Materials & Components
in Fossil Energy Applications

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Development of technically and economically viable processes for the conversion and utilization of fossil fuels is a major objective of the DOE Fossil Energy program. Many new and different processes are being investigated in areas of coal gasification, improved power generation and advanced combustion. As these processes evolve to the pilot plant stage and beyond, materials selection and component design become increasingly important for reliable and economical operation. The newsletter is intended to serve as a medium for exchange of information and experiences pertinent to the use of materials and components among the communities interested in the development of fossil energy systems.

Premature Failure of T-91 Superheater Tubes in an HRSG

Heat recovery steam generators (HRSGs) are used in cogeneration power plants to produce steam from an exhaust gas stream, and so increase the power output and the efficiency of the plant. Several different designs of HRSGs are in use, (see Materials and Components Issue No.157, pp. 1-3, April 2002). The HRSG in question contained a superheater section made of T-91 steel (9Cr-1 Mo, wt%) and was part of a cogeneration plant that was brought on line in the summer of 2001. Before startup, the tubes had been hydraulically tested at ambient temperature at 150% of the design pressure.

The unit had been started three times, including the initial startup, when several of the T-91 tubes failed, after only 20 hours of service. Five of the tubes were found to be cracked, and two had completely ruptured. The tubes were required to be in conformance with the relevant specification (ASTM A213, GRT19). Apparently, the failure of the five tubes did not occur at the same time. The failures occurred in the immediate vicinity of socket welds between the tubes and stub ends attached to the discharge header. The header and stub ends were specified to be 1.25 Cr-0.5 Mo (wt%) steel (in conformance with ASTM A213, GR11). One of the five ruptured tubes was made available for examination. Failure was found to have taken place in what appeared to be the heat-affected zone (HAZ) of the tube-to-stub end socket weld. The tube sample included a slight bend close to the failure region. The surface of the internal diameter of the tube bend showed a high degree of ovality (a difference of 7.6 mm between the length of the minor and major axes at a nominal I.D. of 51 mm). Further, a 15% loss in wall thickness (5.21-4.42 mm) was noted at the outer curve of the bend (extrados). No other significant loss of metal

was observed. No apparent mechanical damage was found on either the surfaces of the outer or inner diameters of the tube, and no cracking was observed at locations away from the rupture.

Low-power optical microscopy indicated two lines of arc strikes and weld spatter near the rupture location: one of the lines intersected the fracture surface, while the other ran parallel to it precisely along the edge of the fracture. Each line consisted of a linear array of superficial arc strikes and small globules of weld spatter. These were confined to an area that extended about 19 mm around the circumference of the tube. The fracture surface revealed an apparent brittle fracture in regions extending approximately 180 degrees of the tube circumference, and an apparent tensile overload around the remainder of the circumference. There was no evidence of corrosion on the surfaces of the inner or outer diameters of the tube at the failure location.

The composition of the tube material was found to be in conformance with the ASTM requirements. The weld

spatter appeared to contain approximately 12 Cr, 73 Ni, 0.6 0, and 15 Fe (wt%), corresponding to a high-alloy, heat-resistant weld filler metal, rather than to a matching weld filler metal for T-91 tubing. Metallographic cross sections of the tubing revealed weld spatter beads that were not attacked by the chemical etch used for T-91, providing further evidence of a difference in composition between the weld spatter and the tubing. The microstructure of the T-91 tubing away from the weld joint was found to be normal and acceptable, whereas that in the HAZ showed the presence of hard transformation products, apparently resulting from improper weld practice, and the presence of weld spatter. The microhardness of the HAZ at the point of fracture initiation was found to be equivalent to 303 Brinell, with an average hardness along the fracture plane of 287 Brinell. The hardness across the wall thickness, and adjacent to the failure averaged 219 Brinell whereas, at locations remote to the failure and at the outside diameter of the tube, the hardness values ranged from 150-170 Brinell. The metallographic examination also indicated that the failure occurred solely in the HAZ, not in the weld metal nor at the weld fusion line. The hardness of the HAZ remote from the failure region was found to be 250 Brinell, which is within the maximum required by the ASTM specification.

Overall, it was concluded that the premature tube failure was due to embrittlement of the tubing by weld spatter. The resulting hard and brittle HAZ probably cracked during hydrotesting at ambient temperature. The cracking extended part way through the wall thickness, which allowed the tube to withstand internal pressure for a short time. However, it was concluded that cycling of the unit during the three startups resulted in additional crack growth, with final rupture occurring by tensile overload. It appeared that the weld spatter probably originated from activity external to the welding of the tube to the stub ends, such that only a few tubes were affected. The high hardness of the weld spatter indicated that it was deposited after post-welding heat treatment of the superheater coil. Factors that contributed to the early failure were thought to be (1) the proximity of the bend to the socket weld, (2) the large amount of ovality induced during mending, and (3) the loss of wall thickness at the bend extrados, which probably increased the stress magnitude at the socket weld and tubing HAZ.

It was recommended that all accessible superheater tube socket welds should be visually inspected for the presence of weld spatter in close proximity to the tubing HAZ at the socket weld. All weld spatter detected should be removed by precise grinding, and additional post-welding heat treatment should be applied to those tubes containing weld spatter. Also, the metal under the weld spatter should be examined carefully for the presence of cracks, and any detected should be removed. Further, it was recommended that ultrasonic wall thickness measurements be made of all accessible tubes at locations between the apex of the bend and the weld. Analysis of the expected creep life of the tube can be based on the actual wall thicknesses, and the operating temperatures and pressures.

Abstracted from: G. P. Kallenberg, *Capstone Engineering Services, Inc*., "Premature Failure of a 9 Cr-V-Modified Superheater Tube," Paper No. 03491, presented at NACE Corrosion 2003, San Diego, California, March 16-20, 2003. Published by permission of NACE International.

Oxide Exfoliation from Alloy 347HFG in a High-Temperature Steam Boiler

The thickening of thermally-grown oxide scales on the steam-side surfaces of austenitic stainless steels employed as superheaters and re-heaters in steam power plants, and the subsequent exfoliation of these scales is a well-known phenomenon. The current understanding of the mode of exfoliation of oxide scales grown on ferritic and austenitic alloys in steam is that there are distinct oxide features involved, and that these are notably different for the two alloy classes. Ferritic steels form scales typified by two uniformly-thick layers, with the inner layer consisting of a fine-grained Fe-Cr spinel oxide, and the outer layer of columnar-grained, porous magnetite—Fe_3O_4—often with discontinuous patches of haematite—Fe_2O_3—on its outer surface. With time at temperature, scale cracking leads to the formation of a new double-layered (duplex) scale beneath the original; this process can repeat to form multi-layered scale consisting of repeated duplex layers ('laminated' scales). Exfoliation involves separation along the interface between the outermost duplex structures, resulting in the loss of relatively large flakes that have a duplex structure. The scales formed on austenitic steels typically are slower-growing and, while these also are double-layered, there are marked differences compared to those on ferritic steels. The inner layer is a Fe-Cr spinel that usually is of irregular thickness and is adherent to the alloy as a result of preferential

penetration into the alloy along grain boundaries. As on the ferritics, the outer layer is columnar-grained magnetite; on austenitics this develops porosity and, in particular, voids at its interface with the inner layer. As a result, exfoliation from austenitics initiates at this interface, so that the spalled scale consists almost entirely of small flakes of single layers of magnetite.

Exfoliation of scales in boilers is undesirable since the oxide particles can cause blockages in tube bends in vertical superheaters and re-heaters, leading to short-term overheating failures. In addition, if these exfoliated scales become entrained in the steam flow (typically during plant start up), they can cause solid particle erosion of the valve seats and blades of the steam turbine. In some cases, boiler manufactures have used ferritic steels (for their different exfoliation characteristics compared to austenitic steels) in the high-temperature steam paths as a means of avoiding blockage-related tube failures or loose oxide damage on start up. Another approach has been to shot peen the tube wall as a means of promoting the rapid formation of a slow growing, single-layered scale of chromium oxide-based scale on austenitic steels. More recently, a fine-grained version of type 347 stainless steel (type 347HFG) has been introduced with the expectation that the fine alloy grain size will have the same beneficial effect on promoting the formation of a more protective oxide scale as has been found after shot peening.

Experience of oxide exfoliation at the Callide Power Station of CS Energy, Australia
The Callide Power Station of CS Energy is located adjacent to the Callide mine near Biloela (Gladstone), in Queensland, Australia. It consists of three major units: Callide A (1965-vintage, refurbished and recommissioned in 1998) which consists of four, 30 MWe (Mitchell Engineering) boilers that burn black coal from the adjacent mine and generate steam at 510°C and 8.6 MPa. Callide B (commissioned in 1988) consists of two 350 MWe Babcock-Hitachi subcritical boilers that burn black coal and generate steam at 539°C and 17.7 MPa. The Callide Power Plant (Units C3 and C4) was commissioned in 2001, and consists of two supercritical 420 MW units (IHI boilers, Toshiba turbines) burning black coal to generate steam at 566°C and 25.1 MPa

CS Energy has experienced tube blockages at this Station due to magnetite exfoliation from type 321 stainless steel vertical superheaters during boiler cool-down of the 350 MWe units of the Callide-B Plant, which has been involved in campaigns of long, continuous operation. Two blockages have been extensive, and exfoliation continues to occur. This has necessitated the development of a process to remove the loose oxide when the boiler is

removed from service, or at ambient conditions. As a result, two new 420 MWe supercritical boilers were ordered with explicit requirements that the sections of the superheaters and re-heaters that required austenitic steels would be made of materials that would not exfoliate oxides during cool down. The alloy supplied by the boiler manufacturer to meet these requirements was type 347HFG, which was used in three superheaters and one re-heater in each unit.

Callide Power Plant Unit C3
Each time the C3 and C4 boilers are cooled down, a rare-earth magnet is used to make a magnetic survey in each bend of the secondary re-heater and final superheater. At a brief inspection outage on number C3 boiler after approximately 9,500 hours of operation, extensive levels of magnetic attraction (indicating the presence of accumulations of exfoliated magnetite scale) were found in the bends in the vertical, pendant, secondary re-heater. The largest extent of exfoliation occurred from the re-heater, which contains approximately 9 m of type 347HFG tubing extending above the pendant loops. Both tubing and loop bends are 50.8 mm OD, with a wall thickness of 4 mm; the bend radii are approximately 140 mm. During the first year statutory inspection of Unit C3, some eight weeks after the inspection outage, an inlet bend and other tube samples were cut for analysis from the secondary re-heater as well as from the final superheater.

After twenty-two weeks of continuous operation following a boiler cool down, a forced outage occurred in Unit C3. Most of the secondary RH loops exhibited some magnetic attraction and, in fact, approximately six times as much exfoliated oxide was found compared to the first year's statutory inspection. Examination of the tubes removed indicated an average operational temperature of 670°C, based on the sigma phase present in the alloy, and confirmed by thermal readings from an adjacent location. Most of the samples from the secondary re-heater exhibited exfoliation of the outer oxide layers, as is usually found for austenitic alloys; the typical oxide flake thickness was 40 μm. The inner layer of scale was largely intact and, where the outer layer had not spalled (on the outlet leg samples), multi-layered oxides were present. Figure 1 shows a cross section of the oxide scale on the steam-side surface of a tube, and Fig. 2 shows cross sections flakes of spalled outer layer that made up more than 95 percent of the exfoliated scale.

Hematite (Fe_2O_3) was frequently found to be present between an inner and outer magnetite (Fe_3O_4) layer, which is not the structure expected from equilibrium thermodynamic considerations. The loose oxide removed from the inlet leg of the secondary re-heater consisted
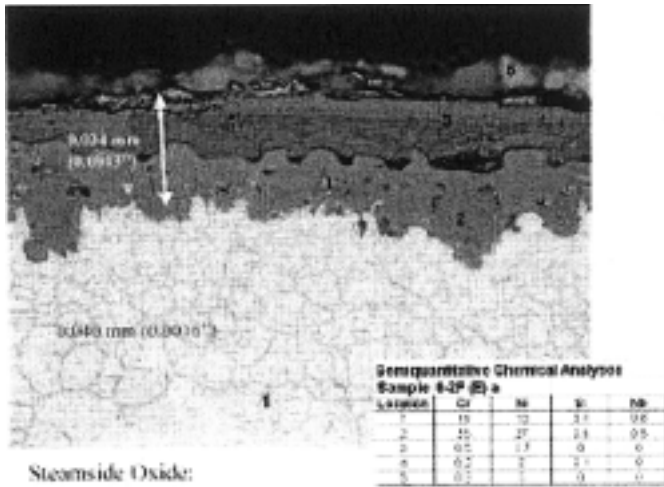
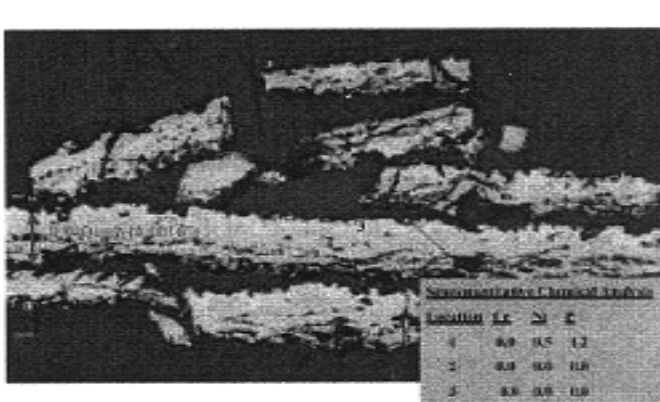**Figure 1. Cross section of the steam-side scale formed on Alloy 347HFG after 11,340 h in Callide Boiler C3**

Figure 2. Cross sections of exfoliated scale samples from a SH inlet bend of Callide Boiler C3.

largely of the outer oxide layer, without indications of multiple layers. Less than 5% of the sample consisted of oxide flakes from the ferritic steels (2.25Cr-1Mo) used in the inlet header or inlet tube legs of the secondary re-heater. The presence of this oxide indicated that the 2.25Cr material had experienced very high temperatures. The typical maximum use temperature of this alloy is in the range 580 to 600°C, and the average secondary re-heater steam inlet manifold temperatures that were recorded averaged between 485 and 510°C.

The resulting data indicated that the secondary re-heater on boiler C3 accumulated approximately twice to three times the amount of oxide in the inlet legs compared to the outlet legs. The arrangement of the secondary re-heater has steam flow counter to the gas stream flow, such that the tubes exposed to the highest-temperature combustion gas flow experienced the highest temperature steam flow. As a result, both the steam temperature and the flue gas temperature are lower for the inlet legs than for the outlet

legs, so that the relative amounts of oxides found to be present were counter-intuitive.

Callide Power Plant Unit C4

This boiler suffered a forced outage after approximately 11,000 hours of operation. Outlet bends from the secondary re-heater contained large amounts of exfoliated oxide (30 to 50% cross sectional blockages), and a video probe image from an outlet tube leg revealed the start of exfoliation immediately above the bend-to-tube straight weld. Subsequent examination indicated that the non-exfoliated tube bend was metallurgically similar to the tube above the weld junction. Oxide banding of the inner layers was present on both samples. On the exfoliated straight tube, a triple layer of magnetite was found on the front arch of the tube (gas stream-side), but not on the rear arch of the same tube, nor on the inlet side sample.

In contrast to the exfoliation observed in Unit C3, the amounts of oxide found in the inlet and outlet bends of the secondary re-heater in boiler C4 were approximately equal. The re-heater metal temperatures for both units are similar. In both units, the metal temperature of the final superheater typically is marginally lower than the secondary re-heater. Experience of exfoliation in the superheaters has been that it is only just detectable using a hand-held magnet.

Mode of Exfoliation

More than 90% of the outer layers (both magnetite and hematite) of the steam-side oxide exfoliated from the secondary re-heater in boiler C3, where as almost all of the inner (spinel) layer remained attached to the tube surface. This is normal behavior for austenitic tubing exposed to steam up to 630°C. The unusual feature observed on type 347HFG tubing was the presence of a middle oxide layer consisting of multiple layers (banding). This feature was found only in areas where the outer layers had not exfoliated and were still in contact with the tubing. This morphology was not seen in samples of exfoliated scale collected from the blocked tube ends, suggesting that this scale morphology was not prone to spall. Further, the thicknesses of the hematite layers within the outermost layers were very variable, and were strongly correlated with the presence of voids or cracking along the inner spinel/magnetite boundary. Compared to the collected, exfoliated scale, the thickest areas of hematite were observed in the oxide scale that had not exfoliated. This is a new observation, since the usual experience is that increasing hematite content of the oxide layer correlates to an increase in the compressive cooling strain generated in the oxide, leading to earlier exfoliation. Based on the tube operating temperatures and oxide thicknesses, cooling strains were estimated from correla-
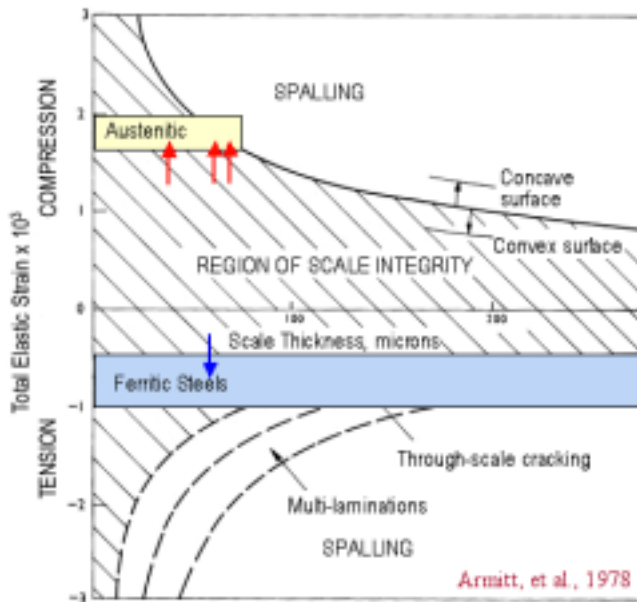
Figure 3. Scale thickness versus cooling strains for 347HFG and 2.25Cr-1Mo under the operating conditions at Callide Boiler C3.

> The red arrows (top) show the measured steam-side oxide thicknesses on the 347HFG tubing.
>
> The blue arrow (bottom) shows the measured steam-side oxide thickness on the 2.25Cr-1Mo tubing.

from the 347HFG tubing. As indicated earlier, this collected oxide did not exhibit laminated middle layers, and generally had thinner hematite layers than the adherent oxide. Since the estimated <u>average</u> tube temperature was about 670°C, it is not unlikely that exposure to higher temperatures was responsible for the different morphologies experienced. Unfortunately the fine-rain structure of the 347HFG alloy introduced specifically to promote slower, more protective oxide scale growth, provided no benefit in terms of slower growth or delayed exfoliation at tube temperatures that approached 700°C.

tions published in 1978 by Armitt, et al., (EPRI Report No. FP-686, Feb. 1978), and these predicted that spallation would have been expected from both the 2.25-1Mo and 347HFG tubes (see Fig. 3).

In these observations, more than 95% of the collected exfoliated oxide was characteristic of the outer oxide

Based on: A. Hughes, *CS Energy*, R.B. Dooley, *EPRI*, and S. Paterson, *Aptech*, "Oxide exfoliation of 347HFG in high-temperature boilers," paper presented at the 7th International Conference and exhibition on *Operating Pressure Equipment*, Sydney City, Australia, 2nd-4th April, 2003. Published by the Institute of Materials Engineering Australasia, Ltd.

Fate of Trace Contaminants from Biomass Fuels in Gasification Systems

A growing interest in the use of biomass and other renewable fuels in power generation systems is being stimulated by the search for electricity generation methods that minimize environmental emissions, utilize readily-renewable fuel sources (which may be 'CO$_2$-neutral'), and which allow diversification in power generation fuel sources. One possible approach is to modify advanced, combined-cycle power systems originally developed for coal firing alone to accept co-firing with coal and biomass. It is thought that this approach could encourage more rapid introduction of such systems into commercial operation. Such systems were originally devised to generate power from coal with much greater efficiencies and lower environmental emissions of SO$_X$, NO$_X$, and CO$_2$ than conventional pulverized coal-fired power generation. Since system reliability is a major concern, it will be necessary to ensure that potentially vulnerable component parts of such systems are manufactured from appropriate materials, and that adequate,

reliable, and predictable component lifetimes will be achieved with unusual fuels and fuel combinations.

While there are significant differences among the various gasification systems that have been developed, both in terms of the operation of the actual gasification process and the requirement for different downstream components with distinct ranges of operative conditions, in all cases the fuel gases produced need to be cooled and cleaned before being burned in gas turbines. From the perspective of materials performance and optimum material selection, it is critically important to understand the component operating conditions and the environments produced in each of the gasification systems. For coal gasification, bulk gas compositions have been published showing the different ranges produced by some of the gasification systems, as well as the variations with coal type. Co-firing with biomass fuels introduces further significant differences, particularly in terms of the minor and trace gas species. This

different balance of containments in the fuel gas produced can affect components throughout the hot gas paths of the gasifier and the gas turbine, as well as altering the trace element emission levels from such systems. For all the components exposed to the fuel gases and products of combustion of these fuel gases, the presence of particles may cause erosion, abrasion, or deposition, and gaseous species (especially H_2S, SO_x, HCl, alkali and other trace metal species) may cause deposition and/or enhanced corrosion. The use of such co-firing will only prove viable where efficient, reliable, low-emission systems can be developed which require a minimum of fuel pretreatment, and which can use existing state-of-the-art components such as hot gas filters, gas cleaning systems, and high-efficiency gas turbines.

There are several possible routes for minor and trace elements to take within a gasification system and then through the gas turbine. These routes vary from no response to the gasification process (so that the minor and trace elements exit with the ash/char/slag), through to the formation of vapor species that can pass through the whole gas path and so be emitted from the process. Between these two extremes, there is a range of possible behaviors that include reactions to form particles and vapor species that can condense onto particles or different components throughout the hot gas path.

The fate of the various trace elements is element-specific and, in addition, can be influenced by both the relative and absolute levels of other elements present in the fuels (such as sulfur and chlorine) and in any sorbents, as well as the composition of the materials used for the hot gas path components. Studies in progress as part of the UK Cleaner Coal Project involve the development of theoretical predictions of trace element behavior, and comparison of the trends identified with measurements made within operating plants and with known operating experience. The ultimate goal of these programs is to enable materials studies to be more closely focused onto using realistic deposit compositions for corrosion testing on materials intended for use within gasifier and gas turbine hot-gas paths.

Initial Modeling Results

The data used for the basis of the thermochemical modeling were drawn from extensive compositional information on potential European biomass fuels, for which analyses were available for all minor and trace metal species. Such fuels included pine wood; wheat straw; a range of grasses; sewage sludge and peat; and coal. The thermodynamic study was used to determine which trace elements are more or less likely to enter the hot-gas paths of gasification systems, condense onto systems compo-

nents, and/or pass through into the gas turbine. The stability of potential product compounds in gasifier fuel gases, and their sensitivity to a number of important process variables was considered. These include:

- two gasifier processes: an oxygen-blown, entrained-flow process (Prenflo); and an air-blown, fluidized-bed process (ABGC);
- atmospheric and pressurized operation;
- temperature ranges covering gasification and hot-gas cleanup processes, as well as component operating temperatures; and
- ranges of sulfur and chlorine levels that represent the potential ranges in fuels.

The elements considered were: As, B, Ba, Be, Ca, Cd, Co, Cu, Hg, K, Mn, Mo, Na, Pb, Sb, Se, Sn, V, and Zn. Chromium, Ni, and Fe were not included since they are major alloying elements and always used in components throughout the fuel gas paths. For a power plant, it is important to note that kinetic effects may arise due to the short gas residence times and/or slow reaction rates that could limit movement towards thermodynamic equilibrium. These effects apply especially to the bulk gases, and will be less significant in the slower-moving boundary layers adjacent to components.

Some results of this thermodynamic study are summarized in Table 1. This lists the major gaseous and condensed phases, and the temperature ranges for any gas-to-solid transformations. Table 2 groups the elements in terms of their volatility, that is, in order of transition from gaseous to condensed phases. As an example, the gas-to-solid transformation temperature of the major species, KCl, was found to increase from ~700 to ~900°C when the pressure was increased from 1-20 atm. Further, it was

Table 1. Summary of Thermodynamic Predictions of Behavior of Trace and Alkali Metal Species in Gasifier Gases

Element	Major Gas Species	Major Solid Species	Gas-Solid Transition Temp. Range (°C)
As	As, As_2, As_4, As_4S	—	
As (+Ni)	As_4S (As)	As_2Ni_5, As_8Ni_{11}	1020-1460
B	BHO_2, $B(OH)_3$	—	
B (+Ca)	$B(OH)_3$,(BHO_2)	$B_2Ca_2O_5$	solid—gas 420-840
Ba	$BaCl_2$, BaClHO	$BaCl_2$, BaS, $BaCO_3$	900-10-40 (or >1200)
Be	BeH_2O_2	BeO	840-960
Ca	—	$CaCl_2$, CaS, $CaCO_3$	
Cd	Cd, $CdCl_2$	CdS	400-540 (or <400)
Co	$CoCl_2$ (Co)	Co, Co_9S_8	600-1340
Cu	CuCl, Cu_3Cl_3, (Cu, CuH)	Cu, Cu_2S	520-960
Hg	Hg	—	
K	KCl, K_2Cl_2	KCl	700-900
Mn	$MnCl_2$ (MnCl)	MnO, MnS	440-1260
Mo	$MoClO_2$, $MoCl_2O$, $MoCl_2O_2$ $(MoHO_2)$	MoS_2	700-1200
Na	NaCl, Na_2Cl_2	NaCl	670-900
Pb	Pb, PbCl, $PbCl_2$, PbS	Pb, PbS	560-640 (or <400)
Sb	SbCl (Sb)	—	
Se	SeH_2 (SeH)	—	
Sn	SnS, $SnCl_2$	SnO_2, SnS	460-560 (or <400)
V	$(VCl_2$, VCl_3, $VOCl_3)$	V_2O_3	
Zn	Zn, $ZnCl_2$	ZnS	460-780

Table 2. Summary of Predicted Volatility of Trace and Alkali Metals in Gasification Gases

Increasing Volatility	Element
↑	Hg, Sb, Se (As, V, B)
	Cd, Pb, Sn, Zn (As, B)
	Co, Cu, K, Mn, Mo, Na
	As, Ba, Be
	Ca (V, As, B)

found that the data for some elements could be greatly affected by inclusion or omission of another element. For example, Ni was found to significantly affect the equilibrium diagram for As. When Ni was absent, the As data were comprised of gaseous species, whereas with Ni present the major As-containing species up to 1000°C was predicted to be solid As_2Ni_5. Although significant variables were the S and Cl levels in the fuel gas (present mostly as H_2S and HCl). An example of these effects is that increased levels of H_2S can result in higher or lower dew points of elements such as Zn and Sn, or different gas phase and/or condensed species, such as for Pb.

The same methods of thermodynamic predictions can be applied to the gas turbine, using the results of the gasifier fuel gas study to identify the elements that can pass through into the gas turbine, as well as realistic ranges for the different contaminant levels. Figure 4 illustrates the results of the prediction of the dew point temperatures for K, plotted as a function of contaminant levels for different SO_x and HCl levels, and gas pressure. In particular, the dew point of K_2SO_4 increases with increasing levels of potassium or SO_x in the gas stream, as well as with increasing gas pressure, but decreases with increasing HCl levels.

Figure 5 summarizes the results from sampling of solid process products recovered from gasifier product gas streams. These data show a wide range of behavior of
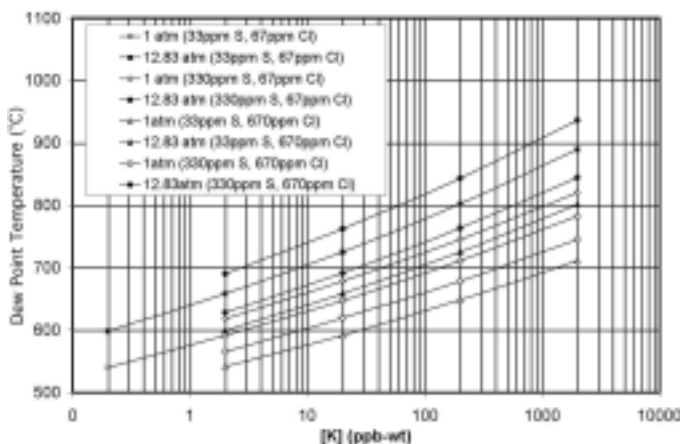
different trace elements in gasification systems, although many elements show similar removal trends. For example, in every system, Co, Cr, and Cu showed high removal rates with solid products collected as bottom
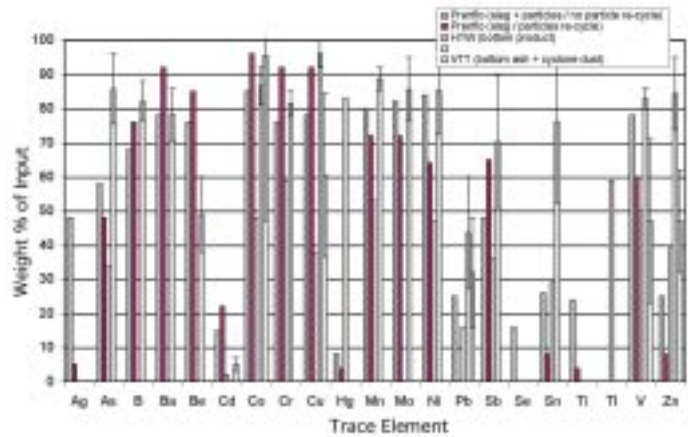

Figure 5. Distribution of trace elements recovered in bottom product/slag and first cyclones in five gasification systems

product/char/ash and primary cyclone (if present), whereas Cd, Hg, Pb, Sc, and Sn showed significantly lower removal rates by this route. These findings are in line with the thermodynamic predictions summarized in Table 3. The presence of trace elements in heat exchange deposits at levels up to several wt % has frequently been observed during component examinations and assessments, but only occasionally reported.

Some data are available for the removal of alkali, trace metals, and chlorine species in gasification systems that incorporate hot gas filters. Since these data are not comprehensive, and were obtained at different filtering temperatures, it is difficult to separate process differences

Table 3. Summary of Predicted Fate of Trace and Alkali Metals Species in Gasification Gases

Trace Element	Majority species always in vapor phase		Majority species always in solid phase		Gas to solid transformation sensitivity			
	ABGC	Prenflo	ABGC	Prenflo	Pressure	Cl	S	Process
As	Y	Y	N	N	—	—	—	—
As (+Ni)	N	N	S	S	Y	Y	Y	(Y)
B	Y	Y	N	N	—	—	—	—
B (+Ca)	N	—	N	—	N	N	N	Y
Ba	N	N	S	—	Y	Y	Y	Y
Be	N	N	N	N	N	N	N	N
Ca	N	N	S	S	(Y)	(Y)	(Y)	(Y)
Cd	S	S	N	N	Y	Y	Y	N
Co	N	N	S	N	Y	Y	Y	(Y)
Cu	N	N	N	N	(Y)	Y	Y	(Y)
Hg	Y	Y	N	N	—	—	—	—
K	N	N	N	N	Y	Y	Y	(Y)
Mn	N	N	S	N	N	Y	Y	(Y)
Mo	N	N	S	N	(Y)	Y	Y	(Y)
Na	N	N	N	N	Y	Y	Y	(Y)
Pb	S	S	N	N	N	Y	Y	N
Sb	Y	Y	N	N	—	—	—	—
Se	Y	Y	N	N	—	—	—	—
Sn	S	S	N	N	N	Y	Y	N
V	N	Y	Y	N	—	—	—	—
Zn	S	?	N	N	N	Y	Y	N

Figure 4. Dependence of K_2SO_4 dewpoint on gas pressure, S, Cl, and K levels

from differences arising from the use of different filter temperatures. There are also some significant errors in the mass balance closures for some of these sampling data. None of the data sets include a factor for the loss of alkali or trace metals by condensation or deposition onto hot gas components. This area would be particularly important in smaller scale plants, in which such detailed measurements typically are carried out. In many cases, the intended route of removal of contaminants such as alkali metals and Zn is by condensation or reaction with the fine particles present in the gas stream, followed by particle removal the hot gas filter. However, the coldest component in the hot gas path will be the heat exchanger that cools the gases prior to entry into the hot gas filter.

Filter System
The large internal surfaces of the filter unit itself provide another potential sink for alkali and trace metal removal, especially if they are cooler than the gas stream. In a pressurized, air-blown fluidized-bed gasifier pilot plant, for instance, deposits of the low volatility trace elements at levels of several wt % have been observed on the surfaces of pipes on the clean side of the filter units, several meters upstream of the location of the trace metal sampling system. In addition, reduction in S and Cl species has been noted across hot-gas filter units, presumably as a result of reactions with the filter cake formed on the dirty side of the units. The available information show that lowering the filter temperature reduces the amount of vapor-phase species present in the remaining fuel gas stream, and enriches the filter fines in these elements. This is in agreement with the trends from the thermodynamic analysis. Unfortunately, filter operating temperatures cannot simply be lowered to the levels needed to remove most of the vapor species, as the lower limits for filter operation typical are dictated by other gasification parameters. For example, where tar compounds are formed, these need to be kept in the vapor phase to avoid blinding of the filters. The bulk of the available data are for alkali species, despite the fact that elements such as Pb (which may be present at similar or higher levels in gasification fuel gas streams) also are very important in determining gas turbine component lives. Sampling during testing of such filters measured levels of Cd, Pb, and Zn at significant levels in the fuel gas and, in particular, it was found that the levels of Pb, Na, and K were higher than those currently acceptable for gas turbines.

Feasibility Studies for On-Line Electrochemical Corrosion Monitoring in Fireside Applications

The introduction of low-NO$_x$ combustion conditions in coal-fired steam power plants has resulted in some incidences of accelerated fireside corrosion of the furnace walls, especially where separated over-fire air ports (SOFA) are used (see, for instance, Materials and Components Issue 159, pp. 1-3, Aug 2002; 145, pp. 1-3, Apr 2000). While there is still some debate about the actual mechanism by which such corrosion occurs, it is undoubtedly a function of the sulfur content of the coal. A remedial measure commonly used to combat this form of corrosion is the application of a coating of a more corrosion-resistant alloy by the weld overlay technique. However, since the coal burned in a given boiler typically no longer comes from a single source, economic and regulatory considerations now are major drivers in coal purchases, so that some means of characterizing the potential corrosivity of a coal under low-NO$_x$ firing would be extremely useful in making decisions on coal purchases. As a result, there is a continuing interest in corrosion monitoring devices that can provide reliable corrosion information from relatively short-term measurements.

Electrochemical corrosion monitoring devices have been developed and are well accepted for on-line monitoring of corrosion in *aqueous* conditions. The application of these techniques to high-temperature corrosion has been attempted (see Materials and Components Issue 156, pp. 3-6, Feb 2002), but has met with mixed success, partly because of skepticism over the applicability of electrochemical approaches under conditions of dry, high-temperature corrosion.

Laboratory Tests
Recently, systematic testing of such electrochemical probes under conditions of controlled, high-temperature corrosion has been initiated to provide better definition of the signals produced by the probe and their correlation to the corrosive environment. Preliminary studies carried out at the Foster Wheeler Development Corp. facility in Newark, New Jersey were designed to examine the feasibility

of electrochemical corrosion monitoring under conditions considered representative of those in low-NO$_x$ firing conditions. The corrosion monitoring instruments consisted of two SmartCET™ Instruments (InterCorr International, Houston, Texas) which were used to monitor electrochemical noise, linear polarization resistance, harmonic distortion analyses, and conductivity. These tests were carried out at temperatures between 400 and 500°C in both oxidizing and reducing gas mixtures, with and without the presence of surface deposits rich in iron sulfide. Originally, the deposits used consisted of 60 wt% FeS and 40% C, but it was found that the C interfered with the measurements, forming an electrical short circuit between the electrodes. Modified mixtures consisted of 20% SiO$_2$ plus 20% Al$_2$O$_3$ substituted for the C, and in a second test, an addition of 1% FeCO$_3$/NaCl (25-75 mixture) was made. The deposits were applied as suspensions in a camphor/alcohol mixture to give approximately a 2 mm-thick cover over the exposed metal surfaces of the probes. Two metal coupons were also covered with the respective mixtures to provide visual comparisons with the probes.

The test runs consisted of heating the samples in an oven, starting with a nitrogen purge, and ramping the temperature up at 3°C per minute to 400°C, at which point the reducing gas (7 CO, 12 CO$_2$, 6 H$_2$O, 0.11 H$_2$S, balance nitrogen, in volume %) was admitted. After two hours at 400°C, the temperature was ramped at the same rate to 450°C, where it was held for two hours after which it was then ramped further to 500°C, held for two hours, and then cooled down overnight. Electrochemical measurements were made continuously throughout the test cycle, with data logged at 6-minute intervals.

A second test was run with the same probes after light cleaning and the provision of fresh deposits. This time under conditions using an oxidizing gas consisting of 17% CO$_2$, 6% H$_2$O, 0.13% SO$_2$, 1% O$_2$, balance nitrogen. After ramping to 400°C, the oxidizing gas was substituted for the nitrogen and the system maintained at the same temperature for approximately three hours before being ramped at 30°C per minute to 450°C, where it was held for 11 hours. After this it was ramped to 500°C and held for a further eight hours before being purged with nitrogen and refilled with reducing gas for a further four hours.

Results for the initial test in the reducing gas are shown in Fig. 6. The corrosion rates indicated in the Figure were estimated using a best guess approach for the electrochemical constant required in the calculations; principally, the default Stern-Geary constant was set to 30 mV, and the number of electrons for the metallic oxidation

Figure 6. Electrochemical response from reducing gas composition

process was set at two. Comparison of the electrochemically-estimated material loss with the measured overall mass loss after the test indicated that the linear polarization resistance technique was over-estimating the corrosion rate, and that for this application the Stern-Geary constant should be set to less than 30 mV. Nevertheless, it was obvious that an electrochemical corrosion response was initiated when the reducing gas mixture was introduced at 400°C. The plateau in the corrosion rate observed was due to instrument saturation, which was remedied by installing a 100 ohm resistant in series with the test probe. On switching from the reducing gas to the nitrogen purge before cool down, a marked reduction in electrochemical response was observed. Figure 2 indicates the effect of oxidizing and reducing conditions on the electrochemical response. Note that the iron sulfide used to coat the electrodes did not show any evidence of conductivity during operation under nitrogen, but was
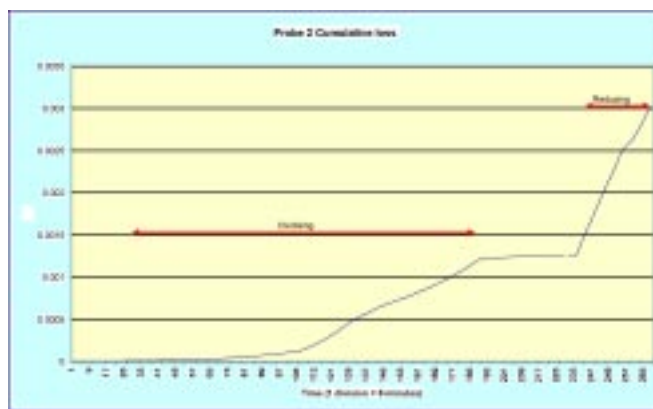

Figure 7. Cumulative weight loss estimated from the electrochemical response under oxidizing and reducing gas composition

quick to react to the presence of both oxidizing and reducing gas mixtures, suggesting that the iron sulfide was behaving as a solid-state electrolyte, or that some decomposition products of the FeS/gas mixture were forming a condensed, conducting, liquid phase.

Figure 8. Configuration of an electrochemical probe for firewall insertion

Figure 9. Configuration of an electrochemical probe for firewall insertion

Field Trials

Similar probes were installed in the Harrison No. 2 unit during the May 2001 outage. A total of ten probes: five of carbon steel, and five of a typical weld overlay material (alloy C 276) were installed. The general appearance of an individual probe is shown in Figs. 8 and 9. These probes were configured to fit through the webbing between the vertical furnace wall tubes, and relied on cooling from the tubes themselves to maintain operating temperatures representative of the fireside of the tubes. Monitoring measurements were made over the period June-September 2001, after which the probes were removed and examined for the extent of corrosion attack. New probes made of alloy C276, with pre-weighed central electrodes (to facilitate weight loss measurements after test) were installed in

November 2001. The total exposure period was approximately 10 months, during which the probes were occasionally removed and examined while the boiler was online. Corrosion signals were monitored continuously, and the data updated every five minutes. Analysis included linear polarization resistance, harmonic distortion, electrochemical noise, and conductivity. These data were displayed as the corrosion rate and as a cumulative corrosion loss for each probe.

Some representative data comparing the mass due to corrosion with that derived from the electrochemical measurements are compared in Table 4, for several locations across the boiler. Note that the electrochemical technique indicates the same trend as the mass change measurements. In order to be able to derive the absolute

Table 4. Comparison of measured weight loss with cumulative weight loss calculated from electrochemical probe measurements

Location	Weight Loss, mg	
	Direct measurement	SmartCET
1	N/A	55.43
2	97.03	97.6
3	N/A	N/A
4	N/A	16.9
5	2.39	6.3
6	32.26	16.16
7	146.27	58.37
8	20.48	22.46
9	21.63	19.52
10	16.79	12.93

corrosion rate from the electrochemical technique, the factors for translating the electrochemical signals obviously must be obtained, or 'learned.'

Abstracted from: D. A. Eden, *InterCorr International*, and B. Breene, *Energy Systems Associates*, "On-Line Electrochemical Corrosion Monitoring in Fireside Applications," Paper No. 03361, presented NACE Corrosion 2003, San Diego, California, March 2003. Published by permission of NACE International.

Separation of CO_2 from Coal-Based Power Plants

The first steps being taken toward lowering CO_2 emissions from coal-fired power plants depend on increasing the efficiency of the combustion processes, so reducing the CO_2 produced per unit of coal burned. The next logical step would be to remove the CO_2 from the combustion gas, and to dispose of it instead of sending it into the atmosphere. Separation of the CO_2 from combustion gases is a major problem, given the very large amounts released from central coal-fired power stations.

A number of concepts have been proposed, including reducing the volume of flue gas produced through oxygen-firing or high-pressure pulverized coal combustion with integrated heat exchangers; the use of CO_2 separation membranes, etc. All of these are far from being ready for commercialization, so that there are only two options that can be considered as being realistic for application in the next one or two decades. These are:

1. Scrubbing of CO_2 from the flue gas of coal-fired power

plants using MEA amine solution;

2. Implementation of integrated gasification combined cycles (IGCC) with integrated fuel gas de-carbonization, involving converting the CO in the syngas to produce additional hydrogen and CO_2, and removal of the CO_2.

Flue Gas Scrubbing

In the case of flue-gas scrubbing, the configuration of the plant upstream of the CO_2 scrubber remains nominally unaffected. As a result, this option tends to be viewed favorably by the power industry. For a conventional pulverized coal-fired (PC) power plant with an output of 680 MWe, operating at a state-of-art efficiency of 45%, the amount of flue gas to be de-carbonized would be of the order of 2×10^9 scfd, from which approximately 540 tph of CO_2 would have to be removed. The rate of circulation in the scrubbers of MEA required to achieve this task would be of the order of 6-6,000 gpm, while regeneration of the CO_2-laden MEA solution would consume more than 1,200 metric tons per hour of low-pressure steam. Overall, efficiency of the plant would be expected to fall by 10-14 percentage points, resulting in an overall plant efficiency of approximately 33%. This relative fall in efficiency of 27% translates into the need for 27% higher coal consumption per kilowatt hour produced. The electricity output of the former 680 MWe power plant would be reduced to 500 MWe. The additional plant required to perform the scrubbing would consist of 6 parallel absorbers, each 8 m in diameter, while regeneration would require 12 x 6 m-diameter regenerators in parallel. Aqueous, CO_2-laden MEA is an aggressive medium, especially in the absence of H_2S. Considering the very large scrubbing plant required, the environmental impact, and impact on health, caused MEA emitted to the atmosphere may be a significant problem. Further, other potential problems that are yet to be resolved are the behavior of trace components NMEA; its expected degradation rate; and consequent corrosion problems.

Requirements for the IGCC Option

IGCC is considered by the power industry to be complicated and expensive technology, although similar plants have been routinely operated by the chemical industry for decades. As a result, the technology of syngas generation from coal, with downstream removal of all carbon-containing species, has been well proven in chemical plants in, for instance, the ammonia and hydrogen industries. Potential advantages for the IGCC route are that CO_2 must be removed from a comparatively small volume gas-stream under elevated pressure, so that the effort required is lower than that for the MEA option. Further, the carbon-free fuel-gas produced in a coal-fired IGCC plant will be essentially hydrogen.

Acid Gas Removal Issues

In the absence of concern about removing CO_2, the target of IGCC operation is to route as much as possible of the CO_2 to the gas turbine by removing the H_2S with a maximum possible seal activity.

For the case where the major interest is to remove CO_2 as completely and economically as possible from the flue-gas, the requirements placed on the acid-gas removal system are entirely different, since the gas stream to be treated is syngas which is at a higher total pressure and contains a higher content of CO_2, hence the partial pressure of CO_2 in the gas is higher than in the case of flue-gas. Figure 10 compares the CO_2 absorption characteristics of different solvent types as a function of CO_2 partial pressure. Note that the curves for the chemical solvents (MEA and AMDEA) are steepest at low CO_2 partial pressures, and become nearly flat at the higher partial pressures. Such AMEA solutions are best suited for bulk removal of CO_2 at partial pressures up to approximately 0.5 MPa. At higher partial pressures of CO_2, the situation is rapidly approached where a CO_2 molecule will occupy every AMINE molecule so that, as a consequence, the circulation rate of the solution must be raised proportionately to the amount of CO_2 to be removed.

The curves for the selective physical solvents (such as, Selexol and Purisol, which are typically in conventional ICC gas purification), are shown in Fig. 10 and as can be seen they remove only small amounts of CO_2 from the gas while absorbing the H_2S. Figure 10 also indicates the absorption characteristics of the Rectisol process, which uses cold methanol, and which can be seen to achieve the highest loadings of the CO_2 above a CO_2 partial pressure of 0.5 MPa. At this partial pressure, the specific loading is approximately five times higher than for the selective solvents, which results in extremely low absorbent circulation rates. This absorbent appears to have the most
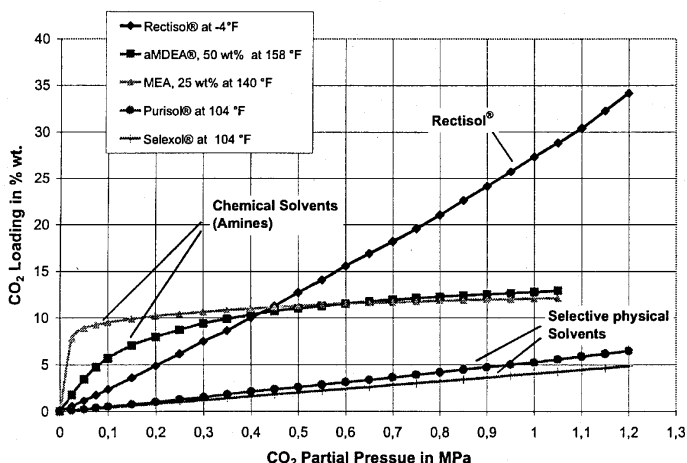

Figure 10. Absorption behavior of different solvent types

desirable characteristics of the absorbent examined for the removal of CO_2 from syngas.

Sorbent Regeneration
Regeneration of these sorbents typically is accomplished by simple flushing or thermal regeneration, which involves stripping by steam. The sorbent used in the physical absorbent processes can be regenerated to an extent greater than 90% by flushing, as indicated in Fig. 11. In the case of Rectisol, the very large high specific loading of CO_2 that is released by flushing leads to a sharp temperature drop (auto refrigeration effect) in which the temperature can fall to –98°F, which enhances the absorption process. For AMDPA, Fig. 2 indicates that at a feed gas CO_2 partial pressure of 1MPa, only 61% of the CO_2 can be released by flushing. This leads to the need for thermal regeneration, or to leaves of a very high circula-
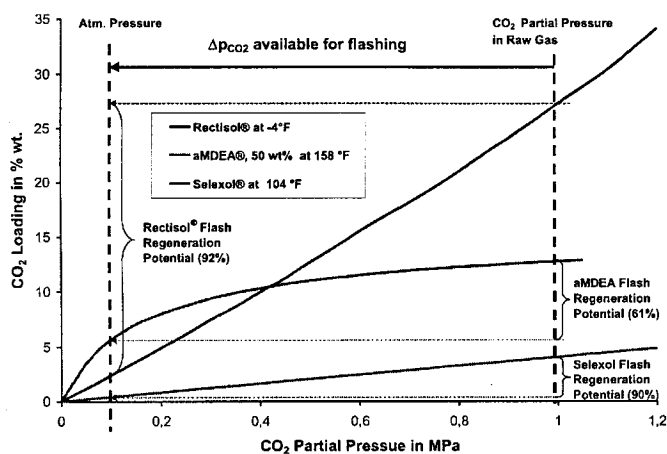
Figure 11. Flash regeneration potential of different solvents

tion rate, in conjunction with a high residual CO_2 content. For MEA, negligible regeneration is possible by flushing alone.

Further advantages of the Rectisol process are that gas desulfurization can be accomplished simultaneously with CO_2 removal, and other trace contaminants such as HCN, NH_3, CS_2, Fe and Ni carbonyls and mercaptans also are completely removed. Further, the extremely low process temperatures (approximately –18°F) at the top of the CO_2
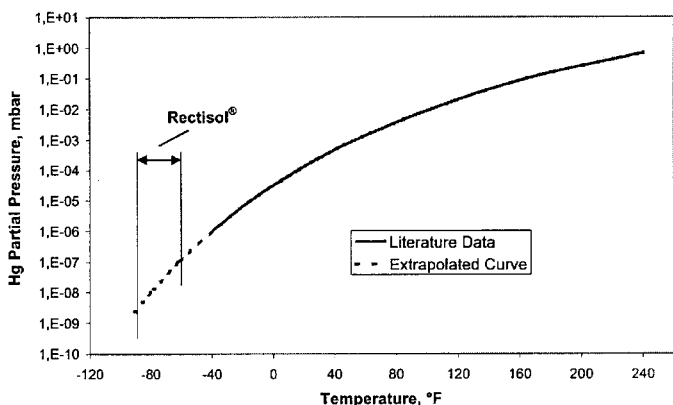
Figure 12. Mercury vapor pressure curve

Process Configuration
Lurgi has developed an integrated gas conditioning system intended to take advantage of the properties of the Rectisol physical absorbent for removing CO_2 and S from syngas. The elements of this system are indicated in Fig. 13, and incorporate the following main features:

• The CO-shift conversion is carried out after S-removal from the syngas in order to obtain high concentrations of H_2S in the acid gas routed to the oxy-Claus process, as well as to produce a pure CO_2 product by effective flash regeneration. H_2S and CO_2 removal using the Rectisol process with an integrated shift conversion is an industrially-proven scheme, which is often incorporated in oil- and coal-based syngas plants for methanol or ammonia syntheses.

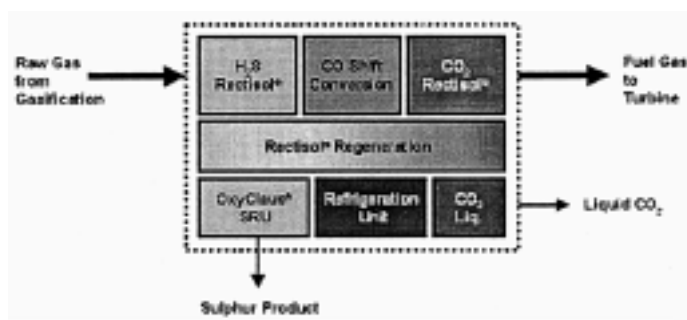• Depressurization from the gasification pressure to the

Figure 13. Elements of the gas conditioning package

gas turbine inlet pressure is accomplished using a turbine expander, which not only recovers energy from the gas, but also considerably cools the gas, so providing a major portion of the refrigeration requirement of the Rectisol process.

• A major portion of pure CO_2 is recovered at an elevated pressure of approximately 0.4 MPa, still minimizing the down-stream effort for compression and liquefaction needed before sequestration.

• The use of oxygen technology in the S-recovery (oxy-Claus) plant reduces the investment required in the S-recovery unit by approximately 30 percent, and also leads to relatively low tail gas flow rates. In this system, the tail gas is hydrogenated and recompressed for recycling to the raw syngas. As a result, the only source of gaseous emissions from this plant is the flue gas from the gas turbine. Such tail gas recompression technology has been in operation commercially for at least 2 years.

Calculations based on an IGCC plant with an electricity output of 500 MW, the de-carbonization process is expected to result in an efficiency drop of 6-8 percent compared to a conventional coal-based IGCC plant. The gas flows involved indicate that the gas conditioning

package could be a single-train design, based on absorbers that are in commercial operation. The projected flue gas emissions from such a plant are indicated in Table1. Inherent features of this process train are very low levels of SO_2, VOC, and mercury. The emissions of NO_x are expected to be very similar to those from a conventional IGCC plant, since they are produced during combustion in the gas turbine.

Abstracted from: U. Koss, and M. Meyer, Lurgi, Oel.Gas.Chemie GmbH, "Zero Emissions IGCC with Rectisol Technology," presented at the *Gasification Technologies 2002 Conference*, San Francisco, October 27-30, 2002

Meetings Calendar

October 13-15, 2003: The ASM *Materials Solutions 2003 Conference and Exposition* will be held at the David A. Lawrence Convention Center, Pittsburgh, Pennsylvania. Symposia include: fuel cell technologies; advances in powder metallurgy; cemented carbides and related hard metals; international conference on combustion turbine hot section components; recent technical advances introducing castings and cast ingots; failure analysis and prevention; protection against high-temperature environmental attack; international conference on joining of advanced and speciality materials; non-destructive inspection of high-,temperature alloys and the influence of processing and structure; and processing and fabrication of advanced materials. For information see the conference website at http://www.asminternational.org/materialssolutions.

October 28, 2003: *The 2003 Conference on Unburned Carbon in Utility Fly Ash* will be held at the Marriott City Center Hotel, Pittsburgh, Pennsylvania. The technical sessions will discuss case studies; control measures; predictive performance tools, including instrumentation; processing and utilization of high loss-on-ignition (LOI) fly ash; beneficiation of high LOI fly ash; and characterization of high LOI fly ash. For information, contact Karen Lockhart at NETL Event Management, P.O. Box 10940, MS 922-174A, Pittsburgh, PA 15236; 'phone: 412.386.4763; fax: 412.386.6486; or e-mail: Karen.lockhart@sa.netl.doe.job.

October 29-30, 2003: *The 2003 Conference on Selective Catalytic Reduction and Non-catalytic Reduction for NO_x Control* will be held at the Marriott City Center, Pittsburgh, Pennsylvania. The technical program includes sessions on ignition control strategies; commercial applications of selective catalysts reduction (SCR); SCR catalyst deactiviation and regeneration; SCR catalyst management; effects of mercury on SCR catalysts; reagent preparation and mixing; commercial application of selective non-catalytic reduction (SNCR); oxidation of SO_2-SO_3 across SNCR catalyst; non-coal applications of NO_x-reduction technologies; and alternative NO_x control technologies. For further information contact Karen Lockhart, NETL Event Management, P.O. Box 10940, MS 922-174A, Pittsburgh, PA 15236; 'phone: 412.386.4763; fax: 412.386.6486; or e-mail: Karen.lockhart@sa.netl.doe.job.

November 2-6, 2003: *The 12th International Conference on Coal Science* will be held at the Cairns Convention Center, Cairns, Queensland, Australia. The program will cover the following topics: coal resources; analysis and characterization; combustion, gasification, liquefaction, pyrolysis, and carbonization; metallurgical application; coal cleaning; low-rank coal; and coal products and by-products. For further information see the conference website at http://www.aie.org.au/iccs.

November 9-12, 2003: *The Materials Science and Technology 2003 Conference*, incorporating the *2003 Fall Meeting of The Minerals, Metals, and Materials Society*, and the *45th Iron and Steel Society Mechanical Working and Processing Conference*, will be held at the Hyatt Regency Downtown, Chicago, Illinois. Symposia will address: affordable metal-matrix composites for high-performance applications; casting and solidification of ferrous alloys; control of melt-related defects in high-temperature alloys; effects of processing on materials properties for nuclear waste deposition; frontiers of X-ray micro- and nano-beam diffraction; Pb-free and Pb-bearing solders; powder materials: current research and industrial practices; processing and properties of structural materials; processing and properties of structural nano-materials; austenite formation and decomposition; process control and optimization in the ferrous and non-ferrous industries; processing-structure-property-performance relationships; and structure-property relationships in high-performance ferrous-based systems possessing composite-like structures. For further information contact Diane Scheuring, TMS, 184 Thorn Hill Road, Warrendale, PA 15086; 'phone: 724.776.9000, ext. 220; fax: 724.776.3770; e-mail: mailto:dscheuring@tms.org.

November 10-12, 2003: The second international conference on *Integrity of High-Temperature Welds* will be held at the Institue of Materials, Minerals, and Mining, London. The eleven technical sessions will address: damage experience with welds at high temperatures; development of welds for high-temperature service; microstructures of weldments and influence of exposure; residual stresses in welds; overview of the EEC project: 'WELDON;' specialized test methods; influence of corrosion and oxidation on weld performance; numerical analysis; full-size component evaluation programs; creep crack growth; and design methods for

welds operating at high temperatures. For details, contact: Lisa Bromley, IOM Communications Ltd., 1 Carlton House Terrace London SW1Y 5DB, England; 'phone: 011.44.207.451.7302; fax: 011.44.207.839.1702; e-mail: lisa.bromley@iom3.org

November 15-21, 2003: The *2003 ASME International Mechanical Engineering Congress and RD&D Expo* will be held at The Marriott Wardman Park Hotel, Washington, D.C. The program includes sessions on advanced energy systems; energy; fluids engineering; fuels and combustion technology; heat transfer; materials; pressure vessels and piping; and tribology. For details, see the conference web site at: http://www.asme.org/congress.

November 18-19, 2003: A workshop on *Environmental Barrier Coatings for Microturbine and Industrial Gas Turbine Ceramics* will be held at the Gaylord Opryland Resort and Convention Center in Nashville, Tennessee. The Workshop is designed to bring together materials suppliers, turbine manufacturers and materials researchers to discuss the near-future use of high-temperature ceramics for various microturbine and industrial gas turbine applications. The first morning of the meeting will feature presentations by Saint-Gobain, Honeywell and Kennametal on the status of ceramics development of turbine application. The remainder of the meeting will focus on the development, characterization, and environmental testing of EBCs. Attendance at this meeting will be limited to U.S. Citizens and Lawful Permanent Residents only. Non-citizens wishing to attend will need to contact Roxanne Raschke at (865) 574-8860 or e-mail raschkera@ornl.gov to provide additional information for the clearance process. Please note that clearances can sometimes take 2 weeks to process. Firther information is available from: Dave Stinton, 'phone: (865) 574-4556, or Roxanne Raschke, 'phone; (865) 574-8860. The workshop has a website at: https://www.ms.ornl.gov/DER/default.html.

November 19-21, 2003: An EPRI-sponsored *International Conference on Materials and Corrosion Experience For Fossil Power Plants* will be held at the Wild Dunes Resort, Isle of Palms, South Carolina. The major goal of the conference is to review, document, and transfer technology from recent experience and developments in understanding the mechanisms, root causes of failures, assessment methodologies, remedial actions, and application of permanent solutions. Presentations will be made by U.S. and foreign utilities, equipment manufacturers, and consulting/research organizations. The technical program will include sessions on: metallurgical characterization methodologies; high-temperature materials; low-temperature corrosion; and high-temperature corrosion. For details, contact: Melissa Wade, Conference Coordinator, EPRI, 1300 W.T. Harris Blvd., Charlotte, NC 28262; 'phone: 704.457.6176; fax: 704.547.6109; or e-mail: melwade@epri.com.

December 1-4, 2003: The *World Conference on Corrosion and Corrosion Maintenance Expo* and Celebration of the Ninth Corrosion Awareness Day, Mumbai, India. See Materials & Components, No. 157 (Calls for Papers) for details.

March 7-10, 2004: The *First International Conference on Fuel Cell Development and Deployment* will be held at the University of Connecticut, Storrs, Connecticut. The intent of the conference is to provide a review of the technological, developmental, and manufacturing status of all types of fuel cells worldwide. In addition, discussion of the progress of pre-commercial installations in both stationary and mobile markets will be facilitated. Abstracts and papers are due on December 15, 2003. The areas of interest include technology aspects including materials; stack and cell issues; balance of plant issues; catalysts; modeling, reliability and durability; fuel cell systems, including molten carbonate fuel cells, solid oxide fuel cells, phosphoric acid fuel cells, PEM fuel cells, and others; demonstration activities; production and scale-up of fuel cells; consumer and OEM issues; the fuel cell infrastructure; and government and policy issues. All questions should forwarded to Laurie Enderle, School of Engineering, 261 Glennbrook Road, Unit 2237, University of Connecticut, Storrs, CT 06269-2237; 'phone: 860.486.3295; fax: 860.486.2269; or e-mail: ctfuelcell@engr.uconn.edu. The conference also has a website at http://www.ctfuelcell.uconn.edu/scic/.

April 19-23, 2004: The *International Conference on Metallurgical Coatings and Thin Films* again will be held at the Town and Country Hotel, San Diego, California. The topics to be considered at the conference will include: coatings for use at high temperatures; hard coatings and vapor deposition technologies; optical thin films; carbon and nitride materials; tribology of coatings and thin films; coating and thin film characterization; applications, manufacturing, and equipment; new horizons in coatings and thin films; principles of pulsed plasmas; self organization and surface response effects in thin film technology under operation; the atomistics of thin film growth; computation and experimental studies; and coatings and thin films for biomedical applications. Each of these symposia will include both oral and poster presentations with up to eight parallel sessions. For information and reservation details, see the conference website at http://www.abs.org/conferences/icmctf/coal.

November 1-4, 2004: *The 2004 International Gas Research Conference* will be held at the Vancouver Conference Centre, Vancouver, British Columbia, Canada. The conference will feature research topics of relevance to the natural gas industry, which will include: gas resources, production, and processing; transmission; distribution; residential and commercial utilization; industrial utilization; general basic research and new topics. For further information, contact Christopher Esson, 1700 South Mount Prospect Road, Des Plaines, Il 60018-1804; 'phone: 847.768.0816; fax:

847.768.0842; e-mail: igrc2004@gastechnology.org. The conference also has a website at http://www.igrc2004.org.

November 17, 2004: The U.S. Department of Energy's (DOE) Office of Fossil Energy will hold it's *Clean Coal and Power Conference* at the Ronald Reagan International Trade Center in Washington, D.C. The conference will be held in conjunction with the *2ⁿᵈ Joint U.S.-People's Republic of China Conference on Clean Energy*, to be held on November 18-19. Technical sessions of the conference will overview the clean coal power initiatives in the U.S. and People's Republic of China, as well as oil, gas, and clean fuel programs; environmental technologies; and climate science. For further information contact: Faith Cline, 'phone: 202.586.7920; fax: 202.586.0734; or e-mail: mailto:faith.cline@hq.doe.gov. Details of the conference can be found on the DOE Fossil Energy website at http://fossil.energy.gov/news/events/cleancoal/index.html.

Calls for Papers

April 18-22, 2004: The *29ᵗʰ International Technical Conference on Coal Utilization and Fuel Systems* will be held at the Sheraton Sand Key Hotel, Clearwater, Florida. Abstracts for papers are to be submitted by December 1, 2003, by email to barbarasak@aol.com. The general topic areas are as follows: environmental and health aspects; advanced power systems and green coal technologies for electric utility applications at new and existing power plants; the utility perspective; opportunity fuels (utilization, properties, transportation, handling, characteristics, combustion/gasification, boiler performance, economics and regulations); domestic and worldwide coal resources quality issues; transportation issues; and international programs, featuring technical developments and programs. Information is available from: Barbara A. Sakkestad, Coal Technology Association, 601 Suffield Drive, Gaithersburg, MD 20878; 'phone: 301.294.6080; fax: 301.294.7480. The conference has a website at www.coaltechnologies.com.

October 26-28, 2004: The *4ᵗʰ EPRI/DOE International Conference on Advances in Materials Technology for Fossil Power Plants* will be held at the Hilton Ocean Front Resort, Hilton Head Island, South Carolina. Presentations will be made by worldwide utilities, equipment manufactures, alloy venders, forging shops, casting houses, universities, national labs, and consulting and research organizations on subjects that will include: plant economics; new materials development concepts; high-temperatures materials used in boilers and turbines in steam power plants; ferritic steels, austenitic steels, and nickel-based alloys; boiler tubes, headers, steam pipes, water walls; turbine rotors, blades, bolts, casings, valves, and high-temperature components. The issues to be addressed include creep; fatigue; toughness; corrosion; weldability; fabricability; coating and claddings; microstructures; advances in design; and field experience. Abstracts should be submitted by March 14, 2004 to: Melissa Wade, EPRI, 1300 W. T. Harris Boulevard, Charlotte, NC 28262; 'phone: 704.547.6176; fax: 704.547.6109; or e-mail: melwade@epri.com.

A Word From Our Sponsor...

At the start of and during this fiscal year, EPRI has suffered a shortfall in income which has led to the need for a major restructuring of the funding of its projects in Strategic Science and Technology. As a result, EPRI reluctantly has decided to withdraw from support of this Newsletter. In light of these straitened circumstances, we have made some changes to try to further reduce the cost of preparing the Newsletter, and intend to continue publication at a reduced rate of four issues per year instead of the previous six.

We intend to continue at present to send out hard copies of each issue to readers on our North American mailing list. Readers also should note that the six most recent issues, as well as a searchable index of article titles and authors, are posted on the ORNL Fossil Energy Program website at: http://www.ornl.gov/fossil/. In some circumstances, the web copies may be missing some articles (pages may be left blank) due to a continuing copyright issue with the publishers of some of the journals from which our articles are abstracted. In such cases, we will supply a pdf file of the unexpurgated issue on request. The only way for foreign readers to access the Newsletter at present is via the web edition, but we are developing a mailing list for those who would like to receive a pdf version on a regular basis.