PDHonline Course M273 (8 PDH)

Fundamentals of Gas Combustion

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LIST OF SYMBOLS USED

ANSI = American National Standards Institute

Btu = British Thermal Unit

vol, (V) = volume (Ft^3)

T(a) = absolute temperature (° R or ° K)

T, t = temperature (° F or ° C)

C = centigrade

F = Fahrenheit

cc, (cm^3) = cubic centimeter

cu ft, (Ft^3) = cubic foot

cu in, (In^3) = cubic inch

cm, (m^3) = cubic meter

ρ = density (lbf / Ft^3)

Sp.Gr = specific gravity

Q = flow rate (Ft^3 / hr.)

P = pressure (inches W.C. or PSI)

H.V. = heating value (Btu / Ft^3)

m = pound mass

μ = compressibility factor (ratio of volume observed to volume of ideal gas)

n = number of moles of gas

K = orifice factor

A = area ($inches^2$)

R = universal gas constant (1545 Ft-lbf / lb-mole ° R)

AF = air-fuel ratio

FA = fuel-air ratio
fpm = feet per minute

fps = feet per second

ft = feet

ft-lb = foot pound

gal = gallon

HHV = higher heating value, Btu/Ft^3

LHV = lower heating value, Btu/$Ft.^3$

in = inch

in-lb = inch-pound

W.C. = inches water column

Kcal = kilocalorie

l = liter

lb = pound

UEL = upper explosive limit (%)

LEL = lower explosive limit (%)

ppm = parts per million

psf = pounds per square foot

psi = pounds per square inch

psia = pounds per square inch, absolute

psig = pounds per square inch, gage

SCF = standard cubic foot (measured at 60 º F and 14.7 psia)

sec = second

STP = standard temperature and pressure (60 º F and 14.7 psia)

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INTRODUCTION

This course is designed to provide an overview of the fundamentals of gas combustion, primarily as applied to gas-fired appliances such as ranges, water heaters, space heating equipment, zone heaters, etc. The principles of combustion are basically universal although the hardware needed to bring about the combustion process and the disposal of the products of combustion varies considerably. We will be studying the following:

1.) Nature of hydrocarbons and fuel gases
2.) Occurrence of fuel gases in nature
3.) Types of fuel gases
4.) The combustion process and the basic chemistry of combustion
5.) Gas burners and gas burner operation
6.) Venting the products of combustion
7.) "Troubleshooting" a gas-fired system; i.e., burner problems
8.) Testing requirements

Included with this course is an appendix that contains information that will be very helpful in understanding the material given in the body of the text itself. I have given significant thought and time to developing a glossary of terms that will be invaluable as you progress through the course. I would also recommend you review the list of symbols and the glossary of terms before starting the course. As with any technology, there is a specific vocabulary that has developed over the years that remains descriptive and usable today and the glossary will aid your understanding of the vocabulary as you progress. This course will NOT give you all of the necessary information to design gas burners or gas-fired systems. It will certainly give you an overview as to the thought processes, the basic background and the testing required to understand the work that is absolutely necessary for success. Successful companies, designing any product, will have those "in-house" specifications, standards and test procedures that supplement existing published. These address specific areas of product design and nomenclature.

Chapter 1

FUEL GAS TYPES

NATURAL GAS: Natural gas is a naturally occurring mixture of hydrocarbons and non-hydrocarbon gases found in porous formations beneath the earth's surface. The principal constituent of natural gas is methane. The natural gas of commerce, supplied to fuel gas markets, usually contains from 80 to 95 percent methane and lesser amounts of ethane and propane. The heating value ranges from 900 to 1200 Btus/Ft^3 and the density varies from 0.58 to 0.79. The six areas of the United States in which natural gas is found are divided into fields, roughly, as follows:

1.) Appalachian
2.) Indiana
3.) Mid-continent
4.) Texas
5.) Rocky Mountains
6.) California

DRY: The term "dry" indicates less than 0.10 gallon of gasoline vapor per 1,000 cubic feet of recovered gas. "Sweet" and "sour" are terms applied to indicate the absence or presence of hydrogen sulfide. The natural gas of commerce is dry although its composition need not be that high in methane. (NOTE: All of the discussion and calculations in this document are made using the values for "dry" natural gas.)

WET: When the amount of condensable hydrocarbons are large enough to warrant removal for commercial recovery or because their continued presence would cause operating difficulty, the natural gas is known as "wet". These liquefiable gases are propane, butanes, pentanes, hexanes, etc. Propane and butane in liquid form are called liquefied petroleum gases. By removing condensable components, the concentration of methane in the finished dry gas will be raised to about 90 %.

Natural gas may be classified in three groups, as follows:

GROUP CLASSIFICATIONS FOR NATURAL GAS

Table 1.1

GROUP	NITROGEN (%)	SPECIFIC GRAVITY	% METHANE	HEATING VALUE
High Inert Type	6.3--16.20	0.660--0.708	71.9--83.2	958--1051
High Methane Type	0.10--2.39	0.590--0.614	87.6--95.7	1008--1071
High Btu Type	1.20--7.50	0.620--0.719	85.00--90.10	1071--1124

Observation will indicate that as the percentage of methane increases, the heating value of the gas increases. The "high average" is 1082 Btu/Ft^3 and the "low average" is 1012 Btu/Ft^3. The "nominal average" is 1047 Btu/Ft^3.

One can see from the table below that the general composition of natural gas varies from location to location across the United States. The analyses were made from average samples taken after the processing plant removed gasoline, liquefied petroleum gases, water vapor and any sulfur. It has been discovered that individual wells in any field may vary appreciably from the average results. The following table will indicate the type of variations that may be found in various major fields within the United States.

Table 1.2 Major Fields of Natural Gas Within the United States

LOCATION	METHANE (%)	GROSS HEATING VALUE	SPECIFIC GRAVITY
California Kettleman, North Dome	87.20	1212	0.69
California Kettleman, North Dome	93.00	1080	0.602
California, Rio Vista	94.20	1038	0.59
California, Ventura	83.60	1260	0.706
California, Ventura	92.70	1083	0.604
Illinois--Indiana	97.00	983	N/A
Kansas, Cunningham	62.30	1011	N/A
Kansas, Hugoton	77.00	1005	0.698
Kansas, Otis	71.80	976	N/A
Kentucky	83.40	1083	N/A
Louisiana, Monroe	91.28	997	0.607
Louisiana, Paradis	92.18	1067	0.615
Michigan	75.80	1081	N/A
Mississippi, Gwinville	95.74	989	0.586
Ohio, Canton	86.10	1082	0.62
Ohio, Hinckley-Medina	80.20	1118	0.65
Oklahoma, Hugoton	75.30	1043	0.71
Oklahoma, Hughes County	79.00	1114	N/A
Oklahoma, Keyes	51.50	835	N/A
Pennsylvania, Green County	85.41	1171	0.667
Pennsylvania, Leidy	96.80	1031	0.575
Pennsylvania, Western Penn	85.60	1112	0.623
Texas, Agua Dulce	90.98	1109	0.0631
Texas, Agua Dulce	93.00	1051	0.599
Texas, Carthage	90.29	1093	0.634
Texas, Carthage	91.73	1038	0.607
Texas, East Texas	63.28	1336	0.794
Texas, Hugoton	76.90	1046	0.698
Texas, Hugoton	79.00	967	0.659
Texas, Keystone	86.20	1133	0.63
Texas, Keystone (formations)	78.77	1279	0.73
Texas, Panhandle	81.76	1090	0.681
Texas, Panhandle	81.50	1061	0.669
Texas, Pledger	94.24	1086	0.613
Texas, Tom O'Connor	90.77	1117	0.633
Texas, Wasson	69.52	1238	0.805
Texas, Wasson	76.87	1030	0.684
West Virginia, Northern	85.86	1158	0.648
West Virginia, Terra Alta	98.75	1027	0.561
West Virginia, Wyoming Country	97.75	1036	0.568

It is important to note the ANSI (Z21.1) requirement for Test Gases specifies the density and heating value for the gases used. That information is as follows:

CHARACTERISTICS OF ANSI TEST GASES

	HEATING VALUE		
	Btu/Ft^3)	**MJ/ M^3)**	**Specific Gravity**
GAS A (Natural)	1075	40.1	0.650
GAS B (Manufactured)	535	19.9	0.380
GAS C (Mixed)	800	29.8	0.500
GAS D (N-Butane)	3200	119.2	2.000
GAS E (Propane HD5)	2500	93.1	1.550
GAS F (Propane-Air)	700	26.1	1.160
GAS G (Butane-Air)	1400	52.2	1.420
GAS H (Propane-Air)	1400	52.2	1.300

Table 1.3 Characteristics of ANSI Test Gases Reprinted from ANSI, Z21.1 Standard, Table VIII.

Any time an appliance is tested in accordance with ANSI specifications, using the gases above, the heating value and the specific gravity must be at, or within allowable tolerances, relative to the preceding data. These values represent the "base line" for all other measurements describing the equipment. Variations from the "base line" will sku the data and make the results meaningless.

As you might suspect, natural gas is found across the earth with major fields being in Argentina, Belgium, Canada, Chile, France, Italy, Japan, Netherlands, Poland, Saudi Arabia, Russia, and Venezuela. We will not investigate the characteristics of these fields in this document, but suffice it to say, the constituents, heating values and specific gravity vary in the same fashion as the natural gas found in the United States. A very good general listing may be found by consulting "The Gas Engineers Handbook".

LIQUEFIED PETROLEUM: The term liquefied petroleum gas (LPG) is applied to certain specific hydrocarbons, which are gaseous, under normal atmospheric conditions, but can be liquefied under moderate pressure at normal temperatures. Liquefied petroleum gases are derived from natural gas or oil refinery gases. In the separation of the more dense hydrocarbons from natural gas, natural gasoline and LPG are produced. Commercially available LPG products do not consist of a single component, but are mixtures of hydrocarbons. LPG is used mainly as a fuel although considerable quantities are consumed in the production of chemicals. LPG is converted, generally, from liquid form to gaseous form either by supplying the latent heat of vaporization from the atmosphere through the storage container walls or by using one or more separately heated vaporizers. LPG has been used in undiluted and diluted form for the following purposes:

a.) augmenting manufactured gas or natural supplies during peak load conditions
b.) standby equipment for use in case of supply failure of the base gas
c.) firing of coke ovens especially during peak loads
d.) enriching to the legal heating requirement gases which have suffered a loss during high pressure transmission
e.) base load or total replacement, especially in small properties

COMMERCIAL PROPANE: Commercial propane is a hydrocarbon product composed predominately of propane and / or propylene with fairly rigid specifications as determined by the NGPA.

COMMERCIAL BUTANE: Commercial butane is a hydrocarbon composed predominately of butanes and / or butylenes with fairly rigid specifications as determined by the NGPA.

PROPANE HD5: Propane HD5 is a special grade of propane for motor fuel and other uses requiring more restrictive specifications than commercial propane.

I am showing again the ANSI test gases to indicate the importance of propane, butane and HD5 in the approval processes for certain gas burner appliances and devices.

CHARACTERISTICS OF ANSI TEST GASES

	HEATING VALUE		
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Reprinted from ANSI, Z21.1 Standard, Table VIII.

It is important to note that the delivery pressures vary significantly from natural gas as follows:

ANSI INLET TEST PRESSURES Table 1.4

	TEST PRESSURE Inches W.C.(kPa)		
	REDUCED	**NORMAL**	**INCREASED**
GAS A (Natural)	**3.5(0.87)**	**7.0(1.74)**	**10.5(2.61)**
GAS B (Manufactured)	**3.0(0.75)**	**6.0(1.49)**	**9.0(2.24)**
GAS C (Mixed)	**3.0(0.75)**	**6.0(1.49)**	**9.0(2.24)**
GAS D (N-Butane)	**8.0(1.99)**	**11.0(2.74)**	**13.0(3.23)**
GAS E (Propane HD5)	**8.0(1.99)**	**11.0(2.74)**	**13.0(3.23)**
GAS F (Propane-Air)	**3.0(0.75)**	**6.0(1.49)**	**9.0(2.24)**
GAS G (Butane-Air)	**3.5(0.87)**	**7.0(1.74)**	**10.5(2.61)**
GAS H (Propane-Air)	**3.0(0.75)**	**6.0(1.49)**	**9.0(2.24)**

As you can see, the delivery pressure for propane and butane are 11.00 inches W.C. whereas natural gas is 7.00 inches W.C. As with heating value and specific gravity, the test pressure is absolutely critical. Reduced, normal and increased pressures **MUST** be held within stated tolerances for the test data to be meaningful.

REFINERY OIL GASES: The predominant production of refinery oil gas has been used for heating refinery equipment. Its composition, principally saturated and unsaturated hydrocarbons, gives it a heating value from 1300 to 2000 Btu/Ft^3, although in well-operated refineries the heating value is generally maintained between 1400 and 1700 Btu/Ft^3. These gases are similar in heating value and specific gravity to the gas produced by cracking gas oil in a carburetted water gas set. There are two types of equipment to produce oil gases: 1.) the "straight shot" and 2.) the Jones process. The introduction of natural gas in the larger centers on the Pacific Coast has decreased the use of this type of gas so that little is now made except in the Pacific Northwest.

COAL GAS: Coal gas is made by the distillation of the volatile matter from coal with some steaming of the coke to produce water gas. This type of gas is generated in so-called retorts. It is very high in hydrogen and methane, with lesser amounts of carbon monoxide and illuminants.

COKE OVEN GAS: Coke oven gases are produced in an analogous manner as retort coal gases. The size of the charge, the operating temperature and several other features of the process are somewhat different and tend to produce larger amounts of by-products and a more uniform coke.

BLAST FURNACE GAS: One by-product from the operation of a blast furnace used in the production of pig iron is called blast furnace gas. It is derived from the partial combustion of coke. Due to the high temperatures needed for making iron, the gas contains 27 % carbon monoxide and over 70 % inert gases, giving it the lowest heating value of any commercially used gases. This, as you may guess, is a huge impediment to its use.

BLUE GAS (WATER GAS): Blue water gas is the reaction of steam with incandescent carbon. The name is derived from the characteristic color of its flame, which is blue because of the high percentage of hydrogen and CO.

CARBURETTED WATER GAS: The manufacture of blue water gas is the first step in the making of carburetted water gas. It is produced from the former by enriching with oil gas made from fuel oil injected into a chamber or chambers heated internally or by the combustion of gas formed in the blue gas generator during the run or on to the fuel bed.

BUTANE-AIR AND PROPANE-AIR: Butane-air or propane-air consists of mixtures of propane or butane and air to produce fuel gases with any desired heating value from 450 to 2000 Btu/Ft^3. Many natural gas companies use them as the gas supply for small communities and as peak load gas.

ACETYLENE: Acetylene is used primarily for cutting and welding operations requiring high flame temperatures. It has also been used as an illuminant for lighting.

The following table will indicate typical values for manufactured gases. As you can see, the heating values are considerably lower than natural or the commercially available LP gases; i.e., propane and butane. This is not a complete list but does indicate the method of manufacturing, giving the nominal heating value and the nominal specific gravity.

MANUFACTURED GASES--TYPICAL ANALYSES

GAS TYPE	SOURCE	SPECIFIC GRAVITY	GROSS HEATING VALUE
Acetylene	Calcium carbide & water	0.91	1499
Blast Furnace	By-product, pig iron	1.04	81
Blue	Coke	0.54	300
Blue	Bituminous Coal	0.55	335
Blue	Coke, steam, oxygen	0.75	262
Butane	Natural gas	2.07	3371
Butane	Refinery gas	2.03	3310
Carbureted Water	Low gravity back run	0.54	536
Carbureted Water	High Btu	0.69	850
Coal	Continuous vertical retort	0.47	358
Coal	Horizontal retort	0.42	532
Coal	Inclined retort	0.47	542
Coke Oven	By-product	0.36	567
Coke Oven	By-product	0.40	580
Coke Oven	9 Hr. charging	0.31	502
Refinery Oil	Blain down blast	0.45	586
Refinery Oil	Coke-fire	0.66	970
Refinery Oil	Twin generator	0.80	1000

Table 1.5 Manufactured Gases—Typical Analyses

As we mentioned earlier, the European requirements are somewhat different than those requirements found in the United States. Consequently, the test gases mandated by various third party testing agencies are different. I have listed those in the appendix to this course.

Chapter 2

GAS CHARACTERISTICS

In this chapter we will discuss the actual chemical and physical characteristics of four (4) fuel gas types. I am omitting from this discussion several gases: coal gas, coke oven gas, blast furnace gas, blue gas, carburetted water gas, etc due to their diminishing usage in the United States. These gases fall under a broad category called manufactured gases. A very brief description is given with this write-up. Natural gas, liquefied petroleum (propane and butane) and manufactured gas are, by far, the most used gases in our country and consequently will be described in detail in this document. A great source for data on the other gases may be found in "The Gas Engineers Handbook", published by The Industrial Press. This may be seen as a reference.

I would like to start this discussion by showing a chart that will detail most of the paraffin-based gases that represent the major constituents in natural, liquefied petroleum and manufactured gas. I have included with this chart the limits of flammability, the ignition temperatures and the flame temperature of an established and stable flame. This information will become valuable in diagnosing a problem in the field and determining if a burner design is proper. I have also included the chemical formula for the gas itself, and as you can see, all of the paraffin gases are compounds of carbon and hydrogen.

PHYSICAL PROPERTIES OF PARAFFIN SUBSTANCES

Substance	Chemical Formula	Density lb/cu ft	Specific Vol cu ft / lb	Sp Gr (air = 1)	cu ft / cu ft of Comb Req O(2)/AIR
Methane	CH(4)	0.042	23.57	0.554	2.0/9.528
Ethane	C(2)H(6)	0.080	12.46	1.049	3.5/16.675
Propane	C(3)H(8)	0.119	8.36	1.561	5.0/23.821
n-Butane	C(4)H(10)	0.158	6.32	2.067	6.5/30.967
iso-Butane	C(4)H(10)	0.158	6.32	2.067	6.5/30.967
n-Pentane	C(5)H(12)	0.190	5.25	2.487	8.0/38.114
iso-Pentane	C(5)H(12)	0.190	5.25	2.487	8.0/38.114
Neopentane	C(5)H(12)	0.190	5.25	2.487	8.0/38.114
n-Hexane	C(6)H(14)	0.227	4.40	2.970	9.5/45.260
Neohexane	C(6)H(14)	0.227	4.40	2.970	9.5/45.260
n-Heptane	C(7)H(16)	N/A	N/A	3.459	11.0/52.406
Triptane	C(7)H(16)	N/A	N/A	3.459	11.0/52.406
n-Octane	C(8)H(18)	N/A	N/A	3.459	12.5/59.552
iso-Octane	C(8)H(18)	N/A	N/A	3.943	12.5/59.552

Table 2.1 Physical Properties of Paraffin Substances

Substance	lb/lb of Comb Req O(2)/AIR	Ignition Temp (F)	Limits of Flammability % gas in air LOWER/UPPER	Flame Temp (F)
Methane	4.049/17.195	1301	5.00/15.00	3484
Ethane	3.688/15.899	968-1166	3.00/12.50	3540
Propane	3.537/15.246	871	2.10/10.10	3573
n-Butane	3.476/14.984	761	1.86/8.41	3583
iso-Butane	3.476/14.984	864	1.80/8.44	3583
n-Pentane	3.554/15.323	588	1.40/7.80	N/A
iso-Pentane	3.554/15.323	788	1.32/N/A	N/A
Neopentane	3.554/15.323	842	N/A/N/A	N/A
n-Hexane	3.535/15.238	478	1.25/6.90	N/A
Neohexane	3.535/15.238	797	N/A/N/A	N/A
n-Heptane	N/A	433	1.00/6.00	N/A
Triptane	N/A	N/A	N/A/N/A	N/A
n-Octane	N/A	428	0.95/3.20	N/A
iso-Octane	N/A	N/A	N/A/N/A	N/A

Table 2.1 Physical Properties of Paraffin Substances (cont.)

NATURAL:

Natural gas, as stated earlier, is found in nature and recovered in fields from coast to coast as well as several areas in other countries. The table below will give some indication as to the verity of constituents that may exist in a typical sample.

TYPICAL COMPOSITION OF NATURAL GAS

Table 2.2

SAMPLE NUMBER	PERCENT OF VARIOUS COMPONENTS				
	CH(4) (METHANE)	C(2)H(6) ETHANE	N(2) NITROGEN	CO(2) CARBON DIOXIDE	0(2) OXYGEN
1	88.20	3.20	7.68	0.16	0.14
2	81.91	17.51	0.11	0.31	0.16
3	98.59	0.00	0.94	0.31	0.16
4	82.56	16.51	0.16	0.31	0.16
5	94.73	2.64	1.89	0.30	0.44
6	66.31	31.70	1.21	0.47	0.31
7	89.04	5.63	4.68	0.21	0.44
8	90.52	4.56	4.29	0.21	0.42
9	98.40	1.00	0.50	0.00	0.10
10	82.60	7.20	7.10	2.70	0.40
11	74.20	18.50	7.30		
12	67.90	26.10	6.00		

As you can see, the major constituent is methane, and from previous information, methane has a specific gravity ranging from 0.56 to 1.29 and a gross heating value between 990 and 2133 Btu/ Ft^3. Please keep in mind that all of the data presented in this document refer to "dry" values. We have earlier discussed that for any fuel gas, there are limits of flammability or maximum and minimum gas-air mixtures within which gas will ignite and burn. For natural gas, those limits are as follows:

LOWER LIMIT OF FLAMMABILITY = 5.00%
UPPER LIMIT OF FLAMMABILITY = 15.00%

The percentage is always given as the percentage of gas in the air-gas mixture.

Another interesting, and sometimes critical characteristic, is the flame speed. The flame speed of a fuel gas is measured using a 1.00 inch tube of specified length. For natural gas, that flame speed is 120 feet per minute. Please note: this is the maximum flame speed and can be altered by varying the constituents in the mixture. This becomes critical when you consider the problem of blowing off or flashing back. The ignition temperature of natural gas varies but is between 1100 and 1200 degrees F.

LIQUEFIED PETROLEUM:

We will discuss two types of liquefied petroleum, **propane and butane**. These two gases are used in this country as fuel gases with propane being the most, by far, in demand. LP is sometimes called "bottled gas". These gases are unique because they can be liquefied under moderate pressures at normal temperatures. LP gases are derived from natural gas or oil refinery gases. Commercially available LP products do not consist of a single component but are mixtures of hydrocarbons. Generally, LP is converted from liquid form to gaseous form by supplying the latent of vaporization to the bottle. This is done through the containment walls by atmospheric temperature or by using a separately heated vaporizer. If the latter is the case, the heating medium may be low pressure steam or some other heated medium, the temperature of which should not be over 250 º F. There are several characteristics that should be noted: 1.) Propane and butane are heavier than air. Their specific gravity is greater than 1.00; consequently, they tend to "fall to the ground". This can provide a hazard. When dealing with either, make sure there are no open flames that can ignite a leak, no matter how small. The limits of flammability are different than natural gas with propane being 2.40 to 9.60 % and butane being 1.90 to 8.60 %. As given above, the limits of flammability for natural gas is 5.00 to 15.00%. Keep in mind that this is the percentage of gas in the gas-air mixture. One significant fact is that natural gas requires approximately 10 cubic feet of air for one cubic foot of gas. Propane requires 23.40 and butane requires 30.00. In other words, for complete combustion there is the need for 2 to 3 times the primary air when firing LP in comparison to natural gas. You can see why it is sometimes very difficult to design a burner with the flexibility to handle natural gas and an LP gas, especially butane.

The following table will show the various physical characteristics of propane and butane.

AVERAGE PROPERTIES OF COMMERCIAL LPG

Table 2.3

	Propane	Butane
Vapor Pressure, psig		
70 deg F	124	31
90 deg F	167	49
100 deg F	192	59
105 deg F	206	65
130 deg F	286	97
Specific Gravity of Liquid	0.509	0.582
Initial Boiling Point (14.7 psia),F	-51	15
Weight/gal liquid @ 60 deg F, lbs	4.24	4.84
Dew Point @14.7 psia, F	-46	24
Specific Heat of Gas, C(p)	0.404	0.382
Specific Gravity (air = 1)	1.52	2.01
Ignition Temperature, F	920-1020	900-1000
Max. Flame Temp, F	3595	3615
Max. Rate of Flame Velocity		
Cm /sec	84.9	87.1
In/ sec	33.4	34.3
Limits of Flammability, %gas-air		
Lower Limit	2.40	1.90
Higher Limit	9.60	8.60
Required for Complete Comb (%)		
cu ft O(2)/cu ft gas	4.90	6.30
cu ft air / cu ft gas	23.40	30.00
lbs O(2)/lb gas	3.60	3.54
lbs air / lb gas	15.58	15.30
Products of Complete Comb		
cu ft CO(2) / cu ft gas	3.00	3.90
cu ft H(2)O / cu ft gas	3.80	4.60
cu ft N(2) / cu ft gas	18.50	23.70
Ultimate CO by Vol.	13.90	14.10
Total Heating Values after Vap		
Btu/cu ft	2522	3261
Btu/ lb	21560	21180
Btu/gal	91500	102591

MANUFACTURED:

Manufactured gas is really no longer used in North America, but is widely used in other parts of the world; consequently, I think it is necessary to briefly cover the very basics. The chart below shows only two characteristics; specific gravity and heating value but, from comparison, there is a great difference between manufactured gas, natural, propane or butane. As you can see, the heating value is considerably lower and that is a real impediment to its use. **NOTE: These gases can be extremely toxic due to the percentage of carbon monoxide (CO) in the raw gas.**

MANUFACTURED GASES--TYPICAL ANALYSES

Table 2.4

GAS TYPE	SOURCE	SPECIFIC GRAVITY	GROSS HEATING VALUE
Acetylene	Calcium carbide & water	0.91	1499
Blast Furnace	By-product, pig iron	1.04	81
Blue	Coke	0.54	300
Blue	Bituminous Coal	0.55	335
Blue	Coke,steam, oxygen	0.75	262
Butane	Natural gas	2.07	3371
Butane	Refinery gas	2.03	3310
Carbureted Water	Low gravity back run	0.54	536
Carbureted Water	High Btu	0.69	850
Coal	Continuous vertical retort	0.47	358
Coal	Horizontal retort	0.42	532
Coal	Inclined retort	0.47	542
Coke Oven	By-product	0.36	567
Coke Oven	By-product	0.40	580
Coke Oven	9 Hr. charging	0.31	502
Refinery Oil	Blain down blast	0.45	586
Refinery Oil	Coke-fire	0.66	970
Refinery Oil	Twin generator	0.80	1000

CALCULATION FOR TOTAL HEATING VALUE AND TOTAL SPECIFIC GRAVITY:

There is a very simple calculation that will aid your efforts in computing the total heating value and the total specific gravity of a mixture when knowing the values for the individual constituents. A table that demonstrates that calculation is given below. Please note, this is multiplication and addition and has nothing to do with the gas itself. The table will work for **any fuel gas**. Here are the steps in developing the calculation:

1. Using a Microsoft Excel spreadsheet, lay out the column headings as shown below.
2. Under "GAS" put the constituents in the mix you know to be present as well as the values for percentage, heating value and specific gravity.

3. Multiply the contents of column 2 times the contents of column 3 and put that value in column 4.
4. Multiply the contents of column 2 times the contents of column 5 and put that value in column 6.
5. Add the individual values of column 4 and put that total at the bottom of the column.
6. Add the individual values of column 6 and put that total at the bottom of the column.

These values represent the TOTAL HEATING VALUE AND THE TOTAL SPECIFIC GRAVITY of the mixture. These are valuable numbers and are used in numerous calculations relating to the combustion of gas-fired systems.

GAS	MIXTURE %	HEATING VALUE Btu/Ft^3	CONTRIBUTION TO FINAL MIX Btu/Ft^3	SP.GR	CONTRIBUTION TO FINAL MIX SP.GR
METHANE	0.70	1012	708.4	0.554	0.3878
ETHANE	0.10	1786	178.6	1.038	0.1038
PROPANE	0.10	2563	256.3	1.552	0.1552
NITROGEN	0.10	0	0	0.967	0.0967
TOTAL MIXTURE			1143.3		0.7435

Table 2.5 Table for Computing Total Heating Value and Total Specific Gravity

Chapter 3

COMBUSTION OF GASES

Combustion is one of the most fundamental processes on earth and one of the most important. Hundreds of examples in everyday life support the importance and benefits of the combustion process. The internal combustion engine, a fireplace on a cold winter's day, a galvanizing kettle keeping the zinc molten for deposition onto a metal substrate, the lighting of your grandfather's pipe, etc. All are examples of how the combustion process aids our lives and provides some of the comforts we enjoy on a daily basis. A remarkable number of commercial and industrial operations begin and / or end with burning a fuel to produce heat, light or the refinement and collection of the products of combustion for later use as a component in other processes.

I suspect thousands of years ago the first combustion noticed by our "caveman" ancestors was the ignition of dry grass or trees by lightning as it struck the earth. You have to believe there were more than a few singed fingers before they realized the process produced light and heat. They were able to "capture" the results and sustain their great good fortune by continuing to add fuel, thus prolonging the benefit. You also have to believe that they came to realize that some substances, such as rain, would extinguish that fire. It was indeed a learning process, but one they obviously mastered as time progressed.

There are actually three very beneficial byproducts to the combustion process: 1.) Light 2.) Heat and 3.) The products of combustion. We will be taking a look at all three as well as the conditions necessary to produce the initiation of the combustion process. We will also consider the equipment; i.e burners, gas delivery system, venting, etc necessary to sustain the process.

The official definition of the combustion process, as described by "The Gas Engineers Handbook" is 'the chemical reaction of oxygen with combustible materials accompanied by the evolution of light and rapid production of heat'. Three things must be present for the initiation and support of the process: 1.) Fuel, 2.) Oxygen and 3.) Heat source. ALL must be present; otherwise, burning will not start nor will it continue after starting. Oxygen will not burn, fuel alone will not burn and the two, when combined, will not burn unless the ignition temperature of the fuel is reached. This ignition temperature may be obtained by an open flame, a spark ignition device, spontaneous combustion, hypergolic fuel and oxidizer, etc. Let's consider several definitions. These also come from the Gas Engineers Handbook.

Oxidation—The reaction of oxygen and a combustible substance which takes place slowly without the generation of light and heat. Over time, the generation of heat may be appreciable but the dissipation of that heat does not produce the combustion process. We will not be considering oxidation with this paper.

Spontaneous combustion—This is a process in which the fuel and oxygen oxidize slowly but the generation of heat is not completely dissipated. The temperature of the fuel increases slowly until the ignition temperature is reached and the material does ignite.

Perfect combustion—This is a process in which the exact amount of theoretical air or oxygen combines with the fuel to produce water vapor and carbon dioxide; i.e., no pollutants.

Incomplete combustion—Incomplete combustion is, by far, the most prevalent condition that exists when the process occurs at all. The products are carbon monoxide, carbon dioxide, water vapor, hydrogen, aldehydes and possibly other constituents. It occurs when there is inadequate oxygen, chilling of the flames to end the burning process or lifting of the burner flames. This is a very undesirable situation and one that deserves immediate investigation.

Detonative combustion—The propagation of a very sharp pressure shockwave through a gaseous medium. We will not be considering this type of combustion in this write-up.

Hypergolic combustion—When an oxidizer and fuel mix and require no ignition temperature for the initiation of combustion, the process is called hypergolic. Rocket engines used for upper atmospheric combustion sometimes use these substances. We will not be considering this type of combustion.

Please note that we are interested in "controlled combustion" in which the supply of air (oxygen) and the fuel are metered in the proper amounts to achieve ignition and a sustaining of the burner flame. This controlled ignition and burning will preclude explosive combustion, blowing, flashback, yellow tipping, noisy flame, delayed carryover of burner flames and a host of other problems that need investigation and "fixing". Solutions to these problems, and others, may be found in the "Troubleshooting" chapter of this write-up. When we use the term "controlled" we mean the combustion process is allowed to continue until a predetermined condition is met; i.e., reaching a specific temperature by virtue of a thermostat, thermistor or other regulating device. We will not discuss the various control devices available on the market to accomplish this.

The basic concepts of combustion may be best explained by looking at a typical atmospheric burner.

To bring about combustion, the burner entrains primary air through the air shutter into the mixing head. The air shutter can be adjusted to give the proper amount of air depending upon the gas used. Increasing or decreasing the air shutter opening will affect the burner flame and possibly reduce blowing or lifting of the burner flames as they project from the burner ports. The inrush of air through the air shutter is mixed with the gas blowing through the burner orifice. This gas-air mixture then accelerates through the venturi, which is a converging/diverging nozzle, into the mixing tube or mixing zone. Secondary air is entrained into the burner head and the burner ports to accomplish a mixture suitable for ignition.

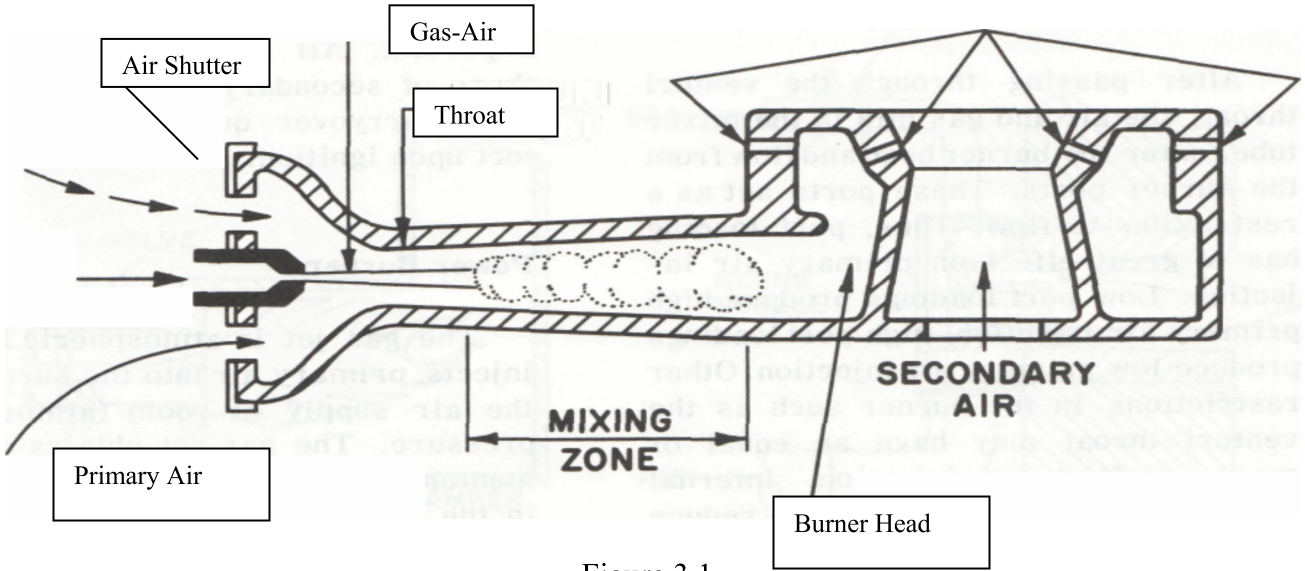


Figure 3.1

An ignition device is assembled in close proximity to the burner ports. Upon startup, combustion occurs at one port and then flame carryover from port to port occurs.

The following is a table that will show the chemical reaction and heats of combustion of pure combustible materials. This table shows not only the reaction, but also the products of combustion created by that reaction. As you can see, the process is chemical in nature with the fuels and the oxidizers being combined by adding a heat source. Also, it becomes evident that one consistent product of combustion is water vapor.

Table 3.1 Chemical Reactions and Heats of Combustion of Pure Combustible Materials
[perfect combustion (except No. 1)]

No.	Combustible material	Reaction	Heat of combustion/[1] Btu per Ib-mole gross	Ib of vapor (except C & S) gross	Ib of vapor net[1']	cu ft gross	cu ft net[1']	gal liquid gross	Cuftgas per gal liquid[0]
1	Carbon (graphite)	C + 0.50_2 = CO	4 46	3,950	3,950				
2	Carbon (coke)	C + 0, = CO, C	7, 0	14,500	14,500				
3	Graphite	+ 0, = CO,	174, 00	14,093	14,093				
4	Carbon monoxide	CO + 0.50-: = $C0_2$	122 40	4,347	4,347	321.37"	321.37"		
5	Hydrogen	H, + 0.50, = H,0	123 10	61,095	51,623	325.02"	274.58"		
	Paraffin hydrocarbons								
6	Methane	CH_4 + *20-!* = $C0_2$ + $2H_20$	382 98	23,875	21,495	1012.32"	911.45"	59,755	59.0
7	Ethane	C,H_6 + 3.50_2 = 2CO, + 3H,0	671 19	22,323	20,418	1773.42"	1622.10"	74,010	41.3
8	Propane	C_3H_8 + 5 0_2 = 3 $C0_2$ + 4 H_20	955 43	21,669	19,937	2523.82"	2322.01"	91,740	35.91
9	re-Butane	C_4H_{10} + 6.5 0, = 4 CO_2 + 5 H_20	1 ,23 13	21,321	19,678	3270.69"	3018.48"	103,787	30.77
10	/so-Butane	C_4H_{10} + 6.5 O_2 = 4 CO, + 5 H_20	1 ,23 23	21,271	19,628	3261.17"	3008.96"	100,176	29.77
11	ra-Pentane	C_5Hi, + 8 0_2 = 5 $C0_2$ + 6 H_20	1 ,52 88	21,095	19,507	4019.65"	3717.15"	105,822	26.35
12	iso-Pentane	C_6Hi» + 80, = $5C0_2$ + $6H_20$	1 ,51 41	21,047	19,459	4010.71"	3708.01"	104,863	26.17
13	Neopentane	C_5Hi, + 8 0, = 5 CO_2 + 6 H_20	1 ,51 44	20,978	19,390	3994	3692	104,603	26.19
14	re-Hexane	C_6H_{14} + 9.5 0_2 = 6 $C0_2$ + 7 H_20	1 ,80 62	20,966	19,415	4768.27"	4415.23"	105,806	22.82
15	Neohexane	C_6H_{14} + 9.5 0, = 6 CO, + 7 H_20	1 ,80 60	20,931	19,380	4760	4407		
16	w-Heptane	C_7H_{16} + 11 0, = 7 CO, + 8 H,0	*2* ,08 53	20,854	19,329	5459	5056	108,907	19.95
17	Triptane	C_7Hi$_6$ + 11 0, = 7 CO_2 + 8 H,0	*2* ,08 52	20,824	19,299	5445	5042		
18	n-Octane	C_8H_{18} + 12.5 0_2 = 8 CO, + 9 H,0	*2* ,37 40	20,796	19,291	6260	5806	111,240	17.77
19	f'so-Octane	C,H,, + 12.5 0, = 8 CO, + 9 H_20	*2* ,37 43	20,770	19,265	6249	5795		
	Olefin series								
20	Ethylene	C,H_4 + 3 0, = 2 CO, + 2 H,0	606 91	21,636	20,275	1603.75"	1502.87"	71,504	44.33
21	Propylene	C_3H_6 + 4.50, = $3C0_2$ + $3H_20$	885 64	21,048	19,687	2339.70"	2188.40"	87,390	37.41
22	Butylene (n-Butene)	C_4H_8-t-60, = 4CO, + $4H_20$	1 ,16 95	20,854	19,493	3084	2885		
23	?'so-Butene	C_4H_8 + 6 0, = 4 CO, + 4 H_20	1 ,16 39	20,737	19,376	3069	2868	102,106	33.27
24	w-Pentene	C,H,,i + 7.5 0,, = 5 $C0_2$ + 5 H,0	1 ,45 05	20,720	19,359	3837	3585		
	Aromatic series								
25	Benzene	C_6H_6+7.50, = 6CO,+ 3H,0	1 ,42 30	18,184	17,451	3751.68"	3600.52"	129,724	34.63
27	Toluene	C_7H_8 + 9 0, = 7 CO, + 4 H,O	1 ,70 53	18,501	17,672	4486.44"	4284.81"	129,003	28.68
27	jw-Xylene	CsH,,, + 10.5 0, = 8 CO, + 5 H,0	1 ,97 04	18,633	17,734	5223	4971	127,988	24.50
	Miscellaneous gases								
28	Acetylene	CoH., + 2.50, = $2C0_2$+ H_20	559 83	21,502	20,769	1476.55"	1426.17"		
29	Naphthalene	CioH$_h$ + 12 0, = 10 CO_2 + 4 H,0	*2* ,21 59	17,303"	16,708"	5854'	5654°		
30	Methyl alcohol	CH_3OH + 1.5 0_2 = CO +2 H,0	328 68	10,258	9,066	868	767	66,775	76.93
31	Ethyl alcohol	C H OH + 3 o = 2 co + 3 H O	606 29	13,161	11,917	1600	1449	85,360	53.35
32	Ammonia'	NH_3 + 0.750, = 0.5N, + 1.5 H,O	164 64	9,667	7,985	441	364		
33	Sulfur	S + O, = SO,	127 80	3,980	3,980				
34	Hydrogen sulfide	H,S + 1.50, = SO, + H_20	241 84	7,097	6,537	646'	595	46,822	72.48
35	Formaldehyde"	HCHO + 0, = CO, + H,0	209 54	6,980	6,344	643	593		
36	Formic acid[c]	HCOOH + 0.5 0_2 = $C0_2$ + H_20	112, 70	2,450	2,035	301	251		
37	Acetaldehyde*	CH_3CHO + 2.5 0, = 2 $C0_2$ + 2 H_20	501 16	11,390	10,523	1360	1259		
38	Nitric oxide[h]	NO + 0.50, = $N0_2$	128 80	4,270	4,270	339*	339		
39	Nitrogen tetroxide[1']	N,0j + 0.50, = NA,	108, 00	1,175	1,175	284-	284		

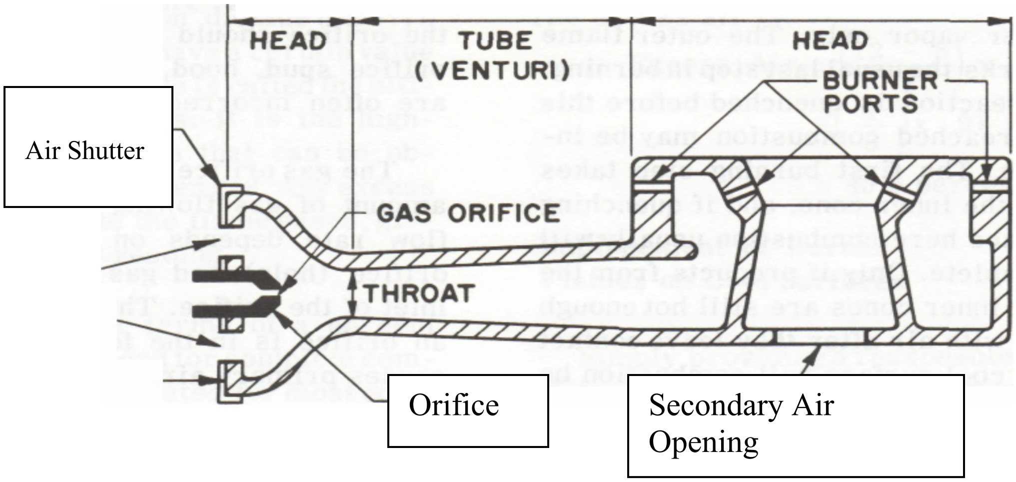
The overwhelming majority of fuels consumed in this country for the combustion process are 1.) natural gas, 2.) propane gas and 3.) iso-octane (gasoline). In the United States, all gas-fired appliances use natural gas and propane as their primary fuels. Across the world, we do find that manufactured gas, butane and in some cases sewage gas, are used as the "fuels of choice". When they are used, caution is needed to make sure the burner design and the fuel delivery system are proper and flexible enough to support the fuel and enough primary and secondary air are provided for complete combustion. Burner flexibility and fuel gas interchangeability are covered in separate chapters of this course and are very important considerations for any burner system.

Burner flexibility, through burner and system design, is very difficult to achieve. It is not uncommon at all to find burners designed for European products, to be unacceptable for use in the United States.

I would like to state now that several physical laws define the process of combustion. I have listed these laws in the Appendix; i.e., " Governing Laws of Combustion". They are accompanied by a very brief explanation of the law. I think their application to the combustion process is fairly evident, especially the First, Second and Third laws of Thermodynamics, as well as the "Ideal Gas Law".

Chapter 4

ATMOSPHERIC BURNER COMPONENTS
Figure 4.1



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GAS ORIFICE:

The purpose of the gas orifice is to meter the flow of gas into the burner head. The input rate is a predetermined value, generally measured in Btu/hr. This rate is determined by the design engineer and is based upon the heat transfer considerations and the overall desired efficiency of the combustion and heat transfer process. The input rate translates to Ft^3 / hr (or flow rate) to the burner. Gas flowing from the orifice enters the mixer head and then passes through the throat of the venturi. The velocity of the gas pulls primary air through the air shutter and into the mixing tube to produce a homogeneous mixture. The formula to calculate the flow rate for a gas orifice is as follows:

$$q = 1658.5\ KA \sqrt{H/d}$$ where

q = gas discharge in Ft^3 / hr
K = coefficient of discharge (This is dependent upon orifice design and is given in the following table.)
A = area of orifice in in^2
H = gas pressure in W.C.
d = specific gravity of gas

There are three general types of gas orifices: 1.) fixed orifice with a drilled opening in a suitable threaded fitting, 2.) adjustable orifice, comprised of one moving part and one stationary part and 3.) pressure reduction orifice. The most commonly used is the fixed orifice. A fixed gas orifice will fall into one of five different types with the following coefficients of discharge.

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

Table 4.1

It becomes necessary to downrate a burner with increasing altitude. As we have mentioned before, the National Fuel Gas Code (ANSI Z223.1) specifies that above 2,000 feet, the gas-fired device should be derated 4% for every 1,000 feet above sea level.

Table 4.2

Orifice Size at Sea Level	Orifice Size Required at Other Elevations								
	2000	3000	4000	5000	6000	7000	8000	9000	10000
53	54	54	54	54	54	54	55	55	55
54	54	55	55	55	55	55	56	56	56
55	55	55	55	56	56	56	56	56	57
56	56	56	57	57	57	58	59	59	60
57	58	59	59	60	60	61	62	63	63
58	59	60	60	61	62	62	63	63	64
59	60	61	61	62	62	63	64	64	65
60	61	61	62	63	63	64	64	65	65
61	62	62	63	63	64	65	65	66	66
62	63	63	64	64	65	65	66	66	67
63	64	64	65	65	65	66	66	67	68
64	65	65	65	66	66	66	67	67	68
65	65	66	66	66	67	67	68	68	69
66	67	67	68	68	68	69	69	69	70
67	68	68	68	69	69	69	70	70	70
68	68	69	69	69	70	70	70	71	71
69	70	70	70	70	71	71	71	72	72
70	70	71	71	71	71	72	72	73	73
71	72	72	72	73	73	73	74	74	74
72	73	73	73	73	74	74	74	74	75
73	73	74	74	74	74	75	75	75	76
74	74	75	75	75	75	76	76	76	76
75	75	76	76	76	76	77	77	77	77
76	76	76	77	77	77	77	77	77	77
77	77	77	77	78	78	78	78	78	78
78	78	78	78	79	79	79	79	80	80

I have given orifice charts that will cross-reference fuel gas type, orifice drill size pressure and burner input. These charts are given in the appendix to this course. Please note also that the heating value is specified for each chart.

AIR SHUTTER: The only purpose of an air shutter, when required, is to control the flow of primary air being entrained into the burner head. The device is usually a sheet metal collar or sheetmetal ring design to turn around a burner head. It can rotate to give 100 % area or some value down to 0 % area. Generally, the full opening through the air shutter and mixer face should be approximately 1.25 to 2.25 times the total port area. The larger openings are desirable for high gas inputs and high primary air injection. The area of the primary air openings is critical to acceptable combustion. There are definitely calculations that can be accomplished to provide for that area. There has been a trend through the past several years to design "out" the air shutter. This can be accomplished easily if the burner is required to burn only one gas type. If it becomes necessary to burn various types of gas fuels, the air shutter becomes a very desirable feature to achieve proper combustion and flame appearance.

VENTURI THROAT: The venturi throat is a constriction in the mixing tube that accelerates the gas / air mixture as it travels down the mixing tube and into the burner head. It basically works as a converging / diverging nozzle to accelerate the mixture. This increase in velocity serves to entrain primary air into the burner head for mixing. There is a definite relationship between the throat area and the port area. For acceptable combustion and proper flame appearance, that ratio varies depending upon the type of fuel gas burned. An example is, with a throat to port ration of 0.22 to 0.91 for natural gas and a throat to port ration of 0.24 to 0.68 for manufactured gas, the primary aeration is identical and acceptable combustion may be had. Slotted port or ribbon burners used in oven cavities and water heaters, typically, do not have venturis as generally defined.

MIXING TUBE: In a mixing tube, air entrained by the gas stream issuing from the orifice creates a gas-air mixture which enters the burner head. The turbulence from the process provides for a homogeneous mixture that is accumulated in the burner head and then ejected through the burner ports. The pressure driving the process must be constant and maintained through the burning process. This pressure is dependent upon the type of gas and its specific gravity. Proper mixing is also dependent upon the angle of divergence of the mixing tube. Generally, for atmospheric burners, a 2 to 3 degree angle is suggested. It is very important to note that if the angle of divergence approaches or exceeds 7 degrees, friction losses due to enlargement may be appreciable. It is definitely the case where greater flexibility and better operating characteristics are obtained with the venturi-type mixing tube than with a straight-sided tube.

BURNER HEAD: The burner head is a part of the burner, which receives the gas-air mixture, distributes that mixture to the ports and ultimately expels the mixture through the ports. The diameter, number of ports, head depth, angle of discharge through the burner ports and any stability rings inside the burner head are critical to good combustion. It is critical that the design provide for even distribution to all ports and that an even conversion of velocity pressure in the mixing tube be transformed to static pressure in the burner head. The shape and size of the burner head must be adapted to the space available. This size and diameter will determine the number of ports and, consequently, the port loading.

BURNER PORTS: The burner ports are critical by virtue of number, control of flame height, ejection velocity, yellow tipping, ignition time, flame carryover, and burner head temperatures. Different fuel gases may require different designs in port configuration. Depending upon the design, a drilled port may be preferable to cast or slotted ports.

BURNER CAP: Some burners will have a burner cap that rests upon a mating burner head. This is not uncommon on range top burners. The most common design mistake is providing for a burner cap that can be re-installed improperly after cleaning or maintenance. The burner caps, if differing in diameter, must not be interchangeable from one burner to another unless the burner inputs are identical. This is critical.

BURNER TYPES

ATMOSPHERIC BURNERS: Practically all domestic and commercial gas appliances, and many industrial gas units, employ atmospheric gas burners. There are undoubtedly more burners of this type in existence today than any other type of burner. An atmospheric burner is a "Bunsen" type burner in which primary air is premixed with gas. Secondary air is supplied around the flame for complete combustion. The "Bunsen" burner was described years ago by Robert Wilhelm von Bunsen, but the first American technical literature on the subject was presented in 1921 by the National Bureau of Standards. A description of that type burner and the flame it produces, is given in the appendix.

POWER BURNERS: A power burner is generally used when high input rates are needed to provide a specific input. Unlike atmospheric burners, a power burner does not rely on the entrainment of primary air by virtue of gas injection into the burner head. All primary air is supplied and mixed by the blower assembly prior to ignition. A power burner, generally, does not require chimney height to achieve venting of the products of combustion. Power burners do require electricity to drive the blower, and this may be problematic in some situations. Another potential irritant is the noise generated by the blower assembly in the mixing process. A description of power burners is given in the appendix.

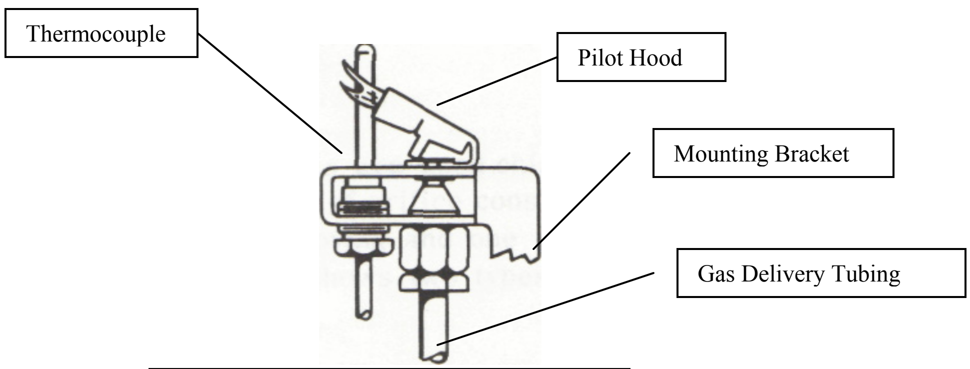
FORCED AND INDUCED DRAFT BURNERS: An induced draft burner becomes necessary when the resistance to flow is great enough to create back drafts without an eductor fan. A fan or blower of adequate size is located on the outlet of the vent system to forcefully evacuate the products of combustion from the burning process. This fan must be on just prior to the initiation of the combustion process and remain on during the combustion process. Interlocking devices must be provided that will disallow combustion if the fan does not actuate. This is critical and is a safety issue if not provided for in the system design.

PREMIXING AND PRESSURE POWER BURNERS: With these burners, all or almost all of the primary air is premixed with the fuel gas before actual burning starts. Burners of this type can provide gas-air mixtures at reasonable pressures needed to overcome high combustion chamber pressures. One great advantage is the ability to provide a wide range of burner inputs; also, the gas-air mixtures can be controlled accurately.

JET BURNERS: Jet burners are single port burners in which the gas orifice, primary air openings and burner port are contained in a single small fitting. There is usually no provision for adjustment of primary air. The downside to this type of burner is noise. A jet burner is considerably louder than a typical atmospheric burner due to the process of injecting the gas-air mixture. A jet burner is generally used when higher inputs are required.

IMPINGEMENT TARGET BURNERS: The basic components of a target type burner are 1.) burner orifice and 2.) target. Of course, gas piping and controls are necessary for the process; but, basically the advantages are simplicity, low cost and ease of servicing. There is no air shutter, no venturi, no mixing tube, no burner head and no burner ports. The disadvantages are noise and some limitations for using natural, propane and butane gases. These burners are used on a very limited basis, certainly in today's appliances.

PILOT BURNERS: Pilot burners provide the necessary heat source for main burner ignition. The characteristics of a pilot burner are identical to those for a main burner, although the input for a pilot burner is considerably smaller than any main burner. There are two types of pilot burners: 1.) Standing pilot and 2.) Intermittent pilot. A standing pilot remains lit when the main burner is off and on. It's always burning. An intermittent pilot is only lit and burning prior to the need to light the main burner. Generally, a spark ignition system will light the pilot burner and then the pilot burner will ignite the main burner. The use of pilot burners is diminishing due to pilot outage and the costs to operate. An example of a pilot burner is shown below.



Target Type Pilot Burner
Figure 4.2

Chapter 5

INTERCHANGEABILITY OF GASES

Two gases may be regarded as interchangeable if their flame characteristics are satisfactory after substitution of one gas for another. A flame which does not lift, yellow tip, produce carbon (sooting), produce carbon monoxide in excess percentages or flash back, is considered satisfactory in this frame of reference. One way to look at interchangeability is to check for similarities of flow through an orifice. Interchangeability is very important due to the need to substitute one gas for another during periods of increased demand. (This is not to be confused with "peak shaving".)

There are several mathematical models used to evaluate the interchangeability of gases. These are as follows:

AGA Interchangeability Indexes:

- " C " Factor—Research involving 250 different gas mixtures.
- Lifting, Flashback and Yellow Tipping—How gases over 800 Btu/Ft^3 could supplement or be substituted for natural or high-Btu gases, where I(L) = lifting index, I(F) = flashback index and I(Y) = yellow tipping index.

Other Indexes:

- Knoy Formulas
- Weaver Indexes
- Bureau of Mines Interchangeability Studies
- Wobbe Index-- The Wobbe Index is the main indicator of interchangeability of fuel gases, such as natural gas, LPG, manufactured gas, etc. This index is not used that frequently in the United States or Canada but is used over the remainder of the world and provides a great comparison of fuel gas characteristics. It basically compares the heat input factor of a burner at constant pressure. The Wobbe Index is defined by the following equation.

$$\text{Wobbe Index} = HV / \sqrt{Sp.Gr.}$$

where HV = heating value and Sp Gr = the specific gravity of the gaseous fuel. The table below will indicate the Wobbe Index of several gases.

Table 5.1

WOBBE INDEX				
GAS	UPPER INDEX	LOWER INDEX	UPPER INDEX	LOWER INDEX
	kCAL/m^3	kCAL/m^3	Btu/Ft^3	Btu/Ft^3
Hydrogen	11,528	9,715	1295.7472	1091.966
Methane	12,735	11,452	1431.414	1287.2048
Ethane	16,298	14,931	1831.8952	1678.2444
Ethylene	15,253	14,344	1714.4372	1612.2656
Natural gas	12,837	11,597	1442.8788	1303.5028
Propane	19,376	17,817	2177.8624	2002.6308
Propylene	18,413	17,180	2069.6212	1931.032
n-butane	22,066	20,336	2480.2184	2285.7664
Iso-butane	21,980	20,247	2470.552	2275.7628
Butylene-1	21,142	19,728	2376.3608	2217.4272
LPG	20,755	19,106	2332.862	2147.5144
Acetylene	14,655	14,141	1647.222	1589.4484
Carbon monoxide	3,060	3,060	343.944	343.944

There are three ranges or families of fuel gases that have been agreed upon internationally based upon the Wobbe Index. Family 1 covers manufactured gases, family 2 covers natural gases (high and low ranges), and family 3 is for LPG. It is very important to note that burners and combustion systems are designed to burn fuel gases within a family. This is not always the case without "tweaking" the system; i.e. adjustment of air shutter, etc.

Chapter 6

VENTING GAS-FIRED SYSTEMS

Venting is defined as the removal of combustion products or flue gases to the outdoors through a system of piping, ducts, flues, vents, chimneys or stacks especially designed for that purpose. Vents attached to a product use heat energy(or sensible heat), to produce the necessary flow of combustion products from the combustion chamber of the appliance or the product. There are certainly cases in which a well-designed product is vented improperly thereby causing all kinds of problems. Great care must be taken when considering the design of a vent system. When multiple gas products are connected to a common main vent, the design must be very carefully considered.

Not all gas-fired products need to be vented. The following products, according to ANSI 21.30, do **NOT** need the products of combustion removed from the area of use:

1. Listed ranges
2. Built-in domestic cooking products; i.e., wall ovens and cooktops
3. Hot plates
4. Laundry stoves
5. Listed Type 1 clothes dryers
6. Listed water heaters with inputs over 5,000 Btus/hr.
7. Listed refrigerators
8. Room heaters listed for unvented use
9. Certain laboratory equipment (all to be listed as such)

Other products, such as the following, certainly do:

1. Water heaters or hot water boilers over 5,000 Btus/hr.
2. Unit heaters and duct furnaces
3. Incinerators
4. Type 2 clothes dryers
5. Appliances equipped with gas conversion burners
6. Other listed products outfitted with draft hoods

The total burner input generally determines whether or not the gas-fired device needs to have the products of combustion evacuated from the area. The American Gas Association and ANSI have definite requirements for listing depending upon the product and its use. Those documents may be consulted when questions arise as to the need for product venting.

One cubic foot of natural gas, burned with just enough primary air for complete combustion, produces eleven (11) cubic feet of combustion products. Usually, two to five cubic feet of excess air is needed to complete the combustion process. This results in the formation of one cubic foot of carbon dioxide, two cubic feet of water and eight cubic feet of nitrogen. Depending upon the process, other products may result also. Provisions are usually made (and required) to remove these products of combustion from the home or working area. This is accomplished in one or two ways: natural draft or forced draft.

With natural draft, the hot flue gases pass into a duct, a chimney or vent and flow upward by virtue of convection and conduction. As you know, hot air rises and this is exactly what happens in a gravity or natural draft vent system. The hotter the gases in the vent and the higher the "stack", the greater will be the venting forces. If a "draft hood" is required by the gas-fired device, secondary air is entrained into the vent providing for dilution air and a cooling down of the products of combustion. There is also a drop in the percentage of flue products by virtue of secondary air and mixing. The proper vent diameter and configuration must be designed to aid the flow of flue gases upward. Care must always be taken to ensure the minimal resistance to the flow of gases. Too many "elbows" or a vent length too long can retard and / or restrain the flow and create a stagnant condition in the combustion chamber itself. It is also very important to provide a vent cap on the discharge of the vent so as to preclude downdrafts. Building codes for local municipalities, cities and regions; i.e., "The Southern Building Code" will give detailed information as to what type vents are demanded and guidelines for installation. These codes must be followed by appropriate inspections made by qualified inspectors. This will insure successful and trouble-free operation of the gas-fired systems. Please note that acceptable venting may vary depending upon the appliance or equipment used. Specific information regarding vent height, lateral vent length and diameter vs input; i.e., Btu/hr, may be derived from the tables provided by the local codes. **PLEASE NOTE:** Local codes will always take precedence over "national codes".

It is important to note also that, on occasion, there may be a need to "tie in" two, three, four, etc gas-fired appliances to one vent system. This is also covered by local codes and is frequently accomplished with no issues. Here again, proper practices and the appropriate inspection is a must to guarantee usage of the device with no troubling issues. A multistory common vent system will entail very specific vent design and require vent connectors into a common vent at increasing heights. The operation of a single appliance on a multistory stack constitutes the most critical operating condition. This **MUST** be done correctly and with the proper inspection oversight.

The other type of venting is power venting. Power venting may solve many special venting problems. With this system, a blower is assembled in line with the vent and the products of combustion are forcibly removed from the combustion chamber. There are those cases in which the length and configuration of the vent will dictate the need for a power vent system

Chapter 7

"TROUBLESHOOTING" FUEL GAS COMBUSTION SYSTEMS

Mechanical and electromechanical gas systems are subject to the same "gremlins" that plague all other systems. Sometimes things just don't work correctly. This may be due to installation errors, environmental influences, improper initial design, mishandling or just plain wear and tear. When issues do occur, it's good to be able to diagnose the root cause, not just the symptoms, and bring about a proper "fix". In this chapter, we will discuss those things that can go wrong, the cause / effect relationship and how to make the necessary changes that will bring about an amenable solution. **PLEASE NOTE:** A prudent individual will not attempt to make those changes outside his or her experience level. A qualified technician must be called when the effort to diagnose and fix the problem is beyond one's ability to resolve. Most trained gas technicians have the experience to bring about a solution to the common problems that can and do occur. Also, **NEVER NEVER** attempt to alter a design to solve a problem. The gas-fired system you have purchased and installed has been tested and approved by the American Gas Association. The components, as designed, are integral to the success of the entire system and are not to be altered in any way, form or fashion. With these things in mind, here are several potential problems that really put a system into distress.

LOW PRESSURE OR PRESSURE DROP:

Low pressure is mentioned first because it is definitely a problem that can create issues with ignition, carryover, sooting (carboning), flashback and noisy extinction. When we consider a gas distribution system, we look at a.) the fuel gas source, b.) the gas regulation device, c.) the gas piping and supply system, d.) gas burner and e.) the venting that disposes of the products of combustion. The very first thing to check if any of the above problems seem to be present is the incoming pressure itself. In most natural gas systems, the supply pressure is at or below 20 inches W.C. but must be regulated to some working pressure the system can handle. For natural gas systems, this pressure is approximately 3.5 to 4.00 inches W.C. For liquefied petroleum; i.e., propane and butane, the delivery pressure is approximately 10.5 to 11.00 inches W.C. Some power burners will fire at higher pressures, but these pressures are generated by forced or assisted mixing of the gas and air bringing about the proper ratio of gas-air prior to delivery to the combustion zone. The "mechanics" of a power burner will not be discussed here although the process of combustion is identical to the process for an atmospheric burner. Pressures downstream of the gas pressure regulator MUST be maintained to provide proper operation. A decrease in pressure will negate an ideal burner design and create issues. There are three sources for the drop in pressure as follows:

1.) Low delivery pressure.
2.) Incorrect gas pressure regulator setting
3.) Overly complex gas distribution upstream of the burners.

Fluctuating supply pressures should be corrected so that a steady pressure is maintained prior to regulation. These pressures can be measured with a manometer. Usually, pressure "taps" are provided upstream of the regulator to allow for that measurement. It is not uncommon in outlying communities to supply natural gas using smaller diameter piping but with greater internal gas pressures. This generally necessitates an intermediate gas pressure regulator, which reduces the pressure to a usable value, usually less than 20.00 inches W.C. Another pressure regulator is needed at the appliance to further reduce the pressure to 3.5 or 4.00 inches W.C. If instability in gas pressure results, both regulators become suspect and must be investigated.

For "bottled gas" systems; i.e., propane or butane, the regulator on the bottle will provide regulated pressures between 10.50 and 11.00 inches W.C. to the delivery system. Variations in delivery pressure can create issues with burner operation and must be corrected for proper combustion. In the United States and Canada, the most common system is the two-stage system. A regulator at the tank or bottle drops the pressure from 125 PSIG to approximately 15 PSIG. Then, a second regulator mounted on the outside of the house, drops the pressure down to 10.50 or 11.00 inches W.C. This allows for smaller supply lines between the tank(s) and the gas-fired appliance.

Regulators must be set to deliver pressures in line with those recommended by the manufacturer of the appliance or equipment being used. Each piece of equipment has been designed to fire at a specified pressure. This pressure may be found on the rating plate affixed to the equipment and must be maintained while the equipment is in use. The American Gas Association requires that a "gas appliance regulator be provided with each appliance". (Paragraph 1.9.2, page 17, ANSI Z 21.1)

Sometimes the gas delivery system to the burner is too long, too small in diameter or too complex, as far as angles, bends and fittings, etc to provide adequate delivery pressure. Pressure drop can occur due to the placement of elbows and bends at improper intervals in the delivery system. The pressure directly upstream of the burner inlet should be checked and must be in line with the pressure displayed on the rating plate. A good indicator that you have a pressure drop problem is when the orifice size, necessary for the proper rate, is two or three sizes larger than indicated charts call for. Please note: **IT IS IMPERATIVE THAT THE BURNER ORIFICE AND REGULATOR BE PROPER FOR THE GAS USED IN THE SYSTEM.** A system outfitted for natural gas, yet firing liquefied petroleum, will create overfiring. A system outfitted for LP and firing natural gas will produce an input significantly under the input designated by the rating plate**. MAKE SURE THE EQUIPMENT AND THE GAS BEING FIRED ARE COMPATIBLE**.

<u>**DROP IN PRESSURE IS THE ENEMY**</u>.

DELAYED IGNITION:

The American Gas Association prescribes the acceptable time for burner ignition. For most gas-fired appliances, that time is four (4) seconds. This time is critical because of the continuous flow of gas into the burner during the initial ignition attempt. Excessive time to light could create an explosive condition and possible flame rollout, creating a hazardous condition. There are some ignition systems that will not allow the flow of gas over a specified time to light. These systems are called "flame failure systems" and are controlled by FFDs; i.e., flame failure devices. Generally, they consist of a thermocouple generating the amperage necessary to actuate a solenoid device installed in line with the gas tubing that supplies the burner. This amperage is generally measured in milliamps. If the proper amperage is not achieved, the system "locks out" and burner ignition will not occur. These systems are primarily found in Western Europe and the Pacific Rim but are not required at this time in the United States.

IMPROPER CARRYOVER OF BURNER FLAMES:

In a burner system that operates properly, all burner ports will discharge the gas-air mixture and ignition will occur at the burner ports. The ports may be of differing configurations, round, slotted, etc but ignition must occur at each port. Failure to light at any port may create issues with the production of excessive carbon monoxide and / or sooting. Initial flame ignition occurs at a descrete point on the burner itself. The device that provides the heat source is generally one of the following: standing pilot, "glow-bar" or electronic ignition system. Some burners will have ignition ports, and when lit, will provide for the carryover to the remaining burner ports. This carryover will occur within a very few seconds resulting in all ports supporting a flame. Failure to carryover may be caused by port obstruction, improper design of the burner or burner ports or damage to existing ports. Misalignment of burner parts is also a common contributor to failure to light and failure to carryover. Make sure that the alignment and spacing of the ignition device relative to the burner itself is correct and proper. Shipment and installation may have created forces to dislodge the burner, creating burner misalignment. If this occurs, consult the manufacturer of the equipment for the proper spacing.

SOOTING:

Sooting is the process of depositing unburned particles of carbon on adjoining surfaces. Impingement of the burner flames onto burner grates or adjoining surfaces may cool the flames prematurely and deposit carbon at the point of impact. The combustion process is interrupted and cannot be completed. This can coat the burner grates and blacken cooking utensils and, at times, create elevated carbon monoxide levels. The impingement problem may cause a yellowing of the flame, which could be an indicator of sooting. If this occurs, you will want to check for the following conditions:

a.) Input to the burner. An overated burner can create flame heights that extend beyond the boundaries of the combustion zone.
b.) Excessive pressure. Pressure exceeding the "nominal" pressure as prescribed by the "Use and Care Manuals" can create overfiring.
c.) Misalignment of burner parts. Proper alignment is a must for all burner parts.
d.) Incorrect burner orifices. Please remember, if you are using LP gas, you must have burner orifices specifically designed and supplied for that LP gas. A natural gas orifice, firing LP, will create an increase in input considerably over the rated input of the burner.
e.) Obstruction of primary air to the burner. All combustion processes must have available enough primary air for complete combustion. Any obstruction to the flow of primary air into the burner could create issues. Check to make sure that the area around the appliance or gas-fired device is clear and offers no impediment to the flow of primary air. (This is one of the biggest problems for gas-fired systems.) If the system is enclosed within a closet, small room, etc, make sure all venting into that room is adequate for the input exhibited on the rating plate of the device. There are standards and "rules of thumb" that can be applied to size the proper ventilation for gas-fired systems located within enclosures.

FLAMES BLOWING OR LIFTING:

Flames that lift from a burner port or ports do so because the discharge velocity of the ignited gas-air mixture is **greater** than the velocity of the burn rate for that mixture. This could also be due to a gas-air mixture in which the primary air is excessive, relative to the proper ratio. Regulating the air shutter on the burner, controlling the gas-air ratio, can control this. All fuel gas-air mixtures have a specific burn rate in which the flame moves through the mixture. This is measured in a 1-inch tube of a specified length and will vary with the percentages of gas and air. There are varying degrees of lifting, but if the velocity is increased, a point will be reached in which the flame is extinguished. Please note that when and if this happens, there will remain the discharge of the gas-air mixture and unburned gas may result. Flame failure devices can and will eliminate this eventuality. Lifting may also result in a noisy burner. The following table from Shnidman will show the primary air limits for lifting and yellow tipping.

Table 7.1

GAS	HEATING VALUE Btu/CuFt	LIFTING LIMIT % PRIMARY AIR	YELLOW TIPPING LIMIT % PRIMARY AIR
Natural	1116	54	22
Manufactured	555	100	14
Propane	2503	54	42
Butane	3207	51	45

FLASHBACK:

Flashback occurs when the velocity of the gas-air mixture is **less than** the burn rate for the gas-air mixture. The greater the ignition velocity, the greater the tendency to flashback. Therefore, gases high in hydrogen and carbon monoxide (manufactured gases) will have far greater flashback tendencies than hydrocarbon gases such as natural and the LP gases. Flashback may actually create a condition in which the flame burns at the orifice and can create burner overheating and sooting. This is a bad condition and needs correcting. Careful examination of the burner ports and the burner alignment should be done to determine if debris, port configuration or misalignment of the orifice relative to the burner body is a problem. We have determined that a misalignment of only three (3) degrees can create flashback or unstable flames. The tendency to flashback varies with the type of fuel gas, port size, port depth, primary air, gas input and temperature of the ports and the gas-air mixture. Another possibility for flashback is the momentary excessive downdraft on the flame. Flashback generally creates an objectionable sound similar to the noise created during extinction.

YELLOW TIPPING:

Yellow tipping may be observed when the primary air supply is decreased to the point where yellow tips first occur. The table above will indicate that point for the gases given. The opposite extreme is a point where the flames begin to lift or blow off the burner ports. Both conditions are to be avoided. Yellow tipping is not always an indicator of sooting or incomplete combustion. LP gases demonstrate some yellow tipping due to unburned hydrocarbons in the gas-air mixture.

UNSTABLE FLAMES AT THE BURNER CIRCUMFERENCE:

The ideal combustion process will exhibit proper ignition, proper carryover and flames that reach a uniform height around the circumference of the burner head. The port design and number will provide for even distribution and proper port loading; i.e., Btu/ Hr-In² per port around the burner head. Uneven flame height around the burner head will result from 1.) debris in ports creating a disproportionate port loading, 2.) misalignment between the orifice and the burner head, 3.) burner damage due to handling. Cast ports, as opposed to drilled ports, may have slag or debris remaining due to the casting process. This is frequently the cause of instability in the flame pattern and should be corrected.

FLOATING FLAMES:

Floating can result when the supply pressure is lower (or much lower) than required for proper ejection of the gas-air mixture from the burner ports. This can be accompanied by a yellowing of the flame and sooting. A floating flame may be "reaching" for combustion air. It is almost always a precondition for incomplete combustion. Also, if secondary air is inadequate, floating may occur. The burner may also be overrated with the input greater than the stated value on the rating plate. In any atmospheric combustion system, adequate ventilation is necessary to carry the products of combustion to the outside. Blocking this natural draft may create a floating flame.

FLAME ROLLOUT:

Flame rollout generally occurs due to delayed ignition of the burner and / or slow carryover of the burner flames around the burner circumference. It can be a very hazardous condition and one in which injury can occur. Another condition would be the improper changeover from LP to natural gas. The heating value of natural gas is much lower than the heating value of LP gas; consequently overfiring can occur. When a changeover is necessary, the burner orifice and the burner regulator must be changed to allow for the proper input to be had. Firing LP gas on a natural gas orifice will overfire approximately 200 % for propane. For butane gas, an over-firing of 300% will occur. The burner orifice must be considered when changing over from one gas to another occurs. Blocking of the vent system or an inadequately designed ventilation system may also cause flame rollout.

NOISY BURNER FLAMES:

Noise is usually caused by burner flame lifting or blowing off from the burner ports.

NOISY EXTENSION (EXTINCTION POP):

During cessation of ignition, flashback may occur. This is called extinction pop. The occurrence creates a noise or a bang and results when the gas to the burner is turned off.

VENTILATION ISSUES:

For some gas-fired devices, venting is a necessity. This means that the products of combustion are diverted from the burners to the outside atmosphere. The input rate is sufficient to create products of combustion in quantities that must be driven to the outside surroundings. Improper design or restricted venting may create issues that grossly affect the combustion process. Venting also provides for the dilution of combustion products and a needed drop in the temperature of the products of combustion. There are several causes for ventilation issues. These are as follows:

1.) Restrictions in the discharge vents. Check to make sure there are no obstructions in the vent system that would create an impediment to the flow of combustion products.
2.) Damage; i.e., denting, to the vent system due to installation or use.
3.) A vent design that is too long or too "contorted" to allow for proper exhaust of the products of combustion. There may be too many elbows in the system or the elbows may be too close together for proper venting.
4.) This may sound odd but there have been times when "critters" crawl into vents and obstruct the process. (It's warm in there !) I examined a vent system in Wisconsin in which a raccoon had crawled into a vent, got stuck, died and was in the process of decomposing. The only indicators were lazy burner flames and a rather strong odor.

ODOR:

Odor can occur when incomplete combustion does not take place or when all of the fuel gas is not consumed. Normally, the internal pressure of a burner is a negative pressure so that gas is entrained into the burner head. A positive pressure can result in unburned gas and, consequently, odor from the system.

PILOT OUTAGE:

A standing pilot may be one method for burner ignition. Normally, the burner rate for a standing pilot will be less than 2,000 Btu/Hr so the flame is considerably smaller than the actual burner flame it will ignite. Sometimes the ignition of the burner will "snuff out" the standing pilot. If this occurs, please check to see if the following conditions are present:

1.) Misalignment of the pilot relative to the burner head.
2.) Dimension between the pilot bracket and the burner head. (Manufacturer's specifications will dictate this dimension, and it must be maintained for proper and continued ignition.)
3.) All standing pilots have orifices that discharge the gas-air mixture. They are small burners in themselves so the proper orifice must be present. Consult the manufacturer for the proper orifice opening.
4.) Downdrafts in the ventilation system that extinguish the pilot. This can occur due to the ventilation "stack" being too close to outside roof structures or walls thus creating "eddy" currents and downdrafts. Extending the vent may solve this problem. An "assisted" vent or power vent may be necessary to correct the condition.
5.) Obstruction of primary air to the standing pilot. This will create other issues with the main burner, and the results will be obvious.

Most manufacturers are eliminating the standing pilot from their designs due to the problems given above and replacing the ignition systems with spark-ignition devices or "glow-bar" devices. Both, in my opinion, are preferable to the standing pilot.

ALTITUDE:

Altitude is actually not a problem but leads to several problems. As the altitude increases, the atmospheric pressure decreases and the availability of primary air decreases. Generally, there are no corrections for input at altitudes less than 2,000 feet above sea level. As per the National Fuel Gas Code (ANSI Z223.1/ NFPA 54) "above 2,000 feet, the appliance must be derated 4% for every 1,000 feet above sea level". Also, pressure switches and other components do not react the same at higher elevations.

Chapter 8

TESTING REQUIREMENTS

All products, whether gas or electric, will undergo testing to determine the integrity of the design and compliance with minimal safety standards for the particular product in question. The American National Standards Institute (ANSI) provides test and performance standards that are used by third party agencies; i.e., American Gas Association (AGA), Canadian Gas Association (CSA), Underwriters Laboratories, Inc (UL), Electronic Test Laboratories (ETL) etc. These various standards act as the reference for certification. A manufacturer is not required by law to test against the specifications, but prudence does dictate conformance. The test requirements are there to provide for the greatest safety to the installer and user of the equipment. Performance is important, but safety is mandatory.

We are going to discuss the rudimentary requirements in general terms knowing that each gas-fired product will have its own ANSI standards detailing those necessary requirements for safe and effective operation. These may be broken down into the following four classifications:

- Construction
- Performance
- Literature and Markings
- In-house Testing Requirements

CONSTRUCTION AND ASSEMBLY

The actual construction and assembly of any gas-fired product is of the utmost importance and that construction is paramount in obtaining a safe product. ANSI Z21.1 (Household Cooking Appliances) states the following: ' the construction of all parts, whether specifically covered by the various sections of this standard or not, shall be in accordance with reasonable concepts of safety, substantiality and durability'. From the same standard we also may read the following: ' the general construction and assembly shall be of a neat and workmanlike character with parts well fitted and bolts or other fasteners drawn up tightly to give rigidity. Exposed edges, which might be brought in contact with the hand during usage or adjustment of the appliance, shall be smooth. In some standards you may also find a callout for materials that cannot be used. Materials such as asbestos and substances containing heavy metals; i.e., cadmium, lead, etc cannot always be used in fabricated parts or assemblies. These materials may be prohibited in general or prohibited in certain areas of the gas-fired device. Given below is a **partial list** of those construction and assembly areas generally addressed in a typical standard.

- Usage of materials
- Gage of materials
- Electrical wire diameter and insulation thickness
- Coating used to prevent corrosion
- Fasteners used in securing attached parts
- Replaceability of parts with or without special tools

- Temperature limitations for materials used in the assembly to preclude sagging, warping and / or deformation of parts
- Any components or subassemblies requiring adjustment during or after installation shall be accessible for adjustment.
- All electrical devices must be serviceable using tools found in a typical service organization.
- All grounding of electrical parts must be made in a fashion so as not to endanger the installer or service personnel.
- Any fuse or circuit breaker must be accessible for replacement or resetting
- In some cases, actual forces are exerted in testing to prove the structural integrity of the product. These tests are conducted under laboratory conditions.
- Components or subassemblies with glass, Plexiglas or other breakable substances shall withstand loads found during normal usage of the gas-fired device.
- Any part that can be removed or replaced shall be designed and assembled in a manner to allow for the proper replacement relative to the subassembly or structure.
- Bases, legs, casters and frames must be designed to support the structure during all normal use and any abnormal use that could possibly occur
- If abnormal use can occur, that use will be tested for under laboratory conditions to determine any detrimental effects to the equipment.
- Shipping the product to a distributor, installer or user shall not displace any parts or subassemblies to preclude unsafe usage.

PERFORMANCE

Performance requirement will certainly vary depending upon the equipment, BUT most gas-fired consumer product standards are written so that maximum safety is maintained through usage and for the life of the product. For gas-fired products, the following partial list of tests are generally conducted:

- Combustion of gas burners must be within a certain maximum PPM level for marketing and sale to occur, if the product is to be certified by a third party. Combustion is usually tested for at normal pressure, reduced pressure and increased pressure. Generally, that acceptable level is below 800 PPM. This value may vary depending upon the area of usage; i.e., kitchen, laundry room, storage area, etc.
- Burner and pilot operating characteristics (BOC & POC)
- Burner ignition times
- Time for burner flame carryover from port to port
- Component surface temperatures. This test is required to make sure that all surfaces accessible to touch are below temperatures that could cause burns and/or scaring.
- Wall floor and enclosure temperatures.
- Safety, if the product is used in an abnormal fashion
- Venting effectiveness and operation
- Evaluation of potential hazard for clothing ignition
- Evaluation of all safety circuits designed into the product; i.e., hi-potential testing, current leakage, proper ground path, etc.
- Evaluation of all grounding devices for the products. Are those grounding devices secured in a permanent fashion or can they be reattached in a workable fashion?

- Ship testing of packaged products.

LITERATURE AND MARKING

It may sound trite but the literature that accompanies a gas-fired product is of the utmost importance to the installer and the end user. This literature includes, but is not limited to the following:

- Use and Care Manuals
- Installation instructions
- Instructions for converting from one gas to another
- Wiring diagrams
- Gas train layout (when necessary)
- Instructions on the application of components to comply with special requirements; i.e. anti-tip brackets for gas-fired ranges, temperature and pressure relief vales for gas-fired water heaters, etc.
- All marking, warnings, cautions on labels attached to the device itself
- Rating plates that indicate the gas input for the device
- Any unpacking instructions necessary prior to installation
- Any requirements for dual languages must be met. In Canada, English and French is required for all literature and labels. Sears now requires English and Spanish for all literature and labels

IN-HOUSE TESTING REQUIREMENTS

I am including this additional classification to indicate that most manufacturers have in-house design and laboratory testing requirements over any standards requirements. A manufacturer knows its products better than anyone else so, it's only natural that, for the sake of maximum safety, in-house criteria be applied. At General Electric, these in-house requirements are called ETPs or Engineering Test Procedures. They supplement the ANSI requirements, but are not required to be a part of the "data package" sent to a third party testing laboratory for approval and / or certification. The following examples are how ETPs are applied.

- Fabric Ignition ETP. This test is more rigorous than the ANSI fabric ignition test and provides for testing fabric around the periphery of a gas burner. This is a safety requirement to preclude ignition of clothing or low hanging curtains.
- Critical Temperature ETP. A test that applies restrictors to the vent of a gas dryer allowing for the reduction of flue products and the increase in dryer drum temperatures.
- Ship Testing ETP. This test insures integrity of the structure when a product is shipped via UPS, FedEx, DHL, etc for "state-side" use or for international use. The ETP is much more rigorous than the ANSI requirements.
- Environmental testing
- Altitude testing
- Testing necessary to determine continued and safe usage during and after significant weather events. These are only three in-house tests that are performed over and above the

mandated requirements, but they do give you a sense of how a manufacturer provides for the maximum safety of operation and continued use of the product supplied to the market.

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APPENDIX

BASIC CONVERSIONS & GAS FACTS

1 Btu = 252 Calories = 1055 Joules = 778 Ft-lbs

1 Kw-Hr = 3,412 Btu

1 Bar = 14.696 lbs/in^2 = 29.92 in, Hg

27.680 in W.C. = 1 lb/in^2 = 2.493 Ft, Hg = 6.895 Kpa

STP = 60 º F and 30.00 " Hg

1 Gallon of water = 8.345 lbs

1 Ft^3 water = 62.428 lbs

1 liter of water = 2.205 lbs

HV of methane = 1,000 Btu/Ft^3 (nominal)

HV of propane = 2,500 Btu/Ft^3 (nominal)

HV of butane = 3,400 Btu/Ft^3 (nominal)

LISTS OF TABLES

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GOVERNING LAWS OF COMBUSTION

The Effect of Pressure: Boyle's Law: The volume occupied by a given mass of gas varies inversely with the absolute pressure if the temperature is not allowed to change.

PV = constant
V = volume of gas
P = absolute pressure

The Effect of Temperature: Charles' Law: The volume of a given mass of gas is directly proportional to the absolute temperature if the pressure is fixed.

V/T = constant
V = volume of gas
T = absolute temperature

Partial Pressure: Daltons' Law: Daltons' Law holds only for an ideal gas. Each gas of a mixture exerts a partial pressure equal to the pressure, which the same mass of the gas would exert if it were present alone in the given space at the same temperature. Essentially, the law implies independence of action of the molecules of a mixture.

P(t) = P(a) + P(b) + P(c) …..P(n)

Avogadro's Law: Under the same conditions of temperature and pressure equal volumes of all gases contain the same number of molecules.

Solubility of Gases—Henry's Law: At any specified temperature the mass of gas, which will dissolve in a given liquid, is proportional to the partial pressure of the gas in contact with the solution.

P(p) = Kx
P(p) = K'C
P(p) = partial pressure
K = constant
X = mole fraction of solute
K' = constant
C = concentration

Vapor Pressure of Solutions—Raoult's Law: The vapor pressure of a component of a solution is directly proportional to its molar concentration in the solution and to the vapor pressure of the substance in a pure state at the specified temperature.

Ideal Gas Law: It is very useful to have the volume, temperature and pressure expressed in terms of a single equation. This equation is a relationship expressed in terms of energy.

PV = nRT
P = volume
V = absolute pressure
n = number of moles of gas
R = universal gas constant

Compressibility Factor: A method sometimes found useful for correcting for deviations from the ideal gas law is to insert a specific correction factor in the ideal equation as a multiplier. With this being the case, the corrected equation becomes:

$$PV = \mu NRT$$

P = pressure
V = volume
μ = ratio of volume one actually observes to volume which would be observed of same substance if it were an ideal gas.
T = absolute temperature

By adding the compressibility factor, the equation in place of the Ideal Gas Law becomes the following:

$$\frac{P(2)V(2)}{\mu(2)T(2)} = \frac{P(1)V(1)}{\mu(1)T(1)}$$

Where (1) and (2) represent different states of the same gas mixture.

The First Law of Thermodynamics: The first Law states that during any cycle a closed system undergoes, the cyclic integral of the heat is equal to the cyclic integral of work. This is basically a statement of the Conservation of Energy; energy cannot be created or destroyed.

The Second Law of Thermodynamics: The second Law gives information as to the limitations, which govern the transformation of heat into work, and states that heat of itself cannot pass from a colder body to a hotter body. In other words, all systems tend to approach a state of equilibrium. This implies that it is impossible to build a heat engine having a thermal efficiency of 100 per cent.

The Third Law of Thermodynamics: The third Law states that the entropy of a pure substance is zero at absolute zero.

DEFINITION OF TERMS

Air-Gas Ratio—The ratio of combustion air supply flow rate to the fuel gas supply flow rate. This ratio does **NOT** include any secondary air and is given as a percentage, i.e. Ft^3 / Hr (air) / Ft^3 / Hr (gas).

Air Shutter—An adjustable device on the primary air openings of a burner, used to control the amount of primary air introduced into the burner body. The opening or closing of the air shutter may alter the appearance of the burner flame and / or the flame characteristics, i.e. floating, blowing off, etc.

Aldehyde—A class of compounds, which may be produced during **incomplete** combustion of a fuel gas. Aldehydes have a pungent and distinct odor.

Altitude—Elevation above sea level, measured in feet or meters. Generally, burner inputs are adjusted downward relative to increasing altitude due to the decreasing amount of atmospheric air; consequently, combustion air.

ANSI (American National Standards Institute)—The American National Standard Institute is a private non-profit organization that oversees the development of voluntary consensus standards for products, services, processes, systems, and personnel in the United States. The organization also coordinates US standards with international standards so that American products can be used worldwide. For example, standards make sure that people who own cameras can find the film they need for them anywhere around the globe.

Atmospheric Pressure—The pressure exerted on the earth's surface by the atmosphere above it. Atmospheric pressures will decrease as the altitude increases above sea level.

British Thermal Unit—(Btu) The quantity of heat required to raise the temperature of one pound of fresh water one degree F. Btus are the basic measurement in the English system for indicating the caloric value of energy released during the combustion process.

Burner—An atmospheric gas burner is a device designed to entrain air necessary for combustion, premix that air, and deliver that air-gas mixture to the combustion zone. Most atmospheric burners are designed to burn natural gas, propane gas, butane gas, mixed gas and manufactured gas.

Burner Flexibility—The ability of a burner to be converted thereby allowing for the combustion of other gases, i.e. natural to propane, natural to butane, mixed gas to natural etc. Please note: in order for a burner to work properly, the correct orifice, the correct air shutter opening and the correct delivery pressure must be used. When converting from one gas to another, an orifice change and a regulator change are generally required. **IT IS IMPERATIVE TO CHECK THE USERS MANUAL PRIOR TO MAKING THE CONVERSION FROM ONE GAS TO ANOTHER. MAKE SURE THE PROPER COMPONENTS ARE USED AND EXPERIENCED PERSONNEL ARE AVAILABLE FOR THE CONVERSION PROCESS.**

Burner Port(s)—The opening in a burner head in which the air-fuel mixture is discharged for burning. A very critical calculation is port loading in which the Btu/Hr per port is determined. This value may indicate a burner flame that will "float", "lift" or " flash back ".

Butane Gas—A hydrocarbon fuel gas heavier than methane and propane with the chemical composition of C_4H_{10}. It is a major constituent of liquefied petroleum (LP) gas.

Carbon Dioxide—Carbon dioxide (CO_2) is a constituent of air. The percentage of carbon dioxide is a measure of **complete** combustion.

Carbon Monoxide—Carbon monoxide (CO) is a product of combustion and a measure of **incomplete** combustion. Carbon monoxide can pose a health risk if present in certain amounts and inhaled for over a lengthy time.

Combustion—A reaction between a fuel and air initiated by a heat source. This is, generally, a rapid oxidation and is accompanied by the generation of heat and light. (Please note: there are fuels and oxidizers that are "hypergolic" and combust when in contact with each other. These substances will not be considered in this discussion.)

Combustion Air—The air supplied to a burner in the combustion process. This air will be primary air and secondary air and will contain the oxygen necessary to sustain the combustion process.

Products of Combustion—Constituents resulting from the combustion of fuel and the oxygen in air, including inert gases, aldehydes, water vapor, NO(x), but excluding excess air.

Density—The weight of a substance per unit volume. In English measurements, this would be lbs / Ft ^{3}.

Dilution Air—Air that enters a vent, draft hood or other device and serves to reduce the temperature of the products of combustion and the concentration of any carbon monoxide.

Discharge Coefficient—This coefficient is the ratio of the actual flow of fuel gas through burner orifice to the flow, which would be expected through the same orifice under the same conditions of operation if the orifice were a "perfect one". This multiplier is always less than 1.00 and is dependent upon the internal characteristics of the device, i.e. channel length, angle of approach, etc.

Draft Hood—A device built into an appliance, or made part of a vent system designed to, 1.) assure the ready escape of the products of combustion in the event of no draft, backdraft, or stoppage beyond the draft hood; 2.) prevent a backdraft from entering the appliance and 3.) neutralize the effect of stack action of a chimney or gas vent upon the operation of the appliance.

Downdraft—Excessive high air pressure existing at the outlet of chimney or stack which tends to make gases flow downward in the stack or vent system.

Energy--A scalar physical quantity, which is a property of objects, and systems. According to the First Law of Thermodynamics, energy is conserved by nature and can neither be created or destroyed. Energy is often defined as the ability to do work. For our purposes here, we will use the units as Btu/Hr.

Excess Air—Air that results, in excess, relative to the process of complete combustion. This value is usually expressed as a percentage of the air required for complete combustion.

Flame Rollout—A condition in which the burner flame exceeds the volume of the combustion chamber. This may be momentary, upon ignition, or permanent depending upon the input of the burner. It is not a good condition and may pose a very hazardous threat relative to combustibles in and around the combustion zone and the appliance.

Flame Velocity—The speed at which the flame moves through the air-fuel mixture. This is usually measured in inches per second and becomes critical when looking at lifting and " blow-off" at the burner ports.

Flammability Limits—The Upper Explosive Limit (UEL) and Lower Explosive Limit (LEL) are always given as a percentage of the gas in an air-gas mixture. There will be no combustion unless the air-gas mixture is between the UEL and the LEL.

Flashback—This is a very undesirable condition in which the velocity of the burner flame is greater than the velocity of the air-gas mixture being discharged through the burner ports. This may result in burning at the orifice, which is a condition that can create overheating and sooting.

Floating Flames—An undesirable condition indicating that there may be incomplete combustion. Floating flames are reaching for oxygen, consequently combustion air.

Flow Rate—This is a measure of the flow of a fluid in a conduit or a mechanical device. In our study, it is the flow of gas and / or air being entrained into the burner. It is measured in Ft^3/Hr or CC / Hr.

Flue—Some products must have openings for the products of combustion to escape. These products are generally vented to the outside so that the products will not accumulate inside the dwelling.

Fuel—Any substance, which is combustible, may be called a fuel.

Fuel Gas—Any substance in a gaseous form used for the purpose of combustion.

Gas Meter—A gas meter is a mechanical device that indicates the quantity and the rate of a fuel gas flowing through accompanying piping.

Heating Value—All combustibles have heating values, generally measured in Btu/ Ft^3. This is the energy released per volume of gas ignited during the combustion process. In America, we use the Gross or Higher Heating Value whereas in Europe, the net or Lower Heating Value is used for calculating purposes.

Hydrocarbon—Any number of compounds composed of Hydrogen and Carbon atoms.

Ignition—The act of initiating the combustion process.

Ignition Temperature—The minimum temperature at which combustion is initiated.

Impingement—The act of burner flames hitting an adjoining colder surface. This may cause a sudden drop in flame temperature and deposition of carbon onto the adjoining surface. This occurrence is also called quenching.

Incomplete Combustion——Incomplete combustion occurs where there is not enough oxidant available to combine and react with fuel. When this occurs, carbon monoxide is produced. In the process of combustion, using an atmospheric burner, incomplete combustion is generally the rule and not the exception BUT we do measure the level of incomplete combustion, making sure the present in hazardous quantities.

Inerts—Non-combustible substances in a fuel or in flue gases. Nitrogen and carbon dioxide are examples of inert substances. An inert gas or constituent has no caloric value.

Injection—The drawing of primary air into the head of a burner prior to mixing with fuel. This is usually accomplished by designing a converging / diverging section of the venture downstream of the burner head.

Input Rate—The input rate may be expressed in units of Ft^3 / Hr or Btu / Hr. Normally, Btu/Hr for gas-fired products is the way input is defined.

Lean Mixture—A lean mixture is one in which the quantity of fuel, relative to the air-gas combination, is less than needed for complete combustion.

Lifting Flames—A condition in which the burner flames separate from the burner ports. This is also called "blowing off" and is a very undesirable condition.

Limit Gases—Limit gases are used for test purposes only in gas laboratories. The major constituent is usually greater than 95% of the total mix.

Limits of Flammability—Air-gas mixtures will only burn within certain limitations. The ratio of fuel and air must be within the Upper and Lower Explosive Limits and is always given as a percentage of the gas / air mixture.

Liquefied Petroleum Gases—The terms "Liquefied Petroleum Gases", "LPG" and "LP" Gases include any fuel gas which is composed, predominantly, of any of the following hydrocarbons, or mixtures of them: propane, butane, propylene or isobutane.

LNG—Liquefied Natural Gas

Manufactured Gas—A fuel gas, which is artificially produced by some process, as opposed to natural gas, which is found in nature. Manufactured gas, generally, is no longer used in North America but is produced in other parts of the world. It is basically made from coke or coal and has a composition that varied from city to city. The heating value is approximately 500 Btu / Ft^3.

Methane—CH(4). Methane is found in nature and is the major constituent of natural gas.

Mixed Gas—A gas fuel in which the heating value of the mixture is enhanced by blending natural, propane, butane, etc.

Mixer or Mixing Tube—That portion of a burner in which the gas and entrained air are combined into a homogenous mixture in preparation for ignition.

Natural Gas—Basically 90% methane with other light hydrocarbons making up the remainder of the "mix". The heating value of natural gas will vary depending upon the region in which it is found.

NGPA—Natural Gas Policy Act (of 1978)

Odorant—Some gases, including natural gas, are odorless and colorless in their natural state. An odorant is added for the purposes of detecting a gas leak. This is done in the city of use and is mandated by law.

Orifice—An opening in a plug or "spud" which controls the flow of fuel gas into a burner for mixing. An orifice, properly sized, can provide for complete combustion. When improperly sized, can create a nightmare for the engineer or technician.

Parts per Million—Generally used as the measure of carbon monoxide in the products of combustion.

1%	10,000 PPM
0.10%	1,000 PPM
0.01%	100 PPM
0.001%	10 PPM

According to the American Gas Association, 0.08 % or 800 PPM is the maximum concentration of carbon monoxide allowed in the products of combustion.

Port—The portion of a burner in which the air-gas mixture is discharged and ignited. There will be multiple ports on most atmospheric gas burners.

Port Loading—Port loading is Btu/ Hr-In^2 or Btu / Hr-Ft^2 and is a very important factor in burner design. Overloading can create flame irregularities such as blowing off, floating and incomplete combustion.

Pressure—Pressure is the force exerted on the earth due to the atmosphere. It is measured in pounds per square inch (PSI), millibars, inches of mercury or inches of water (water column pressure).

Pressure Drop—The loss of pressure in a gas delivery system, generally, is a measure of the drop in water column pressure between the gas inlet and the burner orifice. Pressure drop **is the enemy** and one of the most problematic issues for a gas-fired product.

Pressure Regulator- A mechanical device for controlling the downstream pressure relative to the delivery pressure. It is typically measured in PSI or inches water column.

Primary Air—The air entrained by the injection of fuel gas into the head of a burner. This air is mixed with the fuel gas and then delivered to the burner head and ultimately the burner ports.

Propane Gas —Often referred to as LP (Liquefied Petroleum). It is also called "bottled gas". HD5 propane is approximately 90 % C(3)H(8) with a specific gravity of approximately 0.50. The heating value and specific gravity will vary depending upon the location in which it is found.

Rich Mixture—A rich mixture is one in which the gas in an air-gas mixture is greater than would be necessary for complete combustion.

Saturated Gas vs Dry Gas— In the natural gas industry, all of the gas calculations are accomplished considering only a dry basis. Standard temperature and pressure are calculated on a dry basis.

Secondary Air—Secondary air is that air available at the burner ports and is available at the point of combustion.

Soft Flame—A flame that is partially deprived of primary air. This flame may "float" over the burner ports and appear to move from point to point around the burner.

Soot—Small particles of carbon that result from incomplete combustion and impingement. They may be deposited on the burner, vent system and other adjoining surfaces, including cooking utensils.

Specific Gravity—Weight per unit volume relative to the weight per unit volume of air. Specific gravity is relative to weight / volume of air.

Standard Conditions (STP)—Pressure and temperature usually selected to be the reference points and conditions for measuring the properties of gases. In appliance work, standard conditions are 30 inches of mercury and 60 degree F.

Static Pressure—The pressure exerted by a motionless gas, usually measured in PSI or inches water column.

Therm—A unit of energy equal to 100,000 Btu.

Total Air—Primary air plus secondary air plus excess air supplied to a burner.

Total Pressure—The sum of static pressure plus gage pressure. Total pressure is also called velocity pressure.

Town Gas—Also known as manufactured gas.

Toxicity—The natural gases such as natural, methane, propane, butane etc are not toxic. The only way they can harm an individual is by displacing the air so suffocation occurs. Manufactured gases were very toxic because they contained significant quantities of carbon monoxide, which is toxic.

Ultimate Carbon Dioxide—The Stoichiometric percentage of carbon dioxide resulting from complete combustion.

Vent—The structure of a gas-fired device that allows for the discharge of the products of combustion. For most appliances, this is a sheetmetal structure that accepts dilution air for cooling and provides for the reduction of concentrated carbon monoxide.

Venture—That portion of a burner in which the air-gas mixture is propelled into the burner head for ignition. It usually is a converging/diverging device.

Water Column Pressure—Abbreviated as W.C. and is a measure of pressure. One inch W.C. is equivalent to 0.578 ounces per square inch.

Wobbe Index—The main indicator of the interchangeability of fuel gases and is defined as follows:

$$I(w) = \text{Higher Heating Value of Gas} / (\text{Specific Gravity of gas})^{1/2}$$

Yellow Tipping—A condition in which the burner flames exhibit a yellow color at the very tip of the flame. Yellow tipping may be an indicator of sooting.

1400 LP-Air Gas—Propane gas, with a heating value of 2500 Btu/Ft^3, mixed with air to produce a heating value of 1400 Btu / Ft^3. This is often done by gas utilities and is called "peak shaving". The purpose being to approximate the heating value of natural gas.

Cielo Technologies, LLC

Physiological Effect of Carbon Monoxide

Table A-1

Parts of Carbon Monoxide per Million Parts of Air	Percent Carbon Monoxide in Air	Effect
50[J]	0.005	Concentration allowable for an exposure of eight hours.
400 to 500'	0.04 - 0.05	Concentration which can be inhaled for 1 hour without appreciable effect.
600 to 700'	0.06 - 0.07	Concentration causing a just appreciable effect after 1 hour of exposure.
1000 to 1200'	0.10 - 0.12	Concentration causing unpleasant but not dangerous symptoms after 1 hour of exposure.
1500 to 2000'	0.15 - 0.20	Dangerous concentration for exposure of 1 hour.

4000 and above[2] 0.40 and above Concentrations which are fatal in exposures of less than 1 hour.

Fluid Pressure (Force per Unit Area)

Table A-2

	kPa	mbar	Inches H2O			Inches Hg		ozf/in^2	Ibf/in^2
			@ 39.2°	@60°	@32°	@32°	@60°		
1 kPa	1.00	10.00	4.02	4.02	4.02	0.295	0.30	2.32	0.15
1 mbar	0.10	1.00	0.40	0.40	0.40	0.030	0.03	0.23	0.02
1 in H_20 (@ 39.2 °F)	0.25	2.49	1.00	1.00	1.00	0.074	0.07	0.58	0.04
1 in H_2O	0.25	2.49	0.10	1.00	1.00	0.073	0.07	0.58	0.04
1 in H_2O	0.25	2.49	0.10	0.10	1.00	0.073	0.07	0.58	0.06
1 inHg (@ 32 °F)	3.39	33.86	0.12	13.61	13.62	1.000	1.00	7.86	0.49
1 in Hg (@ 60 °F)	3.38	33.77	0.14	13.57	13.58	0.10	1.00	7.84	0.49
1 ozf/in^2	0.43	4.31	1.760	1.732	1.73	0.13	0.13	1.00	0.06
1 Ibf/in^2	6.90	68.94	27.68	27.71	27.73	2.04	2.04	16.000	1.00

Natural Gas Delivered By Major Transmission Lines

Table A-3

No	Transmission line and major source of supply	Components of gas- per cent by volume									Gross Heating Value	SpGr	Water Vapor lb/MMCF
		Methane	Ethane	Propane	Butane	Pentane	Hexane plus	CO(2)	O(2)	N(2)			
1	Cities Service Gas Co., from Texas Panhandle	73.48	3.86	4.26	2.13	0.63	0.40	0.10	0.32	11.90	1077	0.694	9.80
2	Cities Service Gas Co. from Oklahoma Hugoton	75.28	6.39	3.76	1.45	0.29	0.29			12.54	1043	0.706	3.50
3	Cities Service Gas Co. from Kansas Hugoton	77.02	3.89	2.58	2.04	0.49	0.13	0.10	0.10	13.65	1005	0.698	3.00
4	Colorado Interstate Gas Co. from Kansas Hugoton	72.40	6.12	3.21	1.20	0.15				16.92	983	0.703	5.80
5	Colorado Interstate Gas Co. from Texas	78.76	5.67	2.88	1.06	0.10				11.53	1007	0.683	8.40
6	El Paso Natural Gas Co. from Permian Basin	81.21	9.42	3.45	0.63	0.04				5.25	1097	0.665	10.0 0
7	Kansas Nebraska Natural Gas Co. from Hugoton	71.25	5.69	3.37	0.98	0.14	0.20	0.10		18.27	956	0.7161	
8	Lone Star Gas Co. from Texas and Oklahoma	85.00	7.10	2.40	0.50	0.40		0.60		4.00	1069	0.650	15.0 0
9	Michigan- Wisconsin	73.1	6.2	4.00	0.9					15.8	973	0.70	3.50
10	Mississippi Pipeline from Monroe	93.17	4.13	0.75	0.22	0.07	0.11	1.22	0.01	0.32	1049		3.0
11	Montana-Dakota Utilities Co. from Montana & the	93.00	6.00	0.20				0.30		0.50	1010	0.600	
12	Natural Gas Pipeline Co. of America from	79.00	6.00	3.70	1.00	0.10				10.20	1039	0.685	8.00
13	Northern Natural Gas Co from Panhandle	75.78	4.97	3.24	2.12			0.20	0.14	13.55	1011	0.685	11.0 8
14	Pacific Gas & Electric Co 34" from El Paso Nat. Gas	81.90	9.30	3.30	0.50					5.00	1100	0.660	Win. 11 Sum .15
15	Panhandle Eastern Trans. Co. from Panhandle	72.40	15.70	0.10				0.20	0.10	11.30	1020	0.680	
16	Southern California Gas Co. from El Paso Nat. Gas	81.40	8.70	3.60	0.60	0.10				5.60	1092	0.670	10.0 0
17	Southern Natural Gas Co. from Monroe and others	94.95	1.30	0.33	0.11	0.09	0.14	0.70		2.39	1008	0.590	5.00
18	Tennessee Gas Transmission Co. from	94.61	3.30	0.99	0.33	0.03	0.18	0.35		0.16	1065	.5967	7.28
19	Texas Eastern Transmission from	92.58	4.27	0.97	0.21	0.04	0.06	0.90		0.95	1051	0.606	3.80
20	Texas Gas Transmission Corp. from Louisiana &	92.80	4.20	0.90	0.20		0.10	1.00		0.80	1049	0.600	
21	Transcontinental Gas Pipeline Corp. from	93.45	3.59	1.27	0.61	0.26	0.22	0.60			1085	.6102	3.50
22	United Gas Pipeline Co. from Refugio to Houston	92.61	3.87	1.15	0.39	0.12	0.07	0.66		1.13	1056	.6049	
23	United Gas Pipeline from Carthage	91.46	4.18	0.94	0.24	0.02	0.09	0.89		2.18	1037	.6074	
24	United Gas Pipeline Co. from Waskom to Dallas	89.55	4.97	0.93	0.38	0.07	0.24	0.91		2.95	1046	.6219	
25	United Gas Pipeline Co. from Slico to Shreveport	92.77	3.35	0.83	0.45	0.18	0.06	1.03		1.33	1044	.6054	
26	United Gas Pipeline Co. from Lirette to Mobile	93.32	3.00	1.06	0.57	0.20	0.20	0.49		1.16	1062	.6063	
27	United Gas Pipeline Co. from Carthage to	92.82	3.55	0.69	0.09	0.03	0.10	1.03		1.71	1029	.5995	
28	United Gas Pipeline Co. from Agua Dulce to Austin	84.73	7.90	2.49	0.76	0.32	0.25	2.54		1.01	1112	.6695	

UTILITY GAS

Table A-4

CubicFeet Per Hour @

Sea Level

Specific Gravity = 0.60 Orifice Coefficient = 0.9

For utility gases of another specific gravity, select factor from Table 5

For altitudes above 2,000 feet, first select the equivalent orifice size at sea level from Table 6.

Orifice Size (Decimal or DMS)	3	3.5	4	5	6	7	8	9	10
.008	.17	.18	.19	.23	.24	.26	.28	.29	.30
.009	.21	.23	.25	.28	.30	.33	.35	.37	.39
.010	.27	.29	.30	.35	.37	.41	.43	.46	.48
.011	.33	.35	.37	.42	.45	.48	.52	.55	.59
.012	.38	.41	.44	.50	.54	.57	.62	.65	.70
80	.48	.52	.55	.63	.69	.73	.79	.83	.88
79	.55	.59	.64	.72	.80	.84	.90	.97	1.01
78	.70	.76	.78	.88	.97	1.04	1.10	1.17	1.24
77	.88	.95	.99	1.11	1.23	1.31	1.38	1.47	1.55
76	1.05	1.13	1.21	1.37	1.52	1.61	1.72	1.83	1.92
75	1.16	1.25	1.34	1.52	1.64	1.79	1.91	2.04	2.14
74	1.33	1.44	1.55	1.74	1.91	2.05	2.18	2.32	2.44
73	1.51	1.63	1.76	1.99	2.17	2.32	2.48	2.64	2.78
72	1.64	1.77	1.90	2.15	2.40	2.52	2.69	2.86	3.00
71	1.82	1.97	2.06	2.33	2.54	2.73	2.91	3.11	3.26
70	2.06	2.22	2.39	2.70	2.97	3.16	3.38	3.59	3.78
69	2.25	2.43	2.61	2.96	3.23	3.47	3.68	3.94	4.14
68	2.52	2.72	2.93	3.26	3.58	3.88	4.14	4.41	4.64
67	2.69	2.91	3.12	3.52	3.87	4.13	4.41	4.69	4.94
66	2.86	3.09	3.32	3.75	4.11	4.39	4.68	4.98	5.24
65	3.14	3.39	3.72	4.28	4.62	4.84	5.16	5.50	5.78
64	3.41	3.68	4.14	4.48	4.91	5.23	5.59	5.95	6.26
63	3.63	3.92	4.19	4.75	5.19	5.55	5.92	6.30	6.63
62	3.78	4.08	4.39	4.96	5.42	5.81	6.20	6.59	6.94
61	4.02	4.34	4.66	5.27	5.77	6.15	6.57	7.00	7.37
60	4.21	4.55	4.89	5.52	5.95	6.47	6.91	7.35	7.74
59	4.41	4.76	5.11	5.78	6.35	6.78	7.25	7.71	8.11
58	4.66	5.03	5.39	6.10	6.68	7.13	7.62	8.11	8.53
57	4.84	5.23	5.63	6.36	6.96	7.44	7.94	8.46	8.90
56	5.68	6.13	6.58	7.35	8.03	8.73	9.32	9.92	10.44
55	7.11	7.68	8.22	9.30	10.1	10.85	11.59	12.34	12.98
54	7.95	8.59	9.23	10.4	11.3	12.25	13.08	13.93	14.65
53	9.30	10.0	10.80	12.2	13.3	14.29	15.27	16.25	17.09
52	10.6	11.4	12.31	13.8	15.2	16.34	17.44	18.57	19.53
51	11.8	12.7	13.69	15.4	16.9	18.16	19.40	20.64	21.71
50	12.8	13.9	14.94	16.8	18.4	19.77	21.12	22.48	23.65
49	14.0	15.2	16.28	18.3	20.2	21.60	23.06	24.56	25.83
48	15.1	16.3	17.62	19.8	21.8	23.31	24.90	26.51	27.89
47	16.2	17.5	18.80	21.2	23.2	24.93	26.62	28.34	29.81
46	17.1	18.5	19.98	22.5	24.7	26.43	28.23	30.05	31.61
45	17.7	19.1	20.52	23.1	25.3	27.18	29.03	30.90	32.51
44	19.4	21.0	22.57	25.5	27.9	29.87	31.89	33.96	35.72
43	20.7	22.3	24.18	27.2	29.8	32.02	34.19	36.41	38.30
42	23.1	24.9	26.50	29.5	32.5	35.24	37.63	40.07	42.14
41	24.0	25.9	28.15	31.6	34.8	37.17	39.70	42.27	44.46
40	25.0	27.0	29.23	33.0	36.2	38.79	41.42	44.10	46.38
39	26.1	28.2	30.20	34.0	37.3	39.97	42.68	45.44	47.80
38	27.0	29.25	31.38	35.46	38.89	41.58	44.40	47.27	49.73
37	28.3	30.6	32.99	37.0	40.8	43.62	46.59	49.60	52.17

LP GASES (BTU/HR at SEA LEVEL)

Table A-5

	Propane	Butane
Heating Value	2,500 Btu/Ft^3	3,175 Btu/Ft^3
Specific Gravity	1.53	2.00
Pressure at Orifice	11"W.C.	11" W.C.
Orifice Coefficient	0.9	0.9

Orifice Drill Size	Propane	Butane
0.008	500	554
0.009	641	709
0.01	791	875
0.011	951	1,053
0.012	1,130	1,250
80	14,300	1,590
79	1,655	1,830
78	2,015	2,230
77	2,545	2,815
76	3,140	3,480
75	3,465	3,840
74	3,985	4,410
73	4,525	5,010
72	4,920	5,450
71	5,320	5,900
70	6,180	6,830
69	6,710	7,430
68	7,560	8,370
67	8,040	8,910
66	8,550	9,470
65	9,630	10,670
64	10,200	11,300
63	10,800	11,900
62	11,360	12,530
61	11,930	13,280
60	12,570	13,840
59	13,220	14,630
58	13,840	15,300
57	14,550	16,090
56	16,990	18,790
55	21,200	23,510
54	23,850	26,300
53	27,790	30,830
52	31,730	35,100
51	35,330	39,400
50	38,500	42,800
49	41,850	45,350
48	45,450	50,300
47	48,400	53,550
46	51,500	57,000
45	52,900	58,500

TABLE A-6

Equivalent Orifice Sizes at High Altitudes (Includes 4% Input Reduction for Each 1,000 Feet)

Orifice Size at • Sea Level	Orifice Size Required at Other Elevations								
	2000	3000	4000	5000	6000	7000	8000	9000	10000
1	2	2	3	3	4	5	7	8	10
2	3	3	4	5	6	7	9	10	12
3	4	5	7	8	9	10	12	13	15
4	6	7	8	9	11	12	13	14	16
5	7	8	9	10	12	13	14	15	17
6	8	9	10	11	12	13	14	16	17
7	9	10	11	12	13	14	15	16	18
8	1	11	12	13	13	15	16	17	18
9	1	12	12	13	14	16	17	18	19
10	1	13	13	14	15	16	17	18	19
11	1	13	14	15	16	17	18	19	20
12	1	14	15	16	17	17	18	19	20
13	1	15	16	17	18	18	19	20	22
14	1	16	17	18	18	19	20	21	23
15	1	17	17	18	19	20	20	22	24
16	1	18	18	19	19	20	22	23	25
17	1	19	19	20	21	22	23	24	26
18		19	20	21	22	23	24	26	27
19	2	20	21	22	23	25	26	27	28
20	2	22	23	24	25	26	27	28	29
21	2	23	24	25	26	27	28	28	29
22	2	24	25	26	27	27	28	29	29
23	2	25	26	27	27	28	29	29	30
24	2	26	27	27	28	28	29	29	30
25	2	27	27	28	28	29	29	30	30
26	2	28	28	28	29	29	30	30	30
27	2	28	29	29	29	30	30	30	31
28	2	29	29	30	30	30	30	31	31
29	2	30	30	30	30	31	31	31	32
30	3	31	31	31	31	32	32	33	35
31	3	32	32	33	34	35	36	37	38
32	3	34	35	35	36	36	37	38	40
33	3	35	36	36	37	38	38	40	41
34	3	36	36	37	37	38	39	40	42
35	3	36	37	37	38	39	40	41	42
36	3	38	38	39	40	41	41	42	43
37	3	39	39	40	41	42	42	43	43
38	3	40	41	41	42	42	43	43	44
39	4	41	41	42	42	43	43	44	44
40	4	42	42	42	43	43	44	44	45
41	-	42	42	43	43	44	44	45	46
42	4	43	43	43	44	44	45	46	47
43	4	44	44	45	45	46	47	47	48
44	4	45	45	46	47	47	48	48	49
45	4	47	47	47	48	48	49	49	50
46	4	47	47	48	48	49	49	50	50
47	4	48	49	49	49	50	50	51	51
48	4	49	49	50	50	50	51	51	52
49	5	50	50	51	51	51	52	52	52
50	5	51	51	51	52	52	52	53	53
51	5	52	52	52	52	53	53	53	54
52	5	53	53	53	53	53	54	54	54

European Limit Test Gases
Table A-7

GAS NAME AND USE	GAS NO	N(2)	CH(4)	C(3)H(8)	C(3)H(6)	H(2)	C(4)
Reference for Natural	G20	0	100	0	0	0	
Sooting	G21	0	87	13	0	0	
Flashback	G22	0	77	0	0	23	
Lifting	G23	7.5	92.5	0	0		
Reference	G25	14	86	0	0	0	
Sooting	G26	13	80	7	0	0	
Lifting	G27	18	82	0	0	0	
Lifting	G231	15	85	0	0	0	
Reference for Butane	G30	0	0	0	0	0	50i
Reference for Propane	G31	0	0	100	0	0	
LP Sooting	G32	0	0	0	100	20	
	G33	12	68	0	0	0	