HEAT RECOVERY OPTIONS FOR DRYERS AND OXIDIZERS

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Introduction

Competitive pressures continuously motivate us to examine our processes for opportunities to increase quality, increase productivity, and decrease costs. Energy intensive processes such as those associated with the manufacture of tape and label products offer opportunities to reduce operating costs through waste heat management. Convection dryers coupled to thermal oxidizers are a fixture in many of these converting operations. Both heat, circulate, and exhaust large volumes of air. With no consideration for thermal efficiency, it’s likely that a large amount of costly, usable energy will be carried out the exhaust stack. For both dryer and oxidizer, the goal of waste heat management is to minimize the volume and temperature of the exhaust stream. Heat recovery is the process of utilizing the excess heat that is generated but not consumed by a process. This heat may be directed back to the process as “primary” heat recovery, utilized by a related or connected process as “secondary” recovery, or provided to an unrelated process as “tertiary” heat recovery.

Primary Heat Recovery in the Dryer

The dryer design and operating conditions will be dictated by the process requirements. Air is supplied at a prescribed volume, temperature, humidity, etc. It impinges on the web, providing heat and mass transfer, and then is removed from the system. The coating enters the dryer wet and exits dry. With no consideration for heat recovery (Figure 1), a small fraction of the energy invested in the heated supply air is transferred to the product being dried. Most is carried away in the exhaust air. For most processes this approach is unnecessarily inefficient. There are a number of primary heat recovery options available to reduce the volume and temperature of the exhaust air stream.

Recirculation

The simplest and most common heat recovery system found in a convection dryer is recirculation (Figure 2). Instead of exhausting the entire waste air stream, a portion is diverted back into the process. Significant energy savings can be realized by recirculating a portion of this spent air. The preheated recirculation air stream is mixed with the required amount of fresh air, reheated, and used again. This system allows drying requirements to be controlled independently from exhaust requirements. Process requirements – humidity, LEL, dryer balance, contaminants, and temperature control specifications determine the amount of exhaust/fresh air. Any amount of exhaust above minimum process requirements is wasted energy. Virtually all convection dryers supplied to the tape and label converting market have recirculation capability. Although recirculation control adds complexity to the dryer design, it’s well recognized that the operating efficiency gains justify the additional equipment cost.

Exhaust Cascade

A cascade arrangement (Figure 3) is an extension of the recirculation air scheme where, rather than exhausting a zone to atmosphere, the exhaust from one zone is used as makeup air for another. Air that is considered waste for one zone may be acceptable as makeup air in another. Humidity, LEL, or dryer balance may be the determining factor. A good example is the last zone of a dryer. Although humidity of the exhaust air is low, a certain exhaust volume is required for temperature control and dryer balance.
This exhaust can be recirculated back to a previous zone. Exhaust cascade has the benefit of reducing the total exhaust volume from the dryer, thereby reducing the air heating requirements. Exhaust cascading does reduce the operating flexibility of the individual dryer zones. Airflow balance and temperature adjustment range may be affected. It’s difficult to justify this type of system purely on an energy recovery basis. Equipment and maintenance costs will outweigh the operating cost savings. This system is often utilized when it’s necessary to minimize the exhaust airflow to an oxidizer or solvent recovery system.

**Exhaust Air-to-Air Heat Exchanger**

An air/air heat exchanger in the exhaust airflow (Figure 4) allows the makeup air to be preheated before entering the dryer. For most tape and label converting processes this arrangement is not economically feasible. The added cost and complexity of the recovery system outweighs the energy savings. This system is often used in metal coating processes that see high temperature, high volume exhaust airflows.

**Primary Heat Recovery in the Oxidizer**

An oxidizer is a pollution control device that operates by heating a volatile organic compound (VOC) laden airstream to its combustion temperature, converting the solvents to carbon dioxide and water. Typically, the combustion chamber operates in the range of 1400°F – 1600°F to achieve adequate VOC destruction. In a direct thermal oxidizer (Figure 5), a burner fires into the exhaust air stream, heating it to the combustion temperature. The clean, hot air stream is exhausted to atmosphere. In this case, all of the energy put into the heating of the air stream, as well as the heat released in the combustion process, is exhausted out the stack as waste heat. Equipment of this design is suitable for intermittent, low flow applications where the capital cost of heat recovery is large compared to the operating cost without. This situation is rarely encountered in converting processes. Most oxidizer designs incorporate a primary heat recovery system to preheat the incoming air stream. A heat exchanger is used to extract heat from the high temperature air stream exiting the combustion chamber and transfer it to the cooler air stream entering the combustion chamber. Depending on the type of heat exchanger employed in the design, an oxidizer is referred to as “recuperative” or “regenerative”. A recuperative oxidizer (Figure 6) utilizes an air-to-air heat exchanger to preheat the incoming air stream. Typical thermal efficiency of a recuperative heat exchanger is 60% - 80%. A regenerative oxidizer (Figure 7) utilizes multiple beds of ceramic heat exchange media. One bed absorbs heat from the outgoing air stream while another bed releases heat to the incoming air stream. At regular intervals, a switching valve reverses the airflow through the media beds. The beds cycle between absorbing heat from the process and releasing heat to the process. Typical thermal efficiency of a regenerative heat exchanger is 85% - 97%. High efficiency heat recovery combined with the exothermic combustion reaction creates the opportunity for the oxidizer to operate without the need for additional fuel. In general, the higher the solvent concentration in the air stream, the lower the heat exchanger efficiency required to maintain this “self-sustaining” operation. Regenerative oxidizers reach this operating condition at solvent concentrations as low as 5% LEL. Recuperative designs, with their lower thermal efficiency need higher solvent concentrations, over 20% LEL, to operate without additional burner input.

**Secondary Heat Recovery**

The oxidizer design and process operating conditions will determine how much excess heat is available for secondary heat recovery. Heat recovery can be accomplished in two different ways: Extracting heat from the stack or extracting heat directly from the combustion chamber. Dryer exhaust air temperature,
solvent concentration, and heat exchanger efficiency determine the oxidizer stack air temperature. As oxidizer efficiency is increased, the stack temperature will decrease. Destruction efficiency requirements determine the combustion chamber temperature. When concentrations rise above the minimum required for self-sustaining operation, excess heat is generated in the combustion chamber. This excess heat presents a great opportunity for heat recovery. Whereas the oxidizer stack temperature will be 100°F to 400°F above the inlet temperature, air from the combustion chamber will be at 1400°F to 1600°F. Depending on the need, various forms of heat recovery options are available.

**Direct Air**

Direct air heat recovery (Figure 8) is an arrangement where heated air from the oxidizer is ducted directly to the process. Coupled to a convection dryer, this air can be utilized as preheated make-up air. This system is simple and requires very little auxiliary equipment; Modulating dampers, fans and pressure control loops. Direct air recovery does require a large amount of high temperature ductwork. This system often proves impractical when space is limited or the oxidizer is located a great distance from the dryer.

**Air-to-Air**

Heat recovery with an air-to-air heat exchanger (Figure 9) is similar to direct air heat recovery. This system should be considered if products of combustion from the oxidizer may contaminate the drying process. It’s important to carefully analyze the dryer operating conditions whenever considering a blended air heating system. Dryer air temperature is directly related to the volume of makeup air. If air volume and temperature requirements cannot be balanced, an auxiliary heating system, such as a gas fired burner, may be required to supplement the heat recovery system.

**Air-to-Oil**

Another recovery method is an air-to-oil heat exchanger. The exhaust air from the oxidizer passes through a heat exchanger, heating a thermal oil. This system offers more operating flexibility for the dryer than the direct air or air-to-air systems. With either of the air systems, the dryer must take a volume of makeup air that is proportional to the heat requirements of that zone. The more heat required, the more makeup air that zone must take. This is often contrary to the optimum operating condition for the dryer. The zones with high evaporation rates, the early zones of the dryer, usually operate at lower temperatures than the latter zones that require much lower exhaust rates. The air-to-oil heat exchanger is better suited to these requirements. An oil-to-air heat exchanger located in the recirculating air stream of the dryer allows the air temperature to be controlled independently from the makeup air volume. The hot oil circulation system is more compact, but more complex and expensive than a ductwork system.

**Air-to-Steam**

Air-to-steam heat recovery systems are similar in design and operation to the air-to-oil system. Hot oil systems can operate at higher temperatures than steam. Steam offers higher heat transfer rates. Typically, steam is preferred in a facility already using steam. Otherwise, a hot oil circulation system will be used.
Absorption Chiller

A less common heat recovery alternative is using waste heat to provide chilled water. Usually, the cost and complexity of these systems are prohibitively high when compared to a conventional compressor system.

Heat Recovery Considerations

It’s important to understand that as the efficiency of the primary heat recovery systems is increased, the amount of heat available for secondary recovery decreases. A well-designed primary heat recovery system may eliminate the need for any secondary system. The design goal for any new system should be to first optimize the primary heat recovery system. Secondary heat recovery requires the interconnection of two separate operating systems. It’s important to thoroughly analyze the operating cycles of both the dryer and oxidizer through their entire range of operation. The dryer provides fuel to the oxidizer, the oxidizer provides heat to the dryer. If supply and demand are not balanced for all operating conditions an auxiliary heat source may be required at the dryer. Generally, it’s not recommended to “overfire” the oxidizer to provide heat to the dryer. This analysis gets even more complex when considering a tertiary heat recovery system. With primary and secondary recovery, the process requiring the heat operates on the same schedule as the process generating the heat. The tertiary recovery system may be providing plant heating or cooling, or energy to another process unrelated to the converting line. Supply and demand are rarely balanced, so tertiary systems are normally considered supplemental.

Designing an efficient heat recovery system is not difficult. Waste heat sources are matched with potential users. The appropriate heat transfer and control system is designed. Determining the feasibility of a heat recovery system is difficult. Heat recovery feasibility is a financial decision. Energy savings must be balanced against capital, operating, and maintenance costs over the life of the system. Accurately quantifying these variables can be extremely difficult. A thorough analysis of potential heat sources and users is necessary. The skill and experience of the system designer is critical. Fluctuating utility prices and changing regulations complicate payback calculations. The science and technology of heat recovery is well developed. The art lies in the application.
Illustrations

Figure 1. Dryer with 100% Exhaust

Figure 2. Dryer with Recirculation
Figure 3. Dryer with Exhaust Cascade

Figure 4. Dryer with Makeup Air Preheat
Figure 5. Direct Thermal Oxidizer (No Primary Heat Recovery)

Figure 6. Recuperative Thermal Oxidizer
Figure 7. Regenerative Thermal Oxidizer

Figure 8. Direct Air Heat Recovery
Figure 9. Air-to-Air Heat Recovery

Figure 10. Air-to-Oil/Steam Heat Recovery