HVAC Air Systems

Exhaust Optimization

Summary

Exhaust airflow rates are typically dictated by process equipment exhaust specifications. Equipment manufacturers' suggested exhaust quantities have been found to be overstated and not science based. For example, a recent study by International Sematech found that exhaust airflows could be reduced in four devices typically found in semiconductor cleanrooms: wet benches, gas cabinets, ion implanters and vertical furnaces. The results of the study reported that a reduction of total exhaust airflow by 28% exists among the four devices tested. The same study, which measured fume capture and containment effectiveness, found one piece of equipment where an increased exhaust rate was required to maintain safe containment.

Principles

- All air exhausted from a cleanroom has to be replaced by conditioned and filtered makeup air.
- For a cleanroom facility operating 24 hours a day, costs for exhaust air range from \$3 to \$5 per cfm (cubic feet per minute) annually.
- Building and fire codes require minimum amounts of exhaust for some types of cleanrooms. For example, the Uniform Building Code's H6 classification, which covers many common semiconductor cleanroom spaces, requires a minimum of 1 cfm/sf of outside air.

Approach

Exhaust systems are provided for a variety of reasons. In most industrial cleanrooms, exhaust design is driven by the need to protect occupants from hazardous fumes generated by or in process equipment, or to remove heat generated by equipment located in the workspace. The first type of exhaust system usually involves the use of fume hoods, wet benches, or equipment-integrated process equipment fume capture systems. The fundamental approach to exhaust optimization must be to verify and improve the safety of workers in the cleanroom.

Often, manufacturer recommendations for exhaust airflow rates are significantly overstated and/or based on a crude face velocity approach to estimating exhaust rates required for containment. Good practice suggests using direct measurements of the containment to set the exhaust rate. Methods such as tracer gas testing verify and document a safe operating condition, resulting in safer use. Studies indicate that proper optimization typically lowers overall facility exhaust flow rates, resulting in energy savings in addition to the safety benefits.

Conditioning makeup air for a cleanroom is expensive. Makeup air goes through several processes before it can be delivered to a cleanroom. Dependent on the space setpoints and the outside climate, the air has to be filtered, heated, cooled, pressurized by a fan, dehumidified and/or humidified. Each CFM of makeup air also results in a CFM of exhaust, which may require treatment before being released. The $3 to $5/cfm energy cost estimate for exhaust air takes into consideration energy for exhaust/scrubber fans and makeup air. Actual annual energy costs vary depending on climate, utility costs, and the efficiency of the air handling systems.

Following are examples of devices found in a cleanroom that can be targeted to reduce the amount of energy-intensive make-up/exhaust air required. In these examples, most of the recommendations require operating the devices below the levels found in the Environmental, Health, and Safety (ESH) Guidelines for Semiconductor Manufacturing Equipment. In all cases, proper measurement of the equipment under its actual operating conditions is required to ensure and enhance operator safety. Case studies have shown that worker safety can typically be verified at rates of exhaust below manufacturer's standard ratings. This highlights that industry guidance and regulatory rules of thumb may be able to be relaxed provided there is adequate alternative scientific evaluation.

Wet Benches

Wet benches are stations for wet etching and cleaning of wafers and devices. Products are automatically processed by being dipped and agitated inside a bath. Exhaust air travels across the surface of the bath to pull away toxic gases generated at the bench. Many wet bench manufacturers use a general standard of 135–180 scfm (standard cfm) of exhaust per linear foot of wet bench. The ESH guidelines recommend maintaining a wet bench face velocity between 40–100 fpm (feet per minute).

Gas Cabinets

Gas cabinets are designed to maintain a face velocity across the access window, similar to that of a fume hood. A static pressure sensor typically maintains the face velocity to ensure a safe working environment. A baffled bypass that allows for a fixed amount of airflow to be exhausted is also a component of a gas cabinet.

A reduction in energy consumption of a gas cabinet can be achieved by eliminating the bypass airways and actively controlling the airflow via a damper based on a static pressure sensor. Once the door is opened on a gas cabinet, the exhaust flow would be increased to what would be required to provide the adequate face velocity. Similarly, when the door on the cabinet is closed the exhaust flow would be reduced to maintain a fixed volume of airflow corresponding to a static pressure setpoint via a volume damper.

Ion Implanters

Ion implanters typically consist of enclosures for gas delivery systems and mechanical equipment. Exhaust for the gas delivery systems is provided for safety. Exhaust is provided for mechanical equipment, such as a vacuum pump, and electrical devices for heat removal.

Vertical Furnace

A vertical furnace has multiple locations where exhaust is required. Typically, a vertical furnace consists of an oven chamber; gas distribution panel (gas “jungle”); liquid chemical distribution system; and a material handling chamber for automated wafer loading, processing, and unloading.

Fume Hoods

Typically, fume hoods use a variable volume and exhaust system, although low face velocity, constant volume hoods can offer the same benefits. A 25% reduction in average exhaust airflow (using a variable air volume system) results in about a 58% reduction in the fan power required. Significant additional energy savings are realized by a 25% reduction in the air that is conditioned. Savings from VAV fume hoods are heavily dependent on the fume hood operators understanding and respecting the benefits of closing the sash when the hood is not in use.

The Berkeley fume hood developed by LBNL also allows for a significant reduction in exhaust air. Tracer gas testing comparing the LBNL hood to a standard fume hood has shown that *improved* containment can be achieve with a 50% reduction in exhaust airflow.

Real World Experiences (Benchmarking Findings / Case Studies)

International Sematech evaluated exhaust flows for four semiconductor process tools – a gas cabinet, an ion implant tool, a wet bench, and a vertical furnace – at Hewlett Packard’s Corvallis, Oregon site.[1] The Sematech study focused on optimizing exhaust airflows for the semiconductor process tools while documenting via tracer gas testing no change or an improvement in worker safety. The four tools combined resulted in an exhaust airflow reduction of 28%, from 2,994 scfm to 2,146 scfm. At an estimated $4/cfm of exhaust, over $3,300 of savings could be realized per year. Optimization of exhaust for these types of tools at a typical semiconductor facility could amount to a savings of more than $33,000 per year.

The wet bench in the study had a width of 35 inches. The recommended exhaust flow based on manufacturers' standards would be 394–525 scfm. This particular bench was operating at 574 scfm and 111 fpm. During optimization, the wet bench exhaust airflow was reduced by 54%. The corresponding face velocity was 66 sfpm, which was well above the face velocity recommended by the ESH guidelines. Most importantly, the wet bench was able to maintain the concentration levels of the gases exhausted.

Testing on a gas cabinet showed that the cabinet was already safely operating at a closed access door flow rate 60% below the manufacturer's recommend airflow. The airflow and face velocity of the gas cabinet were only marginally above the limits required by the local codes, so additional savings were deemed not worth pursuing. Local code and site requirements for face velocity across an open access window do not prohibit turndown during the most common closed-window operating condition. The airflow quantity with the access window closed and the bypass damper closed was expected to be significantly less than when the bypass damper was opened, yet the position of the bypass damper had a negligible impact on the exhaust flow. It was discovered that air was being bypassed through gaps between the filter and door, and also in holes used to route sensor cables and purge lines. With these gaps properly sealed, an estimated 58% savings in exhaust flow could be achieved by reducing flow further in the normal, closed operating condition.

The ion implant tool in this test had three locations at where exhaust was required. The manufacturer recommended 500 cfm for each exhaust location. As a result of the tracer gas testing, the exhaust quantity for the gas cabinet was *increased* to improve the capture efficiency of the box in case of a gas leak. Overall, the exhaust airflows were reduced from 1,612 scfm to 1,232 scfm.

Exhaust reductions were made on a vertical furnace to the oven chamber, and gas distribution panel. The material handling chamber and liquid chemical distribution system were operating at the correct exhaust quantities; therefore, no changes were made.

Table 1. Summary of International Sematech Exhaust Optimization Study

Tool	Baseline Exhaust Flow scfm	Optimized Exhaust Flow scfm	Reduction %
Wet Bench	574	254	56
Gas Cabinet	237	*no change*	0
Ion Implant Tool	1,612	1,232	24
Right Cabinet	778	296	62
Left Cabinet	561	331	41
Gas Cabinet	273	605	(121)[1]
Vertical Furnace	629	474	25
Oven Chamber	459	347	24
Gas Distribution Chamber	29	15	48
Material Handling Chamber	13	*no change*	0
Chemical Distribution System	64	*no change*	0
Exhaust (other)	65	35	45

1. (xx) denotes an increase in exhaust flow.

Related Best Practices

Right Sizing
Air Change Rates
Low Pressure Drop

References

1) "Exhaust Optimization Studies on Four Process Tools at Hewlett Packard's Corvallis Site," Technology Transfer #01034098A-TR, International Sematech, 2001.

Resources

- Lee, Eng Lock; Rumsey, Peter; Sartor, Dale and Weale, John, "Laboratory Low-Pressure Drop Design," *ASHRAE* Journal, August 2002.