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3,383,159

COMBUSTION ELEMENTS

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ABSTRACT OF THE DISCLOSURE

This invention relates to the discovery that combustion elements used for emitting radiant energy can be improved by the incorporation of aluminum upon or within the surface upon which combustion takes place.

This invention relates to infrared generators and, more particularly, to an improved combustion element capable of emitting radiant energy. More specifically, this invention relates to a method of improving the efficiency and usefulness of heretofore known combustion elements and to the improved elements.

Combustion elements, as used herein, refer to devices permeable to the passage of gases which serve to promote gaseous combustion on or below their surfaces in such a fashion that the combustion is flameless and causes the surface of the element to incandesce and emit radiant energy. Combustion elements of this type have found use in various heating devices; for example, in devices used for heating spaces not amenable to central heating such as piers, warehouses, armories, freight cars and the like, as well as in industrial processing and in applications where a conveniently portable and substantially instantaneous source of heat is desired. Convenient combustion elements of this type are disclosed, for example, in U.S. Patents Numbers 3,191,659 and 3,179,156. Such elements conventionally contain gas-permeable ceramic surfaces on a suitable support.

While known combustion elements are frequently satisfactory in use, it is generally required that careful control be exercised over the precise dimensions and operating conditions of the element and, particularly, over the porosity of the element and the back pressure and flow rate through which the gases to be burned enter the combustion element. Additionally, extremely precise control over the ratio of fuel gases such as propane and air must be maintained in order to minimize the amount of combustion byproduct carbon monoxide produced and given off into the surrounding atmosphere. Such conventional elements operate in an entirely satisfactory manner if all parameters are properly adjusted and the one optimum fuel-air ratio and fuel-air mixture flow velocity is employed for the particular porosity and composition of the element. Any deviation from the optimum tends to increase the likelihood of carbon monoxide production and flashback.

It has now been found that powdered aluminum has a very surprising effect upon the performance of combustion elements. When combined in any fashion with a combustion element, powdered aluminum tends to substantially decrease the carbon monoxide production during combustion of a constant fuel-air mixture, while, at the same time increasing resistance to thermal flashback and also increasing one or both of infrared energy output and element life. Furthermore, the aluminum permits a reasonable range of variation in the fuel-air ratio and velocity. Unlike the case of conventional elements, powdered aluminum-containing elements can be adjusted to a low fuel-air ratio and low fuel-air velocity without causing flashback to occur. In addition, the aluminum-

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containing elements can be adjusted to a rich mixture, low mixture velocity or high heat sink conditions without causing flashback.

Many different means for combining the combustion element with aluminum can be employed. For example, powdered aluminum can be applied to the surface of a combustion element. Alternatively, a combustion element can be coated with or dipped into dry powdered aluminum or into an aqueous slurry containing suspended aluminum. A suitable powdered aluminum-containing paint can also be brushed or sprayed on.

A particularly preferred means of combining aluminum with the combustion elements involves admixing powdered aluminum with the components that are used to manufacture the combustion element prior to such manufacture. For example, if the combustion element is manufactured by accreting a plurality of fibres on a foraminous mandrel followed by further treating the accreted fibres to produce the desired element, powdered aluminum can be admixed with the components of the mixture being accreted. This procedure apparently promotes uniformity of aluminum powder throughout the combustion element and, therefore, appears to lead to even better results.

The type of aluminum powder employed is of some consequence, since the oxide contained should be reasonably limited. If alumina (aluminum oxide) powder is employed in place of powdered aluminum the results of this invention are not achieved. This is particularly illustrated by the fact that powdered aluminum enhances the performance of combustion elements already containing alumina. Accordingly, the powdered aluminum should be substantially elemental aluminum and preferably should not contain more than about 15% by weight of impurities. A small quantity of oxide will almost invariably be present because of the nature of aluminum, but such oxides in small quantities can apparently be tolerated but is best minimized. Small quantities of other elements in admixture with or alloyed with the aluminum can be tolerated provided they are substantially non-reactive under the conditions of operation so as not to detract from the efficiency of the inventive improvement.

The aluminum powder particle size can vary widely. For example, aluminum powder averaging in particle size from about 10 mesh to 325 mesh can safely be employed. Smaller particle size aluminum is generally very difficult to handle but if carefully treated could yield reasonably good results too.

The amounts of elemental aluminum employed need not be very large. When applied to the external surface of a combustion element it is generally adequate to apply a visually homogeneous coating of powdered aluminum over the entire element surface. In this context the actual weight percentage of aluminum based upon the weight of the element would have very little meaning, since it would depend to a large extent upon the constituents of the element.

Similarly, when powdered aluminum is incorporated in the constituents used to manufacture the combustion elements, the precise weight percentage of aluminum does not appear to be overly critical. There should be enough aluminum powder employed so as to promote a uniform dispersion of aluminum throughout the final combustion element, and the particles of aluminum should be sufficiently close together as to yield optimum combustion efficiency. The precise quantity of aluminum would generally best be determined by the process of trial and error with respect to any given manufacturing process. As a rough guide it has been found that

the results of this invention can be achieved when aluminum is impregnated in such a fashion that powdered aluminum constitutes on the order of about 20 to 80% by weight, preferably about 30 to 75% by weight of the ceramic material making up the combustion element. This calculation is made ignoring the weight of any metal screen or other support upon which any ceramic materials are supported and ignoring the weight of any external protective screen.

The carbon monoxide level generally deemed to be permissible in the exhaust gases from a combustion element is about 0.04% by volume of the total gas evolved and for some purposes even less. Greater proportions of carbon monoxide are dangerous since its use in a confined space could lead to the build up of a toxic atmosphere.

In a particular series of tests in which a visually homogeneous coating of powdered aluminum was dusted on to three combustion elements which were deliberately manufactured (as in Example 6 below) to have high carbon monoxide emissions and then tested in use with propane gas at 30 p.s.i.g. pressure, the following carbon monoxide levels were achieved in the combustion gases:

TABLE I

Element No.	Carbon monoxide content of exhaust gas percent by volume		
	1	2	3
Control (no aluminum)	0.090	0.1250	0.2650
Aluminum dusted	0.0195	0.0235	0.0355

In each case the carbon monoxide content of the exhaust gases of the undusted combustion element was in excess of the 0.04% figure, but after dusting with aluminum the carbon monoxide content decreased substantially so as to be within the tolerable limits. Similarly, improved results were achieved in infrared intensity and in the lives of the combustion elements.

For reasons as yet unknown the aluminum also serves to increase the life of combustion elements. For example, when a particular combustion element was employed in operation, in the absence of a dusting of aluminum powder on its surface, a life expectancy of between 80 and 300 hours was observed. When identical elements were dusted with aluminum, in service lives in excess of 1000 hours were achieved.

One of the major problems of using combustion elements is the possibility that flashback may occur. Flashback is the name given to the situation in which gas below the surface of the combustion element begins to burn and progressively burns backward in the direction of the fuel supply, making the element inoperative and frequently leading to fires and/or explosions.

There are two types of flashback, both equally dangerous and to be avoided. In the first type, the velocity of gases passing through the element and the element pore size are such that the flame front progressively moves back toward the fuel source prematurely igniting the feed gases. In the second type of flashback, the element surface becomes hotter and hotter with the heat gradually flowing to the internal surface of the element, until an internal temperature sufficient to cause premature fuel ignition occurs.

The combination of known combustion elements with powdered aluminum appears to substantially eliminate the danger of flashback for reasons also as yet unknown; and, accordingly, precise control over flow velocity and fuel-air ratios is no longer critical.

In addition, the use of powdered aluminum increases combustion efficiency and infrared output.

The use of powdered aluminum is of particularly desirable value when employed in connection with the type of combustion elements manufactured in accordance with the procedure described in U.S. Permit No. 3,179,156. In

this method an aqueous slurry of element-forming material is prepared and then accreted upon a foraminous surface through the application of differential pressure, as for example, by a suction force from the interior of a screen, thereby causing fluids to pass through the screen and retaining fibers and other materials on the surface of the screen. After the foraminous surface is coated by accretion from the slurry with the appropriate quantity of materials, the product is removed from the slurry, dried, and subsequently treated in the desired fashion to produce the final combustion element. Generally the slurry will contain a plurality of fibers which should be amorphous and be resistant without melting to temperatures of at least about 1800° F. and preferably at least about 2300° F. and preferably have a diameter of under about 10 microns and be of adequate mechanical strength.

The preferred fibers are inorganic and comprise substantial portions of both alumina and silica. Fiber lengths less than about 1 inch are preferred. However, fiber length should exceed fiber diameter. Other fibers that can be employed include such fibers as quartz fibers, vitreous silica fibers and other generally available ceramic fibers. See, for example, those fibers described in Chapter 8 of "Inorganic Fibres" by C. Z. Carroll-Proczynski. An example of a useful commercially available fiber is "Kaowool," which is produced by terating a melt of alumina and silica above the crystallization temperature. Kaowool fiber is stated by the manufacture to have the following characteristics:

Use limit:	
Continuous, ° F.	2000
Short periods, ° F.	2300
Melting point, ° F.	3200
Fiber diameter:	
Microns (average)	2.8
Inches (average)	0.00011

Air velocity	Pressure drop through clean pad, in inches H ₂ O		
	3 lb./cu. ft.	4 lb./cu. ft.	5 lb./cu. ft.
20 ft./min.	0.20	0.24	0.27
50 ft./min.	0.72	0.88	1.02
70 ft./min.	1.25	1.55	1.85

Chemical analysis:		Percent
Alumina, Al ₂ O ₃	45.1	
Silica, SiO ₂	51.9	
Iron oxide, Fe ₂ O ₃	1.3	
Titania, TiO ₂	1.7	
Magnesia, MgO	Trace	
Calcia, CaO	0.1	
Alkalies as Na ₂ O	0.2	
Boric anhydride, B ₂ O ₃	0.08	

Density.—In bulk form Kaowool may be packed to densities of 3 to 10 lb. per cu. ft.

Kaowool fibers are produced by treatment of a melt of alumina and silica, at a temperature above that at which crystallization takes place, the treatment to produce the fibers being well known.

In the chemical analysis, the alumina may be increased to approximately 53.3%, with corresponding reduction of silica content.

Another fiber which can be used in accordance with this invention is commercially available as "Fiberfrax Ceramic Fiber-Bulk Fiber," manufactured by the Carborundum Company, Niagara Falls, N.Y. The fiber length is up to one and one half inches. The mean diameter of the fibers is two and one half microns. The melting point of the fibers is above 3200° F., and the fibers may be used to 2300° F. The fibers include 51.2% Al₂O₃, 47.4% SiO₂ and trace elements. The bulk fiber, at a density of six pounds per cubic foot, has a thermal conductivity at a mean temperature of 2000° F. of 2.92.

A binding agent should also be contained in the aqueous slurry. For example, a mixture of aluminum nitrate and colloidal alumina can be employed as the binding agent. The purpose of a binding agent is to serve to hold the fibers together both at room temperature and under the conditions of expected use, i.e. under temperatures on the order of 2000° F. Any binders serving this function can be used and in an amount adequate to accomplish this function. Gels formed from aluminum nitrate and colloidal alumina (e.g. "Baymal" colloidal alumina) in gel forming proportions are particularly satisfactory for this purpose. Other gels formed from aluminum nitrate or silica gel can also be used as well as any other conventional material meeting the requirements.

In addition, the slurry preferably also contains a finely divided filler which is non-reactive under the conditions of manufacture and is capable of vaporizing completely without leaving any residue at a temperature between about 200° F. and about 1000° F. Representative fillers include such materials as methyl methacrylate, camphor, and menthol. When an element containing a filler is heated to the curing temperature, the filler vaporizes and escapes, leaving in its place a structure of substantially uniform porosity throughout the element, the pores in the interior being interconnected with those on the surface due to the vaporization of the filler particles. The ratio of the filler when employed, to fibers, will generally vary from about 0.1:1 to 24:1 by weight. The proportion and size of filler of methyl methacrylate or other filler depends upon the desired porosity as well as upon the size of the openings of the foraminous support.

Generally, the quantity of fibrous material added to the slurry is adjusted so as to permit the accretion of the coating on the foraminous base within a reasonable period of time, as for example from about one second to about two minutes. Longer periods of time for accretion do not affect the quality of the product but are economically unjustified. Shorter periods of time than one second are too fast for accurate dimensional control. The lower the fibrous content of the slurry, the longer the time required to build up a coating of a given thickness on the foraminous base. The slurry will also preferably contain from about ¼ to one gram of powdered aluminum per gram of fiber.

After vacuum is applied to the foraminous mandrel assembly, and a sufficient thickness of material has been accreted thereon, the assembly is removed from the slurry and dried in any suitable drying apparatus for a sufficient time to eliminate moisture. A temperature on the order of 100 to 150° F. for a period of one hour is generally satisfactory. Thereafter the product is heated slowly from room temperature to an optimum curing temperature of between about 1000° F. and 1500° F. During this time, the methyl methacrylate or other filler vaporizes, leaving an extremely uniform and highly porous wall structure comprising the refractory fibers coated with aluminum oxide formed from the aluminum nitrate as a result of chemical decomposition thereof and also containing the colloidal alumina and the powdered aluminum. Because of the nature of aluminum, the powdered aluminum particles in the final product will probably have a very fine skin of aluminum oxide on the exterior surface of the particles, but the interior of each particle will be substantially elemental aluminum.

The following examples illustrate the preferred mode of carrying out the invention.

Example 1

The following procedure was employed to manufacture combustion elements used in the tests described in this application:

To form a gallon of gel, 1.0 gram of "Baymal" colloidal alumina and 78.9 grams of aluminum nitrate-9 hydrate are employed per gallon of water. The alumina is added first with agitation such as from a shear pump

for about ten minutes. The required amount of aluminum nitrate, preferably in the form of an aqueous solution of density of about 1.21 to 1.26, is then added slowly with continued agitation. Agitation is then continued for an additional period of time, about five minutes, to form a gel.

When it is desired to form the complete slurry for use in accreting the combustion element, the appropriate quantity of fibers is added to the gel with agitation. When employing Kaowool fiber, about 8.5 gms. of pre-chopped fiber is added per gallon of gel. At this point, agitation using a shear pump is preferably run for two minutes.

Thereafter, about 93.5 gms. of 24-30 mesh methyl methacrylate per gallon of gel is added slowly, care being taken to prevent formation of lumps. This is 11 gms. of filler per gram of fiber. Agitation is continued for a substantial period of time (at least three hours and preferably longer, i.e. about twelve hours) in order to eliminate any entrapped air. At this point it is convenient to add powdered aluminum. 6.5 gms. of Alcoa Type 1220 DF atomized aluminum powder is preferably added per gallon of slurry. This powder has an average particle diameter of 50+ microns, a specific gravity of about 2.72 and an average mesh distribution of 100% through 12 mesh, 35% through 200 mesh and 15% through 325 mesh and rated by the manufacturer as substantially dust-free. The slurry containing the aluminum should not be allowed to stand for more than about twenty-four hours before use.

After the slurry is thoroughly agitated, a foraminous support having a suitable shape, such as a tube where the combustion element is intended to be a tube or some other shape when another shape is desired, is inserted into the slurry and connected to a suitable source of vacuum so as to create a flow of slurry across the openings of the support and thereby cause accretion of solids thereon.

It is apparent that any shape combustion element can be manufactured in this manner, there being no necessity of limiting the product to tubular shape. Furthermore, the element need not be completely composed of ceramic materials. For example, the element can be cube shaped, i.e. containing six sides any one of which or even all of which can be made of porous ceramic materials deposited in accordance with this description. Other sides can be impermeable.

Suitable apparatus for accomplishing the accretion is illustrated in the aforementioned U.S. Patent No. 3,179,156. After accretion to the desired thickness, frequently about ¼ inch, the element comprising the mandrel and the accreted layer is dried either at room temperature for 48 hours or at 160° F. for 3 hours and is then heated slowly using suitable heating equipment to a temperature of between about 1000° F. and 1400° F. and maintained at that temperature for a period of time sufficient to vaporize all of the methyl methacrylate and to burn out any residual carbon. Excess air can be added to insure complete burn out.

Example 2

Several combustion elements were manufactured in tubular form having dimensions of 1.75 inches outer diameter by 6.275 inches long with a thickness of accreted layer of 0.275 inch using a draw time of 14 seconds following the procedure of Example 1 but omitting the presence of powdered aluminum as a slurry component. Thereafter each element was dusted with a powdered metal as shown in Table II. The quantity of powdered metal applied was sufficient to produce a visually homogeneous coating on the element surface. The treated elements were then placed in a radiant module containing a closed cavity. A mixture of natural gas and air was passed into the test device and maintained at a rate of 30,000 B.t.u. per hour. Observations were made to determine the flashback characteristics and also the presence of any hot spots, i.e. areas in which flames appear and also

to determine whether holes appeared or whether cracks occurred. The cavity temperature was maintained at approximately 2000° F. This method of testing is a destructive test frequently employed for this purpose. Only the relative proportions are significant and not the actual values obtained. The results are recorded in Table II as items A through E, inclusive.

The destructive test was then repeated using an identical combustion element, except that the slurry used to prepare it contained powdered aluminum in the proportions set out in Example 1. The results of this test are recorded in Table II as item F.

continued for an additional 10 seconds. The elements were then dried and fired and tested for radiant energy output in a commercial radiant thermopile manufactured by Central Scientific Company. This thermopile was a commercially available instrument consisting of 20 hot and cold junctions which developed approximately 1 millivolt per degree. This device is more sensitive than a thermometer and operates substantially instantaneously to detect radiant energy.

The combustion element was placed in a combustion device intended for the combustion elements of this type and a mixture of propane and oxygen passed therethrough

TABLE II

Treatment	Time, min.	Cavity Temp., ° F.	Flashback	Destruction
(A) No treatment.....	2 3½ 4	1,975 2,000 2,000	----- 40% of core..... 70% of core.....	----- Holes and pitting.
(B) Dusted with Zinc.....	1½ 3 4 5½ 6	1,950 1,975 2,000 2,000 2,000	----- ----- ----- ----- None.....	----- Hot spots. Do. Do. Holes.
(C) Dusted with Nickel.....	1 2½ 4 4½ 7 8 9	1,900 2,000 2,000 2,000 2,000 2,000 2,000	----- ----- ----- ----- 30% of core..... do..... do.....	----- ----- ----- ----- Holes. More holes.
(D) Dusted with Manganese.....	1 1½ 2 3	1,900 1,975 1,975 2,000	----- ----- ----- -----	----- Hot spots, element disintegrating. Very hot spots, element disintegrating.
(E) Dusted with Aluminum.....	4½ 2 5 8 9½ 10½ 11	1,975 2,000 1,975 2,000 2,000 2,000 2,000	None..... ----- ----- ----- 40% of core..... do..... do.....	----- ----- ----- ----- Core shows beginning of cracks, no hot spots. Core cracks worsened, no hot spots.
(F) Produced from Aluminum-Containing Slurry.....	40	2,000	None.....	None.

The data in Table II shows that the untreated combustion element exhibited flashback through 40% of the core after 3½ minutes of operation. The zinc dusted combustion element did not show any flashback after 6 minutes, but did show the beginning of hot spots after 3 minutes of operation. The nickel dusted element showed flashback at 7 minutes of operation with holes occurring immediately thereafter. The manganese dusted element began to disintegrate after only 2 minutes of operation. In contrast, the aluminum dusted combustion element showed neither holes nor hot spots after 11 minutes but cracks began to appear indicating that its useful life was fairly limited and flashback did not occur until 9½ minutes of operation. Thus, dusting with aluminum yielded about a three-fold superiority over the untreated element in this destructive test. None of the other metals employed was as useful. The element produced from an aluminum containing slurry was the most desirable of all since after the destructive test was carried out for 40 minutes at 2000° F., no flashback had yet occurred and no signs of cracking, hot spots or hole formation had occurred.

Example 3

A gallon of a dispersion containing 120 gms. of Baymal colloidal alumina, 78.9 gms. of Al(NO₃)₃·9H₂O, 8.5 gms. Kaowool fibers and 93.5 gms. of methyl methacrylate was prepared in accordance with the procedure of Example 1. 800 ml. of this dispersion was measured out and 0.1% by weight of aluminum was mixed therewith. Three tubular combustion elements were prepared by inserting a tubular screen into the slurry and applying suction to accrete fibers on the screens for a period of 2½ seconds and thereafter removed from the slurry. Vacuum application was

and ignited so as to cause the element to incandesce. The sensing element of the thermopile was located five feet from the reflector in which the element being tested was located.

The aluminum powder employed was a commercial product, Alcoa atomized powder No. 1220 DF.

Additional combustion elements were made up in the same fashion containing 0.2% and 0.3% by weight of aluminum powder respectively. Additional elements were made up without aluminum to serve as controls.

The results obtained in this test are set forth in Table III. These results indicate the substantial increase in radiant energy output when aluminum is employed compared to when it is absent.

TABLE III

Element No. 1	Incorporated Additive	Thermopile reading, millivolts 2	Average percent increase in radiant energy output 3
1.....	None.....	7.8	
2.....	do.....	8.1	
3.....	do.....	7.8	
4.....	0.1% Al.....	9.4	10%
5.....	0.1% Al.....	9.4	
6.....	0.1% Al.....	9.4	
7.....	0.2% Al.....	9.3	
8.....	0.2% Al.....	9.2	10%
9.....	0.2% Al.....	9.1	
10.....	0.3% Al.....	9.1	10%
11.....	0.3% Al.....	9.1	
12.....	0.3% Al.....	8.2	

1 Element size was 2 inches long by 0.95 external diameter by 0.163 inch thickness of deposited material. Draw time was 2½ seconds.
2 Based upon average reading for control elements Nos. 1, 2 and 3 of 7.9 mv.
3 Millivolt reading is directly proportional to radiant energy output.

Example 4

A number of combustion elements in tubular form were

prepared following the procedure of Example 1 but the quantity of Alcoa 1220 aluminum powder added to the slurry varied. After the elements were prepared, they were employed in a radiant heating device having a gas orifice of 0.0060 inch with a mixture of propane and oxygen. Radiant output of the element was tested with a radiometer located 52 inches from the outer tip of the element. Carbon monoxide content of the exhaust gases was measured using an infrared gas analyzer. Results are recorded below on the basis of an average reading with five separate elements.

TABLE IV

Powdered aluminum per pound slurry	Average radiant flux, B.t.u./ft. ² hr.	Average percent carbon monoxide by volume in exhaust gas
(A) 0.5 gram.....	97.8	0.00960
(B) 0.75 gram.....	99.2	0.01230
(C) 1.0 gram.....	100.4	0.00930
(D) 2.0 grams.....	97.6	0.01450

Example 5

Several combustion elements were prepared following the procedure in Example 1 using 0.75 gram powdered aluminum of varying types per pound of slurry. After the elements were prepared, they were employed in a radiant heating device having a gas orifice of 0.0060 inch with a mixture of propane and oxygen. Carbon monoxide content of the exhaust gas was measured by infrared techniques. Results are recorded in Table V.

TABLE V

Type of Al powder	Average particle diameter, microns	Mesh distribution	Percent carbon monoxide by volume in exhaust gases
Alcoa 120....	26	{100% through 40 mesh..... 40% through 325 mesh.....}	0.0145
Alcoa 101....	19-20	{100% through 100 mesh..... 80% through 325 mesh..... 2% on 100 mesh.....}	0.0180
Alcoa 606.....		{<60% through 325 mesh..... 99% through 200 mesh.....}	0.0130
Alcoa 123....	18	{98% through 325 mesh.....}	0.0140

Example 6

Several tubular combustion elements were prepared following the procedure of Example 1 but omitting aluminum and reducing the methacrylate content to 10 grams of fiber in order to decrease porosity and increase CO output beyond acceptable levels as a result of increased back pressure, leading to the inspiration of less air than would otherwise be present. The elements were generally cylindrical in shape and were accreted on a wire mesh mandrel by applying vacuum for 2½ seconds. The final element was 3.15 inches long, with an outer diameter of 0.65 inch and a thickness of accreted material of 0.15 inch. After completion, a homogeneous coating of Alcoa 1220 DF aluminum powder was dusted onto the surface of each. They were tested for carbon monoxide output in a radiant heating device having a 7 mil orifice at several propane gas pressures and constant air rate.

Propane pressure, p.s.i.g.	Percent carbon monoxide by volume in exhaust gas				
	10	15	20	25	30
Control (no Al).....					1 0.1533
A.....	0.0175	0.0175	0.0145	0.0240	0.0195
B.....	0.0170	0.0165	0.0160	0.0210	0.0235
C.....	0.0180	0.0285	0.0215	0.0255	0.0355

¹ Average of three tests.

Infrared radiation output was found to be directly proportional to the propane gas pressure. However, as shown, carbon monoxide levels did not change appreciably.

The precise chemical and/or physical mechanisms by which the powdered aluminum participates in yielding the improved results of this invention are not yet completely understood. In any event powdered aluminum appears to

yield an improvement and when the fibers coated with binding agents are deposited on the foraminous support and powdered aluminum is deposited therewith and hence impregnated throughout the fibrous deposit, the improvement obtained is significantly better than when powdered aluminum is merely dusted on the surface of the finished element.

Having thus described the invention, that which is desired to be protected by Letters Patent is as follows:

1. In a method of manufacturing a combustion element adapted for use in a combustion apparatus and characterized by an ability to promote the substantially flameless, infrared generating combustion of gases flowing therethrough, the method comprising accreting a shaped fibrous element on a foraminous support inserted in a slurry having suspended therein a plurality of fibers of a type, size, composition and concentration and with required binders adequate to yield a combustion element having the desired porosity and infrared generating characteristics, and completing the element, the improvement, which substantially improves the characteristics of the combustion element by increasing its serviceability in use, comprising incorporating at least about 0.1% by weight of powdered, substantially elemental aluminum into the slurry prior to accretion.

2. The method of claim 1 in which the slurry prior to accretion comprises powdered aluminum, a plurality of silica-alumina fibers, a binding agent and a particulate filler capable of volatilizing completely at a temperature between 200° F. and 1100° F.

3. The method of claim 2 in which the binding agent is a mixture of aluminum nitrate and colloidal alumina in gel-forming proportions to one another and the filler is methyl methacrylate.

4. The method of claim 3 wherein substantially all of the particles of the powdered aluminum are smaller than 10 mesh.

5. The method of claim 3 wherein the silica-alumina fibers are amorphous, have a melting point in excess of 2300° F., a length not in excess of about 1 inch and a diameter not in excess of about 10 microns.

6. The method of claim 5 wherein after accretion of the fibrous element on the foraminous base, the element is heated to a temperature sufficient to strengthen the fibrous element and volatilize the methyl methacrylate thereby yielding a substantially uniformly gas permeable structure.

7. A method of improving the characteristics of combustion elements adapted for use in a combustion apparatus capable of passing desired quantities of fuel gas through the elements, said combustion elements being characterized by an ability to promote substantially flameless infrared radiation generating combustion of gases flowing therethrough, the method comprising combining powdered metallic aluminum with a mass of amorphous inorganic fibers so as to distribute the aluminum throughout the mass of fibers, and firing and subsequently operating the resulting mass at a temperature below 2000° F. under such conditions as to maintain the integrity of the metallic aluminum powder.

8. The method as in claim 7 wherein the combustion element is in substantially tubular form.

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JAMES W. WESTHAVER, *Primary Examiner.*

**UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION**

Patent No. 3,383,159

May 14, 1968

Roger M. Smith, Jr.

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

Column 8, TABLE III, texts of footnote numbered "2" should read -- 3 --; texts of footnote numbered "3" should read -- 2 --.

Signed and sealed this 28th day of October 1969.

(SEAL)

Attest:

Edward M. Fletcher, Jr.

Attesting Officer

WILLIAM E. SCHUYLER, JR.

Commissioner of Patents