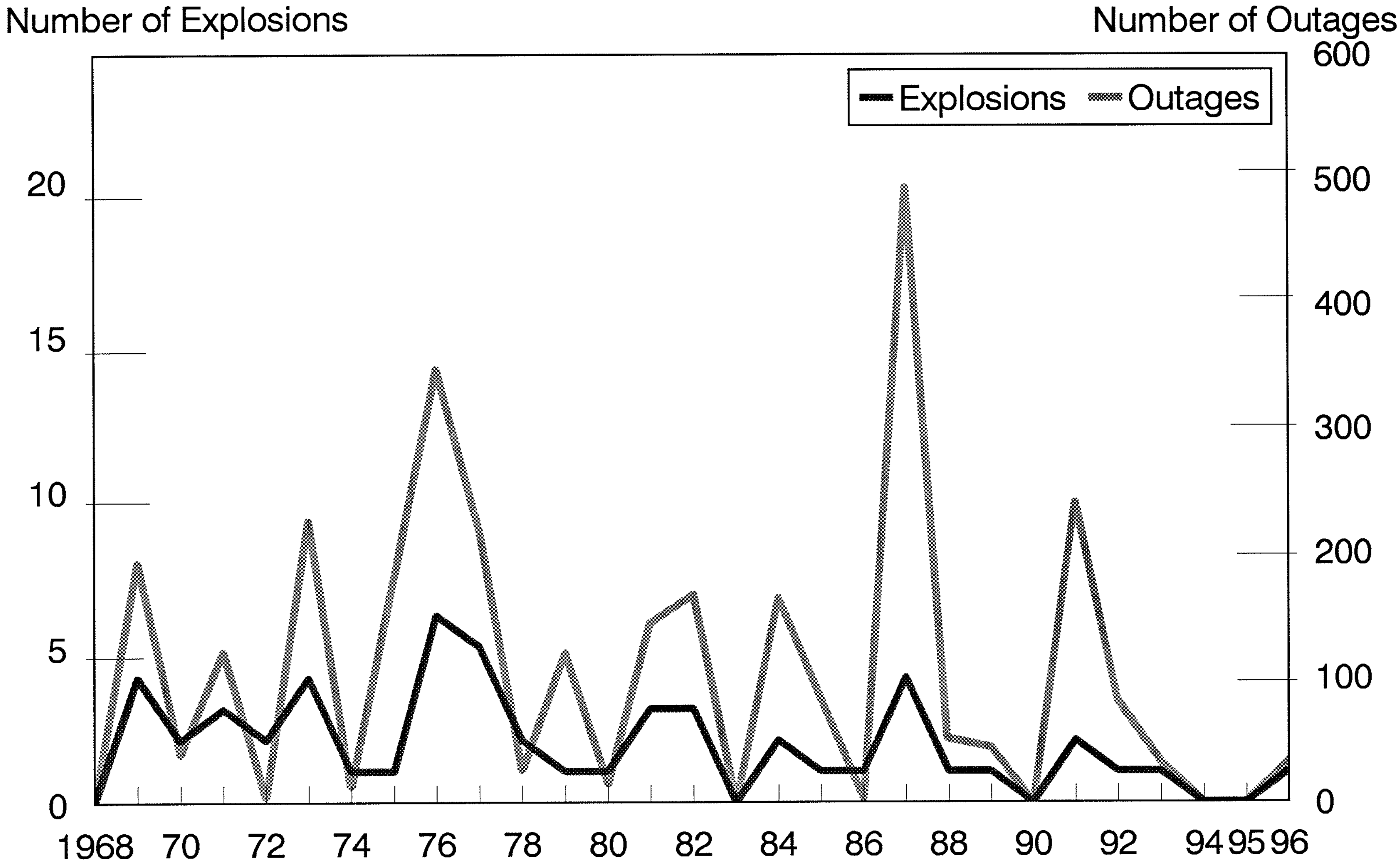
1958 - 1997



U.S. RECOVERY BOILER EXPLOSIONS



NUMBER OF EXPLOSIONS OF RECOVERY BOILERS
& NUMBER OF DAYS OF OUTAGES (U.S. only)



3

AF&PA RECOVERY BOILER PUBLICATIONS

RECOVERY BOILER TRAINING PROGRAM - Incorporates the latest technology - generically applicable to all recovery boilers. Includes 9 modules for Technical Guide of 1,300 pages of text and hundreds of illustrations and diagrams, and 9 modules for Instructor Guides consisting of detailed instructions - 1,400 pages of text, 313 overhead transparencies and 378 handout sheets for classroom use.

RECOVERY BOILER REFERENCE MANUAL - Three volumes of reference material for corporate engineers, boiler operators, supervisors as well as all others involved in inspections and repairs of recovery boilers.

Volume I - Chapter I - Inspections
- Chapter II - Nondestructive Testing

Volume II - Chapter III - Maintenance and Repair Analysis
- Chapter IV - Repair Guidelines and Practices

Volume III - Chapter V - Operational Effects
- Chapter VI - Case History Descriptions

RECOVERY BOILER SAFETY AUDIT GUIDELINES - Developed by AF&PA Operations and Maintenance Subcommittee based on a general consensus of current procedures employed in pulp mills. The purpose of the recovery boiler audit program is to reduce the risk of explosions by evaluating the overall safety and reliability of black liquor recovery boiler operations.

GUIDELINES AND CHECKLIST FOR SPECIFICATION AND CONSTRUCTION OF NEW BLACK LIQUOR RECOVERY BOILERS - Developed by AF&PA Operations and Maintenance Subcommittee to improve existing procedures and lead to a safer, more reliable recovery boiler. It is not intended to serve as a complete boiler specification but can serve as a checklist of major topics and items to be resolved by the manufacturer and the user during boiler specification and proposal discussions.

RECOVERY BOILER TUTOR (RBT) - A computerized recovery boiler simulator and tutor, designed to teach safe and efficient operation of black liquor recovery boilers. Allows operators to control a dynamic interactive model of a kraft recovery boiler. It can be customized to the specifications of any B&W or CE recovery boiler with direct contact evaporators or direct fired units.

"KRAFT RECOVERY BOILERS" - A new comprehensive recovery boiler textbook by the AF&PA and written by seven recovery boiler experts. The book was edited Dr. Terry Adams with contributions from Drs. Jim Frederick, Tom Grace, Mikko Hupa, Honghi Tran, Andy Jones and Kristiina Iisa. It covers all aspects of recovery boilers including: black liquor properties, combustion chemistry, black liquor and char bed burning, air and liquor systems, plugging, corrosion, design, safety and control. The book may be ordered through TAPPI Press, P. O. Box 102556, Atlanta, GA 30368-0556.

AMERICAN FOREST & PAPER ASSOCIATION

Recovery Boiler Program
Measurement Technology Program

AF&PA RECOVERY BOILER PROGRAM

pro.5

893 McLean Avenue, Yonkers, New York 10704
Phone : 914-776-6697 Fax: 914-776-6698

SUOMEN SOODAKATTILAYHDISTYS RY
RAPORTTISARJA

1/97 Suomen Soodakattilayhdistys ry
Konemestaripäivä 1997, 23.-24.1.1997 Pyhätunturi, esitelmät
60V00320-001

2/97 Suomen Soodakattilayhdistys ry
KCL, Söderhjelm, L.: Soodakattilatutkimus tänään ja huomenna
60V00856-001

3/97 Suomen Soodakattilayhdistys ry
Ohje soodakattilan päästöjen laskentaan
60V00924-002

4/97 Suomen Soodakattilayhdistys ry
Soodakattila-alan yhteistoiminta, Vuosikertomus 1996
60V00914-001

5/97 Suomen Soodakattilayhdistys ry
Vuosikokous 1997, 20.3.1997 Rauma, Pöytäkirja
60V00927-001

6/97 Suomen Soodakattilayhdistys ry
Soodakattilalaitoksen suojaussuositus 1997
60V00326-V070-001

7/97 Suomen Soodakattilayhdistys ry
Soodakattilapäivä 1997, 22.10.1997 Helsinki, esitelmät
60V00928-V070-001