A Case Study in Evaluating Biofacility Exhaust Systems

Implementing Mixed-Flow Impeller Technology on MaRS

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In a coordinated effort to create jobs and increase tax revenues, industry, academia, and government are promoting high technology in a big way. Private organizations, municipalities, and educational/medical institutions in many industrialized and developing countries are pooling their resources to create massive research facilities for the bioprocessing industry. Some of these are built on university or medical campuses, whereas others are independent, not affiliated with a specific entity. Many are located in science/research parks. Funding is generally jointly arranged among participants. In most cases such facilities contain advanced research laboratories, including sophisticated biosafety level labs needed for work with highly sensitive materials used for life science research.

One such research facility is being completed now: the "MaRS" (Medical and Related Sciences) Centre in Toronto, Ontario, Canada (www.marsdd.com). MaRS is a new model for research and development facilities (see the "Facilitating" box). It was established five years ago to promote the growth of small research-related technology companies and enable successful commercialization of academic research. MaRS is the first facility of its kind in Canada and is modeled after similar facilities in the United States. One such facility is in Research Triangle Park, NC, and another is under development at the University of British Columbia in Vancouver. In the words of project spokesperson Roger Martin, dean at the Joseph L. Rotman School of Management at the University of Toronto, the essential model for such facilities is to "seamlessly integrate state-of-the-art research and development facilities, commercial business entities, and related support services within an overall interactive campus development."

Product Focus: Facility design, design of laboratory exhaust systems, biotechnology incubators

Process Focus: Laboratory-based R&D

Who Should Read: Business development, project managers, laboratory designers

Keywords: Biosafety-level, reentrainment, mixed-flow impellers, fume-hood exhaust systems, controlled environments

Level: Introduction

"Exhausting" Concerns: As with most facility-design projects, the willingness of designers to demonstrate understanding of the physical impact of their building complex on their community is paramount to their project's acceptance. This is especially true for facilities such as MaRS, for which success will be measured by its attraction of and integration with surrounding agencies and services. Realizing that, the MaRS designers chose to address the facility's environmental impact by exploring options for reducing laboratory exhaust emissions and related noise levels. Their choice: installation of a mixed-flow impeller system.

Photo 1: Mixed-flow impeller systems on the roof of the Toronto Medical DIscovery Tower
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Fume Hood Exhaust Criteria

Although designed for many functions, the scores of research laboratories at the MaRS facility share a common characteristic: Their laboratory workstation fume hoods require safe and efficient exhaust systems to prevent all possibility of exhaust reentrainment into the facility and adjacent buildings; to eliminate neighborhood odors; and to comply with applicable pollution abatement standards. Proper management of exhaust emissions, particularly in BSL (biosafety-level) laboratories, is critical because mismanagement is likely to cause serious implications (see the "Characteristics" box). Consequently, the consulting engineers responsible for exhaust management designs at MaRS (Smith and Andersen, in Toronto) specified mixed-flow impeller roof exhaust systems. In doing so, Smith and Anderson worked closely with Belnor Engineering (Toronto), which represents the manufacturer of these systems.

The exhaust technology for the workstation fume hoods eliminates reentrainment into the workplace, prevents neighborhood odors, and

CHARACTERISTICS OF MIXED FLOW IMPELLER TECHNOLOGY SYSTEMS

Mixed flow impeller systems operate by diluting contaminated exhaust air with unconditioned, outside ambient air through a bypass mixing plenum. The resultant diluted process air is accelerated through an optimized discharge nozzle/windband where nearly twice as much additional fresh air is entrained into the exhaust plume before leaving the fan assembly. Additional fresh air is entrained into the exhaust plume after it leaves the fan assembly through natural aspiration effect. The combination of added mass and high discharge velocity minimizes the risk of contaminated exhaust being reentrained into building fresh-air intakes, doors, windows, and other openings.

As an example, a mixed flow fan moving 80,000 cfm (cubic feet per minute) of combined building and bypass air at an exit velocity of 6300 cfm can send an exhaust air jet plume up to 120 feet high in a 10 mph crosswind. This extremely high velocity exceeds ANSI Z9.5 standards by more than twice the minimum recommendation of 3000 fpm. Because up to 170% of free outside air is induced into the exhaust airstream, a substantially greater airflow is possible for a given amount of exhaust — providing excellent dilution capabilities and greater effective stack heights over conventional centrifugal fans without additional horsepower.

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aids compliance with appropriate pollution abatement standards. It also meets applicable aesthetic codes by eliminating the need for tall exhaust stacks on the roof. That last point is important: Community ordinances often restrict total building height or the height of various appurtenances and accessories above rooflines. In addition, tall exhaust stacks can impart negative connotations in a community — as in, "Here's another neighborhood polluter!"

According to Danny Vistolli at Belnor, Toronto imposed building height restrictions on the MaRS complex mainly because existing buildings in the vicinity are in the heart of the city's downtown. "This was another consideration for use of low-profile mixed-flow impeller exhaust systems," Vistolli said.

SYSTEM INSTALLATION

The complex's mixed-flow impeller systems are mounted on the Toronto Medical Discovery Tower (TMDT) (Photo 1). Twelve low-profile fans are connected with four plenums (each plenum accommodates three individual fans) for a total air-moving capacity of 280,000 cfm (cubic feet per minute). To help assure the project's success, Belnor worked closely with the facility's owners, the contractor (Ellis Don Construction), and Smith and Andersen.

A Belnor spokesperson noted that his firm has quite successfully used such systems before in other projects. He pointed out the need to avoid having tall, unsightly exhaust stacks on a roof: "Tall exhaust stacks would have required significant roof reinforcements, guy wires, pitch pockets, and other expensive hardware and equipment that was not necessary with the mixed-flow technology approach," he commented. His firm is planning to install four more similar systems at the MaRS complex.

ADVANTAGES OF MIXED-FLOW IMPELLERS

Incorporating mixed-flow impeller technology into laboratory fume-hood exhaust systems offers many advantages for research facilities, pharmaceutical pilot plant processing areas, and other enclosed, controlled environment areas such as clean rooms and vivariums. Their low-profile design (typically about 15-feet high compared with ≥25 feet for a conventional exhaust stack) eliminates the need for expensive, maintenance-prone structural reinforcements on a roof (Photo 2). And because they are modularly constructed and substantially shorter than the tall stacks they replace, their simplicity significantly reduces installation time and cost.

The systems are designed to operate continuously for years with minimal maintenance. In comparison with centrifugal-type exhaust fans, the mixed-flow systems have no belts, elbows, flex connectors, or spring vibration isolators to maintain. Their direct-drive motors have bearing lifetimes of L_{10} 100,000 hours: This is a baseline for comparison of motor-bearing lifetimes and refers to a "sample" of 100 motors of which the bearings in ten motors (or 10%) would fail before 100,000 hours. Non-stall characteristics of the system's mixed flow wheel make it ideally suited for constant volume or variable air volume (VAV) applications, along with built-in redundancy and design flexibility. VAV capabilities are achieved by means of the bypass mixing plenum or by using variable frequency drives to provide optimum energy savings.

Expensive "penthouses" are not needed on the rooftop to accommodate maintenance personnel under adverse conditions, but are sometimes required for maintenance of centrifugal rooftop fans. Penthouses can be expensive: A reasonable construction estimate is $50,000. Workers inside a penthouse also can be exposed to noxious and/or toxic fumes while performing regularly scheduled maintenance.

Modular construction of mixed-flow impeller systems often permits retrofitting without interrupting workflow at workstation; the fans can be installed in as few as four hours, without cranes, helicopters, or other heavy construction equipment — another cause of considerable savings over the use of centrifugal fans.

VIBRATION ISSUES

Minimizing vibration is a key consideration with any roof exhaust system. Vibration can be broken down into two components: radial and axial. The radial vibration characteristics of mixed-flow impellers parallel a roofline, substantially lowering the axial component of vibration forced vertically onto the roof. On the other hand, in a conventional centrifugal exhaust system, the high radial component of vibration is forced directly down into the roof, necessitating expensive mounting hardware to protect the fan and roof structure.

CONTROLLING OPERATING COSTS

Mixed-flow impeller fans typically consume about 25% less energy than conventional centrifugal fans and offer shorter payback periods. Typical energy

The MaRS Mission

Located in what is known as the "Discovery District" in downtown Toronto, the MaRS complex encompasses 1.5 million square feet and has cost about $350 million (Canadian). "With its proximity to some of the leading minds and institutions in Toronto's bioscience cluster, MaRS is the perfect site for our drug research and development work in Canada," says Dr. Hunter Jackson of NPS Pharmaceuticals in Salt Lake City, UT. The complex has been constructed in two different phases: Phase One occupies 700,000 ft^2 in two towers, and Phase Two will occupy 600,000 ft^2, with occupancy scheduled by sometime in 2007.

The project was funded by the provincial and federal governments to MaRS, a nonprofit organization organized in 2000 and dedicated to promoting the growth of small research-related companies and the commercialization of academic research. Its development strategy adapts the conventional developer lease-back arrangement (until now most commonly associated with commercial office buildings). MaRS provides a base building designed to accept a full R&D program and related infrastructure, leases out the space, and expects tenants to fit out their spaces with the support services they require. The project is being developed for MaRS through a joint venture with ABE, AMEC (mechanical consultant), Black and McDonald (mechanical/electrical contractor), and Ellis Don (general contractor). ABE has a contract to design and build the fit-up portion on time and within a budget, with a five-year maintenance agreement.

An artist's rendition of a typical MaRS laboratory

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The complex offers turnkey laboratory and office spaces ready for occupation by private and independent organizations — as well as by some of the sponsoring (funding) organizations. Tenants thus far are Toronto Sick Kids research, occupying three floors; and Toronto University Health Network, which has leased the remaining 12 floors on a 30-year lease that includes wet labs, BSL-3 spaces, tissue-culture rooms, and vivariums.

According to Roger Martin, the dean at Joseph L. Rotman School of Management at the University of Toronto, "The global research mission is absolutely clear: innovation, competitiveness, and prosperity arise in the tight geographical conglomeration of highly skilled human capital. They don't cluster randomly, but are drawn by a fertile environment for their work. MaRS can be a critical element of the drive that makes Toronto a magnet for the future of medical and related sciences." This statement is reminiscent of many other statements about stimulating new business activities.

The facility received a boost recently from the Ontario government, which provided around $9 million (Canadian) to build a biotechnology incubator. The incubator will be essential to the lifeblood of fledging bioscience companies and will include wet labs, bioinformatics, an animal facility, nucleomagnetic resonance machines, and powerful information technology. According to John Cook, president and COO of MaRS, the facility — along with its conference center — is expected to become a "huge hub of activity, not just for Toronto, but for the whole country. For the first time, neighboring and research institutions beyond will collaborate to find a common purpose around the commercialization bottleneck," he said. "We have seen a Darwinian effect take place with many of the weaker knowledge-based companies that were in existence — this is a global phenomenon."

A Global Phenomenon

Biotechnology and bioscience research facilities such as the MaRS project are being constructed at a record-setting pace in nearly every US state. In fact, a June 2004 story in *USA Today* indicated that 40 states are using worker pension funds to finance startups in the biosciences market by investing in "private venture-capital funds" (**1**). Those states are attempting to entice biotech organizations of all kinds to establish facilities within their borders so they can take advantage of the revenue generated by these companies and their relatively highly paid work forces. The publication points out that many state governments are concerned that they might miss out on "an industry expected to create high-paying jobs making cancer drugs, medical devices, and disease-resistant crops." It stated that the number of life-science jobs is expected to grow "13% more than overall annual job growth through 2012, based on a study by Battelle Institute and other researchers."

As an example, the article noted that Florida's government will spend over $350 million over the next three years, mainly for a biotech research center near West Palm Beach; this represents approximately 5% (up from 4%) of its total $101 billion pension fund money. Other states with similar ventures include Oregon, Ohio, and Washington; Washington was profiled in a separate article in the *Puget Sound Business Journal,* which commented that the University of Washington is considered "one of the greatest research institutions in the world . . . ") (**2**). The story said that the National Institutes of Health (NIH) will spend $28 billion this year on the industry, its funding the "lifeblood" of biotech — both scientific and commercial.

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CODES AND STANDARDS

The following are some of the North American organizations with guidelines for pollution abatement.

American Conference of Governmental Industrial Hygienists (ACGIH), www.acgih.org/home.htm

American Industrial Hygiene Association (AIHA), www.aiha.org

American Institute of Architects (AIA), ww.aia.org

American National Standards Institute (ANSI), www.ansi.org

American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), www.ashrae.org

Centers for Disease Control and Prevention (CDC), www.cdc.gov

National Fire Prevention Association (NFPA), www.nfpa.org

National Institutes of Health (NIH), www.nih.gov

National Research Council (NRC), www.nationalacademies.org/nrc

Occupational Safety and Health Administration (OSHA), www.osha.gov

US Department of Health and Human Services (DHHS), www.hhs.gov

Canadian counterparts include

Health Canada (HC), www.hc-sc.gc.ca

Canadian Food Inspection Agency (CFIA), www.inspection.gc.ca/english/toce.shtml

reduction is $0.44 per cfm at $0.10/kilowatt-hour, providing an approximate two-year return on investment in many installations. These numbers do not include the substantial energy savings specific to conditioned makeup air facilities required at virtually all Level-3 and -4 BSL facilities. (Makeup air is that brought in from outside a facility to replace exhaust air. For cleanrooms, makeup air is often brought in at a higher rate than exhaust air is removed to provide positive pressure to push contaminants out of the room.)

ADVANTAGES OF AMBIENT HEAT RECOVERY

Many laboratories at the MaRS complex (particularly the BSL-2 and -3 labs) operate in rigidly controlled environments. In such "closed loop" facilities, mixed-flow impeller technology systems can provide unprecedented energy savings. Whenever any enclosed workspace requires 100% conditioned makeup air, savings in the thousands or even hundreds of thousands of dollars a year may be achieved by recovering ambient heat or cooled air from workstation fume hood exhaust before it is dispersed into the atmosphere **(1).**

Heat-recovery coils filled with a solution of glycol and water remove heating and cooling energy before workstation exhaust and ambient temperature room air are discharged into the atmosphere (Figure 1). This "conditioned" air is added to the makeup air brought into the building's intake ventilation system. For each 1 °F of heat added to makeup air by this method, energy costs are lowered by about 3%. For colder climates, annual heating energy cost reductions of 30% or more are not unusual (**2**). Similar savings, although not quite as dramatic, could be achieved for cooling in summer.

Photo 2: A mixed-flow impeller system on the roof of Georgia State University laboratories

Costs for 100% conditioned makeup air can be very high, in many laboratory environments exceeding $4/ft³ year. Because energy costs represent a substantial part of a laboratory's operating budget — and because these costs are on the rise — it makes sense to investigate the potential savings of mixed-flow impeller technology for both new construction and retrofitting.

HEPA FILTRATION

Many BSL laboratory containment facilities must be maintained with precise and repeatable airflow and pressure differentials. Exhaust systems at Level-3 and -4 laboratories typically incorporate high-efficiency particulate air (HEPA) filters. They are usually mounted in series and placed as closely as possible to the laboratory to minimize ductwork runs and prevent contamination from reaching the roof-mounted exhaust fans. Mixed-flow impeller systems permit regulated air flow in such facilities. The self-regulation introduction of outside air allows opening and closing of laboratory workstation fume hoods with uniform air flow.

POLLUTION-ABATEMENT STANDARDS

Managing laboratory workstation exhaust fume hoods at hyper-sensitive BSL laboratories calls for innovative approaches to assure workplace safety and compliance with appropriate pollution-abatement standards. These laboratories present unique problems with regard to pollution abatement issues in general and reentrainment issues in particular. As a result they are governed by rigid codes and standards (in some instances guidelines only) formulated by a number of North American organizations, as listed in the "Codes and Standards" box.

Roof exhaust reentrainment at BSL laboratories may be insidious at times — but often can be dangerous. Highly

Figure 1: A run-around-coil heat recovery flow diagram (WWW.NEUROGEN.COM)

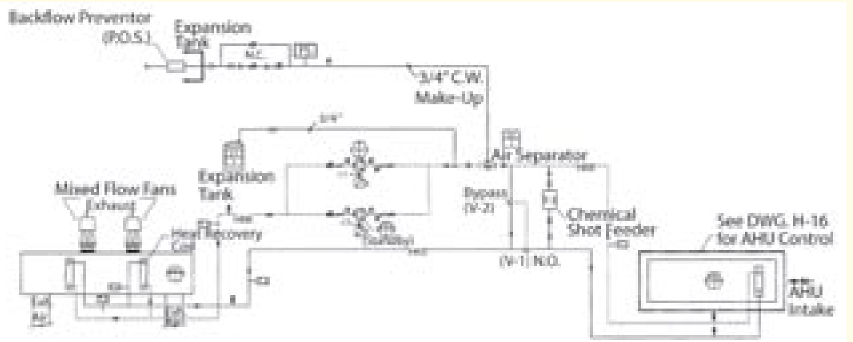

Photo 3: Three mixed-flow impeller systems with HEPA filters for BSL-3 and -4 labs

contagious microorganisms may be present in BSL-3 and -4 laboratories. BSL levels are graded from 1 to 4, with specifications, standards, and guidelines set by many of the organizations mentioned in the box. In most cases these organizations mandate guidelines that identify and specific agents and classes of laboratories required for their presence. The different levels are essentially determined by the degree of risk associated with exposure to various infectious agents within those laboratories. For example, Level 1 agents are usually not placed on the list but are assumed to include all fungal, viral, rickettsial, chlamydial, and parasitic agents that have not been included in higher biosafety levels. For the most part, these agents can be handled safely in a laboratory with no special equipment using techniques generally acceptable for nonpathogenic materials. Typical examples include certain influenza strains, infectious canine hepatitis viruses, and other "low-risk oncogenic viruses " **(1).**

With regard to serious and potentially lethal diseases that may be transmitted through inhalation, laboratories handling them must conform to BSL-3 standards, which are defined for bacterial agents, fungal agents, parasitic agents, and viral agents but also include more virulent and toxic forms than BSL-2 materials.

BSL-4 agents are considered "dangerous and exotic . . . and pose a high individual risk to aerosol transmitted laboratory infections which result in a life threatening disease, or related agents with unknown methods of transmission." According to the infectious agents list, these agents require the most stringent containment condition and are "extremely hazardous" to laboratory personnel or may even cause serious epidemic diseases. Not only are facilities and equipment critical in operation of BSL-4 laboratories, but the guidelines also call for "staff with a level of confidence greater than one would expect in a college department of microbiology, and who have had specific and thorough training and handling dangerous pathogens."

Additionally, BSL laboratories (mainly levels 3 and 4) must incorporate special design and engineering features to prevent harmful microorganisms and other dangerous emissions from being discharged into the environment. Those features could include specially shielded isolation rooms under negative pressure with sophisticated airflow, temperature, pressure, and humidity control, and monitoring systems; they would require 100% conditioned "makeup" air to prevent reuse of the ambient air within an enclosed facility.

NOISE REGULATIONS

The subject of roof-exhaust fan noise is arousing interest today because people are becoming more aware of unwanted noise from hundreds of sources in their daily lives. Many municipalities have laws that regulate noise beyond property lines. Centrifugal-type dedicated roof exhaust systems are generally noisier than mixed-flow impeller-type systems (based on a direct cfm comparison) because the mixed-flow fans are typically in the mid-to-upper 80% efficiency range compared with the mid-to-upper 50% efficiency range for centrifugal fans (based on total efficiency, TE). Because sound is a function of efficiency, mixed-flow technology fans are inherently quieter. In addition, noise generated by peripheral blade-tip speeds plays a role in performance sound levels, and mixed-flow impellers rotate at substantially slower speeds than centrifugal fans for the same amount of work.

Most buildings contain at least two different noise sources with regard to exhaust and ventilation fans: the supply fans that provide conditioned air (the HVAC system) and the laboratory workstation/process exhaust fans mounted on the roof. Each system is usually independent; and each demands a separate set of standards and criteria to minimize noise.

Exhaust acoustics are considered part of a building's aesthetics. Acoustical analysis of exhaust and ventilation systems early on, before installation, can help minimize the acoustic impact on surrounding areas. Obviously facility managers do not want the mechanical sound of exhaust fans to be heard within a building or at the property line whenever possible; and exhaust fan noise should not be detectable in adjacent buildings. To eliminate possible noise problems when building a new facility or refurbishing an existing one, owners and/or managers of many organizations look to independent noise study experts to help determine exhaust system operating noise levels, usually at the property line. Engineers and technicians gather noise information by positioning meters at various places around a facility. The goal is first to determine existing noise levels with the understanding that anything above that level will be noticed and could be perceived as a problem. Increasingly stringent local codes for permitted noise levels at property lines — especially at night — must also be considered.

Once preliminary studies are completed, defined noise limits are set for specific areas surrounding the building. The next step is usually to consult the roof-exhaust fan manufacturer to determine what levels of sound are generated by the proposed exhaust fans; if they exceed recommended noise levels, then options must be explored for abating fan noise and reducing discharge noise.

Noise Abatement Alternatives: If mixed-flow impeller fans are used, and noise is still an issue, accessories are available to reduce sound generated at a property line. They typically include acoustical screens and/or louvers, chevron screen walls, and nozzle silencers that combine sound absorption material with special airflow patterns for passive noise abatement.

ADVANCING BIOSCIENCE RESEARCH

The MaRS Centre represents a major step toward advancing bioscience and biotechnology research, and it represents a fountainhead of things to come in the Americas and throughout the world. The future will bring spectacular and beneficial medical and scientific breakthroughs — a direct result of the research-park concept. Design elements contributing to the successful integration of such research hubs within the communities that support them must account for — among other things — proper management of HVAC systems in general and laboratory exhaust emissions in particular. In light of increasingly stringent environmental and safety standards from regulatory agencies at all levels, companies must give serious consideration to this issue. A sensible and practical approach to planning a new laboratory facility or retrofitting an existing laboratory is to evaluate all exhaust alternatives. Use of mixed-flow impeller technology for sensitive installations has grown significantly over the past few decades with good reason; it appears that it will continue to be a popular and cost-effective approach for eliminating problems commonly associated with exhausting sensitive research laboratories.

References

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