PETROCHEMICAL PLANT COSTS ■ CONTROL VALVES ■ BOXSCORE UPDATE

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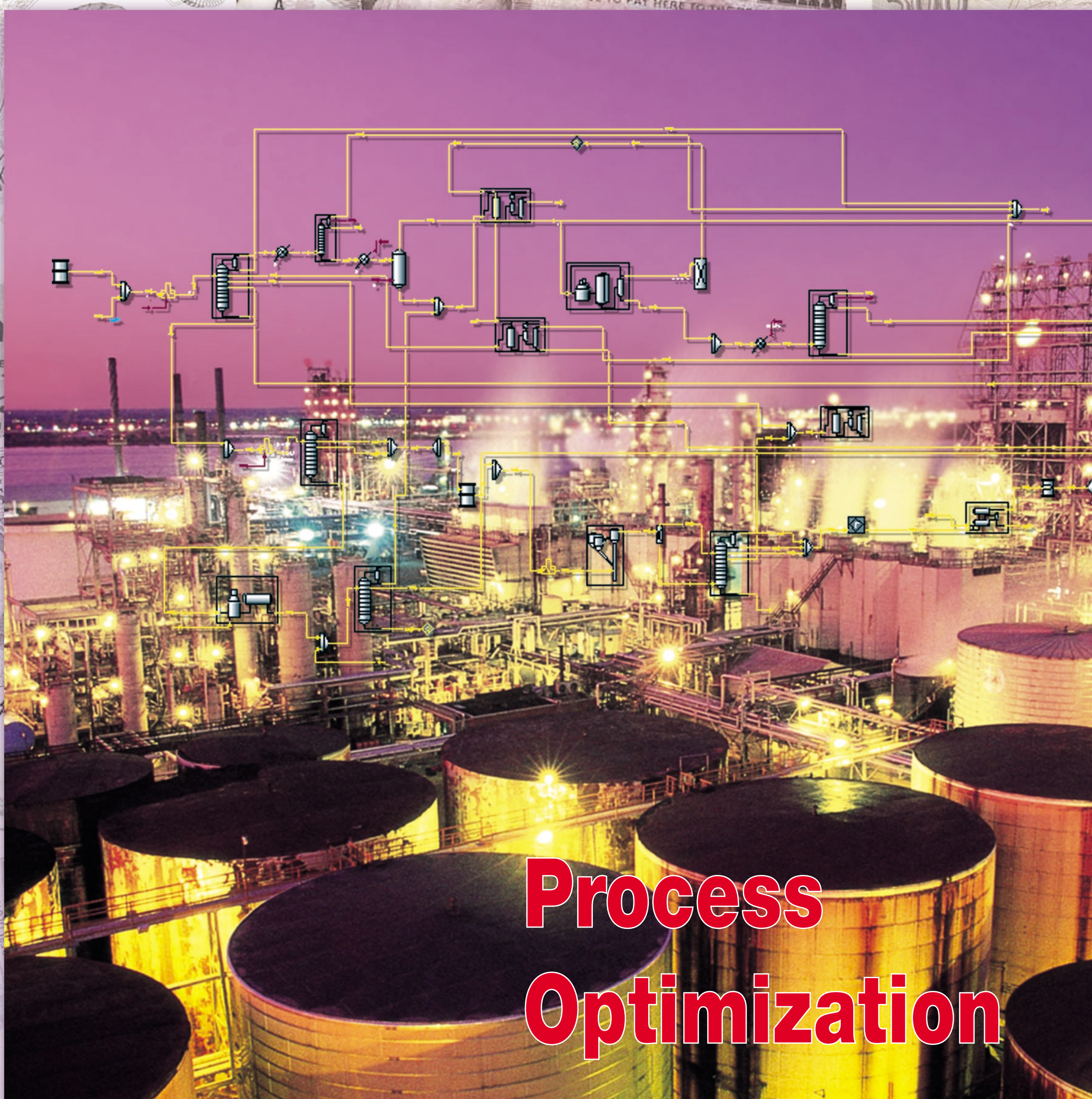

Process Optimization

- Increase furnace output
- Raise control on CDU
- Plan a grassroots refinery

Minimize NO_x emissions cost-effectively

Use this tutorial to evaluate available control technologies and install exactly what you need for current and future NO_x reductions

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As local environmental agencies demand more stringent control of NO_x emissions, companies are challenged to cost-effectively bring combustion equipment into compliance. Because every facility has a unique mix of equipment and regulatory requirements, the most cost-effective NO_x control technology, or optional combinations of technologies, will be different for each situation. In addition to NO_x emissions requirements, operating companies must also be able to install this control equipment to meet compliance deadlines, which can affect scheduled turnaround dates and durations.

For most situations, no single technology will provide the most economic choice for all combustion equipment within an operating plant. By learning about all available options, HPI companies can discover solutions that meet environmental mandates while minimizing capital outlays, operating costs and impact on turnaround schedules.

The following guidelines illustrate the available effective NO_x control technologies. Important factors included in this briefing are: method of operation, positive and negative aspects for each device, and NO_x performance with combinations of several devices. Since capital costs for installation will be site specific, the best estimates of the relative capital and operating costs of each option are compared on a sample case for a 100 MMBtu/hr process heater. This sample heater is assumed to be in good condition and configured to fire refinery-fuel gas (50% methane, 25% propane, 25% hydrogen) through natural-draft, up-fired, round-flame conventional burners with 3% excess oxygen using ambient temperature air—no air preheat (APH)—resulting in base NO_x emissions of 100 ppm (0.131 lb/MMBtu, 57.4 tpy) for the unmodified case. The cost effectiveness of each option is compared in terms of U.S. \$/t of NO_x reduced, calculated by dividing the tons/year of NO_x reduction by the total annual cost (TAC) in U.S. \$/yr determined per the U.S. Environmental Protections Agency's (EPA) alternative control techniques (ACT) document[1] and the information provided in this sample case. Since performance will also be situation specific, the economic effect of potential lost production due to installation time is not considered.

Current low- and ultra-low NO_x burners. Low-NO_x burners can use air staging, fuel staging or internal furnace gas recirculation to lower peak flame temperatures and directly reduce NO_x emissions from combustion. Current-generation low-NO_x burners have been available for over 20 years, with improvements in design to decrease NO_x emissions. In general, current-generation burners can achieve NO_x emissions of 25–50 ppm on ambient air—depending on burner design and application. The newest low-NO_x burners have been called ultra-low due to their enhanced NO_x reduction.

For most cases, current-generation burners are the simplest NO_x-control technology option to install. Changing to low-NO_x burners does not increase plant-operating costs or decrease furnace efficiency. They are also able to reduce NO_x emissions from the furnace without any corresponding increase in CO emissions, another important environmental criterion. Because these installations require no other systems or additional equipment, operating companies have often considered current-generation low- and ultra-low NO_x burners as an "all in one solution" for NO_x control. Even with the decreased NO_x emissions performance achieved over time, the current low-NO_x burners are not always able to meet the most stringent regulations present in some local areas.

When evaluating a low-NO_x burner installation or retrofit, many practical matters must be considered. Since the flame length of current-generation low-NO_x burners is typically longer than conventional burners, it must be evaluated when retrofitting furnaces. The larger diameter of current low-NO_x

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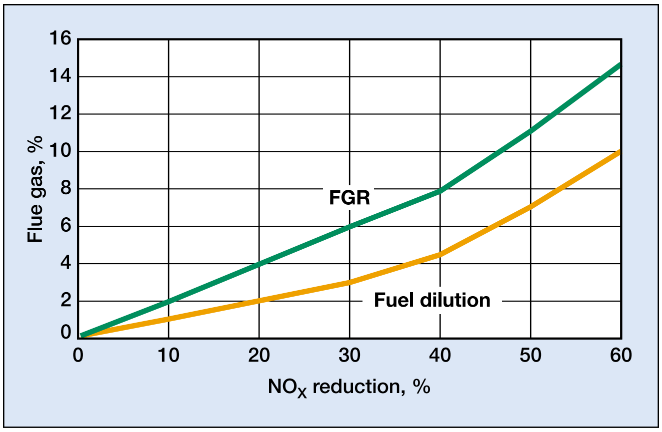

Fig. 1. Comparison of fuel dilution and FGR NO_x reduction vs. flue gas flow (100 MMBtu/hr case).

Table 1. Costs (operating and capital) for low-NO_x burners	
Capital cost estimate	
Burners (10 @ $5,000 each)	$50,000
Installation	80,000
Total	**$130,000**
Operating cost estimate, $/yr	
	No change
10-year net present cost (@8%)	$130,000
Total annual cost	**$14,300**
NO_x emissions performance	
ppm	25
lb/MMBtu	0.033
tpy	14.4
tpy reduction from base	43.1
$/t of NO_x reduced	**$332**

Table 2. Costs (capital and operating) for FGR applications	
Capital cost estimate	
Forced draft and FGR ductwork	$150,000
New forced draft/FGR fan	50,000
Forced draft/FGR fan installation	100,000
Total	**$300,000**
Operating cost estimate, $/yr	
(Assumes no noticeable effect on furnace efficiency)	
Power for FD/FGR fan, 30-hp motor, $0.06/kW-hr	$12,000
10-year net present cost @8%	$380,532
Total annual cost	**$45,000**
NO_x emissions performance	
ppm	30
lb/MMBtu	0.039
tpy	17.2
tpy reduction from base	40.2
$/t of NO_x reduced	**$1,120**

burners may also require modifications to the air plenum, heater floor and/or refractory of the furnace to accommodate their increased size.

Current low-NO_x burners' relative cost. Assume: 1) ample room for installation under the furnace, 2) that the only furnace modifications required are to enlarge the cutouts for the burners and 3) only minimal piping changes are required to connect the gas to the new burners. Table 1 lists the operating and capital costs for low-NO_x burners.

FGR on conventional burners. Flue gas recirculation (FGR) into the combustion air stream of a burner has been used for many years as a NO_x-reduction technique on numerous different combustion applications. Inert components in the flue gas (N_2, CO_2, H_2O) dilute the oxygen concentration in the air stream and provide additional material in the combustion zone that absorbs heat and lowers the flame temperature, thus decreasing NO_x. The greater amount of flue gas recirculated, the lower the NO_x emissions from the burner.

Using FGR only, NO_x emissions on conventional burners can be cut by 50–70%, achieving a level of 30–50 ppm. If waste steam is added into the recirculated flue gas, NO_x can be reduced further to 25–30 ppm. Adding FGR to a conventional burner has not been found to adversely affect the flame envelope. Since flue gas is readily available at the furnace, no cost is incurred for the diluent used in FGR technology.

FGR systems require installing ductwork from the stack to a fan and a forced-draft combustion air system to supply the flue gas/air mixture to the burners. Although FGR flow can sometimes be routed through an existing forced-draft fan, that fan may require upgrading to handle the additional capacity. Due to increased velocities through the furnace, high recirculation rates of FGR systems can shift the heat load from the radiant to the convection section, depending on the furnace design and firing rate. FGR can also require a larger burner size to admit the recirculated flue gas along with the combustion air to keep the pressure drop across the burner low enough for the fan capacity. Adding FGR to a furnace may require combustion air and FGR cold-flow physical modeling or computational fluid dynamics (CFD) modeling to ensure sufficient and uniform flow to all the burners in the ductwork system.

FGR relative cost. Assume: 1) ample room for ductwork and fan installation and 2) that the new fan will supply forced-draft air (no APH) and recirculated flue gas. Table 2 lists the operating and capital costs for FGR installations.

FGR and low-NO_x burners. When a situation demands NO_x emissions below what current-generation low-NO_x burners alone can achieve, FGR can be used to further lower emissions from these burners. Typical emissions for this combination are in the 15–25 ppm range, depending if steam is added to the flue gas. As with conventional burners, adding FGR to low-NO_x burners does not appear to adversely affect their flame envelope.

Applying the two techniques in concert results in the same potential disadvantages as utilizing either one or the other by itself. Combustion air and FGR cold-flow physical modeling or CFD modeling may be required to ensure uniform flow to the burners in the FGR installation.

FGR and low-NO_x burners combination relative cost. Assume: 1) ample room for ductwork and fan installation, 2) ample room for new burner installation, 3) minimal piping modifications for burner

Table 3. Costs (capital and operating) for FGR and low-NO_x burner configuration

Capital cost estimate	
Low-NO_x burners (from Table 1)	$130,000
Forced draft and FGR ductwok	150,000
New forced draft/FGR fan	50,000
Forced draft/FGR fan installation	100,000
Total	**$430,000**
Operating cost estimate, $/yr	
(Assumes no noticeable effect on furnace efficiency)	
Power for FD/FGR fan, 30-hp motor, $0.06/kWh	$12,000
10-year net present cost @8%	$510,532
Total annual cost	**$59,300**
NO_x emissions perfomance	
ppm	20
lb/MMBtu	0.026
tpy	11.5
tpy reduction from base	45.9
$/t of NO_x reduced	**$1,291**

installation and 4) that the new fan will supply forced draft air (no APH) and recirculated flue gas. Table 3 lists the capital and operating costs for the FGR and low-NO_x burner combination.

Fuel dilution on conventional burners. Fuel-dilution technology uses the mixing of recirculated inert furnace flue gas or other inert components with the fuel of the burner *before* combustion. These inert components lower the heating value of the fuel and decrease flame temperatures; thus reducing NO_x emissions. Several pounds of flue gas per pound of fuel can be recirculated in fuel-dilution systems, with greater recirculation rates to produce lower NO_x. Waste steam or atomized water can also be injected into the recirculation ductwork to further lower NO_x emissions.

Like FGR systems, fuel-dilution systems also require ductwork to carry the flue gas from the furnace stack to the burners. Since fuel dilution is more effective at reducing NO_x than FGR (Fig. 1), fuel-dilution systems require less flue gas for the same NO_x reduction, so that smaller, less expensive ducts can be used. One patented method for implementing fuel dilution does not require a fan or compressor to drive the recirculation flow. With this method, the pressure energy of the fuel is used as the motive force in an eductor to draw the furnace flue gas from the stack and mix it with the fuel before combustion in the burner. Implementing this technology may not require new burners, but it does require that existing burners be converted with a retrofit kit that includes the flue gas eductor and new parts that allow the additional flue gas to be passed through the burner along with the fuel. Because the gas side of the burner now handles much more flow, fuel-dilution retrofit kits are outfitted with larger gas port sizes that reduce the potential for gas-tip fouling.

In field applications, fuel dilution on conventional burners has achieved consistent NO_x performance down to 15–20 ppm—an 80–85% NO_x reduction. Further reductions in NO_x levels can be realized when waste steam is introduced into the recirculation flow. Test results have shown that fuel dilution achieves the greatest NO_x reductions when applied to conventional burners.

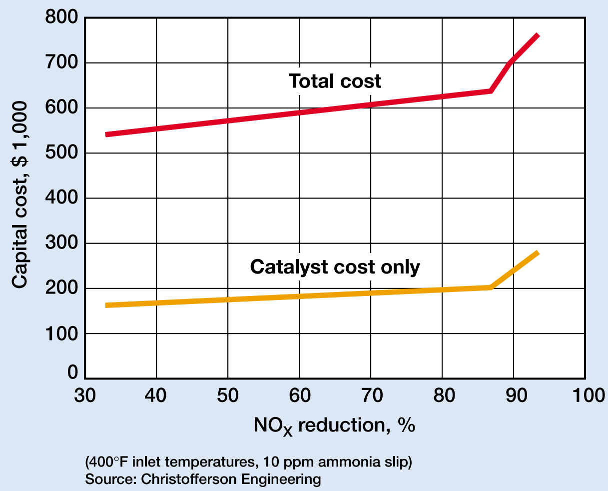

Fig. 2. Estimated capital costs for an SCR system on a 100 MMBtu/hr process heater.

Table 4. Costs (capital and operating) for fuel diluton methods

Capital cost estimate	
Burner retrofit kits (10 @ $4,000 each)	$40,000
Retrofit kit install (10 @ $2,000 each)	20,000
Piping modifications (10 @ $1,000 each)	10,000
Ductwork	150,000
Total	**$220,000**
Operating cost estimate, $/yr	
(Assumes no noticeable effect on furnace efficiency)	
	No change
10-year net present cost @8%	$220,000
Total annual cost	**$24,200**
NO_x emissions perfomance	
ppm	20
lb/MMBtu	0.026
tpy	11.5
tpy reduction from base	45.9
$/t of NO_x reduced	**$527**

The fuel-dilution method discussed above does not appear to affect the flame dimensions of existing burners. Because no recirculation fan is required, there is also no increase in plant operating cost. Since the burners remain in place, fuel dilution provides a definite advantage in situations where it is too costly or impractical to replace the burners, or where there is no room for potentially larger low-NO_x burners. In some situations, a fuel-dilution system may be installed while the furnace continues to operate.

Once modified, burners typically require a small amount of recirculation flow to maintain good flame quality. As with FGR, high-recirculation flowrates can potentially impact the furnace efficiency or shift the load to the convection section. For greatest effectiveness, pressure-driven fuel-dilution systems should use a fuel pressure of 20 psig or more.

Fuel dilution relative cost. Assume: 1) ample room for ductwork and eductor installation around the burners and furnace, 2) minimal piping modifications for switching the fuel to the eductors and 3)

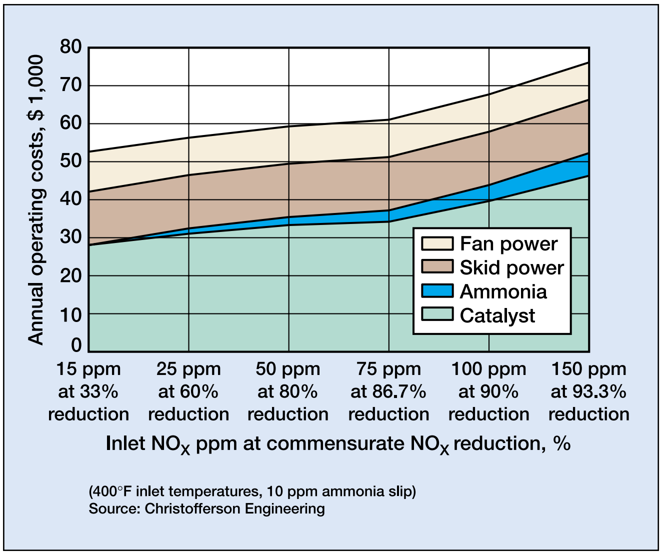

Fig. 3. Estimated annual operating costs for an SCR system on a 100 MMBtu/hr process heater.

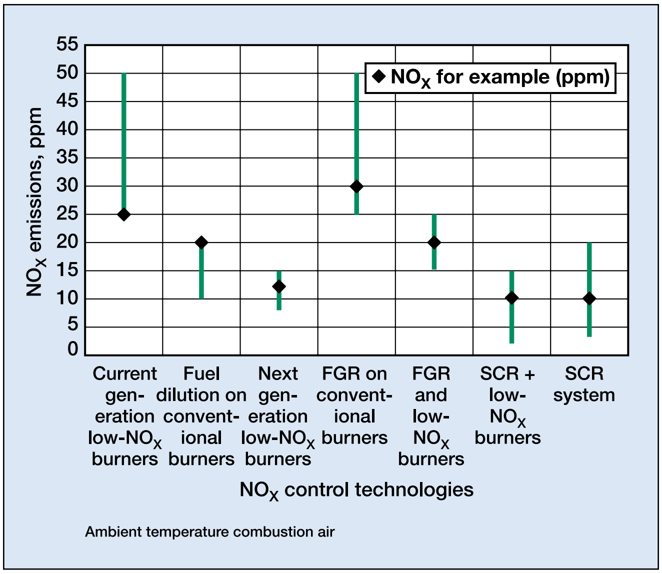

Fig. 4. Typical performance range of various NO_x control technologies.

Table 5. Costs (capital and operating) for an SCR system

Capital cost estimate (installed)	
Catalyst	$236,000
Reactor housing	173,000
Ammonia system	161,000
Ammonia injection grid	10,000
Control system	34,000
New ID fan (installed)	150,000
Engineering	96,000
Total	**$860,000**
Operating cost estimate, $/yr	
Catalyst replacement (6-yr life)	40,000
Power for ammonia skid, $0.06/kWh	14,000
Power for new ID fan, 4-in. WC pressure, $0.06/kWh	10,000
Ammonia	4,000
Total	**$68,000**
10-year net present cost (@8%)	**$1,316,000**
Total annual cost	**$162,600**
NO_x emissions perfomance	
ppm	10
lb/MMBtu	0.013
tpy	5.7
tpy reduction from base	51.7
$/t of NO_x reduced	**$3,148**

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ample room in the burner for a retrofit kit. Table 4 lists the operating and capital costs for the fuel dilution method.

Selective catalytic reduction (SCR) systems with conventional burners. As opposed to the NO_x-control technology options previously discussed, SCR systems do not reduce the amount of NO_x produced in the furnace, but rather remove it from the furnace flue-gas stream using a chemical reaction. Therefore, SCRs can be used with any burner. In the SCR, NO_x is reacted with ammonia (NH_3) in the presence of a catalyst to break down NO_x and change it back to N_2. Some NH_3 carries over from this reaction and can become an additional furnace emission that must be monitored under applicable environmental regulations.

For the SCR to operate properly, the NO_x-reduction reaction *must* take place at the proper temperature. Higher temperatures cause the NH_3 to combust before reacting, and lower temperatures can greatly reduce the destruction effectiveness of the reaction, requiring more catalyst and risking NH_3 emissions. For this reason, SCRs must be installed at the point on the heater where the flue gas is within the temperature band required. On existing installations, this point can sometimes be in the middle of an existing convection section, forcing a major heater reconfiguration. If an installation location with the proper flue gas temperature cannot be found, the operator may need to use a higher cost, low-temperature catalyst or provide additional heat with a duct-burner system to bring the flue gas up to the proper temperature before installing the SCR system.

A complete SCR system is complex and includes a reactor housing for the catalyst and NH_3 injection grid, storage and metering system. Also, an additional induced-draft capacity (either a new fan or retrofit of an existing fan) to overcome pressure drop due to the new catalyst bed and ductwork may be required. Uniform flow across the catalyst bed is critical, and CFD modeling may be necessary to ensure ±15% flow variance across the bed.

NO_x destruction efficiencies for SCR systems can be anywhere from 50–97%. Ultimate NO_x emissions as low as 3 ppm, depending on burners and destruction percent, are possible, making SCRs attractive for units that must meet the most stringent NO_x regulations. The cost (capital and operating) and the complexity of SCR systems, however, are high enough that SCRs are usually installed only on furnaces that cannot meet their NO_x permits by any other means. Figs. 2 and 3 show the estimated installation and annual operating costs for SCR systems of varying destruction efficiencies applied to a 100 MMBtu/hr process heater. These figures assume a 400°F flue-gas inlet temperature, 10-ppm NH_3 slip, and a 4-in. WC pressure drop across the SCR system components.

SCRs may sometimes be used to *over-control* NO_x emissions on one operating unit, while others use low-

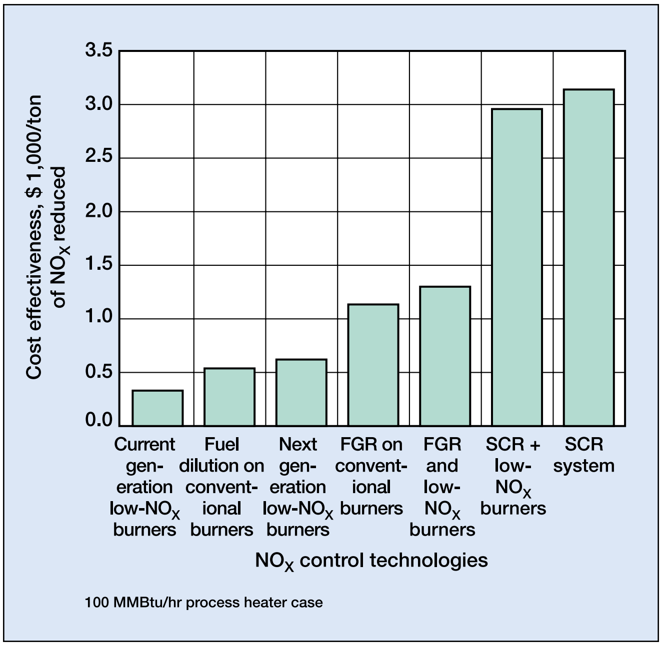

Fig. 5. NO_x control equipment cost-effectiveness in $/t of NO_x reduction.

NO_x burners as their only control. Such a strategy may still meet the plant's "bubble" permit of overall NO_x emissions while reducing the plant-wide investment in NO_x-reduction technologies.

Although SCRs can sometimes be installed directly on the stack of existing furnaces, most installations require furnace modifications (possibly inserting between convection sections) and a large, available plot space. Plants that do not have space near their furnaces for the large SCR equipment may need to duct several furnaces to a common SCR. If this common SCR goes out of service, the operation and emissions' performance of several heaters can be affected. NO_x emissions may well exceed regulatory limits during downtime and maintenance if an SCR system is the only NO_x-control technology used on a furnace.

The SCR catalyst bed can plug or foul over time due to dust, metal scale, or degrading refractory that passes through the furnace ductwork. Some chemicals found in refinery fuel gases, most notably sulfur, can also poison the SCR catalyst, reducing its life and degrading system performance until the catalyst can be replaced. With growing demand for SCR systems, the future availability of the SCR catalyst may well become an issue. The complex nature of an SCR system, and the interdependence of the ductwork, catalyst bed, NH_3-handling system, and fan increase the need for preventive maintenance on the furnace and increase the potential for unscheduled maintenance incidents from equipment failures. Also, operators faced with tight deadlines for compliance must also consider the lead-time for SCR design, manufacture and installation, which can be several months since each application must be specifically engineered.

SCR system relative cost. Assume: 1) ample room for ductwork and fan installation, 2) no heater reconfiguration and 3) 90% destruction efficiency, 10-ppm

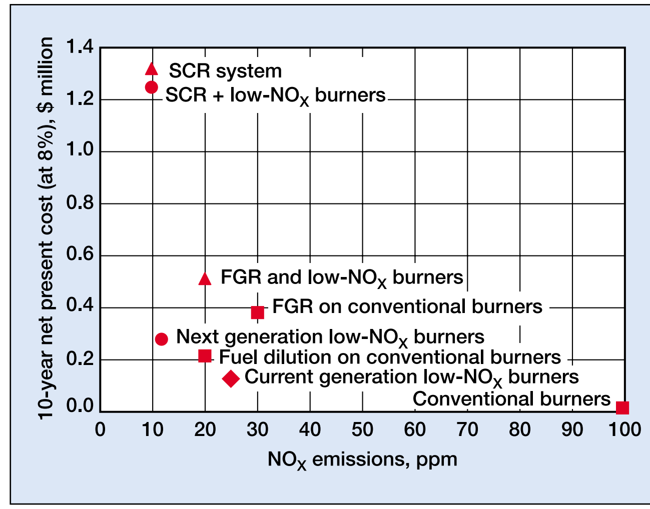

Fig. 6. Cost and performance comparison of NO_x reduction equipment (100 MMBtu/hr).

Table 6. Costs (capital and operating) for SCR and low-NO_x burner arrangement

Capital cost estimate (installed)	
Low-NOx burners (Table 1)	$130,000
Catalyst	186,000
Reactor housing	138,000
Ammonia system	134,000
Ammonia injection grid	10,000
Control system	34,000
New ID fan (installed)	150,000
Engineering	96,000
Total	**$878,000**
Operating cost estimate, $/yr	
Catalyst replacement (6-yr life)	$31,000
Power for ammonia skid, $0.06/kWh	14,000
Power for new ID fan, 4-in. WC dP, $0.06/kWh	10,000
Ammonia	1,000
Total	**$56,000**
10-year net present cost (@8%)	**$1,254,000**
Total annual cost	**$152,580**
NO_x emissions perfomance	
ppm	10
lb/MMBtu	0.013
tpy	5.7
tpy reduction from base	51.7
$/t of NO_x reduced	**$2,954**

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NO_x emissions at SCR outlet w/10-ppm NH_3 slip, 400°F flue gas inlet temperature. Table 5 lists the operating and capital costs for an SCR unit—alone.

SCR with low-NO_x burners. When a plant wishes to reduce the operating cost of an SCR system or minimize their dependence on the SCR system alone, a furnace can be equipped with both an SCR unit and low-NO_x burners. Installing low-NO_x burners reduces the amount of NO_x in the flue gas that the SCR must remove. Consequently, capital and operational costs of the SCR system are greatly lowered. The two technologies, operating in concert, deliver the best NO_x performance achievable on the market today—2–15 ppm, depending on the burners and destruction percent.

The optimum economic combination of these two NO_x-control technologies will be specific for each appli-

Table 7. Costs (capital and operating) for next-generation low-NO_x burners

Capital cost estimate	
Burners (10 @ $20,000 each)	$200,000
Installation	80,000
Total	**$280,000**
Operating cost estimate, $/yr	
	No change
10-yr net present cost (@8%)	$280,000
Total annual cost	**$30,800**
NO_x emission performance	
pm	12
lb/MMBtu	0.016
tpy	6.9
tpy reduction from base	50.5
$/t of NO_x reduced	**$610**

cation, but installing low-NO_x burners with an SCR system can minimize NO_x emissions even when the SCR system is out of service for maintenance or catalyst replacement. A combination SCR and low-NO_x burner system can keep yearly totals of emissions low for all operating conditions and reduce the dependence on proper operation of the SCR system to maintain environmental compliance. This combination shares both the advantages and disadvantages of low-NO_x burners and SCR systems.

SCR with low-NO_x burners relative cost. Assume: 1) ample room for ductwork and fan installation, 2) no heater reconfiguration for SCR, 3) 60% destruction efficiency, 25-ppm NO_x from burners, 10-ppm NO_x emissions at SCR outlet w/10-ppm NH_3 slip, 400°F flue-gas inlet temperature, 4) ample room for low-NO_x burners and 5) minimal piping modifications for burner installation. Table 6 lists the capital and operating costs for the SCR and low-NO_x burner combination installation.

Next-generation low-NO_x burners. The next generation of low-NO_x burners is being developed to achieve NO_x emissions of 5–12 ppm in field applications. Some advanced burners use a combination of lean-premix combustion, fuel staging, and zoned internal furnace gas recirculation to achieve this emissions target. At these NO_x levels, next-generation burners are able to compete with SCR systems at considerably less capital outlay and operating expense.

Unlike current-generation low-NO_x burners, these burners that use lean-premix combustion can exhibit flame lengths similar to conventional burners. The lean-premix technique also allows a reduction in burner size and is comparable to conventional burners; thus eliminating the need for an increased furnace cutout size on retrofits. These features make these burners easier to retrofit into furnaces originally designed for conventional burners. Some next-generation low-NO_x burners are designed as “plug-and-play” units that fit within the tile throats of existing burners and have been installed on the run with no furnace modification.

This technology has been successfully applied to radiant-wall and flat-flame wall-fired burners in commercial applications and is currently being developed on round-flame process burners. Next-generation burners are undergoing continued development and engineering in a wide range of configurations and installations as engineers and technicians approach field replication of laboratory-produced NO_x emission levels in the 8–15 ppm range.

New low-NO_x burners may hold the promise of a return to the simple installation and the “all in one solution” of current-generation low-NO_x burners. Next-generation low-NO_x burner engineering and manufacturing time is reduced to several weeks, eliminating the long lead-time of SCR systems and the potential extensive downtime required for SCR installation. As with current low-NO_x burners, the installation of next-generation low-NO_x burners neither increases plant operating costs nor decreases furnace efficiency.

Advanced lean-premix low-NO_x burner relative cost. Assume: 1) ample room for installation under the furnace and 2) that there are only minimal piping changes required to connect the gas to the new burners. Table 7 lists the operating and capital costs for next-generation lean-premix low-NO_x burners.

NO_x control options. Fig. 4 illustrates the range of NO_x emission’s performance for the presented control technologies with ambient air temperature. The emissions levels used for the 100 MMBtu/hr process heater sample case are also shown on this graph. In Fig. 4, only next-generation low-NO_x burners or SCR systems

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are able to meet some of the newest regulations that require NO_x emissions of less than 10 ppm.

Fig. 5 shows the cost effectiveness, measured in $/t of NO_x reduced, for each technology option, based on the sample 100 MMBtu/hr process-heater case. From this figure, the NO_x control options requiring only the installation of new burners or ductwork (current-generation low-NO_x burners, fuel dilution on conventional burners and next-generation low-NO_x burners) provide the most cost-effective NO_x control, with costs ranging from $332 to $610/t of NO_x reduced. FGR systems, which require a fan for flue gas recirculation, make up the next tier of cost effectiveness with a range of $1,120 to $1,291/t of NO_x reduced, depending on the emissions required.

SCR systems and combinations involving an SCR are the least cost-effective, with expenditures ranging from $2,954 to $3,148/t of NO_x reduced. However, SCRs are able to achieve a lower NO_x emission level than most of the other options. Installing current-generation low-NO_x burners in combination with an SCR system both decreases the overall NO_x produced and cuts the cost of NO_x reduction by $194/t. Since the SCR, low-NO_x burner combination provides two controls on NO_x production (both during and after combustion) and reduces operating costs, it can be an attractive option for operators looking for the most cost-effective way to meet the tightest NO_x regulations.

The 10-year net present cost at 8% of NO_x control equipment versus the emissions performance for the example case is shown in Fig. 6. In this figure, it becomes almost exponentially more expensive to control NO_x to lower levels. Again, the technologies that require only a burner change out or ductwork seem to have an economic advantage over those options requiring recirculation fans or complicated SCR systems.

When evaluating any NO_x reduction project, it is vital to first determine which control technologies will be able to meet the emissions required for individual plant equipment. While realizing the value of identifying the optimum solution for each case, many companies find that evaluating the performance and cost of every available technology can be a daunting task.

When faced with meeting an upcoming NO_x regulation, operating companies should enlist an equipment supplier or engineering company with a wide range of combustion experience to aid in selecting the best technology for each application. ■

LITERATURE CITED

[1] *Alternative Control Techniques Document—NO_x Emissions from Process Heaters* (Revised): EPA-453/R-93-034, September 1993.