CASE STUDY

Modernizing air pre-heating technology at U.S. coal-fired power station to reduce energy inputs and greenhouse gas emissions

INTRODUCTION

Project partners:

- Schuylkill Energy Resources | power producer
- Econotherm | www.econotherm.co.uk | technology supplier

Authors:

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BACKGROUND

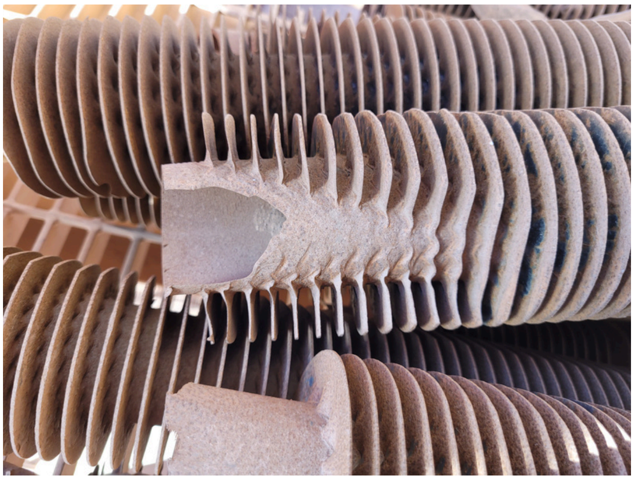
With increasing emphasis on corporate environmental responsibility, industrial operators across various industries are re-exploring opportunities to repurpose otherwise-wasted heat. When implemented effectively, the benefits have shown to be significant, ranging from a reduction in primary energy inputs to fewer greenhouse gas emissions.

Many operators have long started down this path in the form of heat pipe air pre-heaters (APHs). The technology, which traces its origins back more than a century, is touted by its ability to successfully navigate the complexities of recovering energy from often-overlooked streams such as combustion flue gases that come with heavy particulate loads, high activity and extreme temperature fluctuations.

SCHUYLKILL ENERGY RESOURCES

In the case of Schuylkill Energy Resources (SER), the U.S.-based independent power producer had been operating a Q-Dot heat pipe APH at its 80-MW St. Nicholas Electric Power Generation Station in Shenandoah, Pennsylvania, U.S. since 1987. Q-Dot built and installed dozens of large heat pipe APHs in power stations, refineries and chemical plants around the world during the 1980s and '90s. Shuykill's power station in Pennsylvania utilizes waste coal culm and silt to generate steam and electricity.

Over decades, the performance of the heat pipe APH had degraded over time due to several known issues, including pipe corrosion, leakage, degradation of the organic working fluids. SER decided to replace the faulty heat pipes and address the leakage issues affecting the unit.



PHOTOS

Top: Exterior view of the Q-Dot heat pipe APH.

Middle: Prior to its repair, many of the heat pipes had been removed due to breakages and corrosion.

Bottom: Heat pipes from the original Q-Dot heat pipe air pre-heater shows erosion wear.

WHAT IS AN APH?

A heat pipe APH is constructed as a cased unit comprised of an array of heat pipes, each acting as an individual heat exchanger. The heat pipe itself is a sealed tube filled with a small amount of working fluid at saturation condition. The latent heat of that working fluid is used for the energy exchange.

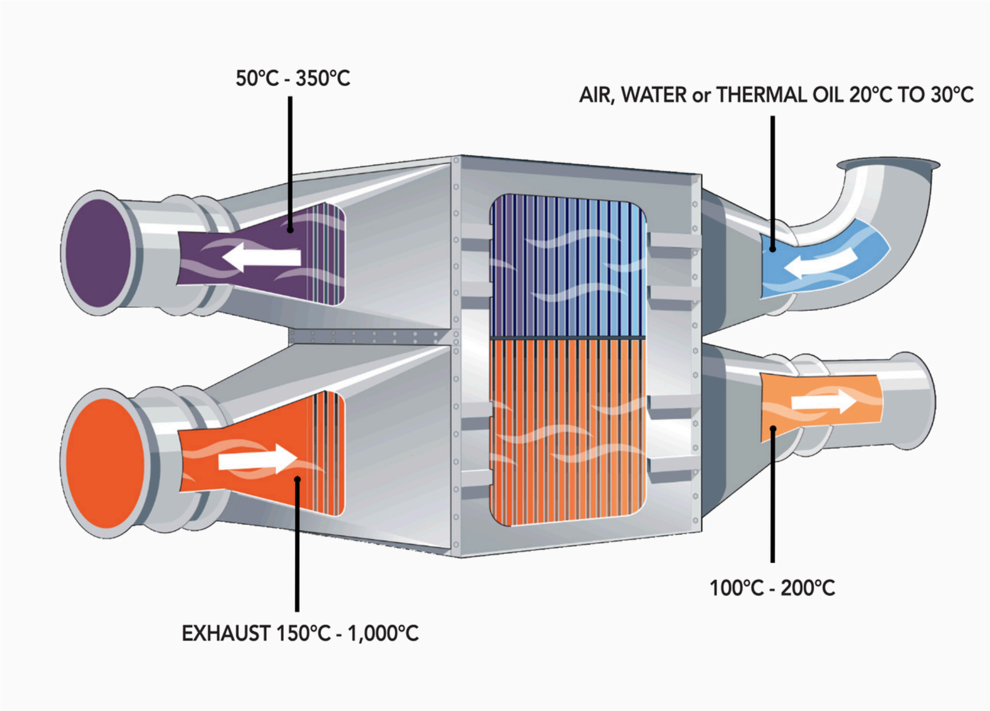
APHs can receive two process streams, which are isolated using a separation plate that contains affixed heat pipes that contact each process stream.

PRIMARY

Also known as the evaporator section, heat pipes contact the hot process stream, causing the liquid working fluid within each heat pipe to boil.

SECONDARY

Or condenser section, each heat pipe contacts a cold process fluid, causing the gaseous working fluid to simultaneously condense.



The ends of the heat pipe are free to expand and contract, preventing mechanical stress on the equipment. Furthermore, heat pipe heat exchangers (HPHEs) are highly customizable: the number of pipes, their spacing, dimensions, orientation, material of construction, type of working fluid and casing dimensions can all be tailored to meet specific application requirements.

In SER's case, the heat pipe APH installed at its power station in Pennsylvania was split on the secondary side to heat both primary and secondary air – comprising 39 rows, each containing 56 pipes arranged in an inline pipe layout for a total of 2,184 pipes.

INITIAL FINDINGS

Initially, the scope of the repairs was to address only the primary air heater. However, the product manufacturer had discontinued support on Q -Dot heat pipe APH, so SER contacted Econotherm, a UK-based company that specializes in the design and manufacturing of industrial waste heat recovery heat exchangers based on heat pipe technology. An inspection and engineering review highlighted critical issues with the initial design:

- An insufficient number of heat pipes were installed, meaning the unit's design prohibited SER from realizing full heat recovery potential.

- The unit had reached its maximum pipe working temperature (PWT). The max PWT in the design condition was 347°C (656°F), which exceeded the critical temperature of toluene (working fluid in the original pipes) of 319°C (605°F). When the temperature reached or exceeded critical levels, the evaporation-condensation cycle ceased. This rendered the heat pipes inoperative.

- The minimum PWT was lower than stated. The design conditions allowed for 90.4°C (194.72°F), which was lower than the stated minimum metal temperature of 103.3°C (218°F). This increased the likelihood of cold end corrosion issues within the unit.

- The length of the heat pipes in the design conditions requires accurate design to avoid hitting heat pipe limits. In the case of SER's existing unit, the design conditions had led to the counter-current limit being exceeded in some areas.

‘BEFORE’

As a result, the Q-Dot heat pipe APH was only achieving 85% of the design performance. Furthermore, the effect of corrosion, removed pipes and poor pipe function had compromised the current APH by 75% relative to its theoretical built capability.

TABLE 1

	Units	Design	Actual (1993)	Actual (2023)	Client expectation
FLUE GAS					
Flow rate (max)	Lbs/hr	819,595 (822,348)			
Entering temp (max)	°F	678 (700)			
Leaving temp (max)	°F	303 (550)		530	
Pressure drop	In wg	3.65	357	394	
Avg. specific heat	Btu/lb °F	0.265			
COMBUSTION AIR					
Flow rate (max)	Lbs/hr	655,600 (655,600)			
Entering temp (max)	°F	114 (114/80)		71-73	
Leaving temp (max/min)	°F	622	572 (593)	(131/250)	(450/450)
Pressure drop	In wg	3.26			
Avg. specific heat	Btw/lb °F	0.244			
Heat recovered	MM Btu/hr	81.48			
Min cold tube temp	°F	218			

SOLUTION

Econotherm's sizing tools indicated that the unit's performance could be improved significantly, even with considerably fewer pipes. Design considerations included:

1.Pipe working temperature: The use of asymmetric fin densities enables control of the PWT. Thus, the typical approach would be to elevate the cold end PWT to minimize cold end corrosion problems such as those experienced in the current Q-Dot APH. Conversely in hot applications, asymmetric fin densities could lower the PWT in the hot end of the unit.

2. Number of heat pipes: Designing to minimize the number of required heat pipes comes with compromises – in this case, the low-end PWT.

3. Single heat pipe type: It is typical in an Econotherm APH to utilize multiple heat pipe types in a single unit, with PWT elevating configurations in the cold end, lowering configurations in the hot end and creating neutral configurations in the middle of the unit. Additionally, considerations regarding pipe material include using several rows of stainless steel-grade pipes at the cold end to enhance corrosion resistance during transient operating conditions. Distilled water rather than the original organic fluid can be used.

4. Heat pipe style: The current unit utilized finned heat pipes, but consideration can be given to plain pipes. This approach would require more units but has the advantage of being able to utilize a more robust pipe with lower fouling and simpler cleaning procedures.

5. Pipe sealing: The current welded approach was not practical and had been shown to be problematic in the current Q-Dot APH. A screw-in collar was preferred but required a slightly greater fin to fin separation in the unit. This resulted in less pipes per row in the unit to remain within the available space.

RESULTS

SER proceeded with the project in 2023. The heat pipe modules were fabricated in Bridgend, Wales, and shipped to site where they were installed in 2024. A U.S. Econotherm contractor partner performed the installation during a scheduled shutdown. The resulting performance achieved is illustrated in Table 2 and 3.

TABLE 2

Transfer mediums	**Unit type**
Gas	Heat Source
Gas	Heat Sink

Flow rates		**Recuperator Exhaust Air**	**Units**
819, 595	Exhaust (SH = 0.265411206086758 K/cal/Kg C	371,762	Kg/h
655,600		297,375	Kg/h

Interface temp		**Recuperator Exhaust Air**	**Units**
530	Exhaust entry	276.7	°C
271	Exhaust exit	133.0	°C
72	Air entry	22.1	°C
429	Air exit	220.43	°C
	LMTD	**8,051**	**GGCF204.7**

Theoretical Available Heat	**Recuperator Exhaust Air**	**Units**
	14,175,563	Kcal/h
	16,483,213	w
	56,254,466	BTU/h

TABLE 3

PA HEATER SUMMARY

Calculated duty from flue gas side	20,125.3	Kw
Calculated duty from air side	14,845.7	Kw
Design duty from glue gas side	16,483.2	Kw
Pre upgrade duty from flue gas side	5,662.2	Kw
Uplifted duty from flue gas side pre/post upgrade	14,463.1	Kw
Primary CA air temp uplift pre/post upgrade	170.2	°C
Spray water volume pre-upgrade	58.64	GPM
Spray water volume post upgrade	0.04	GPM
Spray water volume reduction post upgrade	58.61	GPM

SAVINGS REALIZED

FUEL REDUCTION

Reduction of 57.4 million BTU or 2.9 coal short tonnes per hour burned

ENERGY COSTS

Hourly savings of $173.23 USD based on price per tonne of $187.70/hour*

FINANCIAL IMPACT

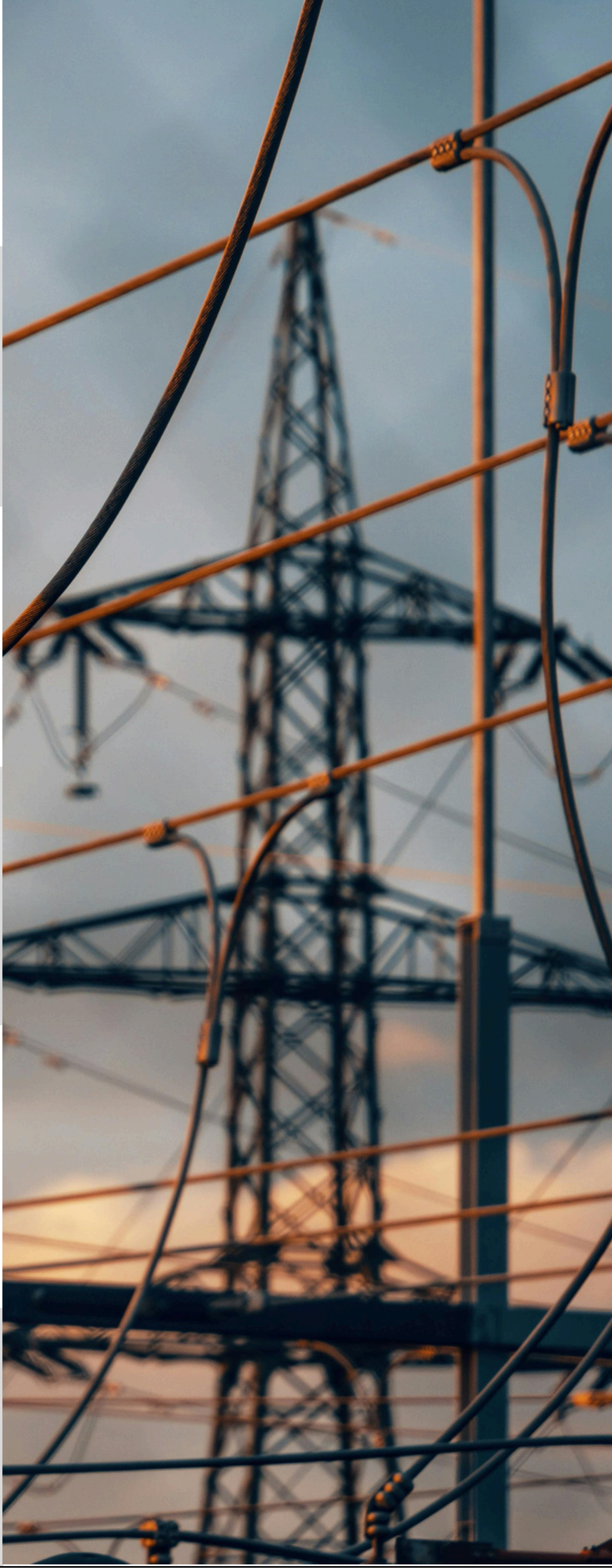
Annual savings of $1.5 million

ENVIRONMENTAL IMPACT

Reduction of 42,959 tonnes of carbon dioxide per annum

WATER USAGE

Substantial reduction in quench water consumed at the power station.



CONCLUSION

As industrial operators continue to seek sustainable solutions, waste heat recovery and reutilization has the potential to become a critical element in maximizing operational efficiencies and turning waste heat into a valuable resource. The success of technologies such as heat pipe air pre-heaters demonstrates that, when designed properly, heat pipes can help those operators transform overlooked energy streams into valuable resources. Furthermore, by addressing the challenges of aging systems and optimizing their design to meet modern demands, operators can better position themselves for within the current energy transition.

ECONOTHERM

Econotherm (UK) Ltd., a Solex Thermal Science company, is a recognized leader in the design and manufacturing of heat pipes and exchangers for industrial waste heat recovery. Based in Wales, UK, Econotherm focuses on difficult-to-recover heat that includes hot and/or dirty exhausts in industries such as power generation, metals, construction, food, mining, oil and gas and pharmaceutical. Econotherm is also at the forefront of heat pipe research and development, having been recognized with green technology awards from Shell Oil and LLGA City Smart for its leading-edge developments. Econotherm has participated in a number of international EU- and UK-funded research and development projects where its deep expertise in heat pipes has contributed to new developments for industrial waste heat recovery solutions.

SCHUYLKILL ENERGY RESOURCES

Schuylkill Energy Resources is an 80-MW independent power producer located in Shenandoah, PA. The company employs approximately 65 personnel, and produces enough power for 65,000 to 86,000 homes. Its Pennsylvania location utilizes 4,200 TPD of waste culm and silt to generate steam and electricity. The by-product CFB ash is then used in land reclamation projects around the United States.

THANK YOU!

ABOUT THE AUTHOR

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Scott is a career-long technical sales specialist for electro-mechanical industrial equipment with extensive experience providing engineered solutions for heat exchangers and energy systems. Scott has led effective sales and engineering teams to serve customers in a wide range of industrial applications on multiple continents and the U.S. At Solex, Scott is responsible for working directly with clients and agents in Canada, the U.S., Mexico, as well as both Central and South America.

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