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(54) **High efficiency fuel injection system for gas appliances**

(57) A unique control system is provided for optimizing and effecting efficient combustion of gas appliances by controlling the proportion of fuel and air variables. The control system provides continuous active feedback of the combustion event by detecting the level of exhaust gases such as CO_2 to trigger the modulation of a gas valve. Based upon the detected level, a control signal is generated by the system and received by a processor to adjust pressure and gas flow for future combuation events. Accordingly, the control System varies the proportion of air to fuel inflow to a prescribed optimum range thereby achieving efficient fuel combustion.

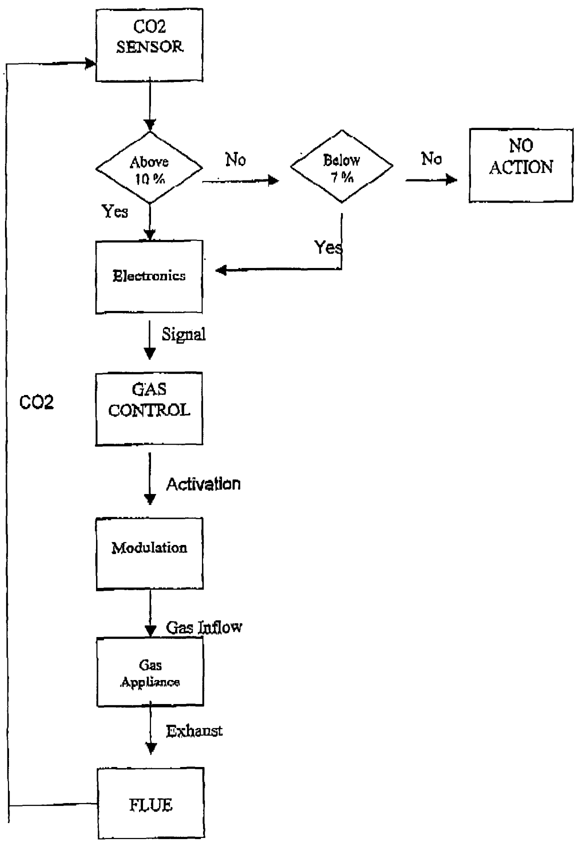

FIG 5

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Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to an improved method and apparatus for improving the efficiency of gas appliances.

[0002] Gas appliances such as water heaters, floor heaters, space heaters, room heaters, boilers, central furnaces, clothes dryers and cooking ranges, have gained wide acceptance with the consuming public. Conventional gas heating appliances typically employ manually operated gas valves to regulate and control gas flow to burners for combustion to generate heat from the burning of natural or propane gas.

[0003] The fixed orifice in a conventional gas valve, however, is not capable of continuous active adjustment of pressure and flow rate of gas into the burner resulting in inefficient combustion, i.e., too little heat and too much exhaust generated from a gas-heating appliance.

[0004] Excessive gas flow with inadequate air in the combustion mixture, or vise versa, will cause less heat and excess exhaust. Moreover, various ambient conditions such as altitudes in different parts of the world, are variable factors that can contribute to combustion efficiency. The components of conventional gas heating appliances are generally fixed and not self-adjusting to account for these various ambient conditions.

[0005] Those skilled in the art have recognized a significant need for a variety of control systems that improved the efficiency of the fuel combustion of gas appliances.

[0006] U.S. Patent No. 6,398,118 issued to Rosen, et al., discloses a system for monitoring and modifying the quality and temperature of air within a conditioned space including a blower unit, a damper unit for selectively admitting outside air into the conditioned space, a temperature moderating unit and a control unit.

[0007] The Rosen system relates to the art of conditioning indoor living and working and other enclosed public spaces. More particularly, the patent discloses a system in which the carbon dioxide (CO_2) level is monitored and controlled by apparatus in which the CO_2 sensor and support circuitry is integral with a thermostat which also serves to conventionally control the temperature range within the conditioned space.

[0008] The principle of operation of the CO_2 sensor is stated to be that, the cell constituting the cathode, anode and solid electrolyte, becomes susceptible to readily measurable change in accordance with the CO_2 concentration at the cell. This known effect appears to be due to a chemical reaction between the CO_2 and the electrolyte which must be selected to enhance the extent of the change in accordance with the gas of interest. Combinations of electrodes and electrolytes suitable for the purpose are discussed, for example, by S. Azad, S.A. Akbar, S.G. Mhaisalkar, L.D. Birkefeld and K.S. Goto in the Journal of the Electrochemical Society, 139, 3690 (1992). One suitable combination, which gives very good results for measuring CO_2 concentration is: platinum (Pt) for the cathode, reference electrode 30; silver (Ag) for the anode, sensing electrode 31; and a mixture of $Na_2\ CO_3$, $BaCO_3$ and $AG_2\ SO_4$ as the solid electrolyte.

[0009] U.S. Patent No. 6,286,482 issued to Flynn, et al., discloses a premixed charge compression ignition engine, and a control system, which effectively initiates combustion by compression ignition and maintains stable combustion while achieving extremely low oxides of nitrogen emissions, good overall efficiency and acceptable combustion noise and cylinder pleasures. The Flynn engine and control system effectively controls the combustion history, that is, the time at which combustion occurs, the rate of combustion, the duration of combustion and/or the completeness of combustion, by controlling the operation of certain control variables providing temperature control, pressure control, control of the mixture's autoignition properties and equivalence ration control. The combustion control system provides active feedback control of the combustion event and includes a sensor, e.g. pressure sensor, for detecting an engine operating condition indicative of the combustion history, e.g. the start of combustion, and generating an associated engine operating condition signal. A processor receives the signal and generates control signals based on the engine operating condition signal for controlling various engine components to control the temperature, pressure, equivalence ration and backlash or autoignition properties so as to variably control the combustion history of future combustion events to achieve stable, low emission combustion, in each cylinder and combustion balancing between the cylinders.

[0010] The Flynn patent discloses a strategy for controlling the start and direction of combustion by varying the air/fuel mixture autoignition properties. The autoignition properties of the air/fuel mixture may be controlled by injecting gas, e.g. air, oxygen, nitrogen, ozone, carbon dioxide, exhaust gas, etc., into the air or air/fuel mixture either in the intake system.

[0011] U.S. Patent No. 6,392,536 issued to Tice, et al. discloses a multi-function detector which has at least two different sensors coupled to a control circuit. In a normal operating mode the control circuit, which would include a programmed processor, processes outputs from both sensors to evaluate if a predetermined condition is present in the environment adjacent to the detector. In this mode the detector exhibits a predetermined sensitivity. In response to a failure of one of the sensors, the control circuit processes the output of the remaining operational sensor or sensors so that the detector will continue to evaluate the condition of the environment with substantially the same sensitivity.

[0012] U.S. Patent No. 5,644,068 issued to Okamoto, et al. discloses a gas sensor of the thermal conductivity type suitable for the quantitative analysis of the fuel vapor content of a fuel-air mixture. The Okamoto gas sensor comprises a sensing element and a compensating element, each of which includes an electrically-heated hot member incorporated into a Wheatstone bridge circuit powered by a constant current supply circuit. The constant current supply circuit is adjusted and regulated such that the hot member of the sensing element is heated with an electric current of such an intensity that corresponds to a point of transition (Y) at which, at the interface of the hot member and the mixture, the predominant mode of heat transfer changes from thermal conduction to natural convection.

[0013] The disclosures of the foregoing patents are hereby incorporated by this reference.

[0014] While recognizing the advantages of control systems utilizing exhaust gases as possible parameters to improve efficiency, these systems do not provide the critical recognition of exhaust gas concentration levels, such as carbon dioxide, for continuous active feedback control of future combustion evente. The present invention achieves these goals.

SUMMARY OF THE INVENTION

[0015] A unique control system is provided for optimizing and for effecting efficient combustion of gas appliances by controlling the proportion of fuel and air variables. The combustion control system provides continuous active feedback control of the combustion event by detecting the level of exhaust gases such as CO_2 within a prescribed optimum range. The system comprises a qualitative and quantitative sensor and processor to trigger the modulation of a valve to adjust pressure and gas flow to combustion chamber of gas appliance, when the concentration of the detected gas falls outside the prescribed optimum range. Accordingly, the control signal varies the proportion of air to fuel inflow to a prescribed optimum range for future events thereby achieving efficient fuel combustion.

[0016] The present invention achieves improved combustion efficiency by adjustment of pressure and fuel flow related to changing ambient conditions. In a presently preferred embodiment, the inventive system comprises a CO_2 sensor to continuously measure the concentration level of carbon dioxide of the combustion chamber. The sensor generates a signal, including detected qualitative and quantitative measurements, that is received by a microprocessor. The processor, in turn, compares the received sensor signal with prescribed levels, and determines whether to adjust a pressure regulator of a gas valve to bring the air/fuel mixture to a prescribed optimum range for future combustion events.

[0017] In one embodied form, the system comprises active feedback control means based upon detection of the concentration of carbon dioxide. Assuming fixed exhaust gas flow from combustion, the prescribed concentration level of carbon dioxide gas for optimum efficiency is within a range of about seven and one half percent (7.5%) to about eight percent (8%). Accordingly, if for example, the sensor detects a concentration level of nine percent (9%) carbon dioxide, the control means will accordingly decrease the air flow into the burner of the gap appliance. If the concentration of carbon dioxide in the exhaust gas is less than seven percent (7%), the control means will proportionately increase the intake air flow to the combustion chamber. Thus greatest combustion efficiency can be achieved by monitoring and maintaining the concentration of carbon dioxide within the prescribed range.

[0018] In a second embodiment, the inventive system comprises a CO_2 sensor, CO sensor, O_2 sensor to trigger the modulation of gas valve to adjust pressure of gas pressure and gas flow to combustion chamber of gas appliance. In operation, modulation will take place, should the detected carbon dioxide concentrate within the gas mixture falls outside a specified range of concentration. Modulation of the inventive gas valve can be to such an extent to minimize gas flow to future combustion events.

[0019] The inventive system comprises a processor that receives the qualitative and quantitative signal from the carbon dioxide sensor and provides feedback control to an electronic control unit (ECU). ECU receives the sensor signal and processes the signal to determine the appropriate adjustment, if any, to the flow of air to be mixed with fuel for combustion in the burner unit. The signal reflecting the carbon dioxide concentration in the exhaust gas is then compared to a predetermined database of desired airflow adjustment values. Based on the comparison of the actual airflow to the desired airflow adjustment value, the ECU then generates a plurality of output signals, for variably controlling a pressure regulator of a gas intake flow valve and other respective components of the system so as to effectively ensure, that the future carbon dioxide concentration in the exhaust gas is maintained within the prescribed optimum range.

[0020] The combustion control scheme is most preferably implemented in software contained in ECU that includes a central processing unit such as a micro-controller, micro-processor, or other suitable micro-computing unit. Accordingly, the unique system achieves high efficiency combustion in a wide variety of gas heating appliances.

BRIEF DESCRIPTION OF THE DRAWING

[0021] Figure 1 is a cross-sectional side view of one embodied CO_2 sensor and Pitot tube in accordance with the present invention.

[0022] Figure 2 is a side sectional view illustrating the system components and placement of a CO_2 sensor in the control processor in accordance with the present invention.

[0023] Figure 3 is a schematic sectional view depicting a gas valve in accordance with one embodied form of the invention.

[0024] Figure 4 is a schematic flow chart indicating the components and interaction of the high efficiency fuel injection system for gas appliances in accordance with the present invention;

[0025] Figure 5 is a schematic flow diagram of one embodied form of the inventive system and further indicating the levels of CO_2 detected to activate the modulation of the inventive gas valve to adjust pressure and flow of gas to the combustion chamber in accordance with one embodied form of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0026] A unique control system is provided for gas appliances to achieve efficient combustion by controlling the proportion of fuel and air variables. The combustion control system provides active feedback control of the combustion event and includes a CO_2 to trigger the modulation of a gas valve to adjust pressure of gas pressure and gas flow to combustion chamber of gas appliance. Detection of other combustion gases such as carbon monoxide and oxygen may also be utilized by the system, with carbon dioxide gas being the principal gas for triggering the modulation of the gas valve. A microprocessor receives the concentration signals from the sensors and generates control signals based on the concentration signal for controlling a pressure regulator of the gas valve so as to variably control future combustion events to achieve maximum fuel combustion efficiency. Accordingly, the control signal varies the proportion of air to fuel inflow to a prescribed optimum range achieving efficient fuel combustion.

[0027] In a presently preferred embodiment, the present invention provides an improved method and apparatus for achieving high efficiency of combustion by comprising active feedback control means based upon detection of the concentration of carbon dioxide within the prescribed optimum range of about 7.5% to about 8.0%. Assuming fixed exhaust gas flow from combustion, if the concentration level of carbon dioxide exceeds about nine percent (9%), the control means will accordingly decrease the air flow into the burner of the gas heating appliance. If the concentration of carbon dioxide in the exhaust gas is less than seven percent (7%), the control means will proportionately increase the intake air flow to the combustion chamber. Thus greatest combustion efficiency can be achieved by monitoring and maintaining the concentration of carbon dioxide within the prescribed range.

[0028] In a second embodiment, the inventive system comprises a CO_2 sensor, CO sensor, and O_2 sensor to trigger the modulation of gas valve to adjust pressure of gas pressure and gas flow to combustion chamber of gas appliance. In operation, modulation will take place if the CO_2 content of the gaseous mixture falls outside the prescribed range of concentration. For instance, in the case of CO_2, modulation is within the range of 7 percent to 9 percent. Gas pressure and flow will be adjusted in responding to changes of concentration, before CO_2 reaches 7 percent or 9 percent. Actually, modulation of gas value can be to such an extent to minimize gas flow.

[0029] The sensor module provides a O-4VDC output scaled to 0-2000 ppm CO_2. The sampling method for detection of the carbon dioxide concentration may be wither flow through or diffusion and can be configured to measure ppm levels up to 5%. The modules include self-calibration algorithm that eliminates the need for on-going calibrations.

[0030] The CO sensor is operational to trigger the modulation of gas valve to lower the amount of gas flow to combustion chamber of gas appliance. If the concentration is less than 65 PPM, the sensor is not activated. Preferably, the CO sensor accumulates concentration up to 65 PPM of carbon monoxide in one hour.

[0031] The O_2 sensor is operational to trigger the modulation of gas valve to lower the amount of gas flow to combustion chamber of gas appliance. If the level is over 19.5 percent, the sensor is not activated.

[0032] The system may use conventional shut off mechanims for instance disclosed in US Patent No. 5838243, which is hereby incorporated by this reference.

[0033] After generating the sensor concentration signal, the control processor will determine the desired adjustment of air inflow by setting the pressure regulator of a gas valve to a prescribed optimum range.

[0034] The modulating gas valve will preferably comply with applicable industry and governmental standards. e.g. AGA Requirements for automatic, non-shutoff modulating gas valves No. 1-92 (1992) which is hereby incorporated by this reference.

[0035] This standard applies to produced automatic modulating valves, herein after referred to as valves, hereinafter referred to as valves, and the valve control system, constructed entirely of new, unused parts and materials. These valves may be individual valves, valves utilized as parts of automatic gas ignition systems, or the modulating valve functions of combination controls.

[0036] These valves are intended to be used to vary the gas input rate to the appliance, as a function of the signal from the gas valve control system. These valves are not intended to provide for complete shutoff of the gas flow to the main burners.

[0037] Those skilled in the art will recognize that the inventive system is capable of activation and modulation by detection of carbon dioxide levels, within a prescribed range of from about 6% to about 10%.

[0038] The following summary provides the modulation parameters to improve combustion efficiencies:

Activation:

[0039]

- Range of sensor between about 6% to 10% of CO_2 concentration
- .5% of CO_2 changes would activate gas control to modulate outlet pressure by .36" W.C. to .39" W.C.
- If 9% of CO_2 by the sensor, gas control would modulate pressure downward to 2.87" W.C. from 4.0" W.C.
- If 6.5% of CO_2 by the sensor, gas control would modulate pressure upward to 4.25" W.C. from 4.0" W.C.

[0040] Typically, the mechanisms of valves will be protected by substantial enclosures so as to prevent interference with the safe operation of the devices.

[0041] Pins, stems, or other linkage passing through the valve body or casing shall be sealed to provide gastight construction.

[0042] Diaphragm type automatic valves in which a flexible nonmetallic diaphragm constitutes the only gas seal and which utilise control gas on the atmospheric side of the diaphragm shall have the atmospheric side of the main diaphragm enclosed in a gastight casing with means provided for bleeding the control gas.

[0043] Valves in which a flexible nonmetallic diaphragm constitutes the only gas seal shall have the atmospheric side of the diaphragm enclosed to limit the leakage to atmosphere in the event of diaphragm rupture to not more than 1.0 cubic foot per hour at the maximum pressure rating of the valve when tested with a gas having a specific gravity of 1.55 or shall be provided with means for venting the gas in the event of diaphragm rupture.

[0044] The CO_2 Sensor module communicates over an synchronous, UART interface at 9600 baud, no parity, 8 data bits, and 1 stop bit. When the host computer of PC communicates with the sensor, the host computer sends a request to the sensor, and the sensor returns a response. The host computer acts as a master, initiating all communications, and the sensor acts as a slave, responding with a reply.

[0045] Preferably, sensor commands and replies are wrapped in a secure communications protocol to insure the integrity and reliability of the data exchange. One suitable communications protocol for the serial interface and the command set for the module CO_2 Sensor are set forth below.

[0046] Each command to the sensor consists of a length byte, a command byte, and any additional data required by the command. Each response from the sensor consists of a length byte and the response data if any. Both the command to the sensor and the response from the sensor are wrapped in a communications protocol layer.

Command: <length><command>additional_data>

Response: <length><response_data>

[0047] The communications protocol consists of two flag bytes (0xFF) and an address byte as a header, and a two-byte CRC as a trailer. In addition, if the byte 0xFF occurs anywhere in the message body or CRC trailer, the protocol inserts a null (0x00) byte immediately following the 0xFF byte. The inserted 0x00 byte is for transmission purposes only, and is not included in the determination of the message length or the calculation of the CRC.

Header	Message Body	Trailer
<flag><flag><address>	<Command/Response>	<crc_lsb><crc_msb>

[0048] When receiving a command or response, the flags and any inserted 0x00 bytes must be stripped from the message before calculating the verification CRC. A verification CRC should be computed on all received messages from the sensor and compared with the CRC in the massage trailer. If the verification CRC matches the trailer CRC, then the data from the sensor was transmitted correctly with a high degree of certainty.

[0049] In response to the concentration signal from the sensor module the air flow from a gas valve will be adjusted by pressure regulator before it flows to burner, prior to combustion chamber. If concentration of carbon dioxide is more than 9 percent (9%), gas flow will be adjusted upward to increase its mixture with air, and if concentration of carbon dioxide is less than 7 percent (7%), gas flow will be adjusted downward to decrease its mixture with air.

[0050] Figure 4 is a schematic flow chart indicating the components and interaction of the high efficiency fuel injection system for gas appliances in accordance with the present invention;

[0051] Figure 5 is a schematic flow diagram of the inventive system and further indicating the levels of CO_2 detected to activate the modulation of the inventive gas valve to adjust pressure and flow of gas to the combustion chamber in accordance with one embodied form of the present invention.

[0052] In the CO_2 module, a bus interfaces to both an external processor and the A/D converter which is collecting the CO_2 data. When the module is collecting data, its serial shift clock is configured to generate its own internal clock. That is, the module is said to be operating in "master" mode. When the CO_2 module is communicating with an external processor, it relies upon the external processor to supply the clock pulse, called the "slave" mode.

[0053] Thus, to an external process, the CO_2 module appears as a slave on the bus. The external processor is the master, meaning that it provides the SK clock signal for both sending and receiving data across the bus. From the CO_2 module's point of view, during communications with an external processor, is SI (serial in) and SK (serial clock) are inputs, and its SO (serial out) is an output. Additionally, there are two digital handshake lines that an external processor uses to communicate with the CO_2 module.

[0054] Every data exchange between an external processor and the CO_2 module starts with the external processor sending a request data-packet--several, bytes--to the CO_2 module. The CO_2 module then responds by returning a response data-packet to the external processor. The request data packet contains a command byte, and perhaps one or more parameter bytes.

[0055] After receiving each byte in a request data packet, the CO_2 module raises the UB_ACK handshaking line. When it is ready to receive the next byte it lowers UB_ACK. The external processor must send the next byte to the CO_2 module within 10 milliseconds from the time the UB_ACK line goes low. This handshaking between bytes provides flow control and insures that the external processor does not overrun the CO_2 module's input buffer and that the CO_2 module does not wait indefinitely for the external processor to send the next byte. After receiving the final byte of the request data-packet, the CO_2 module again raises UB_ACK.

[0056] When the CO_2 module has processed the request and is ready to send the first byte of the response data-packet, the CO_2 module lowers UB_ACK. The external processor has 10 milliseconds from the time the UB_ACK lines goes low in order to start the clock and receive the byte. After transmitting the byte, the CO_2 module raises UB_ACK, and lowers it again when it is ready to transmit the next byte. The process continues until all bytes of the response data-packet have been transmitted to the external processor. The 10 millisecond time limit insures that the CO_2 module does not wait indefinitely for the external processor to start the clock to receive the byte.

[0057] After sending the final byte in a response, the CO_2 module raises UB_ACK and leave it high. The external processor then raises UB_REQ, concluding the data interchange. UB_REQ must stay high longer than a specified minimum before the external processor lowers it to start the next data exchange.

[0058] At the conclusion of a response data packet, the CO_2 module will wait approximately 100 milliseconds after the final UB_ACK goes high before initiating its return to master mode and the resuming of data collection. If the external processor raises and lowers UB_REQ during this delay interval, the module stays in slave mode and immediately services the new request. The delay interval gives the external processor the opportunity to send a series of commands in rapid succession to the module. Note that the CO_2 module is not functioning as a sensor while it is in the slave mode.

[0059] The raising of UB_REQ, together with the expiration of the delay time interval, is the signal to the CO_2 module to return to Microwire master mode and resume its A/D converter data collection. Microwire mode conversion and re-initialization for data collection is a time consuming process, and the module has only three opportunities during the process to abort and respond to a new UB_REQ. Hence, for non-PPM/Temperature request, it is most time-efficient to start the next UB-REQ during the delay interval following the previous request.

[0060] If the external processor needs to terminate an incomplete data exchange it raises the UB_REQ line. When the CO_2 module see this, it discards the contents of its communication buffers and then respond by raising the UB_ACK.

[0061] If the CO_2 module needs to terminate an incomplete data exchange, it raise UB_ACK. If UB_ACK remains high longer than the maximum time specified for UB_ACK High Between Bytes, then the external processor must recognize this as termination of an incomplete data exchange. For example, if the CO_2 module receives bytes that do not correspond to a valid request data-packet then it raises UB_ACK and holds it high, signaling termination of an incomplete data exchange.

[0062] The CO_2 module starts a 10 millisecond timeout timer each time it lowers UB_ACK. The external processor must respond by starting the serial shift clock within this interval so that the module can transmit or receive the pending byte. If the external processor fails to start the clock, the CO_2 module presumes that the communication has been aborted and will raise UB_ACK.

[0063] If either the external processor or the CO_2 module terminates a data exchange, no new communication can be initiated until both UB_ACK and UB_REQ have return to the high state. The new command then starts with the external processor lowering UB_REQ as described above.

[0064] The inventive system comprises a processor that receives the qualitative and quantitative signal from the carbon dioxide sensor and provides feedback control to an electronic control unit (ECU). ECU receives the sensor signal and processes the signal to determine the appropriate adjustment, if any, to the flow of air to be mixed with fuel for combustion in the burner unit. The signal reflecting the carbon dioxide concentration in the exhaust gas is then compared to a predetermined database of desired airflow adjustment values. Based on the comparison of the actual airflow to the desired airflow adjustment value, the ECU then generates a plurality of output signals, for variably controlling a pressure regulator of a gas intake flow valve and other respective components of the system so as to effectively ensure, that the future carbon dioxide concentration in the exhaust gas is maintained within the prescribed optimum range.

[0065] The combustion control scheme is most preferably implemented in software contained in ECU that includes a central processing unit such as a micro-controller, micro-processor, or other suitable micro-computing unit. Accordingly, the unique system achieves high efficiency combustion in a wide variety of gas heating appliances.

[0066] The following example provides the presently preferred parameters for achieving high efficiency combustion:

EXAMPLE

General

[0067]

- 02 reaches 18.2%, CO is present dangerous level of 80PPM per hour. In testing, 18% of O2, CO detector still shows 43PPM per hour.
- Accuracy of CO sensor alone, without CO_2 sensor) cannot be counted for real application.
- Monitoring CO2 concentration is preferred to measure and monitor for combustion efficiency of a gas heating appliance.

Function Required for Gas Control

[0068]

- Range of Regulation; minimum 20,000 BTU per hour, maximum 200,000 BTU per hour
- Operating Inlet pressure: max. 1/2 PST, Natural gas 7.0" w.c., LP 11.0" W.C.
- Range of Modulation: Natural gas 1.7"-4" w.c. +/-.3" w.c., LP 5"-10" w.c. +/-.5" w.c.

Mechanical Requirement for Gas Control:

[0069] 1/2" or 3/4" Inlet and Outlet

Electrical Requirement

[0070]

- Gas Control: 24 VAC
- Sensor: 5 VDC, Analog output: 0 -4 VDC
- Modulation: 5 VDC

Configuration: Furnace T1. Sampling system T2, Sensor T3

[0071]

- Copper Tubing needs to be short to minimize differential of T1 and T2, dia. of .25" to .5"
- Copper Tubing in vertical coil to cool the flue down to 140 degreed F. and remove condensation
- At 1cc/min. flow rate of CO2 sapling from T1, through T2, to T3

Operation Requirement

[0072]

- Preferred range of CO2 concentration for optimum combustion efficiency is about 7.5% to 8.0%
- If 9% of CO2, outlet gas pressure should be modulated downward from 4.0" to 2.97"
- If 6.5%, outlet gas pressure should be modulated upward from 4.0" to 4.5" w.c.
- If 9.5%, outlet gas pressure should be modulated downward by 1" w.c.
- A .5% change of CO_2 would result in a modulation of outlet pressure by .36 - .39" w.c.

Sensor

[0073]

- Power consumption: 150mA peak, 30mA average. Power supply 5VDC +/-5%.

- Range of measuring: 7% to 11%, accuracy +/-5% of reading
- Gravity flow rate of CO_2 is 1cc per minute
- Operational temperature is 10 to 185 degrees F., relative humidity 0 to 100%, non-condensing
- Warm Up Time: 20 minutes
- Response Time: TBD as it is up to length of tubing, its area, and flow rate of 1cc/minute
- Step Response Time (to 90% of the step - 5 minutes

Claims

1. A control system for optimizing and for effecting efficient combustion of fuel by a gas appliance, the system comprising in combination:

   a) means for qualitative and quantitative determination of combustion exhaust gas from the gas appliance;
   b) sensor means for detecting the concentration of carbon dioxide present in the combustion exhaust gas;
   c) means converting the detected concentration of carbon dioxide to a digital detected value signal for relay to a central processor unit;
   d) means for comparing the digital detected value signal with a prescribed range of optimum concentration values of carbon dioxide;
   e) means for calculating a correction factor to detected value signal within the prescribed range of optimum concentration values; and converting the detected value signal to a prescribed value signal; and
   f) means for directing the signal derived from step e) to a regulator valve for adjusting the concentration of fuel and air mixture for future combustion events.

2. The control system for optimizing and for effecting efficient combustion as defined in Claim 1, wherein the prescribed range of optimum concentration values of carbon dioxide is from about 6% to about 10%.

3. The control system for optimizing and for effecting efficient combustion as defined in Claim 1, wherein the prescribed range of optimum concentration values of carbon dioxide is from about 7.5% to about 8.0%.

4. The control system for optimizing and for effecting efficient combustion as defined in Claim 1, wherein the sensor means for detecting the concentration of carbon dioxide also comprises sensor means for detecting the concentration of carbon monoxide present in the combustion exhaust gas.

5. The control system for optimizing and for effecting efficient combustion as defined in Claim 1, wherein the sensor means for detecting the concentration of carbon dioxide also comprises sensor means for detecting the concentration of oxygen present in the combustion exhaust gas.

6. The control system for optimizing and for effecting efficient combustion as defined in Claim 1, wherein said means for comparing the digital detected value signal with a prescribed range of optimum concentration values performs the comparison intermittently over time.

7. The control system for optimizing and for effecting efficient combustion as defined in Claim 1, wherein said means for comparing the digital detected value signal with a prescribed range of optimum concentration values performs the comparison on an continuous basis.

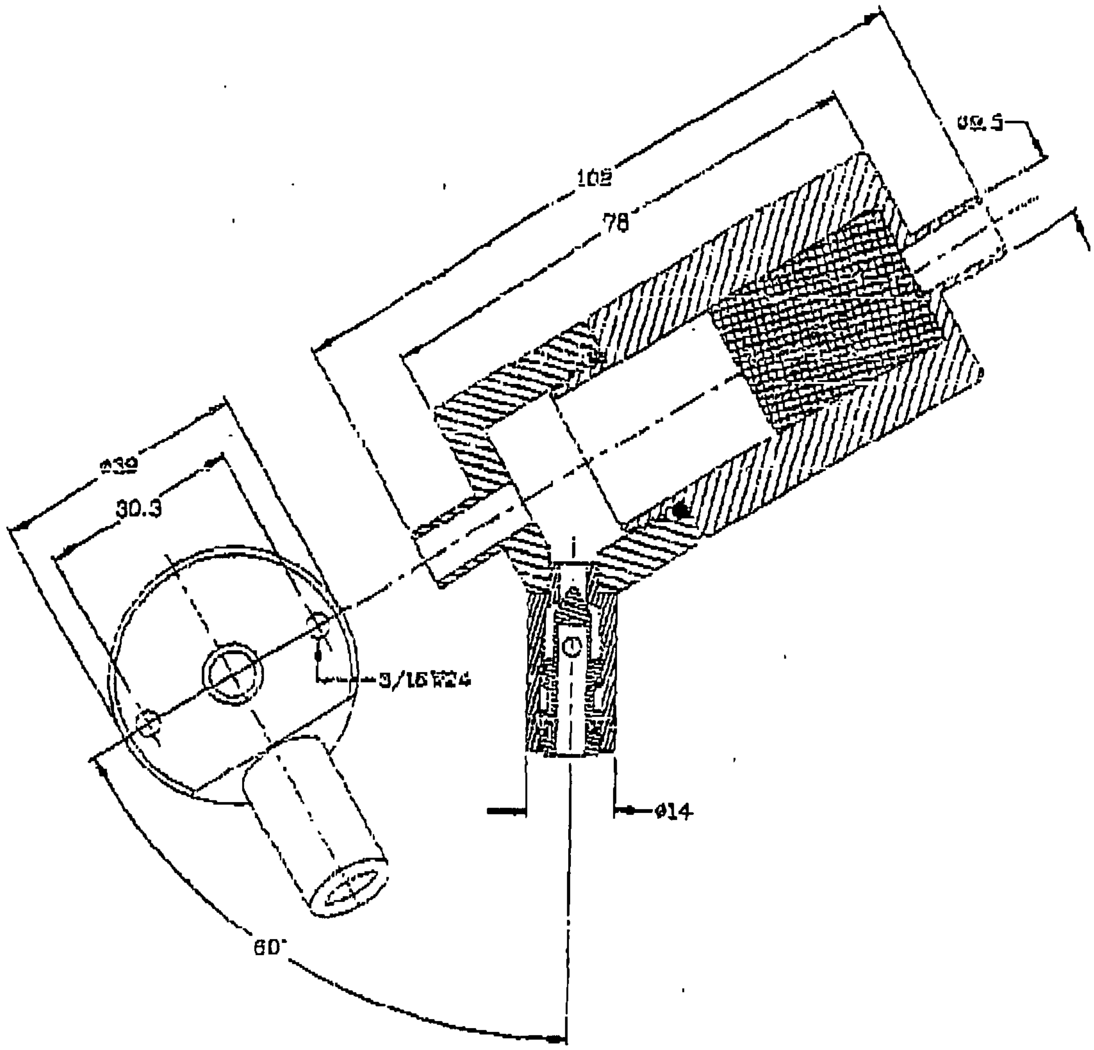

FIG 1

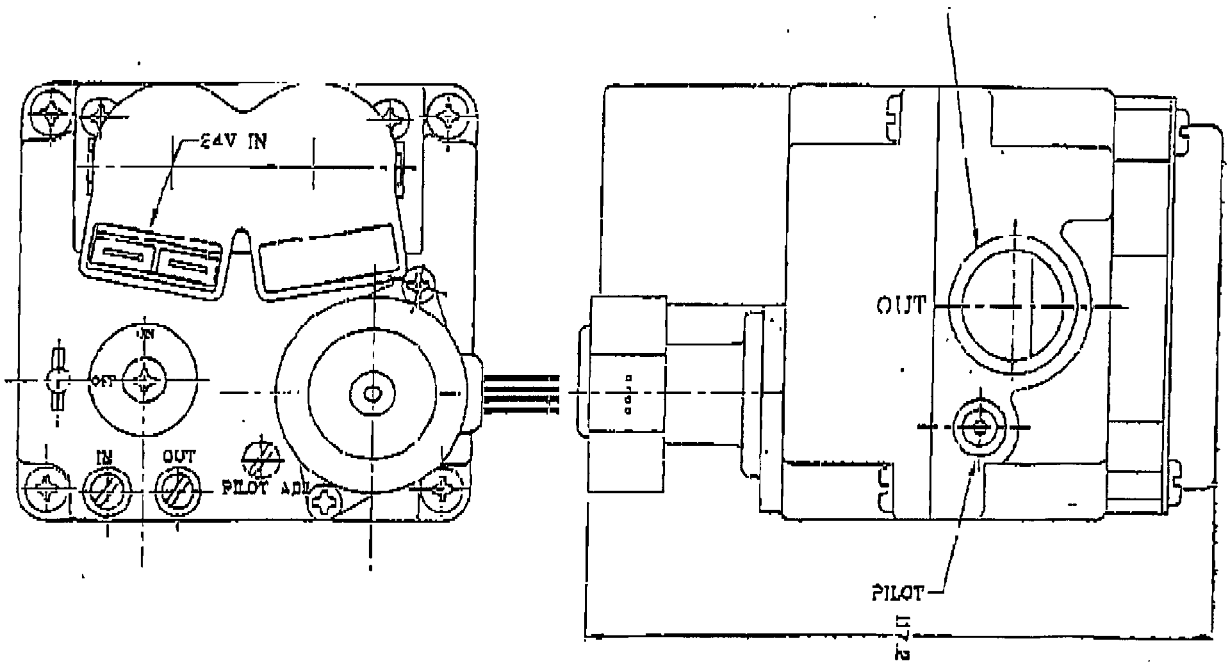

FIG. 2

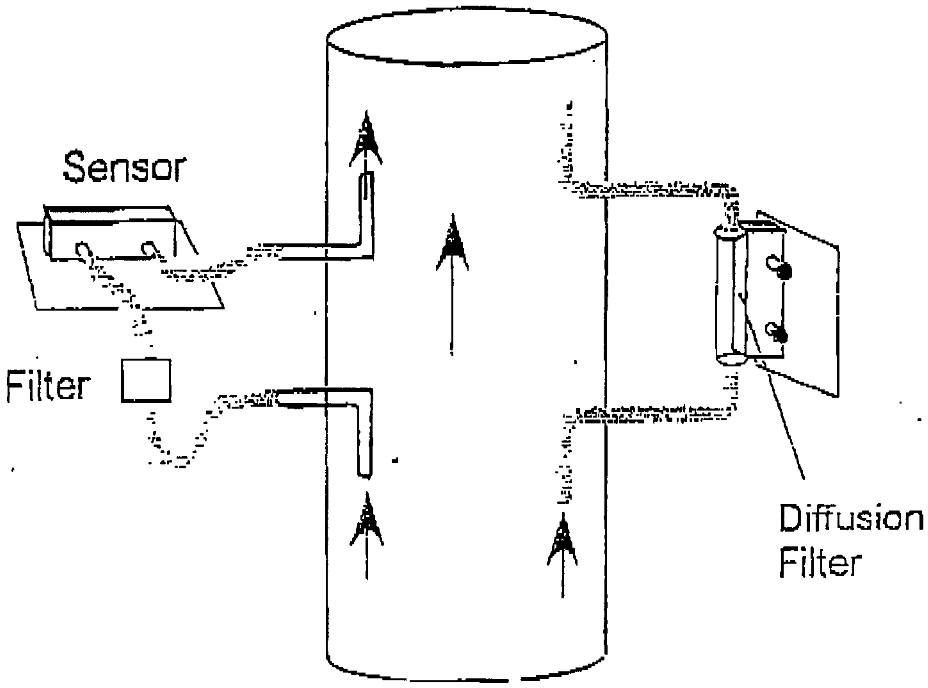

FIG. 3

FLOW CHART OF EFi

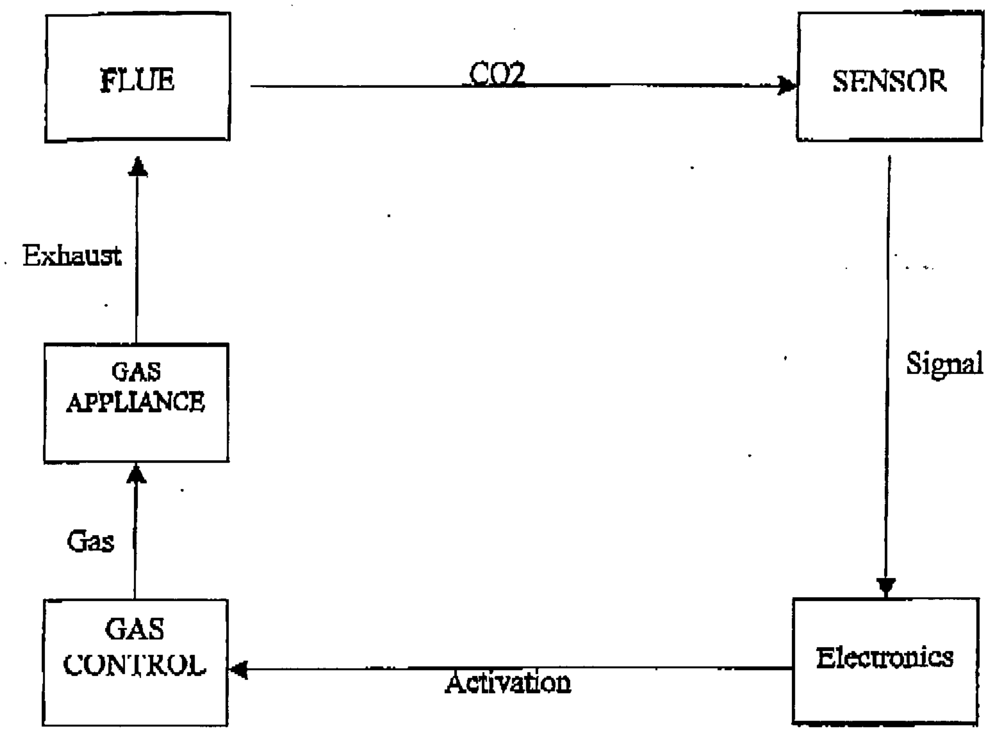

FIG 4

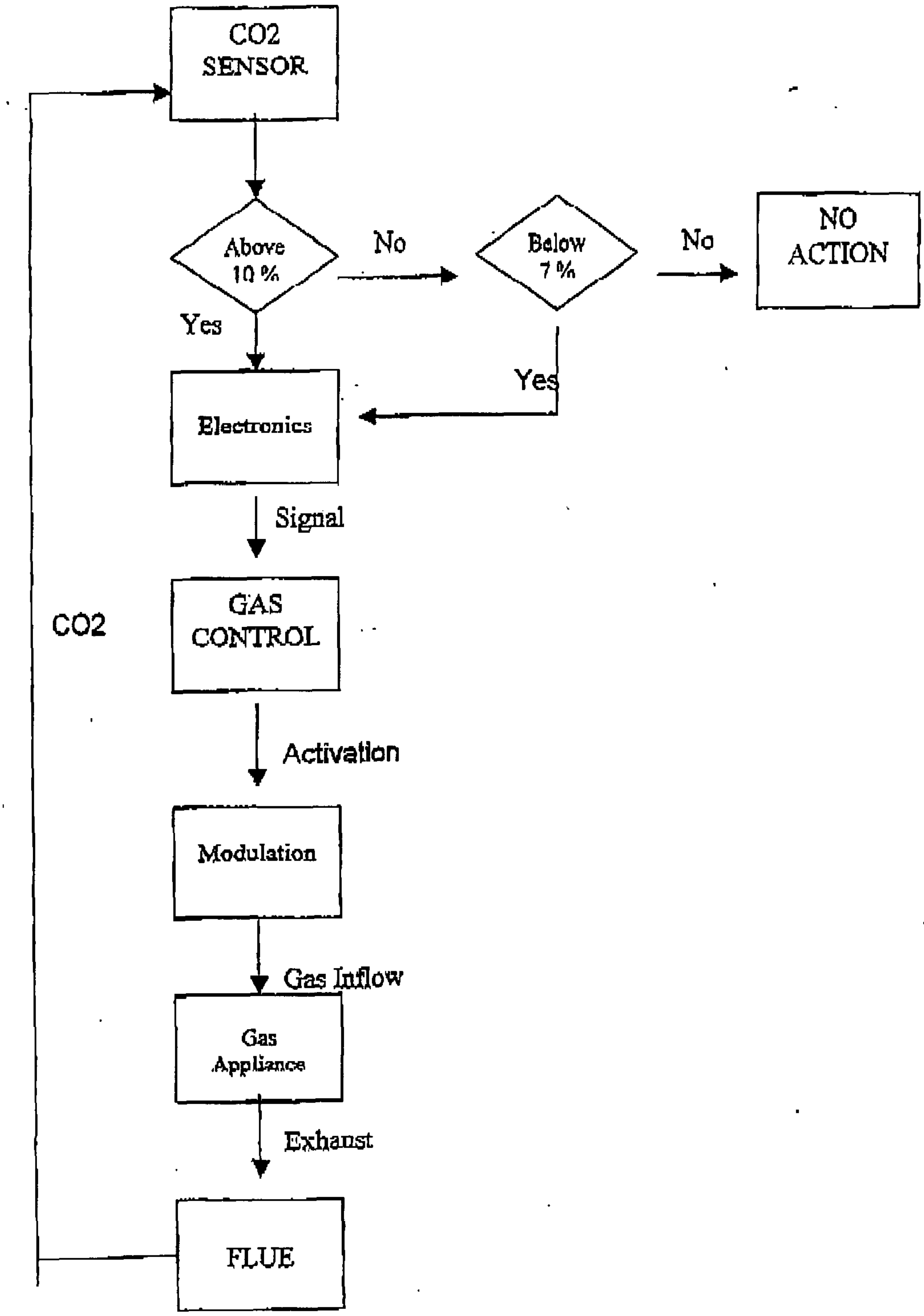
CO2 SENSOR
Above 10 %
No
Below 7 %
No
NO ACTION
Yes
Yes
Electronics
Signal
CO2
GAS CONTROL
Activation
Modulation
Gas Inflow
Gas Appliance
Exhaust
FLUE

FIG 5

REFERENCES CITED IN THE DESCRIPTION

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