# COMMERCIAL COOKING APPLIANCES:

# MOVING TOWARDS THE FUTURE

Craig A. Farnsworth and Robert L. Himmel
American Gas Association Laboratories

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## ABSTRACT

The Research Department of the American Gas Association Laboratories under Gas Research Institute sponsorship is actively involved in improving the efficiency of natural gas-fired commercial cooking equipment. This paper discusses the results from these efforts conducted with participating manufacturers over the past nine years.

Three high efficiency appliances were developed that have had a significant impact in the marketplace. Energy consumption was reduced by at least 40 percent by; 1) modifying a standard convection oven, 2) modifying range ovens to operate as direct-fired convection ovens, and 3) applying infrared burners to a deep fat fryer.

Currently, work is underway to apply pulse combustion to a deep fat fryer and a griddle. Also, the efficiency of an open top range has been improved by applying a power burner system. The pulse combustion deep fat fryer has demonstrated a 50 percent reduction in energy consumption over conventional immersion tube type fryers. The unit will soon be field tested and may be on the market in 1985. The griddle and open top range are in intermediate stages of development; both show promise. The griddle currently demonstrates a reduction in energy consumption of about 20 percent and the open top range about 33 percent relative to conventional designs.

The new A.G.A.L. Gas Appliance Research and Demonstration House is discussed with particular emphasis on the commercial cooking facility that is part of the structure.

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## SUMMARY

Major improvements to commercial ovens and deep fat fryers have had a significant impact on the marketplace due to A.G.A.L. research efforts. We are currently working to apply pulse combustion to both the deep fat fryer and the closed top range, and a power burner system to the open top range. Our new research and development facility greatly expands our capabilities both in the area of building performance and appliance improvement.

## INTRODUCTION

The food service industry is a significant part of the American economy. It accounts for almost 5 percent of the U.S. Gross National Product with over 77 million daily customer transactions(1). Almost 2 percent of the total natural gas and electric energy consumed in the combined residential and commercial sector is in commercial cooking equipment (227 x $10^{12}$ Btu/year for commercial cooking of a total 11,624 x $10^{12}$ Btu/year for the sector(2,3). Table I is a breakdown of commercial cooking equipment into seven categories showing 1975 inventory and energy consumption. The various improvements to be discussed in this paper were made in the first four of these categories. Together they consume 80 percent of the energy attributable to commercial cooking equipment(2).

The hallmark of commercial cooking equipment is that it must reliably withstand long hours of operation and operator abuse. Therefore the equipment is heavy and has high input with standing pilots. The average efficiency of this equipment prior to the improvements described below was about 40 percent. The major concerns for commercial cooking equipment are production capacity, product quality, reliability and flexibility. Any modifications to an appliance to reduce energy consumption cannot reduce these performance factors, otherwise improvements result in a unit with no market potential.

A series of equipment improvements (listed in Table II) have been developed by the A.G.A.L. R&D Department in cooperation with participating manufacturers. The equipment operates at substantially lower input rates than their predecessors and have equal or improved production capacity.

## PREVIOUS EFFORTS

### Ovens (Free-Standing Forced Convection)

The initial research efforts on commercial cooking equipment at A.G.A. Laboratories was targeted at increasing the efficiency of the forced convection-type oven. Three means of improving efficiency were demonstrated during these efforts. They are: (1) direct firing, (2) use of a vent damper, and (3) reduced horse power to the blower motor.

It was found that the most effective way of increasing the efficiency of the forced convection oven was to modify the oven so that it would operate in the direct-fired mode as shown in Figure 1. The conventional (indirect-fired) convection oven is designed so that the hot combustion gases do not enter the oven compartment. The blower motor circulates the air heated by the hot walls around the food for increased heat transfer and even temperature distribution. With the new direct-fired type oven, a tube provides a connection between the hot flue gas and the oven compartment. The hot combustion gases are drawn into the oven cavity through the tube by the negative pressure at the inlet side of the blower and then circulated around the food products. A substantial amount of additional heat is extracted by this direct circulation. The hot gases are then vented out the top of the unit as shown in Figure 1. By incorporating the direct-fired configuration, energy consumption was reduced by approximately 40 percent to perform the same cooking job. Prior to 1978 all convection ovens were of the indirect-fired type. Now a large majority of convection ovens shipped are of the direct-fired type. Currently there are six different major U.S. manufacturers producing these units.

It was demonstrated that inclusion of a vent damper (similar to current furnace applications) could have beneficial results. A 30 percent reduction in fuel gas consumption was measured while maintaining the oven at a preset temperature. Reductions in consumption during cooking operations were also obtained when light loads were being cooked. With a light load, the oven generally cycles on and off to maintain a preset temperature. But with a heavy load, no savings were measured because the burner operates continually.

Finally, a savings in electrical energy was demonstrated in relation to the motor that drives the blower. This blower operates continuously throughout the day. Previous to our efforts a 3/4 h.p. motor was typically applied. It was demonstrated that a 1/4 to 1/3 h.p. motor could perform the same job without deleterious effects on the motor (overheating). Since then, most forced convection oven manufacturers have reduced the power rating of their motors.

### Range Ovens

Following the successes with the free-standing forced convection oven, attention was turned to the range oven. As shown in Figure 2 the conventional natural convection range oven is already direct-fired in a manner similar to residential ovens. A reduction in natural gas consumption of approximately 40 percent was demonstrated by incorporating a blower to force convection of the hot gases in the oven cavity. This oven has both similarities to and differences from the free-standing convection oven previously described. Prior to 1980 all range ovens were of the natural convection type. Since that time, three manufacturers are now marketing direct-fired forced convection range ovens(4,5).

## Deep Fat Fryers

The deep fat fryer consumes a significant portion of the energy in the commercial cooking field, particularly in fast food-type operations. According to the breakdown of Table I the fryer is the second largest single consumer of energy. Infrared burners were successfully applied to the deep fat fryer, resulting in a reduction in input rate of about 40 percent. One of the additional benefits of utilizing the infrared burners was the possibility of providing two different vat configurations for the same vat cabinet (see Figure 3). Typically the width of a fryer was designed for two fryer baskets to be placed side-by-side in the hot oil. This arrangement with both baskets in a common vat is called a single vat fryer with the oil at one set temperature for both baskets. With the infrared burner, the vat can be divided so that there are essentially two separate vats with independently controlled temperatures. This is called a split vat fryer. Depending on the use patterns, this feature itself can result in additional reductions in energy consumption. The first infrared fryer was marketed in 1980. Currently three different manufacturers are offering infrared fryers(6).

## Ventilation

It was recognized that some ventilation system designs and air flow rates (ventilating hoods over the appliances) could have a deleterious effect on the efficiencies of the equipment placed under them. Under certain conditions, gas consumption increases of 20-40 percent were observed when various types of equipment were placed under different ventilating systems. The deep fat fryer with a direct connected hood, and the open top range under a canopy hood were particularly susceptible to the effect of excess ventilation. Both atmospheric and infrared-type burners can be sensitive to the air flow rate and patterns around them. The effect of ventilation puts a limitation on potential improvement of real world efficiency with current burner systems(7).

## CURRENT EFFORTS

Current efforts are targeted at making further improvements in the efficiency of deep fat fryers as well as range top sections. These efforts involve the application of pulse combustion to the deep fat fryer and closed top ranges, and using a power burner with an open top range.

## Pulse Combustion

Pulse combustion is an advanced combustion technology that can result in extremely high efficiencies. An example is the well known Lennox pulse furnace. An acoustically resonating system is set up among the various components shown in Figure 4. The pressure fluctuations resulting from the resonance draw in small charges of air and gas to the mixer head. Each charge is reignited by the residual heat from the previous explosion. Typically this event takes place at a frequency of 30 to 60 Hz. Some of the benefits to this pulsating system are:

- the pulsing flow results in a substantially increased heat transfer coefficient,
- the natural forced draft allows flue gases to be cooled to room temperature with sufficient force remaining to vent the flue gases,
- a pulse combustion burner is unaffected by ventilation, and
- the burner can operate on most common fuel gas compositions with minimal modifications.

Deep Fat Fryers

Application of pulse combustion to a deep fat fryer has provided a substantial decrease in energy consumption (see Figure 3). Other benefits of this development include virtual elimination of the effect of ventilation on operating efficiency and the ability to operate with various fuel gases (see Table III).

Cooking energy consumption and boiling water efficiency (BWE) test results for three deep fat fryers are shown in Table IV. Figure 3 is a schematic representation of the three fryers. It should be recognized that the cooking and BWE results shown are very different tests. The cooking test requires the determination of a potato load size such that the cooking oil temperature will recover back to 375°F within 6-1/2 minutes (± 1/2 minute) after introduction of the load. The Btu/lb. of potatoes cooked is calculated from measured gas consumption to recover oil temperature back to 375°F[9]. The BWE test is a steady state water evaporation test. Both tests, of course, indicate the same general trend of energy consumption reduction.

One of the most significant pieces of information from Table IV is the fuel gas input rate which can provide the same amount of heat to the required 50 lbs. of cooking oil. Comparable potato cooking performance is also obtained from each fryer although the input rates vary dramatically. The average immersion tube fryer consumes approximately 100 MM Btu/year so the 54 percent reduction of input rate (130 - 60/130 x 100 = 54 percent) corresponds to a 54 MM Btu/year/fryer fuel gas savings.

Because pulse combustion is an acoustic process, it is inherently noisy. Design factors that affect sound production include[10]:

- input rate [strongest correlation with $\log_e$ (input rate)],
- air valve spacing,

- tail pipe and vent pipe diameters, and
- exhaust decoupler volume.

Appropriate sizing of the exhaust decoupler and vent pipe on the fryer (maintaining stable operation) has resulted in sound levels approximately the same as ambient sound levels in a commercial kitchen [about 65 dB(A)].

The pulse combustion deep fat fryer will soon be field tested in cooperation with an equipment manufacturer and a major fast food chain. For further information on the pulse fryer development see references 11, 12 and 13.

## Range Top Sections

To complement the greatly improved efficiency of the range oven previously discussed, the efficiency of range top sections are now being improved. Modifications to existing units with atmospheric burners showed possibilities of only 10-15 percent reduction in energy consumption(14). It was decided to redesign and apply advanced burner systems.

A conventional open top range is illustrated in Figure 5. Also shown in Figure 5 is a power burner system, which reduced energy consumption by approximately 33 percent. The increased efficiency is due to several factors. All the air required for combustion is injected as primary air which increases the flame temperature. Essentially all excess air, which carries away useful heat, is eliminated. It is also possible for the pot to be brought much closer to the burner than is possible with atmospheric burners. In addition, the power burner has been found to be insensitive to ventilation effects. This concept has been demonstrated to several manufacturers. One of the manufacturers is in the process of fabricating an engineering model.

The closed top range, or griddle, is illustrated in Figure 6. Pulse combustion has also been successfully applied to this appliance. To date a consumption reduction of approximately 20 percent has been demonstrated. A major problem with the closed top-type range is in attaining a uniform temperature distribution. Preliminary tests indicate that the pulse combustion unit is showing more uniform distribution than conventional gas-fired griddles. This concept has likewise been demonstrated to several manufacturers. An engineering model has been fabricated by one of the manufacturers and provided to A.G.A.L. for testing.

## Ignition and Control Devices

As noted earlier, reliability is a paramount requirement in commercial cooking equipment. Until fairly recently, it was perceived in the industry that the most reliable means of providing ignition was with a high input standing pilot. With the rising cost of fuel this carried an increasingly larger cost penalty. There is a growing acceptance due to market pressure of interrupted-type ignition devices, as well as the application of microprocessor-based controls for added performance flexibility. A major concern with applications of solid-state electronics to commercial cooking appliances is the ambient environment. High temperature, rough handling, and dirt laden air can cause significant problems for solid-state electronics[15]. It is felt that with suitable design these problems can be overcome on certain appliances. We are planning to develop a generic-type microprocessor control unit for advanced commercial equipment that could be programmed with appropriate control features for that appliance.

## FUTURE

### Gas Appliance Research and Demonstration House

In May of this year a substantial addition to our research facility was made with the dedication of the Gas Appliance Research and Demonstration House represented in Figure 7. The house combines a modern ranch-style dwelling with residential and commercial cooking research and demonstration facilities. The house is fully instrumented for monitoring ambient conditions in the rooms, as well as computer-controlled data acquisition. Of particular interest to this paper is the commercial cooking research and demonstration facility. This 1,200 sq. ft. room has 34 linear feet of vent hoods. Each of the three hoods is of a different design as shown in Table V. The interaction of appliance/vent and building structure/vent can be carefully monitored and analyzed. Both gas and electric equipment can be tested under the same conditions. This facility also allows new equipment to be readily demonstrated and field tested in a realistic setting. We plan to continue equipment improvement work in our expanded facility. Anticipated near-term efforts will be aimed at steam equipment and pizza ovens. Other work aimed at different categories, special equipment and advanced equipment, will result from a study of food preparation techniques.

## ACKNOWLEDGEMENT

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Table I. Commercial cooking equipment; 1975 inventory and energy consumption.

| | Equipment Type | Total Inventory, ($10^3$ Units) | Gas Equipment, Percent | Total Energy Consumption, ($10^{12}$ Btu/Year)/ Percent of Total | Gas Consumption, Percent |
|---|---|---|---|---|---|
| 1. | Ranges and braising pans | 458 | 86 | 54/24 | 93 |
| 2. | Deck and convection ovens | 572 | 75 | 41/18 | 86 |
| 3. | Griddles and grills | 475 | 75 | 38/17 | 86 |
| 4. | Fryers | 526 | 80 | 48/21 | 89 |
| 5. | Broilers | 162 | 80 | 13/ 6 | 89 |
| 6. | Steam equipment | 243 | 69 | 26/11 | 82 |
| 7. | Miscellaneous | 562 | 36 | 7/ 3 | 27 |
| | TOTAL | 2,998 | 70 | 227/100 | 87 |

From Hurley (1978)

Table II. Commercial cooking equipment; recent improvements through A.G.A.L. research work.

| Equipment Type | Improvement | Approximate Reduction in Consumption, Percent | Number of Manufacturers Manufacturing | Approximate Year First Commercialized |
|---|---|---|---|---|
| Forced convection oven | Direct-fired | 40 | 6 | 1978 |
| Range oven | Forced convection | 40 | 3 | 1980 |
| Deep fat fryer | Infrared burners | 40 | 3 | 1981 |
| Deep fat fryer | Pulse combustion burners | 50 | Field testing 1 manufacturer | Near Future |
| Fry top range (griddle) | Pulse combustion burners | 20 | Proof-of-concept 7 manufacturers | To be determined |
| Open top range | Power burners | 33 | Proof-of-concept 7 manufacturers | To be determined |

Table III. Fuel flexibility of pulse combustion deep fat fryer.

| Gas | Input, KBtu/Hr | $CO_2$, Percent | CO, Percent Air-Free | Flue Temperature, °F |
|---|---|---|---|---|
| Natural ① | 32.6 | 9.9 | .029 | 685 |
| 1400 LP-Air ① | 33.4 | 10.6 | .005 | 619 |
| Manufactured ② | 31.3 | 8.7 | .008 | 676 |
| Butane ② | 31.2 | 11.0 | .014 | 687 |
| Propane ② | 32.5 | 10.5 | .012 | 664 |

① - Same gas and air settings.

② - Adjustment made for rate and excess aeration.

Table IV. Cooking and efficiency performance of three deep fat fryers.

| | Immersion Tube | Infrared | Pulse Combustion |
|---|---|---|---|
| Input Rate, Btu/hr ① | 130,000 | 80,000 | 60,000 |
| Cooking Test ② Change in consumption, percent relative to immersion tube. | 0 | -26 | -40 |
| Flue temperature, °F | 1200 | 950 | 428 |
| Flue Loss, % | 41 | 31 | 19 |
| Efficiency, ③ Percentage point increase relative to immersion tube. | 0 | +25 | +35 |

① - For vat that holds 50 lbs. of cooking oil.

② - Per ANSI Z83.13-1980 (Test 2.13)
Frozen french fries used instead of prescribed fresh potatoes to provide more uniform test conditions and convenience.

③ - Boiling water efficiency (BWE) test.

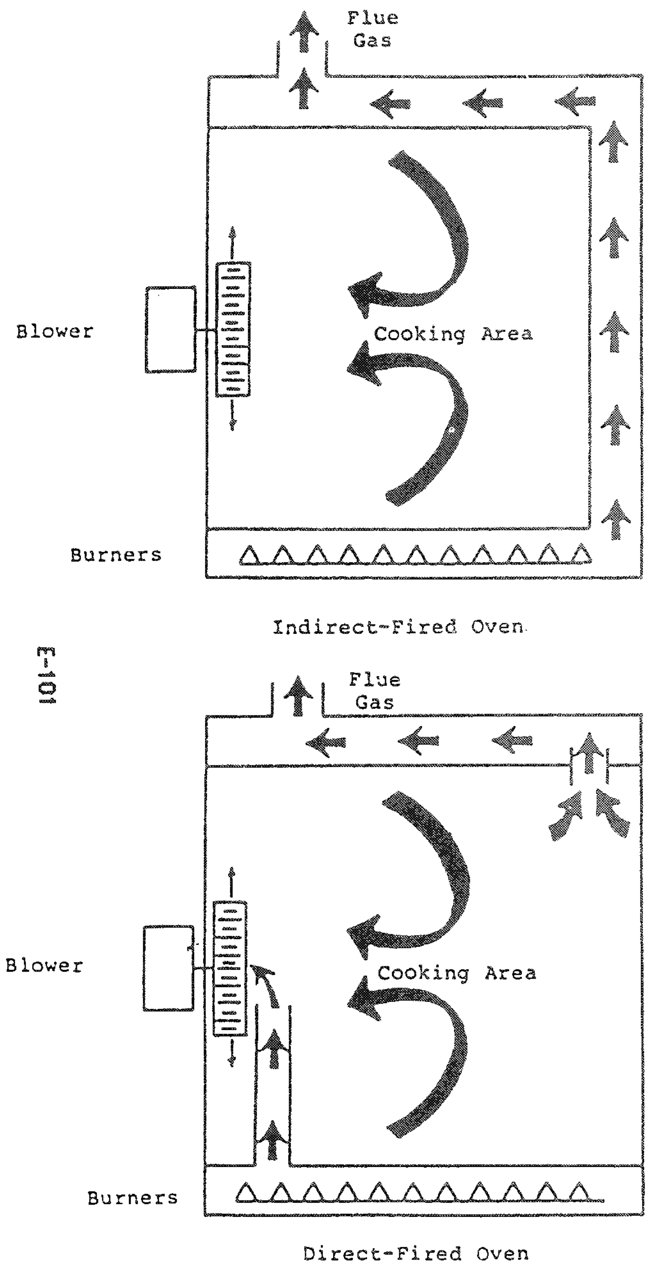


Figure 1. Schematic diagrams of direct- and indirect-fired forced convection ovens.

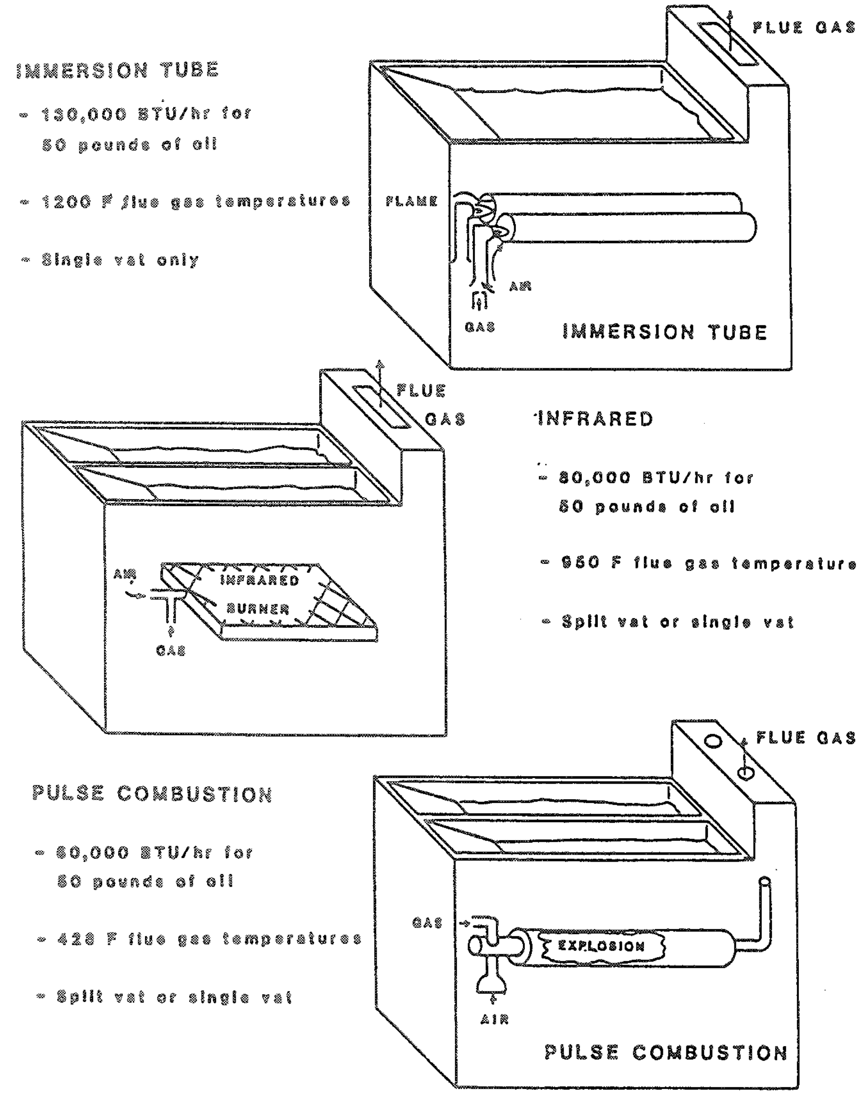


Figure 3. Three deep fat fryers.

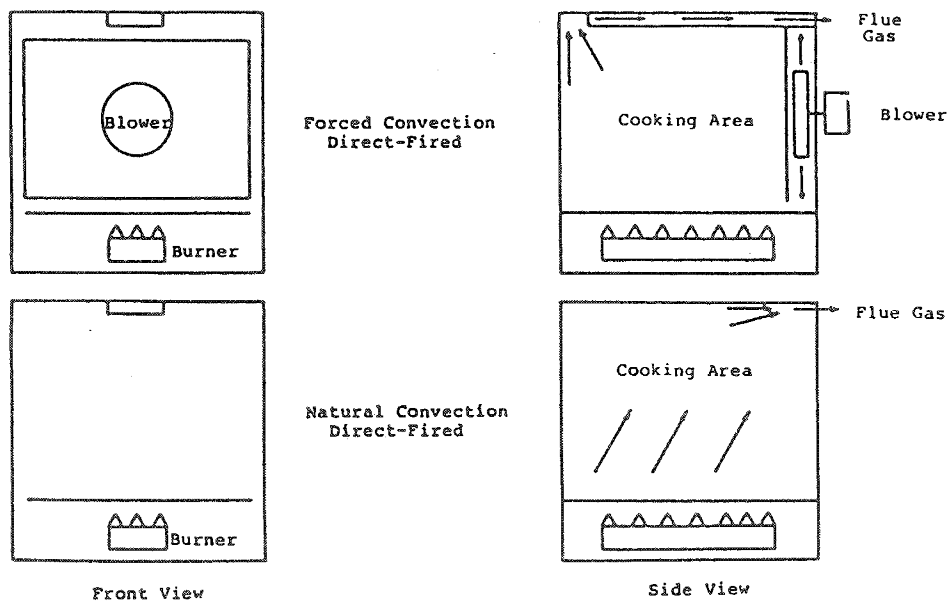


Figure 2. Range ovens, direct-fired; natural and forced convection.

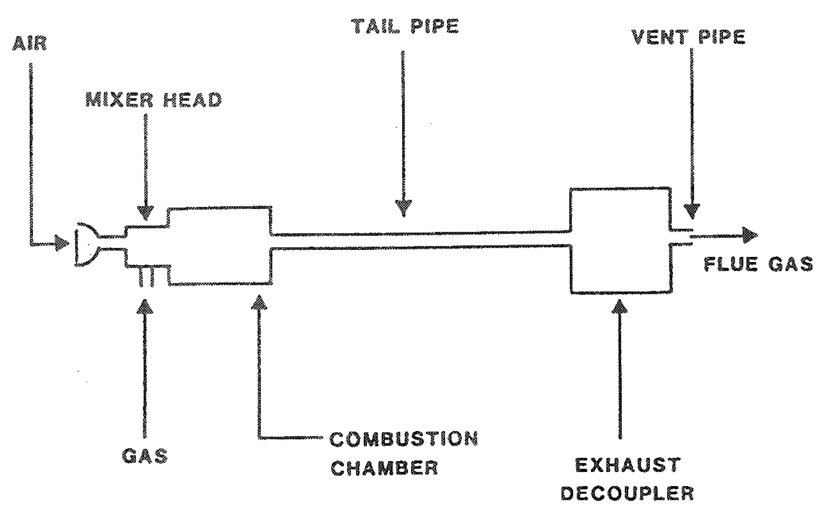


Figure 4. Pulse combustion schematic.

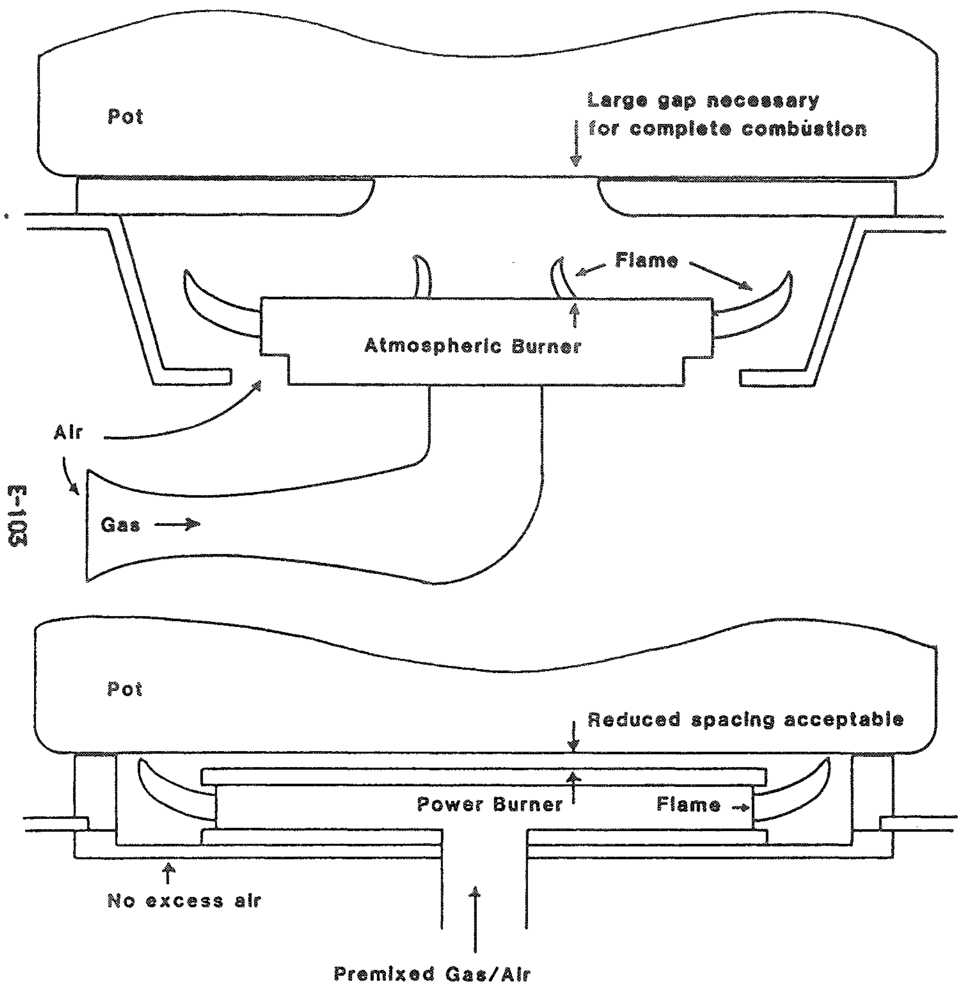


Figure 5. Open top range:
Atmospheric and power burner

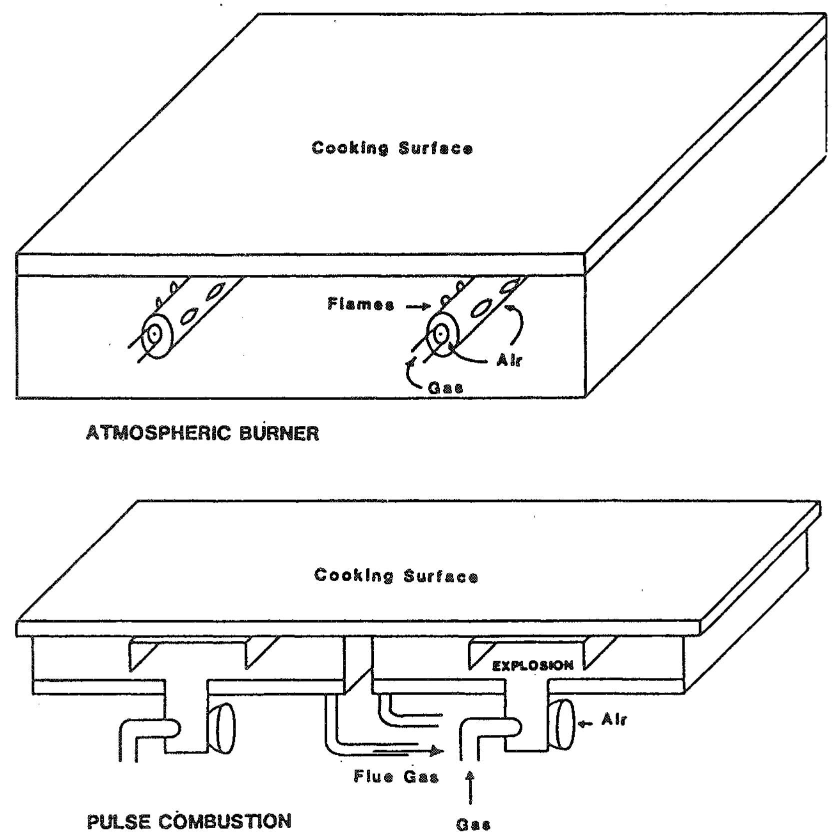


Figure 6. Closed top range (griddle):
Atmospheric burner and pulse
combustion

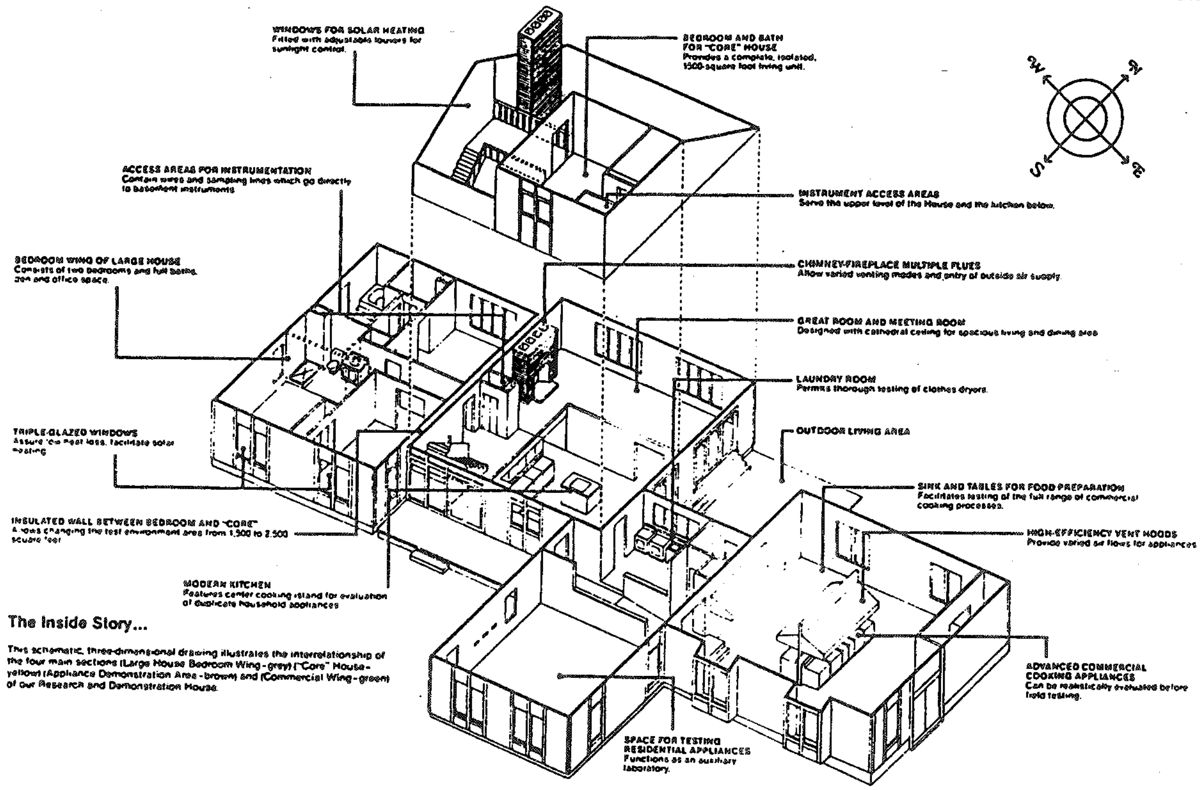


Figure 7. A.G.A.L. gas appliance research and demonstration house

Table V. Description of three ventilating hoods in A.G.A.L. commercial cooking test and demonstration facility (all three recirculating type hoods).

| Hood | General Description |
|---|---|
| A | - 10 feet long<br>- 2750 CFM<br>- proportional control to draw up to 80 percent of air required from outdoors<br>- untempered makeup air |
| B | - 12 feet long<br>- 2-6 foot sections<br>- 4800 CFM<br>- 80 percent of air required from outdoors<br>- untempered makeup air |
| C | - 12 feet long<br>- 3600 CFM<br>- 89 percent of air required from outdoors<br>- can be tempered by direct-fired makeup air heaters |