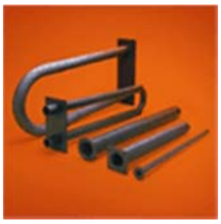
Radiant Tube Technology

Burning Natural Gas with Increased Radiant Efficiency






Radiant Tube Technology, The results of the research showed that systems that use multilayered (large pore) combustion surfaces can provide high radiant performance. Radiant efficiencies as high as 49% have been obtained for a number of firing rates. These efficiencies are around twice those achieved by American commercial surface burners. Two systems of creating the multilayer effect have been shown to give results. Both are being further investigated to prove reliability of the combustion system and the durability of the materials.

The use of a porous membrane (alumina) to divide a zone of very high temperature from premixed explosive gas has been proved and the effect of transpirational cooling, in preventing flash-back has been demonstrated.

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Materials and designs have been selected that withstand the temperatures and associated stresses, and provide the correct balance between conduction, emittance, radiance and reflection. By optimising the geometry in which these materials are used, even better performances can be expected.

GLOSSARY (1)

Absorptivity (a). The ratio of the actual absorption power to that of a perfect radiator (or black body).

Emissivity (e). The ratio of actual emissive power to that of a perfect radiator (or black body). Note that at thermal equilibrium e = a.

Firing Rate. The energy put into the candle, and presented in terms of kilowatts/unit area of superficial surface. Measured in kW/m2.

Reflectivity (r). Is the fraction of energy reflected by a body, ie the compleme absorptivity. Note a + r = 1.

Radiant Candle. A ceramic structure that acts as a near surface burner to increa the radiance produced by gas combustion.

Radiant Efficiency. As measured by the consortium's calorimeter and radiometer. that percentage of the energy released during combustion that appears as radiant

Radiance. In this report means the intensity of radiation emitted from the burne

INTRODUCTION

During an investigation of options for converting a nuclear reactor to fossil fuel firing, the combustion of natural gas was considered as being one option for refuelling. The concept was to use the pressure vessel as a fire-tube boiler, and to as closely as possible replicate the 'nuclear fire' so as to avoid the complete scrapping of the heat transfer system, and to allow the operation of the plant at close to its original design mode and capacity.

The conversion scheme was presented as an alternate scheme to the combined cycle concepts:- constructing gas turbines with waste heat boilers connected to the existing (but modified) turbine generator (2).

The necessity of using radiant heat as against convective heat became apparent after initial calculations indicated the convective energy transfer would not be sufficient to match the power density provided by the nuclear core, in the very restricted (small volume) reactor vessel. (The problem of raising steam by the direct firing of natural gas is that very large heat transfer surfaces are required, since around 95% of the energy is only available as convective heat.)

A system of burning natural gas in long tubular 'candles' was envisaged, such that intense radiant heat which was produced would heat the fire tubes through which the candles were placed. Temperatures of over 1000° C would be required to achieve significant heat transfer by radiation. During the study it became obvious that other commercial devices could benefit from such a burner.

TECHNOLOGICAL AND COMMERCIAL NEED

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Industry has many uses for steam. The technology of raising steam in a conventional way is well understood with the efficiencies of steam raising apparatus being slowly increased over the last two hundred years. There is still a need to increase the efficiencies of steam raising in order to conserve fuel and reduce greenhouse gases, (eg to ensure that maximum use is made of the carbon content of natural gas), and there is also a need to reduce the size and cost of the equipment per given unit of steam production to conserve industrial space and gain production efficiencies. Environmental concerns require that combustion be controlled such that minimum pollutants are produced (eg NOx and CO).

It is believed that the technology will have application to 'all levels' of steam raising that involve the use of natural gas, other combustible gases (including synthetic gases) or readily volatilised clean liquid fuels. The smallest applications would be commercial/small industrial steam generation (eg laundries, institutional kitchens and possibly transport), medium scale applications would be larger industrial applications (eg packaged food preparation, cloth manufacture or small power stations), whilst the largest applications would be major industrial steam raising (eg oil refineries) and large power stations.

Other uses could be in creation of very hot surfaces for surface coatings applications or in radiant space heating.

MATERIALS CONSIDERATIONS

Early in the project, discussions were held with materials scientists from Australian Nuclear Science & Technology Organisation (ANSTO) regarding the candle (Radiant Tube, RT) construction. The ANSTO group confirmed that the Radiant Tubes could probably be constructed out of ceramic materials with the required porosity and temperature resistance.

Questions regarding the required RT surface temperature arose. The estimated temperatures of 1200 – 1800° C required to achieve significant heat transfer by radiation were considered likely to produce slumping in the ceramics (particularly at the upper end of the range), given the expected carrying load of the tubes. From discussions and calculations carried out amongst the authors, transpirational cooling (from the movement of the gas through the porous ceramic), was considered to be more than adequate to keep the inner side of the RTs 'cool', thus preventing slumping. Support from inner steel tubes was also practicable if required.

The physical properties of conductivity, absorptivity, emissivity and reflectivity of the ceramic materials proved to be very important in understanding the required thermal process to achieve high radiance, and thus in designing the candles. The catalytic behaviour of the ceramic itself was possibly important in achieving the required temperatures/radiance, but it was not detected during these experiments.

TECHNICAL RESULTS

We have achieved radiant efficiencies of 49% in some of our Sub-Surface Burners (Table 1 & Figure 1). This compares very favourably with efficiencies of around 25% in similar tubes produced by foreign competitors. Further, we have demonstrated ceramic combinations, that will provide even higher radiant efficiencies in plate burner systems, with good reliability. (Patents have been sought for the developed technology.)

Technology

Emissivity from natural gas flames is usually low and restricts the heat transfer to basically convective exchange. This leads to very large furnace volumes or tube areas and thus low power density systems. One application of the system is to burn natural gas or similar fuels in tubular 'candles', such that intense radiant heat is produced. This heat (energy) would radiate to the fire-tubes in which the candles were placed. The major mechanism of heat transfer would be radiation, with convection and conduction taking secondary and tertiary roles.

To achieve the above results, it was required to produced candles - Radiant Tubes - that have been made of multi layers of porous ceramics.

Candle Description	Firing Rate kW/m2	Radiant Efficiency %	Maximum Temperature ° C	NOx ng/J	CO/CO_2
Wound 10	328	49.0	1080	4.6	-
Wound 10	400	41.0	1060	4.6	0.001
Wound 10	552	35.0	1080	6.2	0.001
Wound 13	424	44.0	1320	-	0.002
Wound 13	516	43.3	1360	-	-
Wound 13	616	39.0	1350	-	0.001
Wound 13	695	39.6	1400	-	0.001
US burner 1	375	20.0	970	13.3	0.001
US burner 2	337	25.0	1000	8.5	<0.001

Table 1: Selected Candle Performance

Interpretation of Performance Table:

The wound burners, that incorporated spacing between windings, produced exceptional radiant performances at lower temperatures. NOx levels and CO/CO2 ratios were very good for Wound Candle 10, whilst the CO/CO2 were only marginally above the standard for surface burners for the foam burner. NOx levels produced by burner Wound Candle 10, were less than those produced by the US specimens3. The benefit of having a emissive SiC base layer was demonstrated for higher firing rates for Wound Candle 13. See Figure 1. Further RTT was able to better the radiant performance of the US burner 1 with mono layered wound burner, a simple unit, see Figure 2.

Of major note was the flat temperature response for various firing rates for the wound candles. Radiant efficiency did fall off with increasing firing rates (inputs), Figure 1, but remain very significant for all candles tested. (Note: The radiance performance was measured by the radiometer and calorimeter. The correlation of the measurements was very close.

Experiments were carried out on simplified candles that did not have the inner porous ceramic tube. All such candles failed, thus demonstrating the necessity of the inner porous ceramic tube and its ability to act as a heat barrier for the structures. In only one example did noticeable burn-back occur due to cracking. In this case the stainless steel tube actually burnt.

In a test on a plate burner, a thermocouple placed beneath the lower layer of ceramic indicated a temperature of around 57° C for a firing rate of around

300 kW/m2 but when the firing rate was increased to over 600 kW/m2 , the temperature fell to under 30° C. This is a good example of transpirational cooling, the principal on which the maintenance of the separation of very high temperature, and low temperature zones is achieved. Further it is the principal that prevents the propagation of flame through the porous, poorly conductive, material where premixed gas and air are used.

Another feature of the candles that were developed by RTT was the relatively high 'back pressure' that was applied to those burners. Table 2 presents a comparison of the burner pressures applied to Candle 10, and the US burners.

Table 2. Burner Back Pressures

Candle Description	Firing Rate kW/m2	Burner Pressure kPa
Wound 10	328	3.8
Wound 10	400	4.0
Wound 10	552	4.9
US burner 1	375	0.4
US burner 2	337	1.0

The burner back pressures are a function of the relatively lower permeability of the alumina inner tubes used in producing candles. The smaller pore sizes, and increased gas velocity would have assisted the transpirational cooling effect. It is however indicated that the effect may be over done, and that lower pressure drops could tolerated. The use of inner tubes with higher permeability and/or thinner sections could still provide sufficient transpirational cooling.

SCIENTIFIC BACKGROUND AND TECHNICAL RAMIFICATIONS

The encapsulation of the combustion process is the key to the creation of highly radiative zones during combustion. Zones that can provide for the complete combustion of both the hydrogen and carbon contained in fuels have been created, by using structures with reflective, conductive and emissive features. The combustion of hydrogen and carbon contained in natural gas occurs through a series of complex reactions4.

Glassman (5) infers that the initiating reactions are relatively slow.

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$$CH_4 + O_2 \longrightarrow CH_3 + HO_2 \qquad (1)$$

or at higher temperatures,

$$CH_4 + M \longrightarrow CH_3 + M + H \qquad (2)$$

where M stands for a catalyst.

The structures developed by the project apparently give sufficient residence time in the reactive zones to complete the slower reactions, and turn energy released by those reactions into radiant energy. Other writers6 have also reported that the first reaction in the combustion of methane is the production of radicals CH3 and H, with this reaction 'consuming heat, and giving rise to some delay', that is what is inferred in the literature is that the initiating reactions are strongly endothermic. If this is the case, a combustion system that incorporates energy/heat reflection back towards the gas inlet zone must provide more rapid (and complete) ingnition of the in-coming mixed gases.

Whatever is the case, the experimental burner structure appeared to capture the combustion within it and thus raise temperature and radiance from the structure.

Methane because of its lack of carbon - carbon bonds, and because of the 'tightness' of the hydrogen-carbon bonds presents special problems to achieving radiant combustion, and in fact combustion. The problems are two fold. Firstly considerable activation energy is required to begin the process of parting hydrogen radicals from the methane molecule as the initial oxidation stage, and secondly the oxidation of the carbon monoxide to carbon dioxide is a relatively slow and sometimes incomplete process.

A simplified picture of the complete combustion of methane occurs according to the following reaction;

$CH_4 + 2\ O_2 \rightarrow 2H_2O + CO_2$ .... - 802 kJ/mole (3)

with the combustion of carbon monoxide intermediary product by the following reaction;

$CO + 0.5\ O_2 \rightarrow CO_2$ .... - 283 kJ/mole (4).

The blue flame seen towards the outside of most combustion zones is the combustion of the carbon monoxide. To encapsulate this reaction close or within the radiating structure would clearly increase the radiant efficiency.

The main features of the improved burners (See Figures 2 & 3) were:-

1. The combustion occurred within the outer pore structure (large pores, of 3 - 5 mm diameter) which reflected the heat back to achieve 'increased enthalpy burning and enhanced CO combustion.

2. The outer (large pore) structure was designed to reduce thermal stresses which would otherwise destroy the structures at the temperatures gradients involved.

3. The use of high emissivity materials which reduced the maximum temperatures of both the inner and outer structures improved the radiant efficiency and lowered thermal stresses..

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TECHNICAL RESULTS - FINDINGS AND CONCLUSIONS

Specifically the following was achieved:

1. An increase in the heat flux of radiant tube burners,

2. The doubling of the radiant output of radiant tube burners and

3. The creation of forerunner industrial designs using the information collected by the above activities.

The technology that has been developed will increase heat transfer rates, enabling size reduction (or increased output) of steam raising plant. This has been demonstrated without unfavourable and possibly improved environmental consequences.

The project has achieved most of its objectives. The one outstanding difficulty has been the reliability and durability of some ceramics. The internal alumina tubes used for gas distribution (sourced from the US) have been of variable quality and have not been readily available. We will look for other sources of this material (preferably in Australia) and improvements in fabrication techniques.

The reticulated ceramic foam annular sections used as a radiating structure exhibited a series of structural failures. We however believe that considerable improvement in the performance in such foams could be achieved with further work on geometry and restraints. Reduced surface temperatures by use of higher emissivity materials may help.

Silicon Carbide (SiC) proved to be a very interesting material, because of its high radiant emissivity and high thermal conductivity. It is intended to press on with research involving the performance of that material in a second phase of the project.

APPLICATIONS AND BENEFITS

The immediate application of the technology that will be sought is in replacing high capacity electric elements and imported radiant gas tubes in locally produced small commercial boilers. Work on the reliability of the burners will be undertaken so as to offer boiler manufacturers a gas fired alternative to present systems. Entry into the marketplace will depend on further development (procurement) of durable ceramics .

Gas Utilities will be able to offer improved gas usage systems to their customers. By demonstrating increased energy efficiency, improved space efficiency and lower emissions, natural gas will attract more support in the gas reticulation/use business. Gas fired boiler manufacturers will have a new product, that can compete with other systems of industrial steam generation, electricity and oil. The relative compactness of the units will be an attractive selling point. Their clean operation will be a further advantage. Other applications could include metallurgical heat treatment, space heating, surface drying and enamelling.

Figures

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