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NATIONAL FIRE PROTECTION ASSOCIATION

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See Official NFPA Definitions at the back of this pamphlet.

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Standard for
Industrial Furnaces Using Vacuum as an Atmosphere

NFPA 86D–1978

1978 Edition of NFPA 86D

This document was prepared by the Subcommittee on Class D Furnaces, was approved by the Committee on Ovens and Furnaces, and this present edition was adopted by the Association on November 14, 1978, at its Fall Meeting in Montreal, Quebec, Canada. Revisions are essentially editorial. It was released by the Standards Council for publication on December 4, 1978.

Changes other than editorial are denoted by a vertical line in the margin of the pages in which they appear.

Origin and Development of NFPA 86D

With the increased use of vacuum furnaces in industry, a Sectional Committee under the Committee on Ovens and Furnaces was organized in 1974 to prepare a standard covering these Class D Furnaces. The first edition was adopted by the Association at the 1976 NFPA Fall Meeting.

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This list represents the membership at the time the Committee was balloted on the text of this edition. Since that time, changes in the membership may have occurred.

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Standard for

Industrial Furnaces Using Vacuum as an Atmosphere

NFPA 86D–1978

NOTICE

An asterisk (*) following the number or letter designating a paragraph indicates explanatory material on that paragraph in Appendix A.

Foreword

The standard is for ovens and furnaces as set forth under classification as follows:

Class A ovens or furnaces are those operating at approximately atmospheric pressures and temperatures below 1400°F (760°C) where there is an explosion hazard from either, or a combination of, the fuel in use; or flammable volatiles from material in the oven or catalytic combustion system; i.e., flammable volatiles from paints and other finishing processes such as dipped or sprayed material, impregnated material, coated fabrics, etc.

Class B ovens or furnaces are those operating at or above atmospheric pressure and temperatures exceeding approximately 1400°F (760°C).

Class C furnaces are those in which there is an explosion hazard due to a flammable special atmosphere being used for treatment of material in process. This type of furnace may use any type of heating system and includes the atmosphere generator.

Class D furnaces are vacuum furnaces which operate at temperatures above ambient to over 5000°F (2760°C) and at pressures normally below atmosphere, using any type of heating system. These furnaces may include the use of special processing atmospheres.

Chapter 1 Introduction

1-1 Scope. This standard is for ovens and furnaces operating from ambient temperatures to over 5000°F (2760°C) and at pressures normally below atmospheric to 10^{-8} Torr (1.33×10^{-6} Pa).

NOTE: This edition applies to cold-wall vacuum furnaces only.

1-2* Types of Furnaces. The requirements for vacuum furnaces determine the type of furnace walls, size of furnace, the special atmospheres required, or the reduction from normal atmosphere down to special vacuum of 10^{-8} Torr (1.33×10^{-6} Pa).

Vacuum furnaces generally are described as either cold-wall furnaces, hot-wall furnaces or furnaces used for casting or melting of metal at high temperatures up to 5000°F (2760°C). There may be other special types.

1-2.1* The cold-wall furnace types are further described as being an electric furnace which is heated by electrical induction, electrical resistance or electron beam.

NOTE: This standard does not cover fuel-fired cold-wall furnaces.

1-2.2* The hot-wall furnace may be either gas-fired or an electrically heated furnace.

1-2.3 Special furnaces are available for casting and melting of steel, iron, copper and other metals. These furnaces are heated using either induction heating, electron beam, or electric arc.

NOTE: Reference should be made to these various types of furnaces by taking special note of Table A-1-2, Vacuum Furnace Protection. This table describes the heating system requirement and notes the principal items supplied as a part of the furnace which includes the (A) Vacuum System, (B) Heating System, (C) Cooling System, (D) Process Atmosphere Cycle, (E) Material Handling, (F) Instrument Control, (G) Hazards of Heating Systems and (H) Personnel Safety Hazards. Each item is included in the table for the 10 principal furnace types.

1-3 It is a general practice for the vacuum vessel to be a type of pressure vessel and be designed in accordance with the latest published requirements of Section 8 of the *ASME Boiler and Pressure Vessel Code.* This vessel should be built to exact design specifications and should permit operating at high vacuum atmospheres. *(See 2-6.13.)*

1-4 Vacuum furnaces using either an induction, a resistance, an electron beam, or electric arc heating system will include an electric power supply with a high demand current. Safety consideration should be given for the high voltage supply used for either an electron beam or the electric arc furnace unit.

1-5 All cold-wall vacuum furnaces require a specifically designed cooling system for maintaining the vacuum furnace vessel at proper temperatures. These cooling systems are critical as the furnace vessel walls must be maintained at safe temperatures when the furnace operates at maximum temperatures.

The furnace cooling system may include, in addition to the vessel cooling system, one or more methods for cooling material in process. The systems may include gas quenching, oil quenching, or water quenching. Internal and/or external heat exchangers may be used and generally require supplementary cooling. Special atmospheres may be used during the furnace heat treatment process. This special atmosphere may be hydrogen, nitrogen, methane, argon, helium or a combination of several of these gases.

1-6 **Definitions** *(Reference—American Vacuum Society)*. For the purpose of this standard, the following definitions shall apply:

Absolute Pressure. A term used in engineering literature to indicate pressure above the absolute zero value corresponding to empty space or the absolute zero of temperature as distinguished from gage pressure.

NOTE: In vacuum technology, pressure always corresponds to absolute pressure not gage pressure, and therefore the term absolute pressure is not required.

Absorption. The binding of gas in the interior of a solid (or liquid).

Adsorbate. The gas removed from the gas phase by adsorption.

Adsorbent. The material which takes up the gas by adsorption.

Adsorption. Condensing of gas on the surface of a solid.

Air-Inlet Valve. A valve used for letting atmospheric air into a vacuum system. (Also called a vacuum breaker.)

Atmospheric Pressure. The pressure of the atmosphere at a specified place and time.

Batch Process Furnace. A furnace into which the work is introduced all at one time.

Booster Pump. A vapor pump or a specially designed mechanical pump used between a vapor pump and a fore pump to increase the maximum gas throughput which can be handled.

NOTE: The limiting or breaking forepressure of the booster at this maximum throughput must be appreciably greater than that of the vapor pump which it backs.

Centrifugal Pump. A pump without a discharge valve which moves the gas from the axis to the circumference by the propelling action of a rapidly rotating member provided with ducts, blades, or vanes.

Cold Trap. A vessel designed to hold a coolant, or cooled by coils in which a coolant circulates, inserted into a vacuum system so as to condense on its inner surface vapors present in the system.

Compound Mechanical Pump. A mechanical pump having two or more stages in series.

Condensation Rate. The number of molecules which condense on a surface per square centimeter per second.

Continuous Process Furnace. A furnace into which the work charge is more or less continuously introduced.

Diffusion Pump. A vapor pump having boiler pressures less than a few Torr and capable of pumping gas at intake pressures not normally exceeding about 20 milliTorr (2.7 Pa) and discharge pressures (forepressures) not normally exceeding about 500 milliTorr (66.7 Pa).

NOTE: The pumping action of each vapor jet occurs by the diffusion of gas molecules through the low-density scattered vapor into the denser forward moving core of a freely expanding vapor jet.

Displacement. The geometric volume swept out per unit time by the working mechanism of mechanical pumps at normal frequency.

Duplex Mechanical Pump. A mechanical pump having two single stage units in parallel operated by the same drive.

Fore Pump. The pump which produces the necessary fore vacuum for a pump which is incapable of discharging gases at atmospheric pressure. (Sometimes called the backing pump.)

Free Air Displacement. The volume of air passed per unit time through a mechanical pump when the pressure on the intake and exhaust sides is equal to atmospheric pressure. (Also called free air capacity.)

Gas Ballast. The venting of the compression chamber of a mechanical pump to the atmosphere to prevent condensation of condensable vapors within the pump. (Also called vented exhaust.)

Gas Ballast Pump. A mechanical pump (usually of the rotary type) equipped with an inlet and valve through which a suitable quantity of atmospheric air or "dry" gas can be admitted into the compression chamber so as to prevent condensation of vapors within the chamber by maintaining the partial pressure of the vapors below the saturation value. (Sometimes called a vented-exhaust mechanical pump.)

High Vacuum. A pressure less than some upper limit, such as 1 mm Hg or 1 μ Hg.

Holding Pump. A fore pump used to hold a vapor pump at efficient operating conditions while a roughing pump reduces the system pressure to a point at which the valve between the vapor pump and the system can be opened without stopping the flow of vapor from the nozzles.

Implosion. The rapid inward collapsing of the walls of a vacuum system or device as the result of failure of the walls to sustain the atmospheric pressure. Usually followed by an outward scattering of the pieces with possible danger to nearby equipment and personnel.

Inleakage Rate. The combined leak rate (in pressure-volume units per unit time) from all existing leaks in a specified evacuated vessel, sometimes expressed in terms of the rate of rise of pressure in the isolated vessel.

Inlet Pressure. The "total static pressure" measured in a standard testing chamber by a vacuum gage located near the inlet port.

Leak. A hole, or porosity, in the wall of an enclosure capable of passing gas from one side of the wall to the other under action of a pressure or concentration differential existing across the wall.

Leak Detector. A device for detecting and locating leaks, and indicating the magnitude thereof.

Leak Rate. The quantity of gas in pressure-volume units at room temperature flowing into the system or through the pump from an external source in unit time.

NOTE: Recommended unit is Torr liter per second at 20°C. (Also expressed in micron-liter per second, or micron cubic feet per minute, or cc-atmos/sec at 25°C.)

Low Vacuum. The condition in a gas-filled space at pressures less than 760 Torr (101 kPa) and greater than some lower limit.

Manometer. An instrument for measuring pressure of gases and vapors whether above or below atmospheric pressure.

McLeod Gage. A liquid level vacuum gage in which a known volume of the gas, at the pressure to be measured, is compressed by the movement of a liquid column to a much smaller known volume, at which the resulting higher pressure is measured.

NOTE: Particular designs are named after the inventors of various trade names.

Mean Free Path (of any particle). The average distance that a particle travels between successive collisions with the other particles of an ensemble.

Mechanical Pump. A pump which moves the gas by the cyclic motion of a system of mechanical parts such as piston, eccentric rotors, vanes, valves, etc.

Micron of Mercury. A unit of pressure equal to 1/1000th of one millimeter of mercury pressure. Abbreviated as μ of Hg or μ Hg.

Millimeter of Mercury. A unit of pressure corresponding to a column of mercury exactly one millimeter high at 0°C under standard acceleration of gravity of 980.665 cm/sec^2.

MilliTorr. A proposed new unit of pressure equal to 10^{-3} Torr (1.3×10^{-1} Pa).

Oil Separator. An oil reservoir with baffles to reduce the loss of oil by droplets in the exhaust.

Operators. The individuals responsible for the start-up, operation, shutdown, and emergency handling of the specific installation or furnace, and the associated equipment.

Outgassing. The spontaneous evolution of gas from a material in a vacuum.

Partial Pressure. The pressure of a designated component of a gaseous mixture.

Pump-Down Factor. The product of the time to pump down to a given pressure and the displacement (for a service factor of one) divided by the volume of the system ($F = t\ D/V$).

Pump Fluid. The operating fluid used in vapor pumps or in liquid sealed mechanical pumps. (Sometimes called working medium, working fluid, or pump oil.)

Rate of Rise. The time rate of pressure increase at a given time in a vacuum system which is suddenly isolated from the pump by a valve.

NOTE: The volume and temperature of the system are held constant during the rate of rise measurement.

Reciprocating Pump. A pump which moves the gas by means of a system or reciprocating pistons and valves.

Roots Blower Pump. A rotary blower pump having a pair of two-lobe inter-engaging impellers of special design.

Rotary Blower Pump. A pump without a discharge valve which moves the gas by the propelling action of one or more rapidly rotating members provided with lobes, blades, or vanes. (Sometimes called a mechanical booster pump when used in series with a mechanical fore pump.)

NOTE: Rotary blowers are sometimes classified as either axial flow or cross flow types depending on the direction of flow of gas.

Rotary Piston Pump. A liquid-sealed mechanical pump employing a rotor, stator and sliding vanes.

Roughing Line. A line running from a mechanical pump to a vacuum chamber through which preliminary pumping is conducted in the rough vacuum range.

Roughing Pump. The pump used to reduce the system pressure to the point at which a vapor pump (or other pump requiring a fore vacuum) can take hold and operate efficiently.

NOTE: The roughing pump may then also be used as the fore pump for the vapor pump, or the roughing pump may be shut off and a smaller pump used as fore pump when the gas load is relatively small.

Roughing Time. The time required to pump a given system from atmospheric pressure to the take-hold pressure for the vapor pump (or other high-vacuum pump) or to a pressure at which valves to the vapor pump can be opened without stopping the flow of vapor from the nozzles.

Time of Evacuation. The time required to pump a given system from atmospheric pressure to a specified pressure. (Also known as pump-down time or time of exhaust.)

Torr. A suggested international standard term to replace the English term millimeter of mercury and its abbreviation mm of Hg.

Ultimate Pressure. The limiting pressure approached in the vacuum system after sufficient pumping time to establish that further reductions in pressure will be negligible. (Sometimes called the ultimate vacuum.)

NOTE: The terms blank-off pressure or base pressure are also sometimes used in referring to a pump under test.

Vacuum. A given space filled with gas at pressures below atmospheric pressure.

Vacuum Gage. A manometer for pressures below 760 Torr (101 kPa).

NOTE: Terms such as vacuum gage, Pirani gage, ionization gage, etc., should be used only when referring to the complete gage and not merely to the gage tube.

Vacuum Impregnation. A process for filling voids or interstices with a fluid by first subjecting the article to a vacuum, then flooding with the desired fluid, and breaking the vacuum.

Vacuum Manifold. An enclosure with several ports so that a number of vacuum devices may be attached to it at one time for evacuation and processing.

Vacuum System. A chamber, or chambers, having walls capable of withstanding atmospheric pressure having an opening through which the gas can be removed through a pipe or manifold to a pumping system.

NOTE: The pumping system may or may not be considered as part of the vacuum system. A complete vacuum system contains all necessary pumps, gages, valves, and other components necessary to carry out some particular process; such a system is referred to in England as a vacuum plant.

Vacuum Thermal Insulation. The use of evacuated space for reduction of conductive and convective heat transfer.

Vapor. A gas whose temperature is below its critical temperature, so that it can be condensed to the liquid or solid state by increase of pressure alone.

Vapor Pressure. The sum of the partial pressures of all the vapors in a system, or the partial pressure of a specified vapor.

Vapor Pump. Any pump employing a vapor jet as the pumping means. (Applies to diffusion pumps and ejector pumps.)

1-7* Approvals, Plans, and Specifications.

(a) Before new equipment is installed or existing equipment remodeled, complete plans and specifications shall be submitted for approval to the authority having jurisdiction. Plans shall be drawn to an indicated scale, and show all essential details as to location, construction, heating equipment, fuel piping, heat input, and safety control wiring diagrams. The plans shall include a list of equipment giving manufacturer and type number.

(b) Any deviation from this standard will require special permission from the authority having jurisdiction.

(c) Wiring diagrams and sequence of operations for all controls, including "ladder type" schematic diagrams, shall be provided. [*See Figures A-1-7 (a), (b), and (c).*]

1-8 Electrical.

All wiring in and around furnaces shall be in accordance with the *National Electrical Code*, NFPA 70.

1-9 Operator Training.

(a) It is fully recognized that the most essential safety consideration is the selection of alert and competent operators. Their knowledge and training are vital to continued safe operation.

(b) New operators shall be thoroughly instructed and shall demonstrate an adequate understanding of the equipment and its operations.

(c) Regular operators shall receive scheduled retraining to maintain a high level of proficiency and effectiveness.

(d) Operators shall have access to operating instructions at all times.

NOTE: An outline of these instructions should be posted at the furnace.

(e) Operating instructions shall be provided by the equipment manufacturer. These instructions shall include schematic piping and wiring diagrams.

NOTE: All instructions should include:
(1) Start-up procedures.
(2) Shutdown procedures.
(3) Emergency procedures.
(4) Maintenance procedures.

(f) Operator training shall include, where applicable:

(1) Combustion of air-gas mixtures.
(2) Explosion hazards.
(3) Sources of ignition and ignition temperature.
(4) Atmosphere gas analysis.
(5) Handling of flammable atmosphere gases.
(6) Handling of toxic atmosphere gases.
(7) Functions of control and safety devices.

Chapter 2 Location and Construction

2-1 Location of Cold-Wall Vacuum Furnaces and Related Equipment.

2-1.1 General.

2-1.1.1 Cold-wall vacuum furnaces and related equipment shall be located with consideration to the possibility of fire resulting from overheating, ignition of quench oil, ignition of pump oil, etc., or from escaping of processing atmosphere where applicable, with the resulting possibility of building equipment damage and injury to personnel.

2-1.1.2 Consideration shall be given to the location of furnaces to provide protection against damage by heat, vibration, and mechanical hazards.

2-2 Grade Location.

NOTE: Cold-wall vacuum furnaces designed for use with special flammable atmospheres should be located at or above grade to make maximum use of natural ventilation and to minimize restrictions to adequate explosion relief and sufficient air supply for personnel who may be working in confined quarters.

2-2.1 When basements or other confining areas must be used, consideration shall be given to ventilation and the ability to safely provide the required explosion relief and sufficient air supply for all personnel who may be working in confined quarters.

2-2.2 In the event that furnaces are below grade level, consideration shall be given to ventilation and the prevention of stagnant areas that may be depleted of oxygen and cause asphixiation.

NOTE: Cold-wall furnaces designed for use with inert gas backfilling or quenching should be located above grade level to make use of natural ventilation and to assure an adequate supply of air to personnel.

2-3 Structural Members of Buildings. Although cold-wall furnaces do not present a particular adverse temperature effect on building structures, consideration shall be given to structural loading.

2-4 Location in Regard to Stock, Processes, and Personnel.

2-4.1 Stock and Processes.

NOTE: Cold-wall Class D furnaces should be well separated from unrelated stock, power equipment, process equipment, and separated from fire protection facilities in order to minimize interruption of production, and to provide protection in the event of accidents.

2-4.2 Personnel. Cold-wall furnaces shall not obstruct personnel travel to exitways, particularly when large doors are in the open position.

2-4.3 Finishing Operations. Cold-wall Class D furnaces shall be safely located and protected from exposure to flammable liquid dip tanks, spray booths, flow coaters, or storage and mixing rooms or areas. This shall not apply to integral quench systems.

NOTE: The hazard is particularly severe when vapors from dipping operations may flow by gravity to heating units at, or near, floor level.

2-5 Floors and Clearances.

2-5.1 Cold-wall Class D vacuum furnaces shall be located for ready accessibility, with adequate space above, and on all sides, to permit inspection and maintenance. The space above, below and around the equipment shall be properly ventilated to keep temperatures at combustible floors, ceilings and walls below 160°F (71°C).

2-5.2 Cold-wall Class D vacuum furnaces shall be located on, or above, noncombustible floors. If such a location is not possible, then one of the following procedures shall be employed:

2-5.2.1 Remove combustible floor members and replace with a monolithic concrete slab which extends a minimum of 3 ft (1 m) beyond the outer extremities of the furnace.

2-5.2.2 Air channels shall be provided between the floor and the equipment (perpendicular to the axis of the equipment and/or noncombustible insulation). This shall be adequate to prevent surface temperatures of floor members from exceeding 160°F (71°C).

2-5.3 Where electrical wiring will be present in the channels of certain types of floors, the wiring shall be installed in accordance with Article 356 (cellular metal floor raceways) of the *National Electrical Code*, NFPA 70.

2-5.4 Floors beneath mechanical pumps and related equipment shall be vibration free and be provided with a noncombustible, nonporous surface to prevent the floors from becoming oil soaked.

2-5.5 Where furnace ducts or stacks penetrate combustible walls, floors or roofs, clearances and insulation shall be provided to prevent surface temperatures of combustible members from exceeding 160°F (71°C).

2-6 Construction of Furnaces.

2-6.1 Cold-wall Class D vacuum furnaces and related equipment shall be built in a substantial manner with due regard to the fire hazard inherent in equipment operating at elevated temperatures, the hazard to operators from high temperatures and mechanical equipment, and the need of ensuring reliable, safe operation over the expected maximum life of the equipment.

2-6.2 Furnace internals and all material therein exposed simultaneously to elevated temperature and air (oxygen), including the basic vessel and internal support structures, shall be constructed of noncombustible and nonvolatile material.

2-6.3 Furnace structural supports and material handling equipment shall be designed with adequate factors of safety at the maximum operating temperatures, with consideration given to the strains imposed by expansion and contraction and any other mechanical/electrical design and safety standards.

2-6.4 Adequate facilities for access shall be provided to permit proper inspection and maintenance. Ladders, walkways, and so forth shall be designed in accordance with applicable standards.

2-6.5 Heating devices and heating elements of all types shall be substantially constructed or located to resist mechanical damage from falling work, trucking, or other mechanical hazards inherent in industrial use.

2-6.6 Radiation shields, refractory material, and materials of insulation shall be retained or supported so they will not fall out of place.

2-6.7 Water cooled components, such as vacuum vessels, shall be designed with minimum wall thicknesses in accordance with corrosion tables and vessel standards *(see ASME Pressure Vessel Code, Section 8).*

NOTE: Where subject to corrosion, metal parts should be adequately protected.

2-6.8 Items of instrumentation and control equipment which can be centrally grouped together shall be so brought to a singular location and mounted for ease of observation, adjustment, and maintenance and for protection against unavoidable hazards including physical and temperature damage and exposure to other ambient hazards. Design of electrical components and the interconnection thereof shall be in conformance with current NEMA standards and with NFPA 70.

2-6.9 External parts of furnaces which operate at temperatures in excess of 160°F (71°C) shall be guarded by location, guard rails, shields or insulation to prevent accidental contact with personnel. All parts of equipment operating at elevated temperatures shall be installed in accordance with Section 2-5, Floors and Clearances.

2-6.10 Pressure relief ports or gas burn-off ports of the furnace shall be so located or guarded so as to prevent injury to personnel from discharge of hot gas.

2-6.11 If sight ports are provided, they shall be properly protected from radiant heat and physical damage.

2-6.12 Water cooling system devices such as relief valves, open sight drains, and waterflow switches shall be designed and installed for ready observation by operator.

2-6.13 The basic vessel or vacuum chamber shall be designed in general accord with the *ASME Boiler and Pressure Vessel Code,* Division 1, Section 8, and shall not have a rate-of-rise greater than 5×10^{-3} Torr (66.7×10^{-2}Pa) per hour.

2-7 Furnace Exhaust Systems. Furnace exhaust systems shall be in accordance with requirements of Chapter 4.

NOTE: The need for a furnace exhaust system for removal of products of combustion, heat, toxic gases, and other objectionable gases will depend on the heating processes, type of combustion, hazard to personnel, and all applicable air pollution control regulations.

2-8 Auxiliary Equipment, Access and Mounting.

2-8.1 Mounting for auxiliary equipment, such as control instruments, pumps, and safety devices, shall provide protection against damage by heat, vibration and mechanical hazards.

2-8.2 Auxiliary equipment, such as conveyors, racks, shelves, baskets, and hangers, shall be of nomcombustible material.

2-9 Pumping Systems.

2-9.1 Pumping systems shall consist of pumps, valves, related protective equipment, measuring and control instrumentation that produce and control the level of vacuum in a vacuum furnace.

NOTE: Vacuum pumps may be the ejector, mechanical or diffusion type.

2-9.2 Vacuum pumps shall be of sufficient capacity and efficiency to produce the level of vacuums intended for the process. *(See Appendix B for general pump information.)*

NOTE: Where automatic pump control modes are provided, a manual control mode should also be provided as an override.

2-9.3 Mechanical pumps utilizing hydrocarbon oils shall not be used for pumping gases with oxygen contents greater than 25 percent by volume.

2-9.4 Diffusion pumps and other pumps employing a heating source shall include thermostats or other automatic temperature controlling devices.

NOTE: It is recommended that diffusion pumps be charged with a vacuum grade of silicone based fluid to reduce the risk of explosion on inadvertent exposure to air when heated *(see 2-11.8)*. Diffusion pump fluids with equivalent or superior fire resistance may be considered.

2-9.5 A fluid level gage shall be installed on diffusion pumps with a pump fluid capacity over one quart.

2-9.6 When petroleum or other combustible fluids are used, the system shall be designed to minimize the possibility of fluid release which may result in a fire or explosion.

2-9.7 Sufficient cooling shall be provided for diffusion pumps so as to prevent excess vapors from backstreaming into furnace chambers and to mechanical pumps to prevent overheating of the pump fluids.

2-9.8 Protection from fly wheels, belts and other moving parts shall conform to the requirements of applicable standards.

2-9.9 Electrical wiring, switches and complementary electrical equipment shall conform to the requirements of the *National Electrical Code*, NFPA 70.

2-10 Vacuum Gages and Controls.

2-10.1 Vacuum gages and vacuum controls shall be selected for a particular system with consideration to vacuum level, sensitivity and expected contamination.

NOTE: Vacuum gages may contain controlling devices to sequentially operate equipment.

2-10.2 Suitable vacuum gages shall be installed so levels of vacuum may be ascertained in the furnace chamber and between vacuum pumps of multipump systems.

2-10.3 Vacuum gage controls that operate in conjunction with sequential controls shall be interlocked to prevent damage to furnace components or work load.

2-10.4 Hot wire filament gages shall not be used at pressures above 1×10^{-1} Torr (13.3 Pa).

NOTE: In the presence of explosive vapors or combustible atmospheres, use of hot wire filament gages can be hazardous.

2-11 Vacuum Piping Systems.

2-11.1 Vacuum pipe lines, valves, and manifolds shall be designed to withstand differential pressures, sufficient conductance for the application, and a maximum leak rate as required by the process but no greater than the leak rate specified by the manufacturer for the furnace.

NOTE: Pipes and manifolds should be as short and as large in cross section as practical, consistent with good maintenance and economic consideration.

2-11.2 Pipes, valves, and manifolds shall be mounted so as to provide protection against damage by heat, vibration, and mechanical hazard.

2-11.3 Allowable leakage of valves and vacuum lines shall depend upon the requirements of the process.

2-11.4 Isolation vacuum valves shall be installed between the mechanical fore pumps and the remaining system including the furnace chamber. These valves, if powered, shall automatically close when there is a loss of power to the fore pump or the control switch for the fore pump is in the "off" position.

2-11.5 Where applicable, a bypass shall be provided between the furnace and roughing and/or fore pump so that the chamber can be rough pumped while the diffusion pump remains isolated.

2-11.6 Inlet gas quenching valves shall be designed to operate at applicable pressures on the gas side and on the vacuum side.

2-11.7 A pressure relief valve shall be provided on the furnace, where pressurized backfilling is employed. It shall be located on the chamber side of all vacuum valves and shall be set for a safe positive pressure limit consistent with the furnace chamber design criteria *(see Section 5-3, Safety Controls for Vacuum Systems).*

2-11.8 A warning plate shall be affixed to diffusion pumps covering safe methods of servicing pump stating the following: Do not open oil drain or fill plugs for service until pump heater is at room temperature otherwise ignition of pump oil can occur with rapid expansion of gas causing damage to pump and furnace hot zone.

2-12 Water Cooling Systems.

2-12.1 A water cooling system of a cold-wall vacuum furnace shall include the apparatus, equipment and method used to cool vacuum chamber walls, electrical terminals, seals, work load and, when applicable, the interior of the furnace. Integral liquid quench systems are covered under Chapter 6.

2-12.2 Closed cooling systems shall be provided with a pressure relief valve to prevent rupture of lines, coils, and chamber due to accidental overheating of the cooling water.

2-12.3 Consideration shall be given to provide pressure and temperature gages on exit cooling lines and shall be mandatory on closed cooling systems *(see 5-3.3).*

2-12.4 If cooling water is discharged into an open drain, provisions shall be made for visual inspection of water flow at outlets.

2-12.5 If heat from the electric power terminals can damage seals during processing cycles, provision shall be made to cool the terminals.

2-12.6 When water is used as a cooling medium, the control valve shall stay open in the event of a power failure or coil failure so that cooling water is guaranteed for the unit.

2-13 Gas Quenching Systems.

NOTE: After the thermal cycle has been completed, the work load is either transferred to a gas quenching vestibule or is gas quenched in the heating zone. Gas quenching is performed by introducing a cooling gas (usually nitrogen, hydrogen, argon or helium) until the pressure reaches a predetermined level (usually from −2 psig to 12 psig above atmospheric), and recirculating the cooling gas through a heat exchanger and over the work by means of a fan or blower. The heat exchanger and fans or blower are either internal (within the furnace vacuum chamber) or external (outside the furnace vacuum chamber).

2-13.1 Internal Heat Exchanger. Internal heat exchangers installed in the furnace chamber for the purpose of extracting heat from a recirculating cooling gas shall be protected from excessive pressure and heat damage, and also mechanical damage while loading or unloading the furnace.

2-13.1.1 Heat exchangers, components, and connections shall be free from water and air leaks.

2-13.1.2 Heat exchangers shall be mounted to prevent vibration or thermal damage that could cause a rupture during processing cycles.

2-13.1.3 Heat exchanger components shall have sufficient strength to resist permanent deformation while exposed to the simultaneous maximum pressure of the coolant source and the maximum vacuum and/or pressure attained in the furnace.

2-13.2 External Heat Exchangers. External heat exchangers used for the purpose of extracting heat from a recirculating cooling gas shall be enclosed in a vacuum-tight chamber that has a leak rate not exceeding the leak rate specified by the manufacturer for the furnace chamber.

2-13.2.1 Heat exchangers, components, and connections shall be free from water and air leaks.

2-13.2.2 Heat exchangers shall be mounted to prevent vibration or thermal damage that could cause a rupture during processing cycles.

2-13.2.3 Heat exchanger components shall have sufficient strength to resist permanent deformation while exposed to the simultaneous maximum pressure of the coolant source and the maximum vacuum and/or pressure attained in the furnace.

2-13.2.4 If external heat exchangers are used, they shall be installed on the inlet of recirculating fans and blowers.

2-13.3 Fans and Blowers.

2-13.3.1 Internal Fans and Blowers. Internal fans and blowers used to circulate cooling gas within the furnace chamber and through a heat exchanger shall be constructed to resist damage by the hot gases generated at the highest temperature and heaviest mass work load warranted by the manufacturer of the furnace and mechanically designed to operate at pressure as low as approximately 7 psi (48 kPa) absolute.

2-13.3.1.1 All fans and blowers shall be so interlocked as to be inoperable when exposed to the operator.

2-13.3.2 **External Fans and Blowers.** External fans and blowers shall be enclosed in a vacuum-tight chamber or casing that has a leak rate not exceeding the leak rate specified for the furnace.

2-13.3.2.1 Fans and blowers that are automatically sequenced in the processing cycle shall have a manual override control.

2-13.3.2.2 Direct electrically driven fans and blowers shall have a pressure switch control that prevents operation below 7 psi (48 kPa) absolute to prevent motor failure.

2-13.3.2.3 Where motor windings are exposed to argon gas or other ionizing gases, the voltage on the motor shall be limited to 260 volts maximum.

NOTE: Motors may be operated at higher voltages (480 volts) if the partial pressure is above 15 in. Hg (51 kPa). A pressure interlock should be considered.

2-13.4 Quenching Gas.

2-13.4.1 The recirculating gas shall be one that is not harmful to the elements, furnace heat shields or insulation or work when introduced at the quenching temperature.

2-13.4.2 **Recirculating Cooling Gas Lines.** Consideration shall be given to the inclusion of isolating valves between an external heat exchanger system and the furnace chamber.

NOTE: Automatically controlled isolation valves sequenced in the processing cycle should have a manual over-ride control.

2-13.4.2.1 All lines shall be vacuum-tight with a maximum leak rate as specified for the furnace chamber.

2-14 Heating Elements and Insulation.

2-14.1 Material for heating elements shall have a vapor pressure lower than the lowest pressure at the manufacturer's specified maximum temperature.

2-14.2 Internal electrical insulation material shall remain nonconductive through the full range of vacuum and temperature limits specified by the manufacturer.

2-15 Heat Baffles and Reflectors.

2-15.1 Baffles, reflectors, and hangers shall be designed to minimize warpage due to expansion and contraction.

2-15.2 Baffles, reflectors, and hangers shall be of heat resistant material that will not sag, rupture or crack under normal operating limits specified by the manufacturer.

2-15.3 Baffles and reflectors shall be accessible and removable for the purpose of cleaning and repairing.

Chapter 3 Heating System for Cold-Wall, Resistance Heated Vacuum Furnaces

3-1 General.

3-1.1 For the purpose of this standard, the term "furnace heating system" shall include the electrical power supply, generally 240/480 volt, 3 phase, 60 Hz, the heating elements and the furnace insulation and/or heat shields.

NOTE: The source of heat is a result of electrical heating (I^2R) of the internal heating elements. The transfer of heat into and throughout such a furnace is principally by radiation.

3-1.2 Electrical installation shall be in accordance with the *National Electrical Code*, NFPA 70, and as described hereafter.

3-1.3 All components, such as the vacuum chamber and control cabinet, shall be grounded.

3-2 Power Supply.

3-2.1* It shall be the purpose of the power supply to transform the relatively high voltage power line to low voltage, high current, power suitable for energizing the heating elements. Consideration shall be given to furnishing the power supply with a means of proportional control.

NOTE: Generally this is accomplished with either a saturable core reactor transformer, an adjustable auto transformer, a solid state silicon-controlled rectifier unit, or an electronic ignitron system or equivalent. The most common variable power supply is the saturable core reactor transformer. An example of a schematic is indicated in Figure A-3-2.1. (The design of the power supply is specific for each individual furnace and size.)

3-2.2 The power supply shall contain a stepdown transformer, a control device such as a saturable core reactor transformer, primary fuses or circuit breakers for electrical protection, an electrical disconnect switch for service, and a power controller to accept a control signal from the furnace temperature controller.

NOTE: The power supply output voltage should be limited to a maximum of 80 volts to prevent electrical breakdown or internal furnace arcing. As the atmospheric pressure is reduced in the hot zone area and the heating elements, the arcing voltage changes. Arcing voltage change is a function of electrical spacing and pressure. This function is not linear but has a minimum value for most gases utilized as cooling or partial pressure media in vacuum furnaces. If the voltage stress and mean free path relationship reaches a critical value, corona discharge and arcing commences as a result of field emission of electrons.

3-2.3 Assuming a three phase power line, every attempt shall be made to provide balanced line currents across all three phases as a result of heating element load.

3-3 Heating Elements.

3-3.1 The design may take several forms such as rods, bars, sheet or cloth but shall be limited to materials that will not vaporize under minimum vacuum and maximum temperature.

NOTE: Suitable materials are generally graphite, molybdenum, tantalum, tungsten and others.

3-3.2 The heating element placement and geometry shall be carefully considered to achieve proper heating rate, maintaining operating temperature, and to meet temperature uniformity specifications. The heating elements are electrically energized and shall be supported in such a way as not to come in contact with work pieces or fixtures and as not to come in contact with furnace heat shield or insulation retainer materials.

NOTE: In the event of contact, electrical short circuits can result in major damage to the heating elements, work, or furnace parts.

3-3.3* Heating element support hangers and insulators shall be of compatible materials to provide electrical insulation and nonreacting materials at specified vacuum levels and temperatures.

NOTE: Since material surfaces are generally oxide-free in vacuum, reaction occurs easily in the solid state. Some eutectic temperatures are indicated in Table A-3-3.3.

3-3.4 When heating elements are connected in series or parallel circuits, connections shall be free of arcing and easily disassembled.

3-3.5 Heating element power terminal and vessel feed-through design shall be considered for vacuum integrity and heating effects. Vacuum mating surfaces shall be free from dirt and scratches and equivalent to O-Ring designs.

3-3.6 Power terminal connection points to power supply cables shall be covered or housed to prevent high current electrical hazard to personnel.

3-4 Furnace Thermal Insulation and Heat Shields.

NOTE: The heat energy produced by the heating elements transfers into the work principally via radiation and through the insulation or heat shields into the cooled walls of the vacuum vessel. The cooling medium is continually circulated through the walls of the vessel, maintaining a cold wall. Generally water is used as the cooling medium.

3-4.1 Insulation shall not break down at specified vacuum levels and temperatures.

NOTE: Examples of proper insulation may be graphite wool, alumina/silica fibers, and other material.

3-4.2 Multiple layers of metal heat shields shall be suitable assuming that these materials are in accord with the temperature and vacuum specification.

NOTE: Molybdenum, tantalum, tungsten, palladium and 304/316 stainless steel are examples.

3-4.3 Careful attention shall be given to retain either the insulation or heat shields to prevent contact with the heating elements.

3-4.4* Since most furnace designs utilize forced gas quenching, care shall be taken to prevent insulation from breaking up and becoming "air-borne," thereby blocking heat exchangers and causing vacuum valve seals to leak.

Chapter 4 Equipment Ventilation

4-1 Mechanical vacuum pumps with capacity larger than 15 cubic feet per minute ($7 \times 10^{-3} m^3/s$) shall be vented to a safe location in accordance with all applicable codes and air pollution control regulations.

4-2 An oil drip leg in accord with the vacuum pump manufacturer's recommendation shall be designed into the vent piping system.

4-3 Vent piping shall be free from gas or oil leaks and shall be of noncombustible pipe construction.

Consideration shall be given to provide an oil mist separator when the discharge vapor concentration is excessive.

4-4 Where contaminants are exhausted from a furnace and related equipment into a room, consideration shall be given to provide the room with mechanical ventilation consisting of an air intake system bringing in air from the outside and an exhaust system exhausting an equal amount of air to the outside.

Consideration shall be given to ascertain that the supply air is uniformly distributed within the area, and that the exhaust duct is arranged to eliminate all pockets and dead air areas at either floor or ceiling levels, depending on the type of contaminant being evolved.

4-5 When any reactive gases or other combustible gases are exhausted, precautionary procedures for pumping, purging or operating shall be in accordance with the manufacturer's recommendations.

4-6 Personnel shall never enter a chamber in which atmospheres other than air have been used without first purging the chamber with air to remove residual gas.

NOTE 1: Purging may be accomplished by evacuating the chamber to one Torr or less and refilling with air. When purging the chamber directly with air changes, sufficient cycles should be run to dilute any residual gases below threshold limits. Additional consideration should be given to providing personnel with special safety equipment before entering the chamber and additional personnel should be in attendance outside of the chamber.

NOTE 2: Gas atmosphere densities can be greater or less than air, and thus consideration should be given to air inlet and outlet locations for direct purging.

Chapter 5 Safety Control Equipment for Cold-Wall Vacuum Furnaces

5-1 General Requirements.

5-1.1 For safety of personnel and protection of property against explosion, implosion, or fire, careful consideration shall be given to all hazards peculiar to each individual installation connected with the utilization of a resistance-heated, electric, cold-wall vacuum furnace. All auxiliary apparatus utilized in the operation of the furnace shall be safeguarded to avoid these hazards.

5-1.2 Safety devices shall be used which will provide protection against:

(a) Overtemperature where the furnace is self-destructive;

(b) Both explosion and implosion due to excessive pressures;

(c) Explosion and fire due to misuse of atmospheres and/or internal quenching media;

(d) The misuse of the vacuum pumping system and other auxiliary equipment, such as out-of-sequence operation and accidental introduction of air.

5-1.3 Safety devices shall be properly specified and installed where prescribed in this standard. Safety devices shall not be shorted out or bypassed in the system.

5-1.4 All safety control equipment, as well as the furnace itself, shall be inspected and maintained in accordance with a maintenance check list. *(See typical check list in A-9-2.)*

5-1.5 Where special maintenance and inspection procedures are required due to the nature of the equipment, plant management and the authority having jurisdiction shall prescribe the time interval at which the equipment and the controls shall be tested for service reliability, based on the recommendations of the equipment manufacturer.

NOTE: Partial protection caused by the failure of any one safety device could be more dangerous than no protection at all.

5-2 Safety Controls for Electric Heating Systems.

5-2.1 Safety control application for the heating system in such furnaces shall provide for protection from excess temperature, for protection of the heating element, radiant shields, and/or insulation, and for the safety of the operator of such a furnace. Safety control instruments shall be of the fail-safe type.

NOTE: For a description of electric heating systems in vacuum cold-wall resistance furnaces, refer to Chapter 3.

5-2.2 Electric heating equipment in a vacuum cold-wall furnace shall not be operable until sufficient cooling water is provided to prevent overheating of the vessel, power terminals, and other cooled systems.

5-2.3 Electric heating equipment in a vacuum cold-wall furnace shall not be operable until a sufficient vacuum level has been attained inside the furnace chamber in order to provide protection for the furnace elements, radiant shields, and/or insulation.

5-2.4 Electric heating equipment in vacuum furnaces shall be equipped with a main disconnect device, capable of deenergizing the entire heating system under load in accordance with NFPA 70 and current NEMA standards. *(See 3-2.1 and 3-2.2.)*

5-2.5 All controls, using thermal protection or trip mechanisms, shall be so located or protected as to preclude faulty operation due to abnormal temperatures or other furnace hazards.

5-2.6 Material handling or positioning controls shall be arranged for proper sequence of operation with other furnace (special atmosphere and safety controls), and also to assure emergency action as may be needed in the event of malfunction of the material handling system.

Exception: It is permissible to install provision for operating conveyors manually or by means of a constant pressure push button for the purpose of removing material from the furnace in event of malfunction in the automatic system.

5-2.7 Where a furnace is subject to damage, an excess furnace temperature limit control shall be provided for annunciation and interruption of power supply to the furnace heating system.

5-2.7.1 Manual reset shall be provided to prevent automatic restoration of power.

5-2.7.2 These controls shall be in addition to any normal operating temperature control devices.

5-2.8 Branch circuits and branch circuit protection for all electrical circuits in the furnace heating system shall be provided in accordance with the *National Electrical Code*, NFPA 70.

5-3 Safety Controls for Vacuum Furnace Systems.

5-3.1 Pressure controls shall be installed on all cold-wall vacuum furnaces to prevent excessively high pressures beyond the inherent design of the vacuum vessel. These controls are designed to prevent damage due to excessive pressures, damage due to oxidation of internal equipment materials, and harm to the safety of the furnace operator.

5-3.2* An indicating or recording vacuum gage shall be employed to read pressures in the vessel chamber, in the foreline of the vacuum system, and at critical areas of the vacuum system. Wherever vacuum levels are below 1×10^{-3} Torr (1.3×10^{-1} Pa) an ionization type gage or equivalent shall be employed.

NOTE: The calibration of all vacuum gages should follow the standards specified by the American Vacuum Society. For a description of the various types of vacuum gages, see A-5-3.2.

5-3.3 Wherever a closed loop cooling water system (not an open sight drain system) is utilized, temperature or flow sensing devices shall be located at exit water lines to sense and indicate the temperature or flow of the cooling water. Consideration shall be given to having these devices connected to alarms and to deenergize the furnace system, whenever a set temperature is exceeded. In any case these sensing devices shall be connected to indicating instruments that can be read by the furnace operator.

5-3.4 The vacuum chamber (and the cooling or quench vestibule, if separate) shall be equipped with a pressure relief valve that protects the chamber, attachments, and doors from excessive gas pressure during the pressurizing or cooling cycles.

In order to relieve excess pressure on the vacuum chamber cooling water jacket, a pressure relief device shall be installed.

5-3.5 Automatic valves shall be provided to close the holding pump, foreline, roughing, and main vacuum valves in the event of a power supply or other valve actuating medium failure, in order to prevent pump oil or air from passing through the system or causing damage to the furnace and/or load.

5-3.6 Consideration shall be given to the installation of a visible device that indicates the on-off condition of each vacuum pump whether it is operated manually or automatically. In an automatic pumping system the use of an alarm to indicate the interruption of an operation shall also be given consideration.

5-3.7 Wherever liquid nitrogen is employed as a coolant in cold traps, consideration shall be given to the installation of a liquid level sensor and controller with an alarm to indicate low levels of nitrogen.

5-3.8 A decal or sign shall be posted at each diffusion pump where it can easily be seen by maintenance personnel with a warning that the oil filler plug is not to be loosened or removed unless the diffusion pump oil is at room temperature.

5-4 Safety Controls for Internal Quench Vacuum Furnaces.

5-4.1 Wherever a vacuum furnace has an internal liquid quench chamber, in addition to the above safety controls, the following controls shall be provided:

5-4.1.1 Automatic temperature controls shall be installed in pressure type water-cooling and oil-cooling systems to insure the desired jacket temperature.

5-4.1.2 Wherever an external door adjacent to the quench chamber is employed, the operation of such door shall be interlocked so that it cannot be opened unless the elevator is in its full loading or quenching position.

Exception: A manual override may be used in emergencies.

5-4.1.3 Controls for the admittance and maintenance of protective atmosphere within the upper quench chamber shall conform to the controls described under Section 5-5.

5-4.1.4 The quench reservoir shall be equipped with a reliable quench medium level indicator. If of the sight glass type, the level indicator shall be of heavy duty construction and protected from mechanical damage.

A limit switch shall be interlocked into the load transfer system to prevent transfer of the load in the heat chamber to the quench rack unless the quench rack is in proper position, when the furnace arrangement dictates.

5-4.1.5 The quench tank shall be equiped with a low level device arranged to sound an alarm, prevent start of quenching and shut off heating medium in case of a low level condition.

5-4.1.6 Excess temperature limit control shall be provided, and suitably interlocked to automatically shut off the quench heating medium, and shall require operator attention in case of excessive quench medium temperature. Excess temperature limit shall be interlocked to prevent start of quenching in case of excessive quench medium temperature. Audible and/or visual alarms shall be provided.

5-4.1.7 When agitation of the quench medium is required to prevent overheating, then the agitation shall be interlocked to prevent quenching until the agitator has been started.

5-4.1.8 When a combustible liquid quench medium is used with water jackets or internal water-cooled heat exchanger, a water detector shall be provided for the quench tank to sound an audible alarm, and interlocked to prevent quenching in the event that water content of the quench medium exceeds 0.35 percent by volume.

5-5 Safety Controls for Vacuum Furnaces with Special Atmospheres Operating at Partial Vacuum Levels.

5-5.1 Wherever a gas atmosphere is provided in a vacuum furnace under partial vacuum levels the following additional safety controls shall be utilized.

5-5.1.1 A manual shutoff valve shall be provided in any flammable atmosphere gas supply pipe to the vacuum furnace.

5-5.1.2 Consideration shall be given to the installation of a preset pressure controller to operate a control valve automatically for the introduction of gases for partial pressure operation.

5-5.1.3 In the event of the use of any flammable atmospheres, automatic valves interlocked to prevent introduction of such atmospheres until a vacuum level of less than 1×10^{-1} Torr (13.3 Pa) is attained shall be provided.

5-5.1.3.1 In the event that a multichamber or continuous type vacuum furnace is equipped with flammable atmospheres, each chamber shall be provided with interlocking valves to prevent the introduction of such atmospheres until a vacuum level of less than 1×10^{-1} Torr (13.3 Pa) is attained in the respective chamber.

5-5.1.4 When a flammable or reactive atmosphere is used, an atmosphere gas supply monitoring device shall be provided to permit the operator to visually determine the adequacy of gas flow at all times.

5-5.1.5 Audible and/or visual alarms shall be provided to alert the furnace operator of abnormal flammable atmosphere flow conditions detected by monitoring devices, thus giving the operator the necessary time to actuate emergency shutdown procedures.

Consideration shall be given to the installation of an emergency inert gas purging system where using flammable atmospheres which may consist of:

(a) ASME coded storage tank(s) sized to hold a minimum of 5 furnace volumes (scf) of inert gas which is free of oxygen and contains less than 4 percent total combustibles.

(b) Tank pressure monitoring devices to indicate abnormally low or high tank pressure.

(c) ASME tank relief devices sized, constructed and tested in accordance with the *ASME Boiler and Pressure Vessel Code,* Section 8, Division 1.

(d) Operator's actuation station having necessary hand valves, regulators, relief valves, flow and pressure monitoring devices.

(e) Separate furnace inlets for introduction of emergency inert gas.

(f) Audible and/or visual alarms to alert operator of abnormal tank pressures, and abnormal purge flow rate.

(g) Gas analyzing equipment for assuring furnace is purged.

Chapter 6 Integral Liquid Quench Vacuum Furnaces

6-1 General.

NOTE: Integral liquid quench systems may be constructed within the furnace vacuum chamber or may be in quench vestibules separated from the heating portion of the chamber with a door or vacuum-tight valve. Semicontinuous furnaces employ valves on each end of the hot vacuum zone. These furnaces may be divided into three separate chambers: a loading vestibule, hot vacuum chamber, and cooling vestibule. With this arrangement, cooling or pressurizing the hot vacuum chamber is not required for loading and unloading. Cooling vestibules are often equipped with elevators so that loads may be either vacuum, gas, or oil quenched.

6-2 Requirements.

6-2.1 The vacuum chamber and/or quench vestibule shall be equipped with a pressure relief valve that protects from excessive pressure during the backfilling portion of the cycle.

NOTE 1: The integral quench tank, using a combustible liquid, may be subject to the introduction or accumulation of water from a number of sources which, when exposed to the heat released from quenching of work, flashes to steam. The resulting increase in volume causes over-pressurization of the quench vestibule.

NOTE 2: Cooling medium for the vacuum vessel and furnace cover should be controlled by restricting the flow or by recirculation to maintain vessel walls above ambient dewpoint temperatures.

6-2.2 When quench vestibules are used with semicontinuous furnaces, the quench vestibule shall be vacuum tight and shall be constructed of noncombustible materials with due regard to the fire and explosion hazards. Attention to mechanical functions and corrosive conditions is vital to ensuring reliable, safe operations.

NOTE: The quench vestibule's design and size are dependent upon end use. If the quench vestibule doubles as atmosphere gas cooling chamber, forced cooling is normally required, provided by water, jackets, plate coils, or tubing tracing.

6-2.3 If an intermediate door between furnace and quench vestibule is employed it shall be closed during the quenching operation to serve as a baffle.

6-2.4 Manual facilities shall be provided to permit opening of the outer quench vestibule door. Opening of this door under emergency conditions shall be an operating personnel decision.

6-3 Construction of Quenching Tanks.

NOTE: These requirements are intended to cover any design using water as a cooling medium, where, by means of leakage or condensation, the quench medium is exposed to an accumulation of water.

6-3.1 The quench tank shall be designed and constructed to contain the quench medium capacity at the expected operating temperature and with maximum work load volume.

6-3.1.1 The quench tank shall be tested for leaks prior to use.

6-3.1.2 The quench tank shall be designed and operated with a maximum quench medium level, when elevator and work load are submerged, of not less than 6 in. (152 mm) below door or any opening into the furnace.

6-3.1.3 The quench tank shall have sufficient capacity to quench a maximum gross load with a maximum temperature rise that will not exceed 50°F (10°C) below the flash point and cooling capabilities to recover quench medium temperature between minimum design quench cycles.

6-3.2 When hot rolled steel plate is used, oil or other compatible coolant shall be used in place of water.

NOTE 1: Although hot rolled steel plate has been used for many years with water cooling, it is not to be recommended as corrosion is continuous and its physical state difficult to determine.

NOTE 2: Jacketed stainless steel plate may be used, with water as a coolant, to eliminate the hazards of corrosion of hot rolled steel. However, unless all of the stainless steel is of the stabilized type, such as columbium or titanium or the low carbon L-Series type, corrosion can take place faster than in hot rolled steel due to carbide precipitation in the steel at the welds. If used, a careful study should be made as to compatibility of materials and welding techniques employed.

Steel plate coils, attached by thermo contact cement to the external surfaces of the quench chamber, fabricated of hot rolled steel plate, have produced acceptable heat transfer, and careful attention given to the design of the junction of the upper and lower chambers minimizes the possibility of water leak into the quench reservoir.

Steel plate coils can be used with either water or oil type coolants, although the eventual plugging of the passages with rust and mineral deposits can be anticipated when water is used as a coolant. The use of stainless steel plate coils, while a more expensive construction method, will considerably reduce the possibility of plugging the water passages.

Serpentine coil formed from a noncorrosive tubing material brazed or welded to the exterior surfaces of a cooling chamber, fabricated of hot rolled steel plate, has produced acceptable heat transfer. When careful attention is given to the design of the junction of the upper and lower quench vestibule, the possibility of a water leak into the quench tank is minimized.

NOTE 3: This paragraph does not apply to the vacuum furnace chamber.

6-3.3 If a water-cooled exchanger is employed, the quench oil circulating pump shall be installed on the inlet side of the heat exchanger and the quench medium pressure shall always exceed that of the cooling water.

6-4 Elevators.

6-4.1 The elevator's function shall be to immerse the work charge into the quench medium with minimum splash. At termination of the timed quench cycle, the elevator shall be raised to drain position at hearth level.

6-4.2 The elevating mechanism shall be substantially supported by structural members to handle the maximum rated loads.

6-4.3 Elevator guides or ways shall be provided to ensure uniform stabilized movement of the elevator in the confined areas of the quench tank.

6-4.4 Tray guides and/or stops shall be provided to ensure tray is properly positioned on the elevator.

6-5 Cooling Systems.

NOTE: Quench medium tanks generally utilize a cooling system to maintain the general quench medium at an operating temperature to reduce the quantity of quench media required. Three basic cooling systems are in general use, consisting of:

(a) Internal cooler, where heat transfer medium is circulated through heat exchanger within quench tanks.

(b) External cooler, where quench medium is withdrawn from quench tank, circulated through a water-cooled heat exchanger, and returned.

(c) External cooler, where quench medium is withdrawn from quench tank, circulated through an air-cooled heat exchanger, and returned.

6-5.1 Consideration shall be given to the use of noncorrosive materials for the construction of internal tank cooled heat exchangers.

6-5.2 The heat exchanger shall be subjected to a minimum pressure test of 150 percent of maximum designed working pressure after installation in quench tank.

NOTE: The heat exchanger should be subjected to similar test prior to being placed in service, and at periodic intervals thereafter, to ascertain that it is free of leaks.

6-5.3 The heat exchanger shall be located within the quench tank in such a manner as not to be subject to mechanical damage by the elevator or load to be quenched.

6-5.4 The cooling medium flow shall be controlled by an automatic temperature controller.

6-5.5 If it is possible to completely close off the internal heat exchanger, a pressure relief shall be provided, terminating in a safe location.

NOTE: Tubes of the heat exchanger which are exposed to contact with water should be constructed of noncorrosive materials.

6-5.6 The heat exchanger, after fabrication, shall be subjected to a minimum pressure test of 150 percent of the maximum design working pressure.

NOTE: The heat exchanger should be subjected to similar test prior to being placed in service, and at periodic intervals thereafter, to ascertain that it is free of leaks.

6-5.7 The pressure of the quench medium through the heat exchanger shall be greater than the water pressure applied.

6-5.8 External air-cooled heat exchangers installed out-of-doors shall be structurally reinforced to withstand anticipated wind forces without damage at elevation at which it is mounted.

External air-cooled heat exchangers installed out-of-doors or which utilize supplemental water cooling shall be constructed of materials suitably protected against corrosion.

6-5.9 External water-cooled heat exchangers shall incorporate protective features.

6-5.9.1 The oil pressure through the heat exchanger shall be maintained greater than the water pressure.

6-5.9.2 If it is possible to completely close off the external heat exchanger, a pressure relief shall be provided, terminating in a safe location.

6-5.10 External Air-Cooled System.

6-5.10.1 An external heat exchanger installed out-of-doors shall be provided with lightning protection if located in an exposed, rooftop location.

6-5.10.2 If the air-cooled heat exchanger is installed in a rooftop location, it shall be installed in a curbed or diked area, drained to a safe location outside of the building.

6-6 Electric Immersion Heaters.

6-6.1 Electric heaters shall be of a sheath type construction.

6-6.2 Heaters shall be installed so that the hot sheath is fully submerged in the quench medium at all times.

6-6.3 The quench medium of electrically heated quench tanks shall be supervised by:

(a) A temperature controller arranged to maintain quench medium at proper temperature and interlocked to shut off the immersion heating when excess temperature is detected.

(b) A quench medium level control interlocked to shut off the immersion heating when low level is detected.

6-6.4 The electrical heating control system shall be interlocked with the quench medium agitation or recirculation system to prevent localized overheating of the quench medium.

Chapter 7 Bulk Atmosphere Gas Storage Systems

7-1 Construction.

7-1.1 All storage tanks and cylinders shall comply with local, state, and federal codes relating to pressures and type of gas. NFPA standards shall also be followed.

7-1.2 Vessels, controls and piping shall be designated to maintain their integrity under maximum possible pressures and temperatures.

7-2 Location. Locations for tanks and cylinders containing flammable or toxic gases shall be selected with adequate consideration given to exposure to buildings, processes, personnel, and other storage facilities. Tables of distances specified in the various NFPA standards shall be followed.

7-3 Storage systems shall comply with the following NFPA standards:

(a) Liquefied petroleum gas systems shall be in accordance with the *Standard for Liquefied Petroleum Gases,* NFPA 58.

(b) Gas piping shall be in accordance with the *National Fuel Gas Code,* NFPA 54.

(c) Hydrogen storage systems shall be in accordance with the *Standard for Gaseous Hydrogen Systems at Consumer Sites,* NFPA 50A.

(d) Oxygen storage systems shall be in accordance with the *Standard for Bulk Oxygen Systems at Consumer Sites,* NFPA 50.

(e) Processing atmosphere gas storage systems not covered by an NFPA standard (i.e., anhydrous ammonia) shall be installed in accordance with recommendations from the supplier and all applicable local, state and federal codes.

NOTE: Special reference is made to ANSI Standard ANSI/CGA G-2.1-1972/ TFI M-1-1972, *Storage and Handling of Anhydrous Ammonia.*

Chapter 8 Fire Protection for Furnace Areas

8-1 Sprinkler and Spray Systems—General.

NOTE: Furnaces can present fire hazards to the surrounding area in which they will be installed. Consideration must be given to providing fixed fire extinguishing systems to protect against such hazards as overheating, spillage of molten salts or metals, quench tanks, ignition of hydraulic oil, escape of fuel, etc. It is the responsibility of the user to consult with the authority having jurisdiction concerning the necessary requirements for such protection.

Hydrogen fires are not normally extinguished until the supply of hydrogen has been shut off because of the danger of reignition or explosion. In the event of fire, large quantities of water have been sprayed on adjacent equipment to cool the equipment and prevent involvement in the fire. Combination fog and solid stream nozzles have been preferred to permit widest adaptability in fire control. Small hydrogen fires have been extinguished by dry chemical extinguishers or with carbon dioxide, nitrogen and steam. Reignition may occur if a metal surface adjacent to the flame is not cooled with water or other means.

The various conditions under which gaseous hydrogen will be stored at consumer sites, including unattended installations, necessitates coordination between the supplier, consumer and authority having jurisdiction for adequate and reliable fire protection of the system.

Personnel shall be cautioned that hydrogen flames are practically invisible and may only be detected by heat waves.

8-2 Automatic Sprinkler Systems. Automatic sprinkler installations shall conform to the NFPA *Standard for the Installation of Sprinkler Systems,* NFPA 13, for hazardous locations.

8-3 Water Spray Systems. Water spray systems shall be fixed systems, automatic in operation and conforming to the NFPA *Standard for Water Spray Fixed Systems for Fire Protection,* NFPA 15.

8-4 Portable Protection Equipment.

8-4.1 Extinguishers. Approved portable extinguishing equipment shall be provided near the furnace, and related equipment. Such installations shall be in accordance with the NFPA *Standard on Portable Fire Extinguishers,* NFPA 10.

8-4.2 Small Hose Streams. When small hose streams are required, they shall be in accordance with the NFPA *Standard for the Installation of Standpipe and Hose Streams,* NFPA 14.

Chapter 9 Maintenance of Cold-Wall Vacuum Furnaces

9-1 Responsibility. An essential safety aid is an established maintenance program which ensures that the equipment is in proper working order. The equipment manufacturer shall impress upon the user the need for adequate operational checks and maintenance and shall issue complete and clear maintenance instructions. The final responsibility of establishing a maintenance program which ensures that the equipment is in proper working order shall rest with the user.

9-2* Check Lists. The user's operational and maintenance program shall include all listed procedures that are applicable to his furnace. An operational and maintenance check list shall be maintained and is essential to safe operation of the equipment.

Appendix A begins on the following page.

This Appendix is not a part of the requirements of this NFPA document . . . but is included for information purposes only.

Table A-1-2 VACUUM FURNACE PROTECTION

OPERATING AND SUBJECT SAFETY DEVICES	COLD WALL			HOT WALL			CASTING AND MELTING			
					Electric					
	Induction	Resistance	Electric Beam	Gas-Fired	Single Pump	Double Pump	Induction	Electric Beam	Electric Arc	Degassing
A-Vacuum System	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Vacuum Chamber	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Roughing Pump	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Diffusion Pump	op	op	yes	op	op	op	op	yes	op	no
Holding Pump	op	op	op	op	op	op	op	op	op	op
Retort	no	no	no	yes	yes	yes	no	no	no	no
Multi-chamber	op	op	op	op	op	op	op	op	op	op
Internal Fan [Temp. uniformity]	no	op	no	op	op	op	no	no	no	no
B-Heating System	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
High Voltage	no	no	yes	no	no	no	no	yes	yes	no
High Current	yes	yes	no	no	yes	yes	yes	yes	yes	no
C-Cooling System										
Work Cooling	yes	yes	yes	op	op	op	op	op	no	no
Gas Quench	op	op	op	op	op	op	op	op	no	no
Oil Quench	op	op	no	no	no	no	no	no	no	no
Water Quench	op	op	no	no	no	no	no	no	no	no
Fans-Blower	op	op	op	op	op	op	op	op	no	no
Port-Bungs	op	op	op	op	op	op	no	no	no	no
External-Internal Heat Exchanger	op	op	op	op	op	op	op	op	op	op
Equipment Water Cooling	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes

Table A-1-2 VACUUM FURNACE PROTECTION (continued)

OPERATING AND SUBJECT SAFETY DEVICES	COLD WALL			HOT WALL			CASTING AND MELTING			
					Electric					
	Induction	Resistance	Electric Beam	Gas-Fired	Single Pump	Double Pump	Induction	Electric Beam	Electric Arc	Degassing
D-Process Atmosphere Cycle										
Hydrogen	op	op	no	op	op	op	no	no	no	no
Nitrogen	op	op	no	op	op	op	no	no	no	no
Methane	op	op	no	op	op	op	no	no	no	no
Argon	op	op	no	op	op	op	no	no	no	no
Helium	op	op	no	op	op	op	no	no	no	no
E-Material Handling										
Internal	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
External	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
F-Instrument Controls										
Temperature	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Vacuum	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Pressure	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Flow	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Electrical	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes

yes — means equipment is provided or condition is present

op — optional and there may be a choice

(continued on following page)

Table A-1-2 VACUUM FURNACE PROTECTION (continued)

OPERATING AND SUBJECT SAFETY DEVICES	COLD WALL			HOT WALL			CASTING AND MELTING			
					Electric					
	Induc-tion	Resis-tance	Electric Beam	Gas-Fired	Single Pump	Double Pump	Induc-tion	Electric Beam	Electric Arc	De-gassing
H-Hazards of Heating System				[Refer to NFPA 86A–86B–86C]						
Gas-Fired	no	no	no	yes	no	no	no	no	no	no
Electric Heated	yes	yes	yes	no	yes	yes	yes	yes	yes	no
Cooling Water to be Circulating	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Over Heating	yes	yes	yes	yes	yes	yes	yes	yes	yes	no
Steam Build-up	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Diffusion Pump Element	yes	yes	yes	yes	yes	yes	op	yes	op	op
Pump Element Over Heating	yes	yes	yes	yes	yes	yes	op	yes	op	op
Accumulation of Air	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Hydrogen Accum.	op	op	op	op	op	op	no	no	no	no
Other Combustibles	no	no	no	no	no	no	no	no	no	no
Water in Oil Explosion	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Radiation	no	no	yes	no	no	no	no	yes	yes	no
Water Sentinel	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Electrical Short Safety Shut-down	yes	yes	yes	——	yes	yes	yes	yes	yes	yes
J-Person Safety Hazards	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes

yes — means equipment is provided or condition is present

op — optional and there may be a choice

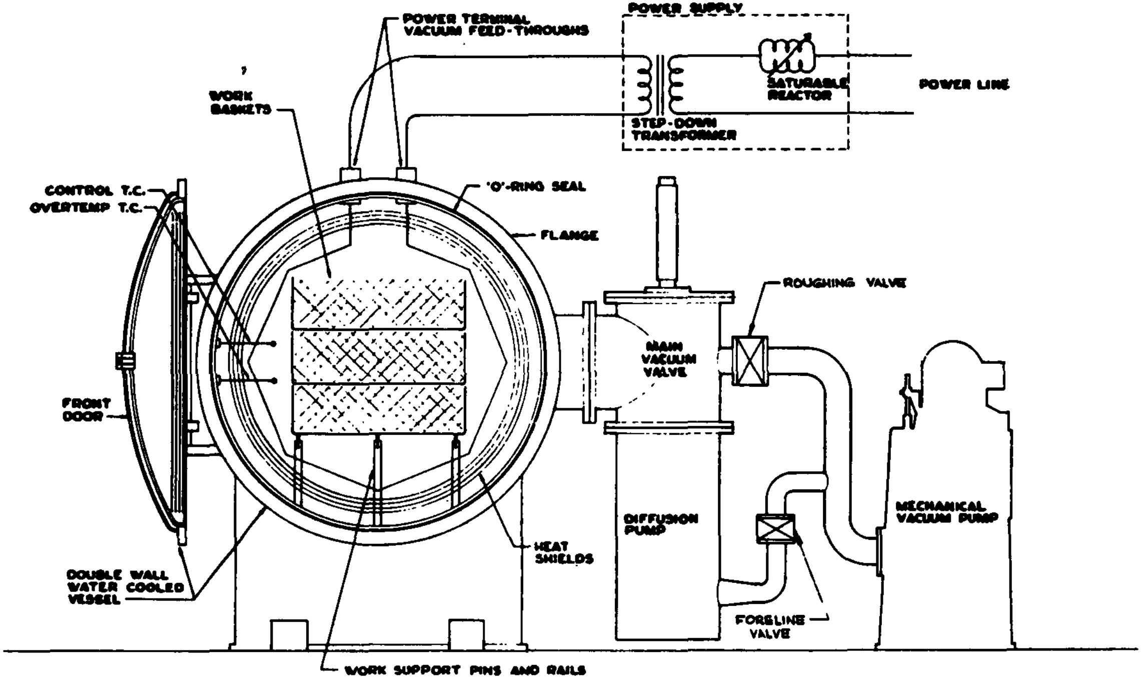


Figure A-1-2.1(a) Example of Cold-Wall, Horizontal, Front Loading Vacuum Furnace.

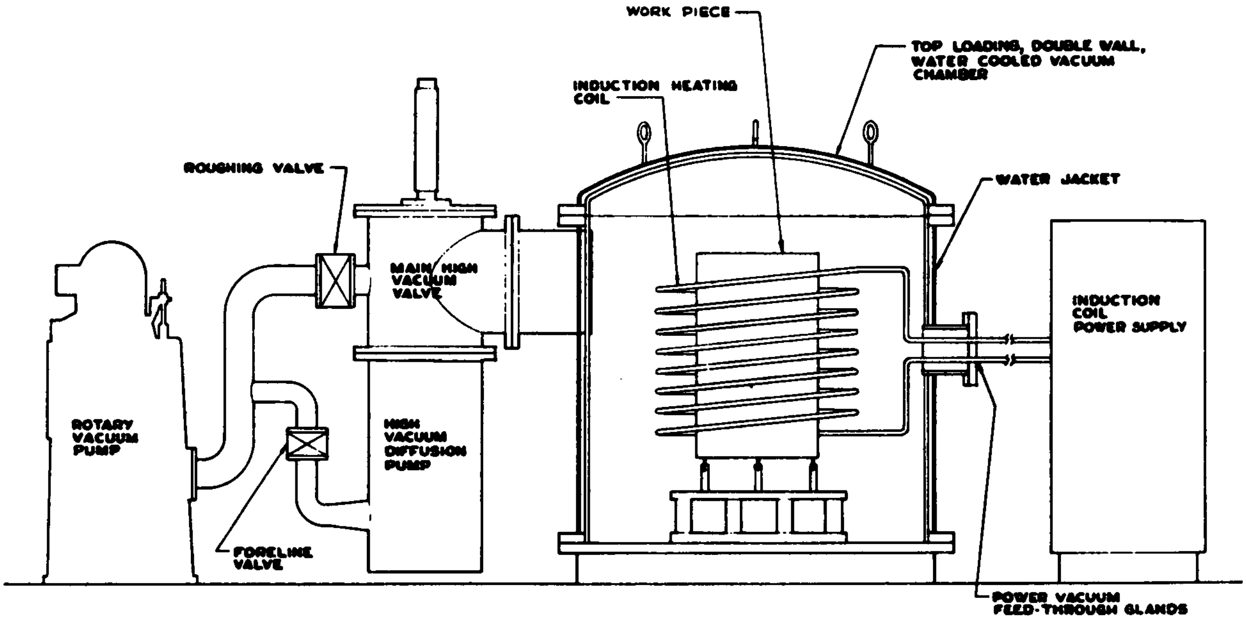


Figure A-1-2.1(b) Example of Cold-Wall, Induction Heated Vacuum Furnace.

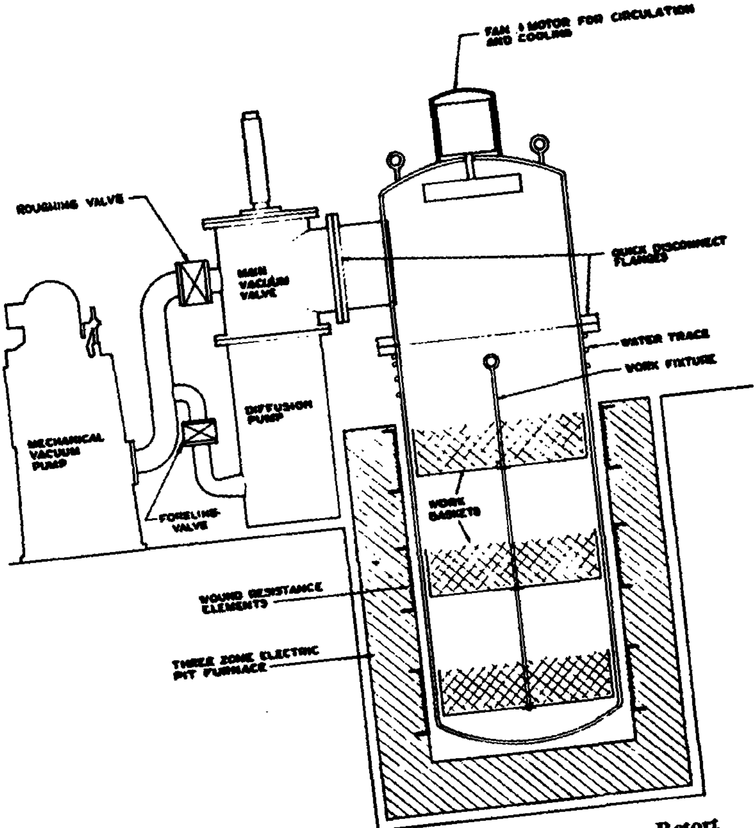


Figure A-1-2.2 Example of Hot-Wall, Single Pump Retort Vacuum Furnace.

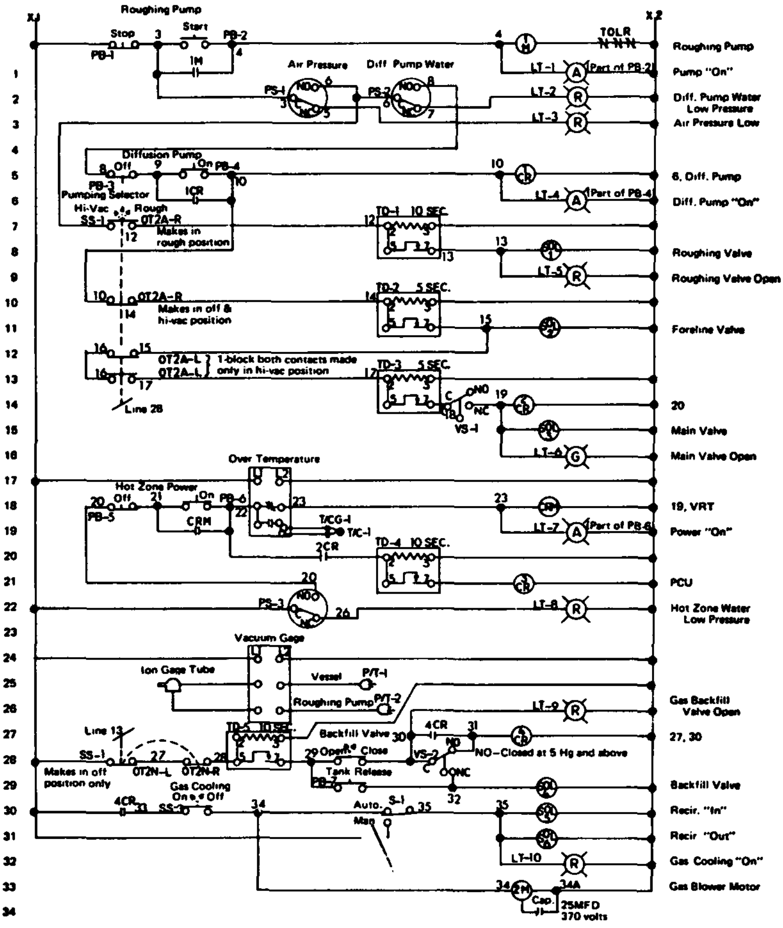


Figure A-1-7(a) Example of Control Wiring Diagram.

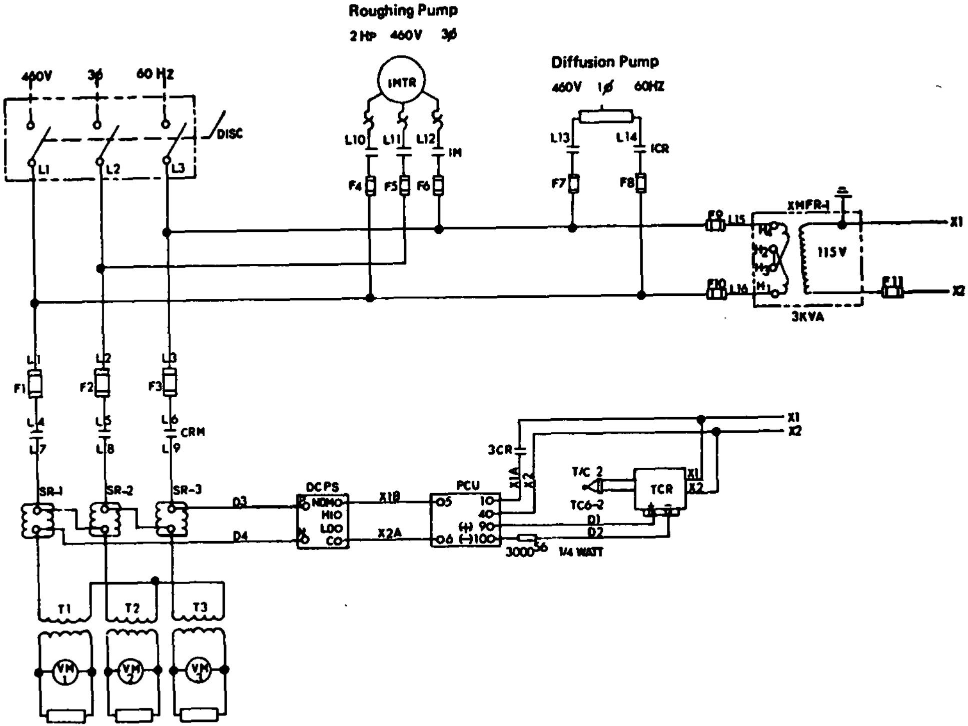


Figure A-1-7(b) Example of Control Wiring Diagram.

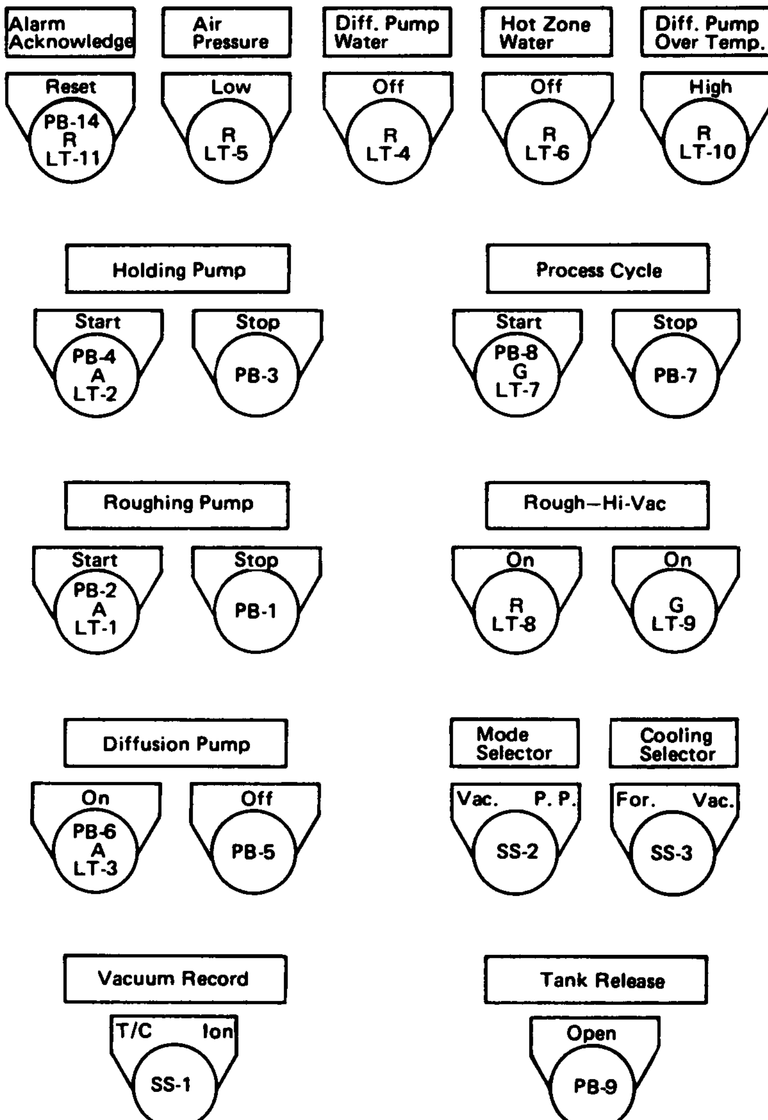


Figure A-1-7(c) Example of Control Panel.

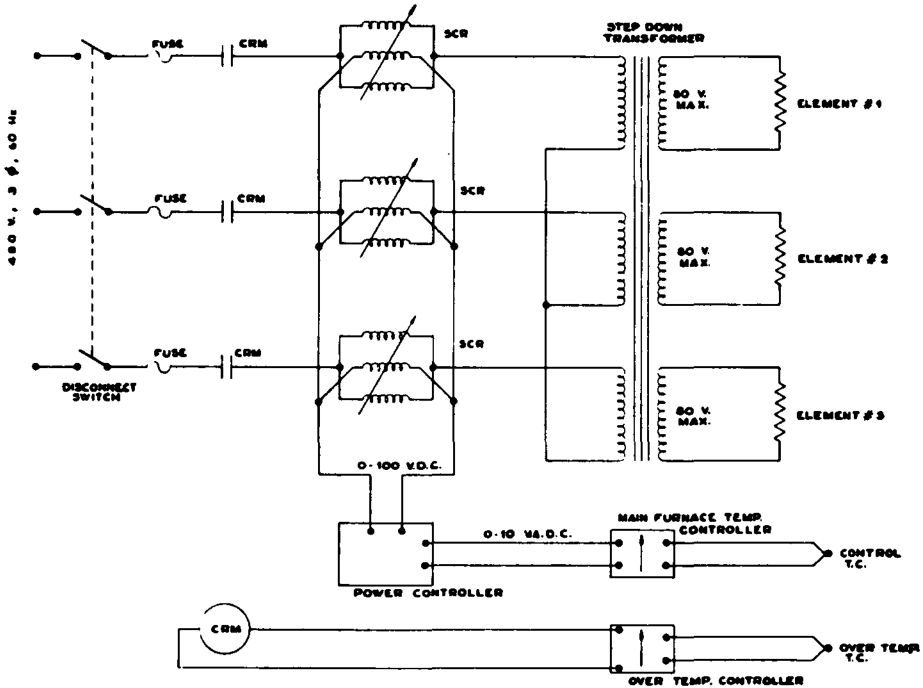


Figure A-3-2.1 Example of Power Supply.

Table A-3-3.3

When dissimilar metals are heated in contact with each other, particularly when oxide-free and in a vacuum furnace, they can react and form alloys, or a eutectic. The result is an alloy that melts at a considerably lower temperature than the melting points of either base metal.

Some eutectic forming materials are listed with critical melting temperature. Operating temperatures near or above these points should be carefully considered.

Moly/Nickel	2310°F	(1266°C)
Moly/Titanium	2210°F	(1210°C)
Moly/Carbon	2700°F	(1482°C)
Nickel/Carbon	2130°F	(1166°C)
Nickel/Tantalum	2450°F	(1343°C)
Nickel/Titanium	1730°F	(943°C)

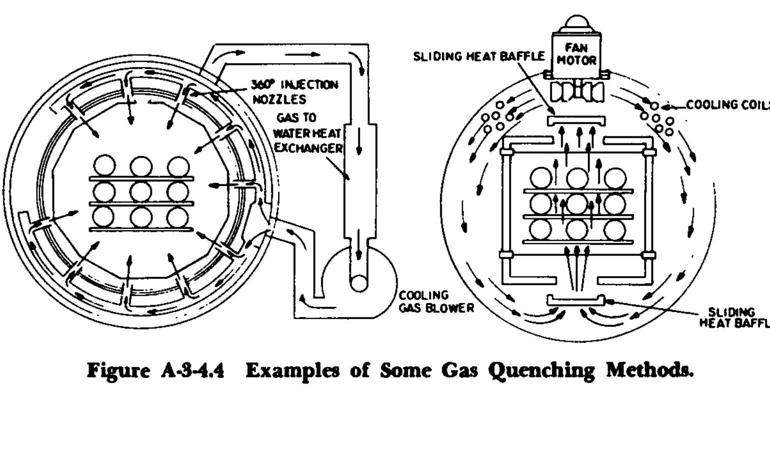


Figure A-3-4.4 Examples of Some Gas Quenching Methods.

A-5-3.2 Types of Vacuum Gages.

A. Mechanical Gages. The bellows and diaphragm mechanical gages operate on a differential between atmospheric and process pressure. They are compensated for atmospheric pressure changes and calibrated for absolute pressure units. They are not suited for high-vacuum work, being limited to approximately 1 mm Hg (133 Pa) abs. Readout is approximately linear except when calibrated in altitude units. Electrical output is available.

B. McLeod Gage. For high-vacuum work the McLeod gage is often used as a primary standard for the calibration of other, more easily used instruments. The gage is limited to intermittent sampling rather than continuous use. It operates on the principle of compressing a large known volume (V_1) of gas at unknown system pressure (P_1) into a much smaller volume (V_2) at a known higher pressure (P_2). From Boyle's Law at constant temperature we derive P_1 equals P_2V_2/V_1. The gage is then calibrated to read P_1 directly.

C. Thermal Gages. The operation of a thermal gage is based on the theory that energy dissipated from a hot surface is proportional to the pressure of the surrounding gas. Some makes of thermal gages are subject to contamination by vaporized materials and this possibility should be checked on with the gage manufacturer.

(1) *Thermocouple Gage.* The thermocouple gage contains a "V" shaped filament with a small thermocouple attached to the point. At low absolute pressures the cooling effect on the heated filament is proportional to the pressure of the surrounding gas. Thus, the thermocouple emf can be used to indicate pressure. In order to compensate for ambient temperature, an identical second unit is sealed in an evacuated tube. The differential output of the two thermocouples is proportional to the pressure.

(2) *Pirani Gage.* The Pirani gage employs a Wheatstone bridge circuit. This circuit balances the resistance of a tungsten filament sealed off in high vacuum against that of a tungsten filament which can lose heat by conduction to the gas being measured. In the Pirani gage, the resistance of the filament rather than its temperature is used as an indication of pressure.

(3) *Bimetal Gage.* A bimetallic spiral is heated by a stabilized power source. Any change of pressure causes a change of temperature and, thus, a deflection of the spiral, which is linked to a pointer on scale, to indicate pressure.

D. Ionization Gages. Two types of ionization gages are discussed here. They are: (1) the hot cathode gage (hot filament), and (2) cold cathode gage (also called the "Phillips" or discharge gage). The principle of operation is that collisions between molecules and electrons result in formation of ions. The rate of ion formation varies directly with pressure. Measurement of the ion current can be translated into units of gas pressure.

(1) *Hot Filament Gage.* This gage is constructed like an electron tube. It has a tungsten filament surrounded by a coil grid, which in turn is surrounded by a collector plate. Electrons emitted from heated filament are accelerated toward the positively charged coil grid. The accelerated electrons pass through the coil grid into the space between it and the negatively charged collector plate. Some electrons collide with gas molecules from the vacuum system to produce positive ions. The positive current is a function of the number of ions formed, and hence is a measure of the pressure of the system.

Ionization gage sensing elements are extremely delicate and must be carefully handled. Their filaments can burn out if accidentally exposed to high pressures [above 1×10^{-3} mm Hg (1.3×10^{-1} Pa) absolute]. The advantages of this type of gage are high sensitivity and the ability to measure extremely high vacuums.

(2) *Cold Cathode Gages.* Cold cathode gages employ the principle of the measurement of an ion current produced by a high-voltage discharge. Electrons from the cathode of the sensing element are caused to spiral as they move across a magnetic field to the anode. With this spiralling, the electron mean free path greatly exceeds the distance between electrodes. Therefore, the possibility of a collision with gas molecules present is increased, producing greater sensitivity (due to greater ion current) and thus sustaining the cathode discharge at lower pressure (i.e., high vacuum).

The sensing elements are rugged and are well-suited to production applications where unskilled help might make filament burnout a problem.

A-9-2 Maintenance Check List.

General. A program of regular inspection and maintenance of the vacuum furnace is essential to the safe operation of the equipment and should be instituted and followed rigorously. Basic heating devices, such as heating elements or induction coils, should be designed for ease of maintenance. If special tools are required, these should be supplied by the furnace manufacturer.

Vacuum System. Mechanical vacuum pumps should be checked and repaired as required. A partial list follows:

Drive belts are not worn.
Drive belts' tension is proper.
No oil leaks at the shaft seals.
Correct oil level.
Oil is free of dirt and water accumulation.
Drip legs are drained.
Mounting bolts are tight.
Vacuum lines and vibration couplings are tight.

The high vacuum diffusion pump should be checked and repaired as required. A partial list follows:
Correct water flow for cooling.
Heating elements are tight and indicate proper electrical parameters.
Oil level is correct.
Oil is not contaminated.

Control vacuum valves should be checked and repaired. A partial list follows:
Air supply filter drained and operating.
Air supply oiler filled to correct level and operating.
Pilot valves not leaking excess air.
Moving O-Ring seals cleaned or changed where indicating excess wear.

Numerous stationary and moving vacuum seals, O-Rings and other rubber gaskets are associated with the main vacuum vessel. These seals should be inspected properly to ensure cleanliness, freedom from cracks or gouges, and retaining elasticity. The main front and rear door or bottom head, where work regularly passes, should receive particular attention.

Hot Zone. Heating elements should be inspected and replaced or repaired as required at regular intervals for excessive distortion or sagging, cracking, indication of melting or alloying, and electrical short circuit to either work or other hot zone components. Support or separator insulators should be inspected, and replaced if required for cracks or breaks, melting or alloying, and severe metalization causing electrical breakdown. Heating element terminations should be periodically inspected for tight connections and ensured to be free from arcing.

Heat shields or insulating and other hot zone components should be checked and repaired, as required. A partial list follows:
Broken or loose retaining rods or bars.
Broken, cracked, or severely warped first shield or retainer shield.
Sagging or reacted insulation.

Warped or broken work support components such as pillars or rails.
Moving drive gears or carriers for correct alignment, clearance, and wear points.
Leaking shaft seals or other excess fluid accumulation.
Excessive contamination due to work evaporation or process accumulation.

The power supply should be inspected and corrected as required. A partial list follows:
Primary and secondary wiring and cables tight and free from overheating.
Proper ventilation and air cooling or proper water flow per unit or transformer.
Control relays or contactors should be free of contact pitting or arcing, which could result in contact welding.
Power supply voltage should be maintained within reasonable limits to ensure against overloading.

NOTE: Under voltage can result in operational failure of any one of the numerous vacuum furnace systems.

Thermocouples. A regular replacement program should be established for all control and safety thermocouples.

NOTE: Effective life of thermocouples varies depending on the environment and process, temperature and vacuum, and these factors must be considered in setting up a replacement program.

Instrumentation. Temperature and vacuum instrumentation should be set up on a regular calibration and test schedule.

Many components of the vacuum furnace require water cooling; drain lines should be inspected for proper flow and temperature of the cooling water. Pressure regulators, strainers, and safety vents should be inspected for proper setting and maintained free from dirt and contamination.

If an evaporative cooling tower is integral to the furnace system, the tower should be cleaned, motor and bearings greased, and water strainer cleaned on a regular basis.

Interlocks and Alarms. Periodic checks of all safety interlocks and alarms should be performed. Particular attention should be given to overtemperature safety devices, low air pressure, insufficient cooling water, vacuum, oil temperature, and low oil alarms.

The following continuous observations should be made:

(a) Review auxiliary vacuum instrumentation for proper indication of system performance, i.e., foreline, holding pump, mechanical pump and diffusion pump operating temperature.

(b) Review power instrumentation and trim or zone control settings.

(c) Check instrumentation for "on conditions" chart paper, and active operation.

(d) Check oil level in mechanical pumps and diffusion pump.

(e) Check mechanical vacuum pump, blowers, gas fans, oil pumps for unusual noise or vibration. Review V-Belt drive, belt tension and belt fatigue.

(f) Check quench gas pressure and available capacity.

(g) Check for proper operation of ventilation equipment if required in the particular installation.

The following regular shift observations should be made:

(a) Review auxiliary vacuum instrumentation for proper indication of system performance, i.e., foreline, holding pump, mechanical pump and diffusion pump operating temperature.

(b) Review power instrumentation and trim or zone control settings.

(c) Check instrumentation for "on conditions" chart paper, and active operation.

(d) Check oil level in mechanical pumps and diffusion pump.

(e) Check mechanical vacuum pumps, blowers, gas fans, oil pumps for unusual noise or vibration. Review V-Belt drive, belt tension and belt fatigue.

(f) Check quench gas pressure and available capacity.

The following weekly checks should be made:

(a) Review hot zone for normal condition of heating elements, heat shields or retainers, insulators, and work support or mechanism.

(b) Test thermocouples and lead wires for broken insulators, shorts, and loose connections.

(c) Test visible or audible alarms for proper signals.

The following monthly observations should be made:

(a) Test interlock sequence of all safety equipment. Manually make each interlock fail, noting that related equipment shuts down or stops as required.

(b) Inspect all electrical switches and contacts, repair as required.

(c) Test all temperature instrument fail-safe devices, making certain that the control instrument or recorder drives in the proper direction.

(d) Clean all water, gas compressor and pump strainers.
(e) Test automatic or manual turn-down equipment.
(f) Change mechanical pump oil and diffusion pump oil if required.
(g) Test pressure relief valves, clean if necessary.
(h) Inspect air, inert gas, water, and hydraulic lines for leaks.

The following periodic checks should be made:

NOTE: Frequency of maintenance of the following will depend on the recommendations of the equipment manufacturer.

(a) Inspect vacuum chamber O-Ring and other gaskets for proper sealing.
(b) Review the vacuum chamber vessel for evidence of hot spots indicating improper water cooling.
(c) Review furnace internals in detail for heating element, heat shield, and work support or mechanism failure or deterioration.
(d) Lubricate instrumentation, motors, drives, valves, blowers, compressors, pumps, and other components.
(e) With brush or other devices remove major build-up of oxides and contamination from the hot zone and accessible areas of the cold wall chamber. Blow out contaminate with a dry air hose.
(f) Run furnace to near maximum design temperature and maximum vacuum to boil out furnace contamination.
(g) Install new exhaust valve springs and discs and clean and flush oil from the mechanical vacuum pumps. Replace spring and O-Ring in the gas ballast valves.
(h) Run blank-off test for mechanical vacuum pump to ensure meeting process parameter.

Appendix B Pump Data

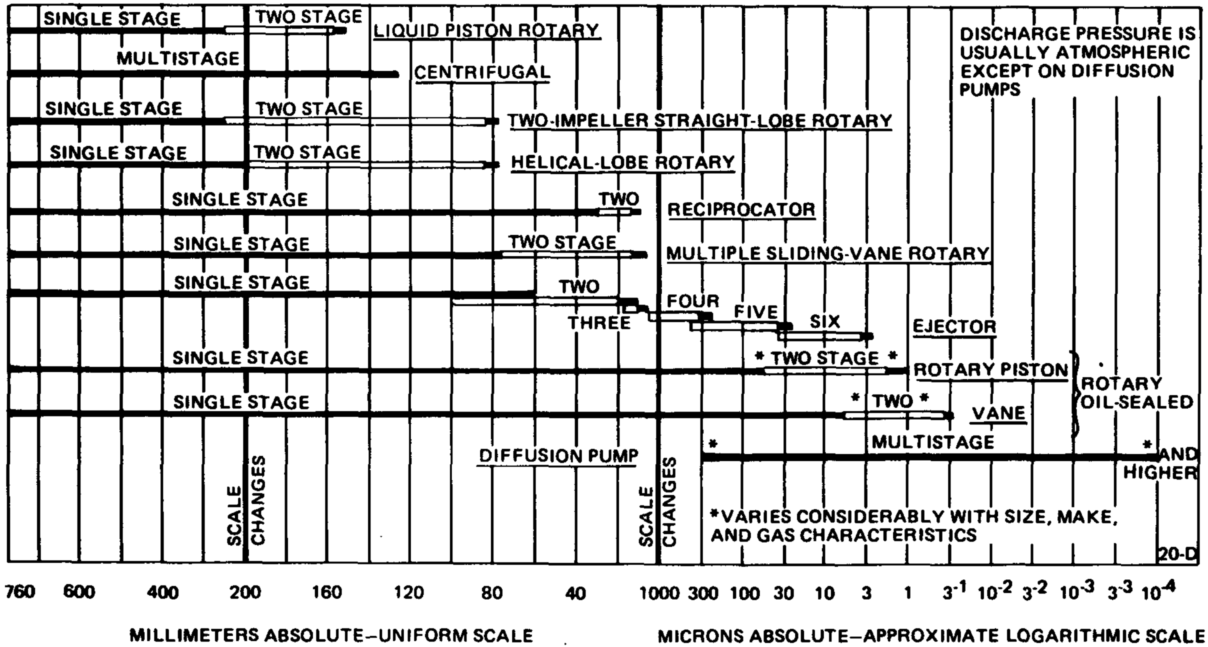
Pump Ranges

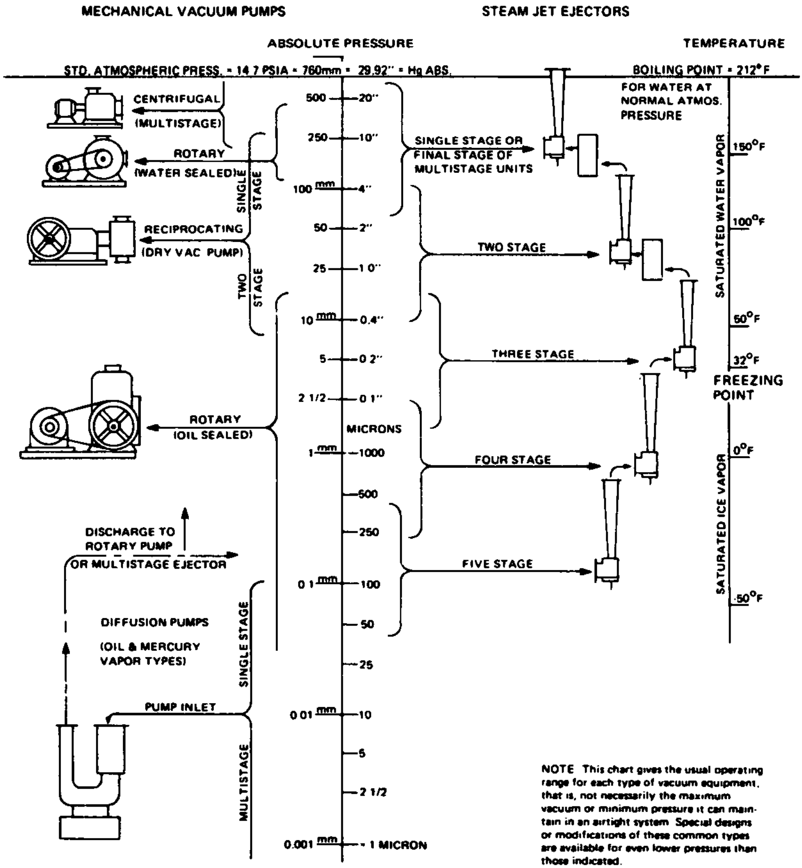
This Appendix is not a part of the requirements of this NFPA document . . . but is included for information purposes only.

Type of Pump	Range of Vacuum
Centrifugal or Reciprocating Mechanical	760 Torr to 10 Torr (101 kPa to 1.3 kPa)
Steam Ejector	760 Torr to 0.050 Torr (101 kPa to 6.7 Pa)
Rotary Oil Sealed Mechanical	760 Torr to 0.010 Torr (101 kPa to 1.3 Pa)
Blowers (Mechanical Boosters)	1 Torr to .001 Torr (133 Pa to 1.3×10^{-1} Pa)
Oil Ejector	0.5 Torr to .001 Torr (66 Pa to 1.3×10^{-1} Pa)
Diffusion	.300 Torr to 10^{-7} Torr (40 Pa to 1.3×10^{-5} Pa)
* Cryogenic Devices (i.e., liquid nitrogen cold traps)	.001 Torr (1.3×10^{-1} Pa)
* Getter	.001 Torr (1.3×10^{-1} Pa)
* Ion	.001 Torr (1.3×10^{-1} Pa)
* Molecular	.001 Torr (1.3×10^{-1} Pa)

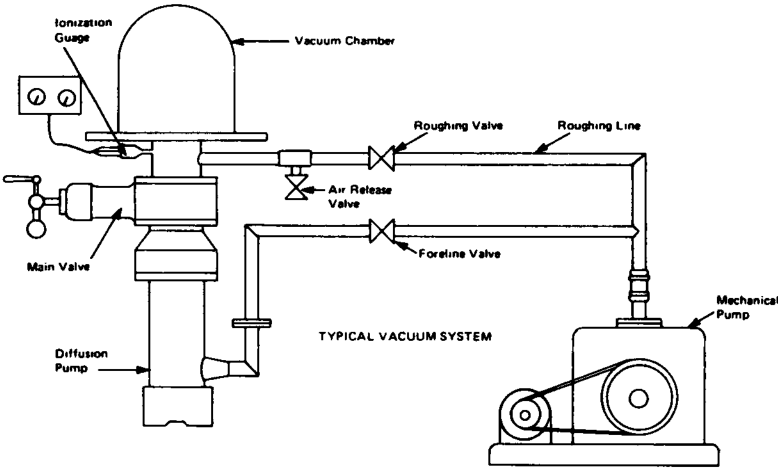
* Generally associated with small specialized systems.

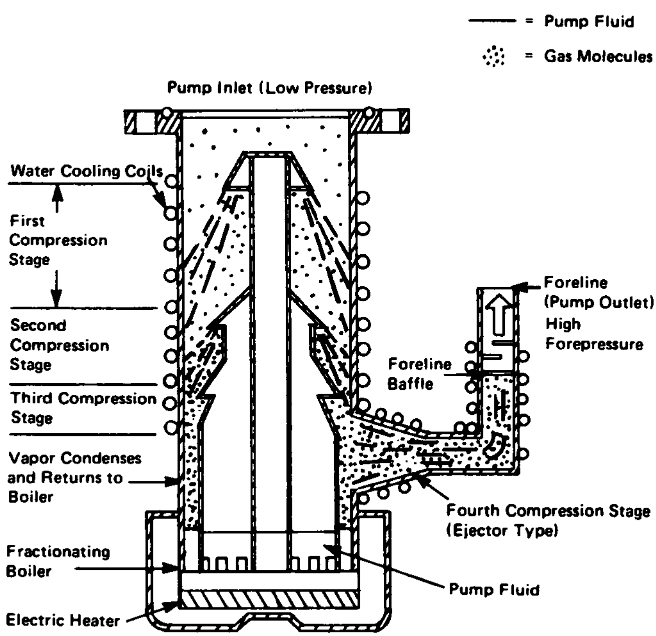
Below are approximate minimum commercial absolute pressure capabilities of the principal types of vacuum pumps.





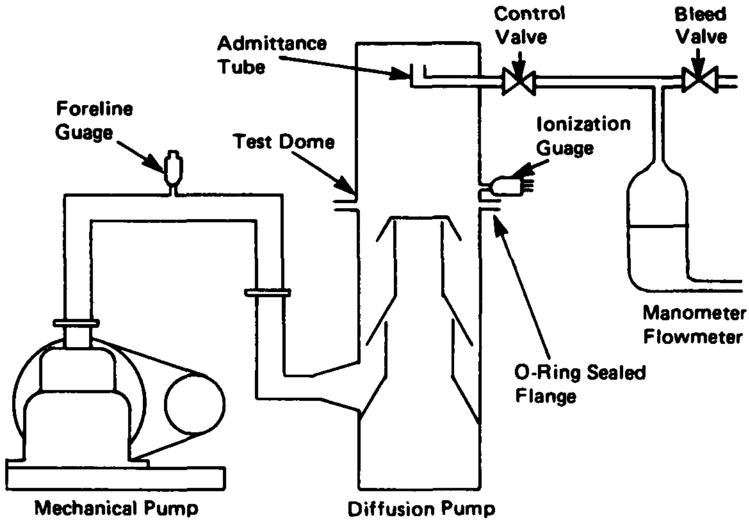
Common types of vacuum-producing equipment used in commercial processes are indicated on this chart, together with the approximate operating range of each one. The central logarithmic scale shows absolute pressures in terms of both millimeters and inches of mercury. The right-hand scale gives the temperatures at which water or ice vaporizes at the corresponding pressures. Combinations of equipment are necessary to obtain extremely low pressures.





HOW A DIFFUSION PUMP WORKS

TEST SET-UP SCHEMATIC



Typical test set-up used to determine effective pumping speeds with variables indicated in the speed curve graph.

Appendix C Engineering Data

This Appendix is not a part of the requirements of this NFPA document . . . but is included for information purposes only.

Conversion of Gas Flows *)

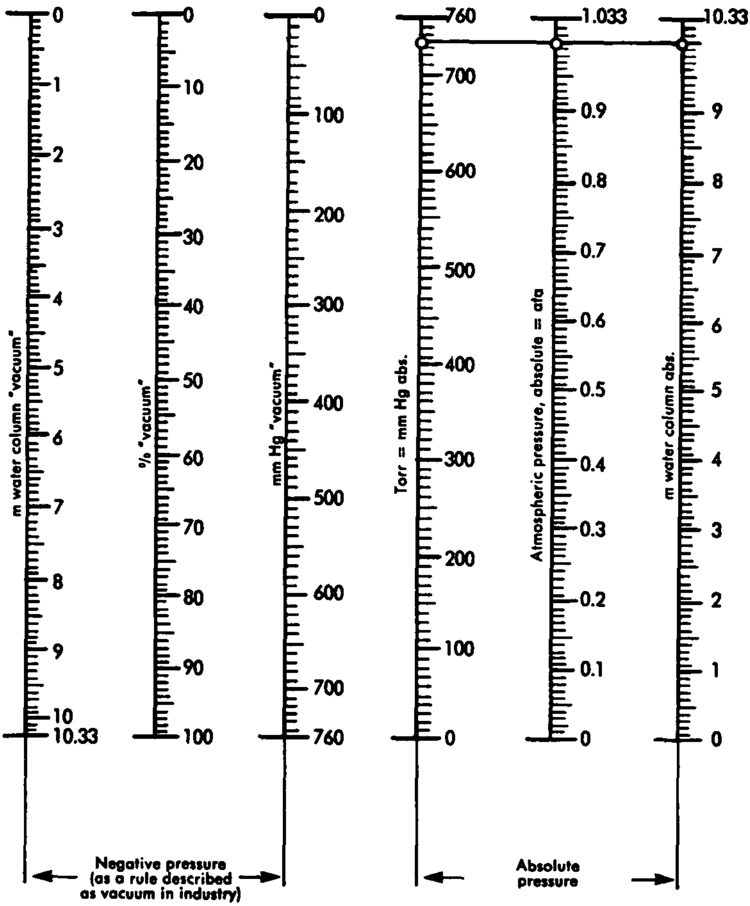
Unit	Torr · l · s⁻¹	Micron · cu. ft · min⁻¹	atm · cm³ · h⁻¹	Micron · l · s⁻¹
Torr · l · s^{-1}	1	2120	4738	10^3
Micron · cu. ft · min^{-1}	$4.719 \cdot 10^{-4}$	1	2.236	0.4719
atm · $cm^3 \cdot h^{-1}$	$2.110 \cdot 10^{-4}$	0.447	1	0.21
Micron · l · s^{-1}	10^{-3}	2.120	4.738	1

Conversion of Pumping Speeds*)

Unit	l · s^{-1}	$m^3 \cdot h^{-1}$	cu. ft · min^{-1}
l · s^{-1}	1	3.60	2.12
$m^3 \cdot h^{-1}$	0.278	1	0.589
cu. ft · min^{-1}	0.472	1.70	1

*) conversion is effected by multiplying with the factors shown in the table.

Comparison of Units of Pressure Used in the Rough Vacuum Range



Conversion from °C to °F