CHX Heat Recovery – THE Solution

Steam Plant Systems, Inc.

CHX – THE SOLUTION

- Welcome & Introduction
- What is a Condensing Heat Exchanger?
- Design Considerations & Corrosion
- Typical System P&ID's
- Fuels Fired & Tube Selection
- Company History
- Manufacturing
- Independent Research
- Is Flue Gas Side Corrosion Really a Concern When Firing on Natural Gas?
- Conclusion, Summary, & Performance Example

INTRODUCTION

Genivar Ontario, Inc.
Enbridge Gas Distribution, Inc.
Union Gas, LTD

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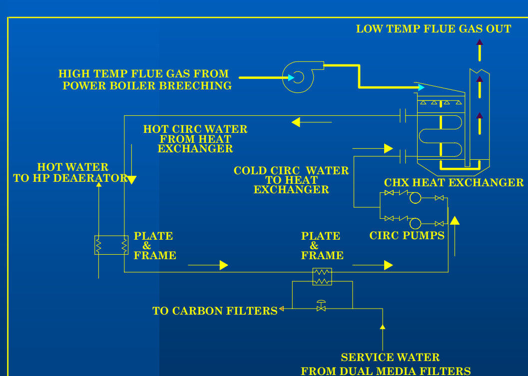
Condensing Heat Exchanger Corp.



Proven Track Record

- **Boiler Flue Gas Heat Recovery**

WHAT IS A CONDENSING HEAT EXCHANGER?

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Definition of "Condensing Heat Exchanger"

A heat exchanger designed to recover heat from a hot exhaust gas stream by lowering the gas temperature to a value below both the acid vapor dew point and the water vapor dew point.

DESIGN CONSIDERATIONS & CORROSION

- Natural Gas
- Fuel Oil
- Condensation

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QUESTION

- Is the condensate formed in a condensing heat exchanger from the combustion of natural gas corrosive?
- How about from the combustion of fuel oil?

- THE FACT IS THAT BOTH ARE

EXTREMELY CORROSIVE!

What are the acid and water vapor dew points?

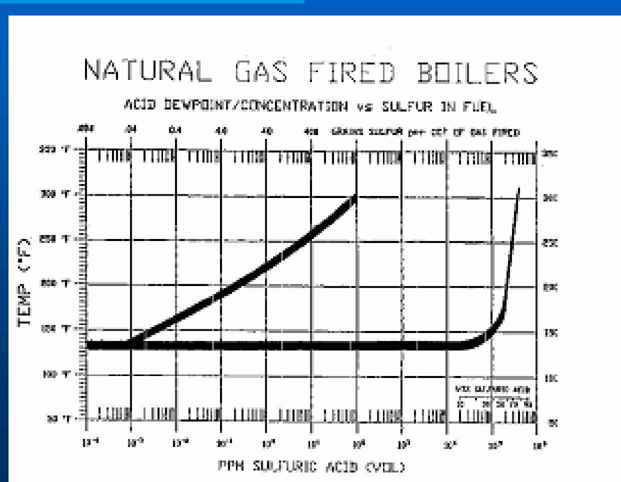
NATURAL GAS

Acid Dew Point ~ 130-170F due to Sulfur in the gas (0.04 – 0.4 Grains/CCF or 1.1 – 11.3 PPM) + ambient chlorides in the air.
Water Vapor Dew Point is ~ 135F depending on E.A.

FUEL OIL

Acid Dew Point ~ 150-250+ depending on S in fuel
Water Vapor Dew Point ~ 110-115F

Natural Gas Dew Point Curve



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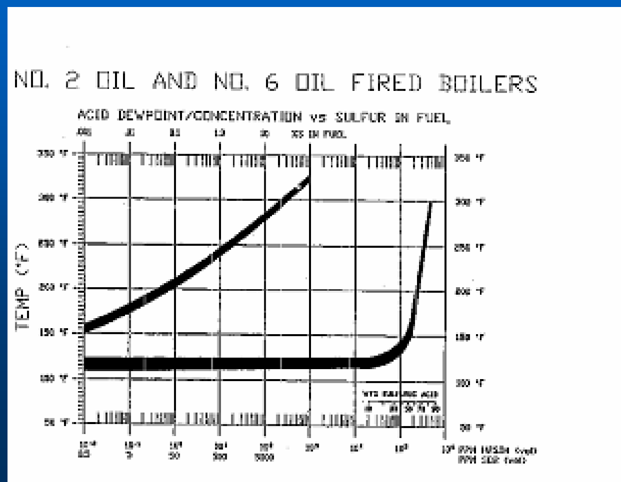
Fuel Oil Dew Point Curve



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When does condensation take place?

When the bulk gas stream temperature falls below the acid or water vapor dew point

OR

Whenever the gas stream contacts a heat exchanger tube surface that is below either the acid or water vapor dew point.

TYPICAL SYSTEM P&ID’s

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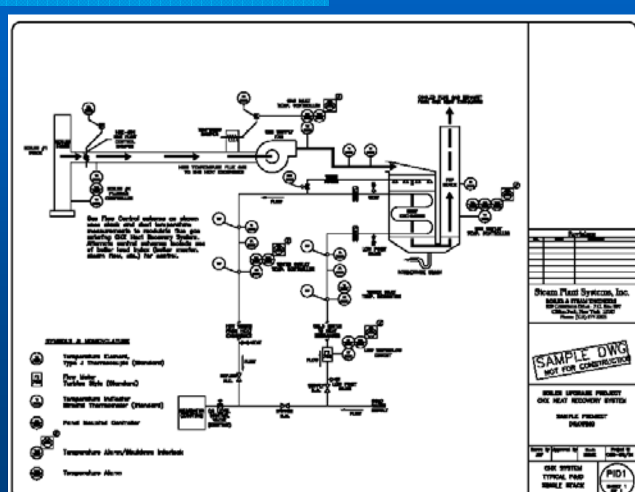
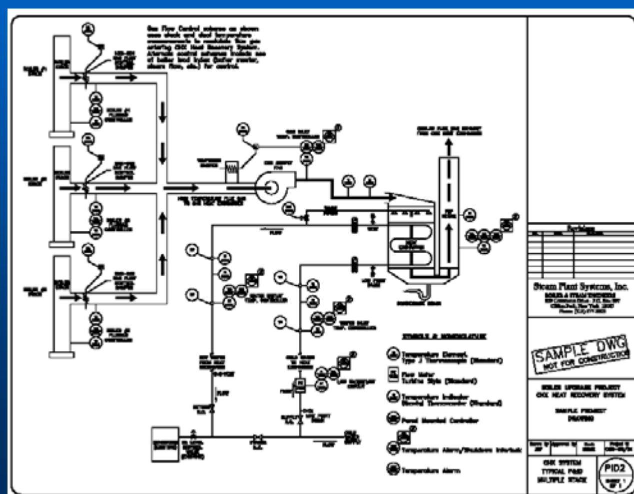
1 Boiler P&ID



3 Boiler P&ID



FUEL FIRED & TUBE SELECTION

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Can a Condensing Heat Exchanger Be Considered for Exhaust Gas Heat Recovery From Any Fired Fuel?

ABSOLUTELY

As long as it is properly designed and constructed.

- **Bare Tube Design – All fuels including, Natural Gas, Biogas, Fuel Oils, Wood, Bark, Sludge, Refuse, Coal, TDF, Solvents, etc.**
- **Finned Tube Design – Natural gas only***

* - Water outlet temperature limits apply

COMPANY HISTORY

- **Mission**
- **Experience**
- **Capabilities**

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CHX Company History

- Condensing Heat Exchanger was founded in 1977
- Company Mission
  - Flue gas heat recovery operating below the acid & water vapor dew points
  - Provide equipment design which is unrestricted by boiler fuel selection and operating outlet water temperature
  - COMPANY EXPERIENCE – 31 YEARS

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Company Experience

- 31 year proven track record in MANUFACTURING (NOT Subcontracting) CHX systems for low temperature flue gas heat recovery
- Customers with systems in continuous operation since 1980
- Any Fuel – Any Temperature
  - Oil, Natural Gas, Biogas, Wood, Sludge …
  - Exhaust gas outlet temperatures below 100F

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CHX IN HOUSE CAPABILITIES

- All Engineering & Design
- COMPLETE Heat Recovery System Fabrication & Assembly
- Control System Fabrication & Integration
- Site Assembly, Start up, & Training

- CHX DOES NOT SUBCONTRACT HEAT EXCHANGER FABRICATION

MANUFACTURING

- Teflon COVERED Surfaces
- Quality Control
- Tube to Tube-Sheet Seals
- Simple Proven Design

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Equipment Design

- Complete Corrosion Protection
- Teflon Covered Surfaces
  - Tubes
  - Tube Sheets
  - Side Sheets

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Teflon Covered Surfaces

- All tubing material used in the heat exchanger construction is protected from flue gas corrosion by an extruded 15 mil Teflon Covering

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Teflon Covered Surfaces

- All tube sheet and side sheet surfaces are protected from flue gas corrosion by an applied 60 mil Teflon Covering

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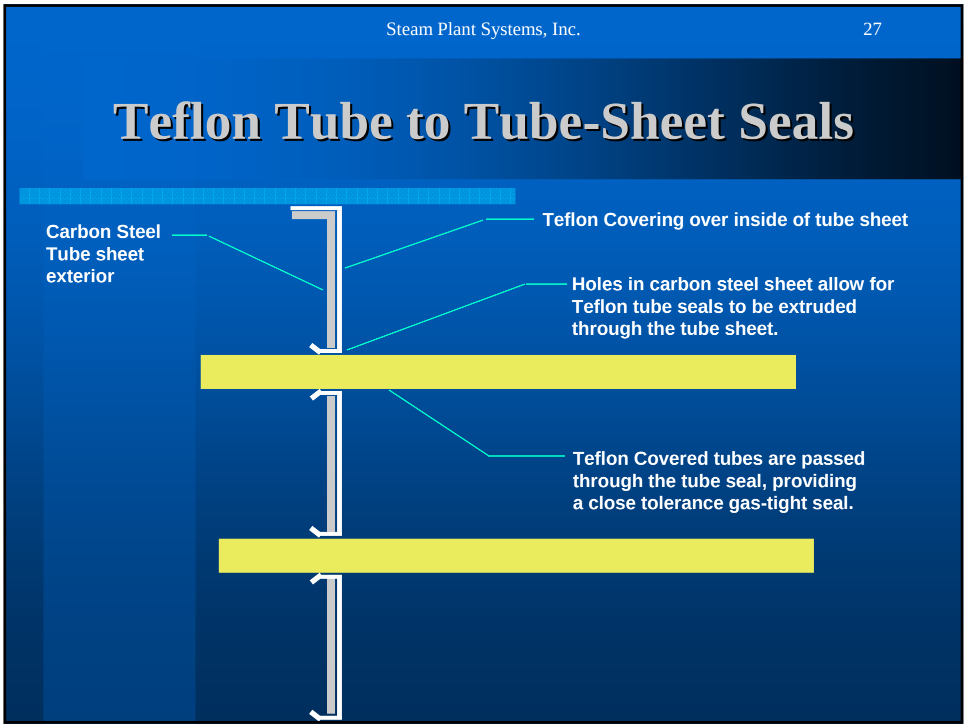
Quality Control

- On any application with sulfur bearing fuels (including natural gas), any metal tube exposure to flue gas will result in rapid failure due to aggressive corrosive attack

- CHX tubes are 100% Teflon Covered & tested during the extrusion process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Teflon Tube to Tube-Sheet Seals
Carbon Steel Tube sheet exterior
Teflon Covering over inside of tube sheet
Holes in carbon steel sheet allow for Teflon tube seals to be extruded through the tube sheet.
Teflon Covered tubes are passed through the tube seal, providing a close tolerance gas-tight seal.


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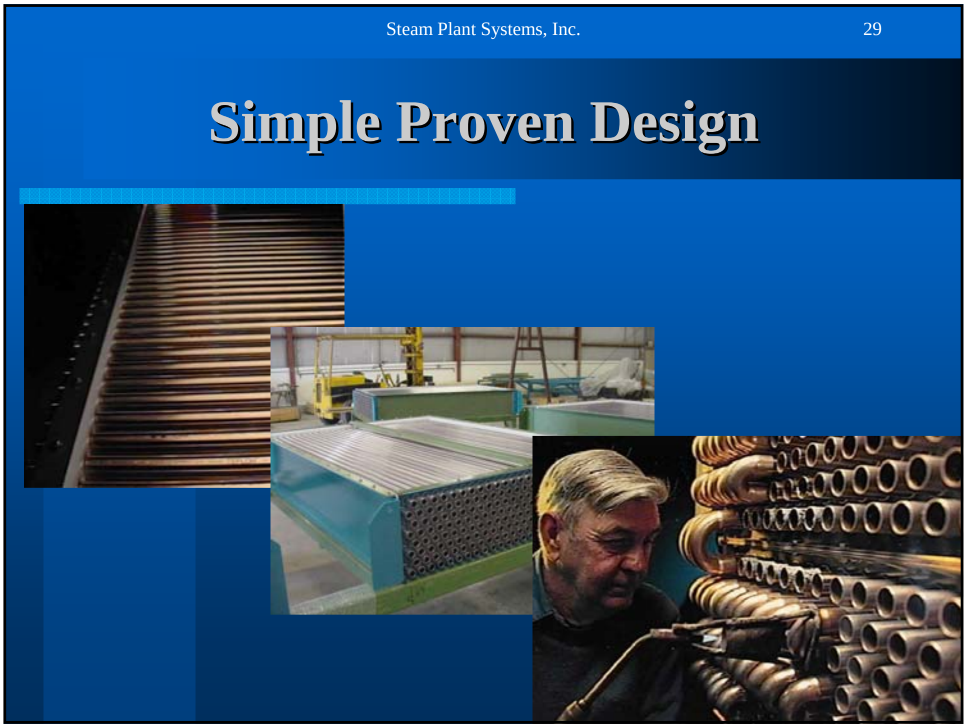
Teflon Tube to Tube-Sheet Seals
Dynamic Design
Impervious to Corrosion
Allows for Thermal Expansion
Simple tube replacement
100% Reliable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Simple Proven Design


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Simple Proven Design
Brand New Tubes
Five Years in Service

INDEPENDENT RESEARCH

- GATC, BCL, AGA, GRI, BNL, ANL, CGA, EPRI, B&W, & ADL
- Why Teflon Covered Tubes?
- Why Not Coatings?
- Design Considerations

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Independent Research

- Gas Appliance Technology Center (GATC)
- Battelle-Columbus Laboratories (BCL)
- American Gas Association (AGA)
- Gas Research Institute (GRI)
- Brookhaven National Laboratory (BNL)
- Argonne National Laboratory (ANL)
- Canadian Gas Association (CGA)
- Canadian Gas Research Institute (CGRI)
- Electric Power Research Institute (EPRI)
- Babcock & Wilcox (B&W)
- Arthur D. Little (ADL)

Independent Research

The following major points will be addressed for natural gas applications –

- **Acids (HCl, H2SO4, etc.) concentrate within a Condensing Heat Exchanger.**
- **Coated tubes, both bare and finned, do not work and will fail.**
- **Standard metallurgy is satisfactory only for natural gas firing when heating water to a maximum temperature of ~ 130F.**

THE REASONS FOR THE CHX HEAT EXCHANGER TEFLON COVERED TUBE DESIGN

- REASON # 1 - The next 17 slides provide **documented independent research** from **Internationally recognized Laboratories, Associations, and Corporations** addressing:
  - **Sources of corrosion**
  - **Corrosion test results**
  - **Test results for coatings**
- **REASON # 2 – See Reason # 1, above.**
- **REASON # 3 – See Reason # 2, above.**
- **REASON # 4 – Knowledge of Competitor's failures.**

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Why Not Coatings?

- EPRI Materials Evaluation CS-3700
  - "All of the coatings failed in some manner during the exposures"
- Argonne National Laboratory ANL-83-81
  - "Several plastics and several coating methods were used to coat various finned and corrugated tubes… It is clear that such a thin coating does not give adequate protection."
- EPRI Condensing Heat Exchanger Demonstration Project
  - "It is well documented that coatings, even Teflon coatings, do not provide the level of protection required to eliminate corrosion form the acids formed when combustion gases condense."

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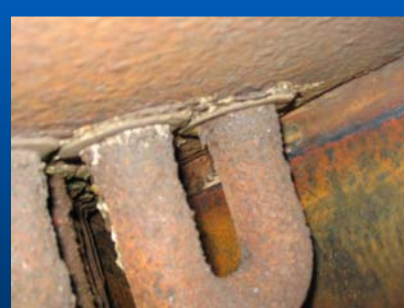
Design Considerations

- Particulate Accumulation
- Coating Failure
- Loss of Corrosion Protection
- Rapid Failure From Flue Gas Corrosive Attack
- This photo illustrates the failure of a competitor's tube to tube-sheet seal



IS FLUE GAS SIDE CORROSION REALLY A CONCERN WHEN FIRING ON NATURAL GAS?

- Why Not Use Finned Tube?
- Sources of Corrosion & Test Results
- Coatings vs. Coverings
- Independent Testing & Evaluation

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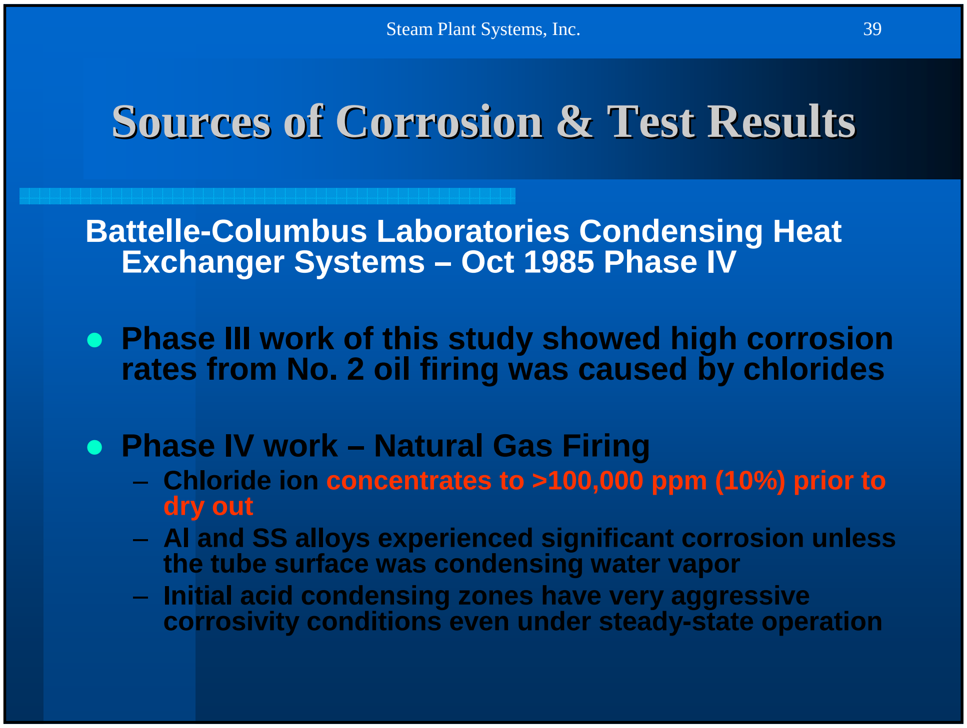
Why Not Finned Tube?

Experience Database

David S. Hibbard and Associates, Metallurgical Consultants, 3/18/86

304L SS with carbon steel fins fails in 4 months on natural gas fired application - Heat exchanger manufacturer suggests replacement with Carpenter 7-Mo+

- **Recommended against using finned tubes since sections of the heat exchanger were condensing acid only and not being diluted with condensate.**
  - **Fin base is a stress riser point for stress cracking**
  - **If fins are not integral, there is a crevice**
  - **Expect acid concentrations of 75% and higher**
  - **Finned tubes are not suitable for condensate drainage**
  - **FINNED TUBES CANNOT BE COVERED**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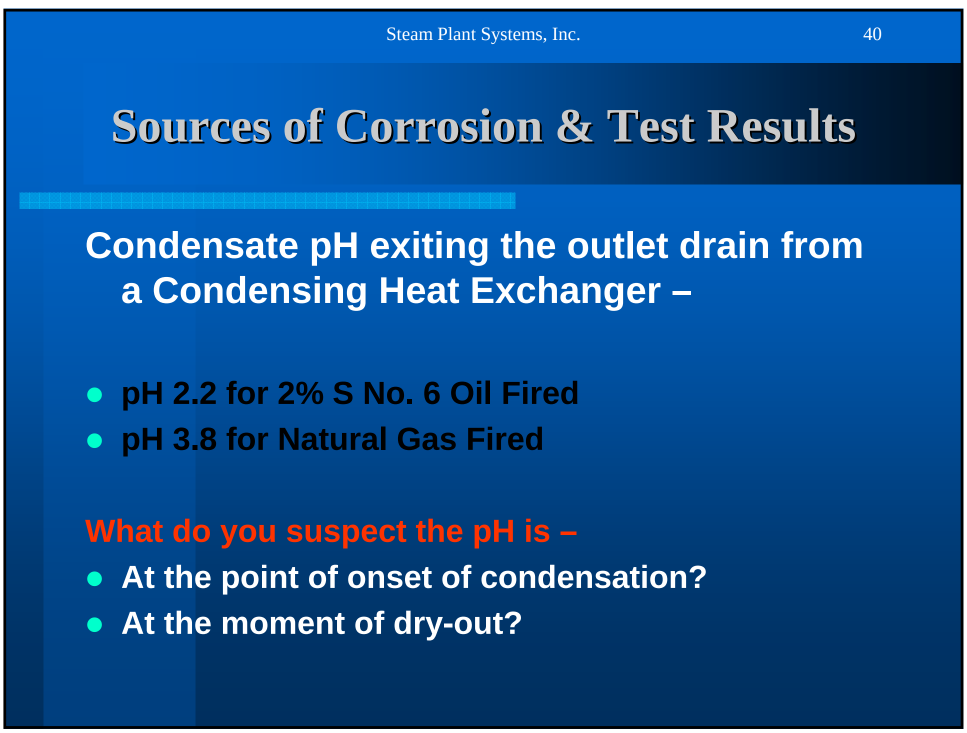
Sources of Corrosion & Test Results
Battelle-Columbus Laboratories Condensing Heat Exchanger Systems – Oct 1985 Phase IV
Phase III work of this study showed high corrosion rates from No. 2 oil firing was caused by chlorides
Phase IV work – Natural Gas Firing
– Chloride ion concentrates to >100,000 ppm (10%) prior to dry out
– Al and SS alloys experienced significant corrosion unless the tube surface was condensing water vapor
– Initial acid condensing zones have very aggressive corrosivity conditions even under steady-state operation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Sources of Corrosion & Test Results
Condensate pH exiting the outlet drain from a Condensing Heat Exchanger –
pH 2.2 for 2% S No. 6 Oil Fired
pH 3.8 for Natural Gas Fired
What do you suspect the pH is –
At the point of onset of condensation?
At the moment of dry-out?

Sources of Corrosion & Test Results

GATC, BCL, AGA, GRI - Research on Heat-Exchanger Corrosion, September 1984

- Factors influencing local condensate corrosivity are design dependent making the corrosivity issue highly unit-specific
  - Crevices create oxygen deficient zones and a reducing environment
  - Early condensate locations result in high corrosivity
  - Corrosivity increases due to cyclic dry-out
- Chlorides and sulfur were found in all corrosion deposits
- Modes of attack are: General, Pitting, Weld Crevice, Joint Crevice, and Stress Corrosion
- **The most corrosive location is the point of onset of acid condensation**

Sources of Corrosion & Test Results

- Canadian Gas Research Institute – Evaluation of Stainless Steel Materials for Resisting Chloride-Induced Corrosion in Condensing & Partially Condensing Gas Fired Units
- "A total of 20 candidate materials selected from the four principal classes of stainless steels were evaluated for resistance to chloride-induced corrosion from combustion air in condensing and partially condensing gas-fired units"
- The commodity grade stainless steels types 316, 304, 304L, and 430 appeared acceptable in the fully condensing zones, however, for partially condensing operation showed failures in as little as one year.
- "The corrosion experienced in a condensing heat exchanger is strongly influenced by its geometry."

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Test Results

GATC, BCL, AGA, GRI - Research on Heat-Exchanger Corrosion, September 1984

Materials that exhibited SIGNIFICANT CORROSIVE ATTACK in one or more corrosion modes:

Austenitic Stainless Steels - 304, 304L, 309, 310, & 316L
Ferritic Stainless Steels - 409, 430, 439, 444, & ELI-T18-2
Duplex Stainless Steels - 329, 44LN, 2205, & Ferralium
Nickel-based Alloys - 800, 600, 6-8, & 671
All Aluminum and Copper-Based Alloys Tested
Duriron

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Sources of Corrosion & Test Results

Argonne National Laboratory – Plastic Heat Exchangers, 9/83

"The liquid which condenses has a much higher concentration than the flue gas does. When the vapor condenses, the acid condenses first, with relatively little water, producing a very concentrated acid solution. For example, a flue gas with 10% water vapor and 50 ppm acid vapor will produce a condensate approximately 84 weight % sulfuric acid."

- **Teflon has a slippery non-stick surface expected to resist fouling, is easy to clean, and has excellent acid resistance**
- **Finned tube coatings (including Teflon) had inadequate corrosion protection on the fin edges and experienced severe corrosion and blistering.**
- **Teflon Shrink Film Performance was EXCELLENT!**

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Sources of Corrosion & Test Results

Battelle-Columbus Laboratories Condensing Heat Exchanger Systems – August 1985 Phase IV

"During transient operation of heating equipment, there often exists some surface area of a condensing heat exchanger that experiences a temperature transition from below the local dew-point to above the dew-point. Depending on the design, this condition provides the opportunity for condensate droplets that are large enough to be visible to produce extremely high concentrations of acid ions. It may seem that the initial concentration is unimportant; whether it is 0.1 ppm or 100 ppm to start with, it still reaches about 100,000 ppm (10% acid) at the moment of dry-out."

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Sources of Corrosion & Test Results

Condensate pH exiting the outlet drain from a Condensing Heat Exchanger –

- **pH 2.2 for 2% S No. 6 Oil Fired**
- **pH 3.8 for Natural Gas Fired**

NOW what do you suspect the pH is –

- **At the point of onset of condensation?**
- **At the moment of dry-out?**

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Sources of Corrosion & Test Results

Gas Research Institute – Technology Report for Corrosion-Resistant Condensing Heat Exchangers, October 1985.

"Those alloys that showed some corrosion resistance might provide adequate service in an environment which consists of stable conditions – i.e. continuously wet or dry zones. It has been shown, however, that these conditions DO NOT EXIST in a Condensing Heat Exchanger due to the changing operating conditions and shifting wet and dry zones."

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Coatings vs. Coverings

Battelle-Columbus Laboratory - Applications of Polymeric Materials For Condensing Heat Exchangers, Sept. 1983

- Coatings are sensitive to the presence of pinholes
- Thickness must be at least 10 mils
- Coverings, rather than coatings, are pinhole free
- Coatings depend on adhesion to the substrate

Independent Testing & Evaluation

Brookhaven National Laboratory
Emissions and Thermal Efficiency Evaluation At A Flue Gas Condensing Economizer, June 1981

- 2% Sulfur No. 6 Oil Condensing Heat Exchanger Report
  - Data From Evaluation of CHX Teflon Covered Design
- Particulate Removal Efficiencies
  - Soluble Particulate Removal – 19%; Insoluble Removal – 86%
  - TSP – 70%
- Flue Gas Properties
  - SO_2 for Oil Fired Applications – 980 ppm (Study Data)
  - Particulate for Oil Fired Applications – 85 mg/m^3 (Study Data)

Independent Testing & Evaluation

Arthur D. Little - Performance Test Results on the B&W IFGT System, February 1992

- Proven reliability based on a detailed evaluation of three CHX installations for IBM, US Army, NYSERDA
- Testing directed toward removal efficiency for particulates, SO_x, and HCl.
- Condensation without corrosion is made possible by Teflon covered tubes and walls

Independent Testing & Evaluation

Babcock & Wilcox - Pilot Performance of the IFGT Condensing Heat Exchanger, March 1995

- **Teflon ensures adequate material lifetime in the corrosive condensing environment**
- **Demonstrated performance and lifetime**
- **Alloy C70600 and 304L SS are commonly used tube materials in boiler water applications**
- **Particulate mass loading of 1-30 grams/MMBtu (1.2-30 pph)**

Conclusion, Summary, and Performance Example

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YOU BE THE JUDGE

Years of independent research and history have proven that for conventional finned tube metallurgy to work in a condensing heat exchanger application –

- The fuel fired MUST be natural gas and
- The water outlet temperature MUST be limited to ~ 130F to make certain that the entire heat exchanger is condensing in order to prevent the acid concentration effect.

For this application and this application ONLY, CHX will offer an extended surface SS tube design.

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CHX Condensing Heat Exchanger

- 2X the Price of Others For Good Reason – Materials of Construction, AND
  - 31 years in business
  - 5 years of R&D
  - 25+ years of references
  - 30 years of design experience
  - Track record based warranty of five (5) years
  - ALL MANUFACTURING DONE IN HOUSE
  - CORROSION IMPERVIOUS bare tube design

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CHX Heat Recovery – Proven Track Record in The Toughest Applications

Early High Sulfur Fuel Oil Applications -

- Morgan Linen – 26 years
- IBM – 23 years
- Quail Uniform – 22 years
- Friskies – 22 years
- Rochester District Heating – 20 years
- Morflex Chemicals – 19 years
- LAACP – 18 Years

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CHX Heat Recovery – Best In Class

- Teflon Covered Tubes
- Teflon Covered Side Sheets
- Teflon Tube Seals
- 31 Proven Years
  - Experience
  - Product
  - People

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COMPANY	PULP & PAPER MILL
LOCATION	USA
CHX PROPOSAL NO.	080505
REPRESENTATIVE	PPE
PROPOSAL STATUS	EXAMPLE
PROPOSAL DATE	AUGUST 5, 2005
APPLICATION	HEAT PROCESS WATER
TOTAL BOILER CAPACITY	150,000 LBS/HOUR

CASE 1 OF 1 — CHX SYSTEM MODEL # 336-108 DW 12

AVERAGE OPERATION

DESIGN PARAMETERS

AVERAGE STEAMLOAD FOR CASE	110,000	LBS/HOUR
AVAILABLE FLUE GAS MASS	131,157	LBS/HOUR
BOILER FEEDWATER TEMPERATURE	270.0	DEGREES F.
STEAM PRESSURE (750 DEG. F)	850	PSIG
EXCESS COMBUSTION AIR	11.45	PERCENT
FLUE GAS TEMP @ SOURCE	356.0	DEGREES F.
MAXIMUM WATERFLOW AVAILABLE TO HX	220	GAL/MIN
FLUE GAS WATER VAPOR DEWPOINT	135.7	DEGREES F.
FLUE GAS DENSITY	0.0490	LBS/CU.FT.
SPECIFIC HEAT OF FLUE GAS	0.2671	BTU/LB DEG. F.
HOURS OF OPERATION FOR CASE	8760	HOURS/YEAR
FUEL FIRED		NATURAL GAS
FUEL COST	$7.00	DOLLARS/MM BTU
EXISTING FUEL TO STEAM EFFICIENCY	81.23	PERCENT
EXISTING THERMAL EFFICIENCY	82.84	PERCENT

HEAT EXCHANGER PERFORMANCE

FLUE GAS MASS FLOW @ HX INLET	131,157	LBS/HOUR
FLUE GAS FLOW @ INLET TO HX	44,570	ACFM
FLUE GAS INLET TEMP	356.0	DEGREES F.
FLUE GAS OUTLET TEMPERATURE	128.3	DEGREES F.
WATERFLOW THROUGH HX	220.0	GAL/MIN
WATER INLET TEMPERATURE	50.0	DEGREES F.
WATER OUTLET TEMPERATURE	188.9	DEGREES F.
SENSIBLE HEAT RECOVERED	7,978,429	BTUS/HOUR
LATENT HEAT RECOVERED	6,918,448	BTUS/HOUR
TOTAL HEAT RECOVERY	14,896,877	BTUS/HOUR
SAVINGS FOR THIS CASE	$1,124,548	DOLLARS/YEAR

ENGINEERING DATA

NEW BOILER FUEL TO STEAM EFFICIENCY	90.99	PERCENT
NEW THERMAL EFFICIENCY	92.60	PERCENT
EFFICIENCY INCREASE	9.76	POINTS
FUEL SAVINGS	12.02	PERCENT
WATERSIDE PRESSURE DROP	13.32	PSIG.
THEORETICAL FAN POWER	77	HORSEPOWER
HEAT EXCHANGER FLUE GAS PRESSURE DROP	7.31	IN. W.C.
PLENUM, DUCT AND BREECHING LOSS	0.88	IN. W.C.
CONDENSATE FLOW RATE	13.7	GAL/MIN

NATURAL GAS ANALYSIS USED FOR THIS CASE

%C	%H2	%N2	%02	%S	%H20	%ASH	HHV
75.20	23.50	1.30	0.00	0.00	0.00	0.00	23000

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SYSTEM SCOPE & PRICE

CHX HEAT EXCHANGER WITH

- **SS Inlet & FRP Outlet Plenums**
- **Inlet & Outlet Water Manifolds**
- **SS Inlet Screen with Automatic Wash System**
- **CHX Fan, Motor, & Inlet Box**
- **Fan Discharge Transition**
- **Unitary System Base**
- **Complete Instrument & Control Package**
- **Flue Gas Flow Control Damper(s)**
- **Engineering, Design, AutoCAD Drawings, Documentation, & Manuals**
- **FACTORY Assembly Supervision, Start up, & Training**

- **US$650,000**


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