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Failed tube T91

Adjacent tube SS347

Failure of Super Heater Tubes (on Oxygenated Treatment)

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Failure of Super Heater Tubes (on Oxygenated Treatment)

Failure of Super Heater Tubes (on AVT (R) Treatment)

Failure of Reheater Tubes

Failure Mechanism	Probable Root Cause
Short term overheating in RH tubing	• **Tube blockage induced (especially exfoliated oxide blockage)** • **Maintenance induced (improper chemical cleaning or repairs)** • **Operation induced (improper startup or shutdown, or overfiring with top heater out of service)**
Long term over-heating/creep	• Influences of initial design and/or material choice • Buildup of internal oxide scale • Overheating due to restricted flow caused by chemical or other • Deposits, scale, debris, etc. • Operating conditions or changes in operation • Blockage or laning of boiler gas passages • Increases in stress due to wall thinning
RH Fireside Corrosion (Sootblower or Ash)	• Influence of overheating of tubes (poor initial design, internal oxide growth during operation, high temperature laning, tube misalignment, operational problems when coal is changed, and rapid startups causing reheater to reach temperature before full steam flow)

Failure of Reheater Tubes

Failure Mechanism	Probable Root Cause
RH Fireside Erosion	• Improper sootblower operation (control of frequency, temperatures, pressures, and travel; and mechanical malfunctions etc.) • Erosive coal ash characteristics • High gas flow velocities (gas lanes, boiler operation, etc.)
Dissimilar Metal Weld Failures (Failures occur where ferritic and austenitic steels are welded together)	• Excessive tube stresses such as caused by improper initial design or improper tube supports • Excessive local tube temperatures • Change in unit operation (increased unit cycling, change of fuel, redesign of adjacent heat duties) • Initial fabrication defects
Stress Corrosion Cracking	• Influence of environment (mainly contamination from carryover of chlorides from chemical cleaning of waterwalls, boiler water carryover, caustic from attemperator spray, condenser cooling water leaks, or ingress of fireside contaminants or flue gas during primary leaks) • Influence of excessive stresses (especially at supports) • Need to change material to a stabilized grade of stainless steel
Out of Service Corrosion	• Out of service internal corrosion damage is usually caused by dissolved oxygen pitting and is very common problem in reheaters.

➢ Scale exfoliation from the steam-side of superheater and reheater tubes can become a problem after some length of service (between 5 and 50kh).

➢ Most exfoliation (from superheaters, main steam line, reheaters) takes place during shut down; then, during start-up (especially at low loads), the exfoliated scale flakes are transported by the steam flow until either they settle out in tube bends, or they reach the turbine.

➢ High heat fluxes, flexing of the components, and creep of the substrate alloy also may be important.

➢ Ferritic steels, such as the 2.25Cr-1Mo alloys (T-22), are observed to undergo scale exfoliation during full cool-down and warm-up cycles, while the 300-series stainless steels typically exfoliate while cooling down.

➢ Recent experience suggests units that experience frequent shutdowns lead to more frequent exfoliation (probably in relatively small amounts)

There are four principal problems associated with the steam path in superheaters and reheaters:

➢ Exfoliation of the steam-side oxides.

➢ The reaction of steam with the steel tubes to form iron oxide which acts as an insulating layer to the transfer of heat. The net effect is to raise tube-metal temperatures which both exacerbates the fire-side problems and leads to early creep failures.

➢ Condensate that collects in the bottom of pendents and in sagged horizontal tubes that leads to oxygen corrosion & pitting.

➢ Weld backing rings or excessive root bead penetration that leads to restricted steam flow.

The exfoliation of steam side scale leads to turbine blade erosion and loss of efficiency. When pieces of oxide spall, the larger pieces collect at the bottom of pendants; and the smaller pieces become entrained in the steam. At the bottom of the circuit, tumbling and abrasion lead to more very fine particlesof oxide becoming entrained within the steam. These oxide particles then lead to turbine blade erosion and loss of turbine efficiency.

➢ The large flakes of oxide that are too big to be moved up the pendant with the steam flow collect at the bottom. When theunit is shut down, any fine oxide particles and condensate collect. When the unit restarts, the evaporating condensate and solid particles of scale siter to form an immovable mass. Locally, the scale acts as an insulating barrier to heat transfer. Net result is that the tube metal temperature is raised and creep damage or short term overheating may occur.
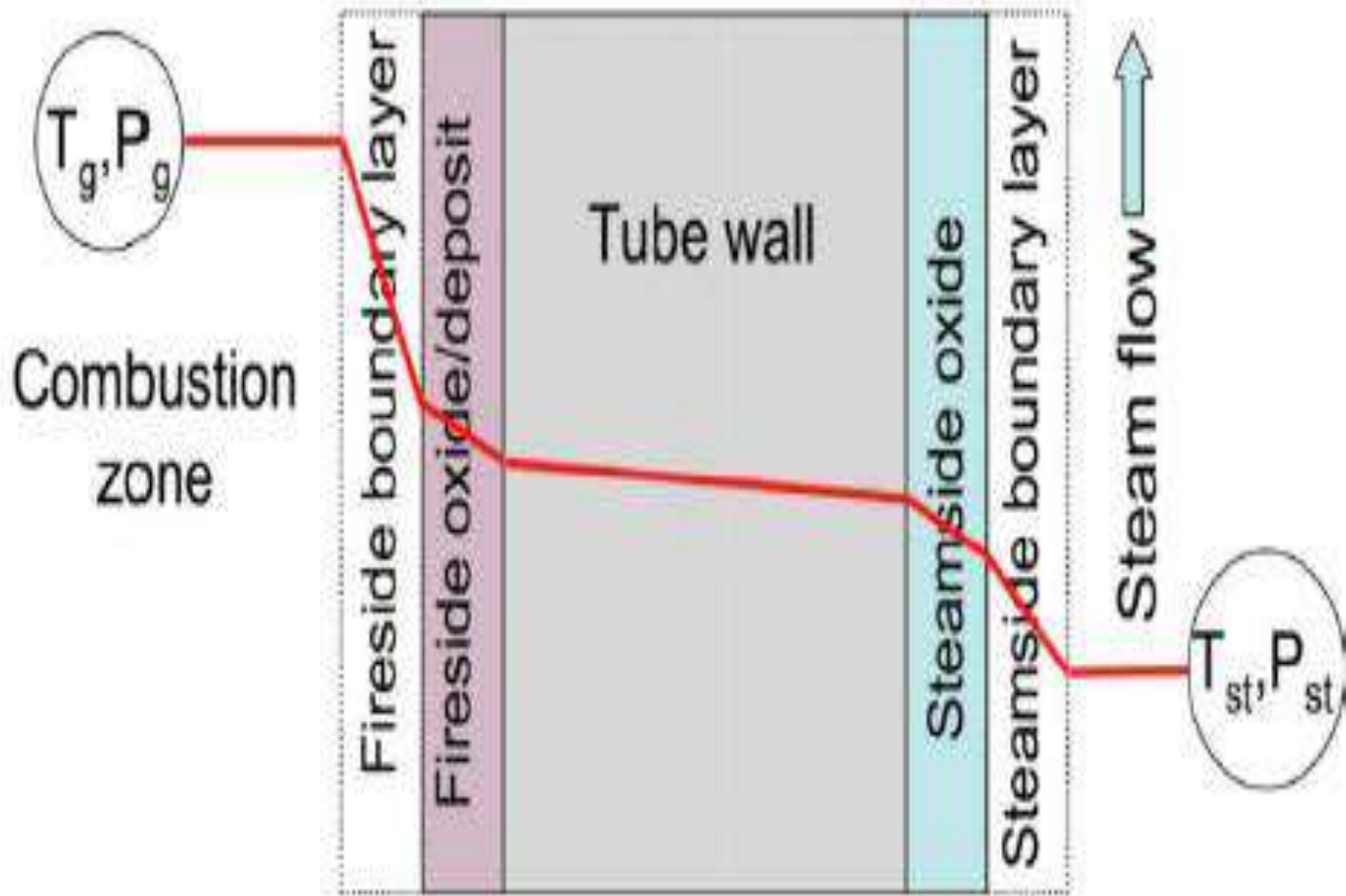
The reaction of steam with steel forms iron oxide, The rate at which the steam side scale develops is related to both the composition of the steel and the temperature of operation. The rate of oxide growth follows the parabolic law with operating temperature. **The increase in metal temperature as a result of the steam side scale formation depends on several factors such as the heat flux; the tube diameter & wall thickness; the thickness of the steam side scale.** The temperature increase is somewhere between 1 and 4 times the scale thickness. Thus **for a superheater with a fairly high heat heat flux, a thickness of 15 mils may raise the tube metal temperature between 50 oF and perhaps as much as 75 oF.**

For a reheater where the heat flux is lower, the increase in metal temperature is somewhat less, around 25 oF to 50 oF. In any case, the increase in tube metal temperature will exacerbate the fire side corrosion.

Any moisture in the steam leads to accelerated oxidation by steam. This requires controlled operation of attempretion spray. Sudden changes in heat fluxes should be avoided as this significantly affects the internal & external oxidation.
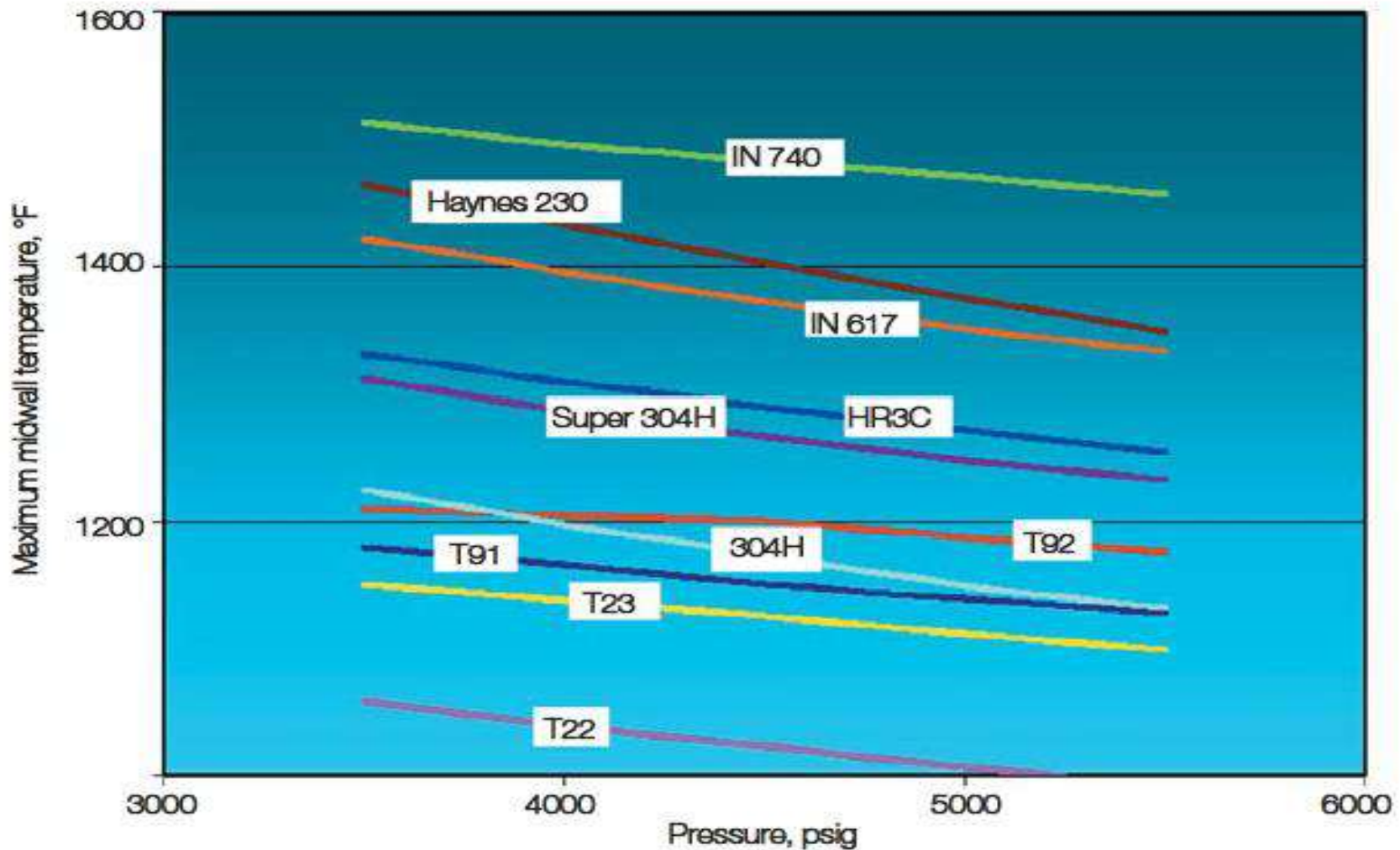
Combustion Effects

Fig. 2 — Maximum usage pressure/temperature. The best ferritic steel can go up to 620°C (1150°F). Developmental ferritics can reach 650°C (1200°F), austenitics can function up to 675°C (1250°F), and nickel alloys function above that, purely based on creep strength. Courtesy of Steve Goodstine,

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FACTORS AFFECTING OXIDATION AND EXFOLIATION

1. Mid-wall metal temperature – (most critical factor, affected by many factors).
2. Ramp-up/Ramp Down rates (higher than designed).
3. Heat distribution within the furnace (imbalance in heat).
4. Sudden changes in coal quality (Improper blended coals and use of coals for which boiler was not designed).
5. Internal & External fouling of tubes (fireside corrosion & internal corrosion).
6. Design tube thicknesses (considering the fuel used).
7. Lay up without drying the tube (condensed water in bends).
8. High attemperator spray (higher use of spray than designed).
9. Steam temperatures higher than permissible temperatures for metals in use (non-availability of metal temperature sensors on all tubes).
10. Conversion from one to another feed water chemistry without adopting chemical cleaning (> 1 year between cleaning & conversion) (Independent of Feed Water Chemistry otherwise).
11. Choice of material of construction (long term protection)

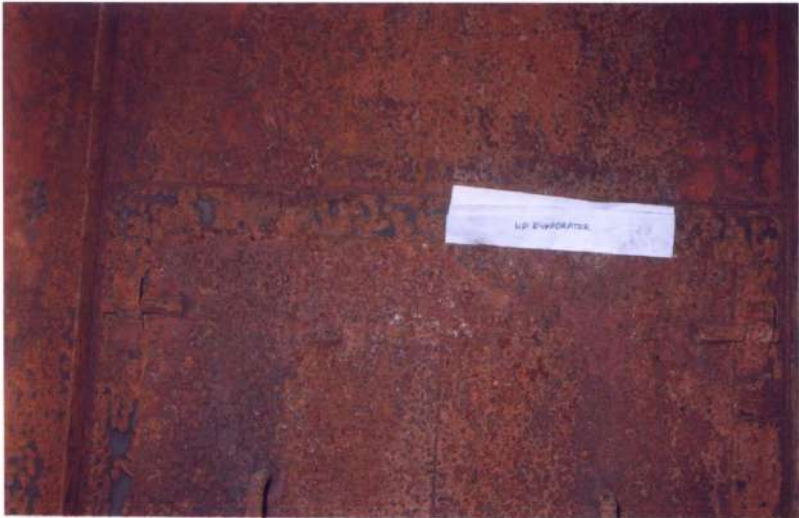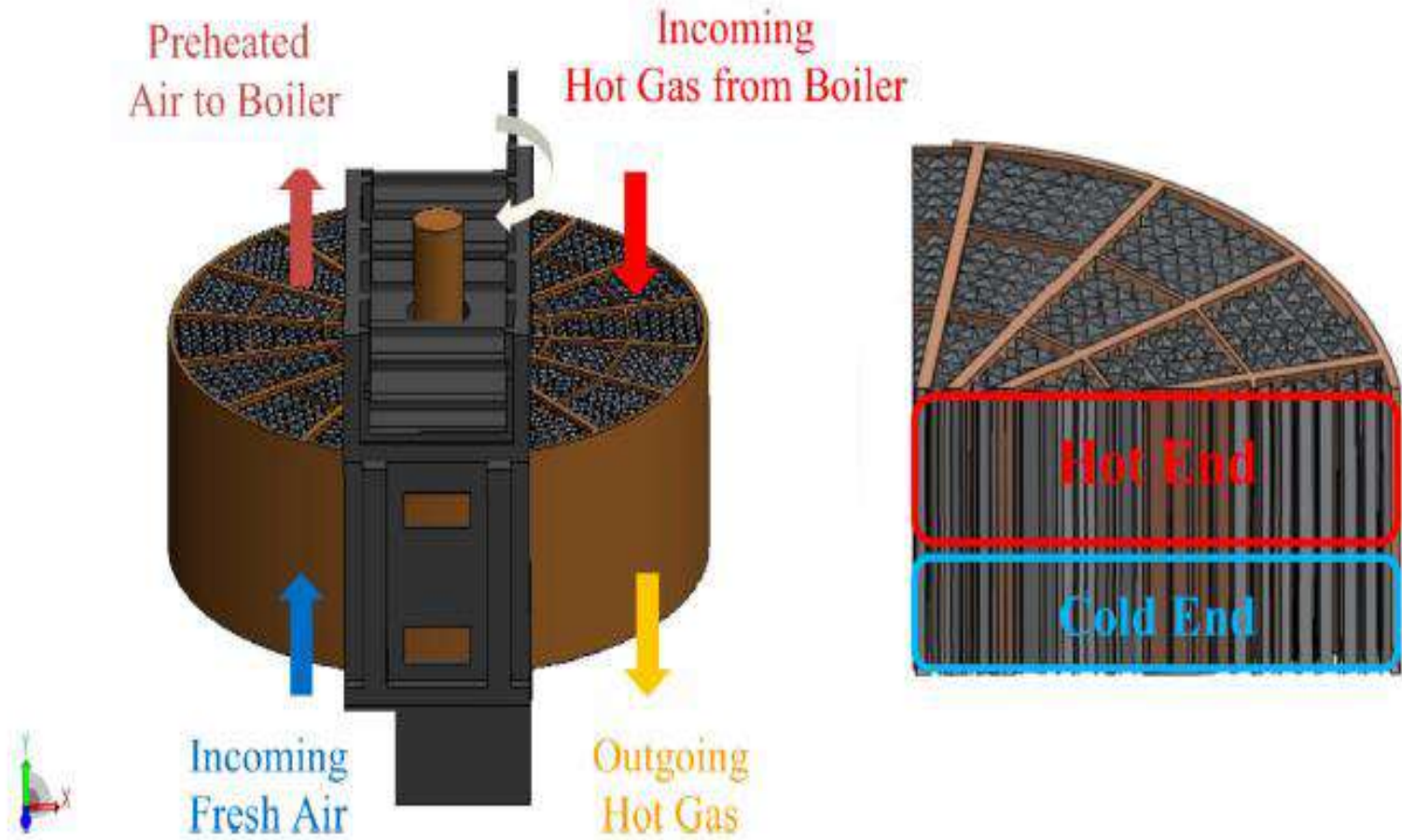# *Acid Dew Point Corrosion*

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Acid Dew Point Corrosion of Air Preheater

A schematic view of the rotary preheater,

Fouling and plugging of air preheater.,

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Loss on ignition (%)			
Temperature	105 ^{0}C	400 ^{0}C	815 ^{0}C
Loss on ignition	1.13	6.5	3.94

Chemical Analysis of deposit		
% Fe as Fe_2O_3	% Ca/Mg as CaO/MgO	% Acid Insolubles
84	4.5	11.5

Chemical Analysis of 1% water extract of Deposit						
pH	Cond	Chloride	Sulphate	Nitrate	Sodium	Potassium
	µs/cm	ppm	ppm	ppm	ppm	ppm
3.4	240	10	57.2	4	0.2	0.1

X-Ray Diffraction	
Phases Identified	FeO (OH), Fe_2O_3 (Sample amorphous in nature)

Acid Dew Point Corrosion of HRSG

S No.	PARAMETER		UNIT	HP EVA & ECO Dust (1.0 %) extract	CPH Area Dust (1.0 %) extract
1	Temperature		Deg C	25	25
2	pH			**2.86**	**2.73**
3	Conductivity		μS	**2297**	**3137**
4	Sulphate	As SO_4^{2-}	ppm	**1040**	**2400**
5	Sodium	As Na^+	ppm	2.9	4.2
6	Potassium	As K^+	ppm	0.3	2.3
7	Nitrate	As NO_3^-	ppm	**17.2**	**22.5**
8	Water Soluble		%	**12.00**	**31.6**
9	Acid Insoluble		%	**14.3**	**13.2**

Sample No.	Description	Fe (%) as Fe_2O_3	Na (%) as Na_2O	Si (%) as SiO_2	Cu (%) as CuO
C- 2084	HP EVA & ECO Area Dust	54.2	0.9	7.6	0.1
C- 2085	CPH Area Dust	40.0	0.5	7.7	0.1

Acid Dew Point Corrosion of HRSG

S. No.	Sample No.	Description	Phase identified
1.	C- 2084	HP EVA & ECO Area Dust	Fe_2O_3, $Fe^{+3}(OH)SO_4.2H_2O$, $FeO(OH)$
2.	C- 2085	CPH Area Dust	Fe_2O_3, $Fe_2S_2O_9.5H_2O$

Sample	Fluoride (ppm)	Chloride (ppm)	Nitrate (ppm)	Bromide (ppm)	Phosphate (ppm)	Sulphate (ppm)
1	Nil	3.17	7.00	Nil	Nil	43.67
2	Nil	1.89	0.812	Nil	Nil	2518.6
3	1.64	1.49	14.46	7.6	Nil	60.14
4	Nil	3.08	16.57	Nil	Nil	1190.8

Acid Dew Point Corrosion
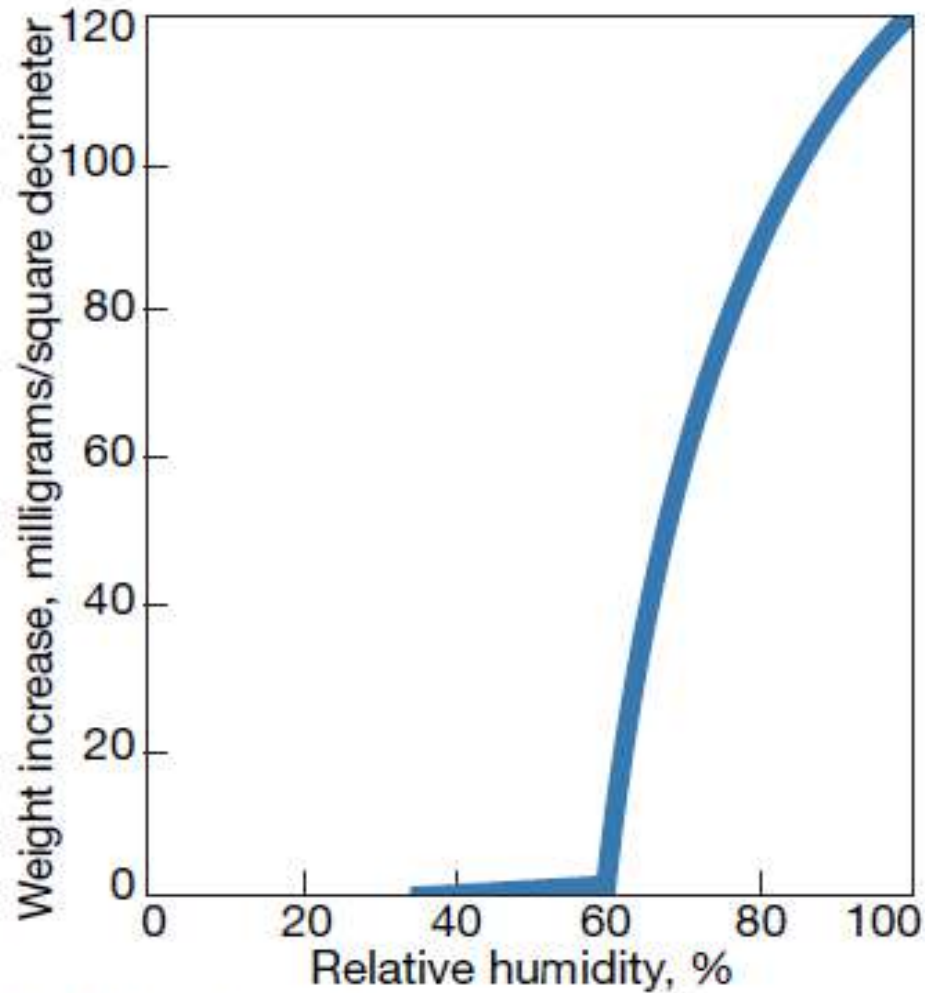
Relationship between corrosion rate and the moisture content of air shows the importance of maintaining relative humidity below about 40%.

Acid Dew Point Corrosion
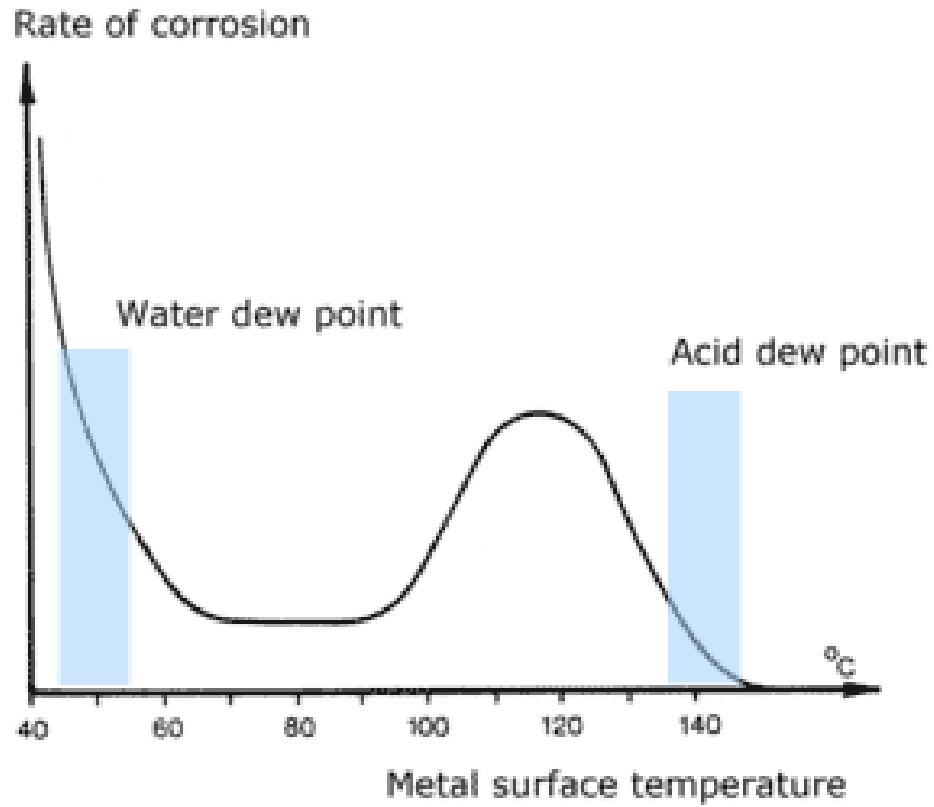
A: Dewpoint equation of SO$_3$ according to Verhoff:

T d=1000/{2.276 - 0.0294ln(PH2O) - 0.0858*ln(PSO3) + 0.0062*ln(PH2O*PSO3)}

B: Dewpoint equation of SO$_2$ according to Kiang:

Td=1000/{3.9526 - 0.1863*ln(PH2O) + 0.000867*ln(PSO2) - 0.00091*ln(PH2O*PSO2)}

C: Dewpoint equation of HCl according to Kiang:

Td=1000/{3.7368 - 0.1591*ln(PH2O) - 0.0326*ln(PHCl) + 0.00269*ln(PH2O*PHCl)}

D: Dewpoint equation of NO$_2$ according to Perry:

Td NO2 = 1000/(3.664 - 0.1446*ln(v%H2O/100*760) - 0.0827*ln(vppmNO2/1000000*760) +
0.00756*ln(v%H2O/100*760)*ln(vppmNO2/1000000*760)) - 273

Pressures (P) in the equations B, C and D are given in mm Hg; in equation A in atmosphere.

Calculated sulphuric acid dewpoint
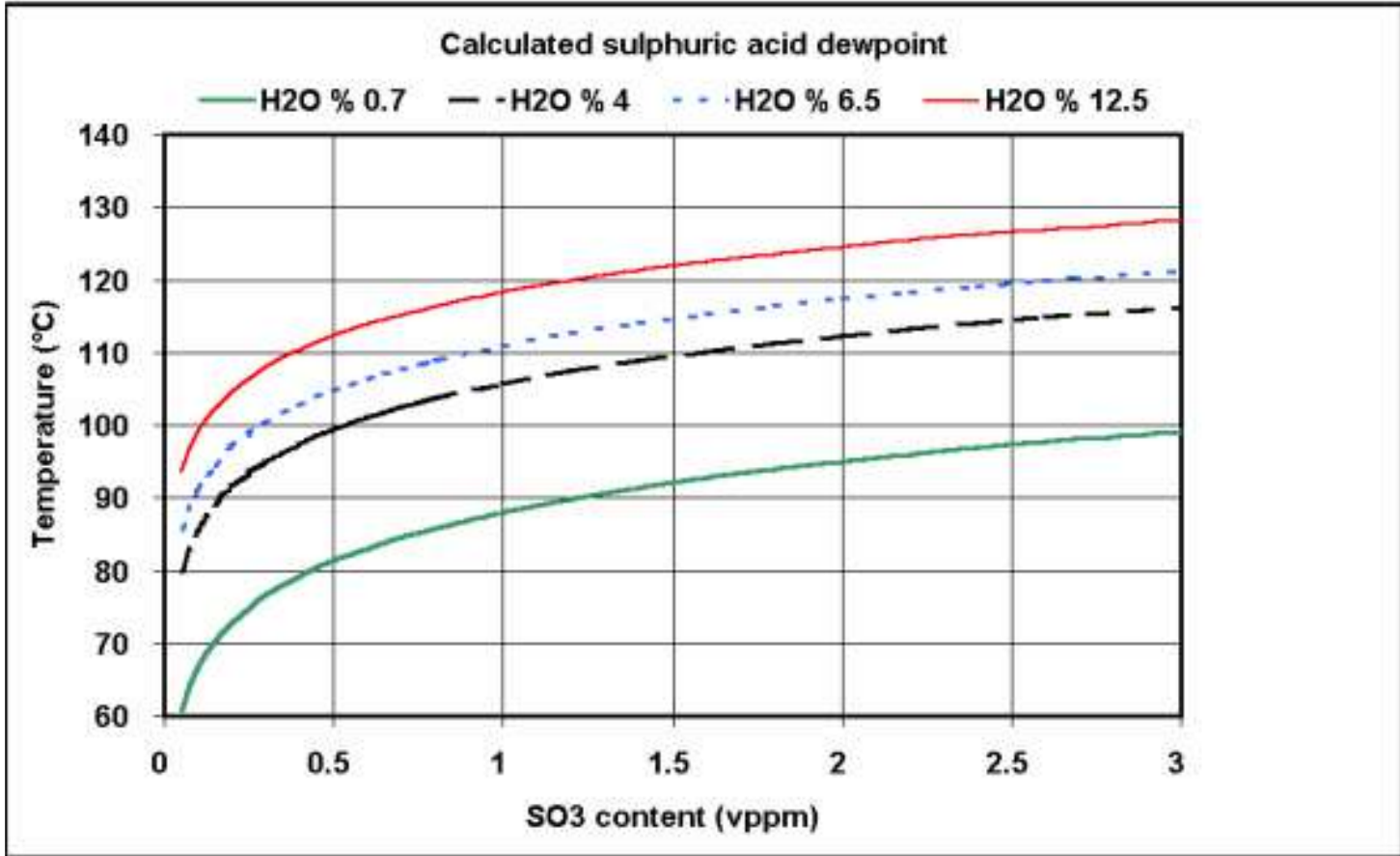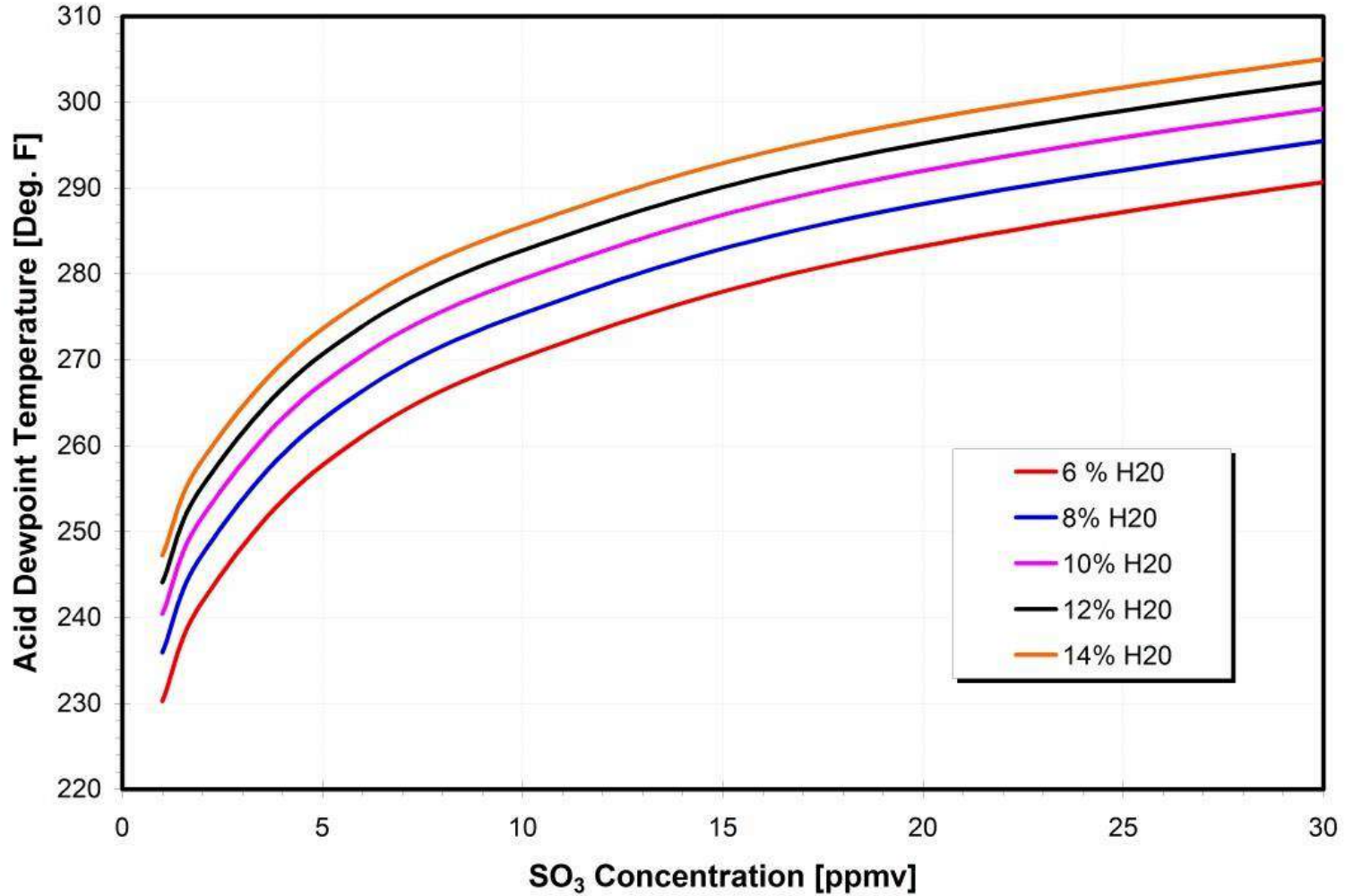
Dew points of SO$_3$ at various water contents of the gas, calculated from the formula of Verhoff.

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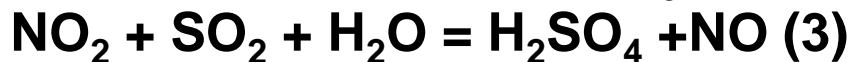**4**. Acid dewpoint temperature as a function of the SO_3 and H_2O concentration.
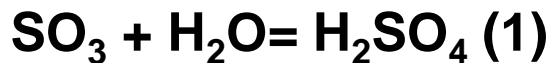*Source: Energy Research Center*

Coal is the fuel used in the majority of power-generation plants over the world.

However, on a global level, coal use accounts for a significant proportion of greenhouse gas emissions, particularly carbon dioxide (CO_2).

When sulfur-bearing fuel is burned, sulfur is converted to sulfur dioxide (SO_2) and sulfur trioxide (SO_3). The sulfur trioxide combines with moisture to form sulfuric acid (H_2SO_4) [See eq.(1)]. During combustion, some nitrogen is oxidized to form nitrogen dioxide (NO_2).

Nitrogen dioxide in the flue gas also reacts with water to give nitric acid [eq.(2)] and with sulfur dioxide and water to form more sulfuric acid [eq.(3)].

$$SO_3 + H_2O = H_2SO_4 \quad (1)$$
$$4NO_2 + 2H_2O + O_2 = 4HNO_3 \quad (2)$$
$$NO_2 + SO_2 + H_2O = H_2SO_4 + NO \quad (3)$$

Acid Dew Point Corrosion

If the flue gas is cooled sufficiently, condensation will occur and liquid will appear on surfaces at temperatures below the dew point.

The liquid phase will contain highly corrosive sulfuric acid. This causes sulfuric acid corrosion, so called low-temperature corrosion.

Low-temperature corrosion needs to be taken into consideration for optimum system design of exhaust gas treatment.
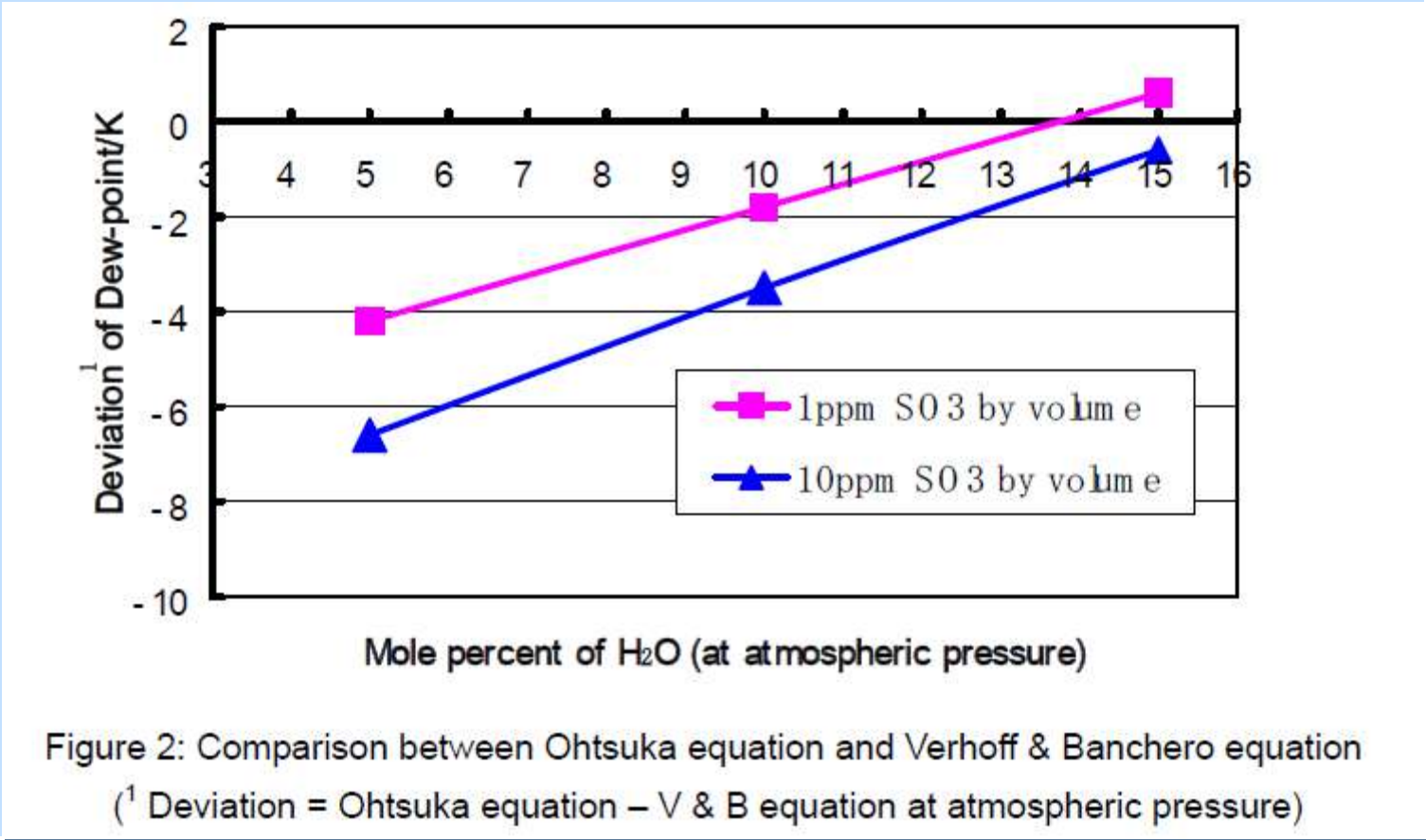
Problems with regard to the prediction of low-temperature corrosion result from the fact that the dew point of flue gases depends not only on the partial pressure of water, but also on the partial pressure of H2SO4. Existing prediction methods for dew points of flue gases are not comprehensive.

The main issues with regard to the dew point may be summarized as follows:

➤ Dew-point equations with experimental data for several flue gas compositions exist, but there are significant discrepancies among the results.
➤ Concentration of H_2SO_4 depends on the SO_3 conversion rate and on the surface temperature of the wall. Therefore, it is important to attempt to control SO_3 content and to predict precisely local surface temperatures.
➤ Reliability of dew-point estimation depends not only on the equation but also on the temperature measurement uncertainty such as an accuracy of duct surface temperature distribution. A precise measuring method is necessary.

A proper prediction of exhaust gas temperatures is required to ensure optimized overall performance and to minimize the potential for low-temperature corrosion.

Figure 2: Comparison between Ohtsuka equation and Verhoff & Banchero equation
([1] Deviation = Ohtsuka equation – V & B equation at atmospheric pressure)

Boilers generating Steam for use in power generation and process power plants use different type of fuels. These fuels contain sulphur to differing percentages. The higher the percentage of sulphur, the higher will be the risk of cold end corrosion in the boiler. The sulphur in the fuel during combustion gets converted to sulphur dioxide. Depending upon the other impurities present in the fuel and excess air levels, some portion of the sulphur dioxide gets converted to sulphur trioxide. The presence of moisture in the flue gas due to moisture in fuel and air, sulphur dioxide, and trioxide, combines with moisture and forms sulphuric acid and sulphuric acid. These acids condense from around 115 degree centigrade to slightly higher than 160 degrees, depending upon the concentration of SO_3 and water-vapour. The basic reactions taking place are

$$S + O_2 \rightarrow SO_2$$
$$SO_2 + O_2 \leftrightarrow SO_3$$
$$H_2O + SO_2 \leftrightarrow H_2SO_3$$
$$H_2O + SO_3 \rightarrow H_2SO_4$$
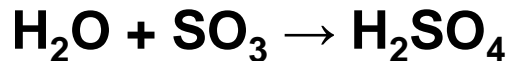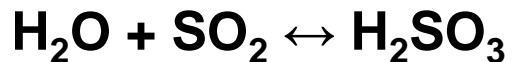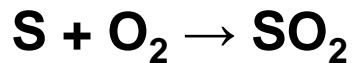
Acid Dew Point Corrosion

ELEVATED WALL TEMP. REDUCES CORROSION RATE*

Fig. 1

Peak corrosion
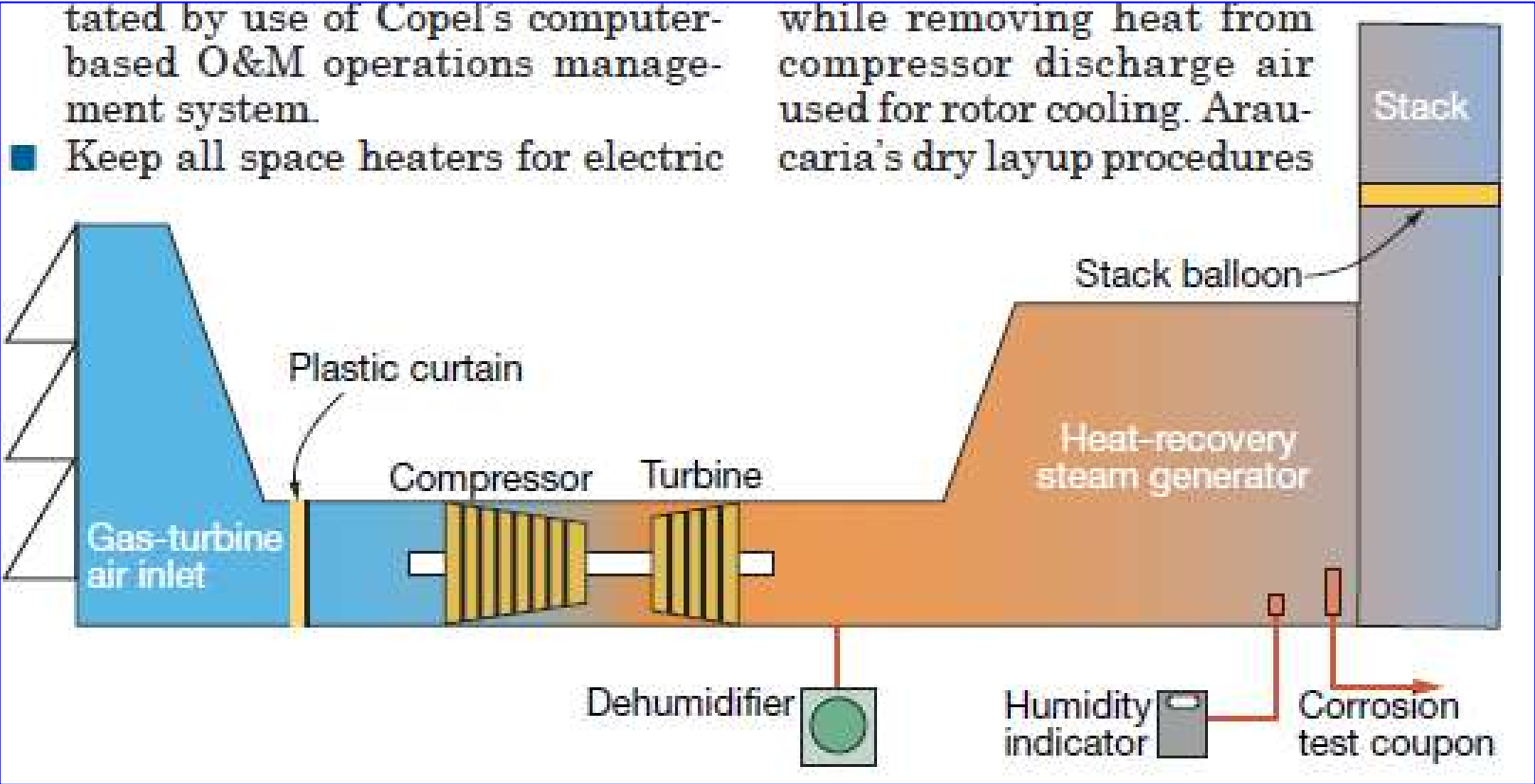
Dewpoint

Corrosion rate

100   110   120   130

Wall temperature, °C.
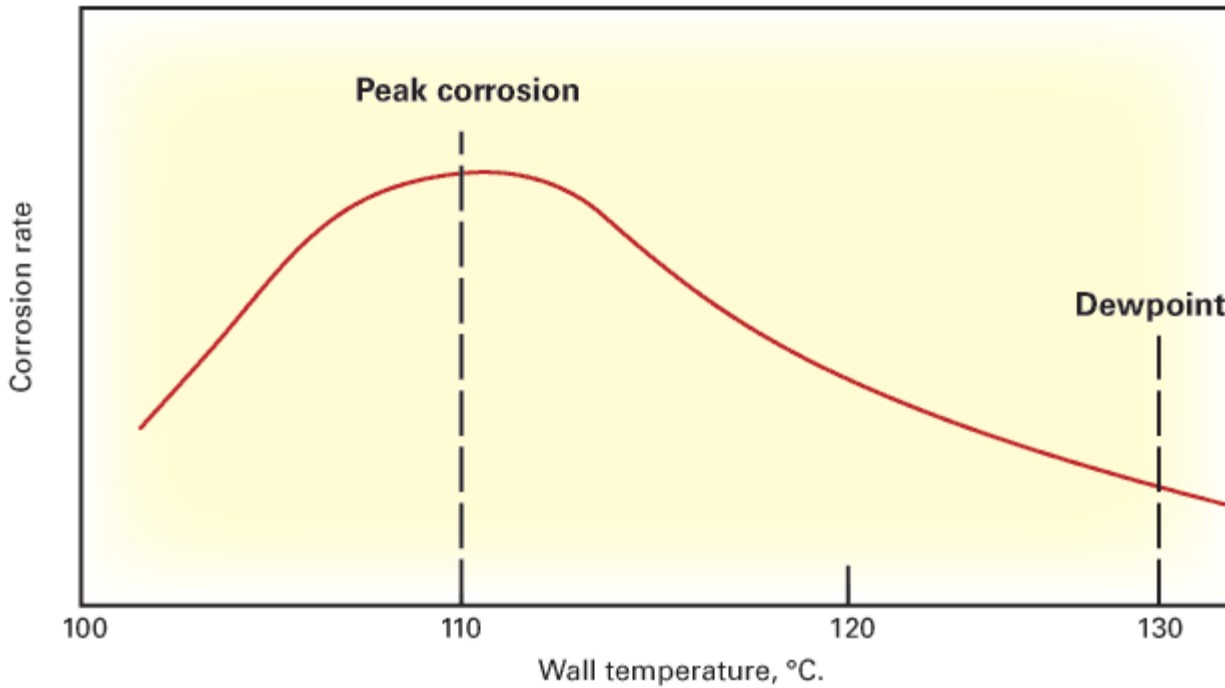
*Reference 3.

tated by use of Copel's computer-based O&M operations management system.
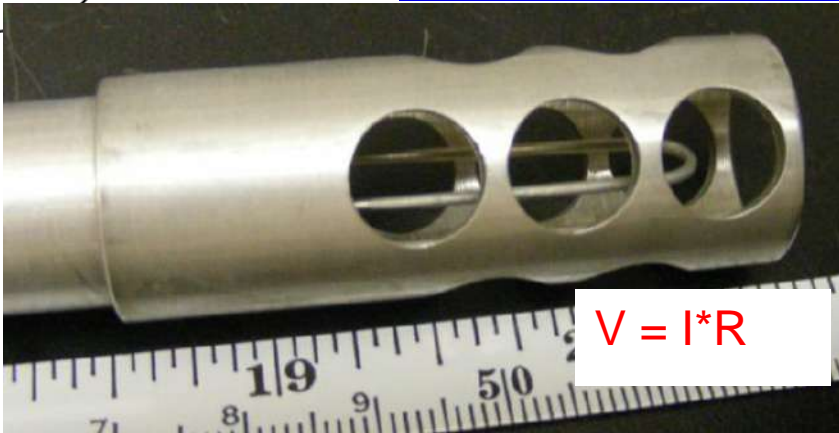
- Keep all space heaters for electric while removing heat from compressor discharge air used for rotor cooling. Araucaria's dry layup procedures
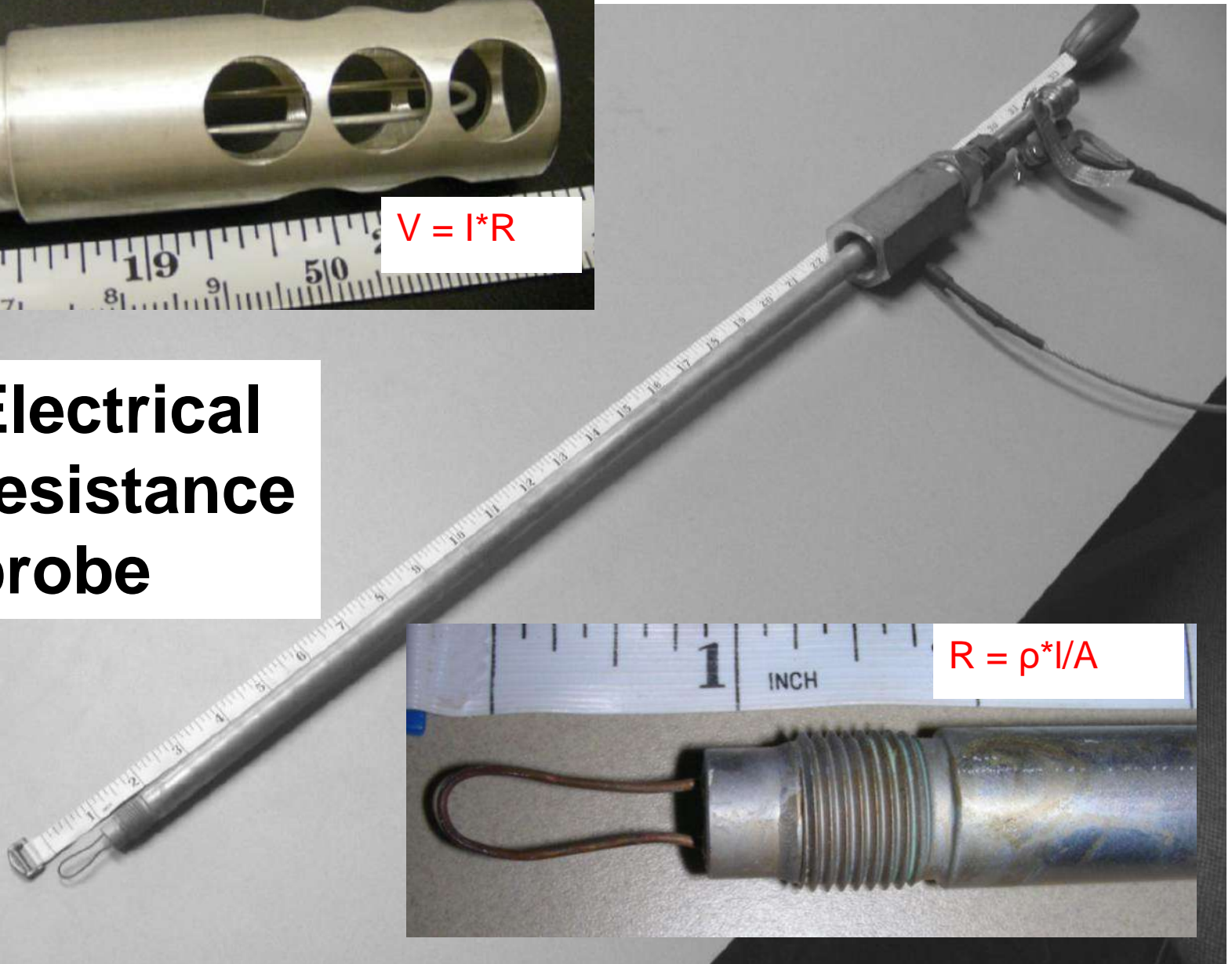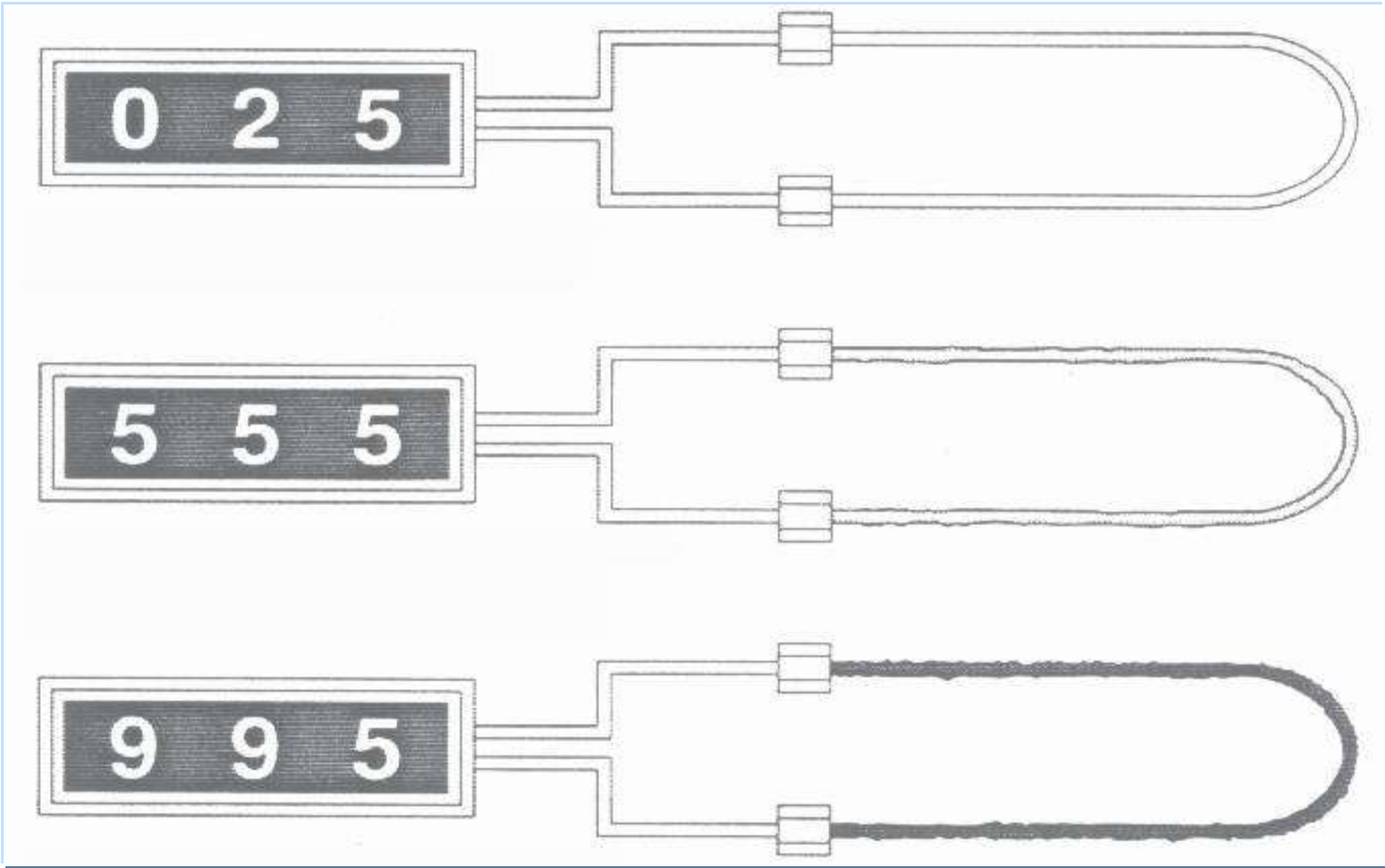
Installation of dehumidifier in HRSG

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$V = I*R$

Electrical resistance probe

$R = \rho*l/A$

Corrosion Monitoring

Online Corrosion Monitoring of HRSGs

➢ Application of Novolac Vinyl Ester Glass Flake coating 1000 – 1200 microns DFT on Structures of CPH and Stack Liners to improve life of the structures.

➢ To improve the performance of the HRSGs, there is a need to remove the deposited corrosion/flue gas condensation products from the boilers. Some methods of cleaning are indicated further.

➢ Proper preservation of water-side and gas-side portions of Boilers during shut down of the unit.

➢ Prevent ingress of humidity & rainwater into the HRSG systems. One possible method of keeping the gas side system dry is to install duct balloons at the entrance of HRSG from gas turbine and in the stack.

➢ It might be worthwhile to install online corrosion monitoring system to keep a check on the corrosion initiation, progress and control.

➢ Ceramic Enamel lining of Air-Preheater Baskets on the Cold End

➢ Waste Heat Recovery from Flue Gas for preheating and other applications

Waste Heat Recovery From Flue Gas

Following proximate analysis of coal sample has been taken for the studies:

FC = 30.02, M = 11, VM = 22.69, Ash = 36.29

Further; S = 0.33, FCO_2 = 0.998, FCO = 0.00059, O_2 = 2.68,

HHV = 33429.62 KJ/Kg

Coal consumption in tph = 130.548138

Raw Coal analysis

NET O2 = 4.789688

Excess air in % = 14.628821

Theoretical air fuel ratio = 6.605937Kg/Kg of fuel

Actual air fuel ratio = 7.572308Kg/Kg of fuel

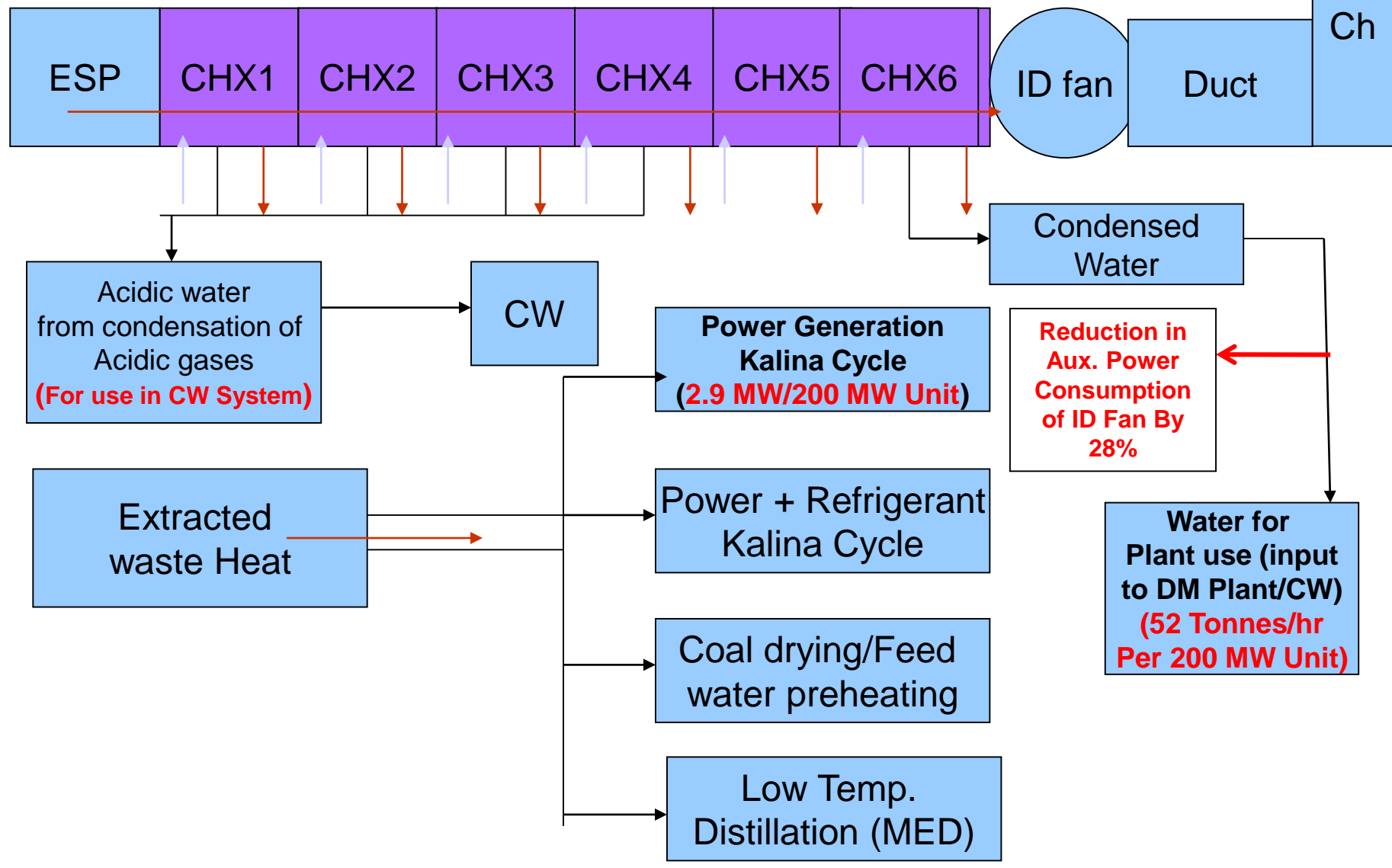**FLUE GAS ANALYSIS**

CO2 = 18.49709

CO = 0.005468

SO2 = 0.047715

N2 = 78.393008

O2 = 3.056719

Theoretical

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ESP | CHX1 | CHX2 | CHX3 | CHX4 | CHX5 | CHX6 | ID fan | Duct | Ch

CO_2 + N_2

Acidic water from condensation of Acidic gases (For use in CW System)

CW

Condensed Water

Power Generation Kalina Cycle (2.9 MW/200 MW Unit)

Reduction in Aux. Power Consumption of ID Fan By 28%

Extracted waste Heat

Power + Refrigerant Kalina Cycle

Water for Plant use (input to DM Plant/CW) (52 Tonnes/hr Per 200 MW Unit)

Coal drying/Feed water preheating

Low Temp. Distillation (MED)

Conceptual project on Moisture Extraction from Flue gases

Pilot Test Heat Exchanger

Experimental Set up at Station A

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CONCLUSIONS

CONCLUSIONS

➢ Emission control systems are yet to be installed on all units especially subcritical units, so first hand experience of effect of flexible operation on these systems is not known.

➢ Studies and modelling conducted by various organizations indicates negative impact of Flexible Operation on emission control systems.

➢ Cyclic operation and poor lay-up procedures affect the performance of components in cycle chemistry systems. Guidelines have been developed by US EPRI and VGB for proper lay-up and start-up of Cycle Chemistry for cyclic units.

➢ Improved monitoring and controls can help in managing transients during flexible operation, however; for some systems it may be necessary to augment the existing systems for meeting the requirements during flexible operation.

➢ Some research was carried out for extraction of moisture which can help during flexible operations. Further studies may be carried out

CONCLUSIONS

➢ Some effects of flexibility on Environmental Pollution Control Systems, acid dew point corrosion and on failures of SH, RH due to changes in flue gas temperatures and frequent start-up or shut down temperature changes in steam are discussed.

➢ Some research was carried out for extraction of moisture and waste heat recovery which can help during flexible operations. Further studies may be carried out.

➢ During Cyclic operations of the units guidelines such as those from VGB S 010 and EPRI 1021767 should be used for operating boiler water treatment

➢ During shut down the plant systems shall be properly preserved as per EPRI 1015657 or VGB S 116

Conserve Resources

Thank You