Originally appeared in:
CHEMICAL ENGINEERING

November 1989 issue, pgs 239-244
Reprinted with publisher's permission.

HOW TO BOOST THE PERFORMANCE OF FIRED HEATERS

Selective revamping can hike thermal efficiency and capacity

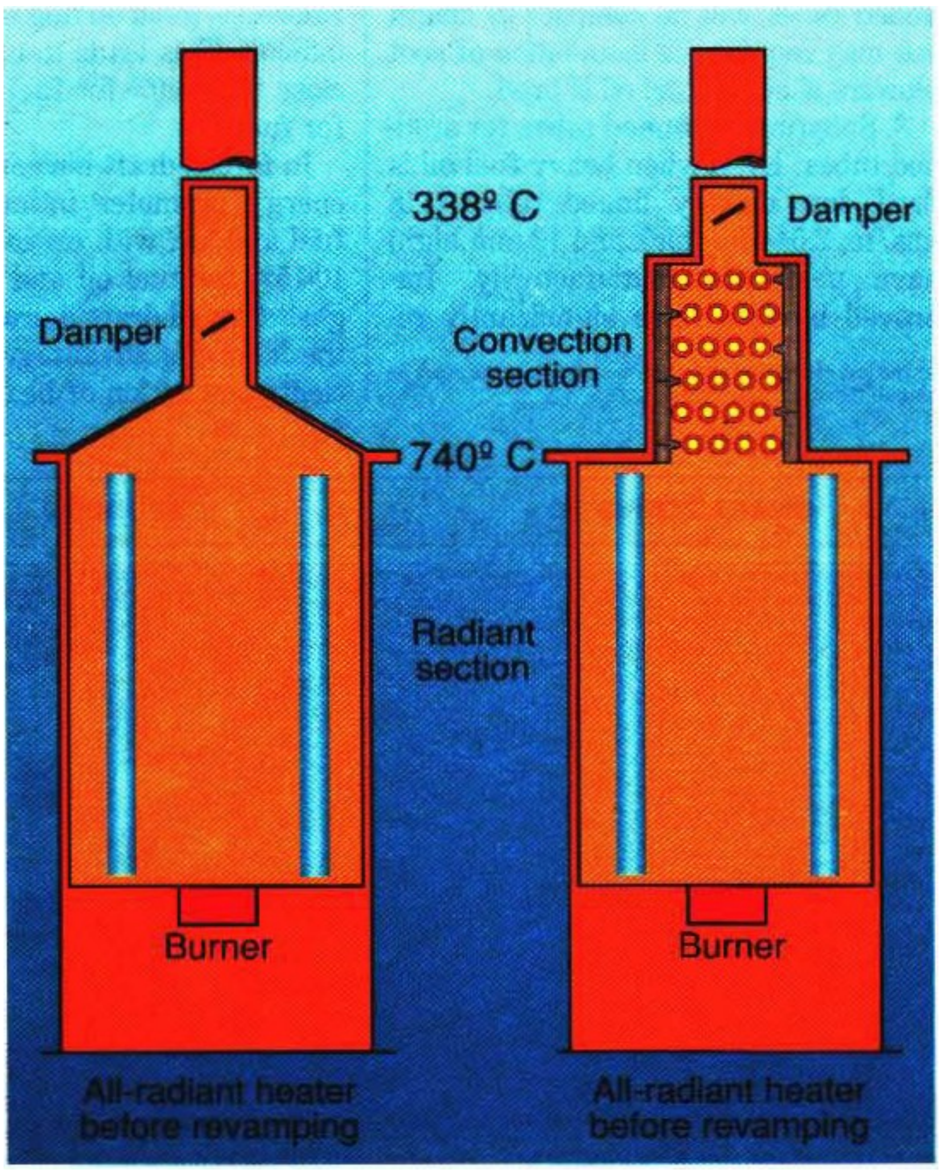


FIGURE 1.
Adding a convection section to a heater can result in a significant annual fuel saving.

A. Garg, Engineers India Ltd.

A fired heater is an insulated enclosure in which heat liberated by the combustion of fuel is transferred to a process fluid flowing through tubular coils. Typically, the coils are arranged along the walls and roof of the combustion chamber, where heat is transferred primarily by radiation. Heat can also be transferred via convection in a separate tubebank.

Revamping a fired heater to recover energy from its fluegas can be justified at today's low fuel prices, even if its heat duty is as low as 1-million kcal/ h. A heater - particularly one that is overfired -can also be changed to make it operate at a higher heat duty. The upper limit of fired-heater thermal efficiency is about 92% (LHV).*

Several revamping schemes can improve fired heater performance. The major ones are

* Lower Heating Value; Higher Heating Value (HHV) is the total heat obtained from the combustion of fuel at 15°C. LHV is HHV minus the latent heat of vaporization of the water formed by the combustion of the hydrogen in the fuel. The net thermal efficiency of fired heaters is based on LHV, that of boilers on HHV.

HEATER OPERATING PARAMETERS BEFORE AND AFTER CONVECTION RETROFITTING		
Parameter	**Before**	**After**
Heater duty, million kcal/h	1.86	1.86
Thermal efficiency, %	60	81
Fuel fired, million kcal/h	3.10	2.30
Fluegas temperature at stack, °C	740	338
Fuel saving, metric ton/yr	—	630
Radiant flux, kcal/(h)(m²)	28,604	22,347
Fluid pressure drop, kg/cm²	1.4	1.8
Stack height, m	21	18.5
Inlet fluid temperature, °C	290	290

TABLE 1. Adding a convection section to this heater hiked its thermal efficiency by 35%

installing a convection section in an all-radiant heater, enlarging the heat transfer area of the convection section, converting a natural-draft heater to a forced-draft one, and adding air preheating or steam-generation equipment.

Installing a convection section

Most heaters with a heat duty of up to 3 million kcal/h were built entirely as radiant heaters. They generally have a net thermal efficiency of from 55% to 65%, and their fluegas temperatures range upwards from 700°C. The installation of a convection section in these heaters could recover additional heat and bring down their fluegas temperatures to within 50-100°C of their inlet feed temperatures. Doing this could boost their thermal efficiencies up to 80%, and sometimes even higher.

If the revamped heater is operated at the same heat duty, the radiant heat flux is reduced or additional heat duty is extracted in the convection section. Such an investment will normally be paid out in two to three years.

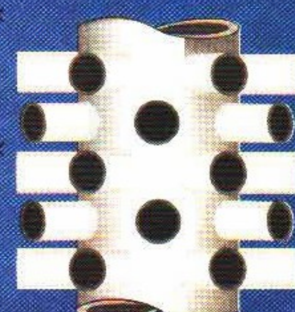
This alteration should be preceded by a careful checking of the heater's existing foundation and structure to ensure that the additional loading can be safely borne. More space will be taken up if an outboard convection bank (one mounted on an independent external structure) is added. Normally, the height of the stack must be raised. Sometimes, an induced-draft fan has to be installed to overcome the extra draft loss. Also, the pressure of the process fluid may have to be hiked to offset the additional tube pressure drop. A typical all-radiant fired heater to which a convection section has been added is shown in Figure 1. Listed in Table 1 are design and operating parameters of a vertical, cylindrical, all-radiant, forced-draft fired heater before and after it was retrofitted with a convection section.

Increasing convection surface

The heat transferred to the process fluid passing through the convection section can be boosted by the addition of heat-transfer surface, to reduce the fluegas temperature to the stack to within 50-100°C of the fluid inlet temperature. This can be done by:

1. Adding tubes. Two additional rows of tubes can be installed in the convection section of most heaters without making a major change, except for relocating the inlet piping terminal. If space for adding tubes has not been provided, the convection section can be extended into the breeching or offtake to make space.

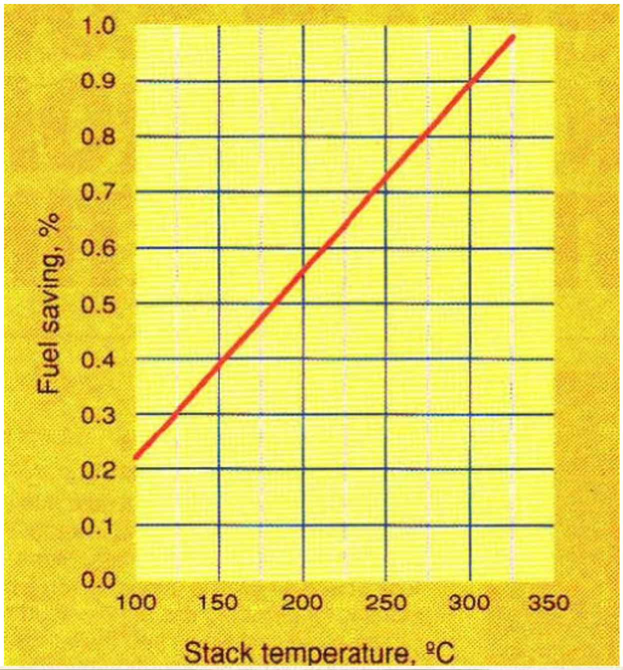
2. Replacing bare tubes with extended -surface tubes, to gain more heat-transfer area. A typical studded tube provides 2 to 3 times more heat-transfer area than a bare tube, and a filmed tube 4 to 5 times as much. Care must be exercised in the revamping because extended-surface tubes of the same size as the bare tubes will not fit in the existing tubesheets of the convection section. A convection section with studded or finned tubes will be compact in height but may require the installation of soot blowers if heavy fuel



FINNED	CHARACTERISTIC	STUDDED
19 mm high × 2.54 mm thick, 118 fins/meter	Specification for oil firing	25 mm high × 13 mm diameter × 16 studs/plane × 63 planes/meter
25 mm high × 1.27 mm thick, 197 fins/meter 63 planes/meter	Specification for gas firing	25 mm high × 13 mm diameter × 16 studs/plane ×
1.66—2.22	Extended-surface ratio	1
0.5	Ratio of ΔP/row (for same layout)	1

TABLE 2. Finned tubes provide large heat-transfer surface per unit length than do studded tubes but are more difficult to keep clean

FIGURE 2. Per cent efficiency improvement per 10% reduction in excess air.

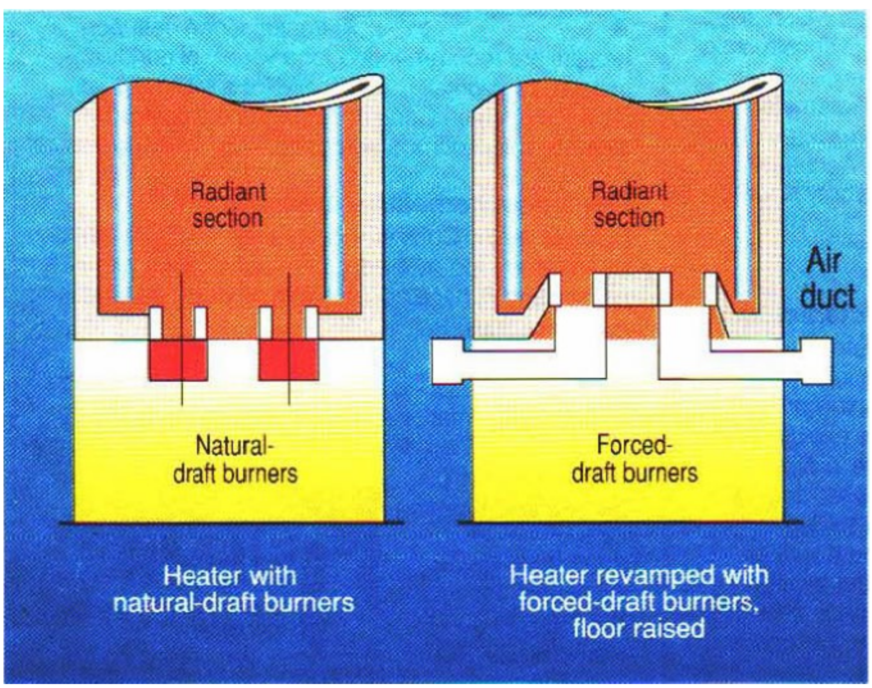


FIRED-HEATER PARAMETERS BEFORE AND AFTER CHANGING BURNERS

Parameter	Before	After
Heater duty, million kcals/h	10.0	10.0
Thermal efficiency, %	79	84
Excess air, %	40	10
Fluegas temperature at stack, °C	340	320
Atomizing steam consumption, kg/kg fuel	0.50	0.15
Flame dimensions, height × diameter, m	4.0 × 1.0	2.0 × 0.6
Fuel saving, metric ton/yr	—	603
Number of burners	8	8
Heat release/burner, million kcal/h	1.6	1.5

TABLE 3. Replacing natural-draft with forced-draft burners reduced fuel usage

FIGURE 3. Replacing burners may require raising the heater floor.



oil is fired.

3. Substituting finned tubes for studded tubes. Even when heavy fuel oil is fired, low density finned tubes (118 fins/m, 2.54-mm thick and 19-mm high) have performed satisfactorily. Improved burners have significantly reduced the formation of soot and ash, and soot blowers can keep finned surfaces clean. Finned tubes provide larger heat-transfer surface than studded tubes, and cause much less pressure drop. The characteristics of the tubes are compared in Table 2.

The additional heat-transfer surface increases the pressure drop, and the lower stack gas temperature reduces the draft. The obvious remedy to the lower draft is to resort to an induced-draft fan or make the stack taller, or do both. However, a load limitation may not allow either option. In such a case, one possibility would be to install a grade-mounted stack or to place the convection section and stack on separate foundations.

Natural to forced draft

The burners of natural-draft heaters require high levels of excess air and have long flame lengths. The air pressure drop available across their registers (which control the supply of combustion air) is limited. Because the combustion air is induced at very low velocities, good mixing of air and fuel is difficult. This leads to excess air levels close to 30-40% for fuel oil and 20-25% for fuel gas.

In forced-draft burners, air pressure energy promotes intimate mixing of fuel and air, with excess air limited to 10-15% for fuel oil and 5-10% for fuel gas. Forced-draft burners also offer the following advantages: (1) more-efficient combustion of heavy fuel oils, (2)reduced particle emission, (3) lower consumption of atomizing steam, (4) better control of flame shape and stability, (5) less oil dripback, (6) quieter operation and (7) the possibility of preheating the combustion air.

For a comprehensive exposition of fired heaters, refer to the four-part series by Herbert L. Berman that appeared in the following issues of *Chemical Engineering:* Part I —Finding the basic design for your application, June 19, 1978, pp. 99-104; Part II — Construction materials, mechanical features, performance monitoring, July 31, 1978, pp. 87-96; Part III — How combustion conditions influence design and operation, Aug. 14, 1978, pp. 129-140; and Part IV — How to reduce your fuel bill, Sept. 11, 1978, pp. 165-169. Also see Good Heater Specifications Pay Off, by A. Garg and H. Ghosh, *Chem. Eng.,* July 18, 1988, pp. 77-80.

A 10% reduction in excess air means a 0.5 to 1.0% fuel saving, depending on the fluegas temperature (Figure 2). Excess-air reduction normally results in a 2-3% fuel saving, as well as in better heat transfer. A 1 to 2% fuel saving in atomizing steam can also be realized.

The total energy saving only from replacing natural-draft with forced-draft burners will not provide an economic return. However, the change can be justified when combined with such benefits as higher capacity and the elimination of flame impingement.

A vacuum heater having natural-draft burners was plagued with short run lengths, chiefly due to flame impingement problems and tube failures. Replacing the burners with forced-draft ones lengthened the runs substantially (Table 8).

Before replacing burners, check the heater floor elevations, because forced-draft burners require ductwork and deeper windboxes. The floor may have to be raised to accommodate the burners (Figure 3). Space should also be available for ducts and fans.

Combustion air preheating

Adding an air preheater has remained the most popular way of

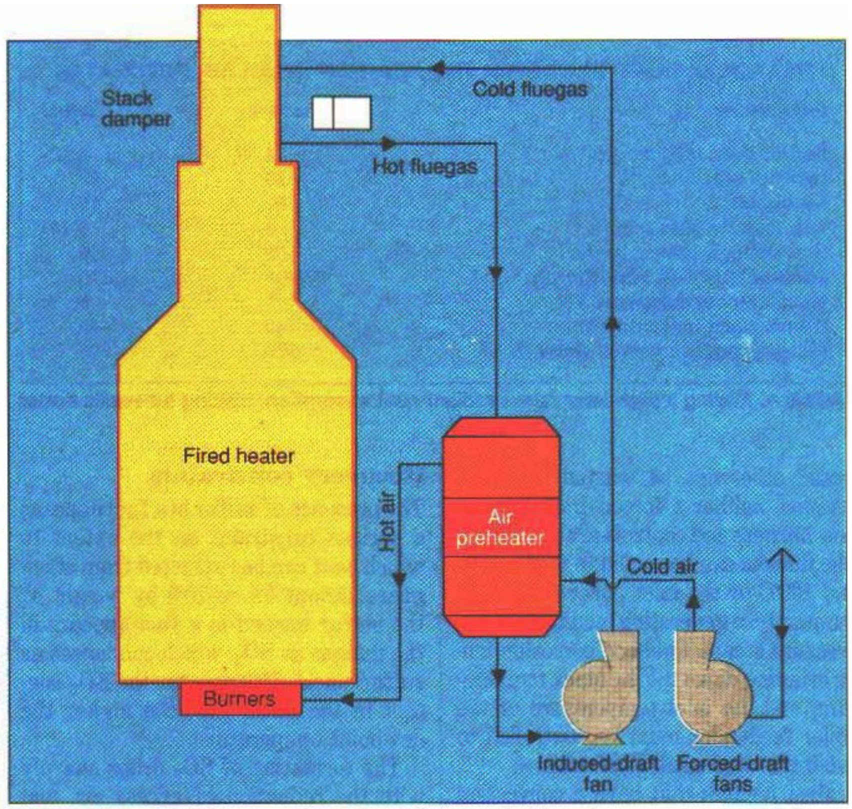
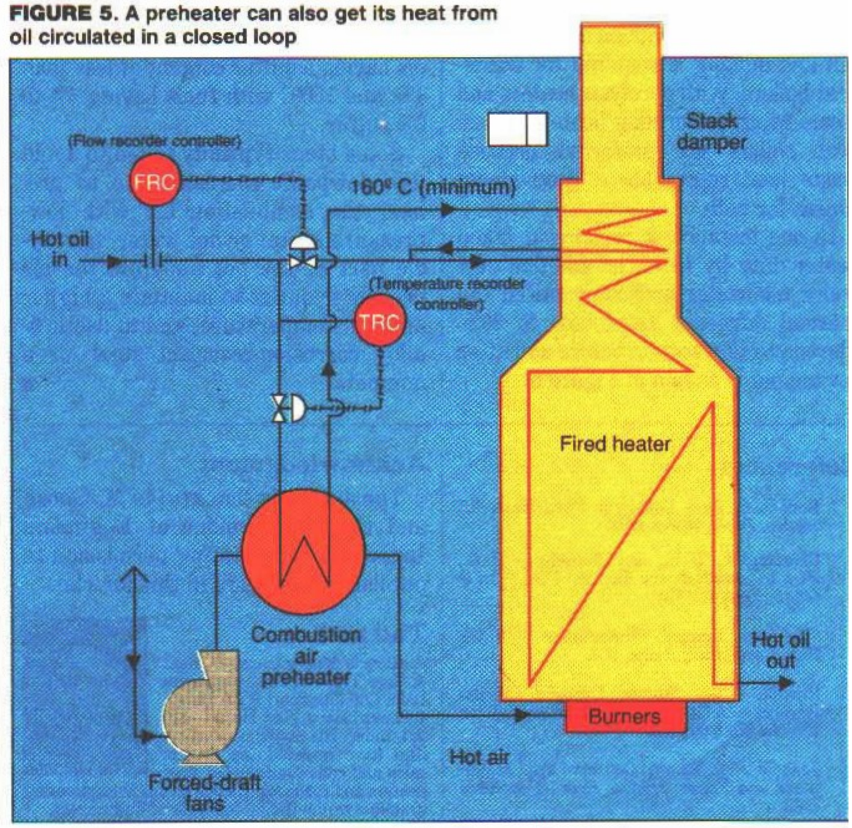


FIGURE 4. A preheater can salvage heat that would otherwise be lost into the atmosphere

FIGURE 5. A preheater can also get its heat from oil circulated in a closed loop



HEATER PARAMETERS AFTER THE ADDITION OF AN AIR PREHEATER

Parameter	Before	After
Heater duty, million kcals/h	4.30	4.73
Thermal efficiency, %	70	87
Excess air, %	40	15
Fuel fired, million kcal/h	6.14	5.44
Fuel savings, metric ton/yr	—	1,050
Radient heat flux, kcal/(h)(m²)	27,700	30,810
Electricity consumption, kW		5
Combustion air temperature	40	145
Fluegas temperature at stack, °C	370	228

TABLE 4. Adding a preheater raises radiant-heat absorption, making tubewalls hotter

revamping fired heaters. Every 20°C drop in the exit fluegas temperature boosts efficiency by 1%. Total savings range from 8% to 18%. An air preheater is economically attractive if the temperature of the fluegas is higher than 350° C. An economic justification must take into account the cost for fan power, as well as the capital cost. Heat is recovered with an existing heater by means of a combustion air preheater installed between the convection section and the stack (Figure 4).

A revamping entails installing forced-draft burners and a forced-draft or induced-draft fan, or both, as well as the air preheater. Space must be available for the preheater, fan, ducts and dampers. The heater should be able to operate with the heat recovery system bypassed. Among the disadvantages of a preheater is the formation of an acid mist and, thus, faster corrosion and more frequent maintenance, and a higher concentration of NOx in the fluegas.

Two types of air preheaters are currently used with fired heaters: the regenerative and the recuperative. Although the recuperative preheater is larger and costlier than the regenerative type, it is simpler, requires less maintenance, resists corrosion and needs no power.

Another preheater is the circulating-liquid type (Figure 5), in which a transfer fluid extracts heat from the heater's convection section and heats the combustion air passing through an exchanger. The heater needs only a forced-draft fan. Because the fluid is pumped from a tank through a closed loop, this arrangement is attractive if a hot oil circulation system already exists in a plant. For low temperatures, boiler feedwater can serve as the transfer fluid.

With the addition of a preheater, the heater must be rerated because preheating boosts the radiant heat absorption. This raises the radiant heat flux and tubewall temperatures. Because the flames are shorter with forced-draft preheated-air burners, this type of fired heater can generally be operated (this should be checked) at about a 10% to 25% higher duty. The parameters of a vertical cylindrical heater be-fore and after being fitted with an air preheater are listed in Table 4.

Steam generation

Waste-heat boilers and boiler feedwater preheaters can be an economical solution to recovering heat from heat-

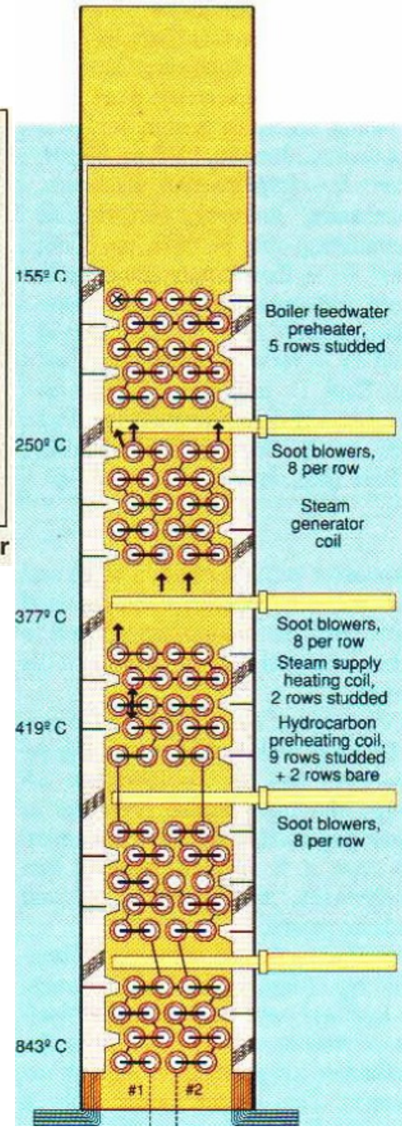
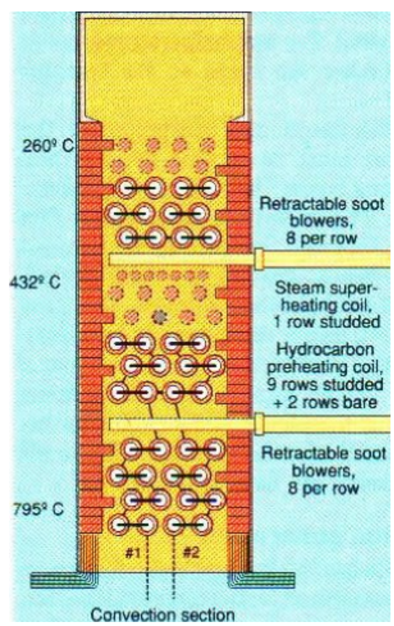


Figure 6. convection section before and after the addition of preheater.



ers that would otherwise be wasted. For this revision, neither a forced-draft fan nor new burners and controls are necessary. The fluegas can be cooled to within 50°C and 100°C of the inlet boiler feed-water temperature generating medium- or low-pressure steam. Cold-end corrosion limits bringing down the stack temperature, and the inlet temperature of the boiler feedwater must be controlled to avoid the condensation of acids.

Most heaters that have a convection section can be fitted with boiler feed-water preheaters in an extended convection section without the need for major modification. Frequently, an outboard convection system with an induced-draft fan and ducting is required for waste -heat boilers. With pyrolysis heaters and steam-naptha-reforming heaters, waste heat boilers are preferred because waste heat represents a good steam source for both.

In one instance, a revamping hiked heater duty by 15%. The addition of a boiler feedwater preheater raised the thermal efficiency from 85% to 90%. The convection section before and after revamping is shown in Figure 6.

Recovery constraints

The presence of sulfur in a fuel imposes a serious constraint on the extent to which heat can be extracted from stack gases. About 6% to 10% by weight of the sulfur burned in a fuel appears in the fluegas as SO_3, which condenses as sulfuric acid. The greater the SO_3, content in the stack gas, the higher the dewpoint temperature.

The formation of SO_3, drops sharply with the reduction of excess air, and rises if vanadium is present in the fuel oil. The tubewall temperature should be kept at least 15°C higher than the sulfur dewpoint. A minimum temperature of 135°C is recommended with fuels having a sulfur content of less than 1%, and 150°C with fuels having 4% to 5% sulfur.

Some steps typically taken to avoid flue dewpoint corrosion are to preheat the combustion air with low-pressure steam or hot water, to recycle part of the hot air from the air preheater outlet to maintain a higher air inlet temperature, and to use low-alloy corrosion-resistant steel, or a nonmetal.

References

1. Bonnet, C., Save Energy in Fired Heaters, *Hydro. Proc.,* March 1982,
2. Cherrin n, D. C., and Michelson, H. D., How to Save Refinery Furnace Fuel," flit & *Gas J,* Sept. a 19'74
3. "Refinery Energy Conservation," Noyes Data Corp., Park Ridge, N.J.
4. Rijwijk, A. G., -Forced Draught Process Burners — A Case History," Du iker Frojkten BV, the Netherlands.
5. Seabold, G., How to Conserve Fuel in Fur-naces and Flares, *Hydro. Proc.,* November 1982.

Acknowledgment

The author is thankful to M. Ghosh and the management of Engineers India Ltd. for granting permission to publish information in this article.

The author

A. Garg *is* deputy manager, Heat & Mass Transfer Div., Engineers India Ltd. (5th floor, P.T.I. Bldg.., 4, Sansad Marg, New Delhi —110 001, India). His career responsibilities have included the design, sales and commissioning of fired heaters and furnaces. He is a chemical engineering graduate of the Indian Institute of Technology.