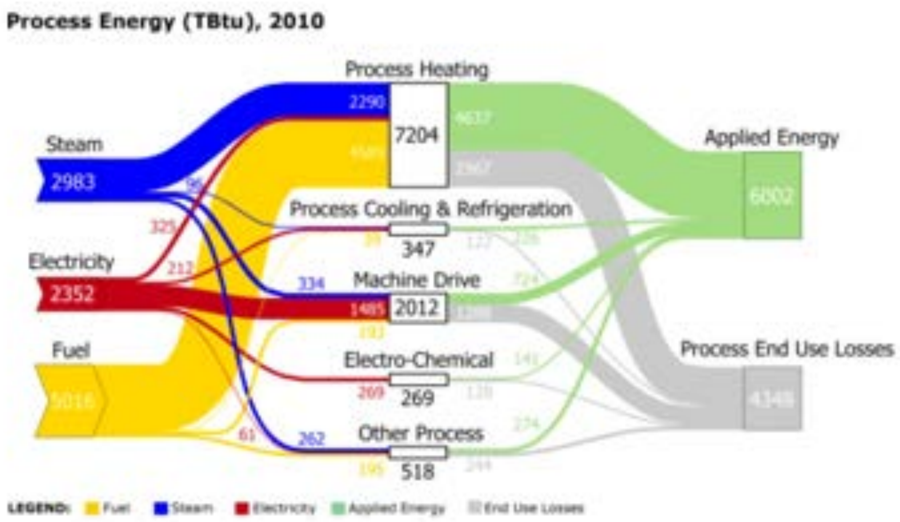
Industrial heating: an overview

Industrial process heating operations are responsible for more than any other of the manufacturing sector's energy demand, accounting for approximately 70% of manufacturing sector process energy

There are a wide range of process heating unit operations, and associated equipment, that are to achieve important materials transformations such as heating, drying, curing, phase change, etc.



Energy is supplied from a diverse range of sources, and includes a combination of electricity, steam, and fuels such as natural gas, coal, biomass and fuel oils.

In 2010, process heating consumed approximately 330 TBtu of electricity, 2,290 TBtu of steam, and 4,590 TBtu of mostly fossil fuels

Process heating technologies are generally designed around four principal energy types:

1. Fuel-based process heating technologies;
2. Electricity-based process heating technologies;
3. Steam-based process heating technologies; and
4. Hybrid process heating technologies.

$Fuel - based$

- Fuel-based process heating systems generate heat energy through combustion of solid, liquid, or gaseous fuels, and transfer it to the material either directly or indirectly.
- Combustion gases can be either in direct contact with the material (i.e., direct heating via convection), or utilize a radiant heat transfer mechanism by routing the hot gases through radiant burner tubes or panels and thus separated from the material (i.e., indirect heating).
- Examples of fuel-based process heating equipment include ovens, fired heaters, kilns, etc.

$Electricity - based$

- Electricity-based process heating systems can also transform materials through direct and indirect processes.
- For example, electric current can be applied directly to suitable materials leading to direct resistance heating; alternatively, high frequency energy can be inductively coupled to suitable materials leading to indirect heating.
- Electricity-based process heating systems (sometimes called electro-technologies) are used to perform operations such as heating, drying, curing.
- Examples of electricity-based process heating technologies include electric arc furnaces, infrared emitters, induction heating, radio frequency drying, laser heating, microwave processing, etc.

Steam – based

- Steam-based process heating systems provide process heating through either direct heating or indirect application of steam.
- Steam is either directly introduced to the process for heating (e.g., steam sparge) or indirectly in contact with the process through a heat transfer mechanism.
- Steam heating accounts for a significant amount of the energy used in lower temperature industrial process heating (<400 deg. F.).
- Use of steam-based systems is largely for industries where heat supply is at or below about 400 deg. F. and where there is availability of low-cost fuel or by products for use in steam generation.
- Use of cogeneration (simultaneous production of steam and electrical power) is another example where steam-based heating systems are commonly used.
- For example, the fuel used to generate steam accounts for 89% of the total fuel used in the pulp and paper industry, 60% of the total fuel used in the chemical manufacturing industry, and 30% of the total fuel used in the petroleum refining industry.

Hybrid

- Hybrid process heating systems utilize a combination of process heating technologies based on different energy sources and/or different heating methods of the same energy source to optimize their energy use and increase overall process thermal efficiency.
- For example: Hybrid boiler systems combining a fuel-based boiler with an electric-based boiler using off-peak electricity are sometimes used in areas with lower cost electricity.
- Combinations of penetrating electromagnetic (EM) energy (e.g. microwave or radio frequency) and convective hot air can yield accelerated drying processes by selectively targeting moisture with the penetrating EM energy, yielding far greater efficiency and product quality than drying processes based solely on convection, which can be rate limited by the thermal conductivity of the material.

Table 1 - Characteristics of common industrial processes that require process heating

Manufacturing Operation	Applications [1]	Typical Temperature Range [3]	Estimated U.S. Energy Use (2010) [4]
Non-Metal Melting	Plastics and rubber manufacturing; food preparation; softening and warming	1710–3000°F	265 TBtu
Smelting and Metal Melting	Casting; steelmaking and other metal production; glass production	1330–3000°F	1,285 TBtu
Calcining	Lime calcining	1150–2140°F	525 TBtu
Metal Heat Treating and Reheating	Hardening; annealing; tempering; forging; rolling	930–2160°F	270 TBtu
Coking	Ironmaking and other metal production	710–2010°F	120 TBtu
Drying	Water and organic compound removal	320–1020°F	1,560 TBtu
Curing and Forming	Coating; polymer production; enameling; molding; extrusion	280–1200°F	145 TBtu
Fluid Heating	Food preparation; chemical production; reforming; distillation; cracking; hydrotreating	230–860°F	2,115 TBtu
Other	Preheating; catalysis; thermal oxidation; incineration; other heating	210–3000°C	925 TBtu
Total			**7,204 TBtu**

Table 2 - R&D Opportunities for Process Heating and Projected Energy Savings [4]

R&D Opportunity	Applications	Estimated Annual Energy Savings Opportunity (TBtu)	Estimated Annual GHG Emissions Savings Opportunity (million metric tons CO_2-eq [MMT])
Advanced non-thermal water removal technologies	Drying and Concentration	500 TBtu	35 MMT
Hybrid distillation	Distillation	240 TBtu	20 MMT
New catalysts and reaction processes to improve yields of conversion processes	Catalysis and Conversion	290 TBtu	15 MMT
Lower-energy, high-temperature material processing (e.g., microwave heating)	Cross-Cutting	150 TBtu	10 MMT
Advanced high-temperature materials for high-temperature processing	Cross-Cutting	150 TBtu	10 MMT
"Super boilers" to produce steam with high efficiency, high reliability, and low footprint	Steam Production	350 TBtu	20 MMT
Waste heat recovery systems	Cross-Cutting	260 TBtu	25 MMT
Net and Near-Net-Shape Design and Manufacturing	Casting, Rolling, Forging, and Powder Metallurgy	140 TBtu	10 MMT
Integrated Manufacturing Control Systems	Cross-Cutting	130 TBtu	10 MMT
Total		**2,210 TBtu**	**155 MMT**

IAC New Director Training

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

September 17-18, 2019

Process Heating

Siddika Pasi, Rutgers University

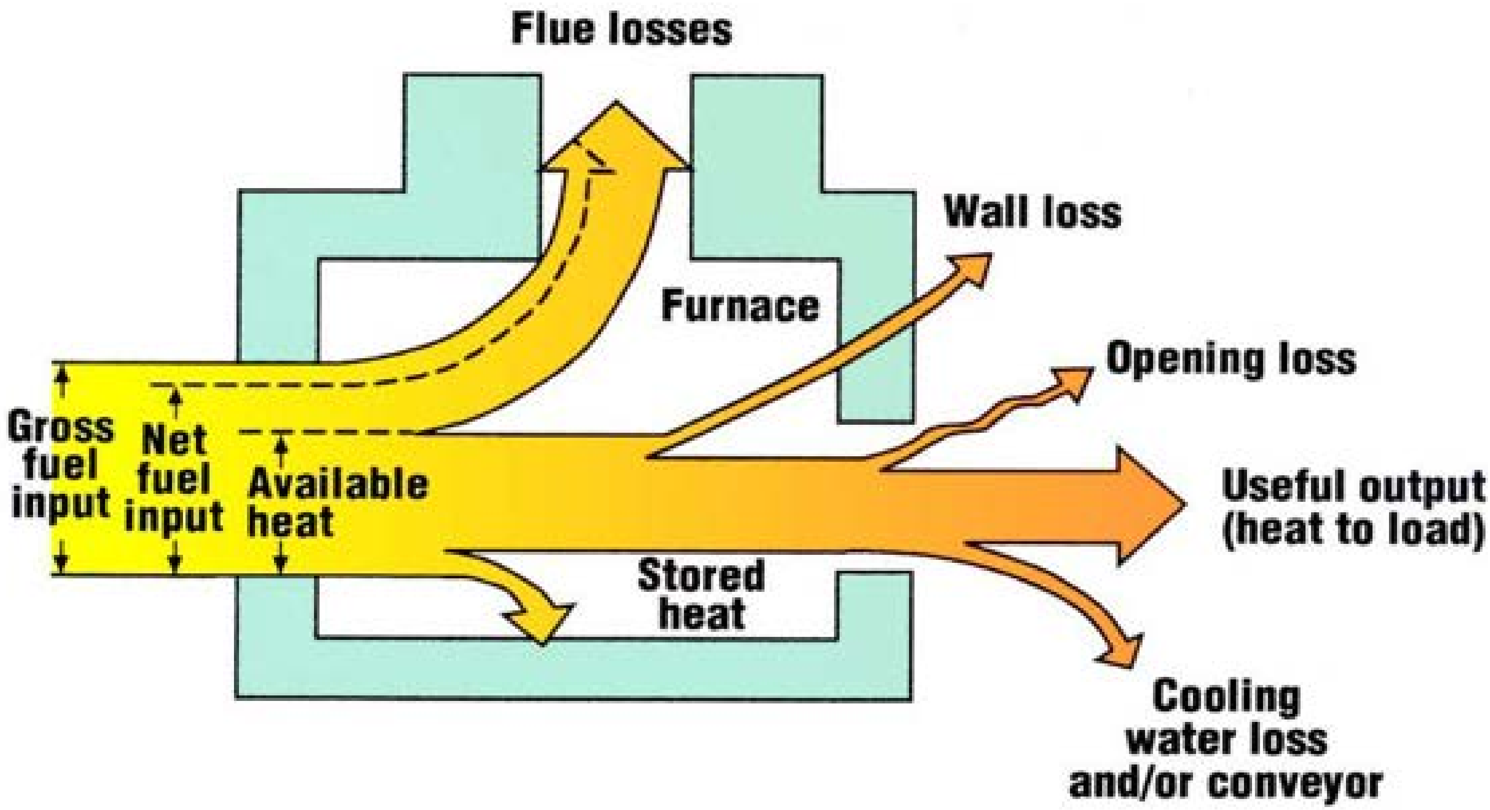
Process Heating Background

- **Process heating equipment:**
  - accounts for 2% to 15% of a product's total cost
- **Accounts for roughly 36% of the total energy used in industrial manufacturing applications**
  - 15% to 85% of energy supplied to process heating equipment is actually used for heating
- **Process heating energy use and costs can often be reduced by 5% to 15% through best practices and system improvements**

Process Heating Background

- **The term covers a huge range of temperatures and processes**
  - High temp: Blast furnaces (2800 °F)
  - Low temp: baking bread (200 °F)
  - Lowest temp: dryers (130 °F)
- **Projects fall into three groups**
  - Efficient Heating
  - Heat containment
  - Waste heat recovery

Process Heating Energy Balance



Heating Efficiency

Usual Suspects

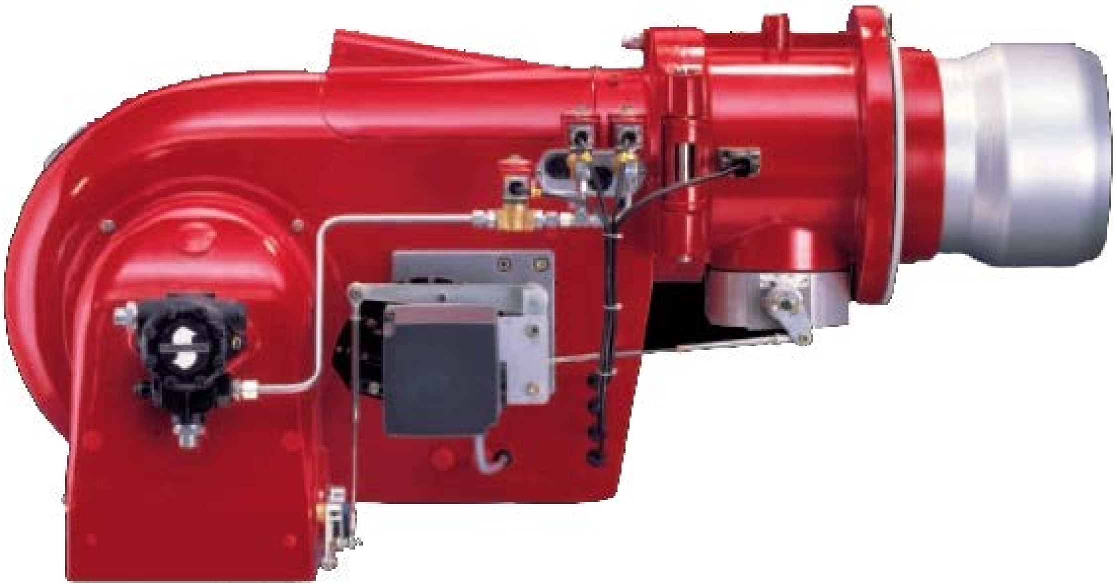
- **Operation & Maintenance:**
  - Check Air-to-Fuel Ratio
  - Check Furnace Pressure Controls
    - Excess negative or positive pressure create problems
  - Utilize Novel combustion technique
    - Higher temperatures using Oxygen Enriched Combustion

The Flue Gas

- Use low cost Flue Gas Analyzer – allows you to take $CO/O_2/CO_2$, efficiency, stack/ambient air temperature, air-to-fuel ratio readings
- Trim combustion to minimize excess air
  - Unused air is simply heated and tossed away, providing nothing in value
  - Savings is gained by not heating and throwing air away
- Only works on “controlled” combustion chambers
  - Not on open flames
- Acceptable excess air depends on the fuel and the application
- Automated trim systems allow even better operations

Fuel switching

- Allows use of most economic fuel
- Also allows use of curtailable rate schedules
- Provides opportunity to use renewable or opportunity fuels



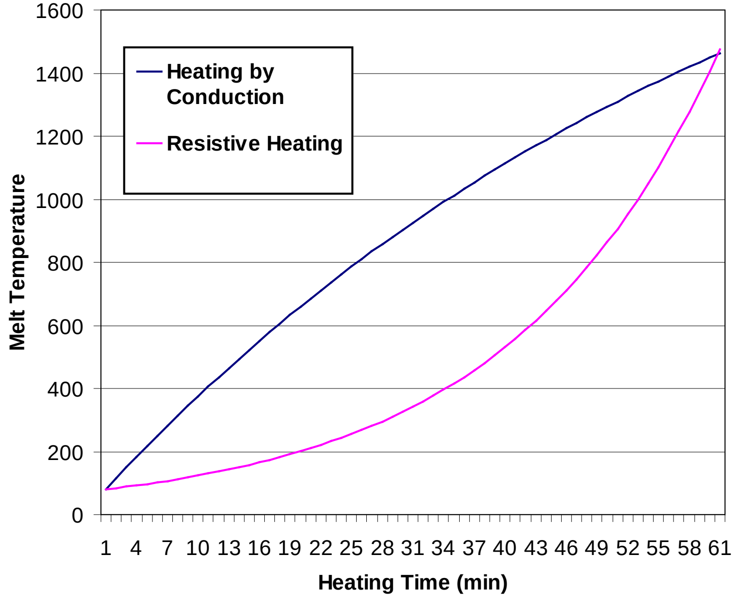
Novel heating technologies: Radiative Heating

- **Heats the material, not the air in between**
- **Good for coatings, drying or thermosetting**
- **Often specific frequencies are used – not good when you change materials a lot**

Novel heating technologies: Inductive Heating

- **Current in the metal (I^2R) heats the metal to melting temps with very little losses to the external environment.**
- **Of equal importance is the rate of heating**
- **There is high "first cost"**

•Conduction heats slowest at high temp
•I^2R heating work fastest at high temp
•Metal losses occur at high temp

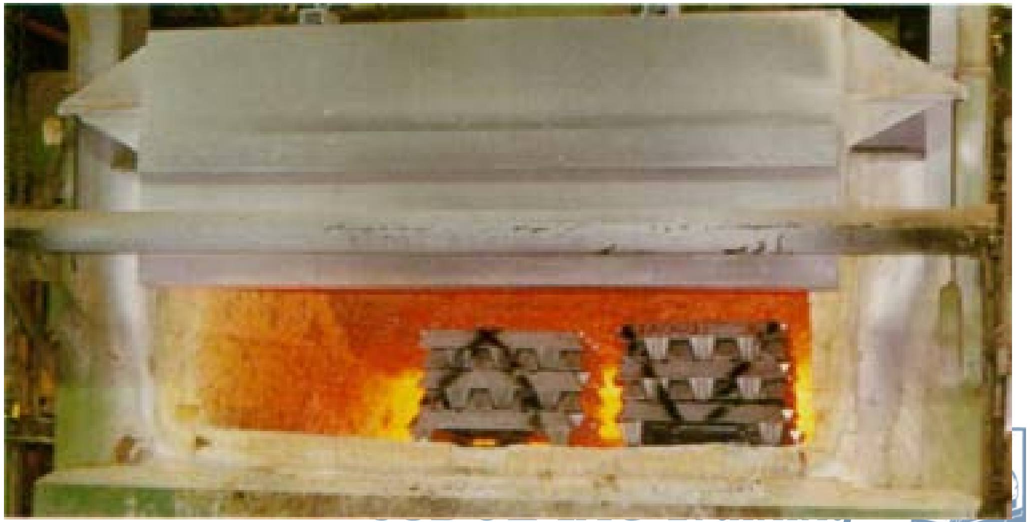


Operational Concern: Internal Scrap Rates

- Many shops operate with a 50% re-melt rate
- Since it is so simple to re-melt scrap, there is little incentive to minimize it
- Remelting costs energy, worker time, and capital expense

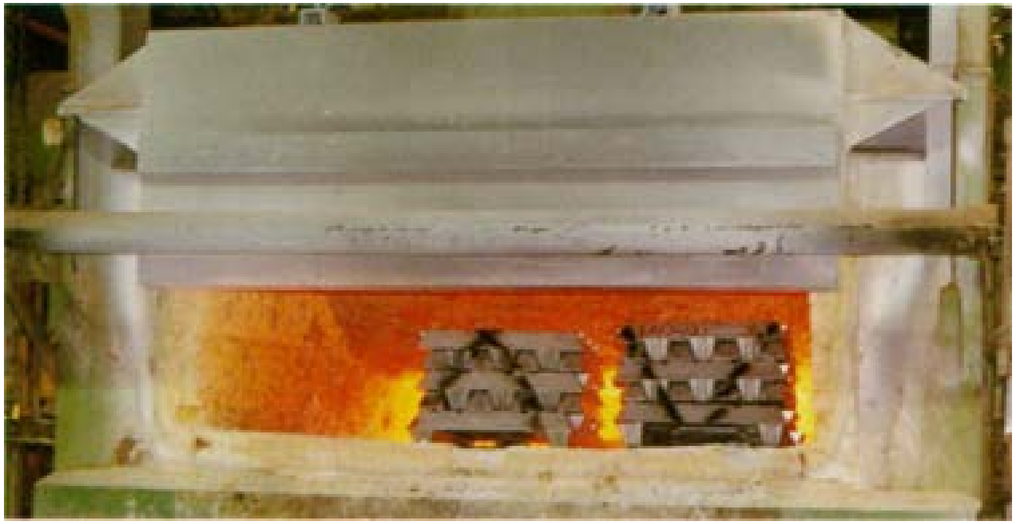
Operational concern: Furnace Setbacks

- **Every 100°F of extra temperature increases the energy cost by 10%.**
- **Many operations seemed frightened of daily or weekend setbacks**
  - Ain't broke, don't mess with it
- **Start with small setbacks and see if product quality remains high**



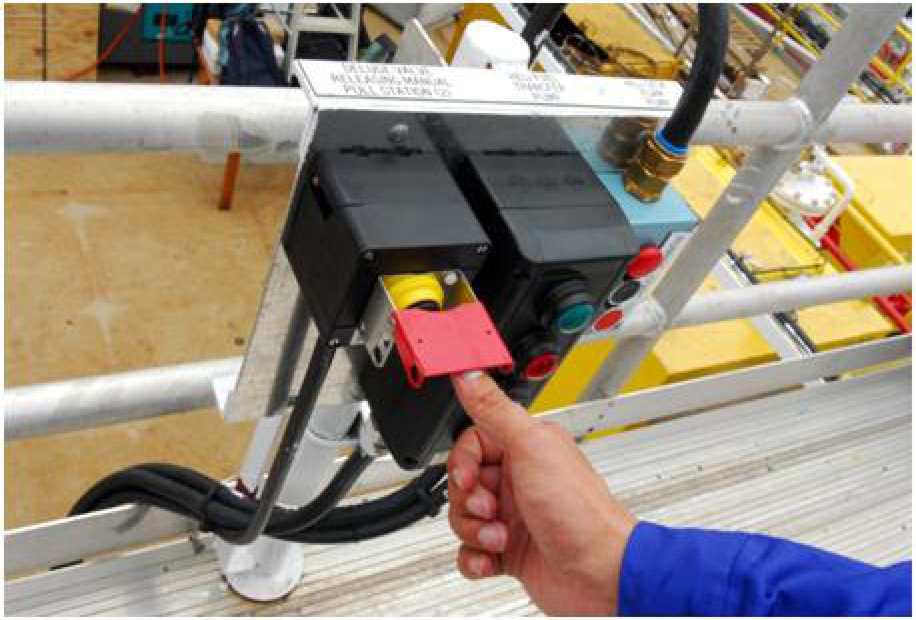
Operational concern: Optimizing loads

- **Empty furnaces are a waste of money**
  - Good scheduling can save lots of energy
- **Heating systems should have off-load strategies**
  - Lower air flow through a furnace
  - Temperature setbacks



Operational concern: problems and fixes

- **Often to solve problems, fixes reduce furnace performance**
  - OK for emergency, but often long lived
  - The dreaded “manual override”
- **Look for:**
  - Uneven temperatures; hot spots
  - Furnace pressure issues
  - Oversized heating systems



Heat Containment

Insulation Systems

Where to look for opportunities

- Boilers, furnaces, kilns, ovens, pipes, etc.
- Most insulation systems reduce the unwanted heat transfer by at least 90% as compared to bare surfaces
- The use of insulation is therefore mandatory for efficient operation of any hot system

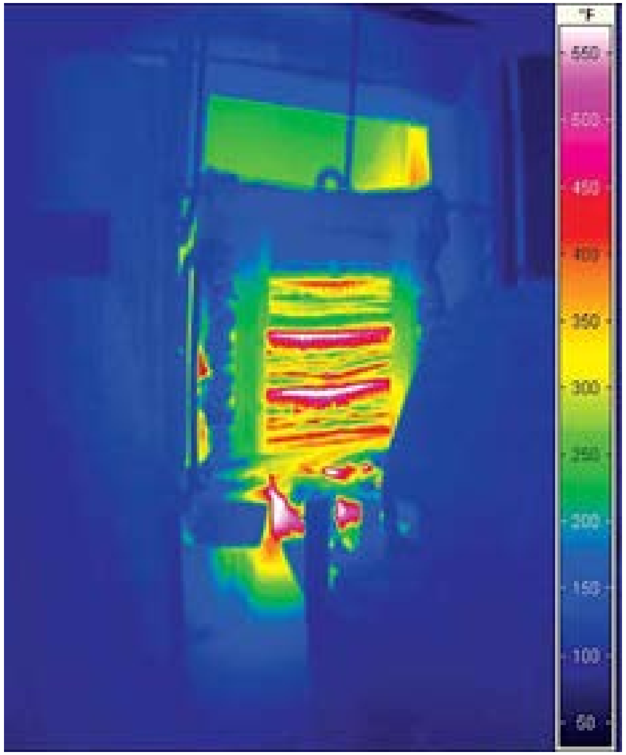
- **Thermal Imaging Cameras are great!**
- **Too hot for my hand**
  - Rule of thumb
  - Insulating insulation not defendable
- **Keep Insulation repaired!**
  - Wet insulation is worse than none

Infiltration

- **Where to look for opportunities**
  - Boilers, furnaces, kilns, ovens, etc.
  - This is the uncontrolled inward air leakage through cracks or fitting gaps
  - Furnace openings can be minimized or closed when not needed
- **Often difficult to measure**
  - At least use smoke to determine general flow rates

“Shields Up, Mr. Sulu”

- **Furnaces and ovens may intentionally have openings**
  - Material loading doors
  - View ports to see the flame
  - Ports to insert measuring or sampling devices
- **Coverings on furnaces are often removed for convenience**
  - Lids on vats
  - Doors on furnaces



Thermal image of open door on furnace

Radiation Shields

- **Cover openings with radiation shields**
  - Reflects heat back to furnace
  - Can be made of flexible ceramic fiber or textile for easy access
  - A tunnel of reflective material can be used for continuously fed furnaces

Flexible heat shield covering

Floating Bath Insulating Balls

- Evaporation removes large amounts of heat
- Dip tanks and the like or moving flows do not handle lids well
- Balls can displace when products are put into tanks

Waste heat recovery

Quality of the waste heat

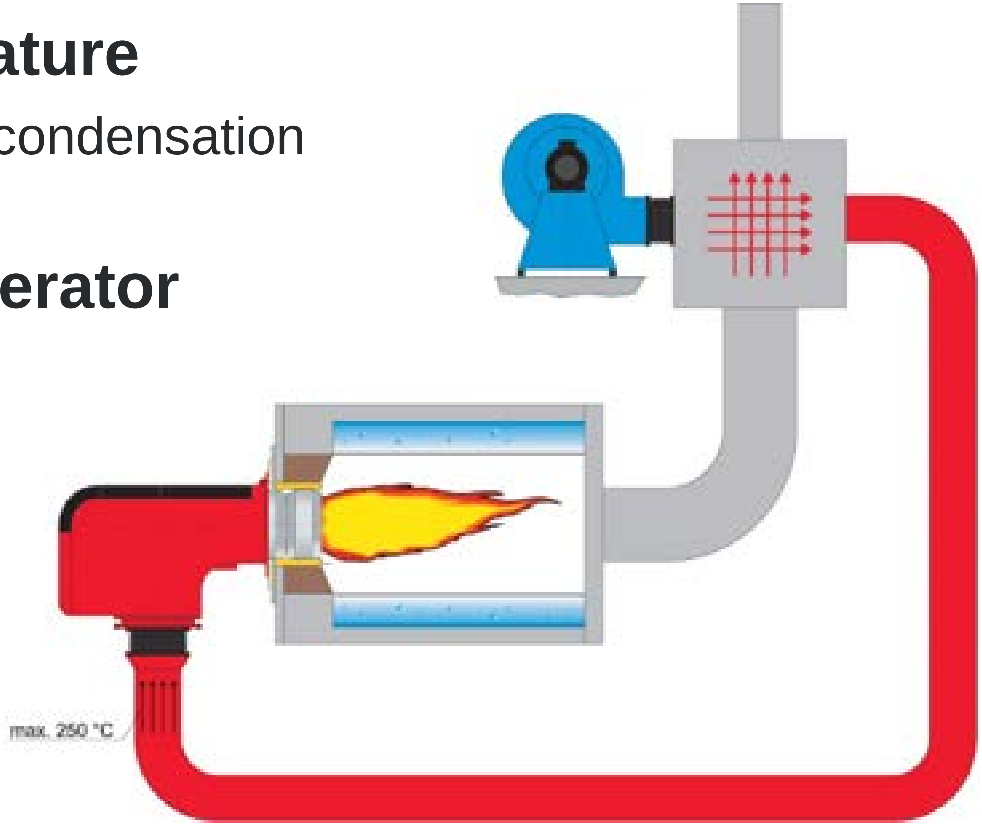
- **Two parameters determine the amount of energy lost**
  - Flow rate of waste stream
  - Temperature of waste stream
- **But higher temps are easier to use, but lower temps are more common**
- **Therefore quality of waste heat depends on temperature**
- **For classification purposes:**
  - High Range: 1,100°F to 3,000°F
    - Equipment: Heating, melting and refining furnaces, kilns, incinerators, and thermal oxidizers
  - Medium Range: 400°F to 1,100°F
    - Equipment: Boiler, engine and turbine exhausts, heat treating furnaces, and baking ovens
  - Low Range: 80°F to 400°F
    - Equipment: Cooling water from heated equipment, process steam condensate, building exhaust

High temp source: exhaust stack

- **Normally source of significant waste heat**
  - Boilers, process fired heaters, combustion or heat-transfer furnaces, etc.
  - Typically additional heat recovery equipment can assist in energy conservation when the measured flue-gas temperature is in excess of 250°F
    - "Anybody can use 600 degree waste heat!"
- **What might be recommended**
  - Preheat combustion air
  - Preheat fuel
  - Preheat product (water, if a boiler)
  - Make power

Preheating combustion air

- **Lowers stack temperature**
  - Keep it high enough so condensation does not occur
- **Regenerator or recuperator**
- **Can be retrofitted**

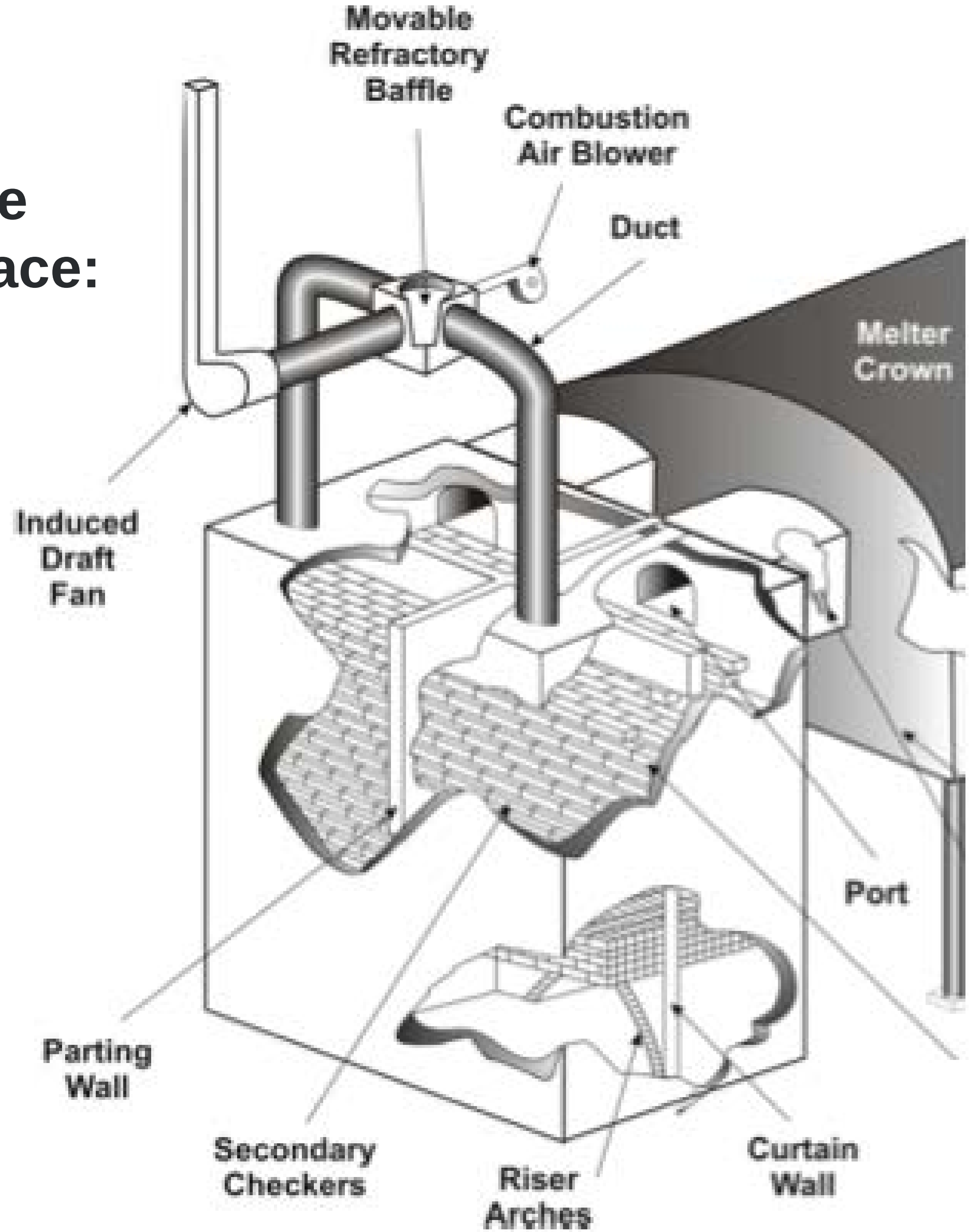


Preheating combustion air

- **Intermediate heating medium can include liquid or solids**
- **Heat water or heat transfer liquid (dowtherm)**
- **Complicated design and only a good idea if absolutely needed**

Preheating combustion air

- **Classic case is the regenerative furnace:**
  - Not easy to retrofit



Preheating of Charges

- Terrific use of low quality waste heat
- Combustion products ok
- Most often recommend staging “hut” for waiting charge
- Low cost implementation compared to preheating combustion air

Why preheat metals?

- **As opposed to water or wet materials, metals melt easier – so most of the energy is involved heating it up to the melting point**
- **Example of aluminum:**

Heat Required From Ambient to Melting Point	255 Btu/lb
Latent Heat of Fusion	170 Btu/lb
Energy Required to Raise Temperature to Holding	30 Btu/lb
TOTAL	455 Btu/lb

Low Quality Waste Heat Recovery

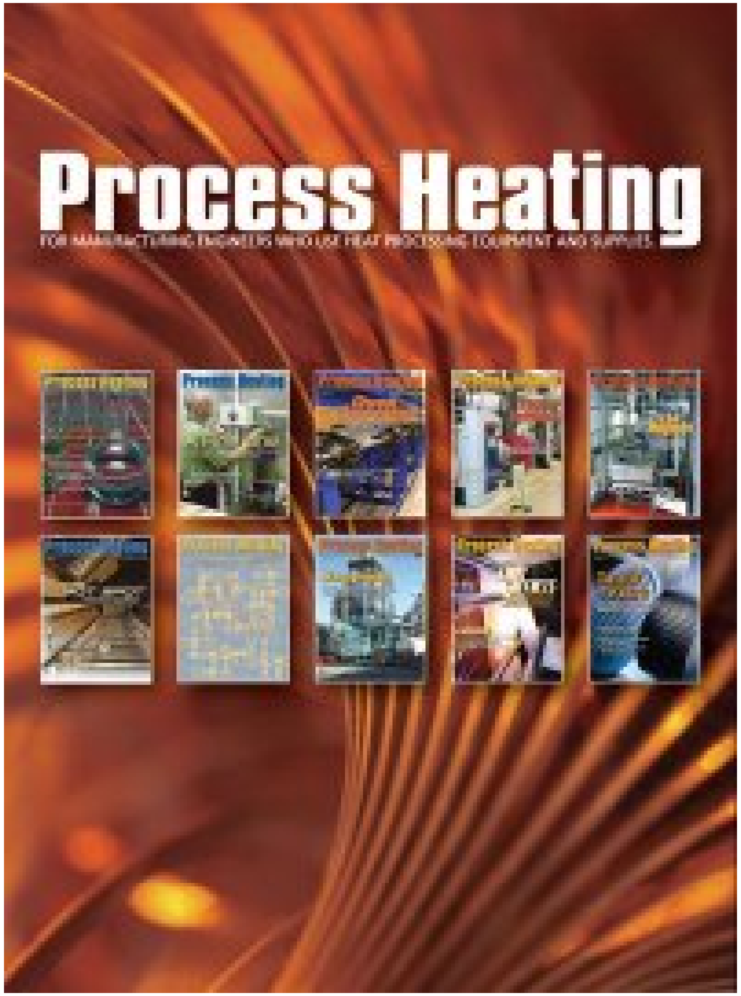
- **Low temperature range waste heat are useful in preheating liquids or gases through use of air preheaters/economizers/ heat exchangers/heat pumps**
- **Also can support space heating needs**
- **Or a plug and play organic rankine cycle system can be used for low grade heat power generation**

Challenge: Low Quality Waste Heat Use

- **New absorption refrigeration schemes need less temperature**
- **Humidity control is providing another good application (desiccant recharge)**

Resources

- **Good Free trade mag:**



USDOE Advanced Manufacturing Office

Assessing Steam Systems

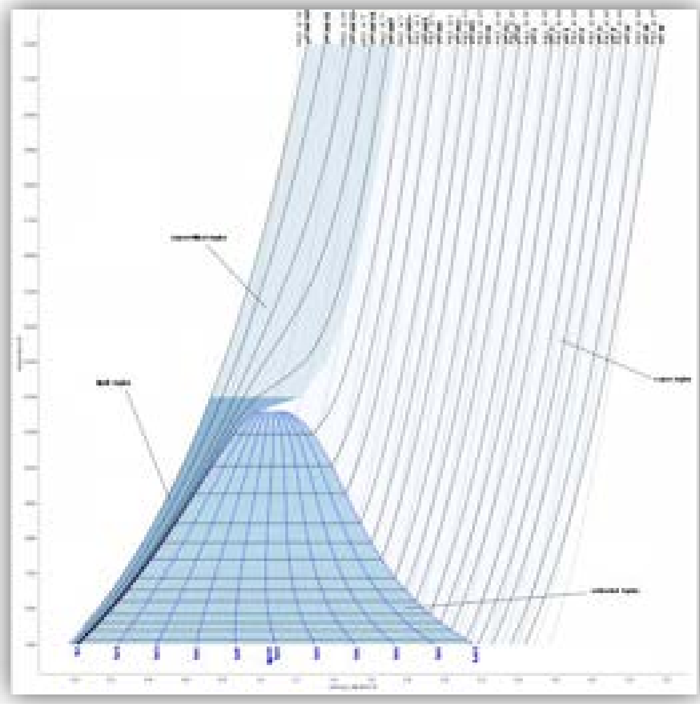
September 17-18, 2019

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

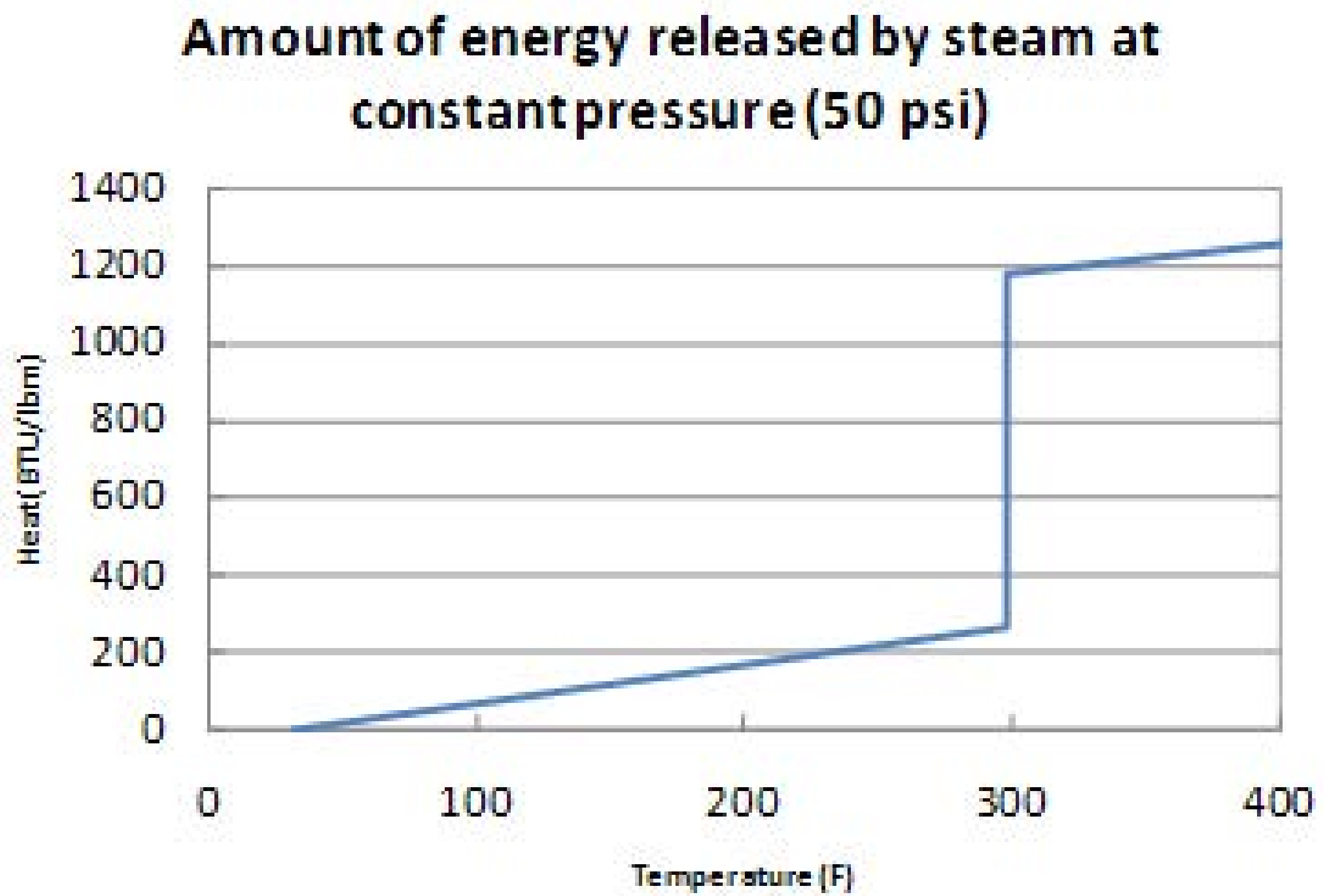
Why is Steam so Useful?

Enthalpy of Vaporization (EoV)

- When water is boiled, a significant amount of energy (EoV) is required to move from the liquid to gas phase (steam)
- This makes steam great for energy storage
- When the steam condenses, it releases this energy
- The condensing temperature is pressure dependent making it very easy to control the temperature



Why is Steam so Useful?

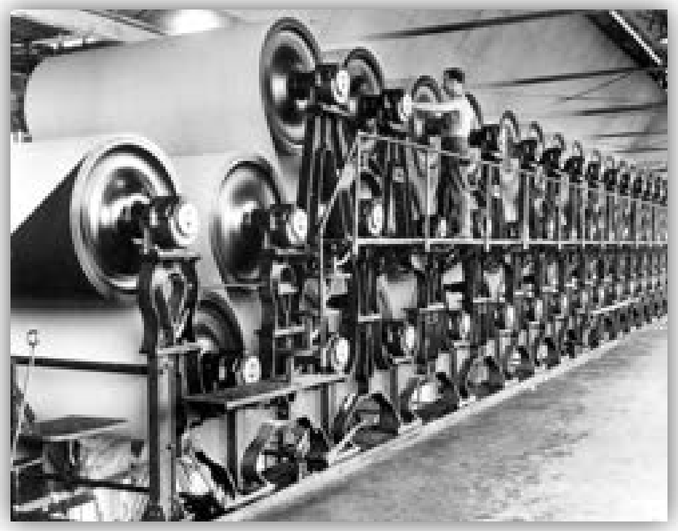


Common Applications

- Electrical Generation
- Space Heating & Cooling
- Cooking
- Drying
- Cleaning
- Sterilization
- Mechanical Effort
- Energy Storage
- And Numerous Applications where Specific Controlled Heating is required.

Steam in Paper Mills

- Paper Mills use steam extensively to dry the wood pulp
- The pulp is moved through a series of rollers or “cans” that are connected to steam lines
- The rollers’ internal pressures are controlled by valves, which in turn control the temperatures
- This temperature control is critical for the quality of the paper
- When not controlled properly, the sheets can break and active roll could be lost and must be reset



Presentation Goals

Discuss the operation of a steam system, its major components, and how to make them more energy efficient.

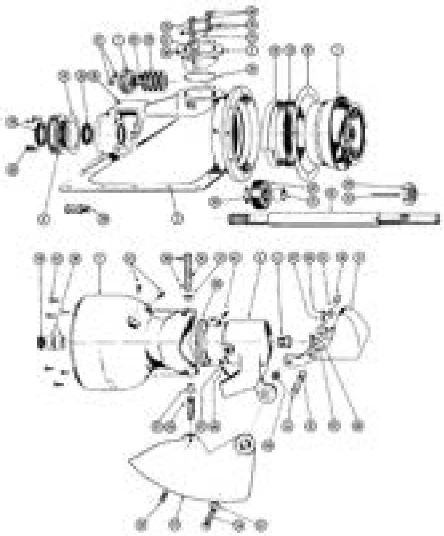
Measurements and Instrumentation

- Infrared Temperature Gun
- Laser Pointer
- TDS Meter
- Ultrasonic Leak Detector
- Combustion Analyzer
- Various Thermocouples
  - Surface, contact, high temp, open air, etc
- Data Loggers
- (if available) Infrared Camera
- Camera – Pictures of steam leaks and bare pipes help get managements attention

Steam System Topics

Steam System Topic Areas:

- Water Treatment
- Boiler Operation
- Steam Distribution
- Steam Equipment and End Users
- Waste Heat Recovery



Operational Topic Areas:

- Production
- Energy Costs
- Personnel

Water Treatment

Make up water quality can vary significantly as it can come from:

- City water, lake water, river water, ocean water, etc
- Treatment Steps May Include:

(Almost Always Included)

- Chemical Treatment
- Dissolved Gas Removed (Deaerators)

(Optional)

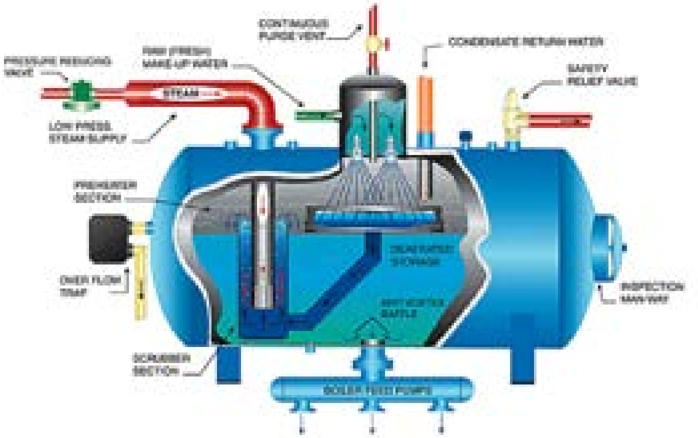
- Large Particle Filters/Strainers
- Reverse Osmosis (RO)
- Softeners

The goal is to remove dissolved and suspended solids and gases that may be damaging to the steam system

Deaerator

Deaerators (DA) remove dissolved gases in the feedwater before it goes to the boiler.

- Any residual dissolved gases will be released when the steam is generated damaging the system
- DAs remove gases by increasing the water temperature to just under boiling.
- At higher temperatures gases want to be gases!
- DAs are generally heated by LP steam from the system
- All DAs vent to remove gases as well as some steam
- If vent rate settings are off gases may get into the system or excess steam may be released



Dissolved Oxygen

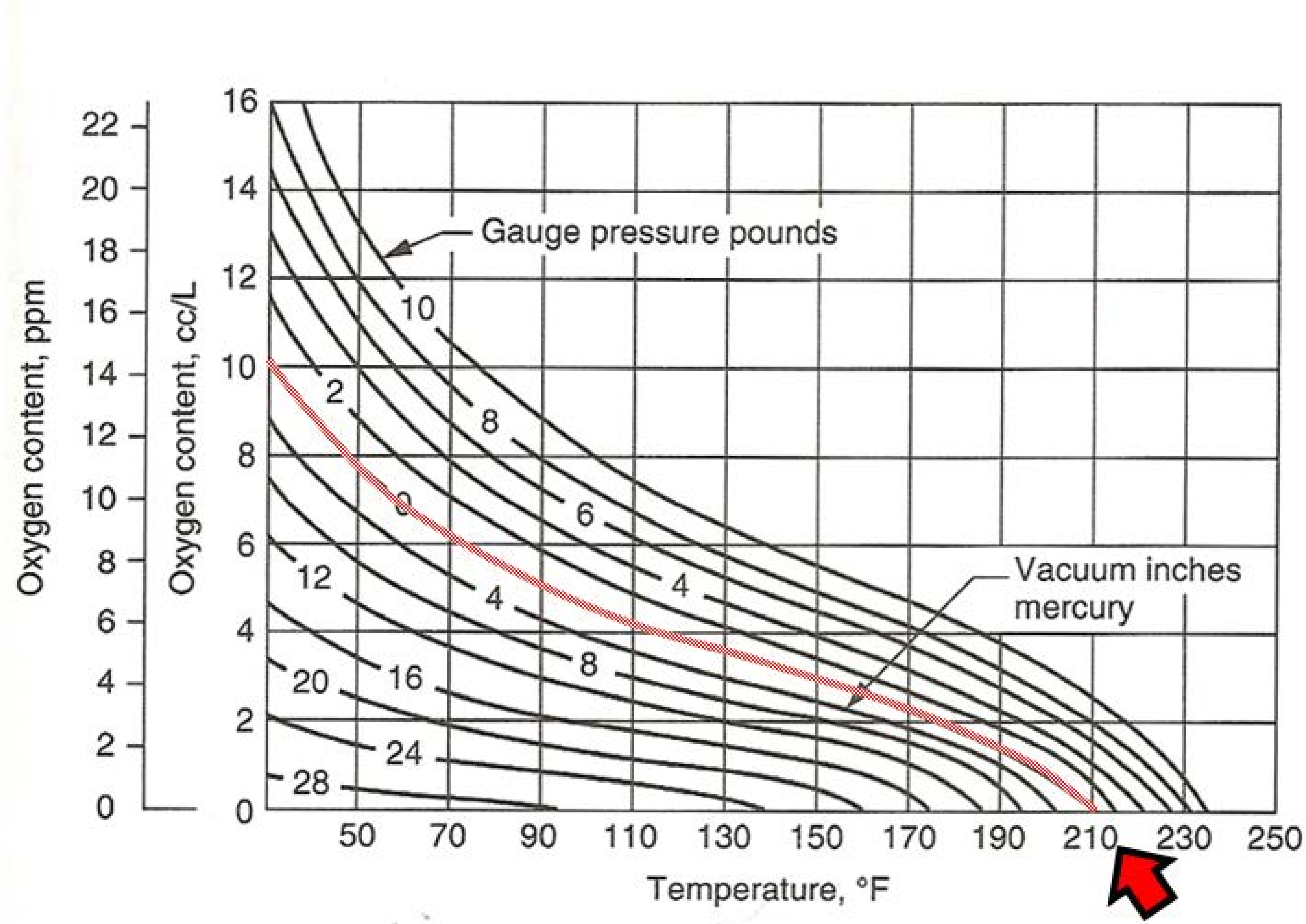
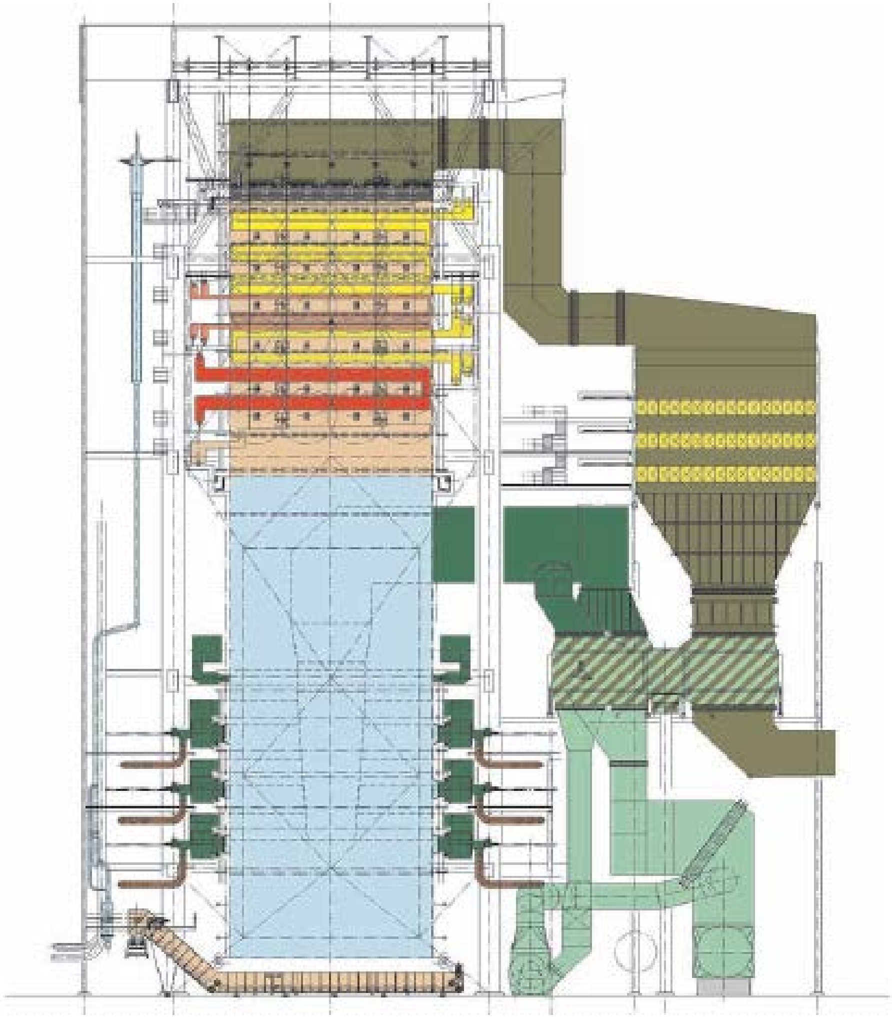


Figure 4.5 Solubility of dissolved oxygen. (*R. W. Lane files.*)

Boilers



Boilers

Things to consider:

- Standard and Alternate Fuels
- Type, Size, and Number of Boilers
- Combustion Air Handling and Control
- Exhaust Temperature and Pollutants
- Blowdown
- Operational Load and Cycles
- Special Considerations

Fuel

Boiler fuel types heavily impact:

- Emission restrictions
- Reporting regulations and requirements
- Operational conditions

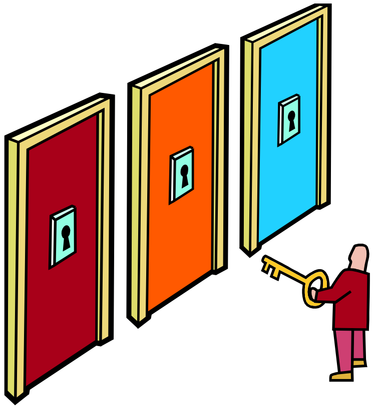
Common Fuels include:

- Natural Gas – Minimal regulation and operational issues
- Coal – Heavy regulations and dirty
- Fuel Oil – Newer boilers must be low sulfur
- Biomass (wood) – Cheap and carbon-neutral, but inconsistent quality and may needed to be dried

Fuel Switching

Boilers may:

- Have been modified to use different fuel
- Be able to use multiple fuels
- If multiple boilers are present that use different fuels, adjusting boiler loads can be equivalent to switching fuels

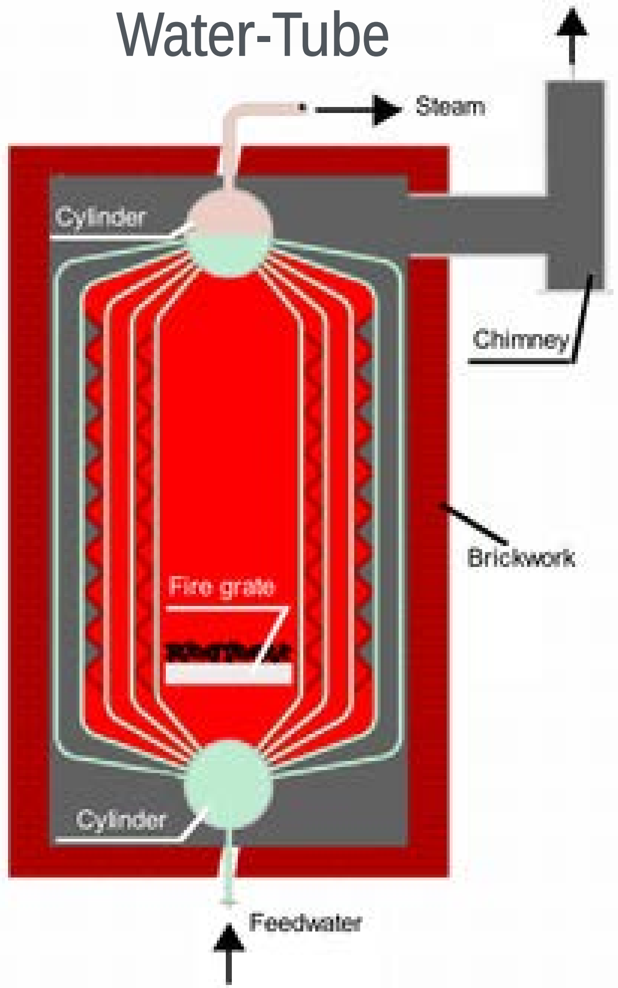


Benefits of fuel switching:

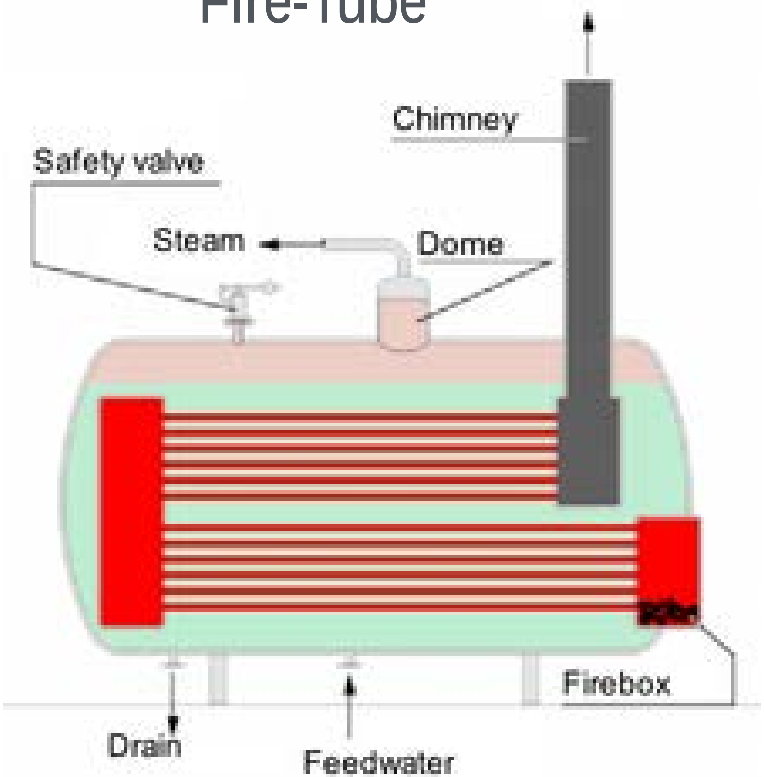
- Cost savings by using cheapest fuel
- Risk mitigation by avoid fuel supply interruption
- Utilities provide cost incentives for being able to disconnect natural gas
- Environmental improvement by reducing emissions

Boiler Types

Water-Tube



Fire-Tube



Types

- Water-Tube are the most common in industry as they work better at higher pressure and higher steam production requirements
- Some boilers will also have a superheating section that continues to heat the steam
- If there is no superheating section, the boiler can only produce saturated steam
  - Superheated steam provides the benefit of being able to lose energy before it condenses
  - However its increased temperature can increase heat losses and it may need to be de-superheated before in can be used in parts of the system.

Blowdown

Blowdown is the removal of water from a boiler to control the concentration of dissolved and suspended solids (DS) in the water. (as a % of feedwater)

- Generally 1% to 3% (lower is better)
- Sometimes hard to control due to valve fouling and wear
- Often too high or low
  - Low: DS will be damaging to boiler
  - High: Excess energy and water losses
- Provides a good potential heat and steam recovery option
  - LP Steam can be flashed
  - Make up water can be heated
- Better water treatment allows for a lower blowdown %

Support Systems

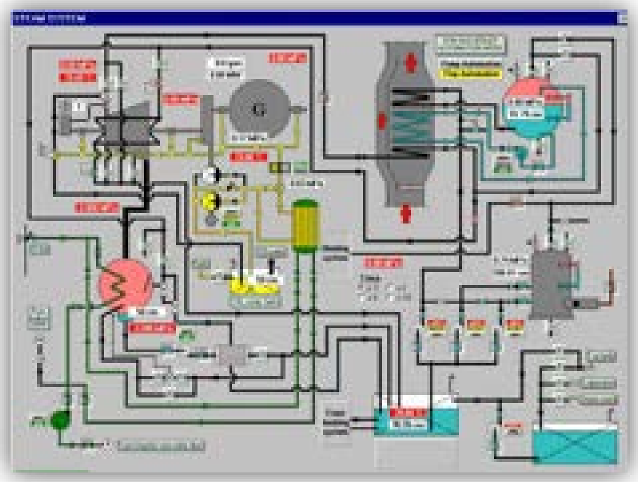
Steam Systems require multiple Pumps and Fans which:

- Also have potential energy savings
- May be steam powered

One of the reasons the IAC focus on whole plant assessments is because every system impacts the others and when evaluating each part, its overall impact must be considered.

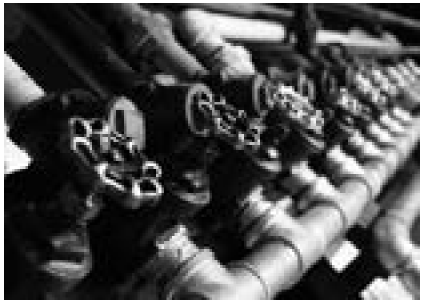
Steam Distribution System

- Steam Pressure Headers
- Pressure Reducing Valves (PRVs)
- Steam Turbines
  - Back Pressure and Condensing
- Insulation
- Steam Traps
- Heat Exchangers
- Flash Tanks
- Condensate Return



Steam Headers

- A steam header is a main steam supply pipeline for a specific pressure
- For each major pressure level of the steam system there is a steam header
- Often the header's design pressure is used to refer to the header (135 psi header is the "135") even though the current pressure might be a bit different
- For smaller systems, there may only be 1 header
- For the largest systems, there could be 5 or more



PRVs

- Pressure Reducing Values (PRVs) reduce the pressure of the steam without reducing the energy content (isenthalpic process)
- PRVs can also desuperheat steam by adding a temperature controlled amount of feedwater
- PRVs are important for system operation but can sometimes be hard to find because they can be very small
- If a PRV has a substantial continuous flow of steam, installation of a back-pressure steam turbine is often an excellent option
- However, even with a back-pressure turbine installed, a PRV must take any variable steam load

Back-Pressure Steam Turbines

- Back-Pressure steam turbines generate power by reducing steam pressure
- The outlet fluid should still be slightly superheated steam
- If water droplets are product in the turbine, severe damage may occur
- Steam turbines in are very efficient generating electricity with the energy they remove
- So steam turbines are rated base on how much entropy they produce referred to as the isentropic efficiency (typical 65%)
- The lower the isentropic efficiency the higher the remaining energy in the steam
- Some turbine may have a lower isentropic efficiency by design to match a require steam heat load

Condensing Steam Turbines

- Similar to back-pressure turbine except that the steam is cooled to condense after the outlet of the turbine resulting in a vacuum pressure at the turbines outlet
- Less efficient than a Back-Pressure turbine that is matched to process steam requirements
- Cooling fluid must also be continuously pumped through the condensing plates and deposed resulting in higher deposal costs and a significant amount of wasted heat
- Cooling fluids could be river or lake water, which requirements minimal treatment for this application

Site Energy vs Source Energy

- Offsite electricity takes more energy to generate and transmit than an equivalent amount of electricity generated onsite. Especially if it is generated by or produces useful waste heat.

- Assessment results, most often, should be reported in terms of “Source” usage to fairly compare savings.

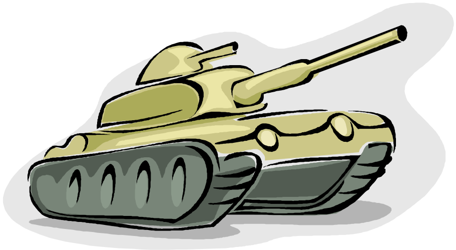
- An example of an issue with “Site” energy usage would be evaluating the savings for a cogeneration recommendation. Use of “Site” energy would make it look like it uses more energy, when it actually uses less.

Heat Exchangers

- Heat Exchanger Types
  - Shell and Tube
  - Plate and Frame
- Used for both process and waste heat recovery applications
- Poorly maintained heat exchangers can be fouled causing poor heat transfer
- Liquid to liquid is generally more efficient then Gas to Gas

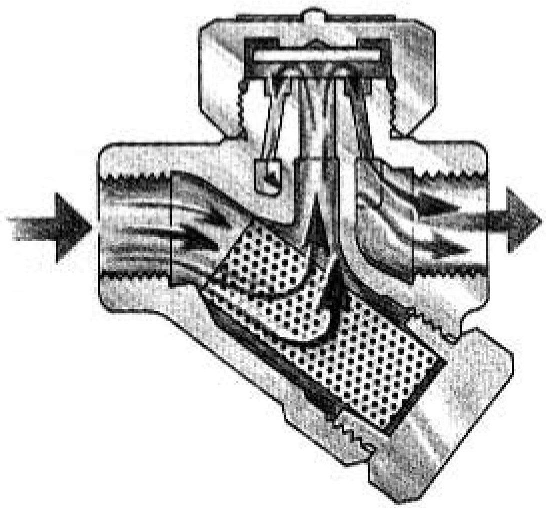
Flash Tank

- Flash tanks are used to separate steam from liquid water when the pressure is reduced
- Blowdown and returned Condensate are often flashed
- Flashed steam can potentially be reused by the system
- If the steam is not reused, it is vented



Steam Traps

- Steam traps remove condensate from steam lines
- Plants can have hundreds to thousands
- Depending on the application there are several different types of steam traps:
  - Balanced Pressure Traps
  - Bimetallic Steam Traps
  - Fixed Temperature Discharge Steam Traps
  - Ball Float Steam Traps
  - Inverted Bucket Steam Traps
  - Thermodynamic Steam Traps



Steam Traps Maintenance

- Steam traps are often the most poorly maintained part of the steam system
- In bad systems, 50% or more of the steam traps may be leaking/blowing or failed/plugged
- This is due to the difficulty of detecting leaks and failures and surveying all of the traps
- Ultrasonic leak detector and infrared camera are useful
- Developing a steam trap database with trap issues and maintenance activities can be helpful for preventative maintenance

Condensate Return

- Condensate is generally collected and returned to the boiler
- The benefits of returning condensate are:
  - Reduced water and water treatment cost
  - Reduced energy costs
  - Reduced sewage and waste water treatment costs
- Condensate is not returned when the:
  - Steam has contacted the process or the condensate could be contaminated in another way
  - Distance is prohibitive
  - Return system may have failed
- Also HP condensate can be flashed to produce lower pressure steam

Insulation

- Steam system require significant insulation for energy efficiency and safety reasons
- Insulation often is damaged over time in an industrial environment and requires repair
- Sometimes this damage is from employees carelessness like standing on or sticking knives in it
- Issues arise from insulating complex shapes like valves and connections
- For cheap steam, plants may not insulate small diameter pipes

The Steam Balance

- A steam balance is a list of all of the systems mass and energy steam flows, which should sum to zero
- One of the best ways to quickly evaluate a steam system is to work up a full steam balance
- Plants often ignore parts of the system, especially LP steam users
- LP steam use is often almost as expensive as HP steam
- Significant system issues can often be detected
  - One plant had a 80 klb/hr feedwater leak that had gone unnoticed until a steam balance put together

Waste Heat Recovery

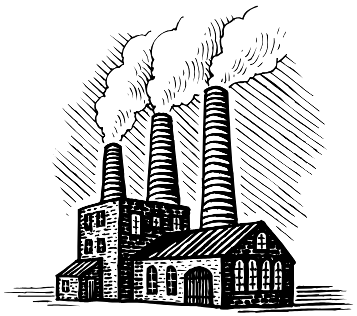
- Waste heat is any system heat losses that may be recovered
- With a steam system this can include:
  - Steam venting
  - Hot water discharge
  - Hot air venting
- Waste heat can be considered free energy
  if it is not the result of poor steam system operation
- Waste heat is primarily recovered with heat exchangers

Absorption Chillers

- Absorption Chillers use steam or hot water to generate cooling
- Reduces waste heat for summer operation of steam systems
- Generally very easy to operate and less operation requirements than a compressed vapor system
- Initial cost to purchase and install can be prohibitive

Production

- Steam system may not be modified when production levels are
  - Ex. Even if the process pressure requirements are significantly reduced, the boiler pressure may be unchanged
- When they are, they are often overhauled just enough to meet production needs without focusing on efficient operation
- As the plant changes their production and steam system, generally:
  - The layout and operation of the steam system gets more complex
  - The potential energy savings increase significantly



Energy Costs

- Steam systems are often operated based on energy prices from when the system was installed and not current rates:
  - Steam may be used for cleaning and to power motors when it is no longer economical
  - Costs for poor insulation and maintenance are often higher than the plant estimates
- Plants may not be correctly comparing various fuel costs
  - Biomass is cheaper but less efficient which can sometimes result in more expensive steam
- Plants may not react effectively to monthly energy cost fluctuations

Personnel

- Standard operation is not Efficient Operations
  - Plants may be so conservative with the operation of a steam system that it can increase operation cost by 20%
- Plant may not have access to equipment to evaluate the system
- Steam End Users are often not responsible for their steam use leading to careless waste
- Management cares most about cost effective not energy efficient operation

Steam Resources

- DOE Steam Resources

  http://energy.gov/eere/amo/steam-systems

- DOE **Steam System Modeler Tool**

  http://energy.gov/eere/amo/articles/steam-system-modeler

- Spirax Sarco has excellence online materials

  http://www.spiraxsarco.com/resources/pages/steam-engineering-tutorials.aspx

Questions