Basics of Atmospheric Burner Design

Quick Dive into Basic Concepts

Basic Principles

Navier–Stokes Equations

3 – dimensional – unsteady

Coordinates: (x,y,z) Time : t Density: ρ Pressure: p Reynolds Number: Re

Velocity Components: (u,v,w) Stress: τ Heat Flux: q Prandtl Number: Pr

Continuity:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0$$

X – Momentum:

$$\frac{\partial(\rho u)}{\partial t} + \frac{\partial(\rho u^2)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} + \frac{\partial(\rho uw)}{\partial z} = -\frac{\partial p}{\partial x} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z}\right]$$

Y – Momentum:

$$\frac{\partial(\rho v)}{\partial t} + \frac{\partial(\rho uv)}{\partial x} + \frac{\partial(\rho v^2)}{\partial y} + \frac{\partial(\rho vw)}{\partial z} = -\frac{\partial p}{\partial y} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{yz}}{\partial z}\right]$$

Z – Momentum:

$$\frac{\partial(\rho w)}{\partial t} + \frac{\partial(\rho uw)}{\partial x} + \frac{\partial(\rho vw)}{\partial y} + \frac{\partial(\rho w^2)}{\partial z} = -\frac{\partial p}{\partial z} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z}\right]$$

Total Energy – Et:

$$\frac{\partial(E_T)}{\partial t} + \frac{\partial(uE_T)}{\partial x} + \frac{\partial(vE_T)}{\partial y} + \frac{\partial(wE_T)}{\partial z} = -\frac{\partial(up)}{\partial x} - \frac{\partial(vp)}{\partial y} - \frac{\partial(wp)}{\partial z}$$

$$+ \frac{1}{Re_r}\left[\frac{\partial}{\partial x}(u\,\tau_{xx} + v\,\tau_{xy} + w\,\tau_{xz}) + \frac{\partial}{\partial y}(u\,\tau_{xy} + v\,\tau_{yy} + w\,\tau_{yz}) + \frac{\partial}{\partial z}(u\,\tau_{xz} + v\,\tau_{yz} + w\,\tau_{zz})\right]$$

$$- \frac{1}{Re_r Pr_r}\left[\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial q_z}{\partial z}\right]$$

Types of Burners

- Atmospheric/natural draft
  - Most common, uses air at atmospheric pressures for mixing
  - Tens of thousands of BTU/hr
- Power
  - Used in large industrial application, uses blowers
  - Millions of BTU/hr

Why Atmospheric?

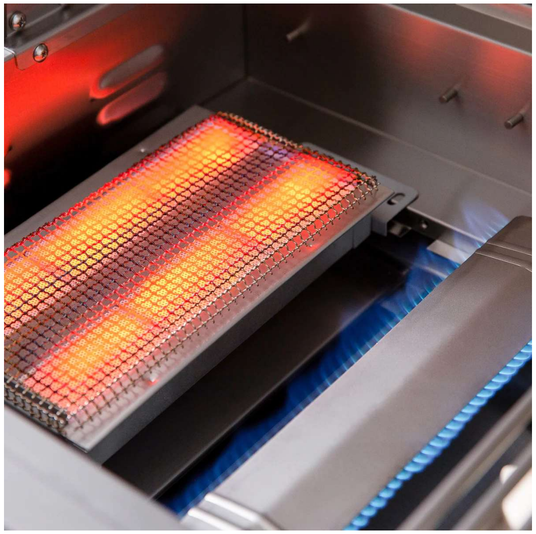
- Versatility – can be made in a wide range of sizes, power outputs, and use a variety of fuels
- Simple construction – can have no moving parts, other than controls
- Cheap
- Safe – usually operate a lower pressures

Characteristics of a Good Burner

- Controllability over a wide pressure range, no flash back
- Uniform distribution of heat
- Complete combustion – no sooty flames or CO
- No lifting of the flame – exit speed of the fuel/air mix is too fast at the ports
- No floating flames – inadequate primary air
- Rapid ignition
- Quiet operation
- Durable – reliable operation through thousands of heating/cooling cycles

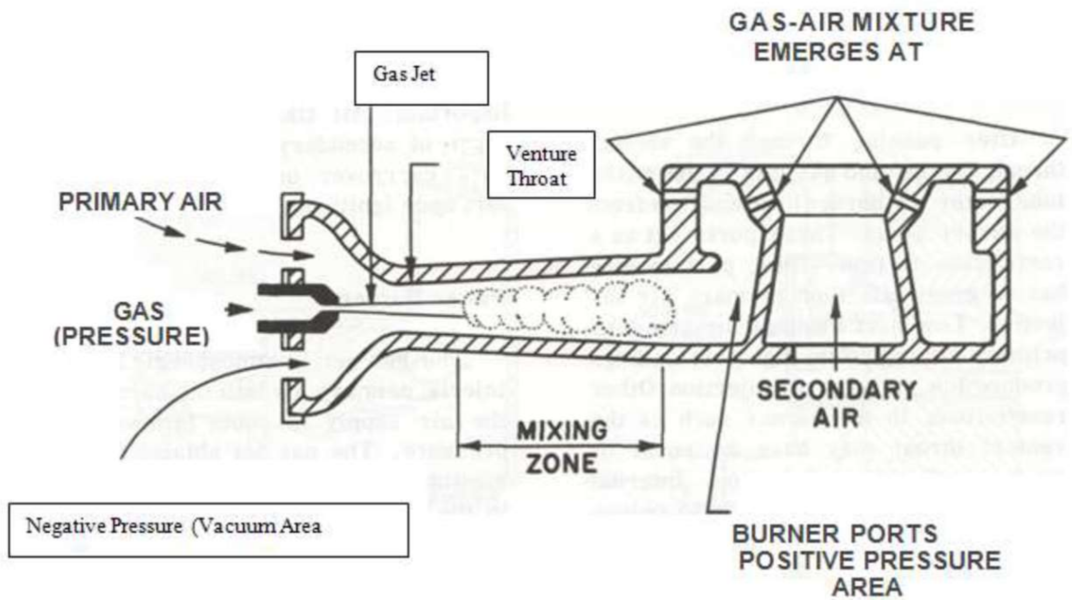
Burner Types

- Drilled Port
- Slotted Port
- Ribbon Port
- Single/Monoport
- Infrared
- Jet/Inshot
- Impingement
- Target
- Pilot



The Role of Air

- Three Types of Air
  - Primary - air introduced to fuel stream before mixing and emitting from burner ports
  - Secondary - other air, can be from any other source
- Primary + Secondary = Total
- Nat gas: 10:1
- Propane: 20:1
- Butane: 30:1
- Anything more is Excess Air



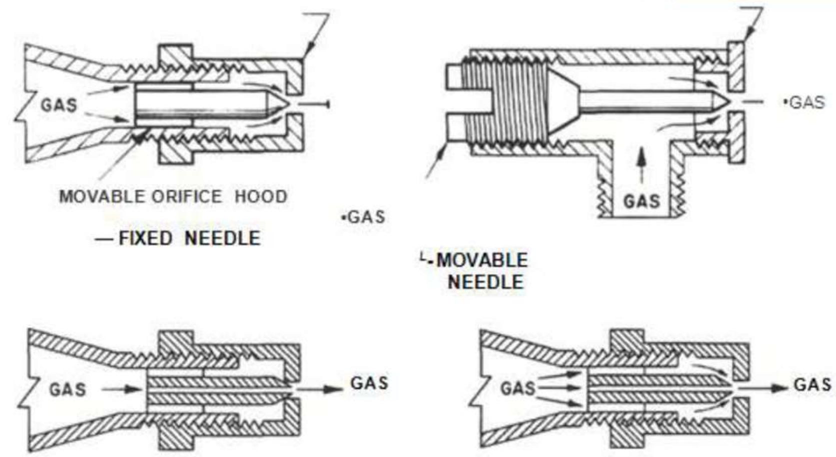
$$\text{Air injecting ability} = \frac{\sqrt[4]{pS_g}}{\sqrt{H}}$$

Ignition Methods

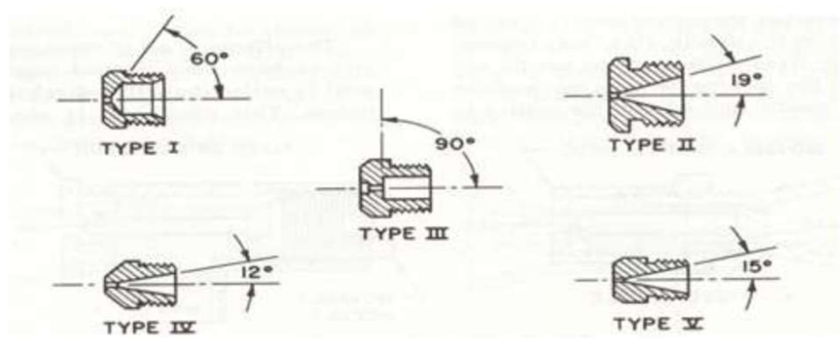
- Pilot
  - Small flame around 500-1000 Btu/Hr
- Sparker
  - Electrical discharge, high voltage/low amperage (usu. ~15k VDC)
  - Above breakdown voltage
- Combination

Parts in Detail - Orifice

- Responsible for regulating gas flow
- Coefficient of Discharge, K, depends on orifice design
- Fixed and Nonadjustable Orifices
- Possible issues:
  - Orifice and mixing body misalignment
  - Obstructed orifice



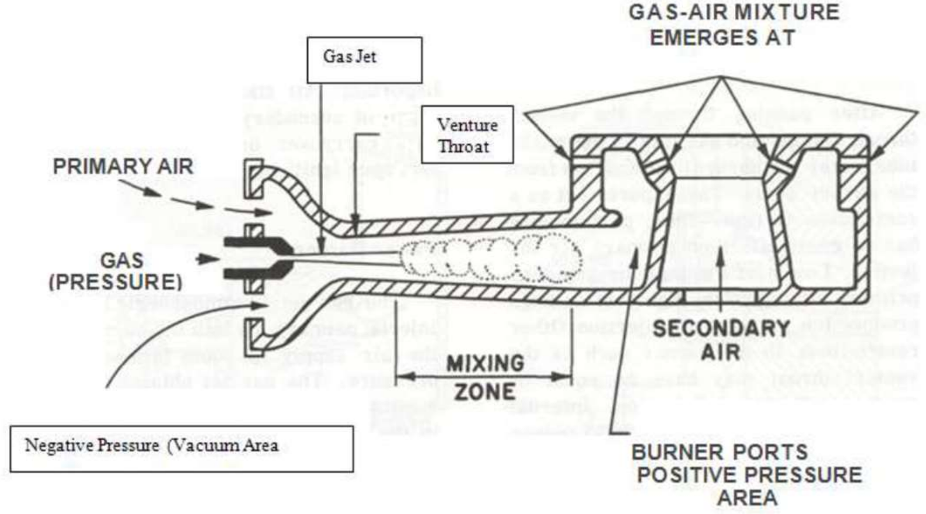
$$q = 1658.5KA\sqrt{\frac{P}{S_g}}$$



ORIFICE TYPE	ORIFICE DISCHARGE COEFFICIENT
I	0.80
II	0.82
III	0.65
IV	0.83
V	0.83

Parts in Detail – Venturi/Mixing Tube

- Venturi accelerates fuel/air mix, aiding in homogenization of the gases
- Throat/port ratio
  - 0.22-0.91 for Nat Gas
  - 0.24-0.68 for manufactured gas
- Mixing tube angle of divergence usu. ~2°-3°
- Straight mixing tubes are not as good as venturi type



$$P = \frac{\sqrt[4]{pS_g}}{\sqrt{H}} * \frac{2.5 * 10^{-5} A_m A_p}{\sqrt{R}} * \frac{23.24}{\sqrt{T}}$$

P = {[(pd)^0.25/(H)^0.50][2.5X10^5(AmAp)/(R)^0.50][(540)^0.50/(T)^0.50]}
For mixing tube internal slope <3.5 deg

The first term has significant effect on burner performance

Parts in Detail – Burner Ports

- Burner port diameter has no significant effect on performance
- Burner depth has pronounced effect on injection of primary air
- Spacing
  - In our scales, the closer the ports are spaced, the greater the primary air needed, though not by much. Single percentage point increases
  - Ports too close together will result in slightly yellow-tipped flame

EFFECT OF PORT DEPTH ON PRIMARY AIR INJECTION--MANUFACTURED GAS

	PRIMARY AIR INJECTED, % OBSERVED	
PORT DEPTH #36 Drill Size	20,000 Btu/Hr per square inch of port area	30,000 Btu/Hr per square inch of port area
0.0469	108.500	80.800
0.1250	107.100	79.400
0.2500	102.000	76.800
0.3125	100.000	75.900
0.3750	97.900	73.500
0.5000	95.900	71.900
0.7500	93.500	69.500

Realities of Atmospheric Burners

- A lot of the designs are experimentally derived, due to the nature of fluid mechanics (Navier-Stokes)
- These designs were well-defined by the 1950’s
- Making your own burners will take some trial and error
- One of those sciences, like thermodynamics, that has lots of tables

My Suggestions for Model Burners

- Use a regulator, if possible
- Try to incorporate venturi
- Lengthen mixing tube
  - Is a mixing "coil" possible?
  - Mixing baffles to increase turbulence?
- Adjustable choke might help
  - Primary air ports on sides and rear of orifice
- Do not recommend Type III orifice
  - Adjustable orifice might be ideal, good luck making one so small

Next Year's Topic

- Units of Measure, US Customary Units and their SI Derivatives