Integrated Approach to Efficiency Improvement in Fired Heaters

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Abstract

An Air-preheater (APH) can provide an effective means to improve efficiency of fired heaters. Efficiency improvement is achieved by means of recycling the waste heat from flue gases as heat for combustion in radiant section. Efficiency can be maximized by recovering lowest level possible heat in flue gases.

Addition / Revamp of APH impacts critical design and operation parameters - efficiency, radiant heat flux, Emissions (NOx and Greenhouse Gases), plot plan and equipment size / foundation.

Integrated approach to evaluate complete fired heater system (including APH) can help avoid any negative impact on fired heaters and maximize the benefit in terms of energy recovery, improved performance and decarbonization.

Recommendation and discussion in the paper includes a case study to highlight the effectiveness of integrated approach.

Integrated Approach to Efficiency Improvement in Fired Heaters

1. Introduction

The world of energy is facing fundamental changes. The lowest cost decarbonization solutions are energy efficiency solutions based on IPCC reports (<20 $/ton of avoided CO2 eq). This major trend drives a particular strong need for increasing energy efficiency solutions and management on existing assets and for new projects.

Industrial actors are more and more impacted by the high variation of energy price over the last decade. A higher resilience to the high fluctuation of energy price is a key competitive advantage. Fired heaters are one of the largest consumer of energy in an operating plant.

Air-preheater (APH) can provide an effective means to drastically improve efficiency of fired heaters. Efficiency improvement is achieved by means of recycling the waste heat from flue gases as heat for combustion in radiant section. Efficiency can be maximized by recovering lowest level possible heat in flue gases.

Typically, APH duty is 10-15% of overall fired duty.

The extent of fuel saving depends on many factors including fuel type / composition, excess air, condition of equipment, flue gas temperature, etc.

In most of the cases, efficiency improvement scheme via APH are evaluated in isolation and not complete system evaluation is done for achieving maximum benefits.

Recycling of waste heat may influence number of parameters (like average radiant flux, emissions, run length, mechanical components, and tube metal temperature)

Integrated approach to evaluate complete fired heater system (including APH) can help avoid any negative impact on fired heaters and maximize the benefit in terms of energy recovery, improved performance and decarbonization.

2. Fired Heater Efficiency and Air preheating System

A fired heater with air-preheating system mainly consists of APH, Forced Draft (FD) fan(s) – normally with electric motor, Induced Draft (ID) fan – normally with electric motor, refractory lined flue gas ducting, combustion air ducting (hot air is normally externally lined), dampers, isolation blinds, flow measurement and additional instrumentation. Flue gases from the fired heater stack is routed via flue gas duct to an outboard APH where it exchanges heat with ambient combustion air. Cold flue gases from the air-preheater is exhausted to the stack via an ID fan. FD fan(s) supplies combustion air to the air-preheater. The air is heated in the APH and hot combustion air is supplied to burners in radiant section.

Figure A shows a simple schematic of a fired heater with an air pre-heating system.

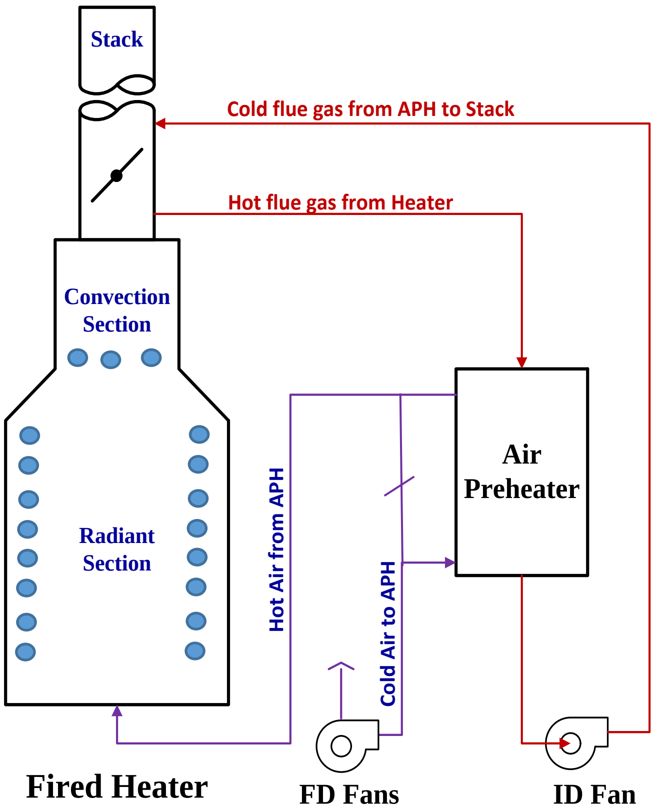

Figure A – Schematic for Fired Heater with APH system

This recovery/exchange of heat help reduce fuel consumption in fired heater and increases overall efficiency. Normally APH help improve overall efficiency by 10-15% and simple payback period is less than 3 years. Benefit of installing increases with increase in size (absorbed duty) of fired heater.

Potential for increase in efficiency depend upon one major parameter – S in fuel gas (it can be in various form). S from fuel gases is converted into SO_2 / SO_3 during combustion in burners. Typically, conversion of SO_2 to SO_3 is 3-5vol% during combustion process and at low temperature, SO_3 converts to weak acid and may cause corrosion by condensation on metallic heat transfer surface. Coated tubes / polymer tubes (shown in Figure B) can help mitigate corrosion of metallic heat transfer surface.

Figure B – Options for Low Level Heat Recovery

There are other parameters, which influence increase in efficiency but to lesser degree.

The heat available from combustion of fuel for heating is equal to flue gas enthalpy change from adiabatic flame temperature and stack temperature. The target flue gas stack temperature shall be determined based on fuel sulfur contents. If the flue gas stack exit temperature is higher than the target flue gas stack temperature, then the heat available in flue gas can be used for efficiency improvements of the fired heater. The integration of fired heater with air-preheater determines the maximum recoverable heat from flue gas.

The net efficiency of a fired heater is equal to total heat absorbed divided by total heat input. The heat absorbed is equal to total heat input minus the total losses. The net heater efficiency can be calculated by following:

$$\eta = \frac{Total\ Heat\ Input - (Stack + Setting)\ Losses}{Total\ Heat\ Input} x100 \qquad \text{(Eq 1)}$$

$$\eta = \frac{LHV + H_a + H_f + H_m - H_s - H_L}{LHV + H_a + H_f + H_m} x100 \qquad \text{(Eq 2)}$$

Where:
η = Net thermal efficiency, %
LHV = Lower heating value of the fuel, Btu/lb of fuel
Ha = Sensible heat of air, Btu/lb of fuel
Hf = Sensible heat of fuel, Btu/lb of fuel
Hm = Sensible heat of atomizing media, Btu/lb of fuel
Hs = Stack heat losses, Btu/lb of fuel
H_L = Setting loss, Btu/lb of fuel

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Figure C provides an estimated efficiency for a case study. It can be noted from this figure that degree of combustion air preheat does not affect the fuel consumption (i.e. fired heater efficiency). Flue gas temperature leaving stack determines overall fired heater efficiency. Whether flue gases are cooled in the convection section or APH, is irrelevant for fired heater efficiency but the same is very important for overall fired heater performance.

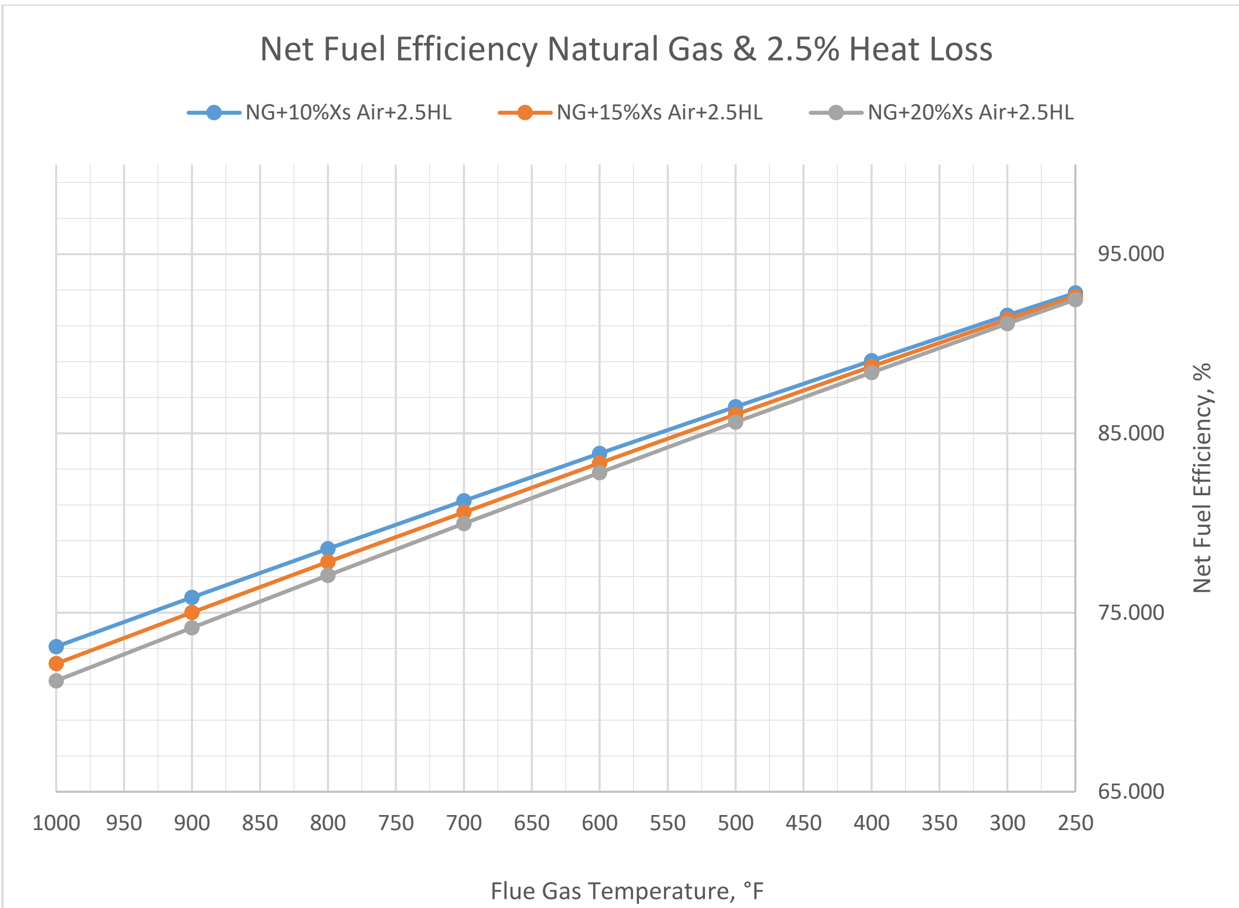

Figure C – Fired Heater Efficiency

There is always potential for recovering more waste heat as shown in Figure D

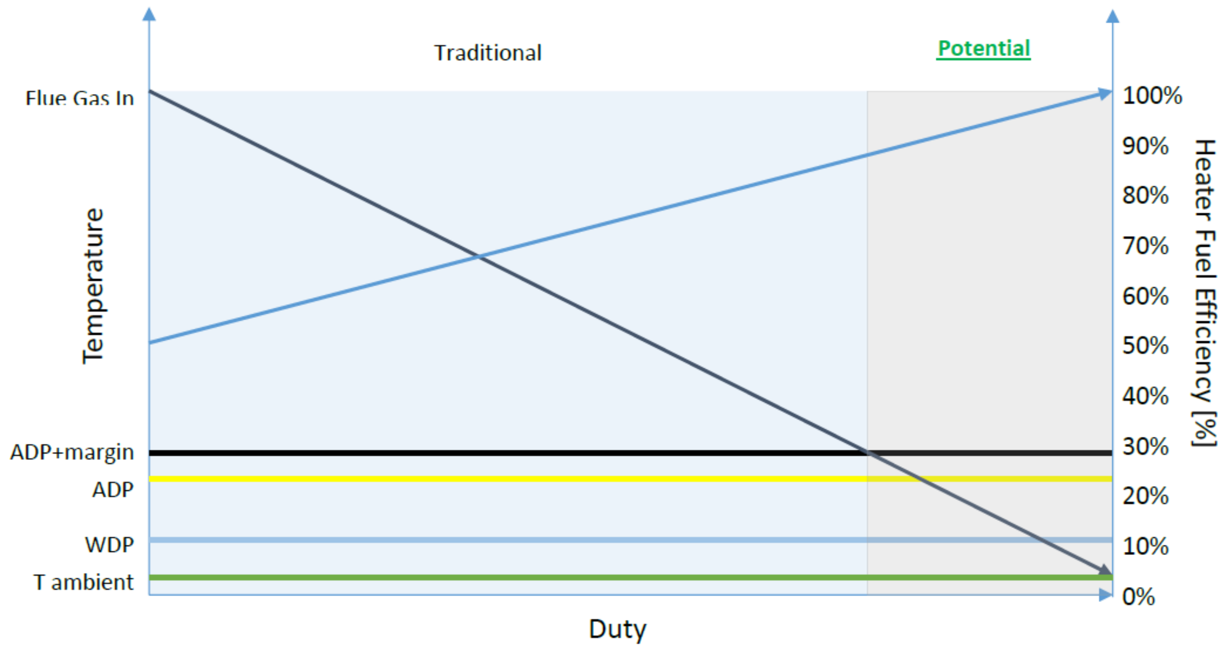

Figure D – Potential for APH Heat Recovery

3. Parameters Impacting & Improving Performance (Mainly Efficiency)

There are multiple options to increase and / or improve efficiency as shown below:

- **Fuel Switch**
- **Reduce Excess Air**
- **Use of O2 enriched Air**
- **Tune Combustion/Furnace Parameter**
- **Add / Modify heat transfer surface area in convection section**
- **Add / Improve APH**

This paper focus on last two options.

Duty split between convection section and APH, proper sizing of APH and overall design of fired heater is very critical for overall performance / life of fired heater.

There are several critical parameters; some of these are listed below, which should be considered and evaluated for a well-designed fired heater with air-preheater for better performance and long and consistent run length:

- **Adiabatic Flame Temperature**
- **Degree of Air Preheat**
- **Degree of Convection Section Preheat**

4. Adiabatic Flame Temperature

The adiabatic flame temperature (AFT) is defined as the temperature of combustion products that would result with no heat loss.

In a fired heater, heat is provided by combustion of fuel and sensible heat of fuel and air. The combustion air is available at ambient temperature and is preheated to air-preheat temperature in an air-preheater. The combustion of fuel in a fired heater results in a flue gas at a flame temperature. Therefore, as combustion air temperature increases, adiabatic flame temperature also increases with it. Figure E shows a summary of the effect of combustion air temperature on adiabatic flame temperature for a case study with a typical natural gas with 15% excess air.

The amount of heat transfer in the radiant section shall be equal to the heat provided by flue gases in dropping the temperature from the adiabatic flame temperature to the flue gas temperature leaving radiant section (also known as bridgewall temperature).

The increase in adiabatic flame temperature will increase the radiant heat flux as well as bridgewall temperature, both adversely affecting the performance and run length of the heater. Figure F shows a summary of case study showing effect of increase in adiabatic flame temperature on radiant heat flux and bridgewall temperature.

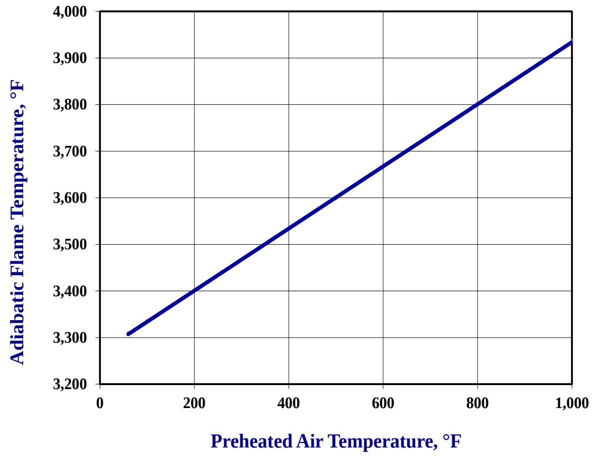

Figure E : Impact of air temperature on AFT

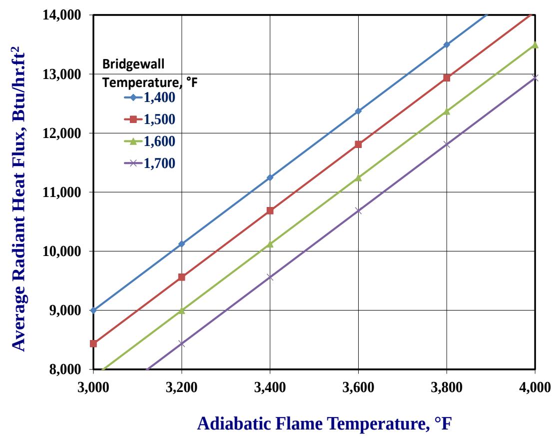

Figure F : Effect of AFT on Radiant Heat flux

5. Degree of Air Preheat

Average radiant heat flux is the amount of heat absorbed per unit heat transfer area in the radiant section. There are recommended average radiant heat flux limits for fired heaters based upon process service/quality of feed and fired heater configuration. Average heat flux is a single point parameter, which can provide gauge to operating issues in a fired heater. The chances of challenges occurring in a fired heater operation increases with an increase in radiant heat flux. An air-preheater recovering the residual heat from cold flue gas is essentially recycling this heat into the radiant section. This recycled heat results into an increase of radiant heat flux.

Figure G shows a summary of case study indicating a proportional increase in average radiant flux with an increase in air-preheater absorbed duty. It should be noted that overall efficiency of the fired heater with air-preheater system is kept the same for this case study. As the air-preheater size increases, the convection section size decreases, so that the overall fired heater efficiency is maintained the same for all data point shown in this figure.

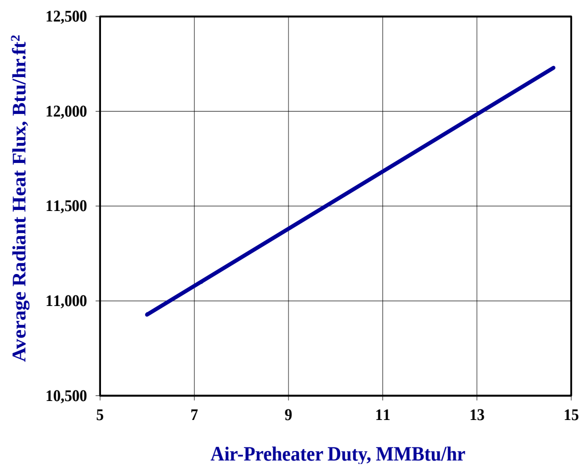

Figure G : Effect of APH Size on Radiant Heat Flux

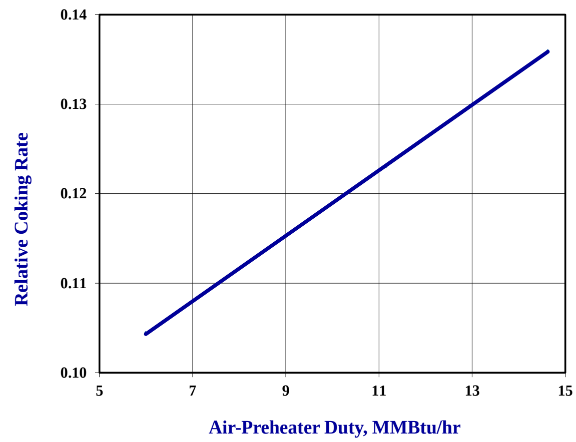

Figure H : Effect of APH Size on Coking Rate

Figure H shows a summary of same case study indicating an increase in relative coking rate with increase in APH duty.

Above shows, it is prudent to optimize the heat recovery in APH along with heat recovery in convection section to increase the run length.

6. Degree of Convection Section Preheat

The size of convection section plays a major role in fired heater performance. Generally, it is expensive to provide additional heat transfer area in convection section compared to an APH. It is even comparatively more expensive to recover heat in the convection section, if fired heater is using higher-grade metallurgy (e.g. stainless steel tubes). It is primarily due to cost concerns that a fired heater is designed with higher flue gas temperature approach (defined as flue gas temperature leaving convection minus process inlet temperature). A higher temperature approach will result in a larger air-preheater absorbed duty for the same fired heater efficiency. Recommended flue gas temperature approach is between 100-150°F.

The convection section absorbs approximately 30-40% of the total absorbed heat duty in a typical fired heater. In many cases during revamp, one try to use additional available capacity in the APH or install additional surface area in an APH. Also, as the convection section surface degrades with time, the heat absorbed in the convection section reduces, resulting in higher APH duty (by default). However, the increase in APH duty should be avoided, as it will increase the radiant heat flux. To avoid increase in APH duty during fired heater revamp, the convection section heat transfer surface can be augmented with additional surface. Addition of convection section heat transfer surface will increase the convection section absorbed duty resulting in lower duty of the APH. A smaller APH duty will recycle less heat into radiant firebox, which in turn will keep the radiant heat flux lower.

Convection section heat transfer can be increased by several ways during revamp. Some of the most frequently used options are as follows:

- Installation of additional tube rows (e.g. use of future row)
- Replacing bare tubes with extended-surface tubes, if available.
- Increase extension ratio of extended surface i.e. increase extended-surface area per unit length of tube by changing the configuration of extended surface.
- Increasing number of tubes per rows by increasing convection section width.

There are several long-term advantages of using a bigger convection and smaller APH. Some of these advantages are:

- Lower radiant heat flux resulting into less coking and longer run length
- Smaller flue gas and air ducting / no or minimum modification to ducting
- Smaller fan sizes – lower fan operating cost / no or minimum modification to fans

7. Case Study

There is a current Vacuum heater (radiant and convection section) with an outboard APH. APH is a regenerative type APH which is prone to leakage and frequent failure/loss of heat transfer surface.

Heater configuration is Horizontal tube box heater with radiant mounted horizontal convection section.

End user wants to improve the overall efficiency of heater by replacing more efficient APH. Due to existing APH old technology (size, weight, orientation and plot plan), efficiency improvement achievable was very small.

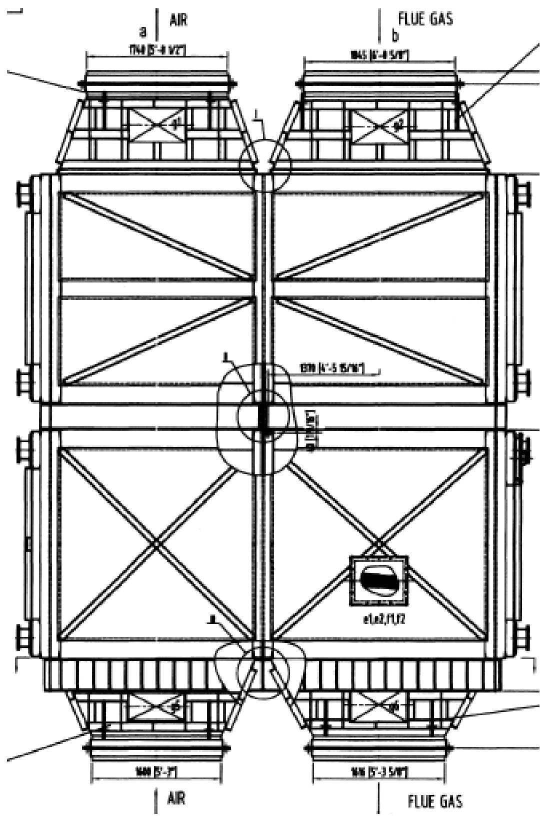

Figure I – Existing APH Configuration

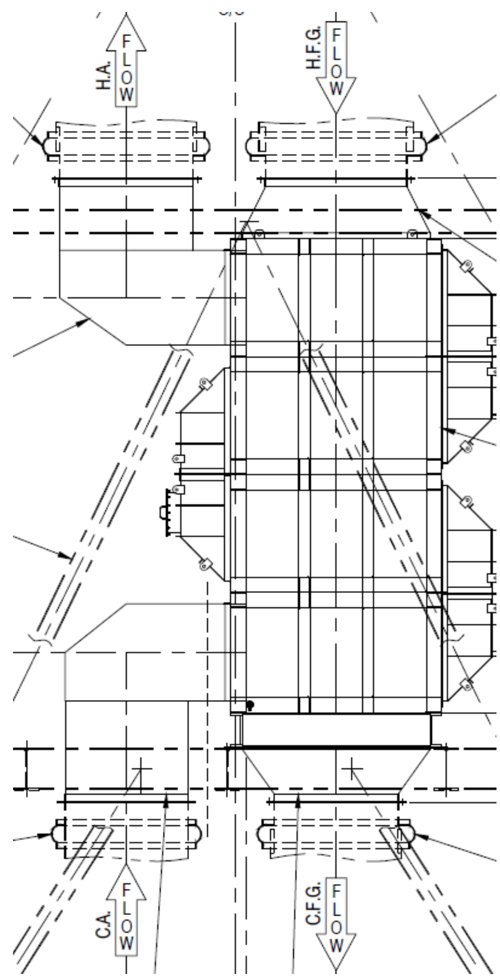

Figure J – New APH Configuration

In order to maximize the efficiency improvement, it was decided to add more heat transfer surface area in convection section. Heat transfer surface was added in the form of more tube rows (space available for future rows) and more finning.

Above allowed to reduce the radiant flux, improve tube metal profile, reduce the duty of heat to be recovered in APH, APH can be more efficient, fit into same plot plan with minimum duct modification and no modification to forced draft and induced draft fan.

Comparison of key performance parameters are shown in table 1 below:

Table 1		
Parameter	**Original Design (Case 1)**	**Upgraded APH and Convection Section (Case 2)**
Total Absorbed Duty (MMBtu/hr)	410	410
APH Duty (MMBtu/hr)	70	35
Overall Efficiency (%, LHV Basis)	80%	90%
Average Radiant Flux (Btu/hr.ft2)	11,900	10,200
Flue Gas Temperature Leaving Convection Section (F)	1100	700
Hot Air Temperature to Burners (F)	800	450
Estimated NOx Change (%)	Base	(-) 60%
Estimated Run length Change (%)	Base	(+) 100%

- ✓ **Lower Radiant Heat Flux** – Case 2 have a relatively lower radiant heat flux and will result in lower coking rate (lower tube metal temperature), therefore, resulting in longer fired heater run length.

- ✓ **Lower NOx** – NOx emission has a direct relationship with hot air temperature. As combustion air temperature is lower for Case 2, it will result in overall lower NOx emission.

- ✓ **Duct / Fan / Plot Plan** – Based on lower overall duty of APH required for Case 2, modification to duct and fans was minimized. Existing foundations was also used with small modification. This also helped reduce overall installation / field modification cost and time.

Above shows, there is overall benefit on heater run length, fuel consumption reduction and GHG reduction utilizing integrated approach.

8. Conclusion

An air-preheater (APH) addition and/or improvement in any fired heater system will help in increasing and/or improving the fired heater efficiency thereby reducing energy consumption and greenhouse gases. Degree of fuel efficiency increase and/or improvement depends upon the flue gas temperature leaving the stack (overall system). Overall efficiency is not impacted whether flue gases are cooled in convection section or in an APH but it impact overall performance and life of fired heater. Major critical parameters like radiant average heat flux, emissions, tube metal temperature, fin tip temperature, duty split / heat recovery, run length must be carefully evaluated when increasing/improving the efficiency. An integrated analysis of air-preheater and fired heater system is essential for a successful operation of fired heater with an air-preheat system.