Enhancing Combustion and Heat Exchange Through Electrical Augmentation

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ABSTRACT

We have observed that software-controlled propagation of insignificant amounts of electrical energy through a flame region enhances both combustion efficiency and the transfer of thermal energy in an electrically conductive burner and heat exchange system. ClearSign Precision Active Control™ technology processes signals and applies them to flames to create an augmented combustion state.

Manipulation of such a system, in response to predicted or observed events within the flame, allows electro-chemical (as opposed to mechanical) control of both the combustion and heat exchange processes. The result is dramatically reduced emissions and heat loss, and an increase in the thermal efficiency of the system.

Keywords: combustion, flame, coal, fuel, particulate, carbon

1 BACKGROUND

ClearSign Precision Active Control™ (PAC) technology can assert very precise control of carbon at formation, and can continue to control for optimum concentrations and particle sizes throughout the combustion and heat exchange process. ClearSign Active Heat Exchange™ technology uses electric field shaping to focus and direct the cloud of charged carbon particles to drive hot gases to the heat exchanger and maximize the use of the exchanger's surface area. Once the carbon has served its useful purpose, PAC is employed to precipitate the carbon particulate away from the reaction for recovery and resale, reducing or eliminating the need for downstream capture. It is believed that this technology enables such precise control over carbon that basic aspects of our process can be applied to the production of high value carbon products such as carbon fiber or carbon nanotubes.

The application of electrical current to a flame has been known for many years to impact the position, shape or stability of a flame and to create a so-called microgravity effect. Other applications have focused on generating wind effects for moving air without mechanical motors or preventing a flame from being lifted of the burner by strong convective forces.

What has not been well understood is that, in addition to the fundamental roles that oxygen, fuel and heat play in combustion reactions, electrons and electrical charge interplay feature prominently in the chemistry of combustion. Even the most sophisticated burners and combustion systems available today leave room for improvement in thermal efficiency, emissions, flexibility and reliability.

Control of electrically charged carbon particles, ions and electrons can provide the ability to optimize conditions for a variety of chemical reactions that in turn maximize the release of energy from the fuel and the delivery of heat to the load while minimizing emissions.

2 PRECISION ACTIVE CONTROL™

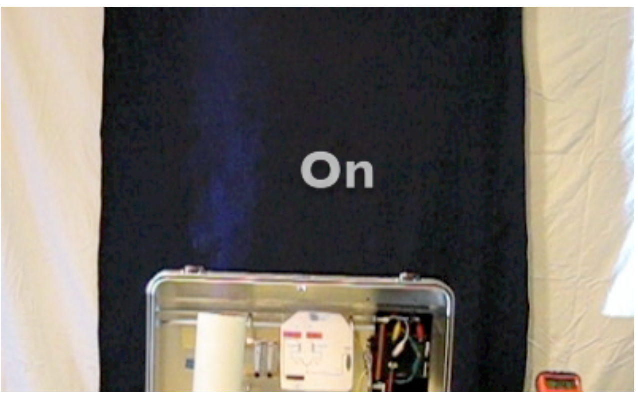
Precision Active Control centers on the delivery of micro-pulses of electrical energy into and through a flame region. These ultra-fast pulses are measured and timed to actively assist in the combustion process by precisely controlling the movement and location of electrons, ions, and charged carbon particles in order to maximize the potential for sustaining high-energy chain reactions and minimize the potential for such reactions to interfere with one another. Electrical energy is supplied by a novel high-voltage power conditioner source. Experiments to date have used very small amounts of current so that overall electrical power consumption is very low, resulting in a substantial net gain in thermal energy (BTU output) produced by the system. Typically, the energy used is about 1/1000 of the BTU content of the output of the flame.

Moreover, since the charge and mass of carbon particles as compared to a given species of ions produced in a combustion reaction vary greatly, the amplitude, duration, repetition rate and polarity of these micro-pulses must be varied accordingly and must be precisely controlled to properly optimize the combustion process.

This approach is enabled by advances in digital control hardware and software capable of the very fast response times required to generate such electrical pulses in a controlled fashion.

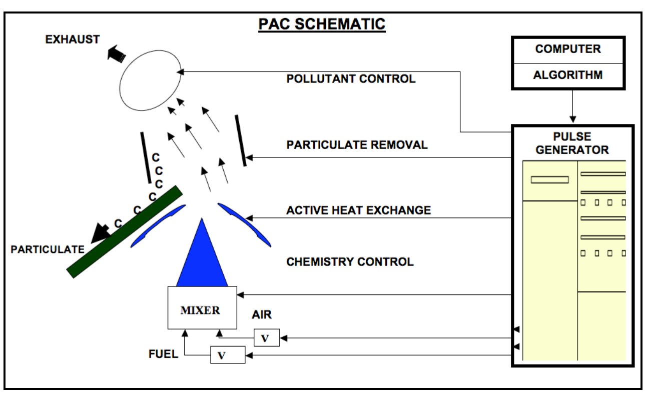
Fine control of charged chemical species allows more precise control of combustion reactions including controlling the formation, concentration and extraction of carbon, so that maximum heat energy is released from the fuel and delivered to the load, improving the thermal efficiency of a combustion system. Because the fuel has been more completely combusted and more carbon is under control, the escaping hot gases contain little or no particulate. The reduced particulate loading of the emissions also means that they will carry less heat energy out of the system.

Test system burning rubber, showing particulate emissions. PAC *disengaged*.



Test system immediately after PAC *engaged*. Particulate emissions are significantly reduced.

The ability to optimize heat generation and capture and then extract carbon to quickly cool the escaping stack gases can potentially greatly simplify the design of systems used to manage emissions or vent (exhaust) hot gases.



Precision Active Control Schematic

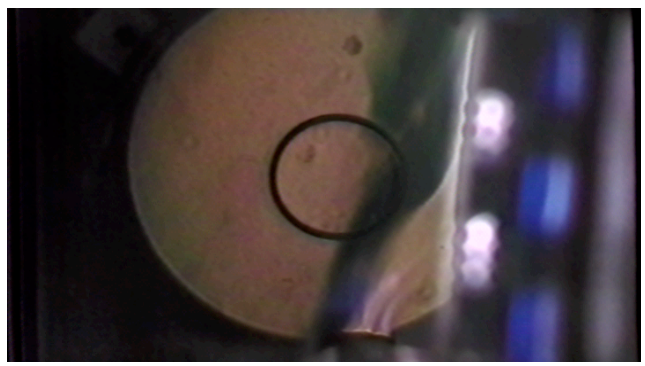
3 ACTIVE HEAT EXCHANGE™

The gain in thermal efficiency from more complete combustion at the burner is further compounded at the system level by asserting active control over the transfer of thermal energy into a heat collection or heat exchange system such as a boiler or furnace. We call this Active Heat Exchange.

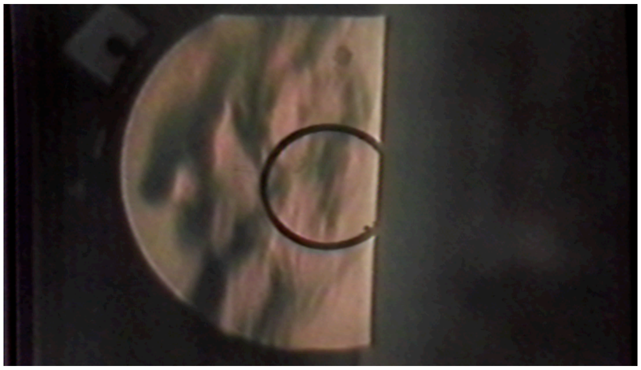
By shaping and manipulating electrical fields to actively focus heat and gases, the hot gases produced in combustion can also be shaped and steered. ClearSign Active Heat Exchange technology maximizes the transfer of heat into a heat collection or heat exchange system to extract maximum heat energy from the fuel combusted.

3.1 Manipulation of Flame and Hot Gases

In the images that follow, Schlieren interference photography is used to view heat (varied gas density verses normal gas density) shown as dark regions being issued above the flame. The examples below show excitation (system on verses off) using this technique. An "on" condition moves the heat to the grounded heat exchange surface. This effect can benefit thermal heat transfer in most types of heat exchange applications.



A Bunsen-type premixed flame is photographed using Schlieren photography to view the resulting hot gas produced by a flame. In this photo, the flame is excited with the resulting flame and hot gases (black portion of the image) being drawn to a metallic heat exchange surface to the right.

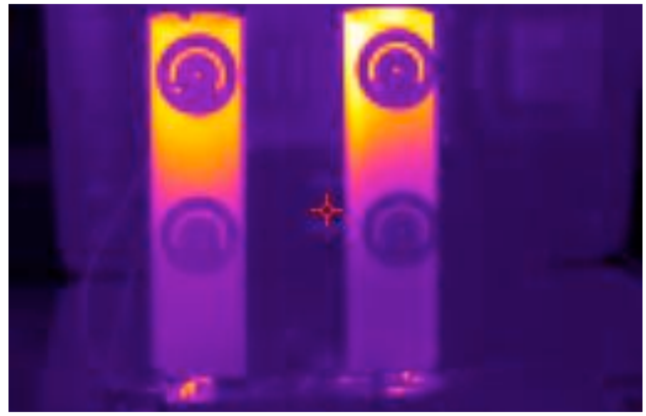


With no signal applied to the flame, a Schlieren photo taken 1.5 feet above the flame shows random distribution of heat with no attraction to the grounded heat exchange surface.

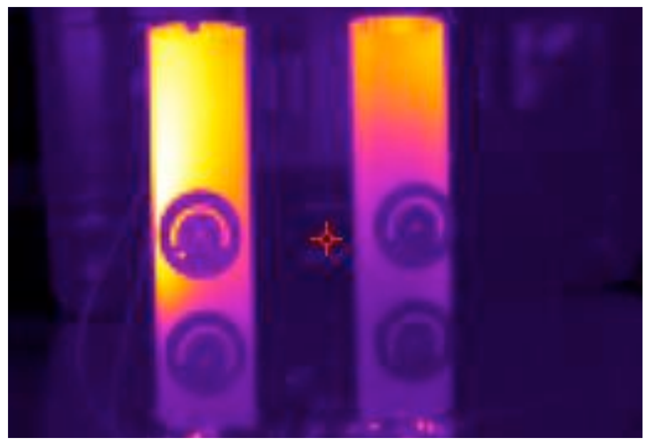
With a signal applied, the hot gases have a residual attractive force that moves the heat to the heat exchange surface. In addition, is it likely that the surface of the heat exchanger's double layer (the molecular layer that generally impedes heat transfer) is broken up, allowing a greater temperature differential to exist and thus more thermal energy to be transferred to the exchanger given a fixed surface area. The forces attracting the heat are electrostatic in nature.

3.2 Thermal Energy Applied to the Heat Exchange Surface

In this next set of IR images, a Fluke Ti20 Thermal Analyzer is used. The tests show that an equivalent amount of thermal energy can be provided to the left (excited) heat exchange surface as the right surface (non-excited), despite fuel flow to the excited exchange surface being only 50% that of the non-excited surface.



15 seconds into excitation. Circuit-engaged test (left) and control (right) stacks burning liquid propane gas, both at approximately 130ºF. Test stack fuel utilization is 0.2 acfh while control stack fuel utilization is 0.4 acfh.



One minute and 45 seconds into excitation. Fuel utilization remains unchanged at 0.2 acfh (left) and .04 acfh (right). Temperature in test (left) stack only has increased and is holding at 186ºF.

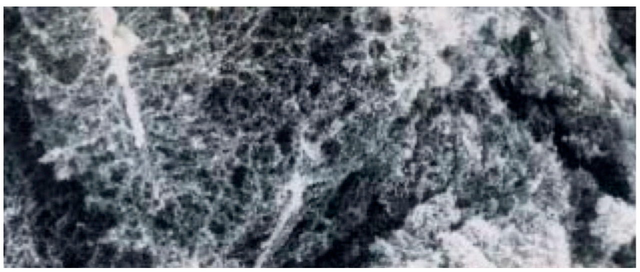
4 TEST DATA AND EXPERIMENTS

Current prototype systems have demonstrated that the application of PAC technology results in meaningful reduction of particulate materials resulting from the combustion process and an overall increase in combustion efficiency. We have also observed a significant improvement in the transfer of thermal energy to the heat exchange surface.

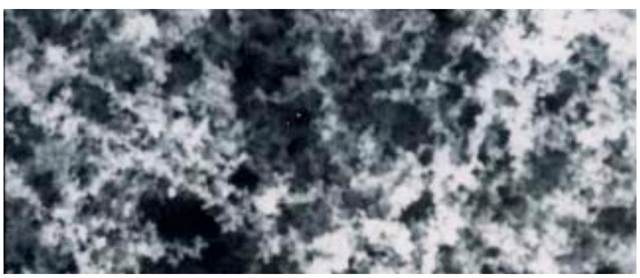
4.1 Particulate Emissions Control

Electron micrographs of soot, and smoke stack opacity measurements, have confirmed the positive effect caused by a pulsed electrical field on both combustion and on carbon control. PAC also causes agglomeration of typical sub-micron-sized carbon particles into particles of much greater size, making them much heavier and, as a result, more manageable. Elimination of downstream carbon using this technique could, in certain cases, obviate the need for an electrostatic precipitator, which could be replaced by a much simpler and less costly cyclonic separator. It could also eliminate the need for gas conditioning for highly resistive fly ash, which is normally difficult to remove without the addition of sulfur trioxide as a conditioning agent. Under certain conditions, the gases produced by combustion may be used directly for hot gas turbine applications, because the gas is clean enough for direct use in this type of energy generating equipment.

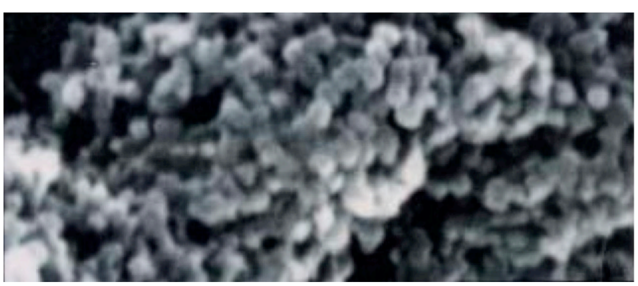
The following images are electron micrographs showing electrically augmented carbon particle growth:



500 x magnification



10,000 x magnification



50,000 x magnification

4.2 Sulfur Compounds

Sulfate and Sulfite compounds have been observed in the ash of certain fuels containing sulfur. These compounds may have been produced due to ozone production reactions and/or ultra-violet generation within the flame using electrical augmentation. This could result in lower concentrations of sulfur compounds out the stack and may result in reduced collection and scrubbing requirements. More detailed experimental work is required to determine the exact mechanisms for formation of sulfur compounds.

4.3 Total Hydrocarbons

More complete fuel combustion has been observed to result in a significant reduction in total hydrocarbon emissions for certain fuels. In wood burning experiments, one of the more difficult to control emissions problems, emissions of total hydrocarbons have been reduced by 97%. Other key impacts of this observation include better utilization of fuel and decreased fouling of heat exchange surfaces. The reduction in total hydrocarbons also makes the burning of non-standard fuel types such as rubber and municipal waste possible. Dioxin production may also be prevented from occurring under certain electric field designs and conditions.

4.4 Carbon compounds from combustion

Tests conducted using the Condor EPA Method 5 have shown PAC technology lowers CO emissions by between 50% and 60%.

4.5 CO_2

Removal of carbon implies the creation of less CO_2. Experiments must confirm how large the effect can be due to reaction control, but our estimates lead us to estimate a reduction of about 10%, possibly more.

5 FURTHER EXPERIMENTS

In order to further validate previous experiments and analysis, and to provide high-value data to support commercial applications, a prototype burner will be constructed. This prototype will consist of a meso-scale software-controlled PAC burner driven by a novel power conditioner system. This apparatus will accommodate multiple fuel types, from solids such as coal, rubber and municipal waste, to gases such as propane and natural gas.

The design will include novel electric field forming configurations, the application of variable field geometries, and the ability to precisely control the makeup and temperatures of the combustion process; augmenting PAC as needed are other standard variables including the provision for C=C templates to create solid carbon growth.

Additionally, the test apparatus will support enhancements to and characterization of advanced thermal heat exchange as well as support a provision for injection of chemical agents used to react with various flue gases such as sulfur compounds and other chemical species needing removal.