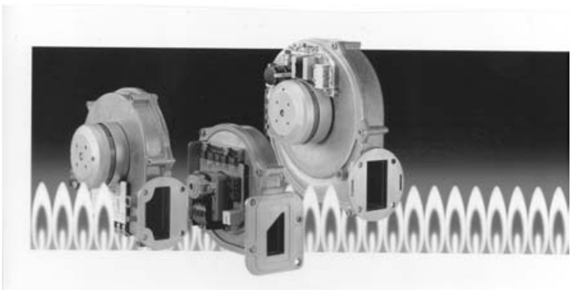
NEW GENERATION OF PREMIX GAS BLOWERS



ABSTRACT

Dramatic improvements in the control and efficiency of gas burner systems is now possible with a new generation of premix gas blowers recently introduced to the North American market. The premix gas blowers are for fixed or modulating gas-fired burner systems rated up to 1,500,000 Btu/hr (~450 kW). Applications include residential and commercial gas furnaces, humidifiers, water heaters, gas-fired food service equipment, and hydrogen fuel cells.

The premix gas blowers deliver a measured air-fuel mixture to the burner with turndown ratios up to 10:1. The gas is injected either at the fan inlet or outlet to ensure optimum combustion efficiency resulting in lower NOx and CO emissions. Product features include die-cast aluminum gas tight housings, anti-static backward curved impellers, resilient motor mounts, AC shaded-pole or brushless DC motors, pulse width modulation (PWM) input for speed control, Hall effect sensor for speed monitoring, optical isolation of AC voltage input from DC controls, and an inlet flange to accept specialty gas valves.

In the new millennium, increased energy and environmental demands will be placed on appliance and combustion engineers. Premix gas blower technology will be a solution to meet these demands.

CONCEPT OF COMBUSTION

Fundamentals

The dictionary definition of combustion is “a chemical reaction accompanied by the production of light and heat”. In terms that are more basic, combustion is the chemical and thermal reaction between an oxidant (e.g. air) and a combustible material (e.g. natural gas).

The general “rule of thumb” for the combustion air requirement for an air and natural gas (methane) mixture is a volumetric ratio of ~10 parts air to 1 part gas. This is also known as the stoichiometric or theoretical air, which is the exact quantity of air necessary to provide the required amount of oxygen for complete combustion.

The products of combustion (i.e. flue products) are primarily carbon dioxide, water vapor, and nitrogen. If incomplete combustion occurs the flue products can also include carbon monoxide, hydrogen and aldehydes in addition to carbon dioxide, water vapor, and nitrogen.

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Variables such as humidity, temperature, barometric pressure, air and gas density, and altitude can also have a significant effect on combustion performance. A general “rule of thumb” is to de-rate the burner 4% for every 1,000 feet of elevation exceeding 1,000 feet above sea level.

Combustion air requirements

In practice complete combustion may also depend on an additional quantity of air required, called excess air. The excess air may range from 5% up to 50% depending on the fuel, burner system and method of air-fuel delivery.

The general relationship to calculate the theoretical air required for methane and propane is based on the volumetric ratio of these fuels with air: Methane requires 9.53 parts air to 1 part gas and Propane requires 23.82 parts air to 1 part gas.

The equation to calculate the theoretical air required for combustion of gaseous fuels is:

$$ft^3 air / ft^3 gas = \sum_i k_i (\%i) \qquad \text{Eq. (1)}$$

Where (i) is the percentage of each gas within the fuel and (k) is the air-fuel constant for the gas (e.g. methane is 9.53 and propane is 23.82).

Example: Calculate the theoretical and excess air required to size a combustion air blower to be installed on a natural gas fired boiler, operating on 15% excess air, with an input rate of 100,000 Btu/hr. Assume the natural gas is made up of 100% methane with a heating value of 1,015 Btu/cf.

Step 1: Determine the volume flow rate of gas in cubic feet per minute. This will be the *1 part* gas required to satisfy Eq. (1).

$$100{,}000 \frac{Btu}{hr} \div 1{,}015 \frac{Btu}{ft^3} \div 60 \frac{\min}{hr} = 1.64 \frac{ft^3}{\min}$$

Step 2: Determine the volume flow rate of theoretical air in cubic feet per minute. This will be the *9.53 parts* air required to satisfy Eq. (1).

$$9.53 \times 1.64 \frac{ft^3}{\min} gas_{Methane} = 15.63 \frac{ft^3}{\min} air_{Theoretical}$$

Step 3: Determine the volume flow rate of excess air in cubic feet per minute.

$$15.63 \frac{ft^3}{\min} air_{Theoretical} \times 0.15 = 2.34 \frac{ft^3}{\min} air_{Excess}$$

Step 4: Sum the theoretical air and the excess air. This will equal the total air required for combustion.

$$15.63 \frac{ft^3}{\min} air_{Theor.} + 2.34 \frac{ft^3}{\min} air_{Excess} = 17.97 \frac{ft^3}{\min} air_{Total}$$

Step 5: If the gas will be mixed with the air before the blower inlet, then sum the total air and gas.

$$17.97 \frac{ft^3}{\min} air_{Total} + 1.64 \frac{ft^3}{\min} gas = 19.61 \frac{ft^3}{\min} Mix_{air+gas}$$

CONCEPT OF PREMIX COMBUSTION SYSTEMS

Fundamentals

A premix combustion system is designed to deliver a measured air-gas mixture to the burner for complete combustion. The gas can be injected upstream or downstream of the blower inlet (see Figure 1).

In addition, premix systems are designed into heating systems with the gas blower located on either the exhaust (induced draft) or supply (forced draft) side of the system. The induced draft systems are used on forced hot air systems with air to air heat exchangers and the forced draft systems are used on hydronic systems with air to water heat exchangers.

The reason for two different types of systems is safety. In the forced hot air (induced draft) system, a crack may occur in the air to air heat exchanger allowing carbon monoxide to infiltrate the fresh air stream. In the hydronic heating (forced draft) system, there are no avenues for carbon monoxide to infiltrate the household due to an enclosed medium (i.e. water).

Benefits of a forced draft system

The benefits of forced draft systems are lower component temperatures, direct air-fuel connection (premix) for improved mixing, and longer life expectancy due to mild to moderate ambient conditions. For the purpose of this paper, we will focus on the forced draft system with gas injected upstream of the blower (Concept 3).

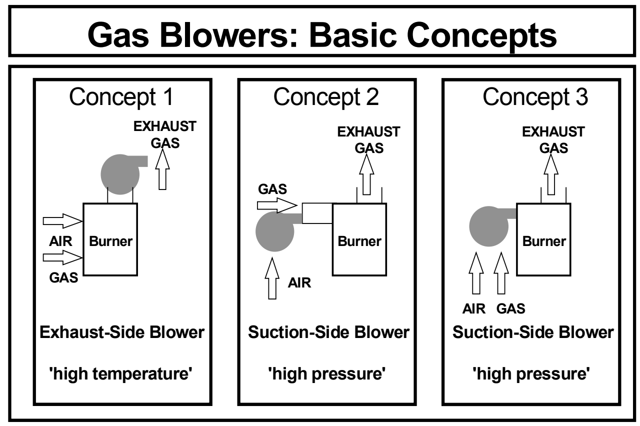

Figure 1

GAS BLOWER ASSEMBLY

Motor

Gas blowers are usually built with one of 3 different motor styles: shaded pole motors, universal motors, or brushless DC motors.

The major advantages of shaded-pole motors are their simple design, construction, and low cost. These motors operate at a low efficiency (20-40%), are built with 1 or 2 speeds, and the maximum speed is limited by the AC line frequency. Life expectancy is ~25,000 hours for a sleeve bearing system.

Universal motors operate at significantly higher speeds and are often speed-controlled with a separate voltage controller. The internal brushes limit the motor life to less than 10,000 hours. In addition, the radio-frequency interference (RFI) changes with brush-wear, becoming a problem in RFI-sensitive applications.

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Brushless DC (BLDC) motors are traditionally powered by a low DC-voltage source (e.g. 12-48V). More recent designs have integrated full-bridge rectifiers to accept AC-line voltage (e.g. 120-230V) and then convert it to an equivalent high DC-voltage. The motor coils are wound for high or low voltage accordingly. The BLDC motor operates at a high efficiency (60-85%).

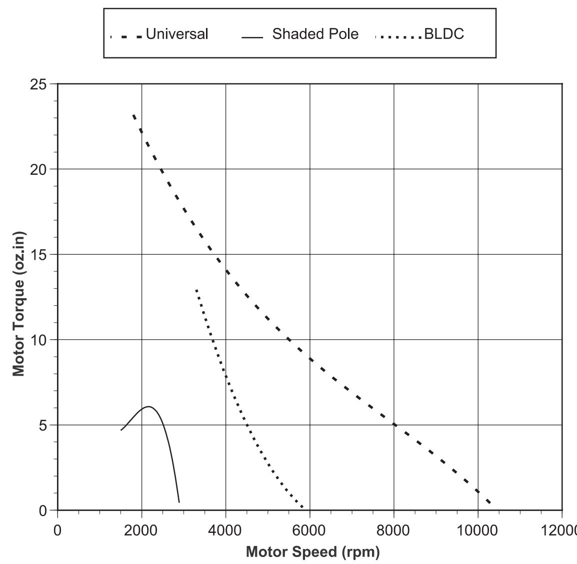
The drive electronics monitors the angular rotor position continuously and then triggers the power-transistors in a sequence to create a rotating stator field and, eventually motor torque. The rotor follows this field synchronously.

The drive electronics also includes built-in speed control (PWM) and speed monitoring interfaces (2 pulses per revolution), RFI filter, inrush current and polarity protection. The BLDC motors have no slip- and low stray-losses so that low bearing temperatures provide motor life expectancies well above 40,000 hours.

Table 1: Motor Characteristics

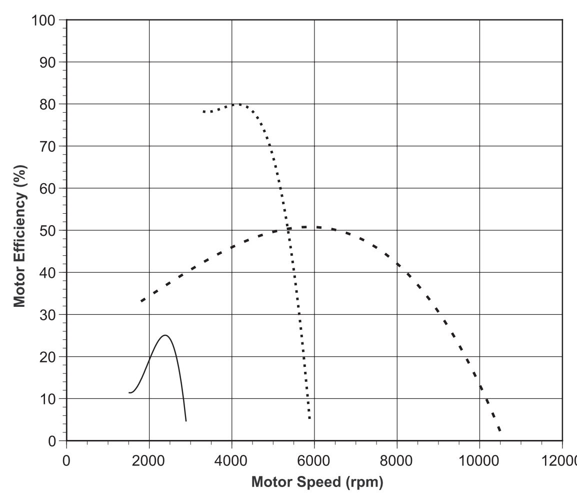
Design Parameter	Shaded Pole Motor	Universal Motor	Brushless DC Motor
Max. Speed	<3600 rpm	High	High
Efficiency	20-40%	50%	60-85%
Life Expectancy	~25K hrs.	~10K hrs.	>40K hrs.
Speed Control	Fixed (1 or 2 speeds)	External component	Full modulation
RFI	Low RFI	Critical	RFI filters
Tachometer	External	External	Built-in

Table 1 shows a comparative summary of the motor characteristics, while Figures 2.1 and 2.2 graphically show the differences in the design performances for each motor type.



Speed-Torque Relationships for Various Motor Designs

Figure 2.1



Speed-Efficiency Relationships for Various Motor Designs

Figure 2.2

Mechanical and Electrical Interfaces

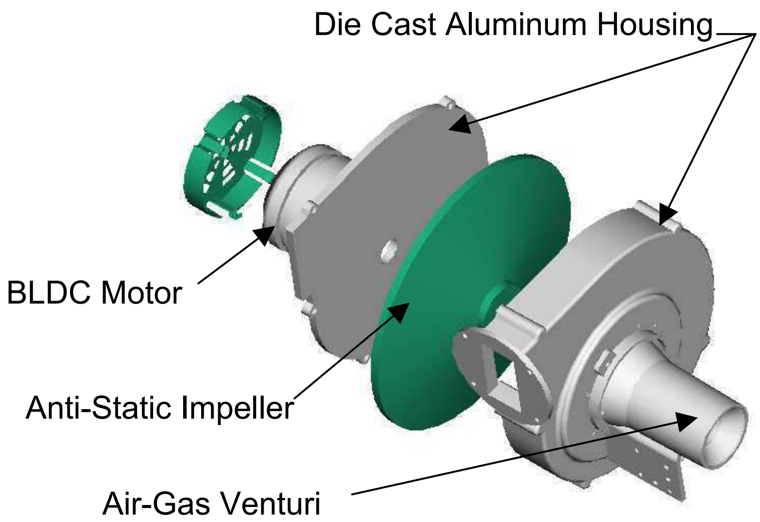
Premix gas blowers are built with non-sparking materials due to the inherent dangers of premature combustion when air and gas are mixed within the fan housing (see Figure 3). Radial impellers or housings have to be made of anti-static materials (e.g. plastic and non-ferrous metals) to prevent hazardous build-up of electrical charges.

A blower housing made of die-cast aluminum is well suited for a premix application because it's a non-ferrous material that can be machined for a 2-piece gas-tight assembly. The blower housing is sealed with a pentane resistant O-ring gasket.

Inlet flanges to accept an O-ring or accommodate a specialty gas valve can also be incorporated into the die-cast mold. This added feature reduces the materials, labor and package size associated with conventional gas systems. The discharge flange can be mounted directly to the burner or burner feed tube to create a complete pre-assembled power burner system.

Vibration isolation components between the motor and blower housing assembly are available to dampen structure borne noise from the motor or burner system. This added feature prevents resonance throughout the entire speed-range of the blower to make the complete appliance well suited for the most noise-sensitive residential and commercial applications.

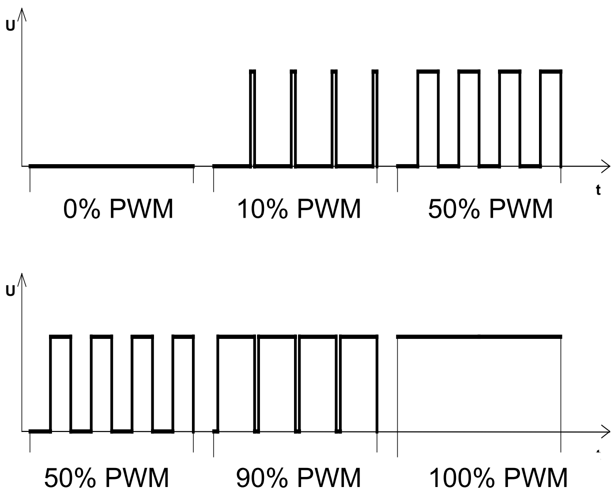
The low DC-voltage motors are polarity sensitive and are built with electronic polarity protection. Incorrect polarity will cause the motor to stop but will not permanently damage the components; however, polarized connectors are recommended to prevent disruptions during blower installation. AC-line supplied motors are not polarity sensitive but the high DC-voltage motors have separate terminals for the AC-line and for the control circuits. Low voltage safety circuits are maintained for the controls by means of opto-isolators. No other barriers are needed to build the electrical control-loops.



Exploded View of Premix Gas Blower
with Inlet Venturi

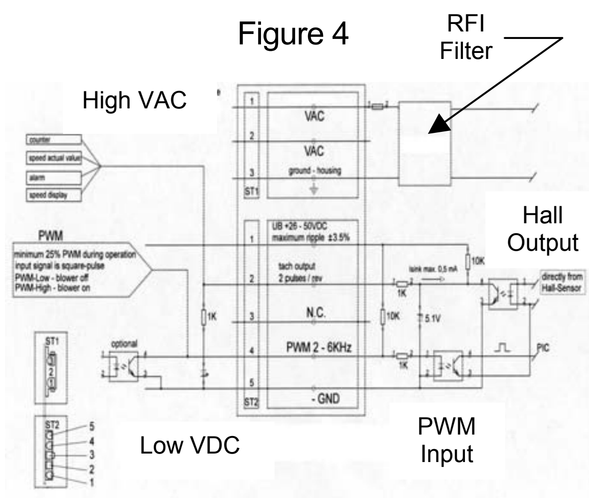
Figure 3

A DC signal output from a Hall sensor of the BLDC motor is available as a pulse train (2 pulses per revolution). This speed detection system can be used to monitor the status of the blower speed continuously. BLDC motors are also available with a range of speed control inputs (e.g. 0-10 VDC or 4-20 mA); however, pulse-width modulated (PWM) control signals (see Figure 4) with 1-10K Hz carrier frequencies are preferred and simple to isolate from the high-voltage circuit of the motor supply (see Figure 5).



Pulse Width Modulation Signal

Figure 4



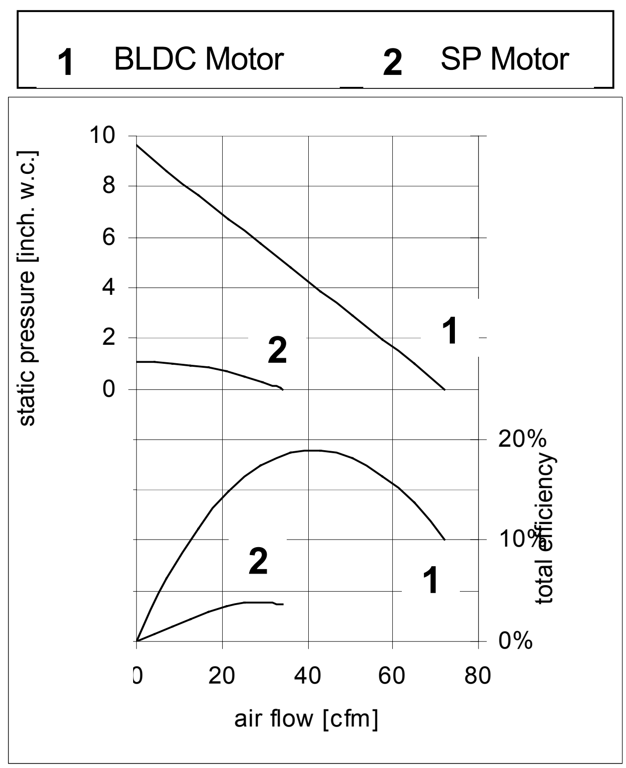
Control Circuit Schematic

Figure 5

Performance

Premix gas blowers are radial-flow blowers built with backward curved impellers that offer the benefit of a stable fan curve throughout a wide range of operation. This feature in combination with a BLDC motor offers a steep air performance curve (i.e. high pressure at low airflow) and higher efficiencies.

Therefore, based on a radial blower design, the BLDC motor compared to the 2 pole shaded pole motor increases the shut-off pressure by a factor of 8, airflow by a factor of 2, and peak efficiency by a factor of 5 (see Figure 6).



Pressure and Efficiency vs. Air Flow

Figure 6

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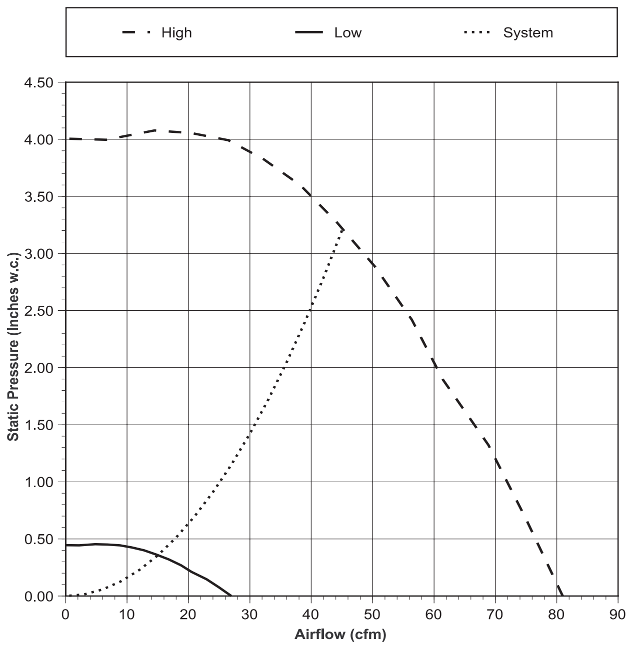
In addition, the BLDC motor allows for modulation of the blower speed and therefore supports mid-range firing rates for long run cycles, while still maintaining a reserve for full-load heat demands (see Figure 7).



Performance Curves vs. System Curve for 3:1 Modulation

Figure 7

The noise level of blowers is based on noise pressure tests measured with a microphone positioned (1) meter from the blower inlet. Third octave band analyses are used to identify prominent tones and noise levels are expressed in dBA.

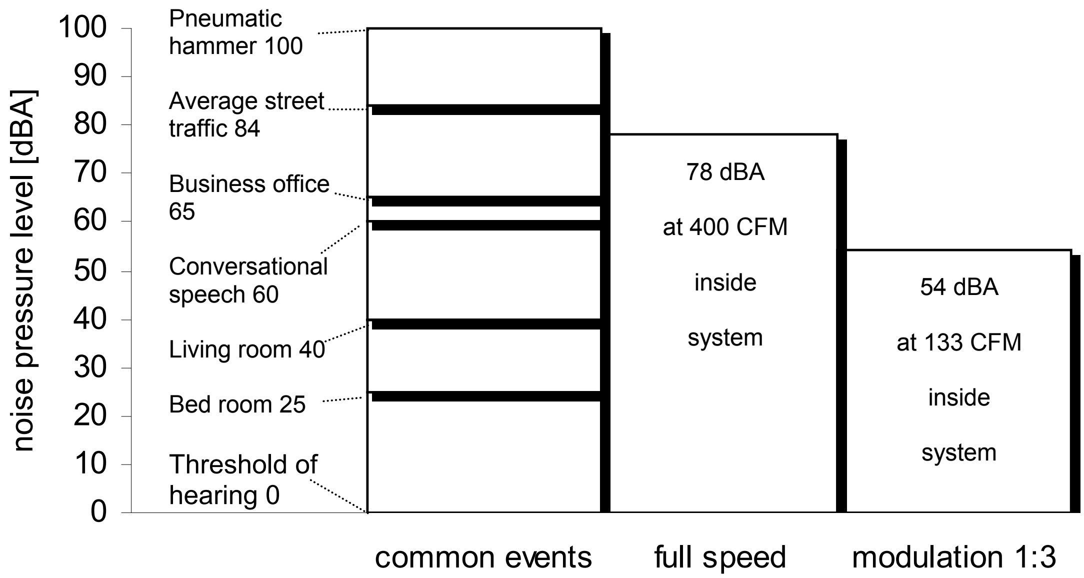
The equation to calculate the change in air noise (dBA) as a function of the blower speed is:

$$\Delta dB[A] = 50 \times \lg\left(\frac{n_1}{n_2}\right) \quad \text{Eq.} \quad (2)$$

For example, the noise level of a premix gas blower, built with a 5” diameter impeller, measured at free air, delivering 73 cfm produces a noise pressure level of 72 dBA. Modulating the airflow by a 3:1 ratio reduces the noise level to 48 dBA. Significant noise reductions often justify the added cost of a full modulating or soft-start boiler control. In addition, the blower noise inside of an appliance can also depend on the mounting conditions and operating point of the blower. Further, the damping affects of burners, venturis, and housings also lead to lower noise levels; however, blower data sheets are based on testing with acoustically transparent system simulators.

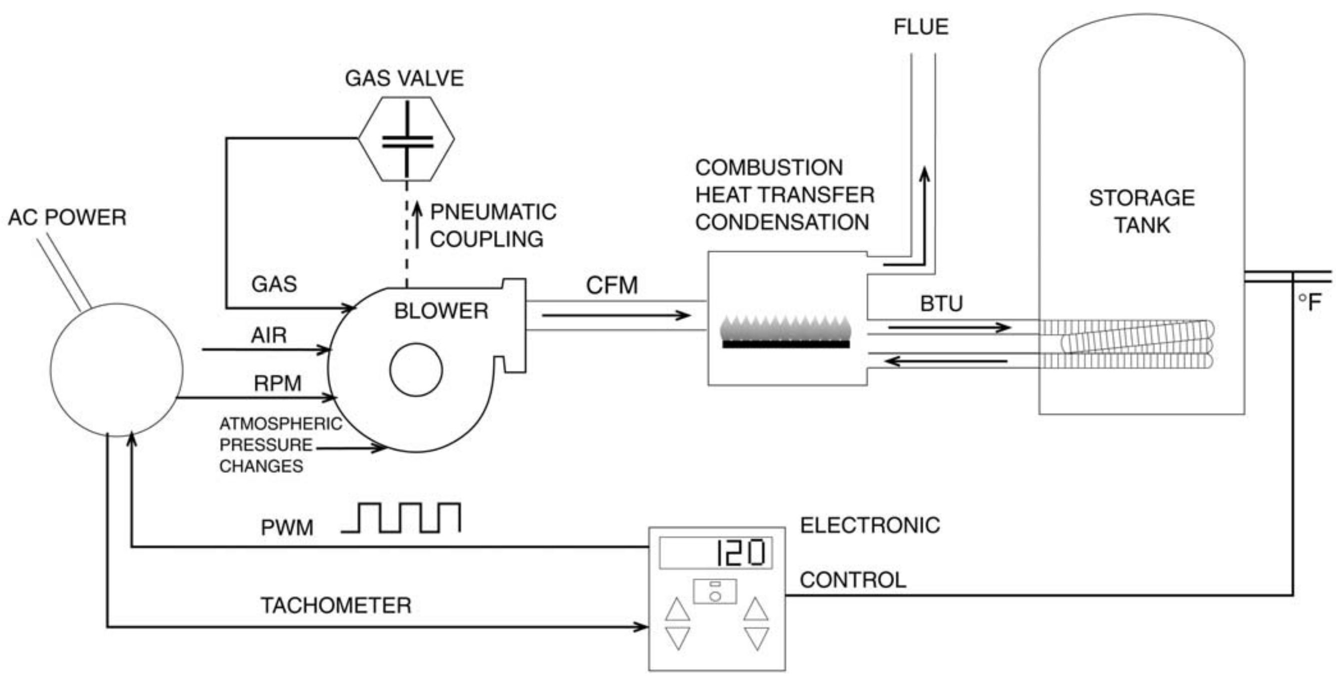
Control logic

The control logic for gas-fired boiler applications are typically open-loop systems; however, the closed-loop system can also be used. As shown in Figure 9, the electronic controller detects a demand for heat. It then evaluates parameters and settings such as time, calendar, start-up characteristics, and PID control parameters. A PWM control signal is then sent to the blower motor, which then reacts with a change in speed. The boiler controller, by means of the tachometer signal (Hall sensor), constantly monitors the blower status. The gas valve is pneumatically coupled with the blower so the gas-air ratio remains constant. The gas is injected into the blower creating a uniform fuel-air mixture. The feedback of the new water temperature eventually closes the control loop.



Noise level of a 10" gas-blower

Figure 8



Control logic for a Boiler Combustion System

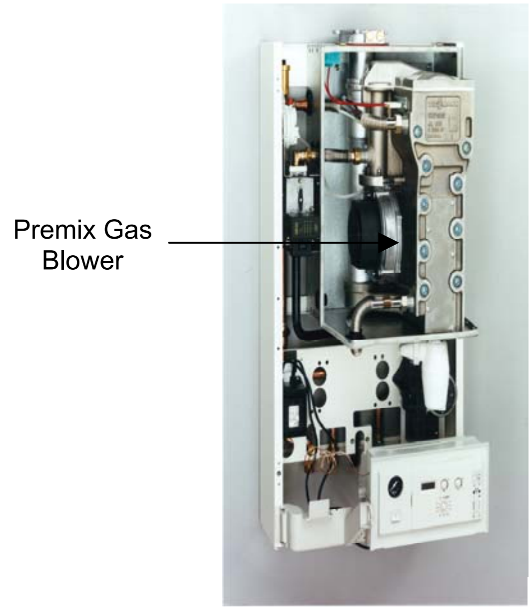
Figure 9

Applications

Applications for this gas boiler technology are for high efficiency commercial boilers and humidifiers as a forced draft system and for high efficiency residential furnaces as an induced draft system.

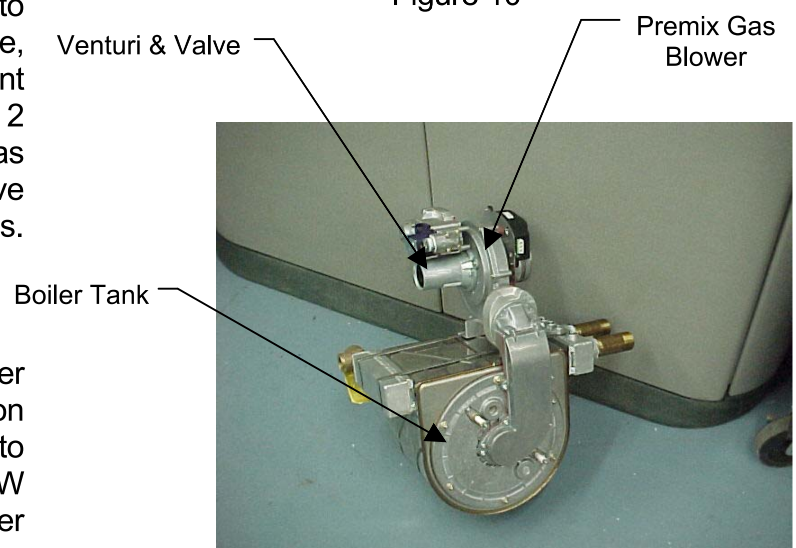
The concept of condensing boilers typically results in premium efficiencies when operated at 25-60% of full load. The higher thermal efficiencies (>90%) result in lower flue temperatures that lack thermal lift and, therefore, benefit from the high-pressure capabilities of the blower. In addition, the modulating blower/burner technology is advantageous to boiler systems with small tanks that demand precise and quick response to re-charge its reserves (see Figures 10 and 11).

Because the technology is relatively new to North America, other sector markets are just beginning to develop applications too. For example, the commercial food service equipment manufacturers find lower pressure, 1 or 2 speed shaded pole motors using a gas tight housing with a combination gas valve venturi suitable for many new applications.



European Gas-Fired Boiler

Figure 10



Gas-Fired Boiler with Special Venturi & Valve System

Figure 11

Summary of Benefits

In summary, the benefits of this blower technology include full speed modulation and monitoring, turn-down ratios up to 10:1, blower systems rated up to 450 kW (~1,500,000 Btu/hr), low power consumption due to high motor efficiencies, gas-tight and anti-spark construction, and lower burner emissions (NOx and CO) with reduced excess air and improved air-fuel controlled mixing.

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