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Prospective Utilization of Porous Medium Combustion Technology for Low Pollutant Emissions and High-Energy Efficiency

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ABSTRACT

This paper presents the capabilities of porous medium combustion technology for energy efficient and environmentally safe system. A brief identification and survey of porous material used in this area is also presented with their operating and limiting parameters. The different areas in which work is progressing like internal combustion engines, steam generation, household and industrial burners, air and water heating systems, air conditioning with vapor absorption and caravan heating systems are also discussed.

Keywords: Porous media PM, Combustion, Materials, Low emission

NOMENCLATURE

S_L = Laminar fellow velocity (m/s)
d_m = Equivalent Porous cavity Diameter (m)
c_p = Specific heat capacity of PM ($J\ Kg^{-1}\ {}^oC^{-1}$)
ρ = Density of PM (Kg/m^3)
θ = The heat conductivity of gas mixture ($W\ m^{-1}\ {}^oK^{-1}$)

1. INTRODUCTION.

Combustion is a basic phenomenon from which we drive out the energy in the form of heat and use it for different purpose. In the last two decades, efficiency of the system hardly gets proper importance since understanding towards environment was also not very good. It's in this modern era, when energy decides the currency of the country, and termed as the entity of dispute, wars are fought for it. Today energy is of prime importance we are only concern that if a fixed amount of fuel is burnt than the energy utilized from it must be approximately equivalent to its calorific value and drawing least impact on the environment. This is all because of the energy economics, which is on run way these days.
A very new and emerging area in the field of combustion is porous media (PM) combustion. Unlike conventional premixed combustion process, the porous burner technology does not operate with a free flame rather the combustion takes place in a three dimensionally arranged cavities of a porous and inert media, resulting in a totally different

flame itself compared to conventional combustion process. There are few very obvious advantages associated in this type of combustion process which are; Wide infinitely variable dynamic power range of 1:20 compared to conventional state of the art burner which shows a power range of 1:3 only, High power density, i.e. burner and heat exchanger are about 10 times smaller in volume than conventional burner and heat exchanger units for comparable loads, Very low emission due to complete combustion CO =< 7mg/KWh and NOx =< 30 mg/KWh over the complete dynamic power range. The emissions are well below than the most stringent norms, Stable combustion for excess air. The combustion process is achieved in terms of power range, emission etc. the most important criterion for combustion is the critical pour size, which determine whether the combustion process would takes place in the porous media or not. If the size of the pours is too small or less than critical pour size the flame propagation will be prohibitive or quenched. If the dimension exceeds the critical pour size flame propagation in the porous medium is possible. The critical pour size may be determined by modified expression of "Péclet Number" (P_e).

$$P_e = \frac{S_L * d_m * c_p * \rho}{\theta}$$

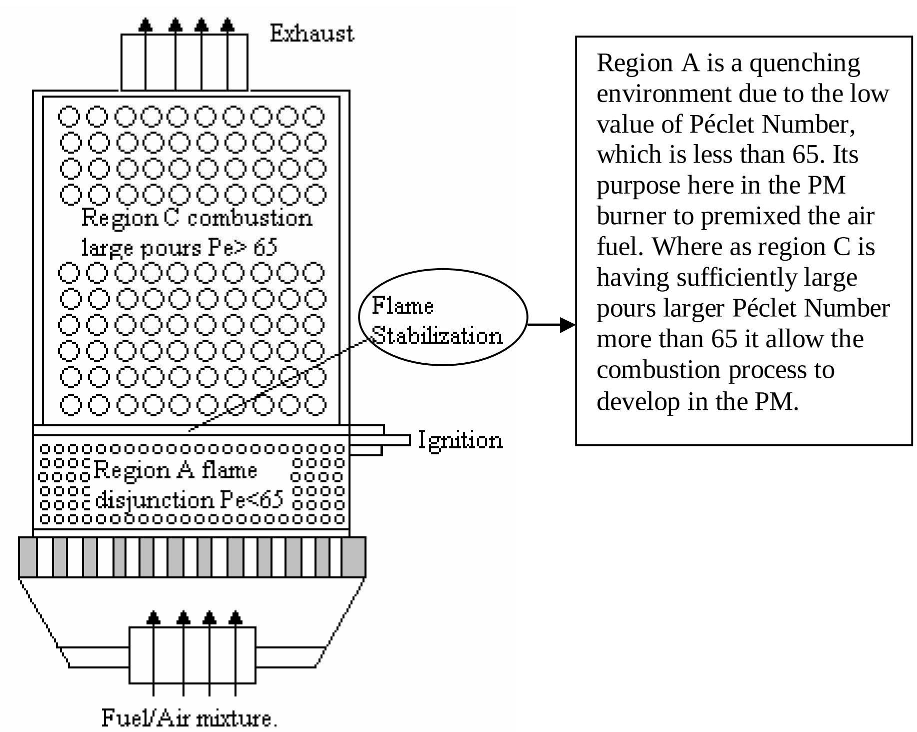

Figure 1.A. typical schematic of porous burner.

The combustion process is stabilized with a sudden change of the pore size corresponding to a change of the Péclet Number inside the combustion reactor. Body properties are chosen in such a way that flame propagation is not possible in region C, but in region A pour size is large enough to help develop the flame. These regions are shown in Figure 1.A.

2.0 MATERIALS USED FOR POROUS MEDIUM

Since this technology depends on high temperature resistant porous materials hence, identification and survey of such material is also necessary. The most important material and form for porous burner are SiC (silicon carbide) foams as well as mixer-like structure made of Al_2O_3 fibers, ZrO_2 foams and C/ SiC structure. In some special application chromium-iron alloys and nickel base alloys are also used. Al_2O_3 and ZrO_2 are having different manufacturing properties these material can be used in temperature range of 1650 ^{o} C above, where as metals and SiC material do not fall in this category, hence they are used in comparatively low temperature applications. However they possess outstanding characteristic with regard to thermal shock, mechanical strength and heat transport capacity etc. The overall performance of a porous body is strongly dependent on combination of base material and porous structure itself. Aluminum oxide can be used to a process temperatures of 1950^{o}C, Although the technical temperature limit is 1700^{o}C. Al_2O_3 – based materials show an intermediate heat conductivity ranging from 5W/(m K) at 1000^{o}C to about 30W/(m K) at 20^{o}C. Also Al_2O_3 shows an intermediate thermal expansion and an intermediate resistance to thermal shock and emissivity of 0.28 at 2000 ^{o} K. High quality SiC can be used to a maximum process temperature 1600^{o}C,a heat conductivity in rang of 20 W/(m K) at 1000 ^{o} C and 150 W/(m K) at 20^{o}C,a very good resistance to thermal shock and a very low thermal expansion and the overall emissivity at 2000^{o}K is about 0.8 to 0.9. Temperature resistant metal alloys may be used for temperature below 1250^{o}C. Their properties features a high heat conductivity ranging from 10 W/(m K) at 20^{o}C to about 28 W/(m K) at 1000 ^{o} C, extremely high thermal expansion and extremely good resistance to thermal shock. The emissivity of metals varies strongly with the surface finish and varies form 0.045 at 200 K to polished nickel of 0.5 in stainless steal. Solid Zirconia present a highest temperature resistance which ranges up to 2300 ^{o} C. Heat conductivity of solid Zirconia is hardly temperature dependant and in the range of 2 W/(m K) to 5 W/(m K). Good conduction and heat transport capacity, low radiations, and intermediate dispersion properties makes it quit suitable from high temperature application.

3.0 APPLICATION OF PM TECHNOLOGY

PM combustion technology can be applied to a variety of thermal engineering fields due to its outstanding properties like complete combustion and hence low emission, wide power regulation. Moreover its utilization and analysis is already done up to some extent. Flame propagation, thermal shock behavior and life expectancy etc. are the few areas, which needs to be dealt in a greater detail. Till the date the technology has been applied to household burner for air and water heating system, caravan-heating systems and preheater of cars, PM burners in steam generator and the latest one in IC engines.

Our household heating is a good area in which the technology has been doing well. Due to improved insulation heating requirements are becoming less. When it comes to eliminating the steps the technology is well identified, generation of power in a thermal power station and transporting it to grid and then distribution incurs a lot of unavoidable losses generating heat without first converting it to electricity. Bypassing the few limiting physical laws, which affect the efficiency directly, is always useful. For Indian conditions we need cooling for about 70 percent time of the year. Using vapor absorption system in place of vapor compression system would drastically decrease the energy requirement in cooling. This all using a PM burner for input heating in Vapor compression cycle. The advantages of low emission high power modulation would further enhance suitability and efficiency of the process. PM technology is also recognized due to its compactness and makes it very suitable for handy applications such as caravan heating systems. It reduces the requirement of numbers of burner for power modulation due to its modulation capability. Temperature control leads to less NOx formation. Heat transfer capability of PM is highly dependent on the type of material used for PM as presented in the discussion above, the property of heat conduction increases as we go to the metal base PM. Heat exchanger embedded in PM used in steam generation is another area of interest and research. For fuel efficiency, power modulation is very necessary PM burners are now designed for combined usage with conventional premixed industrial burners, where in the combination of these two leads to greater range of power modulation. For conventional premixed industrial burners the modulation range is only 1:2.5 where as for PM burners it is up to 1:50, so for a combined usage power modulation of 1: 50 can be achieved and it is without putting emission on stake. Hence, the times when power requirements are very less then these burners are adjusted to very low fuel feed just to keep them alive.

Homogeneous combustion in IC engines can be achieved by a system proposed recently by (Drust et. al/Porous medium combustion in IC engines/315-334).the technique termed as 3D-thermal PM-self-ignition(3D-grid structure of a high temperature) and it uses a 3D-structured PM for volumetric ignition of homogeneous charge. The PM has homogeneous surface temperature over the most of the PM volume, higher than the ignition temperature. In this case the PM-volume defines the combustion chambers volume. We could consider the PM volume as a large number. of hot spots homogeneously distributed through out the combustion chamber volume. This feature provides a thermally controlled 3D ignition system. More over the PM controls the temperature level of the combustion chamber permitting the NOx level almost independent of the engine load or the A/F ratio.

4.0 DISCUSSION OF RESULTS

For the numerical appreciation of the results the following parameters were considered in the range described in the results computed. Ttypical dependencies for two selected materials Aluminum oxide and solid Zirconia have been shown in Figure 4.A and Figure 4.B respectively.

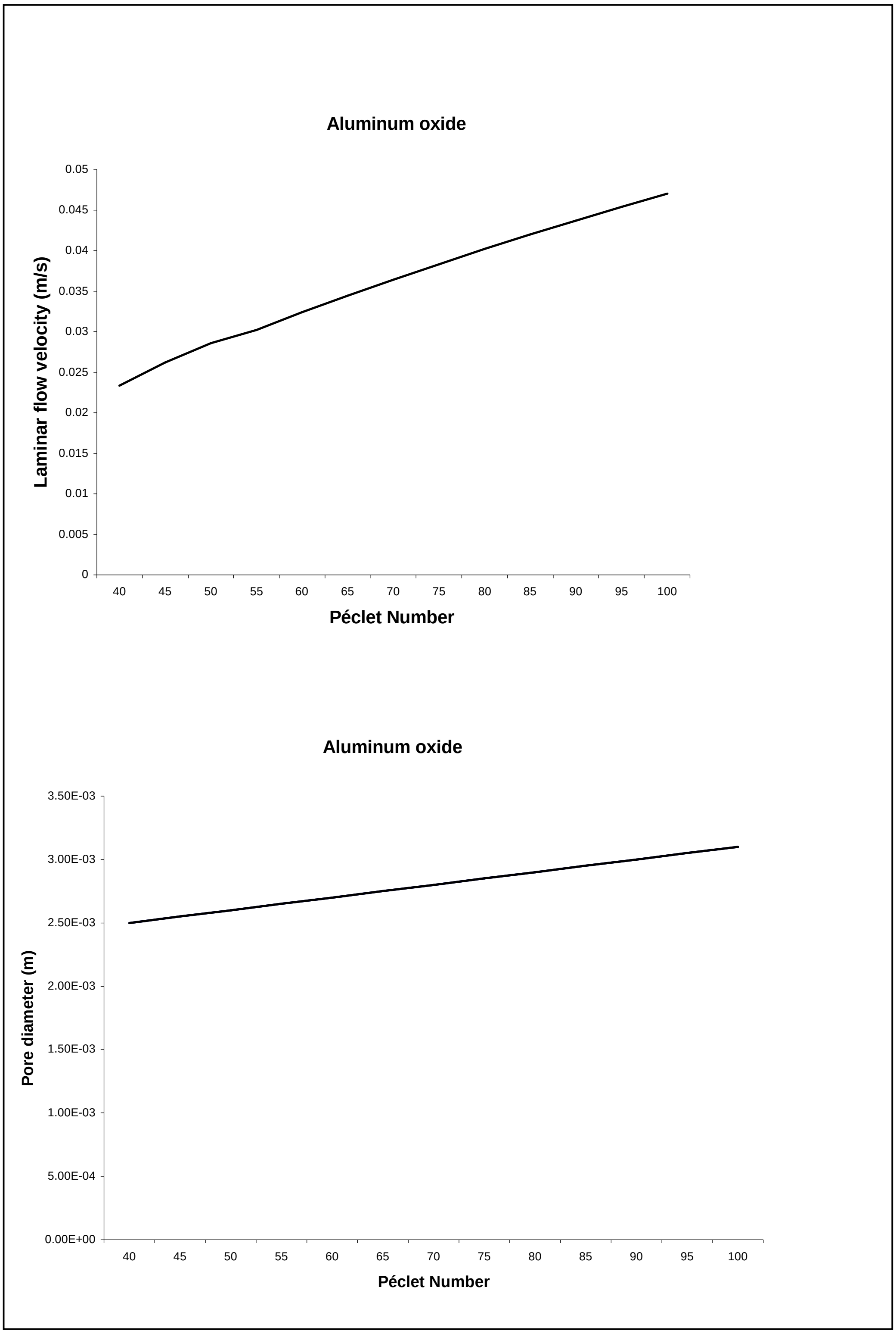

Figure 4.A. Typical dependencies of Péclet Number for Aluminum oxide.

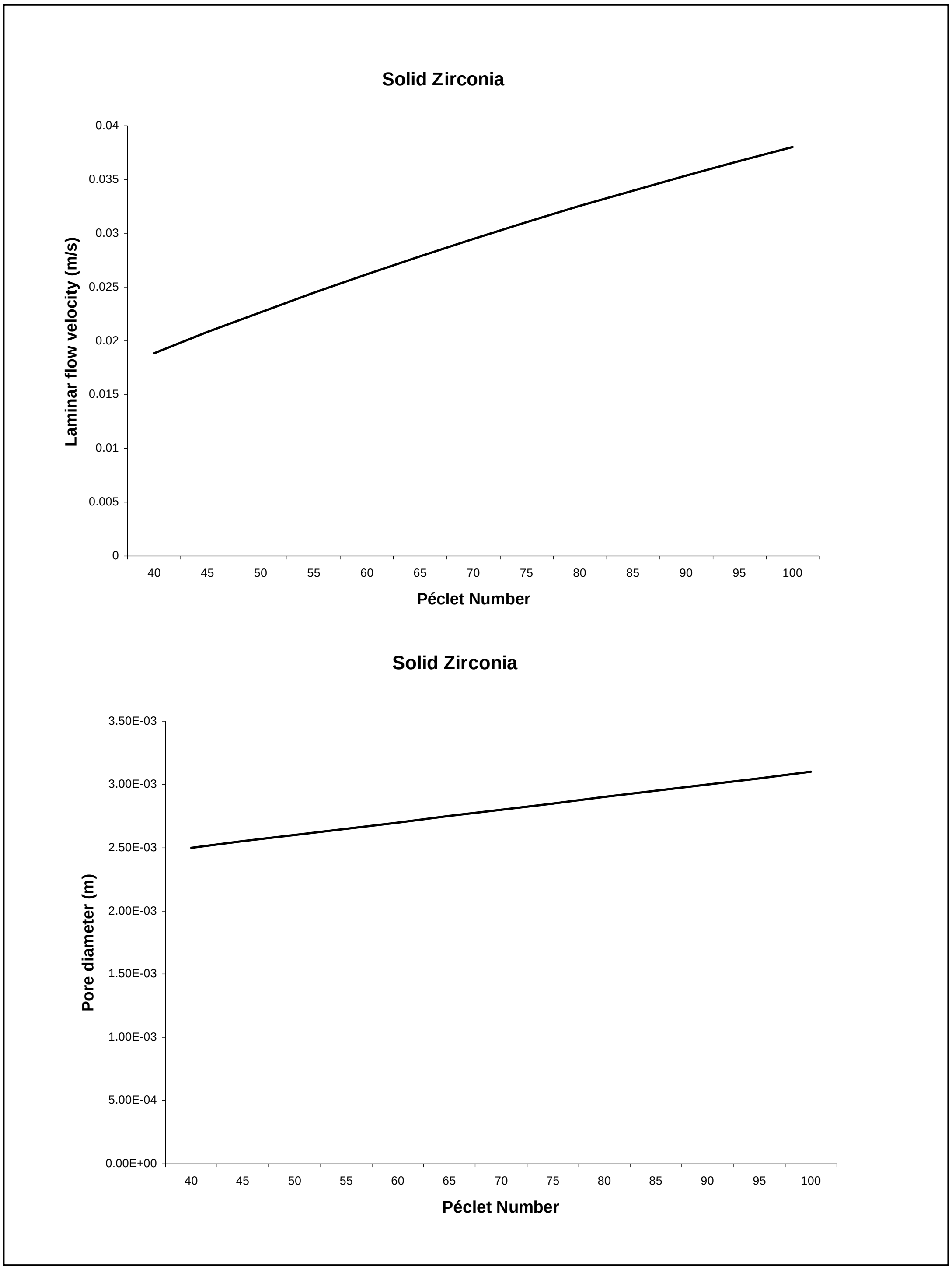

Figure 4.B. Typical dependencies of Péclet Number for Solid Zirconia.

The most important criterion, which determines whether or not a combustion process can takes place inside a porous structure, is the critical diameter of the pore. If the size of the pore is smaller than this critical dimension, flame propagation is prohibited; the flame is always quenched. On the other hand if the pore size exceeds the critical dimension, flame propagation inside the porous structure is possible. The Péclet Number (P_e) which determines the critical pore size has been taken as the objective function and was found to be a function of some important operating parameters like pore size, laminar flame velocity, specific heat capacity, density and fuel-air mixture heat conductivity. The computed results shows that as pore size increase while keeping other parameters constant the Péclet Number (P_e) increases. Higher flame velocities have been found responsible for increase in Péclet Number.

5.0 CONCLUSION AND FURTHER RECOMMENDATIONS

PM technology is very important due to its wide applicability in the field of energy efficiency. The properties inherited by it, like low emission, high power density or compactness of the systems and wide range of power modulation makes it a good alternative in places of conventional technologies. Selection of proper materials for any specific purpose would be achieved by the proper knowledge of such materials. Parameters like specific heat capacity maximum temperature range resistance to thermal shock and coefficient of thermal expansion etc. need to be known. This technology can be further applied as a porous heat transfer matrix for performing endothermic or exothermic chemical reaction, a heat source for Stirling engines and for combustion of hybrid fuels.

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