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IMPROVED RADIANT BURNER MATERIAL

FINAL REPORT

REFERRAL # 643

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REF: PROJECT IDENTIFICATION NUMBER - DOE-DE-FG-01-96EE-15643

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SUMMARY

Under DOE/ERIP funds were made available to Superkinetic, Inc. for the development of an improved radiant burner material. Three single crystal ceramic fibers were produced and two fiber materials were made into felt for testing as radiant burner screens. The materials were alpha alumina and alpha silicon nitride. These fibers were bonded with a high temperture ceramic and made into a structually sound trusswork like screen composed of million psi fiber members. These screens were about 5% solid for 95 porosity as needed to permit the flow of combustable natural gas and air mixture. Combustion test proved that they performed very satisfactory and better than the current state of art screen and showed no visable degrade after testing.

It is recommended that more time and money be put into expanding this technology and test these new materials for their maximum temperature and durability for production applications that require better burner material.

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INTRODUCTION

A radiant burner is an apparatus which provides a uniform, homogeneous heat source. It can burn fuels more efficiently than open flame burners due to the control and spreading of the flame front over a large surface area. Combustion of the fuel and oxidizer, which are fed through a porous ceramic screen, occurs near the surface of the burner screen which then radiates the heat energy. An oxygen resistant material is an advantage for radiant burner screens operating at the high temperatures of the oxygen-rich combustion environment. As the screen's operating temperature increases, radiant burners transfer heat more efficiently. However, the temperature and lifetime limits on current fiber screen materials, prevents them from replacing inefficient open flame burners now used in many high temperature processes. In this write up, we are reporting the use of an oxidation resistance, advanced single crystal fiber material to make screens that will overcome current temperture and oxidation limitations of current burner material and therefore make available the increased fuel efficiency and cleanliness of radiant burners in these and other processes.

PURPOSE

The purpose of this program is to advance the state of the art of radiant burner technology. This can be accomplished by making radiant burners operate more efficiently at higher temperatures through the use of oxidation resistant, higher-temperature, longer-life burner fiber materials. We can accomplish this by first providing high quality single-crystal fibers of sapphire (Al_2O_3) for radiant burner service near 3000°F. These fibers will come in one or two forms: 1) integrated grown mats of short fibers which can be made directly into radiant burner screens, or 2) Individual fibers harvested from mats, then reshaped into felts or papers that will serve as burner screens.

EXISTING METHOD

Current radiant burner materials can operate at about 1800°F for 20,000 hours. However, these radiant burners are not able to operate at the very high temperatures associated with more metal or petrochemical processing applications without significant degradation in the burner lifetime. The lower lifetime is due to the temperture limitations of the fiber materials used in the burner screens and more importantly, the fiber's polycrystalline impure structure. Impurities tend to cluster and defects grow as temperature increases due to increased atomic mobility in the crystal lattice. This leads to larger grain boundaries which further weaken the fiber causing imbrittlement. The larger grain boundary also decreases the fiber's chemical stability by increasing the surface area exposed to the reactive environment.

NEW METHOD

Our purpose of this program is to make a radiant burner screen out of material that overcome the current temperature and oxidation limitations, and long term resistance to degradation. Our approach is to make these burner screens out of single crystal fiber of oxide or oxidation resistance material that have very high temperature resistance in a oxidation environment. Also the single crystal nature of these fibers are not subject to the degradation effect of grain growth recrystalization.

During this program we have developed a high temperature chemical processing technique for making single crystal fiber of alpha alumina (sapphire) alpha silicon nitride, titanium oxide (Rutile) and Zirconium oxide fiber. We were successful in all but the Zirconium oxide fibers which turned out to be very dendritic and not suitable for a burner application.

PROJECT AIM: To manufacture and process single crystal fibers in sufficient quantity and quality so that they can be formed into felts for use in high temperature radiant burner applications. Then to prove the long term, oxidation-resistance and durabiltiy of these felts at operating conditions.

TECHNICAL OBJECTIVES: To grow single-crystal fibers of sapphire or other metal-oxide of suitable length and aspect ratio for forming into felt shapes for use in radiant burners. The felts need to be stable at long-term temperatures up to 3000^{o}F and have porosity necessary for proper flame-front control.

TASK 1 EQUIPMENT & HARDWARE PREPARATION: Design and build the furnace and control assembly capable of growing the quantity and quality of single crystal fiber necessary for completion of this program.

TASK 2 FIBER PRODUCTION: Grow the quantity and quality of fibers needed for formation of felts to be used for radiant burner testing.

TASK 3 FELT FORMATION: Make the felt sample shapes for a testing a specific radiant burner application. These will probably consist of flat swatches of felt fabric for basic research and shaped felt "fingers" for burner tests.

TASK 4 FLAME TESTING: Construct a test apparatus which is capable of simulating the primary radiant burner operating conditions. The apparatus will be capable of studying flame-front characteristics, operation atmosphere and temperature effects on the felt material. A comparison will be made with existing burner material.

TASK 5 PROTOTYPE BURNER TESTING: Assemble prototype burner using high temperature felt material. Perform burner test under actual operating conditions.

TASK 6 SCALE UP COST & ENERGY SAVINGS POTENTIAL: Calculate scale-up costs for total processing of radiant burners including break-outs for fiber production facilities, burner component acquisition and burner assembly facilties. Calculate the total energy savings due to increased burner efficiencies based on the program data. In addition, investigate the energy savings by the use of radiant burners in processes currently using other forms of burner apparatus (e.g. open flame).

TASK 7 REPORTING: Supply quarterly reports and final reports as required to fulfill project commitments.

COMPLETING TASKS:
About the first one third of the program was devoted to the completion of Task 1 (design and building of the furnace and control assembly that gave us the capability for growing of the quality and quantity of single crystal fibers that were necessary for completion of this program). The second third of the program was used in fiber production Task 2, the last third of the program was used in completion of Task 3,4,5,6 & 7.

GROWTH PROCEDURE Each process required a furnace design, temperature controllers, internal growth harware, flow controller and various chemistry for feed gases. For example, the making of sapphire single crystal fibers are by a vapor feed crystalization method using feed material of aluminum metal, a ceramic boat of Al_2O_3 and SiO_2 and a catalyst and gases of hydrogen nitrogen, CO, and CO_2 and temperature up to 1500C. For the growth of silicon nitride fibers, the growth substrate were boxes made of high temperature fire brick, coating with catalyst and the feed gases of hydrogen, nitrogen, CO and NH_4 with temperature up to 1450C. TiO_2 and zirconium fiber growth was performed by a completely different method using a molten salt solution and a recrystallization method, in which the oxide ceramics are first disolved in a molten lithium salt to supersaturation and then slowly cooled for fiber recrystalization to occur in the solidify molten salt.
We experienced very good yields in making very nice but large TiO_2 fibers (Rutile) and only poorly formed dendritic fibers of zirconium oxide. This was all done in a chemical inert crucible in a controlled atmosphere furnace up to 1000C.

DETAILS OF TASKS PERFORMANCE

TASK 1 EQUIPMENT & HARDWARE PREPARATION For the growth of the sapphire and silicon nitride fibers a 4KW powered 4"O.D. quartz tube furnace was built. This furnace has a 12" hot zone and is capable of reach 1500C. The control panel has four separate electronic flow controllers for the feed gases which are directed into a manifold before entering the furnace on the upstream end. The down stream end of the tube has a gas tight hinged door which permits the entrance of the fibers growth modulus and back up insulation. For this task we designed and built the power supply, control panel,the furnace and all required internal growth hardware.

TASK 2 FIBER PRODUCTION - A typical growth cycle for either the sapphire and silicon nitride fibers is 2 to 3 hours at temperature plus the ramp up and down which permitted one growth cycle per day. After the growth cycle the fibers were harvested from the growth module and classified for quality and size and yield, then put into storage to be available for the next step which was fiber felt making.
During the production phase sufficient fiber of both sapphire and silicon nitride were made to permit the formation of 15 to 20 burner felts. The titanium oxide or (Rutile) fiber were too large in diameter and stiff to be suitable for fiber felt making and were not used for that purpose.

TASK 3 FELT FORMATION - By checking with the radiant burner fabrication company "Alzeta of Santa Clara Co." we found tht their preferred size and shape fiber felt for one of their burner applications was a 2" diameter one eight to one quarter inch thick pad. We designed our equipment to supply this size. A typical process used in felting is called the vacuum screen felting process. We start by dispersing an amount of fiber in a high speed blender in alcohol. This process separates the growth bundle and individualizes each fiber in suspension. Care is taken to not over blend since this reduces the fiber aspect ratio which in turn reduces the green strength of the fiber felt. After dispersing the fibers are quickly poured into a fritted glass filter covered with a thin plastic screen (about 300 mesh). The liquid of the suspension is quickly drawn thru the filter leaving a nicely formed felt. After removal of the felt from the filtering apparatus, the felt is dipped into a dilute colloidal suspension and fine ceramic powder which coat each fiber joint.
After drying, the coated felts are fired in a high temperature air furnace to sinter and reaction bond the coated to the fiber. This formed a highly ridged open trusswork of million psi strong single crystal ceramic fibers, fired bonded together into a a super strong, super-light weight structural felt like screen.
These newly formed felt are only 4 to 6% solids or 94 to 96% voids yet very structural sound with the required porosity considered optimal for burner application.
A few dozen burner felt were made to optimize the coating composition and bonding cycle after which eight felts were selected and sent to Alzeta Corportion for burner testing.

TASK 4 FLAME TESTING by us was considered unnecessary since almost the same test is being performed at Alzeta Corporation during their burner testing phase.

TASK 5 PROTOTYPE BURNER TESTING
The Alzeta Corporation has a prototype burner that uses the size burner felt that we have fabricated for them. They tested a number of our fiber felts and they were found to perform very satisfactorily with good surface burning characterics by showing very little or no detectable deterioration after repeated test cycles. They also reported that they experienced no blow back which sometimes occurs if too much heat is conducted back thru the felt from the hot burner surface. Their detailed test report is

included in the appendix to this report. They lauded the performance of our material and say this material should be considered for further development of high temperature burner applications. They also recommended a few applications that require the high temperature performance of our material.

TASK 6 SCALE UP COST & ENERGY SAVINGS POTENTIAL

Very little time and dollars were left on this program to detail scale up and energy saving studies. Preliminary calculations and studies indicate that the fiber felt cost will not add substantial cost to the overall burner cost and with increased performance it should be very cost effective especially for higher performance applications.

TASK 7 REPORTING

The submission of this final report completes this task.

CONCLUSIONS

We conclude that very satisfactory, very strong oxidation resistance single crystal fibers can be grown for use for making fiber felts for radiant burner screen applications. Fibers of alpha alumina, alpha silicon nitride and titanium oxide were made. The best fibers for felting were found to be sapphire and silicon nitride. When these fibers were felted and bonded they formed very satisfactory, high strength, high porosity screens for flame front combustion in radiant burner tests which when tested performed exceptionally good.

RECOMMENDATIONS

We recommend that additional funds be made available to continue this break-thru in radiant burner technology for more efficient combustion of natural gas at significantly higher temperature.