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BLENDING OF HYDROGEN IN NATURAL GAS DISTRIBUTION
SYSTEMS, VOLUME 2

Combustion Tests of Blends in Burners and Appliances

Final Report, June 1, 1976—August 30, 1977

October 1977

Work Performed Under Contract No. EY-76-C-02-2925

Public Service Electric and Gas Company
Newark, New Jersey

U. S. DEPARTMENT OF ENERGY

Division of Energy Storage Systems

MASTER

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BLENDING OF HYDROGEN IN NATURAL
GAS DISTRIBUTION SYSTEMS

Volume II

Combustion Tests of Blends
in Burners and Appliances

Final Report
Performance Period: June 1, 1976 - August 30, 1977

Prepared by
Public Service Electric and Gas Company
80 Park Place
Newark, NJ 07101

Report Date: October 1977

Prepared for the
Energy Research and Development Administration
Office of the Assistant Administrator for Conservation
Division of Energy Storage Systems
Chemical Storage Branch

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FOREWARD

This is the final report of "Blending of Hydrogen In Natural Gas Distribution Systems". It is separated into three volumes:

Volume I	Gas Blends Flow in Distribution System, Mixing Points and Regulatory Standards
Volume II	Combustion Tests of Blends in Burners and Appliances
Volume III	Gas Blends Leakage Tests of Selected Distribution System Components

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C. R. Guerra, PSRC - Research and Development Department
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ABSTRACT

The emerging "hydrogen economy" is a strong contender as one method to supplement or extend the domestic natural gas supply. This volume of the subject study "Blending Hydrogen in Natural Gas Distribution Systems" describes combustion studies to determine the maximum amount of hydrogen that can be blended in natural gas and utilized satisfactorily in typical appliances with no adjustment or conversion.

Eleven pilot burners and twenty three main burners typical of those in current use were operated on hydrogen-natural gas mixtures containing approximately 8, 11, 14, 20, 22, 25 and 31 percent, by volume, hydrogen. The eleven pilot burners and thirteen main burners were tested outside the appliance they were a part of. Ten main burners were tested in their respective appliances. Performance of the various burners tested are as follows:

1. Gas blends containing more than 6% - 11% hydrogen are the limiting mixtures for target type pilot burners.
2. Gas blends containing more than 20 - 22% hydrogen are the limiting mixtures for main burners operating in the open.
3. Gas blends containing more than 22 - 25% hydrogen are the limiting mixtures for main burners tested in appliances.
4. Modification of the orifice in target pilots or increasing the supply pressure to a minimum of 7 inches water column will permit the use of gas blends with 20% hydrogen.

INTRODUCTION

With the developing scarcity of domestic natural gas supply, methods to supplement or extend this premium energy are urgently needed. The emerging "hydrogen economy" is a strong contender to meet this need. The objective of this investigation was to examine one facet in the use of hydrogen in the future: optimization of blending hydrogen in natural gas for distribution by utilities. Of prime importance is the determination of the maximum amount of hydrogen that could be blended in natural gas, and which would function with maximum reliability and efficiency, with minimal or no adjustment or conversion, on the typical utilization devices that operate from utility distributed gas.

Whenever the sendout natural gas is altered or replaced, the chemical, physical and combustion characteristics of the new gas as compared to natural gas must be determined. For satisfactory burner operation five conditions must be met:

1. Little change in heat input to burner
2. No lifting of flames
3. No flashback of flames
4. No excessive yellow tipping of flames
5. No incomplete combustion of fuel

Natural gas consists primarily of methane and ethane, which have low burning velocity and relatively little tendency to form luminous flames. Hydrogen on the other hand has the highest burning velocity of any gas and a density considerably

lower than that of natural gas. Interchangeability of one gas with another depends on an evaluation of the five conditions noted above and several formulas and methods have been developed to determine them (A.G.A., Weaver, Delbourg and Bureau of Mines).

In the past, the Knoy formula ($\text{B.t.u.} \cdot \sqrt{\text{sp.gr.}}$) and an experimentally determined maximum flame speed has been used by PSE&G to evaluate interchangeability. Limiting values derived by the Knoy formula were based on tests of a large number of appliances with a wide variety of mixed gases. A major drawback to this method was that it did not adequately indicate the yellow tipping tendency for some gases which can be a major problem with non-aerated pilot burners. In Europe, a similar method is used based on the Wobbe Number, or heat input factor ($\text{B.t.u.} / \sqrt{\text{sp.gr.}}$), in conjunction with the Weaver Flame Speed Factor (S).

In addition, a set of indexes has also been derived by Weaver^{1*} from both theory and actual tests. Six indexes are defined: Heat Input (J_H), Air Requirement (J_A), Lifting (J_L), Flashback (J_F), Yellow Tip (J_Y) and Incomplete Combustion (J_I). The heat input index is a ratio of Wobbe Numbers. The flame speed factor "S" or the maximum flame speed is used in the calculation of the lifting and flashback index. It has been demonstrated that these indexes give a substantially complete picture of the interchangeability of one gas with another and a closer prediction to experimental observations. Appendix "A" describes the Weaver indexes in greater detail.

*See References

Regardless of calculated interchangeability, actual burner tests must demonstrate the foregoing five conditions for satisfactory interchangeability.

Although interchangeability criteria, which may be calculated from the gas analysis, are available, these methods are not mutually consistent and were developed over 20 years ago. Since that time new varieties of burners have been developed, and others have been modified, and burners which were critical are no longer used.

In addition, use of these criteria to predict ignition or extinction noise; flashback on rapid turn-down or short-cycling; faulty ignition performance, with either thermal elements or flash tubes; and unfamiliar gas odors have not been successful.

The preferred method of assessing interchangeability, is to (1) determine the possible interchangeable mixtures using established criteria, (2) set up in a laboratory selected burners/appliances representative of the most critical types served and (3) operate the proposed mixtures on the critical burners/appliances.

A preliminary study, using the Weaver Indexes of interchangeability indicated that mixtures containing up to approximately 20% hydrogen should be interchangeable with natural gas. Of the five conditions which must be met for satisfactory interchangeability (1) little change in burner input; (2) no lifting of flames; (3) no flashback of flames; (4) no excessive yellow tipping of flames; (5) no incomplete combustion - it appeared

that these mixtures would be critical with respect to flashback. Laboratory tests were undertaken to substantiate the preliminary finding.

For this purpose, 11 pilot burners and 23 main burners representative of the most critical types found in the field, were set up and operated on hydrogen-natural gas mixtures containing approximately 8, 11, 14, 20, 22, 25 and 31 percent hydrogen with the burners adjusted on natural gas. The pilot burners and 13 of the main burners were tested in the open; ten of the main burners were tested in the appliance they were a part of.

CONCLUSIONS AND RECOMMENDATIONS

1. Mixtures of natural gas and hydrogen containing more than 6-11% hydrogen will cause unsatisfactory target pilot burner performance.
2. Mixtures containing more than 20-22% hydrogen will cause unsatisfactory main burner performance.
3. Conversion or replacement of existing critical target type pilot burners or increase in gas supply pressure would enable the use of mixtures containing up to 20% hydrogen.
4. The limiting conditions result from the tendency of target type pilot burner flames to burn back at the orifice and not above it as designed, resulting in reduced thermocouple output.

5. Main burner performance was limited by flashback under turn down conditions with a tendency to noise when the flame was turned off.
6. Minor changes in burner adjustment such as adjustment of primary air has little effect on the amount of hydrogen which can be satisfactorily utilized.
7. Although no tests were performed on industrial equipment, the limiting percentages of hydrogen found for residential equipment should operate satisfactorily on industrial equipment because it is readily capable of adjustment to meet variations in gas composition. Some industries, such as glass, would probably welcome the addition of hydrogen to natural gas since a more clearly defined sharp flame results.
8. The Weaver Indexes of interchangeability do not accurately predict the interchangeability of hydrogen and natural gas mixtures. Additional work needs to be undertaken to modify these indexes to arrive at a method which is universally applicable.
9. A statistical analysis of the number of types of burners in use needs to be undertaken so that accurate predictions can be made as to the costs of conversion, and the extent of the problems which may occur with various substitute gases.

TEST METHODS

The test equipment used in this investigation consisted of 1) eleven pilot burners, 2) thirteen main burners and 3) ten appliances. (See Exhibit 1, 2 and 3 for pictures and descriptions)* Test gases were prepared by mixing natural gas and hydrogen in cylinders and test gas analyses are shown in Exhibit 4. Each test burner was adjusted on natural gas to obtain proper input and the best possible flame characteristics. The following parameters, where applicable, were then evaluated with natural gas and the substitute mixtures of natural gas and hydrogen:

1. Gas rate (input)
2. Inner cone height
3. Primary aeration
4. Occurrence of yellow-tipping
5. Thermocouple output
6. Occurrence of flashback
 - a. Under steady state conditions
 - b. Under modulating conditions
 - c. On ignition
 - d. On turndown
 - e. On extinction
 - f. On short cycling
7. Occurrence of lifting
8. Noise of extinction
9. Incomplete combustion

Where adjustment of the primary air was provided on burners, the above observations were also made with hard and soft flame

*For list of Exhibits see Table of Contents

adjustments. Exhibit 5 shows a matrix of the tests performed on each burner.

Gas rate was measured using wet test meters and correcting readings to standard conditions of 60°F and 30.00 inches mercury pressure absolute. Inner cone height (the distance from the plane of the burner port to the tip of the flame cone) was measured to the nearest 1/16 of an inch. Percent primary air (the amount of air in the air-gas mixtures being supplied to the burner ports expressed as a percentage of that required for complete combustion of the gas) was measured by sampling the unburned gas ahead of the burner ports and using a Thermco air-gas analyzer. Thermocouple output was measured using the Sun-Tek millivolt meter. Occurrence of flashback, noise of extinction, lifting, and yellow tipping were subjective audio-visual observations. Since these measurements were subjective, every attempt was made to eliminate the differences which could arise by having the observations made by at least two technicians. Flame adjustments were made using the following criteria:

1. Soft flame - Inner cones broken at top, lazy wavering flame with just sufficient primary air to eliminate any yellow.
2. Normal flame - Inner cones rounded, soft tips.
3. Hard flame - Inner cones distinct and pointed

Incomplete combustion was evaluated by sampling the products of combustion and analyzing them by the use of a gas chromatograph.

Test gases were prepared in cylinders by adding hydrogen to natural gas and using partial pressures to determine the desired percentage. The heating value of the prepared sample was then determined using a calorimeter to substantiate the desired percentage. In addition, the prepared sample was analyzed by the use of a gas chromatograph. (See Exhibit 4)

EXHIBIT 1

PILOT BURNERS

<u>No.*</u>	<u>Burner Type</u>
P 1	Primary Aerated
P 2	Incinerating
P 3	Primary Aerated
P 4	Non-Aerated
P 5	Non-Aerated
P 6	Non-Aerated
P 7	Target
P 8	Target
P 9	Target
P10	Target
P11	Target (See Exhibit 2 B-6)

*Tag No. in the pictures (following pages) showing the pilot burners tested

EXHIBIT 1A - PILOT BURNER DESCRIPTIONS

<u>No.</u>	<u>Burner Type</u>	<u>Use</u>	<u>Safety Type</u>	<u>Input - Btu/Hr</u>
P 1	Primary Aerated	Boiler, Furnace	Thermocouple	1,505
P 2	Incinerating	Boiler, Furnace	Differential Expansion	742
P 3	Primary Aerated	Boiler, Furnace	Differential Expansion	1,705
P 4	Non-Aerated	Range Oven	Liquid Expansion	632
P 5	Non-Aerated	Range Oven	Liquid Expansion	351
P 6	Non-Aerated	Range Top	---	110
P 7	Target	Boiler, Furnace	Thermopile	1,753
P 8	Target	Boiler, Furnace	Thermocouple	912
P 9	Target	Boiler, Furnace	Thermocouple	852
P10	Target	Boiler, Furnace	Thermocouple	740
P11	Target	Water Heater	Thermocouple	833

EXHIBIT 2

MAIN BURNERS

<u>No.*</u>	<u>Burner Type</u>
B 1	Ribbon
B 2	Ribbon
B 3	Drilled Port
B 4	Drilled Port
B 5	Drilled Port
B 6	Slotted Port with P-11 Target Pilot
B 7	Slotted Port
B 8	Luminous Flame
B 9	Luminous Flame
B10	Drilled Port
B11	Slotted
B12	Single Port
B13	Target

* Tag No. in the pictures (following pages) showing the main burners tested.

EXHIBIT 2A - MAIN BURNER DESCRIPTIONS

<u>No.</u>	<u>Burner Type</u>	<u>Material</u>	<u>Use</u>	<u>Test Input - Btu/Hr</u>	<u>Rated Input - Btu/Hr</u>
B 1	Ribbon	Cast Iron	Boiler	18,878	20,000
B 2	Ribbon	Pressed Steel	Furnace	25,256	25,000
B 3	Drilled Port	Cast Iron	Boiler	76,339	75,000
B 4	Drilled Port	Pressed Steel	Water Heater	40,120	40,000
B 5	Drilled Port	Cast Iron	Water Heater	18,765	18,000
B 6	Slotted Port	Pressed Steel	Water Heater	40,120	40,000
B 7	Slotted Port	Pressed Steel	Furnace	24,332	25,000
B 8	Luminous Flame	Aluminum Alloy	Room Heater	32,413	30,000
B 9	Luminous Flame	Aluminum Alloy	Room Heater	45,711	45,000
B10	Drilled Port	Cast Iron	Range Top	14,262	12,000
B11	Slotted	Pressed Steel	Air Conditioner	18,697	18,000
B12	Single Port	Pressed Steel	Clothes Dryer	28,074	25,000
B13	Target	Pressed Steel	Clothes Dryer	25,109	25,000

EXHIBIT 3

APPLIANCE BURNERS

<u>No.*</u>	<u>Appliance</u>	<u>Burner Type</u>
A 1	Boiler	Single Port
A 2	Furnace	Slotted Port
A 3	Water Heater	Drilled Port
A 4	Furnace	Single Port
A 5	Range Oven	Drilled Port
A 6	Range Top	Slotted Port
A 7	Room Heater	Slotted Port
A 8	Range Oven	Slotted Port
A 9	Range Top	Slotted Port
A10	Clothes Dryer	Single Port

*Tag No. in the pictures(following pages) showing the appliances tested

CAUTION
WHEN PROPERLY HANDLED, GAS IS PERFECTLY SAFE,
AUTOMATIC, CLEAN & CONVENIENT. BUT YOU MUST REMEMBER
THAT GAS IS INFLAMMABLE. DO NOT EXPERIMENT.

A4

A10

EXHIBIT 3A - APPLIANCE BURNER DESCRIPTIONS

<u>No.</u>	<u>Appliance</u>	<u>Burner Type</u>	<u>Burner Material</u>	<u>Test Input - Btu/Hr</u>	<u>Rated Input - Btu/Hr</u>
A 1	Boiler	Single Port	Cast Iron	131,293	130,000
A 2	Furnace	Slotted Port	Pressed Steel	79,976	80,000
A 3	Water Heater	Drilled Port	Cast Iron	37,913	36,000
A 4	Furnace	Single Port	Cast Iron	70,712	75,000
A 5	Range Oven	Drilled Port	Cast Iron	18,599	16,000
A 6	Range Top	Slotted Port	Pressed Steel	10,152	12,000
A 7	Room Heater	Slotted Port	Cast Iron	20,839	20,000
A 8	Range Oven	Slotted Port	Pressed Steel	18,599	19,000
A 9	Range Top	Slotted Port	Pressed Steel	10,152	10,000
A10	Clothes Dryer	Single Port	Pressed Steel	28,269	30,000

EXHIBIT 4 - GAS ANALYSES

Test Gas	Nat	1	2	3	4	5	6	7
Constituent	Percent by Volume							
Methane	96.81	89.14	85.97	83.06	77.45	75.70	72.43	66.69
Ethane	1.88	1.65	1.63	1.61	1.50	1.47	1.40	1.30
Propane	0.18	0.19	0.19	0.15	0.14	0.14	0.18	0.12
Iso-Butane	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.04
N-Butane	0.05	0.04	0.04	0.04	0.04	0.04	0.05	0.03
Iso-Pentane	0.03	0.02	0.01	0.03	0.02	0.02	0.02	0.02
N-Pentane	0.03	0.01	0.02	0.03	0.02	0.02	0.05	0.02
Carbon Dioxide	0.64	0.52	0.50	0.55	0.51	0.50	0.42	0.44
Oxygen	0.01	0.03	0.03	0.01	0.01	0.01	0.13	0.01
Hydrogen	-	8.03	11.24	14.20	20.00	21.81	24.65	31.11
Nitrogen	0.31	0.32	0.32	0.27	0.26	0.24	0.62	0.22
Btu/Cu.Ft. (Dry)	1025	967	945	925	885	872	850	790
Specific Gravity	0.576	0.535	0.519	0.504	0.475	0.466	0.454	0.479

Nat = Natural Gas

EXHIBIT 5 - TEST MATRIX (Cont'd.)

Natural Gas					Hydrogen and Natural Gas Mixture													
Burner No	Input	Primary Air	Flame Characteristic	Thermocouple Output	Inner Cone Height	Input	Inner Cone Height	Primary Air	Flame Characteristic	Thermocouple Output	Flashback					Lifting	Noise of Extinction	Incomplete Combustion
											Steady State	Modulation	Ignition	Turn Down	Extinction			
A 6	X	X X X X	H* N* S*	- - - -	X X X X	X	X X X X	X X X X	X X X X	- - - -	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X
A 7	X	- - - -	N* H* S*	- - - -	- - - -	X	- - - -	- - - -	X X X X	- - - -	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X
A 8	X	X X X X	H* N* S*	- - - -	X X X X	X	X X X X	X X X X	X X X X	- - - -	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X
A 9	X	X X X X	N* H* S*	- - - -	X X X X	X	X X X X	X X X X	X X X X	- - - -	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X
A 10	X	- - - -	S* N* H*	- - - -	- - - -	X	- - - -	- - - -	X X X X	- - - -	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X

* Indicates Adjustments of Burner Primary Air
H - Hard N - Normal S - Soft
C - Closed Air Shutter O - Fully Opened Air Shutter

DISCUSSION OF RESULTS

Pilot Burners - Satisfactory operating characteristics were observed with mixtures containing 14, 20 and 25% hydrogen on all pilot burners used in this investigation, except the target type pilot burners (P8, P9, P10, and P11). (See Exhibit 6) This type of pilot burner is in common use today. It was developed about 15 - 20 years ago to eliminate the most prevalent field problem at the time - pilot failure due to the accumulation of dust and lint in primary air openings of the pilot burner. The principal cause of the unsatisfactory target type pilot burner performance was the tendency of the flame to burn on the orifice and not above it as designed; resulting in reduced thermocouple output. A possible secondary long term effect of the flashback could be the premature destruction of the burner since the metal surfaces will be subjected to temperatures higher than those for which the burner was designed.

In addition to its sensitivity to gas composition, the performance of these target pilot burners were observed to be also related to the supply pressure. Extensive additional tests were run on these burners to determine the supply pressure at which performance became acceptable and what changes could be made to make performance acceptable. Exhibit 7 shows the results of these investigations. At 5.0 inches water column the burners are limited to a maximum of 6% hydrogen. Supply pressures of 5.0 inches water column are commonly found in the northeastern section of the country; whereas

EXHIBIT 6 - PILOT BURNER PERFORMANCE

Burner No	Supply* Pressure	Test Gas	Flame Character	Operation	Millivolt Output	Remarks
P 1	5.0	Nat	Normal - Hard	Satisfactory	28	
	5.0	3	Normal	"	27	
	5.0	4	Normal - Hard	"	28	
	5.0	6	Hard	"	36	
P 2	5.0	Nat	Normal	Satisfactory	-	
	5.0	3	Normal	"	-	
	5.0	4	Normal	"	-	
	5.0	6	Normal	"	-	
P 3	5.0	Nat	Normal	Satisfactory	-	
	5.0	3	Normal	"	-	
	5.0	4	Normal	"	-	
	5.0	6	Normal	"	-	
P 4	5.0	Nat	Slight Yellow Tip	Satisfactory	-	
	5.0	3	Slight Yellow Tip	"	-	
	5.0	4	Slight Yellow Tip	"	-	
	5.0	6	Slight Yellow Tip	"	-	
P 5	5.0	Nat	Slight Yellow Tip	Satisfactory	17	
	5.0	3	Slight Yellow Tip	"	17	
	5.0	4	Slight Yellow Tip	"	17	
	5.0	6	Normal	"	18	

* Inches Water Column

EXHIBIT 6 - PILOT BURNER PERFORMANCE (Cont'd.)

Burner No	Supply* Pressure	Test Gas	Flame Character	Operation	Millivolt Output	Remarks
P 6	5.0	Nat	Slight Yellow Tip	Satisfactory	-	
	5.0	3	-	"	-	
	5.0	4	Slight Yellow Tip	"	-	
	5.0	6	-	-	-	
P 7	5.0	Nat	Soft - Yellow Tip	Satisfactory	580	
	5.0	3	Soft - Yellow Tip	"	560	
	5.0	4	Soft - Yellow Tip	"	540	
	5.0	6	Soft - Yellow Tip	"	640	
P 8	1.0	Nat	Soft	Unsatisfactory	18	Flame burns at orifice
	2.0	Nat	Soft	Satisfactory	24	
	5.0	Nat	Normal	"	27	
	5.0	2	Normal	"	30	
	5.0	3	Normal	Unsatisfactory	22	Flame burns at orifice
	7.0	3	Slight Yellow Tip	Satisfactory	28	
	5.0	3	Normal	"	26	Orifice modified
	5.0	4	Slight Yellow Tip	Unsatisfactory	23	Flame burns at orifice
	9.0	4	Normal	Satisfactory	25	
	5.0	4	Normal	"	25	Orifice modified
	5.0	6	Slight Yellow Tip	Unsatisfactory	22	Flame burns at orifice
	12.0	6	Normal	Satisfactory	24	
	5.0	6	Normal	Satisfactory	26	Orifice modified
P 9	3.0	Nat	Soft	Unsatisfactory	28	Flame burns at orifice
	3.5	Nat	Soft	Satisfactory	30	
	5.0	Nat	Normal	"	30	
	5.0	2	Normal	"	26	
	5.0	3	Slight Yellow Tip	Unsatisfactory	23	Flame burns at orifice
	5.6	3	-	Satisfactory	27	

EXHIBIT 6 - PILOT BURNER PERFORMANCE (Cont'd.)

Burner No	Supply* Pressure	Test Gas	Flame Character	Operation	Millivolt Output	Remarks
P 9 Cont	5.0	4	Soft	Unsatisfactory	-	Flame burns at orifice
	7.0	4	-	Satisfactory	26	
	5.0	6	Slight Yellow Tip	Unsatisfactory	22	Flame burns at orifice
	8.0	6	Normal	Satisfactory	26	
Pl0	3.5	Nat	Soft	Marginal	34	Flame tends to burn at orifice
	4.0	Nat	Soft	Satisfactory	36	
	5.0	Nat	Normal	"	32	
	5.0	1	Normal	Unsatisfactory	38	Flame burns at orifice
	5.0	2	Soft	"	24	" " " "
	7.0	2	Normal	Satisfactory	40	
	5.0	3	Soft	Unsatisfactory	32	Flame burns at orifice
	30.5	3	-	Satisfactory	-	
	5.0	3	-	"	-	Orifice changed
	5.0	4	Soft	Unsatisfactory	27	Flame burns at orifice
	29.0	4	-	Satisfactory	-	
	5.0	4	-	"	-	Orifice changed
	5.0	6	Soft	Unsatisfactory	32	
	36.0	6	Hard	Satisfactory	50	
	15.7	6	Normal	"	38	Orifice changed
Pl1	3.0	Nat	Soft	Marginal	14	Flame tends to burn at orifice
	3.5	Nat	Soft	Satisfactory	17	
	5.0	Nat	Normal - Hard	Satisfactory	17	
	5.0	1	Normal	"	19	
	5.0	2	Normal	"	20	
	5.0	3	Slight Yellow Tip	Unsatisfactory	11	Flame burns at orifice
	5.4	3	Normal	Satisfactory	13	
	5.0	4	Slight Yellow Tip	Unsatisfactory	12	Flame burns at orifice
	5.5	4	Normal	Satisfactory	14	
	5.0	6	Slight Yellow Tip	Unsatisfactory	13	Flame burns at orifice
	6.0	6	Normal	Satisfactory	24	

EXHIBIT 7

TARGET TYPE PILOT PERFORMANCE

7.0 inches water column is generally used in other sections of the country. Raising the supply pressure to 7.0 inches will permit the use of 11% hydrogen in the case of the most critical burner (P10). Changing the orifice in this burner improves performance considerably and would enable the use of mixtures containing up to 19.5% at 5.0 inches water column or 20.5% at 7.0 inches water column. By modifying the design of the second most critical burner (P8), mixtures up to 25% hydrogen can be utilized at 5.0 inches water column. Increasing the supply pressure to 7.0 inches water column would permit the use of mixtures up to 14% hydrogen without modification of this burner. Burners P9 and P11 operated satisfactorily with mixtures containing 14% hydrogen at a supply pressure of 5.0 inches water column and at 7.0 inches water column, these burners would operate satisfactorily with mixtures containing 20% hydrogen.

To increase the amount of hydrogen to 14% which can be utilized at 5.0 inches water column, reorificing or replacement of at least two types of target type pilot burners (P8 and P10) will be required; to go to a 20% hydrogen mix all four target pilot burners require reorificing or replacement. It is difficult to estimate the costs involved in such a program, since the relative number of P8, P9, P10 and P11 pilot burners in field use is not known.

Main Burners - Thirteen burners were tested with mixtures containing 20, 22, 25 and 31% hydrogen. Marginal operation was

noted on one burner with 20% hydrogen and on one burner with 22% hydrogen. (See Exhibit 8) Unsatisfactory operation was noted on one burner with 22% hydrogen, on two burners with 25% hydrogen, and on three burners with 31% hydrogen. In all cases the failures involved flashback, on turn down or short cycling, and noise of extinction. From these data, no more than 20 - 22% hydrogen should be distributed if field problems are to be minimized. Modifying the initial flame adjustment had no effect on these percentages.

Appliances - Tests were conducted on ten appliances using 20, 22 25 and 31% hydrogen. Marginal performance was noted on one appliance with 22% hydrogen, and on one appliance with 25% hydrogen. (See Exhibit 9) The causes of failure involved flashback on turn down or short cycling and noise of extinction. From these data, no more than 22 - 25% hydrogen should be distributed if field problems are to be minimized. Modifying the initial air shutter adjustment had no effect on these percentages. These data are comparable to those obtained for main burners.

Combustion tests were also performed on A2 and A7 with mixtures containing 25% hydrogen and no adverse effect on combustion was noted with the use of hydrogen. (See Exhibit 10)

Gas Input - The effect of the addition of hydrogen to natural gas on burner input is shown in Exhibit 11. Burner performance does not appear to be critical in this respect since the limiting

mixtures noted above will not result in input reductions greater than 6%.

Inner Cone Height - Use of hydrogen in natural gas tends to cause a shortening of cone height (See Exhibit 12), however, no adverse effect on burner performance was noted from this effect. The maximum difference noted was 3/4 inch and this may affect industrial processes where a definite cone height is desired. Such a problem, however, would be more theoretical than actual since the equipment could be readily adjusted for any change in cone height.

Thermocouple Output - With the exception of the target type pilot burners, no adverse effect of the use of hydrogen was noted. (See Exhibit 6)

Lifting, Yellow Tipping - No problems with lifting or yellow tipping were noted.

Primary Air - Only slight changes in primary air injection were noted. These changes resulted in no adverse effect on burner performance. (See Exhibit 13)

Interchangeability Indexes - Exhibit 14 shows the Weaver¹ Indexes for mixtures of hydrogen and natural gas used in this investigation. From the standpoint of lifting, yellow tipping and incomplete combustion, these indexes predict no problems with the use of hydrogen and the experimental results confirm this prediction. In the case of flashback, however, there is considerable variance between the predictions made from the calculated indexes and the

experimental observations especially for target pilots. (The principal reason for the discrepancies may be the fact that the target pilot burner was not developed when the original indexes were developed.) Additional work should be done to improve existing indexes or develop new gas mixture interchangeability models.

Industrial burners - No tests were performed on industrial equipment. Size and input requirements exceeded the capacity of the laboratory facility. The majority of industrial equipment would fall into the following categories:

- Forced Draft Burners
- Induced Draft Burners
- Premixing Burner
- Pressure Power Burners
- Infrared Burners

These types of burners are usually capable of satisfactory operation with a much wider range of change in gas composition than those used in domestic appliances. Consequently, the limits found for the domestic burners tested should be acceptable for industrial equipment. In addition, most industrial equipment can readily adjusted to meet variations in gas composition.

GENERAL COMMENTS

The major utilization constraint to blending hydrogen with natural gas appears to be target-type pilots. One target-type

pilot (P10), that was investigated as part of this study, is particularly sensitive to small quantities of hydrogen in natural gas. Another (P8) was marginal in performance, but not nearly as sensitive as P10. (See Exhibit 7).

A simple modification of the P10 target pilot (change in length of the orifice spud) improved the burner flexibility permitting approximately 20% hydrogen to be blended in natural gas. These types of modifications to target pilots would be easily implemented in the field, but would require field inspections to disclose location of appliances utilizing these types of pilots.

For informational purposes the following are appended.

Appendix A - Weaver Interchangeability Indexes¹

Appendix B - Fundamentals of Gas Combustion²

Appendix C - Schematic of Gas Flow from Natural Gas Well to Burner³

Appendix D - Glossary of Technical Terms

EXHIBIT 8 - MAIN BURNER PERFORMANCE

Burner No	Supply Pressure	Nat. Gas Flame	Test Gas	Flame Character	Operation	Remarks
B 1	3.5	Soft	4	Normal	Satisfactory	
		"	5	Hard	"	
		"	6	Hard	"	
		"	7	Hard	"	
		Normal	6	Hard	"	
		Hard	6	Hard	"	
B 2	3.5	Soft	6	Hard	Satisfactory	
		Normal	4	Normal	"	
		Normal	5	Hard	"	
		"	6	Hard	"	
		"	7	Hard	"	
		Hard	6	Hard	"	
B 3	3.5	Soft	4	Soft	Marginal	Extinction Noise
			5	Soft	Unsatisfactory	Extinction Noise, Flashback on turndown
			6	Soft	"	Extinction Noise, Flashback on turndown
			7	Soft	"	Extinction Noise, Flashback on turndown
B 4	3.7	Normal	4	Yellow Tip	Satisfactory	
			5	Yellow Tip	"	
			6	Yellow Tip	"	
			7	Yellow Tip	"	

EXHIBIT 8 - MAIN BURNER PERFORMANCE (Cont'd.)

Burner No	Supply Pressure	Nat. Gas Flame	Test Gas	Flame Character	Operation	Remarks
B 5	5.0	Soft	4	Soft	Satisfactory	Extinction Noise
		Soft	5	Normal Hard	Satisfactory	
		Soft	6	Normal	Satisfactory	
		Soft	7	Hard	Satisfactory	
		Normal	6	Hard	Satisfactory	
		Hard	6	Hard	Marginal	
B 6	5.0	Normal	4	Normal	Satisfactory	Extinction Noise
			5	Normal	Marginal	
			6	Normal	Unsatisfactory	
			7	Hard	Unsatisfactory	
B 7	3.5	Soft	6	Normal	Satisfactory	Flashback on turndown Flashback on turndown
		Normal	6	Hard	Unsatisfactory	
		Hard	6	Hard	Unsatisfactory	
B 8	5.0	Luminous	6	Luminous	Satisfactory	
B 9	5.0	Luminous	6	Luminous	Satisfactory	
B10	5.0	Soft	6	Normal	Satisfactory	
		Normal	6	Hard	Satisfactory	
		Hard	6	Hard	Satisfactory	
B11	3.5	Soft	6	Normal	Satisfactory	
		Normal	6	Hard	Satisfactory	
		Hard	6	Hard	Satisfactory	

EXHIBIT 8 - MAIN BURNER PERFORMANCE (Cont'd.)

Burner No	Supply Pressure	Nat. Gas Flame	Test Gas	Flame Character	Operation	Remarks
B12	5.0	Soft	6	Normal	Satisfactory	
		Normal	6	Hard	"	
		Hard	6	Hard	"	
B13	5.0	Soft	6	Normal	Satisfactory	
		Normal	6	Hard	"	
		Hard	6	Hard	"	

EXHIBIT 9 - APPLIANCE BURNER PERFORMANCE

Burner No	Supply Pressure	Nat. Gas Flame	Test Gas	Flame Character	Operation	Remarks
A 1	2.0	Soft	4 5 6 7	Soft Normal Normal Hard	Satisfactory " " "	
A 2	3.5	Soft Normal Hard	6 4 5 6 7 6	Normal Normal Hard Hard Hard Hard	Marginal Satisfactory " Marginal Unsatisfactory Marginal	Extinction Noise Extinction Noise Extinction Noise Extinction Noise
A 3	3.5	Normal	4 5 6 7	Normal Normal Normal Hard	Satisfactory " " Unsatisfactory	Extinction Noise, Flashback on short cycling
A 4	3.5	Soft	4 5 6 7	Soft Normal Normal Hard	Satisfactory " " "	
A 5	5.0	Soft Normal Hard	6 4 5 6 7 6	Normal Hard Hard Hard Hard Hard	Satisfactory " " " " "	

EXHIBIT 9 - APPLIANCE BURNER PERFORMANCE (Cont'd.)

Burner No	Supply Pressure	Nat. Gas Flame	Test Gas	Flame Character	Operation	Remarks
A 6	5.0	Soft Normal Hard	6 4 5 6 7 6	Normal Normal Hard Hard Hard Hard	Satisfactory " " " " "	
A 7	3.5	Normal	5	--	Satisfactory	
A 8	5.0	Soft Normal Hard	5 5 5	Normal Hard Hard	Marginal Marginal Marginal	Extinction Noise Extinction Noise Extinction Noise
A 9 1	5.0	Soft Normal Hard	5 5 5	Normal Hard Hard	Satisfactory " "	
A10	3.0	Soft Hard	5 5	Normal Normal	Satisfactory "	

EXHIBIT 10 - COMBUSTION TESTS
Flue Gas Analyses
% By Volume

Burner A 2	Natural Gas Flame Adjustment					
	Soft		Normal		Hard	
Test Gas	Nat	6	Nat	6	Nat	6
Methane	0.01	0.06	0.01	0.01	0.01	0.01
Ethane	0.00	Trace	Trace	Trace	Trace	Trace
Carbon Dioxide	4.42	4.81	3.68	4.39	4.74	4.01
Oxygen	14.87	13.60	16.29	14.42	13.92	14.84
Nitrogen	80.70	81.53	80.02	81.18	81.33	81.14
Burner A 7						
Methane			0.01	0.01		
Ethane			0.00	Trace		
Carbon Dioxide			5.76	5.27		
Oxygen			12.21	13.65		
Nitrogen			82.02	81.07		

EXHIBIT 11
EFFECT OF HYDROGEN
ON
APPLIANCE INPUT

EXHIBIT 12 - INNER CONE HEIGHT

Burner No.	Nat. Gas Flame	Nat. Gas Height	Test Gas	Cone Height	Difference	Burner No.	Nat. Gas Flame	Nat. Gas Height	Test Gas	Cone Height	Difference
P 1	Normal	1 1/4"	3 4 6	1 1/2" 1 3/8" 1 3/16"	+ 1/4 + 1/8 - 1/16	B 2	Normal	1"	4 5 6 7	1/2" 1/4 1/4 1/4	- 1/2 - 3/4 - 3/4 - 3/4
P 2	Normal	1"	3 4 6	1 3/8" 1 1/4 1 1/8	+ 3/8 + 1/4 + 1/8	B 3	Soft	1 3/4"	4 5 6 7	1 1/8" 1 1/8 1 1/8 1	- 5/8 - 5/8 - 5/8 - 5/8
P 3	Normal	2 5/8"	3 4 6	2 5/8" 2 1/2 2 1/2	0 - 1/8 - 1/8	B 5	Soft	1 1/2"	4 5 6	3/8" 1 1	- 1/8 - 1/2 - 1/2
P 4	Soft	3/4"	3 4 6	7/8" 3/4 9/16	+ 1/8 0 - 3/16	B 6	Normal	1 3/16"	4 5 6 7	1 1/4" 1 1/8 1 1/8 1 1/4	+ 1/16 - 1/16 - 1/16 + 1/16
P 5	Soft	3/4"	3 4 6	5/8" 5/8 1/2	- 1/8 - 1/8 - 1/4	A 2	Normal	1 3/16"	4 5 6 7	1 1/8" 1 1/4 1 1/4 3/4	- 1/16 + 1/16 + 1/16 - 7/16
P 7	Soft	2 1/16"	3 4	2 1/8" 2	+ 1/8 - 1/16	A 6	Normal	7/16"	4 5 6 7	3/8" 1/4 1/4 11/16	- 1/16 - 3/16 - 3/16 - 1/4
B 1	Soft	7/8"	4 5 6 7	1/2" 5/8 5/8 1/2	- 3/8 - 1/4 - 1/4 - 3/8		Soft Hard	15/16 3/4	6 6	1/4 5/16	- 11/16 - 7/16

EXHIBIT 13 - PRIMARY AIR

Burner No	Nat. Gas Flame	Nat. Gas % PA	Test Gas	% PA	Burner No	Nat. Gas Flame	Nat. Gas % PA	Test Gas	% PA
B 1	Soft	35	6	37	A 1	Soft	30	4	29
	Normal	46	6	51				5	34
	Hard	52	6	56				6	34
B 2	Normal	60	4	55				7	35
			5	57	A 3	Normal	34	4	40
			6	57				5	31
			7	55				6	31
B 3	Soft	35	4	35				7	34
			7	36	A 8	Soft Normal Hard	30 34 36	5	37
B 5	Soft Normal Hard Soft	33 46 51 33	6	37				5	38
			6	43				5	40
			6	55					
			4	35					
			5	37					
B 7	Soft Normal Hard	40 48 50	6	40					
			6	45					
			6	50					
B10	Soft Normal Hard	34 40 42	6	30					
			6	37					
			6	42					

EXHIBIT 14 - WEAVER INTERCHANGEABILITY INDEXES

Test Gas	% Hydrogen	J _H Input	J _A Air	J _L Lifting	J _F Flashback	J _Y Yellow Tip	J _I Combustion
Limits	-	0.95 to 1.03	-	Above 0.64	Below 0.52	Below 0.30	Below 0.05
Nat.	-	1.00	1.00	0.00	0.00	0.00	0.00
1	8.03	0.98	0.98	1.14	0.19	- 0.03	- 0.04
2	11.24	0.98	0.96	1.20	0.28	- 0.04	- 0.06
3	14.20	0.97	0.96	1.25	0.36	- 0.05	- 0.08
4	20.00	0.95	0.94	1.36	0.54	- 0.07	- 0.11
5	21.81	0.95	0.93	1.39	0.59	- 0.08	- 0.12
6	24.65	0.94	0.92	1.45	0.68	- 0.09	- 0.14
7	31.11	0.93	0.90	1.58	0.86	- 0.11	- 0.18

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APPENDIX A
WEAVER INTERCHANGEABILITY INDEXES

Heat Input

$$J_H = \frac{H}{H_a} \frac{\sqrt{D_a}}{\sqrt{D}}$$

Where H is the heating value (Btu/C.F.) and D is the specific gravity. The subscript "a" indicates the Appliance Adjustment Gas. J_H is a dimensionless ratio that indicates the effect of a change of gas composition on the rate at which heat is produced in an appliance. If I_a is the heat input into an appliance when adjusted, $I = J_H I_a$ is the heat input after the change of gases.¹

The expression $H/\sqrt{D}$ is also known as the heat input factor or Wobbe Number of the gas. Weaver's heat input index is merely a ratio of these factors for the adjustment and substitute gases.

Air Requirement

$$J_A = \frac{A}{A_a} \frac{\sqrt{D_a}}{\sqrt{D}}$$

Shows the change in the primary air that accompanies a change of gas composition. "A" is the number of cubic feet of air required for the combustion of 1 cu. ft. of gas. If P_a is the primary air injected into an appliance, $P = P_a / J_A$ is the primary air which enters the burner after a change of gases.¹ The limitations for this factor are imposed by the lifting, flashback, yellow tip and incomplete combustion indexes.

Lifting

$$J_L = J_A \frac{S}{S_a} \frac{100 - Q}{100 - Q_a}$$

S/S_a is the ratio of flame speeds in corresponding mixtures of two gases with air, and Q is the percentage of oxygen in each gas. J_L shows the relative tendency of flames of substitute gas to lift from the burner ports.

Flashback

$$J_F = \left(\frac{S}{S_a} - 1.4J_A \right) + 0.4$$

J_F shows the relative tendency for the flame of the substitute gas to flash back into the burners.

The Weaver Flame Speed Factor represents the maximum flame speed of the gas with air, expressed as a percentage of the flame speed for hydrogen and is computed from the gas analysis.

$$S = \frac{a Fa + b Fb + cFc \dots}{A + 5Z - 18.8Q + 1}$$

$a, b, c, \dots$ are the fractions by volume of various combustible constituents of the fuel gas; $Fa, Fb, Fc, \dots$ are corresponding values of the coefficient "F", listed in Table B1, "A" has its usual meaning, the volume of air required to burn one volume of gas, and Z

and Q are, respectively, the fraction by volume of inert gases, chiefly carbon dioxide and nitrogen, and of oxygen in the fuel. To obtain the factor "F", the recorded maximum ignition velocity in mixtures of the combustible with air was expressed as a percentage of the maximum ignition velocity of hydrogen with air and multiplied by 1 plus the number of cubic feet of air required to burn 1 cu. ft. of the gas.¹

Yellow Tip

$$J_Y = J_A + \frac{N - N_a}{110} - 1$$

"N" represents the number, in 100 molecules of gas, of carbon atoms easily liberated during combustion. It is taken to be the total number of carbon atoms in the hydrocarbons except one in each molecule of the saturated series. J_Y is a measure of the relative tendency of the substitute gas to produce yellow flames and release soot.¹

Incomplete Combustion

$$J_I = J_A - 0.366 \frac{R}{R_a} - 0.634$$

"R" is the ratio of the number of hydrogen atoms in the gas to the number of carbon atoms in the hydrocarbons only. J_I is a general expression for the relative tendency of the substitute gas to liberate carbon monoxide and is a correction of J_A to take into account the effect of flame impingement in appliances of some types.¹

TABLE B1. FLAME SPEED FACTOR "F"

CHEMICAL FORMULA	GAS	FLAME SPEED FACTOR F
CO	Carbon Monoxide	61
H ₂	Hydrogen	339
CH ₄	Methane	148
C ₂ H ₆	Ethane	301
C ₃ H ₈	Propane	398
C ₄ H ₁₀	Butanes	513
C ₅ H ₁₀	Cyclo-Pentane	556
C ₆ H ₁₂	Pentanes	610
C ₆ H ₁₂	Methyl-Cyclo-Pentane	685
	2-2 Dimethyl Butane	720
	Methyl Pentanes	720
	Hexanes	720
C ₇ H ₁₆	2-4 Dimethyl Pentane	832
	Heptanes	832
C ₂ H ₄	Ethylene	454
C ₃ H ₆	Propylene	674
C ₄ H ₈	Butenes	910
C ₅ H ₁₀	Pentenenes	1130
	2 Methyl 1 Butene	1130
C ₆ H ₁₂	Hexenes	1350
C ₄ H ₆	Butadiene	1220
C ₂ H ₂	Acetylene	776
C ₆ H ₆	Benxene	920
C ₇ H ₈	Toluene	1098

APPENDIX B

FUNDAMENTALS OF GAS COMBUSTION

Prepared by

American Gas Association Laboratories

for

AMERICAN GAS ASSOCIATION

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Arlington, Virginia 22209

and

GAS APPLIANCE MANUFACTURERS ASSOCIATION, INC.

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FOREWORD

This manual was prepared under the direction of the American Gas Association and Gas Appliance Manufacturers Association Joint Committee for Customer Service. It was written by James C. Griffiths, Senior Research Engineer, and J. Fred Parr, Manager of Engineering Services, American Gas Association Laboratories, Cleveland, Ohio.

The manual initially was a project of the Customer Service Committee of the American Gas Association. Its purpose is to provide a text for self-study as well as a text book to be used in the formal classroom.

Hopefully, it will become a useful tool to vocational - technical schools, appliance service and repairmen and utility customer service programs. The text has been prepared so that only a moderate knowledge of mathematics and science is required for understanding.

Further texts in this series will cover the following subject areas:

Venting and Ventilation

Basic Electricity

Basic Appliance Control Systems

Basic Appliance Principles and Operation

Customer Relations

Beginning on Page 77, a glossary is provided for the learner. It is suggested the student familiarize himself with these terms so the text material will be meaningful.

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Fundamentals Of Gas Combustion

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I. HISTORY OF THE USE AND DEVELOPMENT OF FUEL GAS

Legends about the discovery and use of gas date back as far as 2000 B.C. We are told that centuries ago the Chinese piped gas from shallow wells through bamboo poles, and burned the gas to boil sea water to obtain salt. Many early explorers of America reported seeing "burning springs" which were probably jets of gas escaping from holes in the earth. Settlers often struck gas when drilling water wells.

The birthplace of the **natural gas*** industry in the United States is widely accepted to be Fredonia, New York. Settlers there reported gas bubbling from a creek which sometimes ignited to form a "burning spring." In 1821, a young gunsmith, William A. Hart, intrigued by this "creek that burned", dug a well on the creek bank and tapped the gas under the surface. In 1827, the local paper reported that gas from this well served to light two stores, a grist mill and two shops near the creek. Later deeper wells were drilled and in 1858, the first natural gas company in the United States was formed, the Fredonia Gas Light Co.

At first this gas was used mostly for lighting purposes. Simple gas lights using a crimped "fishtail" burner provided light at half the cost of candles. Hart expanded his efforts by drilling a gas well and installing a gas lighthouse on Lake Erie at what is now called Barcelona

Harbor. This beacon used 13 gas lamps in two tiers. It saw active service from 1829 to 1858.

In the 1890's, the use of glowing mantles in gaslights greatly increased light output, but perfection of the electric light soon led the gas industry to seek uses other than lighting for its products.

From this humble start, natural gas pipeline and utilities have grown to become one of our country's largest industries. In 1970, the gas industry supplied over 16 trillion cubic feet of gas to its customers. Gas is used in 42 million homes, offices, plants and factories in 49 states. Plans are underway to supply Hawaii with liquefied natural gas in tankers from Alaska.

Today, gas has indeed a thousand-and-one uses. Iron and steel mills, oil refineries and food service industry are large users of gas. Still others are the glass, cement, automobile and pottery industries. Commercial gas customers include hotels, restaurants, schools, garages and hospitals. Natural gas serves as the raw material to produce many useful chemicals. Currently, gas is used in about 38 million homes every day for heating, cooking, cooling, clothes drying, water heating and incineration, as well as gas lamps and outdoor cooking. Producing electricity from gas heat uses a large part of the annual supply of gas.

*Words which appear in the text in bold face type are defined in the glossary starting on Page 77.

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1816, was the first American city to light its streets with gas. Paris followed in 1820.

The use of manufactured fuel gases has declined greatly in the United States. Today over 99 percent of sales by gas distribution and transmission companies is natural gas. Some manufactured gases are still used in Europe and other parts of the world, but use of natural gas has risen sharply in these areas also in recent years.

Mixed gas, as the name implies, is a man-made mixture of gases. A common example is a mixture of natural gas and manufactured gas.

Odorants Added to Gas

Natural gas processed to remove condensables and moisture, has little or no odor and no color. Odorants are added to the gas before distribution to aid in leak detection. Most odorants used are colorless liquids containing sulfur compounds. These compounds give a garlic-like odor that most people associate with a "gassy" smell. Odorants can be put into a gas stream as liquids by a drip-type odorizer. The odorants vaporize in the pipe lines and mix with the fuel as gases. With the absorption type odorizer, odorants are added to the gas stream in a vapor or gaseous form.

The amount of odorant needed to produce a strong odor in the gas is quite small. The amount of sulfur added in this way is too small to create a problem of corrosion either in the pipelines or by flue gases. The sulfur burns in the gas flame to produce little or no odor or harmful products.

Specific Gravity

The **density** of a substance is the amount of mass (weight) in a given volume. Fresh water, for instance, has a density of 62.4 pounds per cubic foot. Often it is more useful to refer to the **specific gravity** of a substance. Specific gravity is the weight of a substance compared to the same volume of some reference substance. Fresh water is used as the reference substance for liquids and solids. If the specific gravity of a liquid is 2.0, one cubic foot of that liquid will weigh twice as much as a cubic foot of water. That is, the liquid will weigh 124.8 pounds per cubic foot (2.0×62.4).

Gases are quite light, compared to liquids and solids. Specific gravity of a gas is the weight of one cubic foot of that gas compared to one cubic foot of dry air. Both the air and the gas must be at the same pressure and temperature when the comparison is made. The amount of gas in a given volume varies with pressure. Gases are compressed as pressure increases and expanded as pressure is reduced. Gases expand when heated and contract when cooled. In stating the specific gravity of a gas, a pressure and temperature must be clearly stated. Usually a set of conditions is used which is close to average atmospheric conditions. In the gas industry, "standard" conditions of pressure and temperature are 30.0 inches of mercury and 60 F. A pressure of 30 inches of mercury will sustain a column of mercury 30 inches high in a tube with a vacuum on top of the column. Since air is used as the reference gas, its specific gravity is always 1.0. Note that this value of 1.0 has no direct physical meaning with regard to air, such as its density. It is only a relative number or ratio used to express specific gravity of other gases.

Natural gases have specific gravities ranging from 0.4 to 0.8, as shown in Figure 2. This means that a **cubic foot of natural gas** will weigh only 4/10 to 8/10 that of a cubic foot of air. Again, both must be at the same pressure and temperature when compared. The spread of specific gravities of natural gases reflects the differing amounts of lighter and heavier gases in each mixture.

Specific gravity of a gas determines whether that gas will rise or fall when released into the air. Natural gas will rise, having a specific gravity less than 1.0. Usually it will mix readily with the air.

As shown in Figure 3, propane has a specific gravity of 1.5; the specific gravity of butane is 2.0. If these gases are released in air they will fall, instead of rising. Usually they will not mix readily with the air. In fact, the gases may drift to low spots and collect in "pools", creating a hazard if open flames are present.

Manufactured gases usually are lighter than air, with specific gravities ranging from 0.4 to 0.7. Specific gravities of mixed gases depend on the gases used and the amounts of each gas in the mixture. A mixture of natural and manufactured gas with a heating value of 800 Btu per cubic foot has a specific gravity typically of 0.5.

Specific gravity has two other practical aspects. It has an important effect on the flow of gases through orifices, and hence the rating of burners. A gas **orifice** is a small hole in a fitting (spud) used to limit gas flow to burners. Gas flow rate through an orifice depends on the orifice size and gas pressure upstream of the orifice. However, more of a lighter gas will flow through a given orifice size than a heavier gas at the same gas pressure. For instance, about 83 percent more natural gas than butane will flow through the same orifice with the same gas pressure. This effect of specific gravity is taken into account in tables and calculators used to select orifice sizes for burners.

Fig. 2. Specific gravity of natural gas.

Specific gravity also affects gas flow in pipes. A given driving pressure at a pipe inlet will move more lighter gas than heavier gas through that pipe.

Heating Value

Heat energy produced when burning a fuel gas is commonly expressed in **British thermal units** (Btu). One Btu of heat will raise the temperature of one pound of fresh water one degree Fahrenheit, as shown in Figure 4. Burning an ordinary wooden kitchen match produces about 1 Btu of heat.

Fig. 3. Specific gravities of propane and butane.

If 1,000 Btu of heat are added to 10 pounds of water, the water temperature will rise 100 degrees Fahrenheit ($1,000 \div 10 = 100$). Likewise, 5,000 Btu of heat must be added to 100 pounds of water to raise the water temperature 50 degrees Fahrenheit ($5,000 \div 100 = 50$). In equation form:

$$\text{Water temperature rise, degrees F} = \frac{\text{(Btu of heat added)}}{\text{(pounds of water)}}$$

$$\begin{aligned} & \text{(Btu of heat added} = \text{(pounds of water)} \\ & \times \text{(water temperature rise, degrees F)} \end{aligned}$$

The **heating value** (or heat value) of a gas is the amount of heat released when one cubic foot of the gas is completely burned. This heating value is expressed in Btu per cubic foot of gas at standard pressure and temperature.

The more carbon and hydrogen atoms in each molecule of a fuel gas, the higher will be its heating value. Natural gas (which is largely methane) has a heating value of about 950 to 1,150 Btu per cubic foot. The spread of heating values is due to the presence of various other substances found in natural gases. More ethane, propane or butane in the gas raises its heating value. Gases such as nitrogen are **inert** and do not burn. Hence, they do not add to the heating value of the gas. The larger the amount of inert gases present in a natural gas, the lower the heating value will be. In round numbers, propane has a heating value of 2,500 Btu per cubic foot, and butane about 3,200 Btu per cubic foot.

Hourly use of gas varies in different appliances. **Input rates** can be converted from Btu per hour to cubic feet per hour, or from cubic feet per hour to Btu per hour, as follows:

$$\text{Input rate, in Btu per hour} =$$

$$\begin{aligned} & \text{(Heating value of gas, in Btu} \\ & \text{per cubic foot)} \times \text{(Gas flow} \\ & \text{rate, in cubic feet per hour)} \end{aligned}$$

$$\text{Gas flow rate, in cubic feet per hour} =$$

$$\begin{aligned} & \text{(Input rate, in Btu per hour)} \div \\ & \text{(Heating value of gas, in Btu} \\ & \text{per cubic foot)} \end{aligned}$$

For example, a typical 30 gallon storage water heater might have an input rate of 35,000 Btu per hour. Suppose that a 1,000 Btu per cubic foot gas is used. Using the above formula, gas flow rate is equal to $35,000 \text{ Btu} \div 1,000 \text{ Btu gas}$, which figures to be 35 cubic feet of gas per hour. Thus, 35 cubic feet of gas should be supplied to the water heater.

Fig. 4. Illustration of British thermal unit

More examples: A range top burner burns 1.875 cubic feet of butane per hour. Since butane has a heating value of 3,200 Btu per cubic foot, the burner input rate is 6,000 Btu per hour ($1.875 \times 3,200 = 6,000$). This same range top burner operating on natural gas with an enlargement of the orifice would need to burn six cubic feet of gas per hour to have the same input ($6 \times 1,000 = 6,000$).

A 125,000 Btu per hour furnace uses 2,500 Btu per cubic foot propane. This furnace would use 50 cubic feet of propane per hour ($125,000 \div 2,500 = 50$).

Another unit of heat energy which is used in the gas industry is the **therm**. A therm is 100,000 Btu of heat energy. A therm of 1,000 Btu per cubic foot natural gas would be 100 cubic feet of gas ($100,000 \div 1,000 = 100$). A therm of butane is 31.25 cubic feet of that gas ($100,000 \div 3,200 = 31.25$). Forty cubic feet of propane contain a therm of heat energy ($100,000 \div 2,500 = 40$).

III. COMBUSTION OF GAS

The Meaning of Combustion

All matter is made up of basic substances called **elements**. One of the most common elements on earth is oxygen. About 20 percent of our air is oxygen. Many materials react with oxygen, a process called oxidation. Rusting of metals is a common, everyday form of this process. Heat must be added to some oxidation reactions for them to take place and continue. Heat is given off in others. When oxygen acts with a substance to produce large amounts of heat rapidly (and usually light), the process is called **combustion** or burning.

With enough air present, fuel gases will burn in their normal state. Solid or liquid fuels, on the other hand, must be changed to a gas first before they will burn. Usually heat is required to change liquids or solids into gases.

Fig. 5. The combustion triangle.

Requirements for Combustion

Three things needed for combustion to take place are shown as a combustion triangle in Figure 5. Fuel, oxygen (air) and heat (temperature) all must be present. Otherwise, burning will not start or will not sustain itself after it starts. Take away any one of the three and burning will stop.

This fact can be shown by considering ways to put out a wood fire. If all of the unburned wood (fuel) is dragged away from the fire, the fire will soon go out. A heavy blanket may be thrown over the fire. The fresh supply of air (oxygen) is cut off, smothering the fire. Foam type fire extinguishers work in the same way, cutting off the air supply to a fire. Water thrown on the fire chills the wood. Reducing the temperature below the kindling point causes the fire to go out. Of course, heat is needed to start the fire in the first place. The same holds true for a gas "fire". Some source of heat is required that will raise the temperature of the gas to its **ignition temperature** (1100 F - 1200 F).

In burning gas all three elements of fuel, air and heat must be present. Gas alone will not burn. Air which supplies oxygen is needed as well. An open flame (pilot) or electrical means may be used to ignite the gas in gas appliances. Then the gas flame itself provides the heat needed to sustain combustion.

Basic Chemistry of Combustion

Combustion of gas is a chemical reaction between fuel gas and oxygen. Figure 6 illustrates the case of the combustion of methane. The basic elements of common fuel gases are hydrogen (H) and carbon (C). When hydrogen burns, water vapor is produced. The water **molecule**, represented by the symbol H_2O , consists of two hydrogen atoms and one oxygen atom. Complete burning of carbon in fuel gases forms carbon dioxide. Its symbol is CO_2 and it has one atom of carbon and two atoms of oxygen in each **molecule**.

A fuel gas (methane, for example) and oxygen react with each other in burning and so are called reactants. Water vapor and carbon dioxide formed by that burning are called products of combustion.

In Figure 6, the reactants are methane (CH_4) and oxygen. Two molecules of oxygen are required for each molecule of methane. The products are carbon dioxide and water vapor. Burning one molecule of methane produces one molecule of carbon dioxide and two molecules of

water vapor. The total number of each type of atom in the reactants must equal the total number of the same type of atom in the products.

Figure 6 shows complete burning of methane with exactly the amount of oxygen required. This basic model of the burning process should be understood for three reasons: First, it shows that only harmless carbon dioxide and water vapor result if a fuel gas is completely burned. Second, it shows exactly the amount of oxygen needed to completely burn a given fuel gas. Third, it shows that definite amounts of products are formed in completely burning a certain quantity of a fuel gas.

The model shown in Figure 6 is expressed in terms of molecules. This figure also can be expressed in terms of cubic feet of the gases involved, substituting cubic feet for molecules. Two cubic feet of oxygen are needed to completely burn one cubic foot of methane. This process will form one cubic foot of carbon dioxide and two cubic feet of water vapor. Normally, of course, air containing oxygen rather than pure oxygen is used to burn a fuel gas.

Fig. 6. Combustion of methane and oxygen.

Controlled Combustion

Controlled combustion takes place when fuel gas and air are supplied at proper rates to assure complete burning of the gas in a steady flame. When a gas appliance is operating properly, burning starts at the burner ports. Gas flow rate is controlled by gas orifice size and by gas pressure upstream of the orifice. Burners which have some air premixed with the gas before it passes through the **burner ports** are called "blue flame" burners. This air added to the gas is called **primary air**. The rest of the air required for complete combustion is supplied to the burner flames in the **combustion chamber** and is called **secondary air**. "Yellow flame" burners, described in another section, use only secondary air.

Adjustments of gas rate and primary air provide the key to obtaining stable, blue flames on a burner using primary air. **Air shutters** or other devices provide control of primary air. Proper amounts of primary and secondary air are needed for quiet and efficient appliance operation and for complete combustion of the gas. Size of air inlet openings and flue outlets controls secondary air flow.

Explosive Combustion

An explosion is simply very rapid burning which is not under control. If an air-gas mixture is not ignited at the moment it begins to flow from a burner, a mixture of air and gas may collect in a combustion chamber. When the mixture is ignited, it may explode. With proper burner and appliance design and adjustment this condition can be avoided.

Limits of Flammability

Not all air-gas mixtures will burn or explode. Mixtures with zero to four percent natural gas in air are too lean to burn or explode, as shown in Figure 7. Mixtures of 4 to 14 percent natural gas in air can burn with a controlled flame. They also can explode. Whether or not an explosion will occur depends mostly on whether a gas-air mixture is allowed to collect before it is ignited.

Fig. 7. Flammability limits for natural gas. Ignition occurs between lower and upper explosive limits.

If small amounts of gas are added gradually to air, a point will be reached at which the mixture just becomes explosive. The percentage of gas at this point is called the "lower explosive limit" (L.E.L.). If more gas is added, another point will be reached where the mixture will no longer explode. The percent gas at this point is called the "upper explosive limit" (U.E.L.). The lower and upper explosive limits are, for all practical purposes, the same as the

“lower” flammability and “upper” **flammability limits**. The difference in conditions described by the two sets of terms lies in whether or not a fairly high pressure results as the mixture burns. The amount of pressure created depends in part on whether burning takes place in the open or in an enclosed space, and also depends on the direction of flame travel.

A mixture of 15 to 100 percent natural gas in air will not explode. These mixtures also are outside the upper flammability limit. So-called yellow flame burners have no air mixed with the gas before it is burned. However, air mixes with the gas at the flame surface so that the actual quantity of gas present is less than 15 percent at the burning zone.

Flammability and explosive limits are of interest to those dealing with problems and everyday operations in the gas industry. For example, consider **flashtube** ignition of range top burners, Figure 8. A gas-air mixture from the

burner head passes through a charge port into the open end of the flashtube. This mixture is too rich to burn without secondary air, but some air also enters the flashtube at the tube entrance. This additional air causes the mixture to become leaner to a composition that is flammable. When the mixture travels down the tube to the pilot, the flame will carry back from the lighter to the charge port and light the gas at the burner. If the mixture in the flashtube has too much gas (too rich) or has too much air (too lean), the burner will not light.

Flammability limits also enter the picture when primary air adjustments are made on burners. For example, infrared (radiant) burners usually operate with about 100 percent primary air. In other words, the gas-air mixture in the burner head contains all the air ideally required for complete combustion. If too much primary air is used, the mixture may become too lean and fall outside the lower flammability limit and it will not burn on the burner surface.

Fig. 8. Ignition by means of a flashtube.

Unburned gas should not be allowed to collect in combustion chambers or confined spaces because gas-air mixture within the flammability limits will explode if ignited.

Burning Speed

Burning speed is the speed at which flame travels through an air-gas mixture. Burning speed also is called **ignition velocity** or **flame velocity**. The speed of burning depends mostly on the type of gas and the amount of air in the mixture.

Some gases have very high burning speeds. Hydrogen burns fast -- as high as 9.3 feet per second. Methane is a much slower burning gas. Its highest burning speed is about 0.9 foot per second. These are the highest burning speeds for these gases. The amount of air mixed with the gas greatly affects burning speed of the mixture.

Fig. 9. Flame velocities in natural gas-air mixtures.

A mixture of 0 to 4 percent natural gas in air is too lean to burn, so the burning speed is zero. Mixtures with 4 to 14 percent gas will burn. At the lower part of this range burning speed is low, but it increases rapidly with richer mixtures, reaching its peak at about 10 percent gas. Burning speed falls off again in mixtures having 11 to 14 percent gas. With 15 to 100 percent gas the mixture is too rich to burn so burning speed again is zero. The relationship of percentage gas and burning speeds of natural gas-air mixtures is illustrated in Figure 9. Burning speeds of other fuel gases vary with air-gas mixture in the same way. Peak burning speeds occur in mixtures where just about enough air is present for complete burning of the gas. The percentage of gas at this point varies for different fuel gases. Burning speed increases when air-gas mixtures are heated.

These effects of type of gas, air-gas mixture and temperature on burning speed have practical meaning since flame stability is directly related to burning speed. They are also related to burner adjustment and to some service problems which may occur. Burning speed of a flame on a burner can be changed by air adjustment. Substitution of one gas for another also results in a different burning speed. A flame has a zone in which the temperature is higher than elsewhere in the flame. A change in burning speed of a flame can shift the zone of highest temperature away from or closer to the burner. Air-gas mixtures in burners sometimes are preheated with flames or hot surfaces before burning. The resulting increase in burning speed of the mixture increases flame intensity. This method is used to speed up some industrial operations which use gas flames.

Complete Combustion

Figure 6 shows an ideal model of complete burning of methane with oxygen. In gas appliances air, rather than pure oxygen, is used to burn the gas. Air contains about 20 percent oxygen and 80 percent nitrogen.

Figure 10 shows the complete combustion of methane in air in terms of molecules and atoms. The same number of molecules (and atoms) of methane, oxygen, carbon dioxide and water vapor appear as was the case in Figure 6. Figure 10 differs from Figure 6 in that the nitrogen in the air is shown. Four nitrogen molecules are present in air for each oxygen molecule. The nitrogen does not take part in the burning process, so it appears in the products unchanged. The burning process shown in Figure 10 can be expressed in terms of cubic feet of gases, Figure 11. For each cubic foot of methane ten cubic feet of air are needed for complete combustion. Eleven cubic

feet of products are formed. These products consist of one cubic foot of carbon dioxide, two cubic feet of water vapor and eight cubic feet of nitrogen. All of these products must be vented or discharged from an appliance.

In actual practice more air is supplied to the combustion process than the ideal amount shown in Figure 11. This extra air is called **excess air**. The gases vented from an appliance for each cubic foot of methane burned then will be 11 cubic feet plus whatever excess air passes through the appliance. Carbon dioxide and water vapor formed in burning plus the nitrogen in the reactants that entered with the combustion air together are called **combustion products**. The combined combustion products and excess air are called **flue products**.

Water is produced as a vapor in the burning of gas. If the flue products remain hot enough, water is discharged as vapor to the outside through a **vent** system. If the flue products should become

Fig. 10. Combustion of methane and air.

cool, this water vapor starts to condense out as a liquid. The temperature at which liquid water forms from vapor is known as the **dewpoint**.

Fig. 11. Combustion products from burning one cubic foot of natural gas.

Condensing water vapor from combustion products has an advantage. More heat can be recovered since heat is given up when the change takes place. Efficiency or useful heat transfer is improved. But this gain is offset to some degree by some problems which may occur because of the presence of the water (condensate). For example, a storage water heater may drip water on the floor beneath it in the winter. The problem usually occurs when very cold water enters the tank, chilling combustion products below the dewpoint. A more serious problem is corrosion which may occur inside of **heat exchangers**, **flueways** and **vent pipes** where the water condenses. The temperature of the flue products in the center of these passageways may be well above the dewpoint, but close

to the cold walls, the temperature may drop off sharply and condensation may take place on the walls. A range oven door may become momentarily fogged when the oven is first turned on. The gases contact the cool glass and water condenses. As the oven heats the glass heats up and the fogging disappears.

Incomplete Combustion - Causes and Effects

Thus far only complete combustion of gas has been considered. To obtain complete combustion enough air must be supplied to the process. This air must have a reasonably normal oxygen content. It must be mixed well with the gas and/or flame. Complete burning of gas produces harmless carbon dioxide and water vapor. If not enough air is supplied other products will form. Some of these products are harmful, especially carbon monoxide which is represented by the symbol CO.

Poor venting of an appliance restricts flow of air into an appliance. Lack of ventilation around an appliance may lower oxygen content in the air. Spillage of combustion products into the room, in effect, reduces oxygen supply in the air. Since any of these conditions may cause incomplete combustion, adequate ventilation must be provided.

It is vital that an appliance venting system do its job. The importance of providing enough fresh air to the room in which an appliance is located cannot be stressed too strongly. Guides for ventilation are given in American National Standards Institute (ANSI) publication Z21.30 (National Fire Protection Association No. 54), *Installation of Gas Appliances and Gas Piping*.*

*See page 75 for sources for reference materials.

Gas may not burn completely even though enough air is supplied to the burner. Enough heat (temperature) must be present to sustain proper burning. In any fuel gas flame, burning does not take place in one step. Rather, a series of reactions takes place. If the flame is chilled or **quenched** the burning process may not proceed to its normal endpoint. Products other than carbon dioxide and water vapor may escape from the flame. Thus, carbon monoxide can appear in the flue products.

Carbon Monoxide

Carbon monoxide is a toxic gas. It can cause death if enough of it is inhaled. This gas has no odor, color or taste, so that it cannot be detected by bodily senses. Carbon monoxide is flammable. It can produce an explosion in a wider range of mixtures with air than does natural gas. Its flammability limits extend from about 12.5 to 74 percent of the gas in air. Carbon monoxide is highly toxic in a small fraction of one percent in air. Its toxic effect thus is a much more serious problem than the chance of explosion.

Hydrogen gas also can be expected to be present in flue gases if a fuel gas is not completely burned. Hydrogen can burn or explode in air when it makes up about 4 to 74 percent of the mixture. Hydrogen is not toxic - the most serious result of incomplete combustion is the production of carbon monoxide.

Inhaled carbon monoxide is absorbed into the blood. It combines with hemoglobin in the blood to a much greater extent than oxygen and remains in the blood longer than oxygen does. In doing so, it acts to reduce the oxygen-carrying function of the blood. Thus, a person exposed

to carbon monoxide can die of a lack of oxygen.

The amount of carbon monoxide which the blood absorbs depends chiefly on two things: how much carbon monoxide is in the air and the time of exposure. Adverse effects of carbon monoxide on humans are reduced by periods of breathing fresh air. The degree of recovery depends on the number and length of those periods. Over 200 parts of oxygen are needed to replace one part of carbon monoxide in the blood. The exposed person's general state of health and degree of physical activity are other factors involved in the effects of carbon monoxide on the body.

Fig. 12. Effect of carbon monoxide concentration and the exposure time on carbon monoxide absorption by blood and resulting physical impairment. Numbers on each curve are parts of carbon monoxide per 10,000 parts of air.

Table 1, ** lists the effects of various carbon monoxide levels in air on human beings. Figure 12 shows the percentage of carbon monoxide absorbed by blood

**For Tables, see Pages 63 to 73.

and physical effects that result, in terms of time of exposure and percentage of carbon monoxide present in air.

All gas appliance designs tested under ANSI standards have met very rigid tests for combustion, along with other safety tests. For example, ANSI standard Z21.1-1972 for ranges states, "a unit shall produce no carbon monoxide. This provision shall be deemed met when a concentration not in excess of 0.01 percent is produced in a room of 1,000 cubic feet content with 4 air changes occurring during the combustion of gas liberating 60,000 Btu". ANSI standards for other appliances contain similar limits on carbon monoxide produced during test.

Testing for Carbon Monoxide

Several devices can be used to detect carbon monoxide. At least two using color changes are available, based on a tube developed by the National Bureau of Standards. They are referred to as **colorimetric detection devices**. One of these tubes contains chemically treated silica gel. The bulb is opened by breaking off the glass end tips and an air sample is drawn with a bulb through the tube, Figure 13. If carbon monoxide is present in the air the yellow gel changes to green. The intensity of the color change produced depends on the amount of carbon monoxide in the air and on the number of bulb squeezes used. A test can be made in one or two minutes. The amount of carbon monoxide present (from 0.001 to 0.1 percent) can be checked by comparing the color of the gel to a reference card for the number of times the bulb is squeezed.

Another detector is based on color change of activated iodine pentoxide. Ten squeezes of a bulb (taking about 10 seconds) draws a sample through the tube. If

carbon monoxide is present there will be a color change from gray white to a shade of green. The darkness of the green varies with the percent carbon monoxide present. This device has a range of 0.1 to 1.0 percent carbon monoxide.

Fig. 13. Drawing a sample through CO testing tube. The valve in the aspirator controls the air flow.

Another device, a detector ampoule (bulb), detects carbon monoxide in excess of 0.06 percent. The bulb is crushed and hung for 10 minutes in the air being checked. In the presence of carbon monoxide the cotton in the bulb turns gray. The amount of carbon monoxide present is checked by comparing the cotton color to a color chart card.

Other devices to detect and measure carbon monoxide levels in air and to show its presence in blood are available. All of these detectors, and others, are more fully described in *Gas Engineer's Handbook*.

A check for carbon monoxide in the air should be made whenever a customer has been overcome or complains of chronic headaches or nausea. A check should be made if house plants are dying, or there is a chronic odor whose source or cause cannot be located. Condensation on cool surfaces in the house can be a sign of the presence of flue products, which may lead to danger. Only qualified, trained personnel should use carbon monoxide detecting devices.

Certain specific requirements should be met in checking for carbon monoxide. More important than the amount present is the very fact that it is present. Detecting devices should be at room temperature if possible before tests are made. Samples usually should not be taken if their temperature is over 125 F. Thus, it may not always be possible to check flue gases directly, since they should be cooled. However, at least one manufacturer offers equipment for taking flue gas readings.

Figure 14 shows locations at which tests for carbon monoxide should be made: (A) in atmosphere, head high; (B) near gas appliances; (C) close to heat ducts; (D) near appliance diverters and firedoors on appliances in basement or utility room. The operator should test at different points to determine the highest carbon monoxide level in the area.

An appliance may be turned off before arrival. Tests should be made in the following order: (a) in the air before the appliance is started again; (b) just after the appliance is turned on; and (c) after the appliance has operated for about 15 minutes.

Carbon monoxide is only one product of incomplete combustion. **Aldehydes**, another class of compounds, also may be formed in incomplete combustion. While carbon monoxide is odorless, aldehydes have a sharp, penetrating odor. They are readily detected by smell, even at very low concentrations. The odor of aldehydes differs from odorants added to natural gas and the two should not be confused. The absence of aldehydes does not assure that carbon monoxide is not present in flue products. However, if the odor of aldehydes is present then carbon monoxide almost always will be present. Aldehydes themselves also are toxic.

Fig. 14. Suggested locations for sampling to detect carbon monoxide in a home.

IV. GAS BURNERS, DESIGN AND OPERATION

A gas burner is a device to burn gas under control to produce useful heat. Shapes, sizes and styles of gas burners vary greatly. However, gas burners may be classified as one of two basic types: (1) **luminous** (yellow flame) burners; and (2) blue flame (**Bunsen**) burners.

Yellow Flame Burners

Figure 15 shows a simple yellow flame burner. This type of burner is simply a gas supply passageway (or pipe) which feeds gas to a port (or ports). Gas burns on the ports with a yellow flame. No air is premixed with the gas before it exits from the ports to burn. This type of burner was used before the invention of the Bunsen burner. It often took the form of a "bat's wing" or "fishtail" to provide a flat yellow flame for gas lights. Gas is heated inside the flame in the absence of air, forming carbon particles. These particles glow in passing through the flame front, causing the flame to be yellow. Complete burning of the carbon forms carbon dioxide, but if the flames impinge on a cool surface which quenches burning, **soot** (carbon) collects on the surface.

Fig. 15. Luminous flame burner.

As air is used in the combustion process at the flame front in a yellow flame burner, more air flows in to take its place. Some of the air coming into the flame may pass through the flame front to burn with the gas inside the flame envelope as the gas comes from the port. If the path from outside the flame to the unburned gas is very short and enough air gets through to mix with the gas, the gas will burn blue or blue with yellow tips. Range top lighters and fireplace lighters usually operate in this fashion. This type of blue flame burner, which does not use primary air, has also been used for some main appliance burners. Its basic drawback is that the distance from the flame surface to its center must be kept small to attain blue flames; thus, the input rate on each port must be very low. Either the burner must operate with a fairly low gas input rate or a large number of small ports must be used to obtain adequate burner input rate.

Blue Flame (Bunsen) Burner

The blue flame burner was invented about 1842 by Robert Wilhelm von Bunsen. The Bunsen burner mixes some air with fuel gas before the gas reaches the burner ports. Although it is a fairly simple device, **Bunsen-type burners** can work well with a wide variety of fuel gases and over a wide span of gas pressures. Its gas rate can be changed over a large range without adverse effects on its performance. This type of burner offers freedom to tailor flame patterns to match appliance designs. Figure 16 shows a common Bunsen-type burner, its basic

parts and appearances of the flame on the burner.

Fig. 16. Typical Bunsen burner and flame

An orifice is used to regulate gas flow to the burner. Air which is mixed with gas inside the burner body enters through openings in the burner body. A sleeve or shutter is used to adjust size of these openings to control primary air. Gas and air mix in the burner body (mixer tube), then exit to burn on the port.

A Bunsen-type burner flame (with a reasonable amount of primary air) has several color zones. Each of these zones marks a stage in burning of the gas. On the burner tip is a thin, blue cone called the inner or primary cone. Inside the inner cone is a darker area, the unburned, fairly cool gas-air mixture. The inner cone marks the first step in the burning process. There gas is burned to form products such as aldehydes, alcohols, carbon monoxide and hydrogen.

A darker, outer cone surrounds the inner cone of a Bunsen-type flame. Air around the flame diffuses into the flame

to take part in the burning at the outer cone. If enough air is present and other conditions are favorable, products from the inner cone are completely burned here. This burning yields the final products, carbon dioxide and water vapor.

An outer mantle surrounds the cone of a Bunsen-type flame. Since burning usually is completed at the outer cone, there are almost no unburned gases at the outer mantle. This nearly invisible mantle glows only because of the high temperature of the final products of combustion.

Temperature of a gas flame can vary, depending on a number of factors. Two major factors are the type of fuel gas and the amount of air premixed with the gas. Flame temperatures are not the same at all points in the flame. Referring to Figure 16, temperature in the unburned air-gas mixture inside the inner cone is fairly low. Highest flame temperatures usually occur at a point just above the outer flame cone.

A cold body placed in a flame reduces flame temperature in the area of contact. Too great a drop in flame temperature can quench the flame. If this condition occurs, products such as carbon monoxide can escape from the flame before they are completely burned. Usually the outer mantle of a blue flame can impinge on cool surfaces without causing incomplete combustion of the gas. But inner and outer cones, especially the inner cone, should not impinge on surfaces colder than about 1200 F.

Primary Air, Secondary Air, Excess Air

Air which is mixed with gas before the gas leaves a burner port to burn is

called **primary air**. In most gas burners only part of the air ideally needed for burning the gas is supplied as primary air. For example, a burner may operate with five cubic feet of primary air per cubic foot of natural gas used. This amount is about half the air ideally needed to burn the gas (10 cubic feet of air per cubic foot of gas). The primary air percentage for this burner would be said to be 50.

The rest of the air needed for complete burning of gas is supplied as **secondary air** from around the flames. In an ideal case, primary air and secondary air should equal exactly 100 percent of the air required for complete combustion. This ideal case assumes that all of the oxygen in the air supplied is used in burning the gas. In actual practice this ideal situation is seldom, if ever, achieved. Some additional air must be supplied to assure that enough air is available to complete burning of the gas. All air actually supplied to a burner is called **total air**. Total air equals the sum of all primary and secondary air supplied. The air in excess of the ideal amount needed is called **excess air**.

Amounts of primary, secondary, excess and total air for combustion usually are expressed as percentages of the amount needed. Ideally, about 10 cubic feet of air is needed to completely burn one cubic foot of natural gas. Suppose that 15 cubic feet of air is supplied to an appliance for each cubic foot of gas. Total air is 150 percent ($15/10 \times 100\%$). Excess air is 50 percent ($150\% - 100\%$). All combustion air is supplied as either primary or secondary air. Suppose that 5 of the 15 cubic feet of air supplied in the example is primary air. Primary air is

50 percent ($5/10 \times 100\%$). The remaining 10 cubic feet of air supplied would be secondary air and excess air.

Flame Appearance and Stability

Several factors affect flame stability. Among these are: the amount of primary air, burning speed of the fuel gas, port loading, port size and port depth.

With a Bunsen-type burner the air-gas mixture is ignited at the burner ports. The flame tries to travel through the mixture towards the burner head at a rate equivalent to the burning speed for the mixture. As discussed earlier, flame speed varies with air-gas mixture. It is highest in a mixture with about 100 percent primary air. Burning speeds fall off on either side of 100 percent primary air, both for richer and leaner mixtures. Burning speed varies for different gases. A burner port wall also affects burning speed. At or near the port wall the wall quenches the flame, so that at that point burning speed is zero.

The flow velocity of the air-gas mixture flowing from the burner port depends on the amounts of gas and air and size of the port. Greater flows from smaller ports produce greater flow velocities than lower flows from larger ports.

Flow velocity is not the same at all points across a port. Friction of port walls slows down flow velocity until it is zero at or near the walls. Greatest flow velocities are found at the port centerline, falling off on either side of the centerline to zero at the walls. Flow velocities from a port can be shown for various points across a port as arrows. Figure 17 shows such a plot. The length

of each arrow shows the value of flow velocity at that point. If the points of the arrows are connected with a line, the curve obtained is called the flow velocity distribution on the port. This curve usually is parabolic in shape as shown in Figure 17.

Fig. 17. Flow velocity distribution from a burner port.

Flame on a burner port stabilizes at those points where flow velocities out and flame speeds back are equal. The edge of the flame is close to the port edge where flow velocity and flame speed both are zero. In an actual burner the outer edge of the flame base is located slightly above the port level. This distance is called the **dead space**.

After the air-gas mixture leaves the port it slows down. At some distance above the port, flow velocity equals burning speed and the flame stabilizes at that point. Since flow velocity is highest at the port centerline, flame stabilizes at its highest point there. The flame stabilizes at other lower points away from the centerline where flow velocities at the port level fall off. For this reason the inner flame assumes its typical conical shape. Temperatures are higher near the top of the cone, increasing burning speed. Therefore, the flame cone is rounded off at its tip. Effects of each layer of flame on the layer above it act

to further determine the shape of the inner cone.

This balance of flow velocities and burning speeds explains why flames change when primary air or gas rate are adjusted with Bunsen-type burners. When primary air percentage is increased in a burner the flame sharpens and the height of the inner cone decreases. Most burners use less than 100 percent primary air, so burning speed increases as more primary air is used. Recall that highest burning speeds occur with about a 100 percent primary air mixture. Flow velocities from the port also increase as more primary air is used, but not as rapidly as burning speed. Flow velocities across the port thus match burning speed at shorter distances from the port with higher primary air. Shorter, sharper inner cones result.

Increasing gas rates to a burner and opening air shutters to set the same percent primary air causes inner cones to lengthen. Under these new conditions flow velocities out of the port increase. Burning speeds remain the same for the same air-gas mixture. Points where the higher flow velocities have slowed down to again match burning speeds are farther away from the port. These changes produce longer inner cones.

Port loading also is important to obtain stable burner flames. **Port loading** is simply the amount of gas passing through a port and is expressed as Btu per hour per square inch of open port area:

$$\text{Port loading} = \frac{\text{Input rate}}{\text{Port area}}$$

Raising port loadings tends to increase tendencies of burner flames to lift. Lowering port loadings tends to promote **flashback**.

Lifting Burner Flames

Bunsen burner flames with reasonable primary air should be stable and quiet. If too much primary air is used or port loading is too high, flames lift and blow off the ports, Figure 18.

Lifting (blowing) flames can be noisy. Flame cones may rupture, so complete burning does not take place. Aldehydes and carbon monoxide can be formed by blowing flames. All the heat content of the gas may not be released in the appliance under these conditions and efficiency drops. Such a loss in heat transfer of course, is less important than the possibility of forming carbon monoxide.

Any operating factor or gas property that acts to lower burning speed acts to promote lifting flames. The same is true for any operating factor or burner design factor which increases flow velocities from ports.

Burning speeds of fuel gases vary. Natural gas is a fairly slow burning gas, with propane and butane only slightly

higher for a given air-gas mixture. Lifting is more likely to occur with these slow burning gases than with other faster burning gases.

Burning speed in a gas is fastest with about a 100 percent primary air mixture. But with slow burning natural gas, a gain in burning speed with higher primary air is offset by higher flow velocities from ports at higher primary air percentages.

Port loading has a major effect on the lifting of burner flames. Higher port loadings (with primary air maintained at a given level) mean high flow velocities from ports, aggravating lifting problems. **OVERRATING** of burners is a prime cause of lifting flames.

Port size and depth affect lifting tendencies of flames. If ports are enlarged and input rate kept the same, port loading is reduced. Flow velocities from the ports decrease, reducing tendencies for flames to lift. Very shallow ports, such as 1/32 inch, tend to aggravate lifting problems.

Fig. 18. Blowing (lifting) burner flames.

Burners with ports very close together usually are less likely to have lifting flames. Small port spacings provide better inter-piloting between individual flames. Closer port spacing also reduces quenching action of the air above the ports to help prevent lifting. Ribbon-type burners with very close port spacing (and usually low port loadings as well) are notably resistant to lifting flames.

Burner flames are more likely to lift from a cold burner. Part of the reason for this is that primary air injection is highest when the burner is first turned on. As the burner heats up, the percentage of primary air drops off. Equally important, quenching action of the port (and the air just above the port) is less with a hot burner. Burning speed is not reduced as much as with a colder burner, improving resistance to lifting. Often, with bar-type burners, flames may lift from one or two ports near the ends of the burner just after light-up. As the burner heats up, these flames usually settle back down to the ports. Ordinarily this type and degree of lifting flames can be tolerated.

Flashback

Under some conditions, gas-air flow velocity is less than burning speed at some point or points near a burner port. When this takes place the flame tends to strike back through the port to ignite the mixture in the burner head. This condition is known as **flashback**.

As noted earlier, the inner cone of a Bunsen-type flame visibly defines those points where flow velocities and burning speeds are balanced above the port. In a sense, flashback is a condition in which the inner cone is inverted. It

extends into the port, rather than above it, and ignites the mixture in the burner. A flow velocity - burning speed pattern promoting flashback is shown in Figure 19.

Fig. 19. Flow velocity and flame velocity distributions on a burner port under flashback conditions.

With a properly designed and adjusted burner, flashback will not occur during normal burner operation. Under some other conditions it may happen. Any fuel gas property which increases burning speed tends to promote flashback. Any burner operating or design factors which act to decrease flow velocities from the ports also make flashback more likely.

Flashback tendencies are greater with faster burning fuel gases. Natural gas is a fairly slow burning gas, so is less likely to flashback than faster burning gases, such as coke oven manufactured gas. Increasing primary air increases burning speed and thus increases the tendency for flashback.

Sometimes a burner may be underrated, due to an incorrect orifice size or low gas pressure, or both. Flow velocities from ports will be lower than

normal, promoting flashback. A leaking burner valve which lets a small amount of gas flow to the burner also can cause flashback. In multiple burner appliances flashback may occur in one underrated burner. The overall appliance rate can still be close to its rated input despite one underrated burner.

Smaller and deeper burner ports improve resistance to flashback because of quenching effects, reducing burning speed. This quenching action is lessened if the burner ports are hot. The quenching effect of very small ports or porous refractory material in **radiant burners** prevents flashback, in spite of operation with very high primary air and with a glowing surface.

Although flashback may occur in critical designs after the burners heat up, it is still possible for flashback to occur upon ignition of a burner. When a burner is first turned on, gas flow rate usually goes from zero to full rate in a very short time. The mixture in the burner head rapidly changes from all air to the steady-state mixture of gas and air. Flow from burner ports goes from zero to that of normal operation. This period may be very short, lasting only a second or less. It is possible that at some instant the mixture flow from the ports will be low enough and burning speed high enough to cause flashback to take place at ignition. If full rate is reached quickly enough in this starting period, normal ignition should take place. The same is true if the mixture at ignition in that period is either too rich or too lean for flashback to occur.

Flashback on extinction (also known as **extinction pop**) may take place when a burner is turned off. It may take place almost instantly or may be delayed by

several seconds. This is what happens: More primary air flows into the burner, even though the gas jet is cut off and does not inject air. The mixture in the burner changes from the normal operating mixture to all air. Flow rate through the ports falls off toward zero. Under these conditions it is possible for the flame speed to exceed flow velocity at some instant and flashback may occur. The result is a tiny explosion or pop. Extinction pop usually presents no hazard but may be annoying to a householder.

Yellow Tipping of Flames

Figure 20a shows a case where proper amounts of primary air are provided to a burner to give completely blue flames. Reducing primary air causes inner cones to lengthen. Eventually they disappear. Yellow tips appear in the flames as primary air is further reduced, Figure 20b. The flames will become all yellow if no primary air is supplied, Figure 20c.

The yellow tips are caused by glowing carbon particles in the flames. Soot will form if these yellow flames impinge on cool surfaces which quench the combustion reaction before carbon particles have been burned. Carbon monoxide also may be formed by yellow flames, especially if the flames impinge on cool surfaces.

Dust particles in the air may glow as they pass through the flames, causing color streaks to appear in the flames. These color streaks have little or no effect on combustion. Orange - yellow streaks caused by dust should not be confused with true yellow tipping. True yellow tips are usually paler than dust color streaks. Further, true yellow tipping usually can be eliminated by increasing

primary air. Dust streaks may not, or may even be aggravated if more dust enters with increased primary air. Orange-yellow dust streaks disappear when viewed with some tinted glasses, such as brazing goggles. True yellow tips will not.

Fig. 20. Yellow tipping in flames.

Effects of Combustion Air Flow Rates on Appliance Efficiency

It is of course desirable to operate gas appliances in the most efficient way possible consistent with safety. The efficiency depends on putting the heat from the flame into the substance being heated with as little loss as possible. In a given appliance the efficiency of operation will then depend upon the rate of heat transfer which is in turn determined by the

temperature difference between the hot combustion gases and the heated substance. Heat transfer rate is greater with hotter flue gases moving through the heat exchanger. The more excess air flowing through the appliance the lower will be the temperature of the gases doing the heating since the excess air only dilutes the combustion products without adding anything in the way of heat.

Looking at it another way, heat which is lost in flue gases leaving an appliance exhaust opening is waste heat. Such heat losses are called **flue loss**. The less flue products leaving the appliance, the lower is the flue loss. Heating excess air and then throwing it away out the flue reduces efficiency. Excess air flow should be kept low but must be enough to insure complete combustion of the fuel under all conditions of appliance operation. This end is achieved by control of air flow into the appliance.

Control of Combustion Air Flow

Some excess air is needed by virtually all appliances. Slight changes in gas supply or air supply may occur in normal field operation of appliances. Enough excess air must be supplied the burner to provide complete combustion in spite of these changes.

Most appliance burners are operated on less than 100 percent primary air. Infrared (radiant) burners are an exception; however, even these burners usually require some excess air. In most cases, the amount of excess air is set by controlling the amount of secondary air.

Secondary air flow is controlled by the size of air inlet openings into the combustion chamber and by flue outlet size. Size and shape of these openings

are major considerations in appliance design. They should not be altered except when converting an appliance to gas from another fuel.

In the earlier discussion of control of secondary air a vital limitation was specified. Enough air must be supplied to assure complete burning of the gas. If secondary air flow (excess air) is insufficient, incomplete combustion will result. There is no hard and fast rule about the amount of air needed. This value will depend on a number of appliance design factors. Floating flames have a soft and hazy appearance and the flames seem to "reach" for air. They should not be confused with lifting or blowing flames, which are hard, well defined and often noisy. Lifting flames usually settle down on burner ports if primary air is reduced. Reducing primary air will not stop floating flames.

Figure 21 shows a Bunsen-type burner with a secondary air opening around it, as would be the case with a range top burner. The flue outlet dimension

is determined by the bottom of the cooking utensil resting on top of the grates.

Figure 22 shows secondary air openings and flue outlet openings in combustion chambers with enclosed burners, such as in ovens, water heaters and furnaces. Figure 22 also shows floating flames resulting from insufficient air reaching the burner flame.

Any burner flame actually uses only as much air as is needed for complete burning to take place. Any remaining, unused air (excess air) will exit the appliance with the combustion products. Enough excess air must be supplied to assure complete combustion; however, too much excess air causes a loss in efficiency.

Calculation of Excess Air Percentage

The amount of excess air supplied to a burner can be found by measuring carbon dioxide in the flue products. If any gas is burned with exactly the amount of

Fig. 21. Bunsen-type Blue-flame burner on a typical range top.

air needed, the carbon dioxide (CO_2) in the flue products will have a certain value for that gas. This value is called the ultimate CO_2 for that gas. It is the highest CO_2 percentage that can be obtained in burning a given gas. Any excess air used will dilute the flame gases, giving a lower CO_2 reading.

Excess air, in terms of a percent of the ideal air needed for complete combustion, can be calculated for most common fuel gases as follows:

$$\text{Excess Air (Percent)} = \left(\frac{\text{Ultimate } \text{CO}_2 - \text{Observed } \text{CO}_2}{\text{Observed } \text{CO}_2} \right) \times 91$$

where 91 is a constant for most common fuel gases. For example, the ultimate CO_2 for natural gas is about 12 percent.

Suppose that the percent CO_2 in the flue products from a furnace is 8 percent.

The excess air is:

$$\begin{aligned} \text{Excess Air} &= \left(\frac{12 - 8}{8} \right) \times 91 \\ &= \left(\frac{4}{8} \right) \times 91 \\ &= 45.5 \text{ percent} \end{aligned}$$

Impingement of Burner Flames on Cool Surfaces

Simply providing a reasonable amount of excess air will not assure complete burning of the gas. Recall that all three elements of the combustion triangle—fuel, oxygen and heat (temperature)—must be present. If cool surfaces draw away too much heat and quench the flame, combustion will stop at the stage it has reached. Completeness of combustion depends on which part of the flame impinges on the cool surface.

As shown in Figure 23, burning usually will be complete if the flame outer mantle impinges on a cool surface. This

Fig. 22. Secondary aeration of burners in combustion chambers.

mantle usually consists of carbon dioxide and water vapor only. The outer flame cone marks the usual last step in burning. If this reaction is quenched before this step is reached combustion may be incomplete. The first burning step takes place at the inner cone, and if quenching takes place here combustion usually will be incomplete. Only if products from the outer or inner cones are still hot enough to react with air after they leave contact with the cool surface will combustion be complete. Impingement of the inner cone on cool surfaces should be avoided. Yellow tips also should not be allowed to touch cool surfaces, since carbon monoxide or soot, or both, may be produced.

TYPICAL BURNER COMPONENTS

Gas Orifice

Figure 24 shows a typical **atmospheric** appliance burner and its major parts. The gas **orifice**, strictly speaking, is not a part of the burner. But it is such a vital part of the "burner system" that it must be included in the discussion of burners. The term "orifice" means an

opening or hole. The part which contains the orifice should be referred to as an orifice **spud**, hood, or cap. These parts are often incorrectly called "orifices".

The gas orifice regulates or limits the amount of gas flowing to a burner. Gas flow rate depends on the size of the orifice (hole) and gas pressure at the inlet of the orifice. The gas flowing from an orifice is in the form of a jet which causes primary air to flow into the burner tube.

Air Shutter

Some burners are furnished with fixed primary air openings. These designs are to be used with one specific gas at some particular gas pressure at the orifice. Most appliance burners use some sort of device to adjust primary air, such as an air shutter. This shutter is used to adjust the size of air openings to control primary air flow.

Primary air shutters can take a variety of forms, Figure 25. Some of the more common types are: butterfly; modified wing; and rotating disc. American

Fig. 23. Impingement of bunsen-type flames on cold surfaces.

Fig. 24. Typical atmospheric appliance burner.

National Standards Institute (ANSI) standards specify that air shutters shall be substantially made, shall resist rusting and shall be designed so that they can be held firmly in any set position. Air shutter openings should not be susceptible to blockage by lint and dust.

Fig. 25. Some types of air shutters.

A type of primary air control which does not use air shutters is a **spoiler screw** (or **breaker bolt**). A screw is mounted through the burner wall at or

near the burner throat. This screw is moved into and out of the gas jet from the orifice, and "spoils" its flow pattern enough to allow change of the primary air.

Venturi Throat

Most atmospheric appliance burners are necked down to a venturi throat. Venturis have been found to provide better burner flexibility than straight tubes because they maintain more constant primary air injection.

Mixing Tube

The **mixing** (or **mixer**) **tube** serves to carry the air-gas mixture from the venturi throat to the burner head. Gas and air mix as they travel down this tube, giving this part its name.

Burner Head

The burner head contains the burner ports, and provides uniform distribution of air-gas mixture to those ports. Its size and shape can be tailored to fit an appliance combustion chamber and to provide even heat release to heat transfer surfaces.

Burner Ports

The air-gas mixture emerges from the burner head to burn at the ports. These ports serve several purposes: (1) they distribute flames to provide good heat transfer to the heat exchanger; (2) they spread the flames so they can be reached by secondary air; (3) they provide stable, blue flames.

OPERATION OF BURNERS

From the viewpoint of primary air supply, there are two basic types of gas appliance burners: (1) atmospheric burners; and (2) power burners. In atmospheric burners primary air is brought into the burner from outside the appliance at atmospheric pressure. The gas jet streaming from the orifice draws or **injects** primary air into the burner. Power burners supply combustion air by mechanical means such as blowers. This powered air supply may be in the form of primary air, secondary air or both. Secondary air is supplied to yellow flame

burners by natural draft through the combustion chamber (atmospheric) or by an induced draft (power burner).

Atmospheric Burners

Gas flows through a gas **manifold** (including controls), through the gas orifice and into the burner. Orifice size and gas **manifold pressure** establish gas flow rate. In an atmospheric burner, Figure 26, the gas jet from the orifice injects primary air into the burner. Molecules of gas in the jet colliding with molecules of air in the burner venturi, set these air molecules in motion and sweep them along the burner tube in the direction of gas flow. A negative pressure is produced in the **venturi throat** by the air-gas mixture flow through it. Air at atmospheric pressure flows through the primary air openings into the venturi throat.

With a given burner input rate, the amount of air injected by the gas jet increases with: (1) increased number of

Fig. 26. Injection of primary air in an atmospheric burner.

gas molecules; (2) increased velocity of the gas molecules; and (3) higher mass (weight) of the gas molecules. Each of these conditions leads either to more impacts of gas with air molecules or to harder impacts, so that more air molecules are entrained or swept along by the gas.

If heat input rate is maintained constant, primary air injection is greater for a fuel gas with a lower heating value (natural) than a higher one (LPG) since the lower heating value gas has more molecules for each Btu. On the other hand, if the volumetric flow rate instead of the heat input rate is maintained constant, primary air injection is better with gases which have higher specific gravity such as propane or butane because they have heavier molecules.

If a smaller gas orifice is used and gas pressure increased to maintain the same heat input rate, the velocity of the gas molecules in the jet is higher. In other words, injection of primary air is improved by using a smaller orifice and higher manifold pressure.

After passing through the venturi throat, the air and gas mix in the mixer tube, enter the burner head and flow from the burner ports. These ports act as a restriction to flow. Thus, port loading has a great effect on primary air injection. Low port loadings produce high primary air injection; high port loadings produce low primary air injection. Other restrictions in the burner such as the venturi throat may have an equal or greater effect on injection. Internal roughness of the burner can also reduce primary air injection through friction losses.

It is possible to increase primary air in a burner (if necessary) by enlarging burner ports. When reducing port loading in this way, care should be exercised since, if holes are too large, flashback may occur.

Burner temperature also affects primary air injection. As a burner heats up primary air decreases. At the same time, burner temperature affects flame stability. Lifting flames are more likely with a cold burner; flashback with a hot burner. However, higher primary air with a cold burner may cause flashbacks on ignition, particularly with a low port loading on the burner. All of these possibilities must be considered when adjusting a burner.

The air-gas mixture in the burner leaves through the ports to burn on those ports. Not all of the air needed for combustion is supplied as primary air. The burner flames draw in secondary air from around the burner to complete burning of the gas. Poor mixing of the air and gas in the burner and uneven distribution of the mixture to the ports can create problems. An uneven flame pattern can interfere with complete combustion. Arrangement of burner ports is important. All flames must get their share of secondary air and the flames must carryover quickly from port to port upon ignition.

Power Burners

The gas jet in atmospheric burners injects primary air into the burner with the air supply at room (atmospheric) pressure. The gas jet obtains its momentum to inject air from gas pressure in the manifold. In power burners pressure of the gas or air, or both, is boosted by mechanical power (pump or blower).

Power burners are used for many purposes such as conversion burners in homes and in numerous industrial applications. There are four basic types of power burners commonly used. Combinations of the features of various types may be used advantageously in some processes.

Forced and Induced Draft Burners

Figure 27 shows two forced draft-type **power burners**. In this type of burner combustion air is supplied under pressure by a fan.

In forced draft systems, mixing rate of air and gas is fairly slow. As shown at the left in Figure 27, gas and air can be admitted separately. Air-gas mixing takes place in the combustion chamber. The type of burner shown on the right in Figure 27, is commonly referred to as a nozzle mixing burner, in which gas and air mix at the point of combustion. Since air and gas mix slowly, combustion takes place over a large volume. High temperature in the combustion chamber

usually can be achieved only by preheating the combustion air. Control of the air-gas mixture is accomplished manually by adjustment of the gas valve and air valve or shutter. Automatic air-gas mixture control can be achieved with mechanisms which balance air and gas pressures. Another approach makes use of a mechanical linkage between the air and gas throttling devices.

Figure 28 shows an **induced draft** power burner. In this burner design a blower is placed at the flue outlet. This blower draws combustion products from the system, which allows combustion air to flow in. The exhausting device may be a fan or an air injector. Usually this type of burner is used when resistance to flow of flue gases is high, such as in water-immersed heating tubes.

The fan at the flue outlet of an induced draft power burner must be in operation before gas is admitted to the burner. Air and gas supplies must be

Fig. 27. Forced-draft power burners.

interlocked. A pressure or vacuum switch activated by the forced draft fan can be used for this purpose.

Fig. 28. Induced-draft power burners.

Premixing and Pressure Power Burners

Figures 29, 30 and 31 show three types of premixing power burners. In these burners, all, or nearly all, combustion air is premixed with the gas before burning starts. Several methods can be used to premix the gas and air; (1) A fairly high pressure gas jet may be used to premix with air at zero pressure, Figure 29; (2) Air jets at some pressure may be used to inject gas, Figure 30. Usually with this scheme gas pressure is reduced by a special pressure regulator called a zero governor; (3) Gas may be mixed with air in a blower, Figure 31. With this arrangement both air and gas are at relatively low pressure. In each of these designs if only part of the necessary combustion air is

supplied by premixing, secondary air openings around the burner must be provided.

Fig. 29. Premixing power burner. Gas jet mixer type.

Fig. 30. Premixing power burner. Air jet mixer type.

Fig. 31. Premixing power burner. Fan or compressor mixer type.

Figure 32 shows a pressure burner. Air and gas are mixed under pressure, usually between 0.5 to 14 inches water column in a compressor with this type of burner.

Systems of this type can provide air-gas mixtures at any reasonable pressure needed to overcome high combustion

Fig. 32. Pressure burner.

chamber pressures. They also provide a wide range of burner input rates and air-gas mixture combinations. The air-gas mixture can be controlled accurately and independently of the volume delivered. A single premixer of this type can supply a number of burners. All burners may be operated at the same time, or only some of the burners. In either case, air-gas mixture in the operating burners remains the same. When all combustion air is premixed with the gas, some type of flashback arrestor must be used. This arrestor protects the burner from potential damage by flashback into the mixer system.

APPLIANCE BURNER DESIGNS

An appliance burner must have certain characteristics. The most important of these include: (1) complete combustion of the gas; (2) rapid ignition and carry-over of flame across the entire burner; (3) reasonably quiet operation during

ignition, burning and extinction; (4) no excessive lifting of flames from the burner ports; (5) uniform heat spread over the area to be heated; (6) control over a wide range of burner rate turn-down without flashback or flame outage (more important in some appliances than others); (7) sturdy construction to provide a long service life. In addition to these characteristics, cost of manufacturing a burner is of prime importance.

Appliance burners vary greatly in shape and size. They may be considered to be one of seven general types: (1) drilled port; (2) slotted port; (3) ribbon port; (4) single port (monoport); (5) radiant (infrared); (6) jet; or (7) impingement target. Figure 33 shows typical burners of most of these types.

Drilled Port Burners

Drilled port burners have a number of separate, relatively small circular ports. These ports are made by drilling or punching. Formed, pierced or punched ports of roughly circular cross section behave like drilled ports and are treated as such. Often they are referred to as drilled ports even though they have not been made by drilling. Range top burners having a formed burner cap where the ports are formed in the lower edge of the cap are an example. Drilled ports may be used in cast or stamped sheet metal burner bodies. Often cast metal burners have pedestals or bosses (raised flat portions) through which the burner ports are drilled. Bosses provide good port depth without requiring thick burner walls.

Drilled ports lend themselves to a variety of burner shapes: round, bar-types, etc. They can be oriented to provide vertical, horizontal or angled flame

patterns. Horizontal flames are of particular value in range broilers, or in storage water heaters where headroom might be limited. Circular burners with horizontal ports are often used in water heaters to provide even heat distribution over the tank bottom.

Burner port loading should be reasonably low to provide sufficient primary air and stable burner flames. Multiple drilled port burners may require rather a large number of ports to give port area enough for a reasonable port loading. The use of a large number of drilled ports may be a cost disadvantage.

Slotted Port Burners

Slotted port burners can take several forms. For example, bar-type burners may have a series of parallel slots

across the top of the burner. These cross-slots may be saw cuts in a cast burner body, for instance. They may be stamped or punched slots in a sheet metal burner body. Slots may extend along the length of the top surface of a burner bar. These slots can be formed by mounting several flat strips of metal in an opening in the top of the burner head. Spacers between the strips are used to set the slot widths, and to prevent warpage of the strips forming these long slotted ports. Circular burners with a continuous slotted port around the burner head are another common design, used frequently in water heaters. In this design the slotted port is formed between the upper rim of an open burner head and the lower edge of a burner cap on top.

Slotted port burners usually offer an economic design, which lends itself to stamped sheet metal construction. On the other hand, the use of thin slotted ports may aggravate flashback. Flames on

Fig. 33. Typical appliance burners.

closely spaced multiple slots tend to coalesce, or come together, which creates a greater tendency for yellow tipped flames.

Ribbon Port Burners

In a ribbon port burner, alternate flat strips and corrugated strips of metal are mounted alongside each other to form the ports. This ribbon assembly is mounted in an opening in the burner head. Ribbon type port forms have been used in bar-type burners and in round burners with flames fired vertically.

Ribbon port burners offer several operating advantages. Ribbon ports behave like a very large number of drilled ports very close together. A large amount of open port area can be fitted into a given burner head area. Primary air injection is thus improved. The very closely spaced ports provide excellent piloting (flame retention) between ports, so that very high primary air and/or port loadings can be used with this design without causing lifting flames. The depth of the very small ribbon ports is large, set by the width of the corrugated strip used to form the ports. Their quenching action is great, reducing flashback tendencies.

Ordinarily, stainless steel is used for the strips in ribbon ports. Since it costs more than ordinary carbon steel, ribbon burners cost more to make.

Ribbon ports generally are quite small and so this type of burner may be prone to buildup of lint and dust on the underside of the ports. Such a buildup can lead to yellow tipping in the burner flames, sooting and/or incomplete combustion.

Single Port or Monoport Burners

To make a single port burner, the mixer tube is simply extended and gas burned on the end of the tube. There are several types of single port burner designs. In an upshot burner, air-gas mixture flows through the mixer tube, through a bend and into a riser tube to burn vertically at the end of the riser tube (port). Almost always a flame spreader is mounted above the port to spread out the flame. An inshot, single port burner usually fires horizontally. Gas burns on the end of the straight extension of the mixer tube. Again, a flame spreader usually is mounted in front of the burner port to spread the flame. A so-called contoured flame burner can be considered to be a type of single port burner. To make a contoured flame burner, a burner head is mounted on the end of the mixer tube to shape the flame pattern. For example, a burner head might have a fairly long and wide single slot, and fire into a narrow, sectional-type heat exchanger. Ordinarily, a contoured flame burner of this type does not need a flame spreader.

The major advantage of the single port burner lies in its low cost since it is an extremely simple design. The flame produced is a single large flame. To eliminate yellow tipping when burning natural gas, single port burners must be operated with about 50 percent or more primary air. Flames on large single port burners tend to lift. To minimize lifting, single port burners usually have a **flame retention device**, consisting of a crimped ring inserted just inside the lip of the burner port. Single port burners usually are more subject to flashback and are noisier than most other types of burners.

Infrared Radiant Burners

Most appliances rely primarily on convection and conduction to transfer heat from the hot flame to the heated substance. Heat may also be transferred by radiation. In this process a hot surface transmits its thermal energy through space without heating the medium through which it travels. This method of heating is very useful and is applied in such applications as commercial and industrial building heaters, patio heaters, oven broilers and many industrial processes such as paint, textile and paper drying.

Infrared or radiant heating is very fast. Little warmup period is required. Infrared burners can be tailored to produce even radiant heating of heat transfer surfaces or products being heated. Infrared energy is not normally affected by air flowing between the burner and the surface to be heated. Because of the very short flames on infrared burners, more compact heat exchangers can be used with this type of burner. Therefore, flame impingement effects can be minimized. In some uses, such as range broilers and radiant heaters for use outdoors, almost all heat from infrared burners is transferred by radiation. In other enclosed-type appliances such as furnaces, heat is transferred by convection in the appliance by hot combustion products from the burner as well as by radiation. The more heat which can be transferred by radiation from the burner, the less heat needs to be transferred by convection. Therefore, with radiant burners an appliance can be designed to be more efficient or more compact.

Probably the most common type used in appliances is the surface combustion

burner. The radiating surface of the burner is a porous refractory material such as ceramic or stainless steel with small drilled or formed ports or a metal screen. The air-gas mixture passes through the burner face material, and burns on the surface, which then becomes the radiation source. Often a coarse stainless steel screen is mounted a short distance away from the radiating surface. By re-radiating energy to the glowing surface, this screen raises the surface temperature.

When operating most burners it is best to operate with as low a burner temperature as possible in order to inject more primary air so as to avoid flashback. While most atmospheric burners operate with about 35 to 60 percent primary air depending on type of burner and the appliance in which it is used, an infrared burner, on the other hand, requires about 100 percent primary air and is designed to have a hot, glowing burner surface. To make this so, the flame must burn close to the surface of the burner and with a high temperature.

There are a wide variety of infrared burner designs. In some cases, the radiating surface is placed between the flame and the load. A radiant tube burner would be one such burner. Other infrared burners use ceramic refractory radiating surfaces, heated by flame playing on the surfaces. Range broilers often have surfaces such as metal screens heated directly by flames. This type of radiant burner does not require 100 percent primary air as others do since secondary air can reach the burning zone.

Temperature of the radiating surface depends primarily on the heat loading of the surface. Heat loading is expressed as Btu per hour per square inch of surface

area. The loading which can be applied to the surface depends mostly on how much primary air can be injected into the burner. If the primary air falls much below 100 percent, the burner surface cools and eventually ceases to glow. The same is true if much more than 100 percent primary air is supplied to the burner. A typical atmospheric infrared burner surface operates with a surface temperature of 1400 F to 1650 F. Higher surface temperatures are possible with a power burner, since higher surface input loadings can be obtained with a powered primary air supply. Service life of the radiant surface material usually limits the temperature which can be used.

The major drawback of atmospheric infrared burners is that rather low surface heat input loading must be used to provide the high primary air needed. This condition limits heat input rate which can be used with a given burner size. Put another way, a rather large amount of surface area must be used to obtain a desired input rate. Ordinarily, air injection parts of an atmospheric infrared burner (venturi, etc.) are larger than those used in comparable non-radiant type burners. The radiating surface ceases to glow if the surface heat loading is reduced too far. This is a disadvantage for some uses of infrared burners.

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. Usually no provision is made to adjust primary air. This burner (fitting) is mounted in

a pipe at an angle with a second jet burner set next to it. The jets are mounted in such a way that the two streams come together at a point in the space above the ports. Burning takes place where the two streams meet.

Jet burners have been used in applications in which there is a large area to be heated as in large multi-section boilers. The burner pipe and pairs of jet burners can be arranged to cover all of this area. Fast carryover of flame from pairs of jet burners to adjacent pairs always must be assured.

Jet burners of this type usually are noisier than other types of atmospheric burners since burning takes place in the open above the jet ports.

Impingement Target Burners

An **impingement target burner** consists simply of a gas orifice and a target mounted at some fixed distance from the orifice. The gas jet emerges from the orifice and sweeps in air through open space. This air-gas mixture strikes the target and burns there. Flame size depends on target size and input rate. The amount of air drawn into the burner by the gas as it passes out of the orifice through the air, depends on the distance between the orifice and target. The target may be crimped at its outer edge so that tongues of flame are formed. A second plate with a central hole in it may be mounted below the upper target. The flames leaving between the two plates resemble those created by a horizontal, drilled port burner.

The chief advantages of the impingement target burner are simplicity, low

cost, and ease of servicing. No air shutter, venturi, mixer tube, or burner head is needed (unless a double target, as described above, is considered a burner head). Unlike burners which have primary air openings, an impingement target burner is not subject to blockage of the air openings by dirt, dust or lint.

The chief disadvantage of the impingement target burner is its noise of operation. This noise can be reduced by closer spacing of the target from the orifice. The use of flame holding devices built into the target also can help reduce burning noise. Turndown of gas rate with this type of burner is limited to the point where the gas flame drops back to burn on the orifice.

PILOT BURNERS

The main burner in automatic gas appliances (or burners) must be lit each time the appliance operates. Automatic gas **pilots** are commonly used for this purpose. An automatic gas pilot system also acts to cause the gas supply to the burner to be cut off if the pilot flame goes out.

An automatic gas pilot consists of an **automatic pilot device** and a pilot burner. The automatic pilot device either directly shuts off the gas supply to the main burner, or actuates a gas shutoff device when the pilot flame is extinguished.

The pilot burner has two functions. First, it provides the flame to light the main burner. Second, it provides heat energy needed to operate the pilot safety device.

Gas input rates of automatic pilots vary, depending on the type of pilot burner and where the pilot is used. Pilot inputs of 50 to 300 Btu per hour are used in ranges and small appliances. Pilot rates of 300 to 1000 Btu per hour are usual in larger appliances. A pilot rate of up to about 2000 Btu per hour may be sometimes used on conversion burners.

Automatic pilot burners are classified for convenience in terms of whether or not primary air is supplied to the pilot within the pilot burner body. The first type is commonly referred to as primary aerated pilot burners, the second non-primary aerated pilot burners. Figure 34 shows a typical primary aerated pilot burner. Also shown in Figure 34 are two non-primary aerated pilot burner types: a non-primary aerated, blue flame type; and a target-type.

Primary Aerated Pilot Burners

Primary aerated pilots are simply small Bunsen-type burners. They operate on the same principles as larger appliance burners. A separate port may be used to provide a flame to light the main burner and another to heat the automatic pilot device flame sensor. Flame carryover between these ports takes place by a slot or small ports. The trend is toward a single pilot port, with a single flame serving both purposes.

Primary aerated pilots are subject to blocking of primary air openings by dust, dirt, or lint. A variation of the primary aerated pilot is the so-called incinerating-type pilot. In this design, primary air supply is drawn through a duct (tube)

and passes near the pilot flame to burn up any lint or dust in the air.

Non-Primary Aerated Pilot Burners

Non-primary aerated pilots have been developed to overcome service problems of pilot air openings blocked by dirt, dust or lint. Non-primary aerated, blue flame pilots, have no air mixed with the gas before it is burned on the pilot port.

This type of pilot may have a single port, or a number of ports. In either case, the gas flow through each port is low enough so that the pilot flame is essentially blue.

Target-type pilots, Figure 34, are designed so that the gas jet mixes with air in the open. The air-gas mixture burns when it strikes a target placed a short distance from the pilot orifice. In normal operation this type of pilot produces a hard blue pilot flame.

Fig. 34. Typical automatic pilot burners.

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V. BURNER ORIFICES

The main function of a burner orifice is to hold the burner gas input rate to a set level. Since modern appliances are designed to perform best at their rated inputs, this orifice function is very important.

TYPES OF ORIFICES

Three types of orifices are in general use. Each has a definite purpose. These are (1) fixed orifices; (2) adjustable orifices; and (3) universal orifices.

Fixed Orifices

Fixed orifices are the type most commonly used. They consist simply of a drilled opening in an orifice spud. The orifices can be made by drilling or by punching. Orifices are sometimes formed by laser piercing in materials which are difficult to drill or punch, such as sapphire.

There are various designs of fixed orifices. Inside the spud various angles of approach to the orifice are used. The ratio of the orifice diameter to its depth also differs among various orifice spud designs. Figure 35 illustrates five typical fixed orifice spuds.

Adjustable Orifices

Adjustable orifices are used chiefly in ranges. This type of orifice consists of two parts, one moving and one stationary. Figure 36 shows two types of adjustable orifices.

In the adjustable orifice shown on the left in Figure 36, a **needle** inside the orifice spud is stationary. The orifice, in a spud or hood, moves with respect to the needle. By moving the orifice hood closer or farther away from the tapered needle point, the area of the opening (orifice) is changed to adjust gas flow.

Fig. 35. Fixed gas orifices.

In the type of adjustable orifice shown on the right in Figure 36, the orifice spud is stationary. A movable needle is screwed into or out of the orifice opening to adjust the opening size. In either type orifice, gas rate can be adjusted from zero (with the needle tight against the orifice wall) to some full rate. Full rate is set by size of the wide open orifice and gas pressure upstream of the orifice.

Universal Orifices

Universal orifices are designed to operate with either natural gas or liquefied petroleum gas (LPG). They are used chiefly in ranges.

The universal orifice, Figure 37, is a combination of a fixed orifice and an adjustable orifice. The needle is fixed in position, while the orifice hood is free to move. The needle has an orifice drilled through it, sized for LP operation. To operate the range with LP gas, the orifice hood is screwed down until the tapered needle point completely blocks off the orifice in the hood. LP gas rate is set by size of the fixed orifice through the needle and the gas pressure. For natural gas operation, the orifice hood is screwed away from the needle. Gas flows through both the fixed orifice in the needle and through the opening between the shoulder or the needle and edge of the orifice in

the hood. With this arrangement, the natural gas rate is adjustable, while the LP rate is not. To adjust LP rate, the size of the orifice through the needle is changed, by either drilling out the pin orifice or by replacing the needle with one with a smaller orifice.

Orifice Discharge Coefficient (Orifice Constant)

Gas flow rate through an orifice depends basically on three things: (1) orifice size; (2) gas pressure forcing the gas through the orifice; and (3) specific gravity of the gas. With any two of the above factors held constant, a greater volume of gas will flow with: (1) a larger orifice; (2) higher gas pressure; and (3) a lower specific gravity gas.

Less gas always flows through an orifice than the theoretical amount. The actual amount is determined by some orifice spud design factors, such as the angle and shape of the approach in the spud to the orifice, and the depth of orifice with respect to its diameter. In addition, the gas jet tends to become smaller as it leaves the orifice, making the effective size of the orifice smaller.

The effects of all of these spud design factors have been lumped together into what is called the **orifice discharge coefficient**. This coefficient is always less

Fig. 36. Adjustable gas orifices.

than 1.0, which represents maximum possible or perfect flow conditions. The maximum flow multiplied by the orifice discharge coefficient equals actual flow of the gas.

The fixed orifices shown in Figure 35 have the following discharge coefficients: (I) 0.80; (II) 0.82; (III) 0.65 (IV) 0.83; and (V) 0.83. Note that all but one of these orifices have about the same coefficient. The coefficient for orifice III with a flat-bottomed approach hole is much lower than the others. With the same orifice size and gas pressure, gas flow through orifice III would only be about 80 percent of the flow through the other designs.

Ordinarily it is not necessary to be concerned with discharge coefficients when checking or adjusting an appliance. Charts and calculators used to select orifice size have already taken this factor into account. For most orifice spud designs, orifice sizes taken from these charts should give input rates very close to the desired rate. If an orifice must be replaced and only a flat-bottomed one (such as III in Figure 35) is on hand, the rate obtained may be low for the orifice size selected. If rate is not close enough to the desired rate, it may be altered by adjusting gas pressure slightly. If necessary, a larger or smaller orifice size can be used. In any case, if orifices in an appliance are changed rates should be checked by metering gas flow.

Orifice discharge coefficients for adjustable orifices tend to be lower than for fixed orifices. This does not usually present a problem since the burner rate can easily be changed by adjusting the hood or needle.

Measuring Gas Input Rates

Where practical, gas input rates of appliances should be checked by metering gas flow. To obtain an accurate check of rate for one appliance, all other gas appliances and pilots served by the meter should be turned off during the check. *All pilots must be relit after the measurement has been completed.*

If it is impractical to extinguish all the pilots on other appliances, input rates of burners can be measured by the difference method. The rate increase of total gas flow when a burner is turned on is measured.

As an example, suppose that all burners in a gas range are to be checked, such as four top burners and an oven broiler burner. The input rate with the broiler burner on is measured first. Then one of the top burners is turned on. The rate with the two burners operating is measured. The top burner rate is the difference between the two readings. This procedure can be followed for each of the remaining burners. Each

Fig. 37. Universal gas orifice.

time one additional burner is turned on the total rate of all burners operating is measured. The rate obtained with all the other burners operating is subtracted from the new total rate to get the rate of the last burner turned on. This procedure speeds up the measurement of rates for a number of burners with relatively small inputs. It also eliminates the effects of pilots and other gas using devices on the rate flow being metered.

For example, consider checking gas input rates of an oven broiler burner and top burners of a gas range. Suppose the rate with the oven broiler on is measured and found to be 22 cubic feet per hour. With the oven broiler burner still operating, a top burner is then turned on. The gas flow rate of the two burners is found to be 34 cubic feet per hour. The top burner rate is 12 cubic feet per hour ($34 - 22 = 12$). A second top burner is turned on and the total rate of the oven broiler burner and two top burners is found to be 43 cubic feet per hour. The rate of the second top burner is 9 cubic feet per hour ($43 - 34 = 9$). To finally measure the oven broiler rate, it is turned off when the other burners are operating. The reduction in total rate is the oven broiler rate.

Since only changes above a base of input are measured, it is not necessary to turn off all pilots and other appliances. If the oven broiler burner is kept on during the top burner measurements, it cannot be allowed to cycle on and off during the measurements. To be sure cycling does not take place, the oven door should be left open. Other appliances must either be shut off or set so that they do not cycle during the measurements.

This method of checking gas flow of several burners also can be worked in reverse. For example, to check rates of two range top burners and an oven broiler burner, all three burners are turned on. The rate of these three burners is metered and found to be 43 cubic feet per hour. One top burner is turned off. The total rate of the other top burner and oven broiler burner is found to be 34 cubic feet per hour. The rate of the top burner which had been turned off is 9 cubic feet per hour ($43 - 34 = 9$). All three burners are turned on to again obtain a rate of 43 cubic feet per hour. The second top burner is then turned off. The rate of the two remaining burners is observed to be 31 cubic feet per hour, giving a rate of 12 cubic feet per hour for the second top burner ($43 - 31 = 12$). The oven broiler burner rate of 22 cubic feet is found in the same way.

Measuring Gas Flow

Gas flow rate from a meter is calculated from the equation:

$$\text{Gas flow, cubic feet per hour} = \frac{(\text{cubic feet per revolution of meter dial}) \times 3600}{\text{time of one revolution of meter dial in seconds}}$$

The number 3600 converts seconds to hours.

For example, suppose a meter, Figure 38, is used which measures one-half cubic foot per revolution. The time for one revolution of the dial with a furnace operating is found to be 15 seconds. Gas flow rate of the furnace would be:

$$\begin{aligned} \text{Gas flow rate} &= \frac{0.5 \times 3600}{15} \\ &= 120 \text{ cubic feet per hour} \end{aligned}$$

If a meter having 2 cubic feet per revolution of the dial were used in the above example, time for one revolution of the dial would be 60 seconds. Gas flow rate of the furnace would be:

Gas flow rate

$$= \frac{2.0 \times 3600}{60}$$

$$= 120 \text{ cubic feet per hour}$$

Heat input rate is obtained by multiplying gas flow rate by the heating value of the gas. For the above example, the furnace rate (using 1000 Btu per cubic foot natural gas) would be 120,000 Btu per hour (120 x 1000).

Tables have been prepared so that the above equation is not needed to calculate metered gas flow rates. Table 2 lists gas input rates in cubic feet per hour for various times for one revolution of the meter dial with different size meters. One of these dial ranges appears on every meter.

Note that most of the gas flow rates in Table 2 are rounded off to the nearest whole cubic foot per hour. Times for a

revolution of the meter are rounded off to whole seconds. If the observed time falls between two times indicated, the rate can be estimated, using the two times on either side of the observed time.

Two examples will illustrate the use of Table 2. Suppose that a serviceman is checking the rate on a furnace. With a meter that has 5 cubic feet per revolution, he finds that the time for one revolution is 124 seconds. From Table 2 under the column for a 5 cubic foot meter dial, the rate for an observed time of 120 seconds is 150 cubic feet per hour. For 130 seconds flow rate is 138 cubic feet per hour. The difference between the two flow rates for this 10 second time interval is 12 cubic feet per hour (150 - 138 = 12). The observed rate is 4/10 or $[(124 - 120) \div 10]$ of this difference lower than the higher flow rate from Table 2, or 4.8 cubic feet per hour less (12 x 0.4). The rate is (150 - 4.8), or 145.2 cubic feet per hour. If the gas used has a heating value of 1000 Btu per cubic foot, input rate to the furnace is 145,200 Btu per hour (145.2 x 1000).

Fig. 38. Typical domestic gas meter index.

For a second example, suppose that a heater rated at 40,000 Btu per hour is being checked with a meter having 5 cubic feet per revolution. The lowest rate shown in Table 2 for a five-cubic-foot meter is 82 cubic feet per hour. Table 2 could be used directly if the time for only $1/5$ of a revolution of the five cubic foot meter were observed (that is, the time for one cubic foot). A more accurate determination of rate can be made by measuring the time for one complete revolution of the 5 cubic foot meter and dividing that time by 5. This calculation gives the time for one cubic foot. Flow rate then can be read from the one-cubic foot meter column of Table 2. For the 40,000 Btu per hour heater, for example, suppose the time for one revolution of the 5 cubic foot meter is observed to be 445 seconds. The time for one cubic foot of flow is $445 \div 5$ or 89 seconds. In the one cubic foot meter column of Table 2, a time of 88 seconds shows a rate of 41 cubic feet per hour. For 90 seconds, with the one cubic foot meter, flow is shown in Table 2 to be 40 cubic feet per hour. The rate for the measured seconds per cubic foot is halfway between these rates, or 40.5 cubic feet per hour. If the gas heating value is 1000 Btu per cubic foot, input rate to the heater is 40,500 Btu per hour (40.5×1000).

Measuring Gas Pressure

When installing and rating an appliance, it is often necessary to measure gas pressure in the manifold. Most appliances have a pressure tap in the manifold or in the last control valve before the orifices where tubing can be connected to make this measurement. When checking ranges, tubing can be slipped over one of the top burner orifice hoods and the valve opened to make pressure measurements.

Two devices commonly are used to measure gas pressure in an appliance. They are spring gauges and U-tube manometers. Bourdon tube gauges are the most common type of spring gauges. They have a hollow metal tube that is formed in a curve or arc. A pointer is connected to the closed end of the tube by means of levers. When pressure is applied through the open end of the tube, it tends to straighten out, moving the pointer along a round dial. Spring gauges are subject to mechanical damage and must be handled with care. They must also be checked for accuracy from time to time. The pressure gauge is connected to the manifold (or control) and the pressure is indicated directly on the dial. Note that this pressure is above atmospheric pressure. Depending on the pressure gauge, the reading may be expressed in pounds per square inch, ounces per square inch, or in **inches water column** (or **inches mercury column**).

Gas pressure in inches water column is read directly from the second type of pressure-measuring device — the manometer, illustrated in Figure 39. A manometer is simply a U-tube, made of a transparent material, such as glass. Both legs of the U-tube are filled about halfway with tap water. The water level in the manometer with both ends of the tube open to the atmosphere is the zero point.

When measuring gas pressure in an appliance, the tubing from the gas manifold (or control) is connected to one end of the U-tube and the other end of the tube is left open to the room. When gas pressure is applied to the manometer, the water in the gas side of the tube is pushed down, while the water on the open end side rises in the tube. The manometer then

indicates the gas pressure in inches water column that is, the height of a water column that the pressure will support with atmospheric pressure on top of the water column.

Usually a manometer is equipped with a scale (in inches) between two legs of the manometer, with the scale readings extending both above and below a zero point. The pressure reading is obtained by adding the height of water column above the zero point on one side to the height below the zero point on the other.

For example, in Figure 39, the left-hand picture shows zero (atmospheric) pressure on both sides of the manometer. The water level in both legs is at zero. The right-hand picture shows a pressure applied to the manometer. In the left leg of the manometer, the water column is 2 inches below the zero point, while in the right leg the water level is 2 inches below the zero point. The gas pressure being read is thus 4 inches water column ($2 + 2 = 4$).

Fig. 39. U-tube manometer.

It is convenient to initially line up the water level in the two legs of the manometer with zero on the scale with both ends of the tube open to atmospheric pressure. However, this condition is not necessary in reading the manometer. Simply observe the water level above the zero point on the scale in one leg and below the zero point in the other leg and add these two figures together. For example, if the water level in the left leg of the manometer shown in Figure 39 had been 2.5 inches above the scale zero and the water level in the right leg 1.5 inches below that zero point, the measured pressure still would be 4 inches water column ($2.5 + 1.5 = 4.0$). Pressure reading should always be taken with normal gas flow through the appliance.

Sizing Orifices for Desired Gas Flow Rates

Sometimes it is necessary to reorifice an appliance. Tables 3 and 4 have been prepared to give orifice sizes required for given input rates. Both of these tables apply only to appliances installed at elevations up to 2,000 feet.

Use Table 4 directly for propane, butane, or butane-propane mixtures to select an orifice size to obtain a given input rate. Note that the flow rates shown are only for a manifold pressure of **11 inches water column**. As an example of the use of Table 4, suppose that the input rate for an appliance burning butane is 150,000 Btu per hour at 11 inches water column gas pressure. Trace down Butane or Butane-Propane mixtures column of Table 4. A No. 29 DMS orifice gives 145,200 Btu per hour, and a No. 28 DMS orifice gives 152,500 Btu per hour. The larger orifice is used, since its calculated rate is closer to the desired rate of 150,000 Btu per hour.

Table 3 shows orifice sizes needed to obtain various gas flow rates (in cubic feet per hour) with gas pressures ranging from 3 to 10 inches water column. Note that Table 3 applies only to utility gases with a 0.60 specific gravity. For gases with specific gravities of 0.45 to 1.40, Table 5 must be used (along with Table 3) to select orifice sizes to obtain desired gas flow rates.

To use Tables 3 and 5 to select an orifice size, four things must be known; (1) the desired heat input rate in Btu per hour; (2) the heating value of the gas to be used in Btu per cubic foot; (3) the specific gravity of the gas to be burned; and (4) the gas pressure at the orifice in inches water column. If more than one burner is used, such as in a sectional furnace, input rate per burner must be obtained by dividing the appliance input rating by the number of burners.

Suppose that it is necessary to select orifice sizes for a 200,000 Btu per hour furnace using four burners. Gas heating value is 1000 Btu per cubic foot; gas specific gravity is 0.65; and gas manifold pressure is 4 inches water column. The desired input rate per burner is 50,000 Btu per hour ($200,000 \div 4$). Gas flow rate per burner is 50 cubic feet per hour ($50,000 \div 1000$).

Table 5 shows a factor of 0.961 for a 0.65 specific gravity gas. The desired gas flow rate of 50 cubic feet per hour is divided by this factor to obtain 52.0 cubic feet per hour ($50 \div 0.961$). This step gives the equivalent flow rate of a 0.60 specific gravity gas needed to use Table 3. Trace down the 4 inches water column gas pressure column in Table 3 to find the gas flow rate closest to 52.0 cubic feet per hour. With a No. 29 DMS orifice, flow rate is 49.95 cubic

feet per hour. With a No. 28 DMS orifice it is 53.38 cubic feet per hour. The No. 28 DMS orifice would be selected.

Tables 3 and 5 also can be used to estimate an appliance input rate when gas flow cannot be metered but the orifice size used is known. Suppose that gas input rate is to be estimated for a furnace using a single burner with a No. 8 DMS orifice. The utility gas being burned has a heating value of 1000 Btu per cubic foot and a 0.65 specific gravity. Gas pressure at the orifice is 4 inches water column.

First, find the gas flow rate for this furnace from Table 3 for a 0.60 specific gravity gas. Trace down the Orifice Size column of Table 3 to No. 8 DMS. Trace across this line to the Gas Pressure at Orifice column of 4 inches water column. A gas flow rate of 107.24 cubic feet per hour is obtained. This flow rate from Table 3 is only for a 0.60 specific gravity gas. In this example being used, specific gravity of the gas being burned is 0.65. Use Table 5 to find that the factor for 0.65 specific gravity gas is 0.961. Multiply the flow rate obtained from Table 3 by this factor to obtain flow rate with the 0.65 specific gravity gas. Gas flow rate to the furnace is 103.1 cubic feet per hour (107.24×0.961). With a heating value of 1000 Btu per cubic foot of gas, input rate to the furnace is 103,100 Btu per hour (103.1×1000).

Often the desired gas input rate may fall between two drill sizes in Table 3. One of the two orifice sizes may be selected. Best practice is to use the smaller size.

A misaligned orifice can spoil primary air injection. The orifice must be checked to see that there are no burrs,

since burrs may create a high pitched whistle as gas flows by them. If it is necessary to clean out a gas orifice, the hole must not be enlarged during the cleaning. A wood kitchen match or toothpick is a suitable cleaning tool.

If an orifice is found to be oversized, the best procedure is to replace the orifice spud with another spud with the correct size hole in it. If replacement is not possible, the orifice may be resized by peening the opening partially closed by striking the orifice spud face with a sharp tool at a series of points around the orifice. The orifice is then drilled out to the proper size. This method of reducing orifice size should be used only if it is not possible to replace the orifice. Alterations of an orifice must be done with utmost care. A poor job could ruin appliance performance or cause an unsafe condition. Pilot orifices should never be redrilled.

Sizing Inputs by Flame Spread Method

Sometimes it is not practical to meter gas flow rate. When adjustable orifices are used, gas input rate cannot be

estimated from orifice charts for fixed orifices. Under these conditions, it may be necessary to size gas input rates for burners by visual observation of the flames.

Size of burners and number of ports affect flame size. Length of flames on a large burner with many ports are shorter than those on a smaller burner with fewer ports, with both burners operating at the same gas input rate. The amount of primary air also affects visible flame length. The length of soft flames with a lower input rate can be greater than with the same burner operated at a higher input rate and with hard flames. Figure 40 shows this possibility.

The visual method of estimating gas input rate, or of adjusting a burner, is used most often for range top burners. Two things should always be remembered when using this method: (1) considerable experience on the part of the observer is necessary; and (2) the method cannot be considered precise even for an experienced observer.

Fig. 40. Sizing burner rates by flame size.

Compensation for Altitude on Setting Inputs

Atmospheric pressure decreases as the height above sea level increases. At any altitude above sea level, a cubic foot will contain less gas than a cubic foot at sea level. Thus, the heating value of a cubic foot of fuel gas will decrease as height above sea level increases. Specific gravity of a gas with respect to sea level, also decreases with altitude. These changes in heating value and specific gravity tend to offset each other. However, as elevation above sea level is increased, there is less oxygen per cubic foot of air. Therefore, heat input rate should be reduced in an appliance used at higher altitudes for satisfactory operation with this reduced oxygen supply.

Ratings specified by manufacturers for most appliances apply for elevations

up to 2000 feet. For elevations above 2000 feet, ratings should be reduced at the rate of 4 percent for each 1000 feet above sea level. For example, if a furnace is rated at 100,000 Btu at sea level, to rate the furnace at 4,000 feet, the original rating is multiplied by 0.96 four times (once for each 1,000 feet). The input rating at 4,000 feet then is $100,000 \times 0.96 \times 0.96 \times 0.96 \times 0.96 = 85,000$ Btu per hour. At 6,000 feet elevation, the furnace rating would be 78,300 Btu per hour.

Table 6 shows orifice sizes used if an appliance is to be operated at more than 2000 feet above sea level. Enter Table 6 with the orifice size used at sea level to find the required orifice size at other elevations. For example, suppose that No. 28 DSM orifices were used in a furnace at sea level. This furnace is to operate at 5,000 feet above sea level. Table 6 shows that orifice size should be reduced to No. 30 DMS.

VI. VENTING

One cubic foot of natural gas burned with just enough air for complete combustion produces eleven cubic feet of combustion products. This total includes 1 cubic foot of carbon dioxide and 2 cubic feet of water vapor formed in burning the gas. It also includes about 8 cubic feet of nitrogen which did not take part in the burning of each cubic foot of gas. In virtually all appliances, some excess air is used. This volume of excess air is added to the combustion products flowing from the flue outlet of the appliance. Provision is made in most appliances to remove these flue gases from the home, a process referred to as **venting**.

There are basically two types of venting: atmospheric (or gravity) and power venting. Power venting uses a mechanical device, such as a blower, to draw flue gases from the area being vented.

In atmospheric venting, hot flue gases from an appliance pass into a duct, flue pipe, vent, chimney or stack. These various terms mean about the same thing. Venting systems described by these terms differ chiefly in the way they are constructed. They operate in the same way in regard to venting. The term "gravity vent" will be used here to designate a non-powered venting system.

The driving force for a gravity vent stems from the fact that hot gases tend to rise in surrounding cooler air. Venting force is directly related to two factors: (1) the density of the hot gases in the

vent, which depends on average gas temperature in the vent; and (2) the height of the gravity vent. The hotter the gases in the vent and the higher the vent pipe, the greater will be the venting force. The greater the venting force, the greater will be the amount of secondary air which will flow through the appliance.

Range top burners do not have a vent pipe. However, the same principle of venting applies to them. With range top burners, the air around the burner flames is heated and rises since its density is decreased. This heated air is replaced by cooler air flowing upward through the air openings around the burner head.

It is important to understand this basic principle of gravity venting and its effects on the flow of air into the combustion zone of burners. Its practical use lies in dealing with burner problems stemming from poor venting conditions.

Flows of air into and combustion products out of an appliance must be reasonably close to those for which the unit was designed. Most important, enough air must be provided to assure complete combustion. On the other hand, the use of too much excess air can reduce heating efficiency of an appliance. Flue losses tend to increase as the amount of hot flue products passing out of the appliance increases.

A gravity vent pipe cannot be connected directly to the flue outlet of an

appliance. If it were, the amount of air drawn through the combustion chamber would vary with height of the vent pipe. Hence, there would be little or no chance of maintaining the same air flow rate through an appliance for the variety of installation conditions which might be encountered.

Equally or more important, gravity vents are exposed to outdoor winds. These winds can impose pressures at the terminal (exhaust end) of the vent, disturbing **natural draft**. If wind creates a negative pressure at the vent terminal, it will tend to increase the flow out of the terminal. This condition is referred to as an **updraft**. If a wind creates a positive pressure at the vent terminal, it will tend to restrict flow from the vent. This condition is referred to as a **downdraft** or backdraft.

The exception to these comments on gravity vents is the "balanced flue" or "sealed combustion" type of appliance. In these units, the inlet air is drawn from the outside at close to the same point as the flue exhaust leaves the vent terminal. Since wind effects act on both the air inlet and the exhaust outlet, at the same time they cancel out. Balanced flue appliances if properly designed are largely immune to wind effects.

To overcome wind effects, all vented domestic appliances, except for some types of incinerators, use a **draft hood** or draft diverter. Figure 41 shows four common types of draft hood designs.

These draft hoods all have an inlet opening, which is connected to the flue outlet of an appliance, and an outlet opening connected to the vent pipe. The

Fig. 41. Typical gas appliance drafthoods.

common feature of a draft hood by which it differs from other vent fittings is a **relief opening** exposed to the atmosphere. This relief opening usually is located somewhere above the burner level.

Figure 42 shows the operation of a typical draft hood under no-wind venting conditions, and with updraft and down-draft conditions. The amount of (1) flow of combustion products, (2) dilution air entering through the relief opening and (3) vent gases is indicated by the lengths of the arrows denoting those flows.

With normal venting some air is pulled into the draft hood by the natural draft action of the gravity vent. This air mixes with flue products from the appliance. The mixture of products of combustion from the appliance; excess air; and dilution air drawn into the vent through the draft hood relief opening, is referred to as vent gases. In a sense, the relief opening "breaks" the gravity vent system at the draft hood. In doing

so, it ideally minimizes changes in stack action during normal appliance operation.

Updraft in a vent may be increased, either by use of a higher stack or intermittently by the action of wind. When it is, more cool air is drawn through the relief opening into the stack. This action minimizes changes in air flow through the appliance in two ways. First, it cools down the temperature of the vent gases, reducing gravity stack action. Second, any increase in air flow through the gravity vent because of increased updraft is made up mostly by **dilution air** drawn into the stack through the relief opening, rather than through the appliance.

Under downdraft conditions, a draft hood acts to prevent the buildup of a positive pressure at the flue outlet of the appliances. Ideally, a draft hood maintains atmospheric pressure at the flue outlet of the appliance under down-draft conditions. The appliance continues

Fig. 42. Operation of a draft hood under various wind conditions.

to operate as though there were no downdraft. With a draft hood in place, an appliance can continue to operate under temporary downdraft conditions by venting out through the draft hood relief opening. The burner continues

to be supplied with enough air in spite of the downdraft. When the downdraft conditions cease, normal venting conditions resume. Normally these conditions are temporary and of short duration.

VII. BURNER PROBLEMS

Lifting Flames (Blowing Flames)

When lifting flames occur, part of the flame lifts or "dances" on the port. Lifting flames may occur on a few or all of the ports of a burner. Lifting burner flames result when the flow velocity of the air-gas mixture from a port exceeds the flame velocity. The flame cannot stabilize on or just slightly above the burner port, as in normal operation.

How to Recognize

Lifting flames rise from the ports to burn some distance above the port. In some cases, these flames will drop back to the port and lift again intermittently. If flames lift from a number of ports they may create a distinct flame noise.

Results of Lifting Flames

Lifting flames which create a roaring noise in an appliance can lead to a customer complaint. Of a more serious nature, products of incomplete burning may escape the flames if the flame cones break. Unburned gas also may escape, reducing appliance efficiency.

Corrections for Lifting Flames

The simplest way to stop burner flames from lifting is to reduce primary air. However before doing this check the

appliance input rate and reduce it if necessary. Lifting may be observed with only one of several burners in an appliance. Check the orifice size of that burner against the others to make sure the burner is not operating over rated input. When reducing primary air to prevent lifting flames, make sure yellow tipping does not occur.

Contamination of primary or secondary air by combustion products may cause flames to lift. A typical example of this condition is when oven combustion products leak into a range top burner box. Lifting of burner or pilot flames caused by contamination of secondary air is more likely to be a case of smothering of the flames because of a lack of enough air. In extreme cases this problem can cause simmer flame outages and top pilot outages. To cure this situation, eliminate any leakage of combustion products from an oven into the top section.

Flashback

How to Recognize Flashback

When flashback occurs in a burner the air-gas mixture ignites inside the burner to burn near the orifice. This burning in the mixer tube usually creates a roaring noise like a blowtorch.

Results of Flashback

Any flashback condition should be avoided. The burning action inside the

mixer tube does not get enough air. Combustion is incomplete and produces carbon monoxide and aldehydes. This incomplete burning also can produce free carbon (soot) which clogs the inside of the burner. Prolonged burning inside the burner can cause damage.

Corrections for Flashback

Flashback on ignition or during burner operation usually can be eliminated by reducing primary air to the burner. Make sure that the air adjustment does not produce yellow tipping of flames. The burner may be under rate, so check input rate and adjust it to its correct value if necessary. The orifice size may be enlarged, or gas pressure increased if rate is found to be too low. Sometimes only one burner of several in an appliance flashes back, such as in a multi-section furnace. Check the orifice size of that burner against those of the other burners. If flashback occurs with the burner valve in an off position, the valve probably is leaking. Repair the valve or replace it. Replace the burner, or burners, if the above corrections fail to eliminate flashback.

Extinction Pop (Flashback on Extinction)

How to Recognize Extinction Pop

Sometimes a small explosion of gas in the burner head occurs when the burner is shut off. Under these conditions, flashback on extinction has taken place. This problem is commonly called "extinction pop".

Extinction pop, as the name implies, creates a noise or a "bang". Ordinarily

it is not followed by burning in the burner head or mixer tube, since the gas supply is turned off. The pop occurs at the time the gas supply to the burner is shut off. Sometimes it may be delayed for a few seconds.

Results of Extinction Pop

Ordinarily, extinction pop is not unsafe nor hazardous, and will not damage the appliance. It may result in a customer complaint because of the noise created. However, the resultant concussion may blow out the pilot flame. If an automatic pilot safety device is used, it will act to shut off gas supply to the appliance.

Corrections for Extinction Pop

It may be possible to eliminate extinction pop by reducing primary air supplied to the burner. Make sure that this air adjustment does not cause yellow tipping during normal burner operation. It also may help to increase gas pressure and decrease gas orifice size. These changes provide a faster flow of the final air-gas mixture, and allow the air shutter to be closed more than with a larger gas orifice and lower gas pressure. If these actions fail to correct the problem, replace the burner.

Yellow Tipping (Yellow Flames)

How to Recognize Yellow Tipping

Bunsen-type flames should be completely blue. If not enough primary air is supplied yellow tips appear in the flames.

Do not confuse yellow tips with red or orange streaks which sometimes appear in flames. These color streaks usually are due to dust in the air supply and should create no problems. There also have been some reports of humidifiers, operating with softened water, causing orange flames on burners. The use of some tinted glasses, such as brazing goggles, will eliminate those discolorations from view, leaving true yellow tips still visible.

Results of Yellow Tipping

Yellow tipped flames indicate incomplete combustion in appliances designed for blue flame operation. This condition is aggravated if the flames impinge on cool surfaces. Yellow flames which produce soot (carbon) can be a nuisance. Sooting presents a serious

Fig. 43. Wavering flames caused by drafts.

problem if it collects to block flueways. Plugged flueways impede venting of combustion products and reduce the amount of air drawn into the combustion chamber. Incomplete combustion can then take place.

Corrections for Yellow Tipping

Yellow tipping is caused by a lack of enough primary air. This condition may be due simply to an incorrect air shutter adjustment. If this is the case, open air shutters to get rid of the yellow tips. Make sure that this added primary air does not cause lifting flames or flashback.

Lint and dust may block primary air openings, or collect inside the burner tube or on the underside of burner ports to reduce primary air injection, causing yellow tipping. If so, clean and readjust the burner.

A burner orifice spud out of line will reduce primary air injection. Faulty drilling or a dirty orifice can have the same effect. Check the orifice, clean it, realign it or replace it if necessary.

Fluctuating Flames

How to Recognize Fluctuating Flames

Length of burner flames may fluctuate or shorten over a period of time with no readjustments of the burner. This condition usually indicates a non-uniform gas pressure at the orifice.

Results of Fluctuating Flames

Fluctuating flames usually do not create any immediate problems, such as

incomplete combustion, unless flames impinge on cool surfaces. This condition should be corrected, however, since it warns of possible future problems.

Corrections for Fluctuating Flames

Unsteady gas pressures cause flames to fluctuate. Usually this condition indicates problems with the gas pressure regulator, the gas meter or other gas supply problems. Burner flames may shorten, with no change in gas pressure or primary air adjustment. Check the orifice for blockage by dust or dirt from supply lines. Very small pilot orifices are quite prone to blockage. Occasionally, too much grease in pilot valves restricts gas flow to pilot burners. Remove any excess greases.

Unstable or Wavering Flames

How to Recognize Wavering Flames

Drafts across burners may cause flames to waver or appear to be unstable, Figure 43. This condition should not be confused with lifting or floating flames.

Results of Wavering Flames

Wavering burner flames can lead to incomplete burning if flames impinge on cool surfaces. Pilot flames under drafts may go out, or they may be diverted from heating the sensing element of the automatic pilot device. In either case the automatic pilot will shut off gas supply to the appliance.

Corrections for Wavering Flames

Drafts affecting pilot flames may be simply external drafts, such as across

the floor. Protect the pilot flames with suitable baffles. Draft-blown main burner flames may indicate a more serious problem, such as a cracked heat exchanger. Replace or repair a cracked or defective heat exchanger without delay.

Floating Flames

How to Recognize Floating Flames

The difference between floating flames and lifting (or blowing) flames should be clearly understood. Both conditions are undesirable, but the causes and corrective steps are different in each case.

Lifting or blowing flames are well defined and **hard**, and may create a blowing noise. Cutting back on primary air usually stops flames from lifting.

Floating flames are lazy looking. They do not have well defined cones, and appear to be "reaching" for air. They are long, ill-defined, quiet flames which roll around in the combustion chamber sometimes completely off the ports. Usually

Fig. 44. Floating burner flames.

a strong aldehyde odor is present. Figure 44 illustrates floating burner flames.

Results of Floating Flames

Floating flames almost always indicate incomplete combustion. They point to a dangerous condition which requires prompt correction.

If secondary air supply is reduced too far burner flames will float. Combustion products above the burner recirculate lower in the chamber. These products contaminate the air supply, adding to the problem. Often an automatic pilot flame near the port level smothers and goes out. The pilot then acts to shut off the gas supply to the appliance. In doing so the pilot performs a useful service. The shutoff of gas stops further incomplete combustion. It also shows that there is a problem which should be corrected.

Corrections for Floating Flames

A lack of combustion air causes burner flames to float. Several conditions, or a combination of these conditions, can be the cause. The appliance may be overrated. If so, the flue outlet area provided for the rated input may be too small for the increased gas rate. Check appliance rate and reduce it if necessary.

Other conditions may cause poor venting and lead to floating flames. Soot or dust may be blocking flueways. Check flueways and clear any blockage found. Determine, if possible, the reason the flueways blocked up. Check for blockage of burners, and clean them if necessary. Adjust primary air to get rid of

any yellow tipping which may have produced soot to block the flueways. Make sure secondary air inlet openings are not blocked.

Reduced natural draft (venting) through an appliance may take place when it is operated from a cold start. Some floating flames may appear for a brief time until draft is established. When the appliance heats up it should operate in a normal manner.

Flame Rollout

How to Recognize Flame Rollout

When the condition known as flame rollout occurs, flames roll out of the combustion chamber openings when the burner is turned on. Figure 45 shows flame rollout.

Results of Flame Rollout

Flame rollout may create a fire hazard, or scorch appliance finishes, burn wire, or damage controls. The gas in the burner mixer may be ignited, producing flashback.

Corrections for Flame Rollout

Flame rollout is actually a variation of floating flames, with flames reaching for air outside the combustion chamber. Again, the basic cause is a lack of combustion air. This lack of air may be due to overrating of burners, poor draft or blockage in flueways. Apply the corrections for these problems listed earlier for floating flames.

Some appliances use step-type controls. These controls limit initial gas flow to the burner to establish natural

draft in the appliance before full gas rate is allowed to flow. Check the operation of this control, and replace the control if it is faulty.

Gas Odor at Primary Air Openings

Under normal burner operation, a negative pressure (vacuum) should exist inside the primary air openings of a burner, drawing in air. If all gas fed to the burner by the orifice does not flow to the burner head, some gas may spill from the primary air openings. If this condition is found, check the burner body for restrictions, and check the orifice to make certain it is not out of line.

Corrosion of Appliances

Gas appliances are designed and built to give long dependable service

life. In some installations recently, unusually severe corrosion has occurred resulting in customer complaints. This corrosion is attributed to the extensive use of aerosol propellants, hydrocarbons which contain the elements fluorine and chlorine. These elements are called halogens. Halogens in their free state are very corrosive.

When the propellants pass through a flame, they break down and the halogen gases are released. In combination with the water vapor in the flue gases they cause corrosion in heat exchangers, flueways and other appliance parts. Some of the worst cases of this corrosion have been in beauty shops where hair sprays are used and in dry cleaning plants where halogen-containing materials are used as cleaning fluids.

Fig. 45. Flame rollout. Insufficient primary air causes flames to "Roll Out" secondary air opening on start-up.

TABLE 1

Physiological Effect of Carbon Monoxide

Parts of Carbon Monoxide per Million Parts of Air	Percent Carbon Monoxide in Air	Effect
50 ¹	0.005	Concentration allowable for an exposure of eight hours.
400 to 500 ²	0.04 - 0.05	Concentration which can be inhaled for 1 hour without appreciable effect.
600 to 700 ²	0.06 - 0.07	Concentration causing a just appreciable effect after 1 hour of exposure.
1000 to 1200 ²	0.10 - 0.12	Concentration causing unpleasant but not dangerous symptoms after 1 hour of exposure.
1500 to 2000 ²	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.

Sources: 1 - Documentation of Threshold Limit Values, Revised Edition - 1966 - American Conference of Governmental Industrial Hygienists

2 - Gas Engineers Handbook - Industrial Press, Inc. - 1969

TABLE 2

Gas Input to Burner in Cubic Feet Per Hour

Seconds For One Revolution	Cubic Feet Per Hour			
	Size of Test Meter Dial			
	One-Half Cu.Ft.	One Cu.Ft.	Two Cu.Ft.	Five Cu.Ft.
10	180	360	720	1,800
11	164	327	655	1,636
12	150	300	600	1,500
13	138	277	555	1,385
14	129	257	514	1,286
15	120	240	480	1,200
16	112	225	450	1,125
17	106	212	424	1,059
18	100	200	400	1,000
19	95	189	379	947
20	90	180	360	900
21	86	171	343	857
22	82	164	327	818
23	78	157	313	783
24	75	150	300	750
25	72	144	288	720
26	69	138	277	692
27	67	133	267	667
28	64	129	257	643
29	62	124	248	621
30	60	120	240	600
31	58	116	232	581
32	56	113	225	563
33	55	109	218	545
34	53	106	212	529
35	51	103	206	514
36	50	100	200	500
37	49	97	195	486
38	47	95	189	474
39	46	92	185	462
40	45	90	180	450
41	44	88	176	440
42	43	86	172	430
43	42	84	167	420
44	41	82	164	410
45	40	80	160	400
46	39	78	157	391
47	38	77	153	383
48	37	75	150	375
49	37	73	147	367
50	36	72	144	360
51	35	71	141	353
52	35	69	138	346
53	34	68	136	340
54	33	67	133	333
55	33	65	131	327
56	32	64	129	321
57	32	63	126	316
58	31	62	124	310

TABLE 2 (Continued)

Seconds For One Revolution	Cubic Feet Per Hour			
	Size of Test Meter Dial			
	One-Half Cu.Ft.	One Cu.Ft.	Two Cu.Ft.	Five Cu.Ft.
59	30	61	122	305
60	30	60	120	300
62	29	58	116	290
64	29	56	112	281
66	29	54	109	273
68	28	53	106	265
70	26	51	103	257
72	25	50	100	250
74	24	48	97	243
76	24	47	95	237
78	23	46	92	231
80	22	45	90	225
82	22	44	88	220
84	21	43	86	214
86	21	42	84	209
88	20	41	82	205
90	20	40	80	200
94	19	38	76	192
98	18	37	74	184
100	18	36	72	180
104	17	35	69	173
108	17	33	67	167
112	16	32	64	161
116	15	31	62	155
120	15	30	60	150
130	14	28	55	138
140	13	26	51	129
150	12	24	48	120
160	11	22	45	112
170	11	21	42	106
180	10	20	40	100
190	9.5	19	38	95
200	9	18	36	90
210	8.5	17	34	86
220	8	16	33	82

Note: To convert to Btu per hour multiply by the Btu heating value of gas used.

TABLE 3

UTILITY GASES
(Cubic Feet Per Hour at 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)	Gas Pressure at Orifice - Inches Water Column								
	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	10.18	10.85	11.59	12.34	12.98
54	7.95	8.59	9.23	10.45	11.39	12.25	13.08	13.93	14.65
53	9.30	10.04	10.80	12.20	13.32	14.29	15.27	16.25	17.09
52	10.61	11.46	12.31	13.86	15.26	16.34	17.44	18.57	19.53
51	11.82	12.77	13.69	15.47	16.97	18.16	19.40	20.64	21.71
50	12.89	13.92	14.94	16.86	18.48	19.77	21.12	22.48	23.65
49	14.07	15.20	16.28	18.37	20.20	21.60	23.06	24.56	25.83
48	15.15	16.36	17.62	19.88	21.81	23.31	24.90	26.51	27.89
47	16.22	17.52	18.80	21.27	23.21	24.93	26.62	28.34	29.81
46	17.19	18.57	19.98	22.57	24.72	26.43	28.23	30.05	31.61
45	17.73	19.15	20.52	23.10	25.36	27.18	29.03	30.90	32.51
44	19.45	21.01	22.57	25.57	27.93	29.87	31.89	33.96	35.72
43	20.73	22.39	24.18	27.29	29.87	32.02	34.19	36.41	38.30
42	23.10	24.95	26.50	29.50	32.50	35.24	37.63	40.07	42.14
41	24.06	25.98	28.15	31.69	34.81	37.17	39.70	42.27	44.46
40	25.03	27.03	29.23	33.09	36.20	38.79	41.42	44.10	46.38
39	26.11	28.20	30.20	34.05	37.38	39.97	42.68	45.44	47.80
38	27.08	29.25	31.38	35.46	38.89	41.58	44.40	47.27	49.73
37	28.36	30.63	32.99	37.07	40.83	43.62	46.59	49.60	52.17

TABLE 3 (Continued)

Orifice Size (Decimal or DMS)	3	3.5	4	5	6	7	8	9	10
36	29.76	32.14	34.59	39.11	42.76	45.77	48.88	52.04	54.74
35	32.36	34.95	36.86	41.68	45.66	48.78	52.10	55.46	58.34
34	32.45	35.05	37.50	42.44	46.52	49.75	53.12	56.55	59.49
33	33.41	36.08	38.79	43.83	48.03	51.46	54.96	58.62	61.55
32	35.46	38.30	40.94	46.52	50.82	54.26	57.95	61.70	64.89
31	37.82	40.85	43.83	49.64	54.36	58.01	61.96	65.97	69.39
30	43.40	46.87	50.39	57.05	62.09	66.72	71.22	75.86	79.80
29	48.45	52.33	56.19	63.61	69.62	74.45	79.52	84.66	89.04
28	51.78	55.92	59.50	67.00	73.50	79.50	84.92	90.39	95.09
27	54.47	58.83	63.17	71.55	78.32	83.59	89.27	95.04	99.97
26	56.73	61.27	65.86	74.57	81.65	87.24	93.17	99.19	104.57
25	58.87	63.58	68.22	77.14	84.67	90.36	96.50	102.74	108.07
24	60.81	65.67	70.58	79.83	87.56	93.47	99.83	106.28	111.79
23	62.10	67.07	72.20	81.65	89.39	94.55	100.98	107.49	113.07
22	64.89	70.08	75.21	85.10	93.25	99.60	106.39	113.24	119.12
21	66.51	71.83	77.14	87.35	95.63	102.29	109.24	116.29	122.33
20	68.22	73.68	79.08	89.49	97.99	104.75	111.87	119.10	125.28
19	72.20	77.98	83.69	94.76	103.89	110.67	118.55	125.82	132.36
18	75.53	81.57	87.56	97.50	108.52	116.03	123.92	131.93	138.78
17	78.54	84.82	91.10	103.14	112.81	120.33	128.52	136.82	143.91
16	82.19	88.77	95.40	107.98	118.18	126.78	135.39	144.15	151.63
15	85.20	92.02	98.84	111.74	122.48	131.07	139.98	149.03	156.77
14	87.10	94.40	100.78	114.21	124.44	133.22	142.28	151.47	159.33
13	89.92	97.11	104.32	118.18	128.93	138.60	148.02	157.58	165.76
12	93.90	101.41	108.52	123.56	135.37	143.97	153.75	163.69	172.13
11	95.94	103.62	111.31	126.02	137.52	147.20	157.20	167.36	176.03
10	98.30	106.16	114.21	129.25	141.82	151.50	161.81	172.26	181.13
9	100.99	109.07	117.11	132.58	145.05	154.71	165.23	175.91	185.03
8	103.89	112.20	120.65	136.44	149.33	160.08	170.96	182.00	191.44
7	105.93	114.40	123.01	139.23	152.56	163.31	174.38	185.68	195.30
6	109.15	117.88	126.78	142.88	156.83	167.51	178.88	190.46	200.36
5	111.08	119.97	128.93	145.79	160.08	170.82	182.48	194.22	204.30
4	114.75	123.93	133.22	150.41	164.36	176.18	188.16	200.25	210.71
3	119.25	128.79	137.52	156.26	170.78	182.64	195.08	207.66	218.44
2	128.48	138.76	148.61	168.64	184.79	197.66	211.05	224.74	235.58
1	136.35	147.26	158.25	179.33	194.63	209.48	223.65	238.16	250.54
A	145.34	155.48	165.62	189.28	206.18	219.70	236.60	250.12	263.63
B	150.36	160.85	171.33	195.81	213.29	227.25	244.76	258.74	272.73
C	155.45	166.30	177.14	202.44	220.52	234.98	253.06	267.51	281.97
D	160.63	171.84	183.04	209.19	227.87	242.81	261.48	276.44	291.38
E	165.89	177.47	189.05	216.05	235.34	250.77	270.06	285.49	300.93
F	175.43	187.61	199.78	227.75	248.70	265.02	285.40	301.70	318.02
G	180.81	193.43	206.04	235.49	256.50	273.33	294.35	311.18	327.99
H	187.81	200.91	214.01	244.59	266.42	283.89	305.74	323.20	340.67
I	196.38	210.08	223.77	255.75	278.58	296.85	319.68	337.95	356.20
J	203.66	217.87	232.08	265.24	288.92	307.87	331.55	350.49	366.44
K	209.59	224.22	238.84	272.95	297.33	316.82	341.19	360.69	380.18
L	223.23	240.49	257.75	290.71	316.68	337.44	363.40	384.17	404.92
M	231.00	247.12	263.23	300.83	327.69	349.18	376.03	397.52	419.01
N	242.09	258.98	275.06	315.27	343.42	365.94	394.09	416.61	439.13
O	265.05	283.54	302.03	345.18	376.00	400.66	431.47	456.13	480.79
P	276.92	296.24	315.56	360.64	392.84	418.60	450.80	476.56	502.32
Q	292.57	312.98	333.39	381.03	415.05	442.26	476.28	503.49	530.71

TABLE 3 (Continued)

Orifice Size (Decimal or DMS)	3	3.5	4	5	6	7	8	9	10
R	305.03	326.33	347.62	397.26	432.73	461.10	496.59	524.95	553.32
S	321.45	344.01	366.57	418.62	456.01	485.91	523.28	553.19	583.09
T	340.19	363.92	387.65	443.04	482.59	514.24	553.79	585.44	617.09
U	359.46	383.54	409.61	468.14	509.93	543.36	585.17	618.60	652.04
V	377.26	403.58	429.90	491.31	535.17	570.27	614.14	649.23	684.33
W	395.48	423.07	450.66	515.05	561.04	597.83	643.82	680.60	717.39
X	418.34	447.53	476.72	544.82	593.47	632.39	681.03	719.94	758.86
Y	433.23	463.45	493.67	564.20	614.58	654.87	705.25	745.56	785.86
Z	452.75	484.33	515.91	589.64	642.26	684.38	737.02	779.14	821.26

TABLE 4

LP-Gases
(Btu Per Hour at Sea Level)

Btu per Cubic Foot =	<u>Propane</u> 2,500	<u>Butane</u> 3,175
Specific Gravity =	1.53	2.00
Pressure at Orifice, Inches Water Column =	11	11
Orifice Coefficient =	0.9	0.9
For altitudes above 2,000 feet, first select the equivalent orifice size at sea level from Table 6.		

Gas Input, Btu Per Hour For:		
Drill Size (Decimal or DMS)	Propane	Butane or Butane-Propane Mixtures
.008	500	554
.009	641	709
.010	791	875
.011	951	1,053
.012	1,130	1,250
80	1,430	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 4 (Continued)

Drill Size (Decimal or DMS)	Gas Input, Btu Per Hour For:	
	Propane	Butane or Butane-Propane Mixtures
44	58,050	64,350
43	62,200	69,000
42	68,700	76,200
41	72,450	80,200
40	75,400	83,500
39	77,850	86,200
38	81,000	89,550
37	85,000	94,000
36	89,200	98,800
35	95,000	105,300
34	97,000	107,200
33	101,000	111,900
32	105,800	117,000
31	113,200	125,400
30	129,700	143,600
29	145,700	163,400
28	154,700	171,600
27	163,100	180,000
26	169,900	187,900
25	175,500	194,600
24	181,700	201,600
23	186,800	206,400
22	193,500	214,500
21	198,600	220,200
20	203,700	225,000
19	217,100	241,900
18	225,600	249,800

TABLE 5
Factors For Utility Gases of Another Specific Gravity

Specific Gravity	Factor	Specific Gravity	Factor
0.45	1.155	0.95	0.795
0.50	1.095	1.00	0.775
0.55	1.045	1.05	0.756
0.60	1.000	1.10	0.739
0.65	0.961	1.15	0.722
0.70	0.926	1.20	0.707
0.75	0.894	1.25	0.693
0.80	0.866	1.30	0.679
0.85	0.840	1.35	0.667
0.90	0.817	1.40	0.655

To select an orifice size to provide a desired gas flow rate:

- (1) Obtain the factor for the known specific gravity of the gas from above.
- (2) Divide the desired gas flow rate by this factor, which gives the equivalent flow rate with a 0.60 specific gravity gas.
- (3) Using the gas flow rate obtained in (2), use Table 3 to select orifice size.

To estimate gas flow rate for a given orifice size and gas pressure when it is not possible to meter gas flow:

- (1) Use Table 3 to obtain equivalent gas flow rate with a 0.60 specific gravity gas.
- (2) Obtain the factor from Table 5 for the specific gravity of the gas being burned.
- (3) Multiply the rate obtained in (1) by the factor from (2) to estimate gas flow rate to the burner.

TABLE 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	10	11	12	13	13	15	16	17	18
9	11	12	12	13	14	16	17	18	19
10	12	13	13	14	15	16	17	18	19
11	13	13	14	15	16	17	18	19	20
12	13	14	15	16	17	17	18	19	20
13	15	15	16	17	18	18	19	20	22
14	16	16	17	18	18	19	20	21	23
15	16	17	17	18	19	20	20	22	24
16	17	18	18	19	19	20	22	23	25
17	18	19	19	20	21	22	23	24	26
18	19	19	20	21	22	23	24	26	27
19	20	20	21	22	23	25	26	27	28
20	22	22	23	24	25	26	27	28	29
21	23	23	24	25	26	27	28	28	29
22	23	24	25	26	27	27	28	29	29
23	25	25	26	27	27	28	29	29	30
24	25	26	27	27	28	28	29	29	30
25	26	27	27	28	28	29	29	30	30
26	27	28	28	28	29	29	30	30	30
27	28	28	29	29	29	30	30	30	31
28	29	29	29	30	30	30	30	31	31
29	29	30	30	30	30	31	31	31	32
30	30	31	31	31	31	32	32	33	35
31	32	32	32	33	34	35	36	37	38
32	33	34	35	35	36	36	37	38	40
33	35	35	36	36	37	38	38	40	41
34	35	36	36	37	37	38	39	40	42
35	36	36	37	37	38	39	40	41	42
36	37	38	38	39	40	41	41	42	43
37	38	39	39	40	41	42	42	43	43
38	39	40	41	41	42	42	43	43	44
39	40	41	41	42	42	43	43	44	44
40	41	42	42	42	43	43	44	44	45
41	42	42	42	43	43	44	44	45	46
42	42	43	43	43	44	44	45	46	47
43	44	44	44	45	45	46	47	47	48
44	45	45	45	46	47	47	48	48	49
45	46	47	47	47	48	48	49	49	50
46	47	47	47	48	48	49	49	50	50
47	48	48	49	49	49	50	50	51	51
48	49	49	49	50	50	50	51	51	52
49	50	50	50	51	51	51	52	52	52
50	51	51	51	51	52	52	52	53	53
51	51	52	52	52	52	53	53	53	54
52	52	53	53	53	53	53	54	54	54

TABLE 6 (Continued)

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
79	79	80	80	80	80	.013	.012	.012	.012
80	80	.013	.013	.013	.012	.012	.012	.012	.011

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3. *Gas Engineers Handbook*
Industrial Press, Inc., 2200 Madison Avenue
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GLOSSARY

ADJUSTABLE ORIFICE - (See Orifice)

AIR-GAS RATIO - The ratio of combustion air supply flow rate to the fuel gas supply flow rate.

AIR SHUTTER - An adjustable shutter on the primary air openings of a burner, which is used to control the amount of combustion air introduced into the burner body.

ALDEHYDE - A class of compounds, which can be produced during incomplete combustion of a fuel gas. They have a pungent distinct odor.

ATMOSPHERIC BURNER - (See Burner)

ATMOSPHERIC PRESSURE - The pressure exerted upon the earth's surface by the weight of atmosphere above it.

ATOM - The smallest unit of an element which retains the particular properties of that element.

AUTOMATIC GAS PILOT DEVICE - A gas pilot incorporating a device, which acts to automatically shut off the gas supply to the appliance burner if the pilot flame is extinguished.

BACKFIRE PROTECTION - (See Flash-back Arrestor)

BREAKER BOLT - (See Spoiler Screw)

BRITISH THERMAL UNIT - (Btu) - The quantity of heat required to raise the

temperature of one pound of fresh water one degree F.

BUNSEN-TYPE BURNER - A gas burner in which combustion air is injected into the burner by the gas jet emerging from the gas orifice, and this air is premixed with the gas supply within the burner body before the gas burns on the burner port.

BURNER - A device for the final conveyance of gas, or a mixture of gas and air, to the combustion zone. (See also specific type of burner).

1. **Injection Burner.** A burner employing the energy of a jet of gas to inject air for combustion into the burner and mix it with gas.

- a. **Atmospheric Injection Burner.**
A burner in which the air injected into the burner by a jet of gas is supplied to the burner at atmospheric pressure.

2. **Power Burner.** (See also Forced Draft Burner, Induced Draft Burner, Premixing Burner, and Pressure Burner). A burner in which either gas or air or both are supplied at pressures exceeding, for gas, the line pressure, and for air, atmospheric pressure.

3. **Yellow-Flame Burner.** A burner in which secondary air only is depended on for the combustion of the gas.

BURNER FLEXIBILITY - The degree to which a burner can operate with reasonable characteristics with a variety of fuel gases and/or variations in input rate (gas pressure).

BURNER HEAD That portion of a burner beyond the outlet of the mixer tube which contains the burner ports.

BURNER PORT - (See Port)

BURNING SPEED - (See Flame Velocity)

BUTANE - A hydrocarbon fuel gas heavier than methane and propane and a major constituent of liquefied petroleum gases (See).

COLORIMETRIC DETECTION DEVICE - A device for detecting the presence of a particular substance, such as carbon monoxide, in which the presence of that substance will cause a color change in a material in the detector.

COMBUSTION - The rapid oxidation of fuel gases accompanied by the production of heat or heat and light.

COMBUSTION AIR - Air supplied in an appliance specifically for the combustion of a fuel gas.

COMBUSTION CHAMBER - The portion of an appliance within which combustion normally occurs.

COMBUSTION PRODUCTS - Constituents resulting from the combustion of a fuel gas with the oxygen in air, including the inerts, but excluding excess air.

COMPOUND - A distinct substance formed by the chemical combination of two or more elements in definite proportions.

CONDENSABLE - A gas which can be easily converted to liquid form, usually by lowering the temperature and/or increasing pressure.

CONTROLS - Devices designed to regulate the gas, air, water or electricity supplied to a gas appliance. They may be manual, semi-automatic or automatic.

CUBIC FOOT OF GAS - (Standard Conditions). The amount of gas which will occupy 1 cubic foot when at a temperature of 60 F, and under a pressure equivalent to that of 30 inches of mercury.

DEAD SPACE - The short distance between a burner port and the base of a flame.

DENSITY - The weight of a substance per unit volume. As applied to gases, the weight in pounds of a cubic foot of gas at standard pressure and temperature.

DEWPOINT - The temperature at which a vapor will start to condense into its liquid form.

DILUTION AIR - Air which enters a draft hood and mixes with the flue gases.

DISCHARGE COEFFICIENT - The ratio of the actual flow rate of a gas from an orifice or port to the theoretical, calculated flow rate. Always less than 1.0.

DISTILLATION - Removal of gaseous substances from solids or liquids by applying heat.

D.M.S. - Drill Manufacturer's Standard - equivalent to Standard Twist Drill or Steel Wire Gage Numbers.

DRAFT HOOD - (Draft Diverter) A device built into an appliance, or made part of a vent connector from an appliance, which is 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.

DRILLED PORT BURNER - A burner in which the ports have been formed by drilled holes in a thick section in the burner head or by a manufacturing method which results in holes similar in size, shape and depth.

ELEMENT - One of the 96 or more basic substances of which all matter is composed.

EXCESS AIR - Air which passes through an appliance and the appliance flues in excess of that which is required for complete combustion of the gas. Usually expressed as a percentage of the air required for complete combustion of the gas.

EXTINCTION POP - (See Flashback)

FAHRENHEIT - The common scale of temperature measurement in the English system of units. It is based on the freezing point of water being 32 F and the boiling point of water being 212 F at standard pressure conditions.

FIXED ORIFICE - (See Orifice Spud)

FLAME ARRESTOR - (See Flashback Arrestor)

FLAME RETENTION DEVICE - A device added to a burner which aids in holding the flame base close to the burner ports.

FLAME ROLLOUT - A condition where flame rolls out of a combustion chamber when the burner is turned on.

FLAME VELOCITY - The speed at which a flame moves through a fuel-air mixture.

FLAMMABILITY LIMITS - The maximum percentages of a fuel in an air-fuel mixture which will burn.

FLASHBACK - An undesirable flame characteristic in which burner flames strike back into a burner to burn there or to create a pop after the gas supply has been turned off.

FLASHBACK ARRESTOR - A gauze, grid or any other portion of a burner assembly used to avert flashback.

FLASHTUBE - An ignition device, commonly used for igniting gas on range top burners. An air-gas mixture from the

burner body is injected into the end of a short tube. The mixture moves along the tube, is ignited by a standing pilot flame at the other open end of the tube and the flame travels back through the mixture in the flashtube to ignite the gas at the burner ports.

FLOATING FLAMES - An undesirable burner operating condition, usually indicating incomplete combustion in which flames leave the burner ports to "reach" for combustion air.

FLUE GASES, FLUE PRODUCTS - Products of combustion and excess air in appliance flues or heat exchangers before the draft hood.

FLUE LOSS - The heat lost in flue products exiting from the flue outlet of an appliance.

FLUE OUTLET - The opening provided in an appliance for the escape of flue gases.

FLUID - A gas or liquid, as opposed to a solid.

FORCED DRAFT BURNER - A burner in which combustion air is supplied by a fan or blower.

FUEL - Any substance used for combustion.

FUEL GAS - Any substance in a gaseous form when used for combustion.

HARD FLAME - A flame with a hot, tight, well-defined inner cone.

HEAT EXCHANGER - Any device for transferring heat from one fluid to another.

HEATING SURFACE - All surfaces which transmit heat from flames or flue gases to the medium being heated.

HEATING VALUE - The number of British thermal units produced by the complete combustion at constant pressure of one cubic foot of gas. Total heating value includes heat obtained from cooling the products to the initial temperature of the gas and air and condensing the water vapor formed during combustion.

HYDROCARBON - Any of a number of compounds composed of carbon and hydrogen.

IGNITION - The act of starting combustion.

IGNITION TEMPERATURE - The minimum temperature at which combustion can be started.

IGNITION VELOCITY - (See Flame Velocity)

IMPINGEMENT TARGET BURNER - A burner consisting simply of a gas orifice and a target, with the gas jet from the orifice entraining combustion air in the open and the mixture striking and burning on the target surface. No usual burner body is used.

INCHES OF MERCURY COLUMN - A unit used in measuring pressures. One inch of mercury column equals a pressure of 0.491 pounds per square inch.

INCHES OF WATER COLUMN - A unit used in measuring pressures. One inch of water column equals a pressure of 0.578 ounces per square inch. One inch mercury column equals about 13.6 inches water column.

INCOMPLETE COMBUSTION - Combustion in which the fuel is only partially burned.

INDUCED DRAFT BURNER - A burner which depends on draft induced by a fan or blower at the flue outlet to draw in combustion air and vent flue gases.

INERTS - Non-combustible substances in a fuel, or in flue gases, such as nitrogen or carbon dioxide.

INFRARED BURNER - (Radiant Burner). A burner which is designed to operate with a hot, glowing surface. A substantial amount of its energy output is in the form of infrared radiant energy.

INJECTION - Drawing primary air into a gas burner by means of a flow of fuel gas.

INPUT RATE - The quantity of heat or fuel supplied to an appliance, expressed in volume or heat units per unit time, such as cubic feet per hour or Btu per hour.

INPUT RATING - The gas - burning capacity of an appliance in Btu per hour as specified by the manufacturer. Appliance input ratings are based on sea level operation and need not be changed for operation up to 2,000 feet elevation. For operation at elevations above 2,000 feet, input ratings should be reduced at the rate of 4 percent for each 1,000 feet above sea level.

JET BURNER - A burner in which streams of gas or air-gas mixtures collide in air at some point above the burner ports and burn there.

LEAN MIXTURE - An air-gas mixture which contains more air than the amount

needed for complete combustion of the gas.

LIFTING FLAMES - An unstable burner flame condition in which flames lift or blow off the burner port(s).

LIQUEFIED PETROLEUM GASES - The terms "Liquefied Petroleum Gases", "LPG" and "LP Gas" mean and include any fuel gas which is composed predominantly of any of the following hydrocarbons, or mixtures of them: propane, propylene, normal butane or isobutane and butylenes.

LNG - Liquefied natural gas. Natural gas which has been cooled until it becomes a liquid.

LP GAS-AIR MIXTURES - Liquefied petroleum gases distributed at relatively low pressures and normal atmospheric temperatures which have been diluted with air to produce desired heating value and utilization characteristics.

LUMINOUS FLAME BURNER - (See Burner, Yellow Flame)

MANIFOLD - The conduit of an appliance which supplies gas to the individual burners.

MANIFOLD PRESSURE - The gas pressure in an appliance manifold, upstream of burner orifices.

MANUFACTURED GAS - A fuel gas which is artificially produced by some process, as opposed to natural gas, which is found in the earth. Sometimes called town gas.

METHANE - A hydrocarbon gas with the formula CH_4 , the principal component of natural gases.

MIXED GAS - A gas in which the heating value of manufactured gas is raised by co-mingling with natural or LPG (except where natural gas or LPG is used only for "enriching" or "reforming").

MIXER - That portion of a burner where air and gas are mixed before delivery to the burner ports.

1. **Mixer Face.** The air inlet end of of the mixer head.
2. **Mixer Head.** That portion of an injection type burner, usually enlarged, into which primary air flows to mix with the gas stream.
3. **Mixer Throat** (Venturi throat). That portion of the mixer which has the smallest cross-sectional area, and which lies between the mixer head and the mixer tube.
4. **Mixer Tube.** That portion of the mixer which lies between the throat and the burner head.

MOLECULE - The smallest portion of an element or compound which retains the identity and characteristics of the element or compound.

NATURAL DRAFT - The motion of flue products through an appliance generated by hot flue gases rising in a vent connected to the furnace flue outlet.

NATURAL GAS - Any gas found in the earth, as opposed to gases which are manufactured.

NEEDLE, ADJUSTABLE - A tapered projection, coaxial with and movable with respect to a fixed orifice used to regulate the flow of gas.

NEEDLE, FIXED - A tapered projection, the position of which is fixed, coaxial with an orifice which can be moved with respect to the needle to regulate flow of gas.

ODORANT - A substance added to an otherwise odorless, colorless and tasteless gas to give warning of gas leakage and to aid in leak detection.

ORIFICE - An opening in an orifice cap (hood), orifice spud or other device through which gas is discharged, and whereby the flow of gas is limited and/or controlled. (See also Universal Orifice)

Orifice Cap (Hood). A movable fitting having an orifice which permits adjustment of the flow of gas by changing its position with respect to a fixed needle or other device extending into the orifice.

Orifice Discharge Coefficient. (See Discharge Coefficient)

Orifice Spud. A removable plug or cap containing an orifice which permits adjustment of the gas flow either by substitution with a spud having different sized orifices (fixed orifice) or by motion of an adjustable needle into or out of the orifice (adjustable orifice).

OVERRATING - Operation of a gas burner at a greater rate than it was designed for.

PILOT - A small flame which is used to ignite the gas at the main burner.

PORT - Any opening in a burner head through which gas or an air-gas mixture is discharged for ignition.

PORT LOADING - The input rate of a gas burner per unit of port area, obtained by dividing input rate by total port area. Usually expressed in terms of Btu per hour per square inch of port area.

POWER BURNER - (See Burner)

PREMIXING BURNER - A burner in which all, or nearly all, combustion air is mixed with the gas as primary air.

PRESSURE BURNER - A burner in which an air and gas mixture under pressure is supplied, usually at 0.5 to 14 inches water column.

PRESSURE REGULATOR - A device for controlling and maintaining a uniform outlet gas pressure.

PRIMARY AIR - The combustion air introduced into a burner which mixes with the gas before it reaches the port. Usually expressed as a percentage of air required for complete combustion of the gas.

PRIMARY AIR INLET - The opening or openings through which primary air is admitted into a burner.

PROPANE - A hydrocarbon gas heavier than methane but lighter than butane. It is used as a fuel gas alone, mixed with air or as a major constituent of liquefied petroleum gases. (See).

QUENCHING - A reduction in temperature whereby a combustion process is retarded or stopped.

RADIANT BURNER - (See Infrared Burner)

RATE - (See Input)

REGULATOR - (See Pressure Regulator)

RELIEF OPENING - The opening in a draft hood to permit ready escape to the atmosphere of flue products from the draft hood in event of no draft, back draft or stoppage beyond the draft hood, and to permit inspiration of air into the draft hood in the event of a strong chimney updraft.

RICH MIXTURE - A mixture of gas and air containing too much fuel or too little air for complete combustion of the gas.

SECONDARY AIR - Combustion air externally supplied to a burner flame at the point of combustion.

SINGLE PORT BURNER - A burner in which the entire air-gas mixture issues from a single port.

SOFT FLAME - A flame partially deprived of primary air such that the combustion zone is extended and inner cone is ill-defined.

SOOT - A black substance, mostly consisting of small particles of carbon, which can result from incomplete combustion and appear as smoke.

SNG - Supplementary natural gas. Gases which are manufactured to duplicate natural gas.

SPECIFIC GRAVITY - Specific gravity is the ratio of the weight of a given volume of gas to that of the same volume of air, both measured at the same temperature and pressure.

SPOILER SCREW - (Breaker Bolt) A screw or bolt moved in or out of the gas jet in a burner to control primary air injection.

SPUD - (See Orifice)

STANDARD CONDITIONS - Pressure and temperature conditions selected for expressing properties of gases on a common basis. In gas appliance work, these are normally 30 inches of mercury and 60 F.

STATIC PRESSURE - The pressure exerted by a motionless gas.

TARGET BURNER - (See Impingement Burner).

THERM - A unit of heat energy equal to 100,000 Btu.

THROAT - (See Venturi)

TOTAL AIR - The total amount of air supplied to a burner. It is the sum of primary air, secondary air and excess air.

TOTAL PRESSURE - Also called impact pressure. The pressure measured in a moving fluid by an impact tube. It is the sum of the velocity pressure and the static pressure.

TOWN GAS - (See Manufactured Gas).

TURNDOWN - The ratio of maximum to minimum input rates.

ULTIMATE CO₂ - The percentage of carbon dioxide in dry combustion products when a fuel (gas) is completely burned with exactly the amount of air needed for complete combustion. This is the theoretical maximum CO₂ which can be obtained for a given gas in burning the gas in air.

UNIVERSAL ORIFICE - A combination fixed and adjustable orifice designed for the use of two different gases, such as LPG and natural gas.

UPDRAFT - Excessively low air pressure existing at the outlet of a chimney or stack which tends to increase the velocity and volume of gases passing up the stack.

UTILITY GASES - Natural gas, manufactured gas, liquefied petroleum gas-air mixtures or mixtures of any of these gases.

VELOCITY PRESSURE - Pressure exerted by a flowing gas by virtue of its movement in the direction of its motion. It is the difference between total pressure and static pressure.

VENT - A device, such as a pipe, to transmit flue products from an appliance to the outdoors. This term also is used to designate a small hole or opening for the escape of a fluid (such as in a gas control).

VENT GASES - Products of combustion from gas appliances plus excess air, plus dilution air in the venting system above a draft hood.

VENTURI - A section in a pipe or a burner body that narrows down and then flares out again.

VISCOSITY - The property of a fluid to resist flow.

WATER COLUMN - Abbreviated as W.C. A unit used for expressing pressure.

One inch water column equals a pressure of 0.578 ounces per square inch.

YELLOW FLAME BURNER - (See Burner)

YELLOW TIPS - (Yellow Tipping) The appearance of yellow tips in an otherwise blue flame, indicating the need for additional primary air.

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APPENDIX C

SCHEMATIC OF GAS FLOW FROM
NATURAL GAS WELL TO BURNER

NATURAL GAS

from the well to your burner

Diagram of a typical
natural gas flowpath--
from the filmstrip
"Natural Gas-science
behind your burner."

An educational service provided by
your Gas Company
in cooperation with the
American Gas Association

APPENDIX D

GLOSSARY*

APPLIANCE TYPES

- A. Range - A gas appliance for domestic food preparation providing the functions of (1) top or surface cooking, (2) oven cooking, and (3) broiling.
- B. Water Heater - A gas appliance for heating and storing water at a thermostatically controlled temperature for delivery on demand.
- C. Clothes Dryer - A gas appliance for drying wet laundry by means of heat derived from the combustion of fuel gases.
- D. Furnace - A gas appliance for heating air by transfer of heat of combustion through metal to air, and designed to supply heated air through ducts to spaces remote from the appliance location.
- E. Boiler - A gas appliance for supplying steam or hot water primarily intended for space heating application.
- F. Room Heater - A gas appliance for furnishing warm air to the space in which it is installed directly from the heater without duct connections.

AUTOMATIC GAS PILOT DEVICE

A gas pilot incorporating a device, which acts to automatically shut off the gas supply to the appliance burner if the pilot flame is extinguished.

- A. Aerated - (Primary-aerated) Pilots entrain air through air openings in the pilot body by the flow of gas through the pilot orifice. The resultant air-gas mixture burns on the pilot ports or slots. The primary air openings may or may not have protective screens, or air control shutters.

* Supplementary to Glossary in Appendix B

- B. Non-Aerated - (Non-primary aerated) Pilots do not mix any air with the gas before it issues from the pilot port (s) or slot (s) to burn. This type of pilot may use a single port or slot, or a number of ports.
- C. Target Pilots discharge a gas stream from an orifice, entraining air in the open. The air-gas mixture impinges and burns on a target or spreader located a short distance from the pilot orifice.
- D. Incinerating Pilots draw their primary air through a duct or tube past the pilot flame to incinerate any lint in the primary air. The air-gas mixture burns on the pilot ports or slots.

BURNER

A device for the final conveyance of gas, or a mixture of gas and air to the combustion zone. (See also specific type of burner.)

- 1. Injection Burner A burner employing the energy of a jet of gas to inject air for combustion into the burner and mix it with gas.
 - a. Atmospheric Injection Burner.
A burner in which the air injected into the burner by a jet of gas is supplied to the burner at atmospheric pressure.
- 2. Power Burner (Also Forced Draft Burner, Induced Draft Burner, Premixing Burner, and Pressure Burner) A burner in which either gas or air or both are supplied at pressures exceeding, for gas, the line pressure, and for air, atmospheric pressure.
- 3. Yellow-Flame Burner A burner in which secondary air only is depended on for the combustion of the gas.
- 4. Types of Burners
 - a. Drilled port burners have a number of separate, relatively small circular ports, made by drilling or punching.
 - b. Slotted port burners can take several forms. Bar type burners have a series of parallel slots across the top of the burner. These cross slots may be saw cuts in a cast burner body, or may be stamped or punched slots in a sheet metal burner body. Circular burners have a continuous

slotted port around the burner head. In this design, the slotted port is formed between the upper rim of an open burner head and the lower edge of a burner cap on top.

- c. Single port burners consist of an extension of the mixer tube with the gas burned on the end of a tube. A flame spreader is mounted above the port to spread the flame.
- d. Ribbon burners consist of alternate flat strips and corrugated strips of metal mounted alongside each other to form the ports. The ribbon assembly is mounted in an opening in the burner head.
- e. Target burners consist of a gas orifice and target mounted a fixed distance from the orifice. The gas jet emerges from the orifice and sweeps air in through the open space. The air-gas mixture impinges and burns on the target.
- f. Luminous flame burners do not mix any air with the gas before it issues from the ports.

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