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Revision Memo

- 12/98** The highlights of this revision are:
1. Addition of APEX™ and Heat Pipe type air preheaters. pages 3, 5, 6, 7, 27
 2. Addition of Cost and also Construction manual references. page 3
 3. New discussion on OCAP Corrosion. page 6
 4. Addition of process fluid Air Preheat system. page 6
 5. Increase in internal castable lining thickness from 2" to 3" in line with IP's. page 11
 6. Clarify requirement for bypass ducts around Air Preheaters. Page 13
 7. Increase ID fan mechanical design temperature margin. Page 14
 8. Removal of outdated requirement for pressure relief doors and replacement with firebox design pressure constraints and controls. Page 16
 9. Added "S" purpose codes. Pages 16, 17, 20
 10. Correction of performance ratio calculation. Page 16
 11. Added instrumentation to Fig 8 to agree with IP 15-1-1. Page 30
 12. Corrected mass balance. Page 32
 13. General editorial update.



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SCOPE

This section of the Design Practice covers the procedures necessary for the selection, design, and installation of an Air Preheater system. Included are modifications to provisions of other Design Practices, such as [Section VIII-G, Forced Draft Systems](#), which become necessary when an air preheater system is incorporated into a fired heater design. In addition, this document contains guidelines to help determine when an air preheat system should be considered for a fired heater design.

REFERENCES

INTERNATIONAL PRACTICE

[IP 15-1-1](#), Instrumentation for Fired Heaters

ENGINEERING REPORTS

CE.9E.85, Combustion Air Preheat Systems for Small Furnaces (Exxon Chemicals)
 EE.63E.84, Air Preheater Selection Criteria and Design Variables
 EE.61E.82, Operating and Maintenance of Air Preheat Systems
 EE.53E.83, Air Preheater Fire Protection Guidelines

OTHER LITERATURE

API Standard 560, *Fired Heaters for General Refinery Services*.
Cost Engineering Practices, Vol. 2., Equipment Methods and Costs, ER&E Manual No. EEPM-03.
Refinery Construction Materials Manual, ER&E Manual No. EETD 028, December 1996.

BACKGROUND

Air preheaters have been used extensively as a means to reduce the fuel consumption of fired heaters. The most common air preheat concept uses an exchanger to transfer heat from the flue gas exiting a fired heater to its incoming combustion air. This increases the heater's efficiency by lowering its stack temperature below that achieved during normal operation. The cost of the air preheater system must be justified by the resulting fuel savings over a period of several years.

The typical air preheat system consists of a number of different components, in addition to the preheater itself. These include: forced and induced-draft fans; air and flue gas ducting; tight shutoff and modulating dampers, along with special safety controls and instrumentation. An illustration of a typical air preheater installation is presented in [Figure 1](#).

Most of the air preheat installations within Exxon were constructed during the 1970s and early 1980s, in response to a sharp increase in fuel cost, and in anticipation of continued increases in cost. Most new heaters and many existing units were fitted with air preheat systems. However, as of 1993, real fuel costs in much of the world are less than half their 1981 levels, and construction costs have increased significantly. As a result, it is much more difficult to economically justify new air preheat installations. Design efforts must focus on finding ways to both increase the effectiveness of the systems and reduce their cost. In addition, some of the original air preheat installations will soon reach the end of their useful service lives. The principles described in this document can be applied to ensure that replacement or modified equipment will be more durable and cost-effective.

EQUIPMENT TYPES

Five primary types of air preheat equipment are available, four of which are currently in use within Exxon. They are:

1. Rotary, regenerative, such as Ljungstrom.
2. Tubular, recuperative, such as Kablitz/Peabody, and BICAST (formerly DEKA).
3. Plate and frame, recuperative, such as North Atlantic Technologies' OCAP™ and APEX™ - Advanced Plate type, manufactured by Lummus.
4. Indirect fluid air preheater.
5. Heat Pipe Air Preheaters, such as manufactured by Hudson Products, no Exxon installations as of June 1998.

There is no single "best" type of air preheater; each has its advantages and disadvantages for a particular application, and local experience has varied significantly. The following paragraphs describe each type of equipment and list its major advantages and disadvantages, along with a brief synopsis of Exxon field experience.

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ROTARY REGENERATIVE AIR PREHEATERS

The regenerative preheater consists of metallic elements that are alternately heated and cooled. The most common type of regenerative preheater is the Ljungstrom (manufactured in the United States by Combustion Engineering, now a subsidiary of Asea Brown Boveri), shown in **Figure 2**. The metallic elements are contained in a subdivided cylinder that rotates inside a casing. Hot flue gas flows through one side of this cylinder and heats the elements, while the air to be heated flows through the other side. The cylinder rotates and heat is transferred from the heated elements to the cooler air.

Baffles which subdivide the cylinder, along with seals between the cylinder and the casing, limit the amount of leakage from the air side to the flue gas side. Since the air side is at a higher pressure than the flue gas side, leakage is always toward the flue gas side. This leakage, which is usually from 10% to 20% of total flow, must be taken into account in the design of the preheater system.

The regenerative preheater is normally mounted at grade, adjacent to the fired heater. Ambient air is forced through the preheater by a forced draft fan and is carried in ducts from the preheater to the heater burners. The hot flue gas is carried in ducts from the top of the convection section to the preheater. An induced-draft fan draws this flue gas through the convection section, ducting, and preheater and discharges it to the stack. This equipment requires additional plot space to accommodate the preheater, fan and ducts.

LJUNGSTROM AIR PREHEATER

The Ljungstrom rotary regenerative air preheater has been widely used in air preheater applications within Exxon. **Figure 2** is a descriptive illustration of a typical horizontally mounted unit, though mounting can be either horizontal or vertical. Heating elements and other components in various positions within the preheater can be manufactured from different materials to provide resistance to temperature and corrosion. For example, at the hot end, mild carbon steel is used, while intermediate sections may be either Corten or enameled steel, and cold end sections are usually enameled steel. Major advantages of the Ljungstrom units include the following:

1. Potentially lower initial cost compared to tubular air preheaters in larger sizes, i.e., fired heater duty over 200 MBtu/hr (60 MW).
2. Plot space and foundation requirements are less than for a comparable duty tubular air preheater, due to compact size and relatively light weight.
3. Acceptable for services which fire oil or high sulfur fuel gas. In most cases, a single sootblower is used to clean the cold end, although when heavy fouling is expected, an additional sootblower is added at the hot end.
4. Can be oriented for horizontal flue gas and air flow, which usually simplifies ducting arrangement in most applications.
5. Element corrosion damage does not contribute to leakage.
6. Fouling does not significantly affect heat transfer.
7. Wide application within Exxon.

Major disadvantages of the Ljungstrom type are the following:

1. High air leakage rate of 10-20%, which increases over run length due to degradation of seals. This requires forced and induced draft fans to be larger than with tubular preheaters.
2. More susceptible to fouling with sticky deposits on the cold end, which increase pressure drop and corrosion.
3. Horizontal units cannot be effectively water washed and are subject to severe corrosion where wash water collects in the lower casing and seals.
4. Normally requires more maintenance, primarily replacement of baskets and seals. Also, a number of locations have reported failures of the rotor bearings.

TUBULAR AIR PREHEATER

A cast tubular air preheater normally consists of a large rectangular heat exchange bundle. In most designs, combustion air is forced through the tubes, while the hot flue gases pass across the tubes. The tubes are usually finned to improve heat transfer. Some designs have fins on both the flue gas and air side, for maximum heat transfer. The tubes are typically of rectangular cross-section, made of cast iron. In cases where flue gas exit temperature is close to the acid dew point, a bank(s) of glass tubes is used.

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Tubular air preheaters are usually mounted at grade near the heater (see **Figure 1**), with fan and ducting arrangement similar to that of the rotary regenerative preheater. However, the low flue gas pressure drop makes some smaller units suitable for mounting directly on the heater, atop the process convection section, thus eliminating the need for the induced draft fan and ducting. The air ducting must be routed from grade to the preheater and back to the air plenum. Although in some cases the forced draft fan has also been mounted atop the heater, this is not generally recommended due to the difficulty of accessing the fan for maintenance and the potential for vibration damage.

- ◆ A number of companies have produced cast tubular air preheaters over the years. However, business conditions, along with changes in technology licensing and manufacturing agreements, have resulted in many of the manufacturers leaving the business or at least changing names. As of this writing, manufacturers currently producing tubular air preheaters include Kablitz and BICAST, both located in Europe. All these units were commonly referred to as DEKA type. An assembly drawing of a typical cast tubular unit is depicted in **Figure 3**.

The tubular air preheater is constructed of several modules consisting of up to three different types of tube sections, depending on the application. Typically the hottest section of the preheater has cast iron tubes with fins on both the air and flue gas sides. In order to maintain high metal temperatures in the intermediate zone, cast iron tubes with fins only on the flue gas side are used, keeping all metal parts above the flue gas acid dewpoint at all times. If the application calls for an extremely low flue gas exit temperature, a third section, consisting of borosilicate glass tubes, is provided. This section allows the preheater to operate without corrosion below the acid dewpoint. In addition, the glass tube section can be installed downstream of an existing preheater to maximize recovery of available heat.

- ◆ Most current glass tube designs utilize tubes which are not restrained by the tubesheet, minimizing stresses due to differential thermal expansion. This has proven to be more reliable than older designs, however water washing still imposes operating restraints. To minimize the risk of failure due to thermal shock, the temperature difference between the water and the tubes, must not exceed 180°F (100°C) to:

The advantages of the tubular preheater can be summarized as follows:

- ◆ 1. Minimal air leakage, when tube bundles are properly manufactured and installed.
- 2. Requires minimal maintenance as there are no moving parts.
- 3. Modular design allows dimensional flexibility for limited plot space.
- ◆ 4. Less prone to foul due to larger spaces between extended surfaces.
- 5. With glass tube design, provides extremely high efficiency.

This type of preheater also has the following disadvantages:

- 1. Generally higher initial cost for preheater compared with rotary type, particularly for applications over 20 MBtu/hr preheater duty.
- 2. Bulkier construction requires more plot space, vertical clearance, and heavier foundations and structural steel.
- ◆ 3. The glass tubes are easily damaged, which leads to an increase of combustion air leakage to the flue gas.

PLATE AND FRAME AIR PREHEATER

One of the more recent developments in air preheater technology is the plate and frame air preheater, also known as "open channel air preheater," or OCAP™, manufactured by North Atlantic Technologies. The heat exchanger consists of a series of clamped, stacked, parallel plates, which form a series of flow channels for the incoming flue gas and combustion air. The system and auxiliary equipment are essentially the same as for the tubular air preheater. The primary difference is the compact size and light weight of the OCAP™ unit. Application at Exxon to this point has been limited to one location, but it does show some promise, particularly for replacing existing preheaters nearing the end of their useful life. **Figure 4** is a schematic representation of the OCAP™ air preheater.

- ◆ Another development in air preheater technology led to the APEX™ plate type air-preheater. As of June 1998, there are no installations within the Exxon circuit. However a substantial number of units have been manufactured throughout the world. The APEX™ design is a fully welded construction consisting of a heat transfer core, a casing and a sealing mechanism. The heat transfer core is made of a stack of flat plates, seal welded along the alternating passages for the two gasses. Spacers are positioned in an optimum pattern between the plates to ensure the plate alignment in operation. The casing is made of structural plate and is designed to support the unit's own load in addition to external loads. The sealing mechanism is a fully welded construction (proprietary design), which adjusts to the thermal expansion of the casing and core. This provides a low air side leakage rate. The APEX™ units are built up of one or more elementary blocks. This modular construction provides flexibility to maximize cold end metal temperatures.

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This type of unit possesses many of the advantages of the tubular air preheater, with the following additions:

1. Due to its high surface-to-weight ratio, it is lighter and more compact than other tubular preheaters. It can also be provided in a crossflow configuration if overhead clearance is a problem.
2. The preheater itself is less expensive than tubular preheaters of comparable duty. In addition, total erected cost is likely to be lower due to reduced foundations, structural steel, and ducting requirements.
3. It is suitable for mounting directly above the convection section of small heaters, which totally eliminates the need for an induced draft fan.
4. Modular design allows easy integration with Selective Catalytic Reduction (SCR) facilities, used to reduce NO_x.

This type of unit has two primary disadvantages:

1. Potential for fouling tight passages in heavy oil or very high sulfur gas firing, although they have even been used in coal service in the utility industry.
2. Lack of Exxon experience with OCAP™. There is some concern about the long-term viability of the sealing mechanism. No leakage has been reported in the single Exxon application (in service in Singapore since 1990). However, this unit failed after about 5 years operation due to severe flue gas side corrosion. The suspected cause was operational temperatures less than the dewpoint on unprotected plates. Use of multiple pass, all crossflow designs in future applications should be considered. Careful material selection, along with use of enameling of areas subject to condensation is required in future designs.

As mentioned above, the APEX™ offers reduced potential for increased leakage with time, but has not been used in Exxon yet.

INDIRECT FLUID AIR PREHEATER

Another type of air preheater in limited use within Exxon is the indirect fluid air preheater. It can be circulating or once through and is found in one of three general forms, as described below:

1. Intermediate fluid type where a heat transfer fluid is circulated between the flue gas exhaust duct and the combustion air duct, thereby picking up heat from the flue gases and releasing heat to the combustion air.
2. Process waste heat recovery, which utilizes a process stream, which would normally give off heat to the atmosphere, can be used to preheat combustion air in a suitable heat exchanger. This does not significantly reduce heater stack temperature, so it may be possible to obtain further heat recovery through other means, such as a waste heat boiler.
3. A once through fluid type where the fluid used is the process fluid, prior to entering the convection section. See **Figure 5**. This system has the advantage of preheating the combustion air and also reducing the temperature of the process inlet to the convection section. This in turn will increase efficiency by reducing stack temperature.

A typical intermediate fluid type air preheat system is shown schematically in **Figure 5**. This system is similar to a tubular air preheater except that an intermediate fluid, rather than combustion air, is heated within the tubes. This fluid is then circulated to the air duct where another heat exchanger is utilized to heat the combustion air. The fluid is then circulated back to a surge drum to be used again.

Advantages of this type of system are as follows:

1. More adaptable to difficult plot layouts.
2. Can be used to economically transport waste heat over larger distances by replacing ducting with piping.
3. Allows recovered heat to be used to preheat combustion air for fired heaters other than the one from which it was recovered.

The circulating fluid air preheater shares many of the disadvantages of other types of tubular air preheaters, plus the following additional disadvantages:

1. Potential fire hazard if tube rupture occurs on either air or flue gas side. If heat recovery tubes are located in the process convection section, this also increases the risk of tube rupture in the process convection section, particularly with high-sulfur fuels. This can be mitigated by using an offset, or outboard convection section for waste heat recovery.
2. Requires an allowance for startup time to completely fill system with fluid and establish circulation in all parallel passes of exchangers.
3. Limited to maximum air preheat temperatures of 600-650°F (315-340°C) due to degradation of heat transfer fluid at higher temperatures. This can occur at much lower air preheat temperatures if good flue gas distribution through the exchanger is not obtained.

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4. Disposal of used heat transfer fluid can be a problem. In some locations, used, thermally degraded fluid can be considered hazardous waste, and must be disposed of accordingly.
5. Less than spectacular operating experience. Problems have been experienced with tube leaks, with subsequent fires and coking of the heat transfer fluid, in some cases caused by afterburning in the process convection section.

Indirect fluid air preheat systems are not the best choice for most applications, due to their inherent low efficiency and potential operating problems. However, there are some cases where they might be the only economical solution to a heat recovery need. In the event one of these systems is specified, a number of safety considerations should be incorporated into the design of the equipment. These considerations are summarized in **Table 1** and address the following major areas:

1. Means for minimizing leak potential and for dealing with leaks which do occur.
2. Acceptable types of circulating fluids.
3. Operating procedures.
4. Safety equipment and instrumentation.
5. Basic assumptions for performing calculation related to tube leaks.

♦ HEAT PIPE AIR PREHEATERS

Heat pipe air preheaters consist of a tube bank of individual heat pipes. Each heat pipe has a hot end in the flue gas stream and a cold end in the combustion air stream. Each individual pipe is a sealed tube containing a heat transfer liquid. Heat transfer is by a continual process of boiling and condensing the heat transfer fluid. Heat input from the flue gas causes vaporization of the heat transfer fluid in the hot end of the pipe, followed by condensation in the cold end of the pipe as the combustion air removes heat. The tubes are inclined at a small angle to the horizontal, typically 6-10 degrees, however vertical tubes can also be provided. Heat transfer fluids used include assorted hydrocarbons, ammonia or water.

Hudson Products are now manufacturing a range of water filled heat pipes. However as of 1998, only two units are in operation, none at Exxon. There is a limit to the maximum inlet flue gas temperature for the water filled heat pipes due to the water critical temperature. Above this temperature the water does not change phase on heating and does not condense and flow back down the tube on cooling.

Advantages of heat pipes are as follows:

1. No moving parts or controls.
2. Air side and flue gas side can have widely different flow areas.
3. Minimal air leakage into the flue gas.

Disadvantages of heat pipes are as follows:

1. Concerns with the first hydrocarbon and ammonia fluids include combustibility, toxicity and breakdown at high temperatures.
2. Concerns with water based fluids include corrosion and freezing during extended downtimes.
3. Some early designs of hydrocarbon filled heat pipe air preheaters suffered from premature failure as a result of corrosion and or breakdown of the internal operating fluids.
4. Limited to a maximum inlet flue gas temperature of 700-750°F (370-400°C) due to water critical temperature.

PREHEATER APPLICATIONS

ECONOMIC CONSIDERATIONS

- ♦ A number of air preheat systems were installed during the early 1980s, when fuel prices were nearly \$4.00 per MBtu (\$3.80/GJ), and were expected to be at least \$8.00 per MBtu (\$7.60/GJ) by the end of the decade. As of 1998, fuel prices in many locations are around \$2.00-2.50 per MBtu (\$1.90-2.38/GJ) in current dollars, so it is much more difficult to justify installing new air preheat facilities. However, there are situations in which the use of air preheat facilities should be investigated in detail. **Figure 6** depicts graphically the combinations of process duty and stack temperature which may justify the installation of air preheat facilities, for both retrofit and new applications. Note that the curves were produced by comparing yearly energy savings with the total erected cost of an average tubular or Ljungstrom type air preheat system, including ductwork, fans, and instrumentation, assuming a minimum acceptable DCF return of 15% (this will vary with time and from location to location). The use of the curves is explained below:

1. If the economic stack temperature for new designs, or actual stack temperature, for retrofits, falls below the gray band, then air preheat is probably not justified.

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- If the stack temperature lies above the gray band, then air preheat probably is justified.
- If the stack temperature falls within the band, then air preheat MAY be justified, and the application must be studied in more detail.
- Fuel savings are determined by comparing the heater's fuel consumption at the current (for retrofits), or the best economical (for new applications) stack temperature with the amount of fuel consumed at the proposed air preheater's exit temperature (uncorrected for leakage). This temperature should be as low as possible without risking cold-end corrosion problems (see Design Considerations).
- In some cases, strategic considerations, such as a limited fuel supply, or a strong drive for overall energy conservation, may overshadow pure economic considerations.

INVESTMENT

A number of factors must be considered when estimating the incremental investment required for installing an air preheat system, especially for retrofit work. Some of the key considerations are described below:

- Costs for all major components, including ducting, fans, dampers, instrumentation, and in some cases, burners, must be considered, in addition to the cost of the preheater itself.
- These costs can be obtained through the Exxon Cost Engineering Manual. However, some information about the system must be known in order to obtain useful information, as described below:

Air Preheater The stack temperature and process duty of the heater must be known. Note that the Cost Engineering Manual contains costs for Ljungstrom and Tubular units only; costs for other types of preheaters should be obtained from the vendor.

Ducting This is one of the major costs associated with an air preheat project, often exceeding the cost of the preheater itself. In order to develop a reasonable estimate of ducting costs, it is necessary to develop a preliminary equipment layout, which will enable you to estimate the footage of ducting required. It is also necessary to specify duct sizes, along with the thickness and type of insulation.

Fans A preliminary estimate of fan horsepower must be made. Be sure to include appropriate allowances on both flow rate and discharge head.

- For new installations, only incremental investment must be considered. This will include the preheater, fans, ducting, additional instrumentation and larger burners (due to the higher air temperature). Note that the addition of air preheat shifts duty from the convection section to the radiant section, so less convection surface area will be required.
- Less incremental investment is required if the heater is already designed for forced draft firing, since ducting and fans are being provided in the base case. These only need to be upgraded to handle the higher pressure drops, volumes and temperatures associated with the preheater.
- Retrofit costs are much more difficult to determine accurately. Additional factors must be included to account for dismantling and modifying the existing stack and heater floor. More importantly, the new fans will impose additional demands on the plant electrical system. In many cases, extensive power distribution system work will be associated with an air preheat project. Preheat can be added to existing units as long as the tube metal temperatures are not limiting. Adding air preheat will increase tube wall temperatures.

Investment Reduction - With today's lower fuel prices, a conscious effort must often be made to reduce the level of investment associated with a preheat system. This may also make air preheat feasible at lower stack temperatures and heater duty than shown on the curves in **Figure 6**. The following factors should be considered when designing any preheat system, but particularly on smaller heaters where credits are lower. Some of the steps to minimize investment which should be considered, are described below:

- Consider the use of a plate preheater, either OCAP™ or APEX™. This unit is much lighter, and requires much less structural steel and foundation work than a Tubular type preheater.
- Design ducts for a flue gas velocity of 50 ft per second (15 m/s) to reduce the size of the ducting. In addition, where gas composition and temperatures allow, use external insulation rather than internal castable lining. This is particularly true of small-diameter ducting, which is difficult to line internally. Also, ducting which is circular in cross section is generally less expensive than rectangular ducting.
- Air preheated by a process slip stream can be used when the coil inlet temperature is high. This concept is shown in **Figure 5**. The advantage is that the same preheat can be provided at a lower cost and no Induced Draft Fan is required.

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ENVIRONMENTAL CONSIDERATIONS

Flue gas from fired heaters with air preheat contains a higher concentration of Oxides of Nitrogen (NO_x) than that from fired heaters using ambient air. This concentration increases as a function of air preheat temperature, and can be as much as twice the baseline NO_x concentration. This increase can be approximated using existing NO_x prediction tools; however, this will vary significantly depending on the burner used. While this increase in concentration is offset somewhat by the higher heater efficiency, a net increase in NO_x emissions will occur unless some further steps are taken. Options include Low- NO_x burners and post-combustion treatment such as Exxon's THERMAL De NO_x Process or Selective Catalytic Reduction. Net emissions of other pollutants, such as SO_2 , CO, and particulates, will be lowered somewhat due to the reduction in heater firing and/or more complete combustion.

DESIGN CONSIDERATIONS

The "Design Procedure" for an air preheater system involves mainly its effect on the design of the rest of the fired heater system, as illustrated in the sample problem. Key considerations for various aspects of the design are presented below.

- ◆ **Preheater Flue Gas Exit Temperature** - This is perhaps the most important variable to be specified, as it will determine both the efficiency of the system and set requirements for cold-end corrosion protection. The flue gas exit temperature however is an average value. Depending on the design, flow arrangement and flow distributions, local temperatures can be lower than the average and local cold spots can create problems. In general, the flue gas exit temperature should be set as low as possible while maintaining the minimum preheater metal temperature above the point at which unacceptable levels of corrosion will occur. This temperature is a function of the fuel sulfur content, and is defined according to the type of preheater and its materials of construction. Downstream equipment may also be the limiting factor, even with a corrosion-resistant air preheater. **Figure 7** depicts the minimum recommended flue gas exit temperature vs. fuel sulfur content for a number of different preheater types. Note that in all cases, the minimum cold end temperature should be at least 35°F (20°C) above the acid dewpoint temperature unless equipment downstream of the heater has been protected to prevent corrosion from acid attack, or fuel fired is a very clean gas, with H_2S levels of 1000 vppm or less. The problem of cold end corrosion can be reduced by preheating the air slightly before it reaches the preheater using a small steam or other waste heat coil. In general, a 60°F (33°C) increase in air temperature will cause a 20-30°F (10-15°C) increase in cold end temperature, for a given minimum flue gas outlet temperature. This will be sufficient in most cases to prevent cold-end corrosion.

For a Ljungstrom type air preheater, the cold-end temperature is defined as the average of the air inlet temperature, considered for design purposes to be 60°F (15°C), and the preheater outlet temperature, uncorrected for leakage. The minimum allowable cold end temperature varies depending on the materials of construction. For example, with up to 1% sulfur in the fuel, the standard "Class I" Ljungstrom unit is suitable for a minimum uncorrected cold-end temperature of 205°F (96°C), which results in a flue gas outlet temperature of 350°F (176°C). This would correspond to a corrected exit temperature of 320°F (160°C), assuming 10% leakage. This is above the "dewpoint plus 35 degrees" curve depicted in **Figure 7**, so no special measures need to be taken to protect downstream equipment.

A unit with upgraded materials in the cold end and intermediate section (Class II) is suitable for a minimum cold end temperature of 190°F (88°C), which would result in an uncorrected flue gas outlet temperature of 320°F (160°C). However, the corrected outlet temperature would be about 295°F (146°C), which is below the dewpoint plus 35°F (20°C) curve. The uncorrected outlet temperature must be limited to about 345°F (174°C), unless downstream ducting is protected. Similarly, a "Class III" Ljungstrom, which also has an upgraded hot end, would be suitable for an uncorrected exit temperature of 290°F (143°C), but would also be limited to 345°F (174°C) by the downstream equipment.

- ◆ At moderate to high sulfur levels, the cast tubular type air preheater with cast iron tubes is not capable of providing as low a minimum flue gas outlet temperature as the Ljungstrom units. For example, at 1% sulfur, the minimum recommended flue gas exit temperature is 400°F (204°C) versus 350°F (177°C) for the basic Ljungstrom unit. However, at sulfur levels below 0.25 wt% (or below ~1250 vppm H_2S), the tubular becomes more effective, allowing temperatures as low as 220°F (104°C) with very clean gas fuels (Wt% Sulfur < 0.2%, H_2S less than 1000 vppm). Note that a Tubular unit with glass cold-end tubes is capable of operating well below the acid dewpoint temperature; however, strong measures must be taken to protect downstream equipment from corrosion. These costs should be included into the overall costs when selecting the type of air preheater.

Fuels with very low sulfur levels provide an opportunity to obtain very high fired heater efficiencies (as high as 93%), with either tubular, plate and frame, or Ljungstrom units. For example, even a standard Ljungstrom unit is capable of handling minimum uncorrected exit temperatures as low as 245°F (118°C) if the sulfur content of the fuel is below 0.2 wt%. This would produce a minimum metal temperature approximately 35°F (20°C) higher than the water dewpoint of the flue gas. However, care must be taken to ensure that the downstream metal surfaces are also kept above this temperature. Even a very low acid concentration in the condensed water will eventually cause severe corrosion damage.

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DESIGN CONSIDERATIONS (Cont)

Air Preheater Flue Gas Inlet Temperature - The system should be designed for the maximum amount of air preheat possible, since the cost of incremental preheater duty is relatively small. In a grass-roots design, this will allow the convection section surface area to be reduced, lowering the overall cost of the fired heater. The thickness of refractory in the breeching and downstream ducting will need to be increased over that used in a heater without preheat, however.

- In general, most fired heaters which are good candidates for air preheat will have convection section flue gas outlet temperatures of 700-950°F (370-510°C). Most air preheaters can accommodate this temperature range. In fact, both rotary regenerative and tubular preheaters are capable of withstanding flue gas temperatures as high as 1000-1200°F (537-649°C), when materials are suitably upgraded. Heat Pipe air preheaters with water as a working fluid are limited to 700°F (370°C); refer to the heat pipe background discussion, for further information.

In most grass-roots designs, the designer can specify the desired convection section exit temperature. Normally, there is no incentive to specify a temperature higher than 900°F (480°C) or so, unless the heater coil inlet temperature is abnormally high. This temperature will provide preheated air temperature at around 650°F (343°C) for most applications. For heaters firing large amounts of low Btu gas (e.g., FLEXICOKING unit offgas), lower flue gas temperatures into the air preheater are normally required. Flue gas temperatures into the air preheater of 700-750°F (370-400°C) are commonly required to avoid temperature pinch problems at the hot end. This adjustment is needed because of the higher flue gas to air mass flow ratio with low Btu gas.

Air Preheater Air Inlet Temperature - The design basis air temperature will be 60-80°F (15-27°C) in most cases. However, in cold locations, the ambient temperature during much of the year will be lower than this, resulting in lower flue gas exit temperatures and subsequent increased risk of corrosion. In very cold climates, the air can be slightly preheated at the inlet of the forced-draft fan to reduce the chance of ice formation on the fan blades, which effectively increases the ambient temperature. Other locations can either use this same technique, or bypass some of the air flow around the preheater during cooler weather.

Many installations have been built with a small cold air bypass duct around the preheater capable of handling up to 15-20% of the total combustion air flow. A small bypass damper (either manual or automatic) is installed in this duct to regulate the flow to provide the desired flue gas outlet temperature. This bypass can also be used to control flue gas exit temperature during turndown conditions. However, this does reduce the final temperature of the preheated air, resulting in a lower heater efficiency.

Air Preheater Air Exit Temperature - The air temperature leaving the air preheater will be a function of flue gas inlet temperature, air preheater leakage, and the characteristics of the preheater itself. In general, an air preheat temperature 100-200°F (55-110°C) below that of the entering flue gas can be achieved, depending on the preheater's effectiveness (see below). Air preheat temperatures above approximately 650°F (340°C) may require thicker ducting insulation and stainless steel burner components. Note also that higher combustion air temperatures also result in higher concentrations of NO_x in the flue gas.

Air Preheater Effectiveness - The effectiveness of an air preheater is a measure of how closely the hot air temperature approaches the flue gas inlet temperature. This is normally set by the total surface area of the preheater, along with the ratio of air side to flue gas side surface area. Effectiveness is defined by **Eqs. (1) and (2)** as:

$$(EFF)_{fg} = \frac{\Delta T_{fg}}{T_{fg \text{ in}} - T_{air \text{ in}}} \quad \text{Eq. (1)}$$

$$(EFF)_{air} = \frac{\Delta T_{air}}{T_{fg \text{ in}} - T_{air \text{ in}}} \quad \text{Eq. (2)}$$

The ratio of the air side effectiveness to the fuel side effectiveness is called the "X-ratio," and is defined as:

$$X = \frac{(EFF)_{fg}}{(EFF)_{air}} = \frac{\Delta T_{fg}}{\Delta T_{air}} = \frac{(m \text{ Cp})_{air}}{(m \text{ Cp})_{fg}} \quad \text{Eq. (3)}$$

where: m = Mass flow rate lb/hr (kg/s)
Cp = Specific heat of air or flue gas, Btu/lb °F (KJ/kg °C)

This ratio will range from 0.85-0.9, depending on the fuel fired, excess air level, and type of preheater. In operation, this ratio can be calculated based on process data and can provide an indication of fouling or leakage on either the flue gas or the air side.