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Forensic Engineering Analysis of Unvented Gas Appliances in High Altitudes

By James A. Petersen, PE (NAFE 631S)

Abstract

A family moves into a house about 4,000 feet above sea level. They use a refrigerator powered by LP gas. A short time after the refrigerator was installed, they notice and complain about smells and soot. They take their 9-month-old to a hospital in response to persistent crying. A short time later, they notify the refrigerator manufacturer, which examines and tests the refrigerator. They find the refrigerator's burner venturi blocked, generating high levels of carbon monoxide. Twelve years later, the parents bring a lawsuit against the installers of the refrigerator. At that time, the appliance is not available, and the house has been remodeled. A forensic engineering study is assigned to determine the effect high altitude has on this particular appliance design.

Keywords

CO, carbon monoxide, LP-gas, LPG, propane, refrigerator, high altitude, unvented appliance, derating

Introduction

This paper is a discussion of the generation of carbon monoxide (CO) from a naturally aspirated and unvented gas appliance (not derated) installed at a high altitude. The appliance type is a refrigerator, using a small LP-gas fueled flame to power an ammonia absorption system. **Figure 1** shows the subject model refrigerator and its gas train components.

CO is a product of incomplete combustion. Extended exposure above certain levels is toxic. **Figure 2** shows exposure limits from several sources; however, many variations are available. Most organizations agree that an 8-hour exposure of ~9 ppm is acceptable for most of the population.

Unvented gas appliances have low input (gas) ratings. They take combustion air from the living space and discharge their combustion products into that same space. Since the appliances have low gas usage, the amount of CO generated is usually not a health concern. For the most part, unvented heaters are a concern, but cooking appliances (and, in this case, refrigerators) would also be in this category of unvented gas appliances. For comparison, unvented heaters are rated at a maximum of 40,000 BTU/hr[1] while gas refrigerators are much lower. In this situation, they are rated at 2,200 BTU/hr. Gas refrigerators are used in recreational vehicles or remote locations where electricity is not available.

Figure 1
LP-gas refrigerator, front and back.
Lower photo shows gas train components.

James A. Petersen, PE, 1301 Spruce Street, Texarkana, TX 75501; (903) 793-8581; c3h8pete@gmail.com

Organization	Period	CO level	Notes
ASHRAE	8 hrs	9 ppm	From Standard 62.2-2013
USEPA	8 hrs 1 hr	9 ppm 35 ppm	NAAQS (outdoor air) NAAQS (outdoor air)
ACGIH	8 hrs	25 ppm	Threshold Limit Value (*)
NIOSH	8 hrs 15 min	35 ppm 200 ppm	Recommended Exp. Limit (*) Short-term Exposure Limit (*)
OSHA	8 hrs	50 ppm	Permissible Exposure Limit (*)
WHO	24 hrs 8 hrs 1 hr 15 min	6 ppm 9 ppm 30 ppm 87 ppm	indoor air indoor air indoor air indoor air
(*) above indicates a standard for an occupational situation			

Figure 2
Typical exposure duration chart.

Two lawsuits were brought by the homeowners. The first, which was later dismissed, was against the appliance manufacturer. A second lawsuit was brought 12 years later against the gas company that installed the refrigerator. In the period between the first and second lawsuit, the refrigerator was lost, and the residence was rebuilt.

Issues for the forensic engineer on the second case included unvented appliances in general, the derating of those appliances for altitude concerns, and the CO generated — if the appliance is not derated.

Background and Timeline

The family moved to a mountain state in July of 1992. There, they built a cabin in the hills at an altitude of about 4,280 feet above sea level. The cabin did not have running water or electrical service. **Figure 3** shows the cabin about two years after the exposure.

Figure 3
Family cabin about two years after the exposure.

Initially, the cabin was heated by kerosene heaters. This was later supplemented with a wood-burning stove. The family would crack the windows to ventilate the extra heat from the wood stove, and they cooked on an LP-gas oven/range. An LP-gas fuel refrigerator was installed in September of 1992. They would use a gas-powered generator to supply electricity for one to two hours in the evening.

The gas company serviced the refrigerator in October of 1992, answering a complaint about a smell and headaches. They cleaned soot from the refrigerator flue and advised the family to use it but shut it off if they smelled anything again. This refrigerator was swapped out for a new refrigerator about this time.

The mother took her infant son to the hospital in November of 1992 because he was waking up in the night crying. The hospital tested both mother and son for exposure to carbon monoxide and released them. They were advised to shut off the possible source of the CO, so they shut off the LP-gas refrigerator. No records of any hospital tests were available when the second lawsuit was filed. The possible sources of CO included:

- LP-gas fueled refrigerator, ~2200 BTU/hr, (0.86 SCFH), 700 BTU/hr pilot light
- The candles, lanterns (light)
- Kerosene heaters (rating/usage unknown)
- Wood-burning stove
  (removing combustion air from residence)
- LP-gas oven/range (rating/usage unknown)
- Gasoline-powered generator
  (outside, evening only — rating unknown)
- Vehicles

The general timeline is as follows:

- July 1992 — family moved into home the summer of 1992
- September 1992 — refrigerator installed
- October 1992 — complained of smell and soot

- October 1992 — refrigerator replaced, but smell/soot persisted

- November 1992 — 9-month-old infant taken to hospital concerning the crying
  - Hospital tested and released infant
  - Records not available

- March 1993 — initial lawsuit filed; refrigerator tested at residence by manufacturer's expert
  - ~3,500 ppm CO recorded at stack
    - before cleaning dog hair from venturi
    - ~4 minutes after startup
  - High reading after cleaning (shortly after)

- November 2005 — The author was retained on behalf of the appliance installer.
  - Subject refrigerator not available
  - Subject home substantially changed

Preliminary Investigation

In response to the initial lawsuit, the subject refrigerator was tested onsite by an expert for the refrigerator manufacturer. He first tested the refrigerator, as found, and recorded a high CO reading in the flue (~3,500 ppm). An examination revealed the venturi* was blocked with dog hair, and the vent was coated in soot. In addition, he determined the appliance had not been adjusted for high altitudes. He cleaned the venturi and vent, restarted the refrigerator, and recorded a CO reading of more than 2,000 ppm immediately after startup.

The discussion/negotiation between the plaintiff and refrigerator manufacturer is unknown. However, the third-party certification of the appliance design to a national standard (ANSI/AGA Z21.19, *Refrigerators Using Gas Fuel* [2]) was likely disclosed. The plaintiff's explanation was that the high CO reading, after cleaning, was due to the refrigerator not being derated for the altitude. The "as-found" CO reading was due to a lack of derating <u>and</u> the obstruction of the venturi.

The refrigerator manual included instructions for derating the refrigerator. These amounted to increasing the regulated pressure to the appliance†. Additionally, a high-altitude burner orifice (smaller diameter) was available, although not mentioned in the manual. These findings were apparently not disputed by the plaintiff's expert. The first lawsuit was dismissed.

Twelve years later, a lawsuit was filed against the gas company that had installed the refrigerator and did not derate the appliance for altitude. The plaintiff's expert had adopted the manufacturer's expert opinions and further opined that properly operating gas appliances would not generate any CO. He had not done any further testing or research. As mentioned above, the refrigerator was not available, and the residence had been rebuilt.

A literature search turned up the following related documents:

- *National Fuel Gas Code* NFPA 54 – ANSI/AGA Z223.1-1988 [3]

- National Propane Gas Association NPGA #404-1992; *Safety Warning for Operating and Servicing Propane Refrigerators* [4]

- Refrigerator literature

(All literature above circles back to NFPA 54.)

Litigation document production included sales and service records for the subject appliance. These verified that the refrigerator had not been derated for high altitude. NFPA 54, adopted as Code by the state, required that appliances be derated when installed above 2,000 feet per Code or per manufacturer's instructions.

***National Fuel Gas Code* NFPA 54 – ANSI/AGA Z223.1-1988**

"8.1.2 High Altitude. Ratings of gas utilization equipment are based on sea level operation and shall not be changed for operation at elevations up to 2,000 feet (600 m). For operation at elevations above 2,000 feet (600 m), equipment ratings shall be reduced at the rate of 4 percent for each 1,000 feet (300 m) above sea level before selecting appropriately sized equipment.

Exception: As permitted by the authority having jurisdiction."

* The venturi premixes air with the gas to a level below the flammable limit. Combustion occurs after the mixture exits the venturi and burner.

† Initially, this is counterintuitive because increased pressure would result in higher gas flow. The resulting increase in gas velocity; however, draws more air into the venture, diluting the mixture.

Manufacturer's Instructions Regarding Altitude

"...The specified fuel is propane, and the supply pressure is 11 inches of water column at sea level. At higher altitudes, we recommend that the pressure be increased according to the following table:"

ALTITUDE	PRESSURE
0' – 3,280'	11" WC
3,280' – 6,560'	11.8" WC
6,560' – 9840'	13" WC

From a technical (FE) perspective, this second lawsuit did not appear to have a great deal of merit because the subject appliance was identical to the refrigerators in recreational vehicles. These RVs regularly travel to altitudes beyond 4,300 feet and have no instructions regarding derating of any of the appliances. Nevertheless, since the injured party was young, a Code violation existed, and CO poisoning was vaguely familiar to the general public, the client decided to develop information that could be used for this and future cases. The information could be general in nature or specific to the matter at hand. This would include the effect of altitude on CO generation, unvented appliances, and the derating of appliances for altitude.

Basic subjects (questions) were developed to focus the work for this matter:

- How does altitude affect CO production in general?
- How does altitude affect CO production for this particular appliance?
- How does clogging of the venturi on this appliance affect CO production?
- What was the dilution of CO due to normal ventilation of the residence?
- Why was the CO reading so high after cleaning of the subject appliance?

How Does Altitude Affect CO Production in General?

NFPA 54 is rather specific in its formula for derating naturally aspirated appliances: 4% for each 1,000 feet above sea level (after 2,000 feet). This requirement is independent of the appliance type of or its native rating. The requirement had been in NFPA 54 for decades and likely supported by testing; however, that information was not discovered.

Instead, it was decided to conduct testing at various altitudes to obtain data for CO production. Few areas offer the range of altitudes that would allow tests to be conducted and limit variations due to local weather. The Big Island of Hawaii is one of those locations — where 0 to 6,300 feet above sea level is easily realized, and 0 to 9,000/13,000 feet above sea level is possible. Here, tests were conducted at 0, 2,000, 4,000, and 6,300 feet above sea level. A small butane stove was used for the tests, primarily because it was easily moved between tests. **Figure 4** shows the Big Island with test locations.

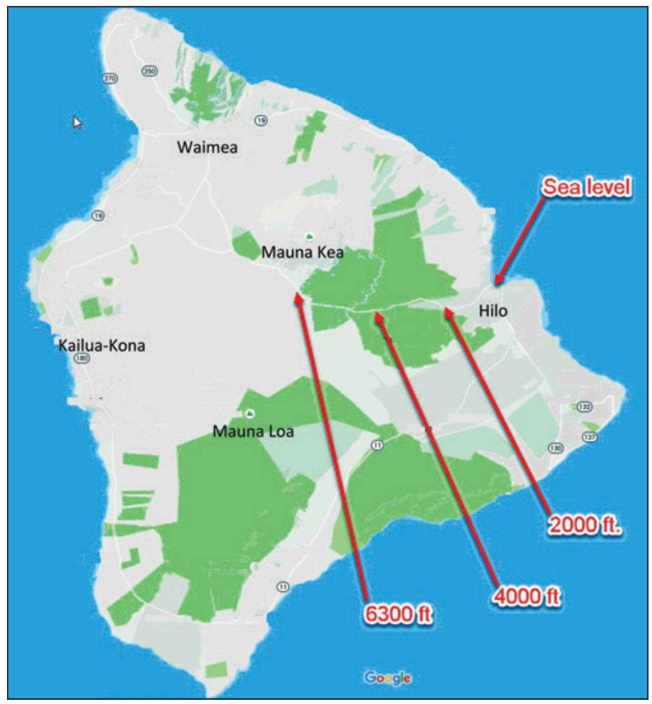

Figure 4
Island of Hawaii, showing test locations.

The methodology followed a field test developed by R. J. Karg and Associates [5]. This procedure was developed, reflecting the requirements for ANSI/CSA Z21.1-2012, *Household Cooking Gas Appliances* [6]. The stove was operated on high for ~5 minutes before collecting the sample so that a "steady-state" mixture would be realized. The combustion products were collected in a 9-inch flower pot, rather than a "hot pot" in the Karg protocol [7]. Combustion products were collected in a bag and analyzed with a standard CO monitor. The results were measurable — ranging from 13 to 28 ppm — and were repeatable, going up and down the mountain. The test setup and results are shown in **Figure 5**.

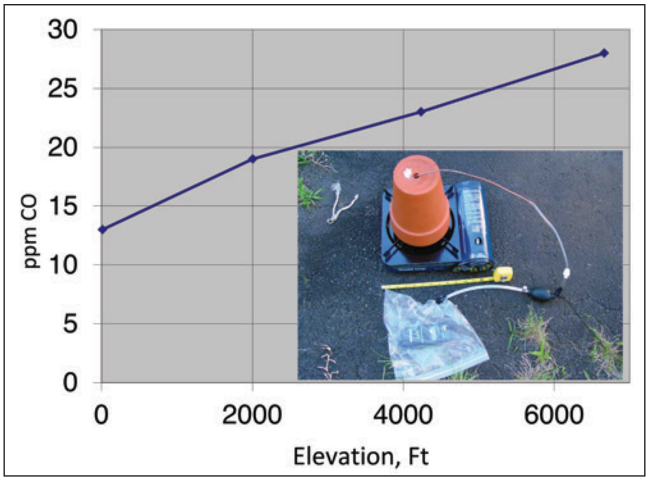

Figure 5
Test setup and chart, showing recorded CO values.

How Does Altitude Affect CO Production for This Particular Appliance?

An exemplar refrigerator was obtained, along with a high-altitude orifice. The refrigerator was mounted in a covered trailer so that it could be easily transported to a high altitude site. A combustion gas analyzer was also obtained to sample directly from refrigerator's flue (a Testo model 325XL). This gas analyzer reports CO content (O_2%, CO_2%) and temperature as well as other values.

Tests were conducted at Texarkana, TX (~280 feet) and Clovis, NM (~4300 feet). Test variables included gas supply pressure and venturi obstruction. The high altitude tests added the high altitude orifice. Results of those tests are shown in Appendices A and B. At low altitude, the CO recorded was quite low until the venturi was fully obstructed. The tests at the higher altitude were higher but still nominal until the venturi was fully obstructed. **Figure 6** shows the rear of the refrigerator and test equipment.

What Was the Dilution of CO Due to Normal Ventilation of the Residence?

The CO readings from the tests above were taken from the flue of the refrigerator. The combustion products included some amount of excess air. This excess air is necessary to ensure complete combustion and eliminate sooting. Once these combustion products leave the flue of the refrigerator, they dilute further with the air in the residence.

To determine the CO content in the living space, the undiluted CO from the flue analysis must be determined. This, in combination with the appliance rating, residence volume, and residence ventilation, can be used to determine the CO exposure.

Figure 6
Rear of refrigerator, sample location and test equipment.

Note: It would have been easier to simply operate the subject appliance as installed in the home and record the ambient CO. Since this is not possible, the flue analysis is needed to model the CO exposure.

The author started with the basic combustion equation for propane:

$$C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$$

Considering the nitrogen content in air:

$$C_3H_8 + 5\ O_2 + 20\ N_2 \rightarrow 3\ CO_2 + 4\ H_2O + 20\ N_2$$

The volumetric relationship for this expanded equation:

$$1 + 5 + 20 \rightarrow 3 + 4 + 20 = 27$$

Burning 1 cubic foot of propane results in 27 cubic feet of combustion products. This relationship is needed to relate the appliance rating to the volume of combustion products exhausted. For propane, 1 cubic foot of gas at standard temperature and pressure is about equal to 2,500 BTU. The orifice for the tested refrigerator flowed, by test, at 0.869 SCFH at 11 in. WC. A higher pressure of 13 in. WC would have resulted in a flow rate of 0.945 SCFH‡.

The CO content is not significant in this combustion equation, being in the order of parts per million. From the flue analysis, the undiluted CO content can be calculated, using the CO reading and the O_2% content:

$$CO_{\text{undiluted}} = (20.9/(20.9 - O_2\%))\times CO_{\text{ppm}}$$

The results of these calculations are shown in Appendices A and B; e.g., an analysis of 5 ppm CO with a 10.3% O_2 content would result in an undiluted 11 ppm, (App. A, top line)§.

The living area volume was calculated from measurements taken by the initial investigators. To be conservative — and eliminate arguments over closed doors impeding mixing — only the common area of the kitchen and living room was calculated. The volume for these two rooms was ~3800 ft^3. Additionally, the refrigerator was assumed to be running continuously.

For this 3800 ft^3 living area, some amount of air changes per hour (ACH) had to be assumed. These values may range from 0.5 for a very tight construction to 1.25 for a very loose construction. Based on the testimony and production, an ACH value of 1.0 was assumed for the model.

Knowing the flue flow rate (FFR), undiluted CO, interior volume (IV) and air changes per hour (ACH), the CO in the living area could be calculated as follows:

$$CO_{\text{living area}} = CO_{\text{undiluted}}\times\left(\frac{FFR}{ACH\times IV}\right)$$

The calculated levels of CO in the living area are shown in Appendices A and B. Values of less than 0.5 ppm are shown as "0."

The calculated values also assume the appliance would be operating continuously — a conservative assumption. Operating at some lower duty cycle would result in lower CO values.

Why Was the CO Reading So High After Cleaning of the Subject Appliance?

High CO readings, especially those beyond the specified range for the instrument, can saturate the sensor. The instrument must be purged with fresh air to "zero" it out. This purging process can take several minutes and is not well discussed in the instrument manuals. For normal technician work, this is not an issue because they operate at relatively low values, allowing the instrument to recover quickly.

At the initial inspection and test, the best explanation for the high readings after the venturi was cleaned is that the instrument was not zeroed out. The initial high reading may have been taken before the appliance had warmed up, creating a higher-than-normal amount of CO.

Opinions and Conclusions

After this testing and analysis, this author developed the following opinions:

- The refrigerator will generate CO, regardless of altitudes, orifices, or pressures at issue in this matter**.
- For this model refrigerator, the levels of CO generated at ~4,000 feet above sea level are not excessive.
- The CO readings measured in the earlier test by others were not due to a failure to derate the refrigerator.
- The CO readings, measured in the earlier test by others, would have been substantially reduced when diluted by the volume of the kitchen and living room.
- The failure to derate the refrigerator did not appreciably contribute to an increased generation of CO.

The matter settled soon after, and the details were not disclosed.

‡ At low pressures, the flow rate through an orifice is a function of the square root of the differential pressure. See Appendices A and B for other flow rates.

§ The Testo model used would calculate undiluted CO automatically.

** ANSI Z21.19, Section 2.4 permits a maximum of 0.03% (or 300 ppm) carbon monoxide in an air free (undiluted) sample of the flue gases.

This paper is not intended to suggest that gas appliances should not be derated for altitude. The lack of adjustment in this matter was not proximate to the generation of an abnormal amount of CO. In investigating CO incidents, it would be preferable to test the subject appliance in its "as-found" condition and settings[8]. Vented appliances may have different results. Variations of the methods described may be used to test other gas appliances. Finally, don't ignore other potential CO contributors.

References

1. ANSI/CSA Z21.11.2-2013. Gas-fired room heaters, volume II, unvented room heaters. Washington DC; American National Standards Institute.

2. ANSI/AGA Z21.19-1990. Refrigerators using gas fuel. Washington DC; American National Standards Institute.

3. ANSI/AGA Z223.1-1988. National fuel gas code. Quincy, MA; National Fire Protection Association.

4. NPGA #404-1992. Safety warning for operating and servicing propane refrigerators. Washington DC; National Propane Gas Association.

5. Field protocol for gas range carbon monoxide emissions testing. For the Chicago Regional Diagnostics Working Group; July 2001. http://www.karg.com/pdf/CO_Field_Protocol_annotated.pdf

6. ANSI/CSA Z21.1-2012. Household cooking gas appliances. Washington DC; American National Standards Institute.

7. RJ Karg Associates/WxWare Diagnostics. CO hot pot assembly instructions. Topsham, MA. http://www.karg.com/pdf/CO%20Hot%20Pot/CO_Hot_Pot_Assembly_Instructions.pdf

8. ASTM E2292-2014. Standard guide for field investigation of carbon monoxide poisoning incidents. West Conshohocken, PA; ASTM International.

Appendix A

Gas Refrigerator Test
Model XXXXX; Fabricated 9-11-2004
7-Sep-06
Texarkana, TX; 280 feet above sea level
Barometric pressure; 29.98 → 29.96

Venturi port condition	Reg. Input Press.	Orifice[4]	Calibrated Orifice Flow @ 11" WC	Actual Orifice Flow @ Actual press.[1]	Flue Temp.	Amb. Temp	O_2	CO (diluted)	CO_2	CO af (undiluted)[2]	Undiluted flow rate into area[3]	Equivalent CO diluted in 3837 FT3/HR
	IN WC	ID	SCFH	SCFH	°F	°F	%	ppm	%	ppm	SCFH	ppm*
Clear	11.0	370	0.869	0.869	304.5	68	10.3	5	7.1	**11**	23.5	0
Clear	10.5	370	0.869	0.849	322.6	68	10.4	5	7	**10**	22.9	0
Clear	10.0	370	0.869	0.829	323.4	68	10.8	5	6.7	**10**	22.4	0
1/2 clogged	11.0	370	0.869	0.869	333.5	68	9.7	4	7.4	**7**	23.5	0
1/2 clogged	10.5	370	0.869	0.849	345.2	68	9.5	4	7.5	**8**	22.9	0
1/2 clogged	10.0	370	0.869	0.829	366.1	68	9.5	4	7.5	**8**	22.4	0
Fully clogged	11.0	370	0.869	0.869	342.6	68	7.9	508	8.6	**814**	23.5	5
Fully clogged	10.5	370	0.869	0.849	308.5	68	8.3	241	8.3	**400**	22.9	2
Fully clogged	10.0	370	0.869	0.829	291.1	68	7.8	355	8.7	**563**	22.4	3

[1]Actual flow = Calibrated flow x $SQRT(P_{act.}/P_{cal.})$
[2]$CO_{af} = CO \times 21 \div (21 - O_2)$
[3]This flow rate is 27 times the actual propane input in SCFH
[4] Orifice marked '370' is the standard orifice.

*Kitchen & living room volume @ 1 change per hour
'0' ppm means less than 0.5 ppm

Mass equations:

$C_3H_8 + 5\,O_2 \longrightarrow 3\,CO_2 + 4\,H_2O$ — Basic combustion equation

$C_3H_8 + 5\,[O_2 + 4\,N_2] \longrightarrow 3\,CO_2 + 4\,H_2O$ — Basic equation considering nitogen content in air

$C_3H_8 + 5\,O_2 + 20\,N_2 \longrightarrow 3\,CO_2 + 4\,H_2O + 20\,N_2$ — Expanded basic equation

Volumetric relationship:

$C_3H_8 + 5\,O_2 + 20\,N_2 \longrightarrow 3\,CO_2 + 4\,H_2O + 20\,N_2$ — Expanded basic equation

$1 + 5 + 20 \longrightarrow 3 + 4 + 20 = 27$ (26 cubic feet of fuel plus air yields 27 cubic feet of combustion products)

E.G. Burning 1 cubic foot of propane yields 27 feet of undiluted flue gas

Appendix B

Gas Refrigerator Test
Model XXXXX; Fabricated 9-11-2004
16-Jul-06
Clovis, NM; 4300 Feet above sea leval
Barometric pressure; 26.13 → 26.07

Venturi port condition	Reg. Input Press. IN WC	Orifice[4] ID	Calibrated Orifice Flow @ 11" WC SCFH	Actual Orifice Flow @ Actual press.[1] SCFH	Flue Temp. °F	Amb. Temp °F	O_2 %	CO (diluted) ppm	CO_2 %	CO af (undiluted)[2] ppm	Undiluted flow rate into area[3] SCFH	Equivalent CO diluted in 3837 FT3/HR ppm*
Clear	11.0	370	0.869	0.869	173.7	91.3	7.4	7	8.9	**11**	23.5	0
Clear	11.8	370	0.869	0.900	189.0	91.3	6.9	8	9.3	**11**	24.3	0
Clear	13.0	370	0.869	0.945	195.7	91.3	6.0	9	9.8	**13**	25.5	0
1/2 clogged	11.0	370	0.869	0.869	197.1	91.3	6.8	12	9.3	**17**	23.5	0
1/2 clogged	11.8	370	0.869	0.900	209.9	91.3	6.1	7	9.8	**10**	24.3	0
1/2 clogged	13.0	370	0.869	0.945	219.3	91.3	5.8	9	10	**13**	25.5	0
Fully clogged	11.0	370	0.869	0.869	212.7	91.3	6.4	1739	9.6	**2501**	23.5	15
Fully clogged	11.8	370	0.869	0.900	211.6	91.3	5.2	2584	10.4	**3440**	24.3	22
Fully clogged	13.0	370	0.869	0.945	203.5	91.3	3.0	>4000	11.9	**>4000**	25.5	>27
Clear	11.0	382	0.623	0.623	214.6	95.2	7.9	7	8.6	**11**	16.8	0
Clear	11.8	382	0.623	0.645	274.4	95.2	7.7	8	8.8	**12**	17.4	0
Clear	13.0	382	0.623	0.677	280.1	95.2	6.5	8	9.6	**11**	18.3	0
1/2 clogged	11.0	382	0.623	0.623	296.6	95.2	16.6	2	2.9	**10**	16.8	0
1/2 clogged	11.8	382	0.623	0.645	306.4	95.2	9.6	6	7.5	**12**	17.4	0
1/2 clogged	13.0	382	0.623	0.677	334.6	95.2	7.3	15	9	**24**	18.3	0
Fully clogged	11.0	382	0.623	0.623	328.7	95.2	9.2	743	7.8	**1317**	16.8	6
Fully clogged	11.8	382	0.623	0.645	294.5	95.2	8.2	1079	8.4	**1777**	17.4	8

[1]Actual flow = Calibrated flow x SQRT($P_{act.}/P_{cal.}$)
[2]CO_{af} = CO x 21 ÷ (21 – O_2)
[3]This flow rate is 27 times the actual propane input in SCFH
[4] Orifice marked '370' is the standard orifice. CR-212-1M is marked '382'

*Kitchen & living room volume @ 1 change per hour
'0' ppm means less than 0.5 ppm

Mass equations:

$C_3H_8 + 5\,O_2 \longrightarrow 3\,CO_2 + 4\,H_2O$ Basic combustion equation

$C_3H_8 + 5\,[O_2 + 4\,N_2] \longrightarrow 3\,CO_2 + 4\,H_2O$ Basic equation considering nitogen content in air

$C_3H_8 + 5\,O_2 + 20\,N_2 \longrightarrow 3\,CO_2 + 4\,H_2O + 20\,N_2$ Expanded basic equation

Volumetric relationship:

$C_3H_8 + 5\,O_2 + 20\,N_2 \longrightarrow 3\,CO_2 + 4\,H_2O + 20\,N_2$ Expanded basic equation

$1 + 5 + 20 \longrightarrow 3 + 4 + 20 = 27$ (26 cubic feet of fuel plus air yields 27 cubic feet of combustion products)

E.G. Burning 1 cubic foot of propane yields 27 feet of undiluted flue gas