Hazardous Exhaust Ductwork Material Selection

A Reference Document Prepared by the I^{2}SL Arizona Chapter

Introduction

Though there is a significant amount of information available relative to the design and operational parameters of hazardous exhaust and fume hoods in laboratories, there is very little direction provided related to the requirements associated with the construction of the ductwork connected to them. Recognizing this deficiency in guidance, and the need for more substantive direction in the selection of hazardous exhaust ductwork material on science and technology related projects, members of the Arizona Chapter of I2SL gathered to collectively investigate and determine the most appropriate products to be used in a variety of applications. This narrative summarizes their findings, with the objective of aiding design professionals, facility owners, and property managers in the selection of the best duct material to use in the laboratory environment under a given situation.

To accomplish this lofty assignment, the investigative team utilized existing planning and design standards from various reputable institutions and organizations across the country as a reference in their discussions and deliberations. In addition, they thoroughly reviewed and analyzed the applicable codes, and guidelines that apply to hazardous exhaust ductwork material in compliance with the regulations that are to be followed in the industry. A brief description of these codes, standards, and guidelines is provided in the section to follow. The recommendations contained herein, are based upon extensive experience with, and a working knowledge of, the types of facilities that incorporate hazardous material use in their research and diagnostic programs.

Applicable Codes, Standards, & Guidelines

The authority having jurisdiction over the location where the facility resides will determine the applicable codes and standards that will apply to hazardous exhaust systems and their construction. In most regions within the United States, this typically comprises at a minimum, approved editions of the International Building Code (IBC), International Mechanical Code (IMC), and relevant editions of the National Fire Protection Association (NFPA) standards. In the absence of direction from the authorities having jurisdiction, it falls to the design professionals to select the codes and standards relevant to the hazardous exhaust systems utilized within the facility.

Section 510 of the International Mechanical Code describes the requirements associated with Hazardous Exhaust Systems and should be reviewed in detail to arrive at an appropriate ductwork design solution. This section of the code not only defines a laboratory environment and the systems it uses to extract harmful substances, but it provides exceptions to the rule, permitting different treatments under certain circumstances including manifolding of laboratory exhaust, when appropriate. Other sections, such as 10.7 addresses an exception for lab ductwork from requirements of automatic suppression.

Per this section hazardous exhaust systems are systems designed to capture and control hazardous emissions generated from product handling and processes and convey those emissions to the outdoors. Hazardous emissions include flammable vapors, gases, fumes, mists or dusts, and volatile or airborne materials posing a health-hazard, such as toxic or corrosive materials. NFPA 704 describes the health-hazard rating of different materials and should be considered in the decision-making process. Sections 510.2 includes insight into the conditions under which a hazardous exhaust system is required, including concentration levels, and health-hazard ratings. Section 510.5 details exceptions that permit manifolding ducts into a common shaft.

The following provides a brief synopsis of the codes, standards, and guidelines typically referenced in the design, construction, and operation of hazardous exhaust systems and fume hoods. Codes contain a comprehensive set of requirements for a project. Codes also include references to standards which are more specific in their scope. Where codes note compliance with standards, these standards then become requirements for the project. Guidelines are developed over time based on accepted practice and are not considered requirements for a project. In the absence of specific direction from codes and standards, however, guidelines help inform system design parameters.

Unfortunately, very little direction is provided within the codes, standards, and guidelines published relative to the selection of hazardous exhaust ductwork. That decision is left to building owners, the design professionals they commission, and other individuals that know the specifics of the research conducted and hazardous materials used in the exhaust system and other areas of the facility. There is a difference between Building Codes, Design Standards, and Guidelines. Building Codes offer no option to deviate from their implementation, whereas Design Standards, and Guidelines are provided to establish an acceptable direction, or recommended approach to a solution. In essence, building codes inform the builder on what needs to be done, whereas standards and guidelines inform you on how to do build it. The below lists indicate codes, standards, and guidelines that are commonly encountered. Consult your local authority having jurisdiction to determine applicable regulations for a specific application.

Codes:

- **International Building Code (IBC).** This code is prepared by the International Code Council, Inc. Note that the code does not address duct materials but notes that when passing through fire-rated barriers, ductwork without dampers (as prohibited in hazardous exhaust ducts by the IMC) shall be steel, ferrous, or copper without the use of dissimilar metals. The use of alternate materials requires either a fire-rated enclosure or approved duct wrap meeting the required fire rating. The code also speaks to the potential need for approved automatic fire suppression systems in ducts.

- **International Mechanical Code (IMC).** This code is prepared by the International Code Council, Inc. This code addresses the different aspects of mechanical systems design and construction. Relative to hazardous exhaust systems duct construction, the code notes either: (1) G90 galvanized sheet steel with minimum nominal thickness based on size and materials exhausted; (2) non-metallic materials that exhibit a flame spread index of 25 or less and a smoke-developed index of 50 or less; or (3) alternate materials where the products being exhausted are detrimental to the duct materials.

Standards:

- **National Fire Protection Association (NFPA) Standards 45.** This standard was prepared by the National Fire Protection Association. Like the IBC, this standard speaks to the protection of hazardous exhaust ducts passing through rated fire barriers and the potential need for approved automatic fire suppression systems. This standard, however, speaks more specifically to the fume hood construction, system configuration, manifolding of systems and control zones, specialty hoods and systems, as well as the inspection, testing, maintenance of these systems.

- **National Fire Protection Association (NFPA) Standards 91.** This standard was prepared by the National Fire Protection Association. This standard specifically speaks to the systems conveying hazardous exhausts and requirements relative to their installation. This standard does not address duct materials (responsibility of the design engineer), but does speak to how these systems are installed, clearances and protection from other systems, ability to support and drain if provided with approved automatic fire suppression systems, and what to do with the drains afterwards.

- **OSHA Part 1910.1450.** OSHA stands for Occupational Safety and Health Administration. The agency regulations regarding fume hood operation are listed in the Code of Federal Regulations Volume 29 Part 1910.1450. This standard addresses several aspects of laboratory design and operation. Relative to fume hoods it is primarily concerned with airflow at the face of the hood, monitoring, maintenance, and exhaust.

- **SMACNA.** Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) is an international trade association with more than 4,500 contributing contractor members. They develop standards and manuals that address all facets of the sheet metal industry, from duct construction and installation to indoor air quality and air pollution control, from energy recovery to roofing. They also have standards for thermoplastic (PVC) and thermoset fiber-reinforced plastic (FRP) duct construction.

- **ANSI/ASHRAE 110.** Method of Testing Performance of Laboratory Fume Hoods. This standard is published by the American National Standards Institute and the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. The standard does not speak to hazardous exhaust duct construction, but instead focuses primarily on the methods of testing laboratory fume hoods and evaluating installed performance and containment.

- **ANSI/AIHA Z9.5.** Titled “The American National Standard for Laboratory Ventilation” this standard is published by ANSI and the American Industrial Hygiene Association (AIHA). This standard covers a variety of laboratory ventilation issues from fume hood and enclosure specific design to general laboratory ventilation and containment. The standard does not speak to exhaust system materials, and instead refers to the ACGIH’s Industrial Ventilation, ASHRAE Handbooks, and NFPA 45.

- **SEFA 1.** SEFA refers to the Scientific Equipment & Furniture Association Recommended Practices. Its publication “SEFA 1 Laboratory Fume Hoods” covers design requirements specific of fume hoods and their components, face velocities and testing. The standard does not speak to the associated hazardous exhaust duct materials.

Guidelines:

- **ASHRAE Laboratory Design Guide**. Published by American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc, this manual provides a comprehensive reference for the planning, design, and operation of laboratories. It gives designer, owners, and system operators the design and control strategies needed to reduce a lab's energy footprint, while ensuring safety, comfort and indoor air quality, and protecting the integrity of laboratory experiments.

- **NIH Design Guidelines.** The National Institutes of Health provide design and construction guidance and direction to institutions and organizations that are funded by the NIH, which include many institutes of higher learning. Detailed narratives are provided that identify the requirements of design and construction of HVAC systems including fume hoods.

- **ACGIH Industrial Ventilation: A Manual for Recommended Practice.** American Conference of Governmental Industrial Hygienists (ACGIH) publishes a document that is used by engineers and industrial hygienists to design and evaluate industrial ventilation systems.

- **ASHRAE Handbook – HVAC Applications.** This guideline is published by American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. The guideline speaks to the design and effectiveness of a variety of hood types, and to the associated hazardous exhaust duct configuration, but does not address exhaust duct materials.

Characteristics of Hazardous Exhaust Effluent

Perhaps the most critical driver in the selection of hazardous exhaust ductwork material is the characteristics of the effluent that will be extracted through the system. The effluent can be subdivided into two separate classifications, organic and inorganic, and is delivered through the ductwork as vapors, fumes, chemical gases, particulate matter, or smoke. The qualitative nature of the effluent is categorized as an acid, a base, a solvent, or an oil. Once within in the hazardous exhaust system, the effluent is then exposed to exhaust valves, dampers, connections, fan blades and connectors, fan motors (depending on configuration), equipment housings, sensors, and other electronic components. Depending on the materials and the concentration of the effluent, this may lead to degradation and ultimate failure of the system or components.

The failure of hazardous exhaust system components occurs through three methods or combination thereof - *corrosion, dissolution or melting*. *Corrosion* destroys metal by causing a chemical or electrochemical action. *Dissolution* negatively effects surfaces by attacking plastics and coatings. *Melting* dissolves plastics and coating through excessive and prolonged temperatures. A failure of plastics or coatings through dissolution or melting then exposes the base metal underneath, allowing for corrosion of the base metal to occur. Of the three mechanisms identified, corrosion is the most common. Minimizing its impact is the key to the longevity of the system.

The corrosive or caustic nature of the hazardous effluent must be identified, and its effect on the material surface understood. The impact the effluent will have on the hazardous exhaust system fluctuates considerably based upon a variety of different factors. The most common of these factors include the following:

1. The caustic nature of the effluent and the average operational temperature
2. The concentration and quantity of chemicals exhausted through the system.
3. The ambient temperature and relative humidity of both the space from which the chemicals are extracted, and the ceiling cavity into which the ductwork passes.
4. Reaction of the effluent to condensation and other moisture sources
5. The length and configuration of the exhaust runs. Round ducts are preferred as they have a more uniform velocity (effluent less likely to settle), can withstand higher static pressures, and are easier to seal. Ducts from fume hoods, for example, should slope back to the fume hood to allow any effluent that condenses out to drain back to the hood.
6. The interaction of effluent from different sources in a common system and their velocities.
7. The quality of the construction of the ductwork, including welds, joints, fabrication, and support elements. Given the potentially aggressive nature of the effluent, any defects in system construction may allow of effluent to collect or become a future point of failure.

In addition to the corrosive or caustic nature of the hazardous effluent being exhausted, other characteristics of the effluent that may influence the decision to select a particular hazardous exhaust duct material type are:

1. The cost to both to procure and to install the product.
2. The expected lifespan of the exhaust system and the extent that modifications are expected.
3. Service, maintenance, and monitoring.
4. The availability of the product in the region
5. The sustainability and energy footprint of the material.
6. Compatibility of the materials with other building systems.
7. Availability of experienced contractors and sub-contractors within the area responsible for performing the installation of the hazardous exhaust system.

Airflow and Velocity

Second in importance is the volume of exhaust and its associated velocity used to carry the effluent through the hazardous exhaust system. Lower velocities do not move the potentially corrosive effluent as quickly through the system, thus providing more opportunity for effluent settling. This becomes more pronounced in problematic pathway areas such as horizontal runs, directional changes, or transitions. Whether the exhaust duct is round or rectangular also has an impact as the round ductwork velocity profile is more uniform and does not have potential eddies or recirculation present in rectangular duct. As duct velocities increase, so do the frictional losses and associated fan energy. A 40% increase in duct velocity will double the pressure drop and increase the fan energy associated with that section by nearly three times. The best approach balances both duct velocity and fan power.

As a rule of thumb, duct velocities should be no lower than 500 feet per minute (fpm) to ensure proper effluent movement. An upper limit of duct velocities in main system ducts is around 2,500 fpm based upon considerations for overall static pressure, energy, and sound.

Most of the focus on duct velocities is for the design condition, but for much of the life of the hazardous exhaust system is spent at a much lower condition. For example, a range of 500 fpm to 2,500 fpm results in a turndown ratio of up to 5:1 on a variable air volume system. A system sized in this manner can operate down to 20% of its design airflow while still maintaining the minimum 500 FPM velocity. While most fume hoods cannot turn down this much, the concept is important to note. Also be aware that the ability to maintain minimum velocities is not critical for general room exhaust ductwork that do not carry effluent, but then comes into play for exhaust mains connected to fume hoods that will carry effluent.

It is important to note that this attention to duct velocities is not limited to the design maximum flow conditions. Most modern designs implement Variable Air Volume (VAV) control schemes. The system designer must consider duct velocities throughout the system's airflow range and strike a balance between high velocities (frictional/energy losses) at maximum flow and low velocities at minimum flow. If we consider the above rule of thumb velocity range (500-2,500 fpm), this affords up to a 5:1 turndown ratio. Experience indicates that this is usually adequate for VAV fume hoods and other typical end use devices.

To reiterate, the above velocity range serves as a rule of thumb. Appropriate duct sizing and velocity largely depends upon the nature of the effluent, duct type (round or rectangular), and its potential for contaminant deposition. Duct velocities and configurations should be designed to prevent the settling and accumulation of particulates and dry aerosols. (Refer to the table below for flow rates of specific effluents.)

TABLE 1 - Industry Accepted Duct Velocities

Nature of Contaminate		Product Examples	Velocity Range - fpm
1	Non-condensable vapors, gases (2)	All forms	500 – 2,000
2	Fumes/Smoke & sub-micron particles (3)	Zinc and Aluminum Oxide fumes	500 – 2,000
3	Condensable vapors & sticky particles (3)	All forms	1,000 – 2,000
4	Very fine light dust (3)(4)	Cotton lint, wood flour, Litho-powder	2,000 – 2,500
5	Dry dust & powders (3)(4)	Cotton dust	2,500 – 3,000
6	Average industrial dust (3)(4)	Shaving's sawdust, grinding dust	3,000 – 4,000
7	Heavy dusts (3)(4)	Metal turnings, lead	4,000 – 4,500
8	Heavy moist dust (3)(4)	Buffing lint (sticky), Lead dust w/ small chips	4,500 or more

Table 1 Notes:

1. A lower limit of 500 FPM provides the ability to accurately measure flow in the dust using commonly applied techniques including Pitot tube travers. Lower duct velocities are routinely observed in VAV exhaust system branch ducts serving VAV fume hoods and do not affect the containment ability of the hood.
2. Fume (generated from heated solids) and smoke are typically composed of submicron sized particles. Deposition rates of submicron particles in ductwork are typically low as discussed in the text.
3. Provisions for drains, access points for inspection, cleanout and/or wash down must be provided if significant quantities can condense or deposit in the duct system.
4. Contaminants of this nature are not usually experienced in a laboratory and should be controlled prior to entering the ductwork system. Particles larger than several microns should be controlled at point of emission.

Industrial Ventilation, Engineering Principles (R. J. Heinsohn, 1991)

Ductwork Material

There are a variety of different materials typically used in the construction of fume hood exhaust ductwork with stainless steel and G90 galvanized metal being most common. Per ANSI Z9.5 a thorough analysis of the chemicals to be exhausted through the system must be completed with the materials selected based on its resistance to the primary corrosive element present. This is often not easy to assess during the initial planning, design and construction of the facility given the fact that many systems may be expected to function for as much as 20 years or longer, with scientific procedures and research objectives changing on a regular basis. The possibility of a change of both chemical type and quantity is very likely, if not guaranteed. For this reason, many organizations and institutions choose to err on the side of caution and require the most corrosive resistant system possible to be installed. However, knowing and understanding the qualities of the material to be used will help in determining the best product to use under given circumstances, with the possibility of combining materials resulting in a more cost-effective solution.

In addition to the requirements identified in ANSI Z9.5, the materials used in each exhaust system must be consistent, compatible with one another, and in accordance with the International Mechanical Code (IMC) and the latest version of ACGIH's Industrial Ventilation - A Manual of Recommended Practice. Laboratory planners and HVAC engineers should work closely with safety officers and scientists to discuss the options prior to arriving at a consensus on the materials selected and used.

As indicated in a previous section, another key component of ductwork material that must be factored into the equation when selecting material is the combustibility of the product used. Per NFPA 45, ductwork from chemical fume hoods and from local exhaust systems are to be constructed exclusively of noncombustible materials, with very few exceptions. However, non-metallic exceptions require that the flame spread index of the material be 25 or less and the smoke generation be 50 or less when tested in accordance with ASTM E84 or ANSI/UL 723.

Below is a list of the typical materials used in fume hood exhaust ductwork with the characteristics of each provided.

G90 Galvanized steel. Subject to acid and alkali attack, particularly at cut edges and under wet conditions; cannot be field welded with-out destroying galvanization; easily formed; low in cost.

Good when provided with thicker wall gages for applications on hazardous exhaust system mains with a minimal amount of fume hoods and less aggressive chemical use.

Stainless steel. A good choice for working with solvents. However, it is subject to acid and chloride compound attack depending on nickel and chromium content of the alloy; relatively high in cost. The most common stainless-steel alloys used for laboratory exhaust systems are 304L and 316L. Cost increases with increasing chromium and nickel content.

Asphaltum-coated steel. Resistant to acids; subject to solvent and oil attack; high flame and smoke rating; base metal vulnerable when exposed by coating imperfections and cut edges; cannot be field welded without destroying coating; moderate cost.

Epoxy-coated steel. Epoxy phenolic resin coatings on mild black steel can be selected for characteristics and applications; they have been successfully applied for both specific and general use, but no one compound is inert or resistive to all effluents. Requires sand blasting to prepare the surface for a shop-applied coating, which should be specified as pinhole free, and field touch-up of coating imperfections or damage caused by shipment and installation; cannot be field welded without destroying coating; cost is moderate.

Plastic-coated galvanized steel. Subject to corrosion at cut edges; cannot be field welded; easily formed; moderate in cost.

Fiberglass. When additional glaze coats are used, this is particularly good for acid applications, including hydrofluoric acid. May require special fire-suppression provisions along with associated pitching of ducts and drains. Special attention to hanger types and spacing is needed to prevent damage as ducts could contain water.

Plastic materials. Type 1 PVC has a particular resistance to specific corrosive effluents. It can be rigid or flexible; limitations include physical strength, flame spread, and smoke developed rating, heat distortion, and high cost of fabrication. Special attention to hanger types and spacing is needed to prevent damage. CPVC has a similar performance but better flame spread & smoke development performance.

Borosilicate glass. For specialized systems with high exposure to certain chemicals such as chlorine.

TABLE 2 - Material Comparison Chart

Duct Material	Cost Range	Corrosion Resistance	Flame spread/ Smoke development
Spiral galvanized metal	$$	Good	Low/Low
Stainless steel	$$$$	Excellent	Low/Low
Carbon steel w/ acid resistant coating	$$	Good	Moderate/Moderate
Fiberglass	$$$	Good	High/High
Polyvinyl chloride (PVC)	$	Good	Low/High
Chlorinated Polyvinyl chloride (CPVC)	$$	Excellent	Low/High
Polyvinylidene chloride (PVDC)	$$	Good	Low/High
Thermoplastic	$$$	Good	Low/High
Glass	$$$$$	Excellent	Low/Low

Ductwork Transitions

The weakest point along the route of a hazardous exhaust system are the transitions points. This would include changes in the direction of the route, and/or transitions from one material to another. More often than not, the failure in the ductwork occurs at these locations. This is due to one, or a combination of the following issues- potential airflow fluctuations, disharmony in material composition, failure to consider galvanic nature of metal, and poor assembly or construction. To sufficiently address these issues, each point of connection should be reviewed thoroughly, with the goal of maximizing the longevity of the joint. Where two dissimilar metals come together, a chemical and thermal resistant dielectric gasket must be installed between the two elements at the flange to prevent any galvanic corrosion or expansion and contraction action to occur. Visual inspection of each connection point must be completed by an expert in ductwork joinery to ensure proper assembly.

Conclusion

In the process of selecting the most appropriate ductwork material used to exhaust hazardous material from a laboratory through fume hoods and other chemical extraction devices, several factors must be considered. Included in these are applicable codes, standards, and guidelines. A thorough analysis of these directives must be completed prior to arriving at the most suitable material. In addition, an understanding of the effluent to be removed must be identified along with the quantities and hazardous characteristics. that will be extracted through the system. The design and construction of the building housing the system should be known and considered. These and other relevant factors are best evaluated for the best solution by a team of experts familiar with the nuances of harmful material exhaust. This would include architects, engineering, lab users, safety officers, and owner representatives.