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Al Hovland, P.E., Conco Systems Inc., Frank G. Lyter, P.E., PPL Generation LLC., US, and Charles Truchot, Air Liquide Corp., France, describe the innovative cleaning of air preheater coils using pressurised liquid nitrogen.

Handling the Pressure

Air heaters in power plants or recovery boilers have traditionally been cleaned with high pressure water, chemicals or steam. These techniques, while effective on moderate air-side fouling of heat exchange surfaces, are usually ineffective on the more tenacious deposits that can develop in coal-fired plants with a buildup of fly ash, dust and oil. If these deposits are not periodically cleaned, the heat transfer in the heaters is reduced, which in turn reduces boiler efficiency and increases a unit's heat rate. Severe fouling on air preheaters and heaters can even reduce the megawatt output of the unit. This paper discusses the recent introduction of a highly effective method of cleaning air heaters using pressurised liquid nitrogen (LN_2). A success story from PPL Generation's Brunner Island plant illustrates the effectiveness of this new technology.

Air heater function and performance

The role of a plant's air heater is to improve boiler efficiency by heating the combustion air using available exhaust flue gases. This preheated air accelerates combustion by producing more rapid ignition and also allows the burning of low-grade fuels.[1] For each 50˚F (27.5˚C) increase in boiler inlet air temperature, the boiler efficiency will increase by 1%. Air heaters can increase plant efficiency by up to 10%.[2]

Air heater configurations can vary widely in power plants. Some units use a Ljungstrom®-type rotary regenerative air heater, or a fixed recuperative tubular air heater. Depending on configuration, many units may also contain a finned tube air preheater immediately after the forced draft fan. The purpose of the air preheater is to keep the primary air heater at a temperature above the dew point or acid saturation point in the primary air heater baskets or coils. If the metal temperature drops below the acid saturation temperature, usually between 190 – 230˚F (88 – 110˚C) but sometimes as high as 260˚F (127˚C), then the risk of dew point corrosion damage becomes considerable. If this is not done, deposits of flue gas products will be formed that will corrode the heat transfer surfaces, partially block the air flow and, in extreme cases, limit the MW capacity of the unit.

While air preheaters play a critical role in increasing boiler efficiency, this increase is only effective if the air heater is maintained and kept clean of air-side fouling.

Liquid nitrogen cleaning technology

The NitroLance™ cleaning system, developed by Conco Systems, uses pressurised liquid nitrogen (LN_2) to clean various types of heat exchangers and industrial surfaces. It can be used to clean tube internals with small rotating insertable jets, or with larger specialised manifolds for external heat exchanger surfaces including delicate finned heat exchanger tubes.

The typical NitroLance process flow is shown in Figure 1. The commercial high purity liquid nitrogen comes from the supplier at -321˚F (-196˚C).[3] The system pressurises it to between 5000 – 55,000 psi. Then, using a temperature controller, the flow is directed while expanding almost 700 times on and into the surface to be cleaned. The controlled flow and temperature is regulated between -160˚F and -250˚F (-107 – -157˚C). The complete system is mounted on a mobile platform that is moved to close proximity of the heat exchangers being cleaned (Figure 2). The NitroLance hose and nozzle extend up to 300 ft from the mobile platform, while delivering LN_2 to the surface being cleaned.

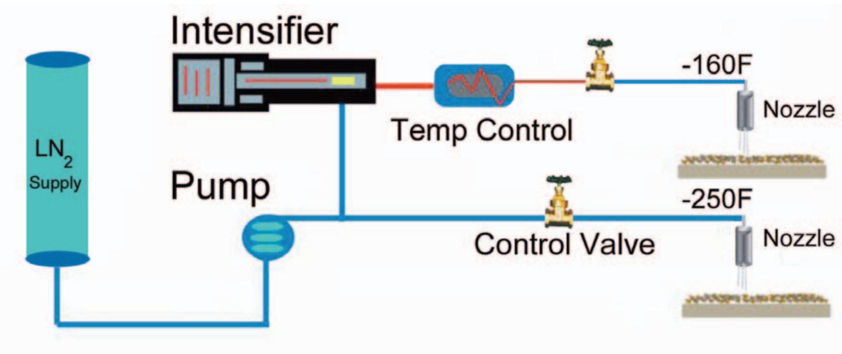

Figure 1. NitroLance process flow.

Figure 2. NitroLance mobile platform with LN_2 tanks, pumps and temperature controller.

Why is liquid nitrogen cleaning so effective?

The NitroLance cleaning system delivers pressurised LN_2 to the cleaning surface and rapidly removes deposits through three mechanisms of action: thermal expansion, mechanical pressure and super cooling (Figure 3).

1. Thermal expansion: As the high density vapour penetrates the cracks and crevices of the fouling deposit it rapidly converts to a gas, expanding nearly 700 times. This rapid expansion, combined with the delivered pressure and cold temperature, causes the fouling deposit to break apart and release its bond with the parent metal.
2. Mechanical pressure: The pressure exerted at the nozzle tip is regulated from 5000 – 55,000 psi based on the equipment being cleaned and fouling characteristics present.
3. Super cooling: The super cool liquid nitrogen (-160 to -250˚F [-107 to -157˚C] at the nozzle) facilitates embrittlement fracturing of fouling deposits.

LN_2 cooling of base metal

An evaluation of the effects of LN_2 on base metal was performed to examine possible changes to the metal's grain boundaries and structure, as well as the potential for shrinkage or modifications of mechanical properties that might

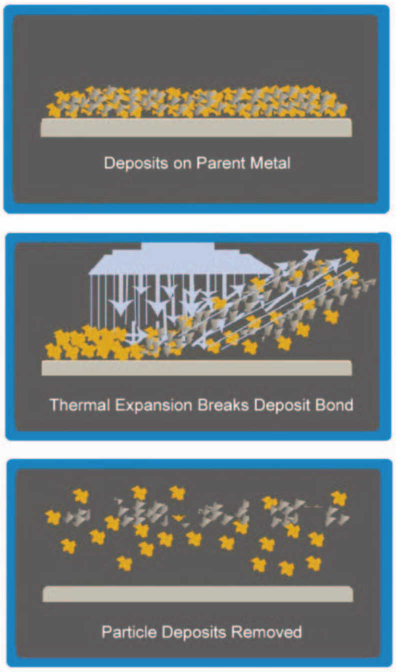

Figure 3. The LN_2 removes the deposit by volumetric expansion, cold temperature and pressure.

result from the cold temperatures. Micro-structural observation and micro-hardness measurements were performed on the material before and after LN_2 cleaning. As shown in Figure 4 and Table 1, LN_2 cleaning of basic carbon steel induced no micro-structural modifications or changes in the surface superficial micro-hardness of the base metal.

Shrinkage or modifications of the mechanical properties of the base metal is avoided due to the cleaning process being performed at a relatively fast rate (greater than 10 ft/min). Combined with this speed and brief contact with the LN_2, the base metal only dropped an average of 9 – 18˚F (5 – 10˚C) in temperature. This small temperature drop induced no notable metal shrinkage and had no notable influence on mechanical properties of the base metal.

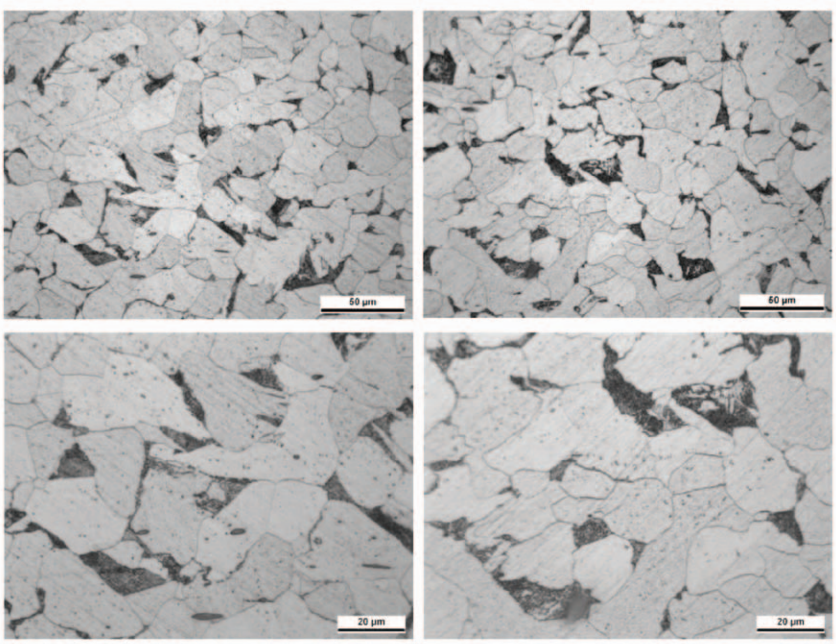

Figure 4. Observation of 3 μm diamond polished ASTM A 516 60 before (left) and after (right) cleaning with NitroLance. The revelation of grain boundaries is made with 4% Nital.

Table 1. Micro hardness measurement

Sample	Vickers scale	Measurement (hardness)			Average hardness
		M1	M2	M3	
ASTM A 516 60/ASME SA 516 60 before NitroLance	HV0.3/15	161	147	146	151
ASTM A 516 60/ASME SA 516 60 after NitroLance	HV0.3/15	146	158	152	152

Zero secondary waste streams

NitroLance is unlike traditional water-based methods of cleaning that can produce hundreds of thousands of gallons of effluent. These methods will now require expensive Environmental Protection Agency (EPA) mandated disposal, cleanup and processing.[4] These include air heater cleaning, boiler tube cleaning, boiler fireside cleaning and many other plant cleaning processes. The benefit of the liquid nitrogen cleaning is that it produces no secondary waste streams. The fouling deposits removed by the NitroLance cleaning process can be easily vacuumed up or blown out of the stack during subsequent normal operations. This lack of effluent production by NitroLance represents a significant cost savings to power plants over traditional water-based methods.

Critical path maintenance benefit

Another consideration, in addition to the cost savings that zero secondary waste represents, is in the area of critical path maintenance activities. NitroLance represented a significantly shorter window needed for cleaning in the fixed length outage at PPL Generation's Brunner Island power plant when compared to water-based methods that have been tried without success in the past. The water-based cleaning methods also required extended clean up and disposal activities upon completion of the cleaning phase. The LN_2 cleaning method was successful and it is estimated that several days were saved in the critical path maintenance compared to traditional cleaning methods, representing significant savings to PPL.

Case study: PPL Generation

This LN_2 cleaning was first conducted at PPL Generation's Montour and Brunner Island power plants in Pennsylvania. These plants use rotary regenerative Ljungstrom air preheaters. Upstream of the rotary air heater (on the air side) are finned tube air preheaters which are

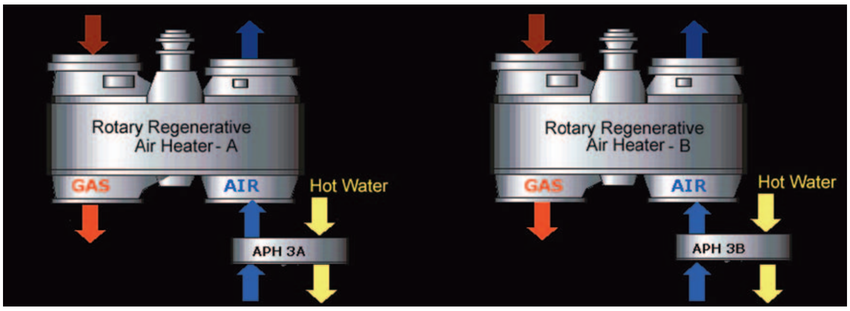

Figure 6. Rotary regenerative air preheaters with steam coil air preheater (hot water).

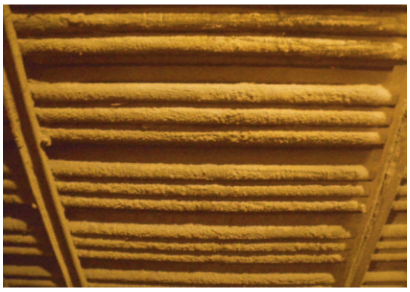

Figure 7. Fouled heat exchanger air preheater coils at Brunner Island's Unit 3.

Figure 8. Cleaning the air preheater at Brunner Island's Unit 3.

heated with hot water. Figure 6 shows a schematic illustration of the plant's air preheating system.

The finned tube air preheaters often get fouled after a few years of plant operation. Additionally, cleaning of the rotary regenerative air preheater located above causes debris to fall onto the steam coil surface, also requiring them to be cleaned. At Brunner Island's Unit 3, a 760 MW coal-fired unit, the fouling was due to fly ash deposits, dust/debris and lube oil that had formed a thick shell over the fin coil surfaces. Since this unit is typically a base-loaded unit, it can only come down for maintenance at scheduled outages. Previous attempted cleanings of the air preheater used methods of water, chemicals and detergents. They were ineffective in removing the tenacious deposit of fly ash and oil. The oil portion of the deposit was only on the "B" side and was caused from a bearing seal leak in the unit's forced draft fan. In operation, this fouling (Figure 7) created restricted combustion air flow on both "A" and "B" sides. Operators attempted to force more air to the "A" side by the cross-connect air ducting. This partially worked, but still created an imbalanced air flow situation. This situation often created a megawatt output reduction during certain weather and operating conditions. As an outage approached for the unit in spring 2010, the NitroLance system was evaluated by PPL engineers and was scheduled for cleaning the fouled "B" side air preheater coils.

Plant coordination meeting

A site evaluation between Conco engineers and plant personnel concluded that installing a new access door in the ducting adjacent to the air heater would be beneficial. Scaffolding would be placed directly under the horizontal air preheater, allowing access to the area to be cleaned. Conco would supply two mobile LN_2 units. Normally, only one mobile unit is required, but due to minimal time allocated in this case, two were required to clean the air heater in one 12 hour shift. The technicians would be equipped with full safety gear including jump suits, full face respirators (with external air), rubber boots and cryogenic insulated gloves.

Cleaning results

At the start of the unit's outage, Conco technicians went into the air preheater coil ducts and quickly cleaned a portion of the fouled tubes. Figure 8 shows the technicians in protective gear with the NitroLance wand and nozzle removing the deposits. The system's delivery pressure was carefully adjusted to make sure that the heat exchangers delicate tube fins (0.012 in. [0.3 mm] thick) were not damaged.

The cleaning of the externally finned heat exchanger was immediate. The fly ash and oil deposits were removed in seconds and a majority of side "B" air

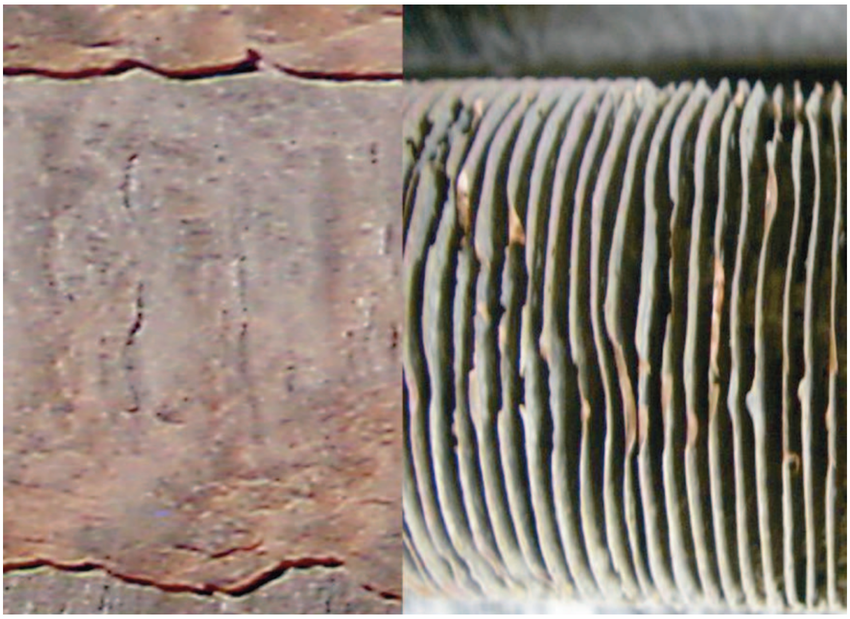

Figure 9. Air preheater coils before (left) and after (right) cleaning with LN_2.

preheater was cleaned in only 12 hours. See Figure 9 for results of cleaning an individual coil. The external tube fins are now functional and no damage was done to the fins by the LN_2 cleaning.

Performance results

After the unit was brought back into service, immediate results showed that the airflow blockage on side "B" was significantly reduced and that sides "A" and "B" have become airflow balanced. In fact, the airflow pressure drop across the air heater was reduced by half (8 in. to 4 in. [20.3 to 10.2 cm] H_2O). Although still higher than original design air flow pressure drop (1.7 in. [4.3 cm] H_2O), the improvement was significant considering only a portion of the air heater was cleaned. The potential exists for additional improvements by going back in at a future outage and cleaning 100% of the tubes to reach the design pressure drop across the preheater coils. Figure 10 illustrates delta pressures for the air heater before and after the LN_2 cleaning at April's outage.

Because of the significant improvement of the air heater being brought closer to original design parameters, the plant is considering delaying the replacement of this air heater, saving PPL an estimated US$ 2.5 – 3 million. Additional benefits of this new cleaning approach include additional savings such as:

- Increased boiler efficiency.
- Improved unit heat rate.
- Megawatt output increase.
- Reduced house load.
- CO_2 emissions reduction.

These benefits were not calculated specifically for this unit due to numerous other maintenance items performed during the outage which also improved the unit's performance. The heat exchanger cleaning with nitrogen resulted in a significant improvement in unit operation by allowing increased air flow through the unit and balancing the air distribution within the boiler. Additionally, this work was

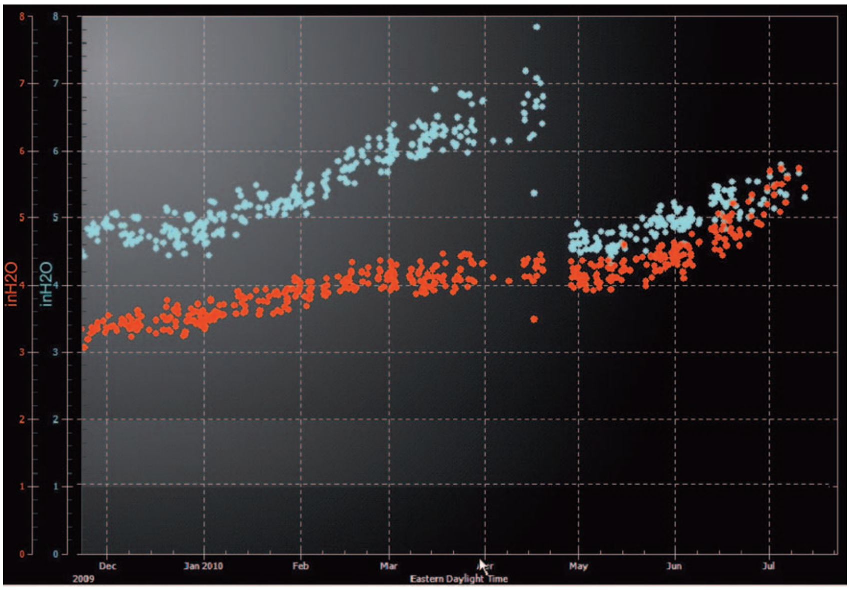

Figure 10. Air heater performance on Brunner Island unit 3.
Blue = delta pressure on air heater side "A" (note improvement in April).
Red = delta pressure on air heater side "B".

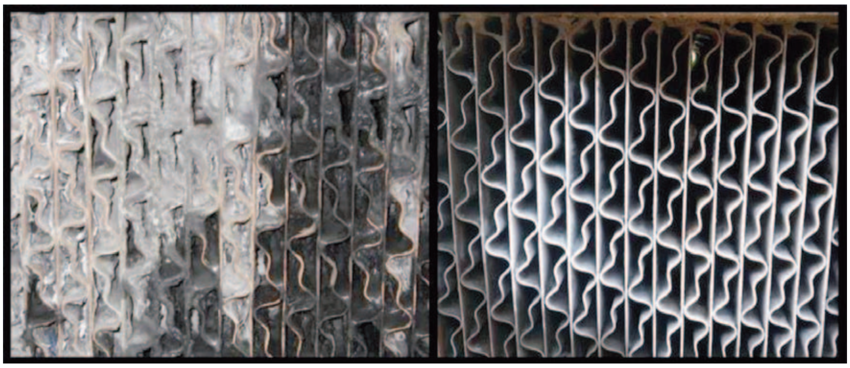

Figure 11. NitroLance cleaning on Ljungstrom baskets – before (left) and after (right) cleaning.

Figure 12. Boiler super heater tubes before (top) and after (bottom) cleaning with NitroLance.

accomplished without increasing the duration of the planned outage.

Other applications of LN_2 cleaning

The cleaning of the steam coil air preheater was so effective that Conco Systems also worked with PPL to test clean sample regenerative air heater baskets. The results from cleaning baskets taken from the Montour plant's Ljungstrom unit showed cleaning results that restored the baskets to a very high level of cleanliness. Figure 11 illustrates the before and after results. To clean the rotary air heaters' lower end baskets in-place during an outage is also possible due to acceptable access heights between the steam coil air heater and most primary air heaters. Soot blowing and other water blasting techniques may now be replaced or supplemented with LN_2 cleaning. The deposits are easily vacuumed up and no waste water removal is needed – thus saving the EPA-mandated expense of collection and removal and waste water processing of potentially thousands of gallons of effluent.

Additionally, this innovative cleaning technique was recently tested boiler superheater tubes at PPL's J. E. Corette power plant in Montana. The results shown in Figure 12 indicate efficient cleaning on the deposits of ash and slag, while not damaging the parent tube material.

Overall, nitrogen cleaning with NitroLance provides a new and significant technique for cleaning various deposits in power plants and industrial facilities without damaging the parent metal. The types of deposits that are easily removable include fly ash, slag, carbon/soot, sulfur and oils.

Conclusion

Air preheaters provide a critical role in boosting boiler efficiency, but when compromised with air-side fouling, can actually reduce plant output. Historically, air preheater cleaning has been accomplished using water, steam or chemicals, which produce a significant volume of effluent that requires tedious handling and disposal at considerable cost. The recent introduction of new technology using pressurised liquid nitrogen not only speeds the cleaning process, but does it without producing secondary waste streams, saving power plants time and money. In addition to air preheaters, liquid nitrogen also appears to be an optimal choice for many other applications within power generation and industrial facilities where its speed of deposit removal and zero-waste benefit is advantageous.

References

1. WOODRUFF, E.B., *Steam Plant Operation* (McGraw-Hill, New York; 2005), pp. 73 – 74.
2. *Steam: Its generation and use*, 41st ed., (The Babcock & Wilcox Co.; 2005).
3. Air Liquide Corp., *Gas Encyclopedia* (encyclopedia.airliquide.com/encyclopedia.asp)
4. Environmental Protection Agency (EPA), Code of Federal Regulations CRFe, Title 40, Part 423, Steam Electric Power Generating Point Source Category (August 2010).