Using Heated Gas to Control Condensation in Exhaust Pipes

Overview

Periodic cleaning of exhaust pipes can be eliminated by controlling the temperature and concentration of effluent gases. This white paper presents the most common approaches to condensation control, and introduces a new technology that can eliminate the need for pipe cleaning.

Dilution

Heating Jackets

Electrically Heated Gas Injection

IR Heated Hot Gas Injection

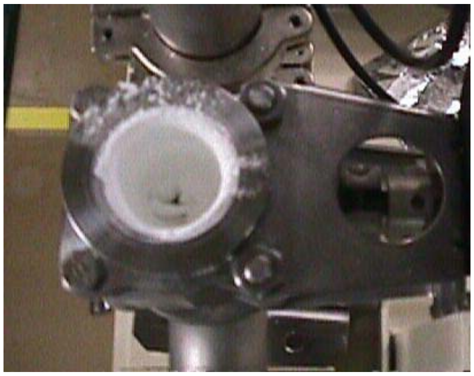
Introduction

Many thin film processes used in semiconductor and flat panel display manufacturing are gas based. Reactants, etchants, and carrier gases are flowed over substrates to create films, or pattern and remove them. Unreacted reagents and by-products are pumped away from process chambers to be scrubbed and exhausted. The final compression is performed by mechanical pumps located 5-10 meters away from reactors. From the mechanical pumps, exhaust gases are passed through scrubbers and finally through fab-wide abatement systems. Proper operation and maintenance of exhaust gas handling systems is critical to successful high-tech manufacturing.

Condensation and Clogging

Exhaust gases from process chambers are compressed in mechanical pumps and transported to scrubbers through stainless steel pipes that can be up to 10 meters long. Adiabatic cooling takes place when gases exit mechanical pumps.[1] Because exhaust lines are typically unheated, reaction by-products and reagents can condense on pipe walls. As a result, lines need to be periodically cleaned, sometimes as often as weekly.

Condensed residues are toxic and pipe cleaning needs to proceed carefully. Moreover, mechanical pumps need to be shut down during pipe cleaning which requires that process tools be shut down as well. Finally, mechanical pumps can be difficult to restart.



In some cases, catastrophic clogging can occur, causing gas flow to reverse and condensate matter to flow upstream into process tools, necessitating extensive cleaning and requalification.

Figure 1 - Exhaust line clogged by effluent condensation

[1] Compression within mechanical pumps raises gas temperature at the exhaust point to about 100 °C.

Cold Dilution

Many technologies have been proposed to mitigate or eliminate pipe cleaning and clogging. The most widely deployed technique consists of injecting room temperature nitrogen immediately downstream of the pump exit point. This is done through a ¼ in. fitting welded to the exhaust pipe, a few centimeters from the pump. Nitrogen injection dilutes reactant by-products and prevents aggregation and condensation. Unfortunately, room temperature gas injection lowers exhaust temperature and can increase condensation.

Heater Jackets

This solidification can be mitigated by the use of external heater jackets placed around the exhaust pipes. Such heater jackets are made to order and they are not energy efficient. They typically use 3-4 kW of continuous power and heat from the outside of the stainless exhaust pipes. Stainless steel is not a good heat conductor and the gas residence time is too short to provide a significant temperature increase. The alternative is to heat the gas before it is injected into the exhaust flow.

Electrically Heated Gas Injection

Resistive heating of dilution gas can be accomplished by 2 methods. In one method, the inert gas is heated by a hot filament placed within the gas inlet (hair-dryer style). Gradual build up on the filament can create a significant fire hazard; therefore, this technique is not widely used.

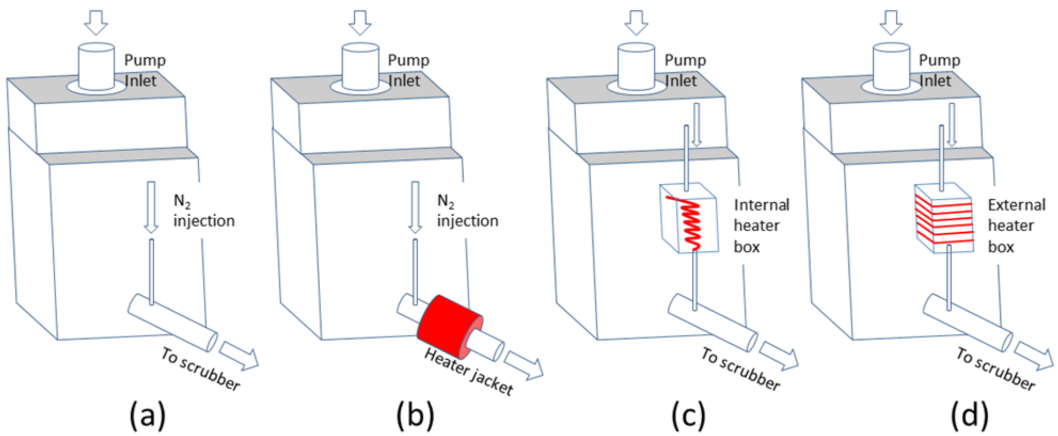


Figure 2 - Various dilution techniques: a) Room temperature N_2 injection, b) Injection with heater jacket around exhaust line, c) Hot injection with internal heated filament, d) Hot injection with external filaments.

In a related technique, external ohmic heaters are placed on the outside of a heat-exchange chamber where the inert gas circulates, before entering into the exhaust flow. This technique can achieve gas injection temperatures of around 150 °C at moderate flows. The wattage needed to achieve this modest heating is significant (3-4 kW) and many such heaters have caught on fire because of the high energy density required at the heating chamber.

Infrared Heated Gas Injection

Vélios is a new device developed and widely used in Taiwan that achieves gas heating through the use of an external halogen light source. A 1 kW halogen bulb is placed at the center of a double-enclosed 4 m SS coil. The long residence time and the small diameter of the coil tubing (1/4 in.) allow for very efficient non-contact heating of the gas. Temperatures of up to 350 °C are readily achieved at flows up to 100 L/min. The hot gas can then be injected directly into the exhaust line. Vélios consists of a SS heater body and controller. Typical power consumption is 500 W.

Dilution with heated gas raises the overall temperature of the exhaust gases. This prevents condensation along the exhaust line, all the way to the scrubber.

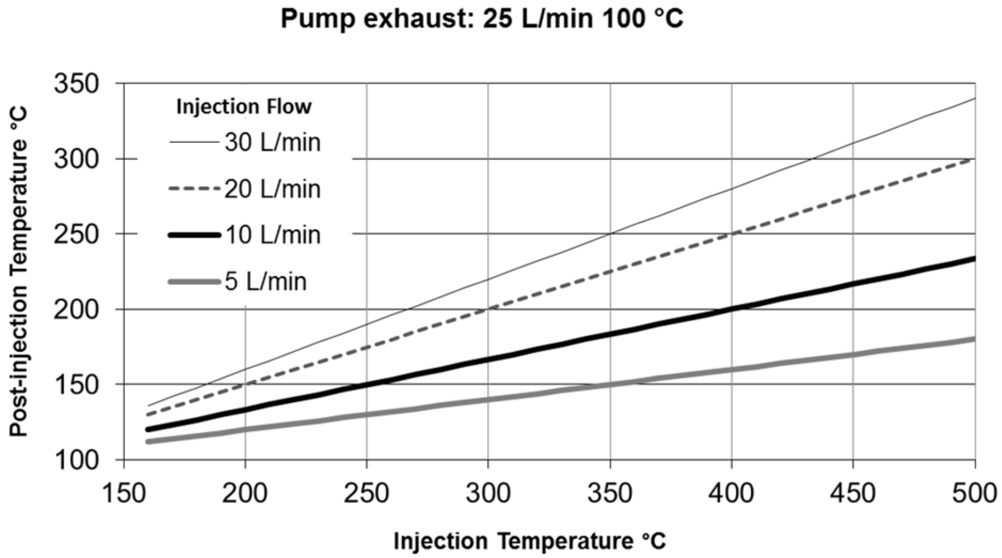


Figure 3 - Post injection temperature for various injection flows and temperature combinations when using an IR heater. In this example, the pump flow is set at 25 L/min and the initial exhaust temperature is 100 °C. Actual operating conditions may vary.

Non-contact heating allows end-users to employ other dilution gases safely, for example air when silane oxidation is required.

Infrared heated exhaust can reach very high temperatures. However, it is recommended in most cases that the final exhaust temperature be kept slightly below 200 °C, to avoid premature decomposition of O-rings located along the exhaust line.

Selecting and Evaluating Gas Injection

Diffusion, etch, chemical vapor deposition, and atomic layer deposition are prone to exhaust condensation. Other processes such as physical vapor deposition do not require exhaust cleaning and do not benefit from gas injection of any kind.

Gas injection prevents condensation. Some reactive chemical mixes need more dilution to stay gaseous while others need more heat. The right system for a given exhaust composition provides the right amount of energy and gas flow.

Scrubber capacity must be considered first. Injection techniques add to the total flow going through the abatement system. The pump flow, under all process conditions, and the injection flow must be safely below the scrubber capacity. Particular attention must be paid to abatement systems servicing multiple mechanical pumps.

Some newer mechanical pumps have on-board heated gas injection. Before additional heating or injection is considered, the effectiveness of such options must be evaluated. In particular, the exhaust temperature must be characterized to avoid over-heating once external heated injected is added.

In some cases, cold traps can be used in lieu of injection. While inexpensive to operate, cold traps need to be periodically cleaned. This affects equipment uptime.

Hot gas injection raises the exhaust temperature in the mixing zone. The temperature drops gradually as the gas travels through the ductwork and to the scrubber, as shown in Figure 4. If possible, the temperature near the injection point and at the scrubber inlet should be monitored. This can be done by means of a thermocouple placed directly within the gas flow through an appropriate KF fitting. Such measurements allow end-users to make more accurate process parameter estimates when using other chemical by-products or pump outlet flows.

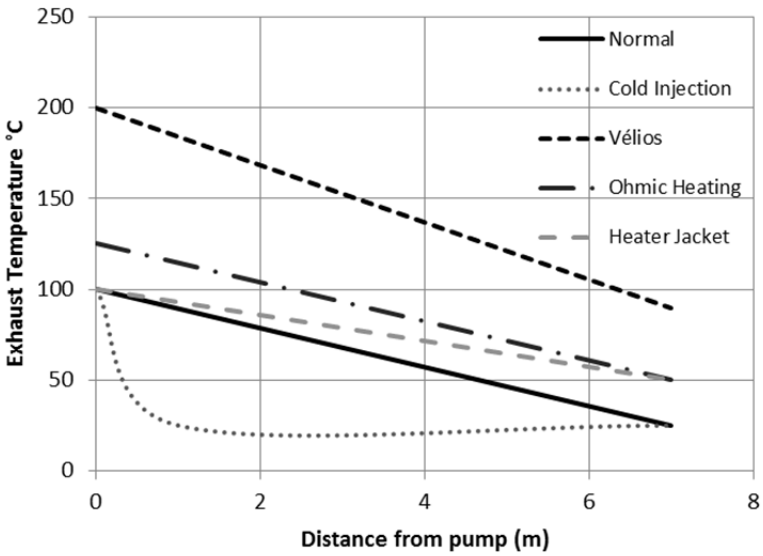


Figure 4 - Exhaust temperature profile for various dilution techniques. These examples are for normal operating conditions and an initial exhaust temperature of 100 °C. On-board heating would change the starting temperature.

Finally, capital costs and operating costs of the various technologies need to be compared. Close attention needs to be paid to on-going power costs.

Summary Table

Regardless of the technique used, exhaust gases cool as they move further away from the pump. Room temperature injection speeds up cooling while heater jackets slow it down. Hot injection changes the starting temperature but does not change the cooling rate as shown in Figure 4.

	Condensation	Power	Total Flow	Maintenance	Exhaust Temp.[2]
No injection	Yes	0 kW	25-30 L/min	Up to weekly	100 to 25 °C
Cold trap	Yes	0 kW	25-30 L/min	Monthly	100 to 25 °C
Cold injection	Sometimes	0 kW	50-100 L/min	Up to weekly	100 to 25 °C
Heater jacket	Periodic	3-4 kW	25-30 L/min	Monthly	100 to 50 °C
Hair dryer style	No	1-2 kW	50-80 L/min	Monthly	120 to 55 °C
External resistive heating	No	3 kW	50-80 L/min	Yearly	120 to 55 °C
IR heating/Vélios	No	500 W	50-100 L/min	None	225 to 70 °C

[2] Exhaust temperature is highest immediately after the pump and drops as gases cool on the way to the scrubber.

Vélios – Additional Information

The Vélios hot gas injection system reduces or eliminates condensation and clogging between the mechanical pump and the scrubber. A proper evaluation will consist in installing one injection system on one tool and conducting periodic visual evaluation of the pipe condition. A reference system pumping the same gaseous by-products should be used as a standard. Additionally, past maintenance records can be used for comparison purposes.

The IR heater and controller require one electrical outlet (110-240V, 20 A, 1 or 2 phases) near the intended pump. It also requires one ¼ inch house nitrogen outlet (150 L/min) fitted with a shutoff valve. Finally, a ¼" male Swagelok fitting must be welded to the 40 mm outlet line, at 90° to the gas flow, within 150 mm of the pump outlet.

The installation process consists of securing the heater body to a shelf or vertical member and connecting it to the exhaust inlet port. The distance between the heater body and the injection point needs to be less than 1 meter, and the gas line needs to be thermally shielded. The lamp and the house gas line are connected to the controller. The controller outlet gas line is connected to the heater inlet. Total installation time should be 1 hour.

Evaluations should last 4-6 months. This period can be shortened with severe condensation problems that disappear with the use of IR heated gas injection.

In most cases, condensation will be eliminated by the Vélios setup. Scrubber performance will be unaffected[3]. The Vélios parameters may need to be adjusted. 30 L/min at 300 °C is recommended as a starting point. Gas flow and temperature adjustments are related to the length of piping between the exhaust and the scrubber, as well as the reactivity of the by-products.

Conclusion

Equipment uptime and maintenance costs are affected by exhaust piping conditions. In many cases, it is possible to mitigate or eliminate condensation and clogging by diluting and heating exhaust gases. Many systems have been released. They vary in their power requirements, dilution potential, and heating capability. IR heating may be the most versatile solution, providing a wider range of temperatures and gas flows at lower power.

[3] The flow from the pump needs to be added to the flow from the Vélios when calculating the impact on the scrubber. If the pump output is 20 L/min and the Vélios is set at 30 L/min, the total flow to the scrubber will be 50 L/min.