Technical Information

Determining Energy Requirements - Air & Gas Heating

Air & Gas Heating — Cryogenics

Industrial gases are usually stored in a liquid state with heat being added to vaporize and boil off the gas as usage requires. General heat equations apply except that pipes, tubes and vessels containing the cryogenic fluid or gas frequently represent a heat source rather than a heat loss. If the size and materials of the tanks or vessels are known, then heat calculations for the temperature rise can be performed as in standard vessel heating or boiler problems. The following example is typical of a cryogenic heating application.

Problem — Vaporize and preheat 30,000 SCFH of liquid Nitrogen (N_2) from -345°F to 70°F at atmospheric conditions. The properties of N_2 from Cryogenic Gas Tables are:
Boiling point, -320°F
Specific heat Btu/lb/°F = 0.474 (liq.), 0.248 (gas)
Latent heat of vaporization = 85.7 Btu/lb
Atm. density of N_2 at 32°F = 0.0784 lb/ft³.

Solution — Amount of liquid N_2 to be vaporized 30,000 SCFH x 0.0784 lb/ft³ = 2,352 lbs/hr

1. **Raise** liquid from -345°F to -320°F (boiling point) ΔT = 25°F.

$$kW = \frac{Wt \times C_p \times \Delta T}{3412 \text{ Btu/kW}} \times SF$$

Where:
Wt = Weight of material in lbs
C_p = Specific heat of the liquid N_2
ΔT = Temperature rise in °F
SF = Suggested safety factor of 20%

$$kW = \frac{2{,}352 \text{ lbs} \times 0.474 \times 25}{3412 \text{ Btu/kW}} \times 1.2 = 9.8 \text{ kW}$$

2. **Vaporize** the liquid N_2

$$kW = \frac{2{,}352 \text{ lbs} \times 85.7}{3412 \text{ Btu/kW}} \times 1.2 = 70.9 \text{ kW}$$

3. **Raise** the temperature of the N_2 from boiling point -320°F to 70°F — ΔT = 390°F.

$$kW = \frac{2{,}352 \text{ lbs} \times 0.248 \times 390}{3412 \text{ Btu/kW}} \times 1.2 = 80 \text{ kW}$$

Total kW/hr required = 9.8 + 70.9 + 80 = 169.7

Equipment Recommendations — Generally, cryogenic applications utilize both a vaporizer unit and a gas preheater. High watt density heaters immersed in the cryogenic fluid can be used for the vaporizer. Standard circulation heaters and watt densities are recommended for gas preheating. Protect the heater terminals from frost and moisture with element seals and liquid tight terminal covers.

Material Recommendations — Ordinary carbon steel is subject to brittle fracture at temperatures below -20°F and is generally not recommended. Stainless steel, high nickel bearing alloys or aluminum alloys may be used. Use Teflon® for gaskets asTeflon® remains pliable at low temperatures.

Air & Gas Heating — Batch Ovens

Most oven applications consist of heating work product inside an insulated enclosure. Heat loss calculations involve the determination of the heat requirements to heat the enclosure and work product using heated air circulated by natural or forced convection. Any make up or ventilation air must also be considered. The following example outlines the calculation of the heat required for a typical oven heating application.

Problem — An oven with inside dimensions of 2 ft H x 3 ft W x 4 ft D is maintained at 350°F. The oven has sheet steel walls with 2 inches of insulation and is ventilated with 400 cfh (ft³/hr) of 70°F air which exhausts to the outside to remove fumes. The oven is charged with 250 lbs of coated steel parts on a steel tray weighing 40 lbs. The process requires the parts to be heated from 70°F to 350°F in 3/4 hour.

Weight of steel = 290 lbs
Specific heat of steel — 0.12 Btu/lb/°F
Weight of air = 0.080 lbs/ft³ at 70°F
Specific heat of air = 0.24 Btu/lb/°F
Temperature rise = 280°F
Surface losses with 2 inch insulation = 18 W/ft²/hr at 280°F temperature difference (Graph G-126S)
Surface area of oven = 52 ft²
Time = 3/4 hr (0.75)
Airflow rate = 400 ft³/hr

Solution —

1. **Calculate** kWh required to heat metal.

$$kW = \frac{290 \text{ lbs} \times 0.12 \text{ Btu/lb/°F} \times 280\text{°F}}{3412 \text{ Btu/kW}} = 2.86 \text{ kW}$$

2. **Calculate** kWh required to heat ventilated air

$$kW = \frac{CFM \times lbs/ft^3 \times C_p \times \Delta T \times t}{3412 \text{ Btu/kW}} = 0.47 \text{ kW}$$

Where:
CFM = Air flow rate (400)
Lbs/ft³ = Density of air (0.080)
C_p = Specific heat of air (0.24)
ΔT = Temperature rise (280)
t = Time in hours (0.75)

3. **Calculate** surface losses. Since the oven is already at temperature, losses are at full value.

$$kW = \frac{18 \text{ W/ft}^3\text{/hr} \times 52 \text{ ft}^2 \text{ area} \times 0.75 \text{ hr}}{1{,}000 \text{ W/kW}} = 0.70 \text{ kW}$$

4. **Total** kW = 2.86 + 0.47 + 0.70 = 4.03 kW

5. **For Oven Applications**, add 30% to cover door losses and other contingencies. kWh required (including safety factor) is

$$kWh = \frac{kW}{t} = \frac{4.03 \text{ kW}}{0.75 \text{ hrs}} = 5.37 \text{ kW} \times 1.3 = 6.98 \text{ kW}$$

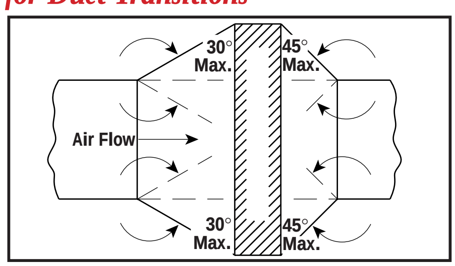
Equipment Recommendations — Several process air heaters, including strip heaters, finstrips, bare tubulars or type OV oven heaters, are suitable for oven heating applications.

Pressure Drop for Process Air Heaters

The pressure drop through TDH and ADH process air heaters with bare tubular or finned tubular elements, CAB heaters with finstrip elements, and ADH and DH air heaters with finned tubular elements will vary considerably depending on product design and construction. Chromalox sales engineering can provide pressure drop calculations for virtually any duct heater (or circulation heater) application. Graphs G-112S3, G-189S1, G-227-2, and G-227ADH on the following page provide guidance for estimating the pressure drop for many Chromalox process air heaters[1]. Graph G-189S1 can be used for most finned tubular applications providing the elements are mounted in a three or six row configuration.

Transitions in Ducts — In some air distribution systems, the duct heater may be considerably larger or smaller than the associated ductwork. The duct heater can be adapted to different size ductwork by installing a sheet metal transition. The transition must be designed so that the slope on the upstream side of the equipment is limited to 30° (see below). On the leaving side, the slope should not be more than 45°.

Recommended Dimensions for Duct Transitions



Note 1 — Contact the factory for pressure drop calculations for duct heaters mounted lengthwise or in series and for GCH gas circulation heaters. These applications require special calculations for proper application and air handler sizing.

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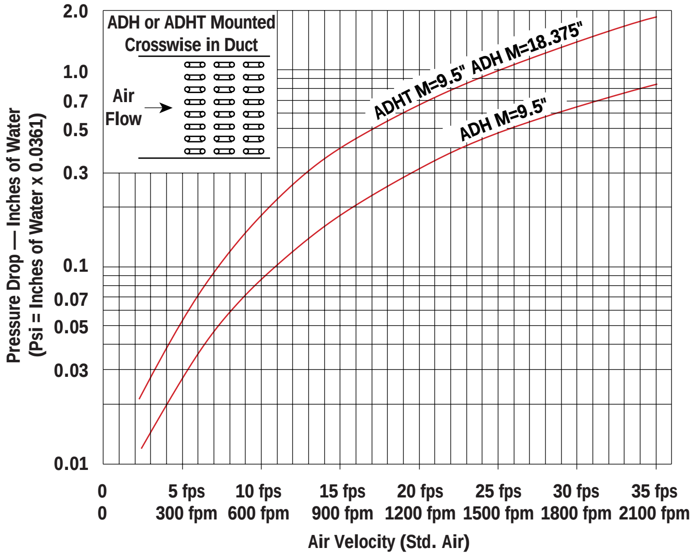
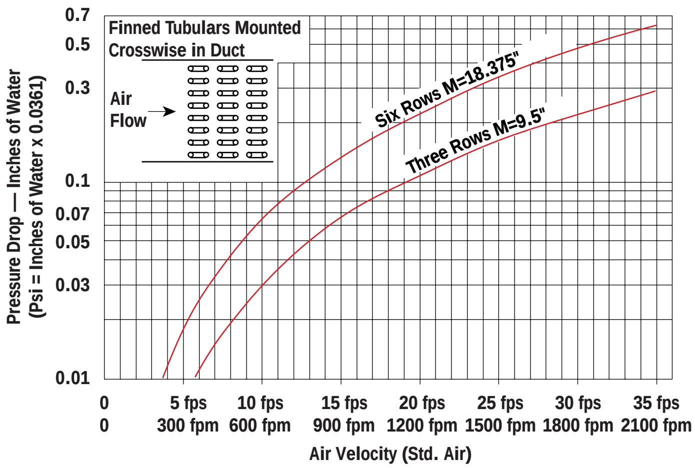
Determining Pressure Drop - Air and Gas Heating

Graph G-227ADH — Pressure Drop Vs. Velocity ADH and ADHT Tubular Element Air Heaters



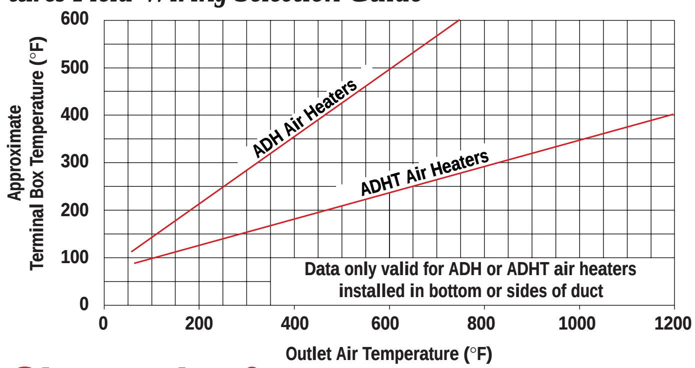
Note — Contact factory for pressure drop calculations for ADH/ADHT air heaters mounted lengthwise in duct and ADHT heaters where M is greater than 9.5"

Graph G-189S1 — Pressure Drop Vs. Velocity Fintube® Elements and Air Heaters

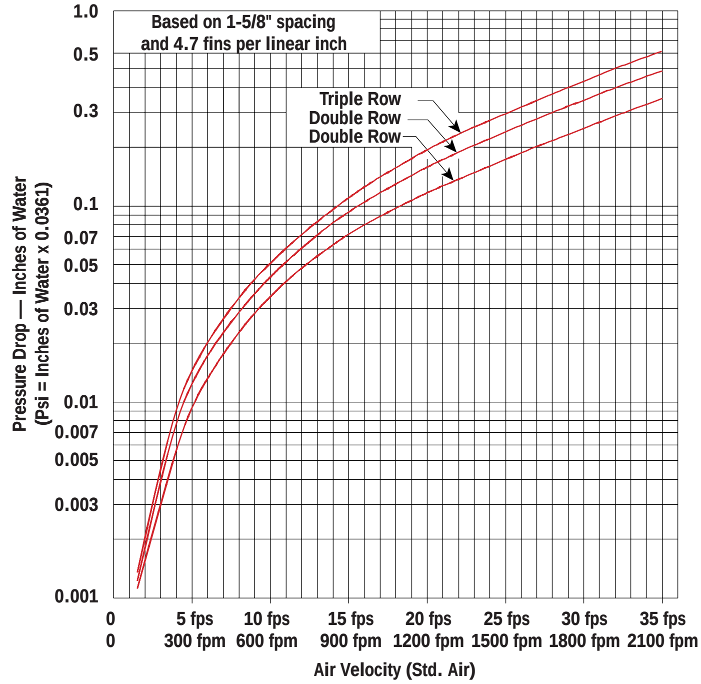


Note — Contact factory for pressure drop calculations for finned tubular element air heaters mounted lengthwise in duct.

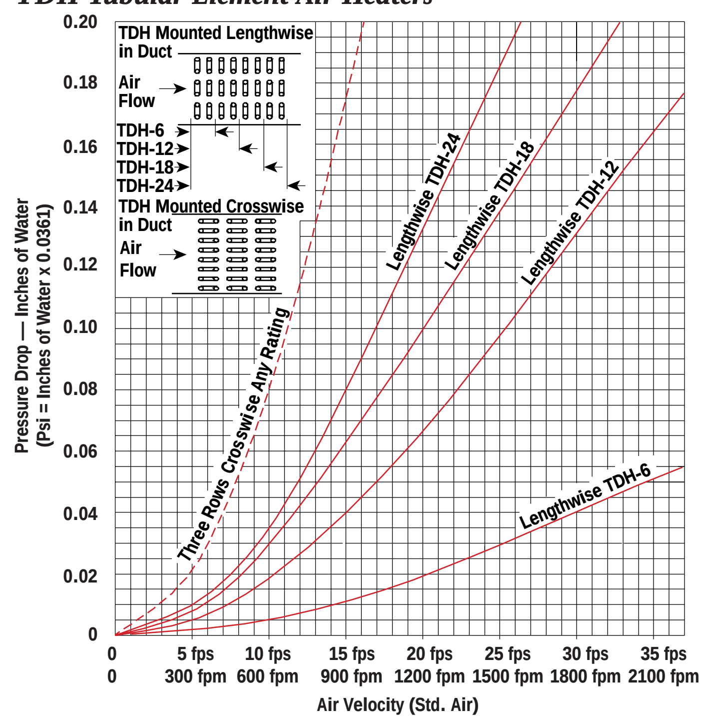
Graph ADHTB — ADH/ADHT Terminal Box Temperatures Field Wiring Selection Guide



Graph G-112S3 — Pressure Drop Vs. Velocity Finstrip® and CAB Air Heaters



Graph G-227-2 — Pressure Drop Vs. Velocity TDH Tubular Element Air Heaters



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Determining Energy Requirements - Air & Gas Heating

Air & Gas Heating with Circulation Heaters

To calculate the heat energy requirements for heating compressed air or gases, the first step is to determine the flow rate in pounds per hour. If the density of the air or gas under the actual pressure is known, the kW requirements can be calculated directly. The following example illustrates this procedure.

Example — Heat 20 ACFM of air at 30 psig from 60°F to 210°F. From the Properties of Air Chart, the density of air at 60°F and 30 psig is 0.232 lb/ft³ with a specific heat of 0.24 Btu/lb/°F. The kW required can be calculated from the formula:

$$kW = \frac{\text{ACFM x lbs/ft}^3 \text{ x 60 min x } C_p \text{ x } \Delta T}{\text{3412 Btu/kW}} \text{ x SF}$$

Where:
ACFM = Actual flow in ft³/min at inlet temperature and gauge pressure (psig)
Lbs/ft³ = Actual density at inlet temperature and gauge pressure (psig)
Cp = Specific heat of air or gas at inlet temperature and gauge pressure (psig)
ΔT = Temperature rise in °F
SF = Suggested Safety Factor

$$kW = \frac{20 \text{ x } 0.232 \text{ x } 60 \text{ x } 0.24 \text{ x } (210 - 60°F)}{3412} \text{ x } 1.2$$

$$kW = \frac{\text{278.4 lbs/hr x 24 x 150}}{3412} \text{ x 1.2 = 3.52 kW}$$

When the density and specific heat of a gas at a specific temperature and pressure are unknown, the actual flow rate can be converted to a known pressure and temperature using the physical laws of gases.

Example — Heat 45 ACFM of Nitrogen (N_2) at 35 psig from 50°F to 300°F. From the Physical and Thermodynamic Properties of Common Gases Chart, the density of Nitrogen at 70°F is 0.073 lb/ft³ with a specific heat of 0.2438 Btu/lb/°F. Convert 45 ACFM at 35 psig and 50°F to SCFM of Nitrogen at 70°F using the following formula:

$$\text{SCFM = ACFM x } \frac{\text{Actual psia}}{\text{14.7 psia}} \text{ x } \frac{\text{Standard T}}{\text{Actual T}}$$

SCFM = Std. ft³/min at 14.7 psia and 70°F
ACFM = Actual flow in ft³/min at inlet temperature and gauge pressure (psig)
Actual psia = gauge pressure in lb/in² + 14.7 psia
14.7 psia = absolute pressure in lb/in²
T = °Rankine (°F + 460)

$$\text{SCFM} = 45 \text{ x } \frac{(35 + 14.7)}{\text{14.7 psia}} \text{ x } \frac{(70 + 460)}{(50 + 460)}$$

SFCM = 158.1 ft³/min

Using the calculated SCFM in place of ACFM in equation A, the kW required is:

$$kW = \frac{158.1 \text{ x } 0.073 \text{ x } 60 \text{ x } 0.2438 \text{ x } (300 - 50)}{3412} \text{ x } 1.2$$

kW = 14.8 kW

Determining Maximum Sheath & Chamber Temperatures

When heating air or gases in insulated pipe chambers or circulation heaters, the pipe wall temperature will normally exceed the outlet gas temperature. Excessively high wall and/or sheath temperatures can create an unsafe or dangerous condition. Maximum sheath and chamber temperatures can be estimated using the mass velocity of the gas and Graph G-237. In the above air heating example, assume a 4.5 kW Series 3 heater rated 23 W/in² has been selected. From Chart 236, the free cross sectional area of a Series 3 (3 inch) heater is 0.044. Calculate mass velocity from the following equation:

$$\text{Mass Velocity (lbs/ft/sec)} = \frac{\text{Flow lbs/hr}}{\text{Free area ft}^2} \div 3{,}600$$

$$\text{Mass Velocity} = \frac{\text{278 lbs/hr}}{\text{0.044 ft}^2} \div 3{,}600$$

Chart 236 — Circulation Heaters Free Internal Cross Sectional Area

Pipe Body Nom. IPS (Std.)	Total Area (Ft²)	Free Area (Ft²)	No. 0.475" Elements
2	0.023	0.018	2
3	0.051	0.044	3
5	0.139	0.124	6
8	0.355	0.303	18
10	0.566	0.481	27
12	0.785	0.696	36
14	0.957	0.847	45
16	1.268	1.091	72
18	1.622	1.357	108

Mass Velocity = 1.75 lbs/ft/sec

On Graph G-237, locate the mass velocity (1.75) on the horizontal axis. From that point, locate a 23 W/in² curve. Read across to the vertical axis (sheath temperature rise above outlet temperature) to 880°F. Adding 880°F + 210°F (outlet temp.) = 1090°F sheath temperature. Averaging the sheath and outlet temperatures (1090°F + 210°F ÷ 2), yields a maximum chamber temperature of 650°F.

Since the maximum chamber wall temperature is less than 750°F, a stock GCH heater with a carbon steel vessel and INCOLOY® elements rated 23 W/in² can be used.

Graph G-237 — Sheath Temperature Vs. Mass Velocity