Jan. 4, 1966 D. R. MATTOON 3,227,241

CERAMIC MUFFLERS

Filed March 16, 1964 3 Sheets-Sheet 1

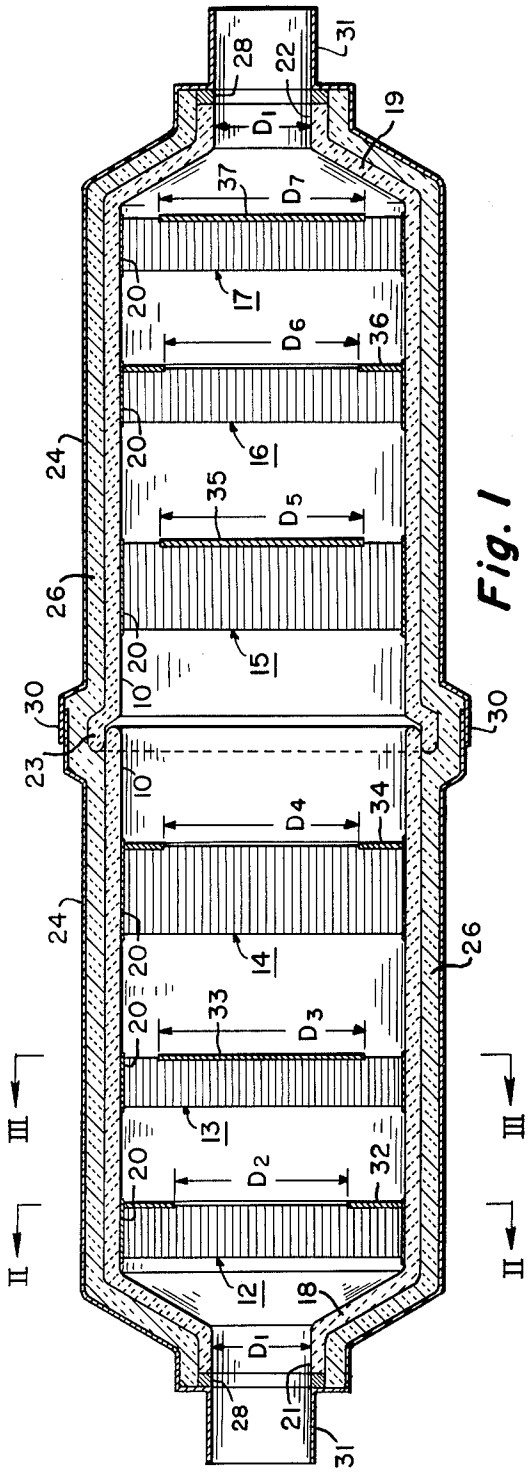



Fig. 1

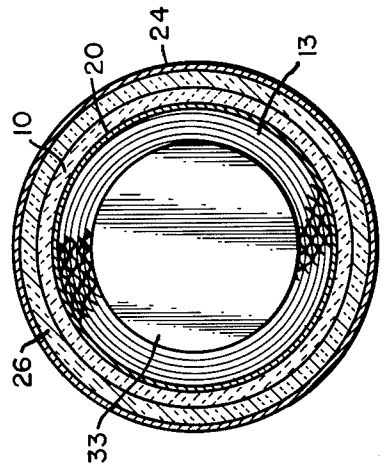



Fig. 3

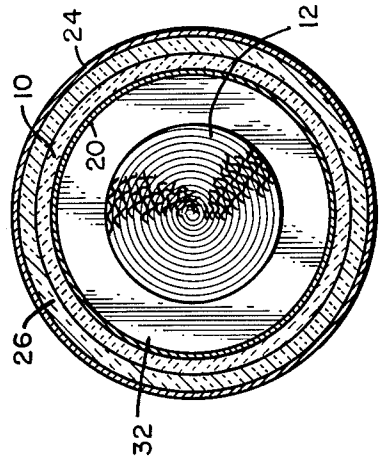



Fig. 2

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Jan. 4, 1966 D. R. MATTOON 3,227,241

CERAMIC MUFFLERS

Filed March 16, 1964 3 Sheets-Sheet 2

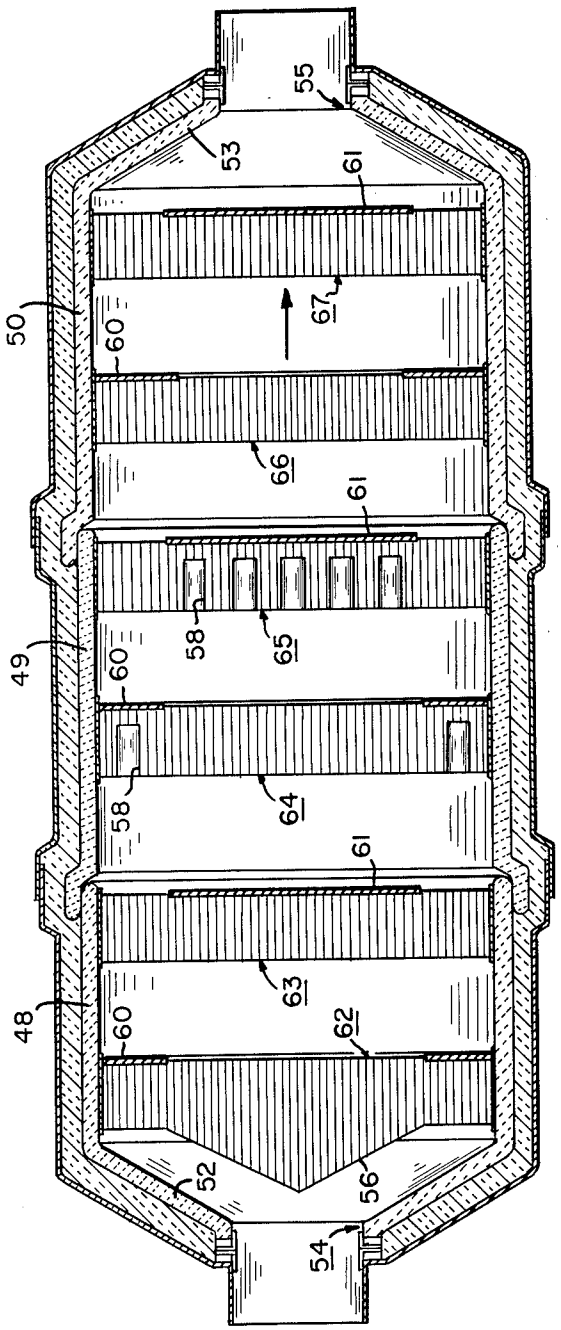



Fig. 5

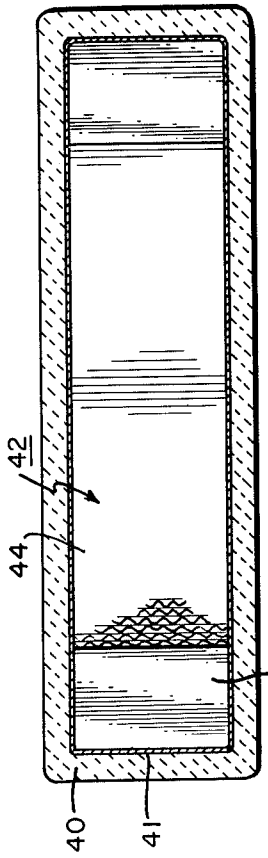



Fig. 4

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CERAMIC MUFFLERS

Filed March 16, 1964 3 Sheets-Sheet 3

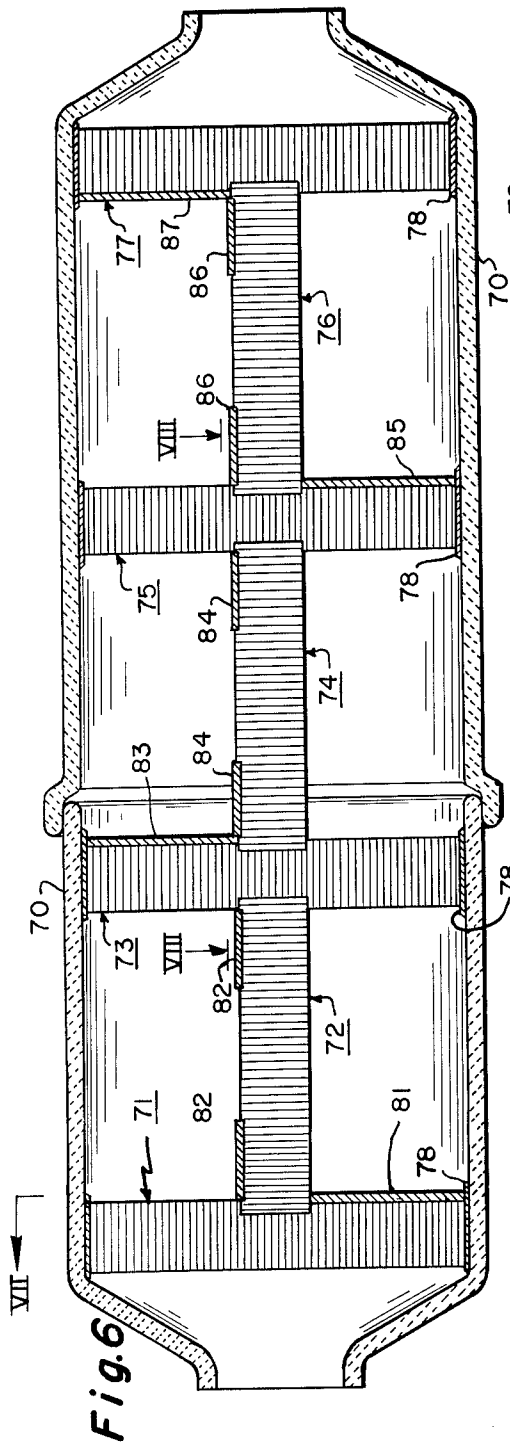



Fig. 6

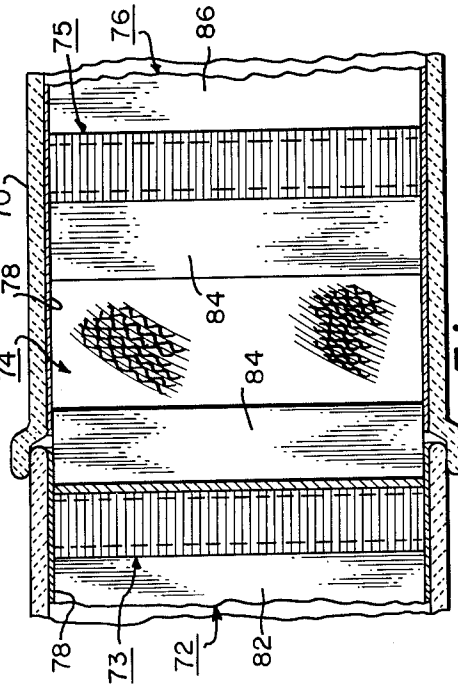



Fig. 8

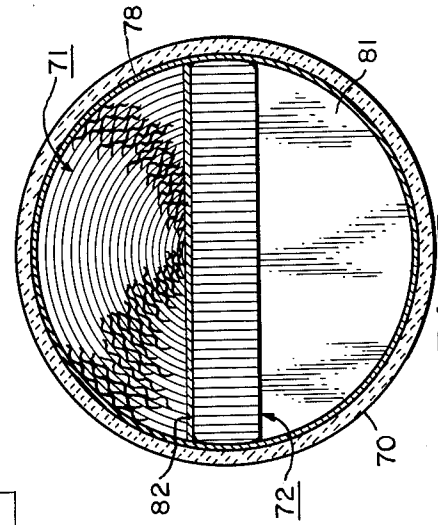



Fig. 7

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United States Patent Office 3,227,241 Patented Jan. 4, 1966



3,227,241

# CERAMIC MUFFLERS

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Filed Mar. 16, 1964, Ser. No. 351,949
22 Claims. (Cl. 181—56)

This invention relates to the deadening or suppressing of sound by means of an acoustic filter or silencer device. In particular, it relates to a novel resistive, ceramic muffer structure for the exhaust system of internal combustion engines and the like.

Sound attenuation or sound deadening of the exhaust gas stream of internal combustion engines is a well-known art. Commonly structures for this purpose are of the nonresistive type (i.e. relatively large flow passages), made of metallic parts and include baffles that serve a sound attenuation function. In some cases, these nonresistive structures are coated or lined with conventional, well-known sound absorbing materials to further improve sound attenuation performance. These devices are usually subject to relatively rapid deterioration due to the severe corrosive chemical and thermal conditions encountered in use and by detrimental build-up of exhaust products on their surfaces.

Resistive type devices wherein the sound deadening is brought about by a multitude of irregular surfaces largely parallel to gas flow have also been proposed for this purpose. These latter devices involved passing the exhaust gases through a porous mass of material, such as a loose packing of refractory granules, balls or fibers, and ruptured cell foamed glass. However, as far as I am aware, no significant success has been had with these resistive type muffling devices. The difficulties encountered include relatively rapid chemically corrosive destruction of supporting metallic parts as well as of the resistive material mass due to vibration and thermal conditions of use, and very importantly the low engine efficiency caused by the very large back pressures inherent in these proposed structures, which problem may be further aggravated by build-up of exhaust products.

Large back pressures severely cut down the engine volumetric efficiency. Thus, for example, the pistons cannot expel all the exhaust gases from the cylinders due to the opposing force of the back pressure, thereby leaving some exhaust gases to mix in the chamber with the intake fuel. This results in untenable dilution of the fuel mixture in present day engine designs.

Recently, it has been found that the foregoing difficulties can be avoided by utilizing, as a resistive element or member, at least one relatively inexpensive, thin walled, ceramic cellular or honeycomb structure sintered to a rigid unitary state or condition and having a plurality of generally regular, unobstructed gas passages of small cross-section extending between and terminating in substantially opposed inlet and outlet surfaces. For effective sound deadening and modestly low or negligible back pressure, this resistive element is essentially characterized by: (1) regular gas passages or cells being defined and separated from one another by the thin ceramic walls so as to provide a cross-sectional area of each individual passage or cell of no more than about 0.010 square inch, preferably within the range of about 0.0002 to 0.003



square inch and (2) the thinness of the cell walls being chosen so that there is at least about 50% of aggregate open space, preferably about 60% to 85%, provided by the collective cell cross-sectional areas in a plane through the honeycomb perpendicular to the axes of the gas passages. The thin walls generally are within the range of about 0.004 to 0.010 inch thick, but can be as thick as 0.015 inch or even somewhat thinner than 0.004 inch.

Other important characteristics of this resistive element, for a muffler used with an internal combustion engine, are that it be made of ceramic material that is highly refractory (i.e. melting or softening temperature substantially exceeding maximum operating or service temperatures) and remains so indefinitely, that has good thermal shock resistance, and that is chemically resistant or inert to the highly corrosive conditions at operating temperatures. The sintered unitary construction provides a high degree of strength to resist indefinitely destruction due to vibration or other mechanical stresses encountered under normal service conditions. Although its contribution to the successful deadening of sound in the above-described ceramic honeycomb resistive element is not positively ascertained, it is believed that the normal resulting cell wall porosity adds to the sound attenuation performance. The usual porosity resulting from the preferred process of construction described below has been measured at 25% to 45%.

Mufflers with one or several ceramic honeycomb resistive elements, as described above, have been found to give almost (but not equally) as good long term sound attenuation performance as prior commercial mufflers for a great variety of engines. Notably, such performance was accompanied by no observable mechanical nor chemical deterioration of the ceramic honeycomb elements. Furthermore, except for a very small zone adjacent the periphery of these elements, no build-up of exhaust products was found.

I have now discovered, and it is a primary object of this invention to provide, a novel muffler or noise suppressor device utilizing a plurality of the ceramic honeycomb gas flow resistive element described above in a unique assembly or construction arrangement that yields superior sound attenuation or deadening in service with internal combustion engines as well as with noise-containing gas streams from other sources. Moreover, my invention provides, as another object thereof, a relatively inexpensive and unique, all-ceramic noise suppressor device capable of providing superior lifetime with excellent sound attenuation or deadening performance.

The all-ceramic noise suppressor device of this invention basically comprises a plurality of gas flow resistive elements arranged in a series defining an irregular gas flow path within a casing and rigidly positioned within the casing by means of a bond. The resistive elements, the casing and the bond are all made of sintered ceramic. Where the device is used with hot gas stream (e.g. exhaust from internal combustion engine), all the sintered ceramic must have essentially similar coefficients of thermal expansion so as to avoid physical destruction in service.

As used in this application, "an irregular gas flow path" is defined as a path configuration other than that of a straight or smooth line configuration parallel to the axis of the series of elements. The "axis of the series" of

elements within the casing can be, but is not necessarily limited to, a straight line configuration. Such "axis of the series" can also be made in other configurations if desired, e.g. sinusoidal or even S-shaped.

The casing includes opposite inlet and outlet end walls. These walls are provided with inlet and outlet ports, respectively.

Basically, each resistive element comprises two different portions. One portion (or portions) comprises an open passage, thin walled, sintered ceramic honeycomb having features, e.g. inlet and outlet surfaces with unobstructed gas passages extending therebetween, maximum thickness of thin walls defining the passages, maximum cross-sectional areas of the gas passages, and minimum aggregate open space or cross sectional area measured in a plane perpendicular to the axes of the gas passages, all as specified above. The total open area of each of these open passage portions must be not less than, and desirably greater than, the area of the inlet port in order to obtain the excellent low back pressure as the gas stream flows through them. Preferably, each open passage portion has a total open area of about two to three times the area of the inlet port. Also, the outlet port should have an area at least equal to the inlet port area for the same reason.

The arrangement of the series of elements is such that the inlet surface of the open passage portion of each succeeding element along the gas flow path is spaced from the outlet surface of the open passage portion of the preceeding element. These spaced surfaces are so constructed and arranged to provide the definition of the irregular gas flow path.

The other portion (or portions) of the resistive elements comprises an imperforate barrier to gas flow. For effective muffling, particularly a high intensity of the lower frequency sounds (e.g. 150–315 c.p.s.), of the exhaust from the larger engines (i.e. 200 or more cubic inches displacement with six or more cylinders) to, and even lower than, the low level of present day commercial mufflers, the imperforate barrier portions each should comprise a close passage, thin walled, sintered ceramic honeycomb having the same restrictive physical features as those specified above for the open passage honeycomb portions, but additionally having a sintered ceramic closure sealing off each gas passage at a point spaced from the inlet surface of the close passage honeycomb toward the outlet surface thereof. The closure provides the imperforate barrier structure while at the same time forming with the honeycomb structure a plurality of dead-end passages or cul de sacs opening on the inlet surface of the close passage honeycomb. An additional or alternative plurality of such cul de sacs or dead-end passages opening on the outlet surface of the close passage portion can be provided, if desired in certain cases, to further assist in absorbing sound. The sound waves in the gas stream passing through the noise suppressor device of this invention containing the cul de sacs, upon reaching the inlet surface of the close passage honeycomb portions, propagate into the dead-end gas passages. Sound energy is then dissipated by cancellation due to the reflectance of the wave from the closed end surface or closure of the gas passage. Of course, it is expected that some sound energy is absorbed by the porous walls.

In some applications where low frequency sounds are not exceedingly troublesome, the imperforate barrier portion can be made of a plain solid ceramic wall or the like without the cul de sacs.

For a better understanding of the invention, several preferred forms with illustrative specific embodiments thereof will now be described in conjunction with the attached drawings wherein:

FIGURE 1 is a longitudinal view in cross section of one specific embodiment of the present invention,

FIGURE 2 is a sectional view taken along line II—II in FIGURE 1,



FIGURE 3 is a sectional view taken along line III—III in FIGURE 1,

FIGURE 4 is a transverse cross sectional view of another specific embodiment of the present invention,

FIGURE 5 is a longitudinal view in cross section of a further composite embodiment of the present invention illustrating several additional variations,

FIGURE 6 is a longitudinal view in cross section of a still further specific embodiment of the present invention,

FIGURE 7 is a sectional view taken along line VII—VII in FIGURE 6, and

FIGURE 8 is a sectional view taken along line VIII—VIII in FIGURE 6.

Referring now to FIGURES 1–3, the all-ceramic muffler or noise suppression device includes a compatible sintered ceramic shell or casing **10** and compatible sintered ceramic honeycomb resistive elements **12–17** rigidly bonded to the casing **10** by means of a compatible sintered ceramic cement **20**.

By the term "compatible," I mean that the sintered ceramics used have essentially similar coefficients of thermal expansion so as to avoid fractures and physical destruction of the device upon being subjected to repeated and substantial changes in temperature. Preferably, the sintered ceramics also should have low thermal expansion coefficients (i.e. $-10$ to $+10\times10^{-7}/°$ C. over extended temperature range) to minimize the thermal stresses in the device. Of course, when the device is used in gas streams not involving elevated temperatures, the described compatibility of thermal expansion coefficients is not essential.

Casing **10** includes an inlet end wall **18** and an outlet end wall **19**. The inlet end wall **18** has an inlet port **21** and outlet end wall **19** has an outlet port **22**. Both ports have diameters $D_1$. Preferably, the casing **10** is made in two sections as shown and provided with a ship's lap **23** to render the two sections separable. Alternatively, casing **10** can be made one unitary piece as desired, e.g. by forming a bond of sintered ceramic cement at ship's lap **23**.

In the embodiment shown in FIGURES 1–3, the resistive elements are of two types, each alternating with the other along the series defining the irregular gas flow path. Each type of element comprises a central portion bounded by an outer portion with each of these portions being substantially symmetrical about the axis of the series. The outer perimeter of these central and outer portions can be of various configurations as desired, e.g. circular, oval, square, rectangular, triangular, polygonal, etc.

The central portions having outside diameters $D_2$, $D_4$, $D_6$ of the first type elements **12**, **14**, **16** and the outer annular portions having inside diameters $D_3$, $D_5$, $D_7$ of the second type elements **13**, **15**, **17** comprise the open passage, thin walled honeycombs described above.

The outer annular portions having inside diameters $D_2$, $D_4$, $D_6$ of the first type elements **12**, **14**, **16** and the central portions having outside diameters $D_3$, $D_5$, $D_7$ of the second type elements **13**, **15**, **17** comprise the imperforate barriers with cul de sacs described above. In this embodiment, the total area of the central portion of the second type element should be at least about equal to the total area of the central portion of adjacent first type elements. Thus, the open cells or open gas passages of one type element are axially opposite the barrier portion of the other type element along the axis of the series. This causes the gas stream to travel a sinuate path as it progresses through the noise suppressor device and results in substantially reducing the outlet sound level below that obtained in a similar device with the open cells all opposite each other in straight-through alignment (i.e. regular gas flow path of straight line configuration).

The cul de sacs of elements **12–17** are formed by providing sintered ceramic coatings **32–37** on the outlet faces

or surfaces of the elements. These coatings 32–37 seal or close off the cells or gas passages terminating at the outlet surface areas covered by the coatings. Coatings 32, 34, 36 form the outer annular barrier zones or portions of elements 12, 14, 16 that surround the central portions of open passage cells. In an opposite manner, coatings 33, 35, 37 form the central circular barrier zones or portions of elements 13, 15, 17 that are surrounded by the outer annular portions of open passage cells.

The number and spacing of the two-portion elements can be varied depending upon the particular type of application. A series of at least four of the elements are necessary for satisfactory muffling the exhaust from the large internal combustion engines whereas only two or three elements can be satisfactorily used for muffling the exhaust from smaller engines, such as those commonly found on agricultural tractors and the like. For the latter type of application, the ceramic honeycomb elements can be advantageously made of a ceramic material having a fairly high specific heat (e.g. about 0.2 or more calories per gram at 25° C.) so as to additionally act as a flame arrestor in the hot exhaust stream.

In situations where the muffler is commonly situated along an exhaust pipe, the superior performance (i.e. sound attenuation, low back pressure, etc.) for large engines is obtained by spacing the elements a distance substantially equal to the sum of the average cell or gas passage length of the two elements forming the spacing and with an average gas passage length for each element within the range of about ½ to 2½ inches. Particularly effective results have been obtained when the spacing has been kept within ±25% of the aforesaid sum of average gas passage lengths.

Where the muffling device (see FIGURE 4) is located in or near the exhaust manifold, the spacing may be advantageously less than as described above relative to the sum of the average gas passage lengths for suitable results (possibly because of the lower viscosity of the exhaust gases in or near the exhaust manifold).

The all-ceramic muffler device can be attached or mounted to an exhaust line or pipe by any suitable means. As shown in FIGURE 1, the muffler device is positioned in an outer shell 24 by a resilient insulating shield 26 and compression gaskets 28. Advantageously, the outer shell 24 is made of corrosion resistant metal and in two separable parts with a telescopic joint 30. Also, shell 24 includes coupling extensions 31 at the inlet and outlet ends.

*Example 1*

A muffler unit made according to the structure shown in FIGURES 1–3 was tested in the exhaust line of a 401 cubic inch, eight cylinder engine and found to give superior performance as compared with the commercial muffler customarily supplied with the engine and with a comparable back pressure of 18" of Hg. The ceramic casing was made of a sintered slip cast mixture of 72% by weight petalite and 28% by weight beta spodumene in accordance with the teachings of U.S. Patent 3,096,159 to H. C. Van Cott. This sintered ceramic exhibits a very low coefficient of thermal expansion of about

$$0\pm2\times10^{-7}/^{\circ}\text{ C.}$$

up to 900° C. The casing was made with a wall thickness of about ¼", an inside diameter of about 6", a total length of about 25½" and port diameters $D_1$ of 2".

The honeycomb elements were made in accordance with the teachings of U.S. Patent 3,112,184 to R. Z. Hollenbach. The ceramic material used consisted of 75% by weight of petalite and 25% by weight of a glass-ceramic having the following approximate composition, by oxide analysis, in weight percent: 70% $SiO_2$, 18% $Al_2O_3$, 5% $TiO_2$, 3% MgO, 3% $Li_2O$ and 1% ZnO. A slurry was formed of this comminuted ceramic material by ball milling it with equal parts of a solution having the following approximate composition, in volume percent: 29.6% isopropanol, 39.8% ethyl acetate, 8.4% Versamid 115 and 22.2% Hysol 6111. Versamid 115 is the trade name of a thermoplastic polymer supplied by General Mills, Inc., and it is prepared by condensation of polymerized unsaturated fatty acids, such as dilinoleic acid, with aliphatic amines such as ethylene diamine. Hysol 6111 is the trade name of an epoxy resin solution, supplied by Houghton Laboratories, Inc., containing 57% by weight of epoxy resin having a viscosity of about 2.5–4.0 poise at 25° C., an epoxide equivalent (grams of resin containing 1 gram chemical equivalent of epoxy) of 595±50, and a melting range of 73–85° C. The slurry was coated onto common 3½ pound tea bag paper and formed into sintered ceramic honeycomb structures in the manner described in the aforementioned U.S. Patent 3,112,184. The firing schedule was as follows:

| Temperature range: | Firing rate |
|---|---|
| Room temp. to 700° C. | 350° C./hr. |
| Hold at 700° C. | 1 hour. |
| 700° C. to 1220° C. | 30 minutes. |
| Cool to room temp. | Furnace rate. |
| Refire to 1240° C. | 300° C./hr. |
| Hold at 1240° C. | 7 hours. |

Thereafter the honeycombs were furnace cooled to handling temperature. These honeycombs were produced with gas passages, taken in cross-section, in the shape of isosceles triangles having a height of about 0.04 inch and a base of about 0.075 inch and with an aggregate open area of about 70% of the total cross-sectional area of the honeycombs in a plane perpendicular to the axes of the gas pasasges. The average cell wall thickness was about 0.006 inch and the wall porosity was about 35–40%. The sintered ceramic honeycombs exhibited coefficients of thermal expansion of about $0\pm2\times10^{-7}/^{\circ}$ C. up to 300° C. or higher.

The honeycomb elements were cut to slightly less than 6 inches in diameter. Elements 12, 13, 16 and 17 were made 1 inch thick (direction parallel to gas passage axes) and elements 14 and 15 were made 1¾ inches thick. The latter two elements were spaced apart 4⅜ inches, each equidistant from the mid-point of the casing. The spacing between elements 13 and 14, and between elements 15 and 16 was 2½ inches. The spacing between elements 12 and 13, and between elements 16 and 17 was 2 inches.

The ceramic cement for rigidly bonding the elements 12–17 to the casing 10 had the following batch composition analytically by weight: 8.72% ZnO, 1.3% $CaF_2$, 3.46% SiC, 1.93% $SO_3$ (from fumed white lead), 6.81% PbO and the remainder glass petalite. A batch of this cement composition was dispersed in a solution of 75% by weight butyl alcohol and 25% by weight toluene and the resulting dispersion coated on the peripheral surface of the honeycomb elements. The same cement dispersion was used to form coatings 32–37 on the outlet surface of the elements. After placing the elements in the above-described positions, the resulting assembly was heated to 1150° C. at about 5° C./minute and held at 1150° C. for about 1 hour to permit the cement to completely foam, sinter and form strong chemical bonds with the honeycombs and the casing. Thereafter, the assembly was furnace cooled to handling temperatures at a rate of about 5° C./minute. The resulting sintered ceramic cement exhibited coefficients of thermal expansion of about $0\text{–}4\times10^{-7}/^{\circ}$ C. up to 300° C. or higher.

The coatings 32–37 were formed so as to provide the following diameters: $D_2$ being 3½ inches; $D_3$, $D_5$ and $D_7$ being 4¼ inches; $D_4$ and $D_5$ being 4 inches.

*Example 2*

Another unit made similar to the structure shown in FIGURES 1–3 was tested in the exhaust line of a 225 cubic inch, six cylinder engine and found to give satisfactory results. The construction of this unit was the same as in Example 1 except for the following specific

features. The total casing length was about 17 inches. The elements 12–17 were each 1 inch thick and spaced apart about 1½ inches. Elements 13, 15 and 17 were made with gas passages, taken in cross-section, in the shape of isosceles triangles having a height of about 0.02 inch and a base of about 0.038 inch and with an aggregate open area of about 60%.

FIGURE 4 shows another form of the noise suppressor device of the invention that can be made in smaller compact shapes for location in the exhaust manifold or closely to it. This form of device comprises, similarly to the ones already described, a sintered ceramic casing 40 of rectangular cross-section. Sintered ceramic cement 41 rigidly holds the resistive elements in place within the casing 40. The solen sintered ceramic element 42 (analogous to element 12 in FIGURE 1) shown comprises a central portion 44 of open cells or gas passages and outer portions 46 of dead-end gas passages or cul de sacs formed by a sintered ceramic coating on the outlet face of the element. The second type element in this unit would have the open cells in similar outer portions and the cul de sacs in a similar central portion. Of course, this unit would be made to conform to the other necessary physical restrictive features described above.

FIGURE 5 illustrates several other modifications that can be made within the present invention. First, the casing can be made in several separable segments 48, 49 and 50. Thus, suitable muffling units can be readily provided for a variety of engines merely by assembling segments 48 and 50 with or without one or more segments 49. In order to conserve space, inlet end wall 52 and outlet end wall 53 can be provided with a stubby inlet port 54 and a stubby outlet port 55, respectively.

As a means for better distribution of the gaseous sound stream across the inlet face of a resistive element, the element can be provided with a forwardly extending central portion 56 having its inlet surface angularly converging at a central furthermost forward point.

In some applications, the sound attenuating or deadening effectiveness of the cul de sac feature can be strengthened or increased by cutting cavities or indentations 58 into the inlet surface portions of the elements opposite the outlet surface portions having the sintered ceramic coatings 60 and 61 sealing shut the gas passages extending between those surfaces. As shown in FIGURE 5, the cavities 58 are circular resonating chambers, but they can be made in other geometric forms as desired. Also, all the elements 62–67 can be provided with cavities 58 or only selected elements can be so provided, as desired for each particular application.

*Example 3*

FIGURES 6–8 show a still further specific embodiment of my invention tested in the exhaust line of a 300 cubic inch, eight cylinder engine with excellent results. The two part casing 70 was made like the casing in Example 1, except that the total length was only about 21". Elements 71–77 were made of the sintered ceramic honeycomb structures used in Example 2. The round elements 71, 73, 75, 77 were slightly less than 6 inches in diameter and one inch thick. Elements 72, 74, 76 were made rectangular (see FIGURE 8) with dimensions 6" x 4¾" x 1" and assembled with the other elements as shown in FIGURE 6. Elements 71, 73, 75, 77 were then rigidly bonded to casing 70 by cement 78 in the same manner as in Example 1.

Prior to assembly, one half of the outlet surfaces of elements 71, 73, 75, 77 were provided with coatings 81, 83, 85, 87 (also in the same manner as Example 1) thereby forming barriers with cul de sacs opening on the inlet surfaces in an alternating pattern through the muffler unit. The other halves of these elements were the open passage portions.

Also prior to assembly, coatings 82, 84, 86 were provided on elements 72, 74, 76 forming outer close passage portions and defining the central open passage portions. Each of the latter can be divided in two by a central close passage portion if desired in certain cases. While coatings 84 are formed on the outlet surface of element 74 to provide cul de sacs opening on the inlet surface, coatings 82 and 86 are formed on the inlet surfaces of elements 72 and 76 to provide cul de sacs opening on the outlet surfaces thereof. This design allows the muffler unit to be positioned so that no cul de sacs open upwardly in a manner that would permit solid particles carried in the gas stream to fill up these cul de sacs and reduce their ability to absorb sound energy.

Although the present invention has been described with respect to specific details of certain embodiments thereof, it is not intended that such details be limitations upon the scope of the invention except insofar as set forth in the claims. Accordingly, it will be appreciated that a variety of ceramic materials and methods of constructing the ceramic structures can be utilized without departing from the invention. For example, the structures can be made from appropriate glass or glass-ceramic materials by known hot glass processes and, as used in this specification, including the claims, the term "ceramic" is used in its most generic sense as encompassing those ceramic materials that are amorphous, crystalline or mixtures of these two physical states.

I claim:

1. An all-ceramic noise suppressor device comprising
   (A) a ceramic casing including opposite inlet and outlet end walls having inlet and outlet ports, respectively,
   (B) a plurality of ceramic gas flow resistive elements arranged in a series defining an irregular gas flow path within said casing intermediate said inlet and outlet end walls, each of said elements comprising two different portions,
      (1) first portions comprising imperforate barriers to gas flow,
      (2) second portions comprising open passage, thin walled honeycombs, each honeycomb having: (a) an inlet surface and an opposed outlet surface, (b) a plurality of unobstructed gas passages extending between said inlet and outlet surfaces, the gas passages being defined by thin walls up to about 0.015 inch thick, the cross-sectional area of each gas passage not exceeding about 0.010 square inch and the aggregate open cross-sectional area of said honeycomb measured in a plane perpendicular to the axes of the gas passages being at least 50 percent of the total cross sectional area of said honeycomb, the inlet surface of said second portions of each succeeding element along the gas flow path being spaced from the outlet surface of said second portions of the preceding element, said spaced surfaces so constructed and arranged together with said first portions to provide the definition of the irregular gas flow path, said aggregate open area of each element being not less than the area of said inlet port, and
   (C) a ceramic bond rigidly positioning said elements in said casing.

2. The device of claim 1 wherein the ceramic of said casing, of said elements and of said bond have essentially similar coefficients of thermal expansion.

3. The device of claim 1 in which the aggregate open area of each element is about two to three times greater than the area of said inlet port, and in which the area of the outlet port is at least equal to the area of said inlet port.

4. The device of claim 1 in which the thin walls of said honeycomb are porous.

5. The device of claim 1 in which said imperforate barriers comprise close passage, thin walled honeycombs having the same restrictive physical features as those

specified for said open passage honeycombs, but additionally having ceramic closures so constructed and arranged to seal off each gas passage and to form a plurality of cul de sacs opening on at least one of said inlet and outlet surfaces of the close passage honeycombs.

6. The device of claim 5 wherein the ceramic of said casing, of said elements and of said bond have essentially low and similar coefficients of thermal expansion.

7. The device of claim 5 in which the thin walls of said honeycombs are porous.

8. The device of claim 7 wherein the porosity of said thin walls is 25 to 45 percent.

9. An all-ceramic noise suppressor device comprising

(A) a ceramic casing including opposite inlet and outlet end walls having inlet and outlet ports, respectively,

(B) a plurality of spaced ceramic gas flow resistive elements arranged in a series defining an irregular gas flow path within said casing intermediate said inlet and outlet end walls, said elements being of a first and a second type, each type alternating with the other type along said gas flow path and comprising a central portion bounded by an outer portion, each of said portions being substantially symmetrical about the axis of said series,

(1) the outer portion of said first type element and the central portion of said second type element comprising imperforate barriers to gas flow,

(2) the central portion of said first type element and the outer portion of said second type element comprising open passage, thin walled honeycombs, each honeycomb having; (a) an inlet surface and an opposed outlet surface, (b) a plurality of unobstructed gas passages extending between said inlet and outlet surfaces, the gas passages being defined by thin walls up to about 0.015 inch thick, the cross-sectional area of each gas passage not exceeding about 0.010 square inch and the aggregate open cross-sectional area of said honeycomb measured in a plane perpendicular to the axes of the gas passages being at least 50 percent of the total cross-sectional area of said honeycomb, the area of the central portion of said second type element being at least about equal to the area of the central portion of adjacent first type elements, the area of the central portion of said first type element and the outer portion of said second type element being greater than the area of said inlet port, and

(C) a ceramic bond rigidly positioning said elements in said casing.

10. The device of claim 9 including at least four of said elements.

11. The device of claim 10 wherein the element adjacent the inlet end wall is of the first type.

12. The device of claim 9 in which each of said imperforate barriers comprise close passage, thin walled honeycombs having the same restrictive physical features as those specified for said open passage honeycombs, but additionally having ceramic closures sealing off each gas passage and spaced from the inlet surface of said close passage honeycomb toward the outlet surface thereof thereby forming a plurality of cul de sacs opening on said inlet surface.

13. The device of claim 12 in which the aggregate open area of the central portion of said first type element and of the outer portion of said second type element is about two to three times greater than the area of said inlet port, and in which the area of the outlet port is at least equal to the area of said inlet port.

14. The device of claim 12 including at least four of said elements.

15. The device of claim 14 wherein the element adjacent the inlet end wall is of the first type.

16. The device of claim 12 wherein adjacent resistive elements are spaced a distance substantially equal to the sum of the average gas passage lengths of the two adjacent elements forming the spacing.

17. The device of claim 16 wherein the average gas passage length of each element is within the range of about ½ to 2½ inches.

18. The device of claim 12 wherein the inlet surface of the outer portion of said first type element and the inlet surface of the central portion of said second type element include cavity forming surfaces.

19. An all-ceramic noise suppressor device comprising

(A) a ceramic casing including opposite inlet and outlet end walls having inlet and outlet ports, respectively.

(B) a plurality of ceramic gas flow resistive elements arranged in a series within said casing intermediate said inlet and outlet end walls, first type elements comprising the element nearest the inlet end wall and every second element thereafter positioned with their largest faces substantially perpendicular to the axis of the series, a second type element positioned between every two successive first type elements with a plane within said second type element parallel to the largest faces thereof intersecting the axis of said series and said second type element abutting said two successive first type elements along substantially diametral lines of the latter elements, each of said first and second type elements comprising two different portions,

(1) substantially one half of each first type element, but on opposite sides of the diametral abutments with said second type element for each successive first type element, and the portions of said second type elements adjacent said diametral abutments constituting first portions comprising imperforate barriers to gas flow,

(2) substantially the other half of each first type element and central portion of said second type element constituting second portions comprising open passage, thin walled honeycombs, each honeycomb having: (a) an inlet surface and an opposed outlet surface, (b) a plurality of unobstructed gas passages extending between said inlet and outlet surfaces, the gas passages being defined by thin walls up to about 0.015 inch thick, the cross-sectional area of each gas passage not exceeding about 0.010 square inch and the aggregate open cross-sectional area of said honeycomb measured in a plane perpendicular to the axes of the gas passages being at least 50 per cent of the total cross-sectional area of said honeycomb, said aggregate open area of each element being greater than the area of said inlet port, and

(C) a ceramic bond rigidly positioning said elements in said casing.

20. The device of claim 19 including at least four of said first type elements and at least three of said second type elements.

21. The device of claim 19 in which said imperforate barriers comprise close passage, thin walled honeycombs having the same restrictive physical features as those specified for said open passage honeycombs, but additionally having ceramic closures so constructed and arranged to seal off each gas passage and to form a plurality of cul de sacs opening on at least one of said inlet and outlet surfaces of the close passage honeycombs.

22. The device of claim 21 including at least four of said first type elements and at least three of said second type elements, said ceramic closures of all said first type elements except the one nearest the outlet end wall and said ceramic closures of every other second type element

as determined from said inlet end wall being located at the outlet surface of said close passage honeycombs thereby forming a plurality of cul de sacs opening on the inlet surface thereof, and said ceramic closures of the first type element nearest the outlet end wall and of the other second type elements being located at the inlet surface of said close passage honeycombs thereby forming a plurality of cul de sacs opening on the outlet surface thereof.


**References Cited by the Examiner**

UNITED STATES PATENTS

| | | | |
|---|---|---|---|
| 1,758,654 | 5/1930 | Dormeyer | 181—49 |
| 2,019,746 | 11/1935 | Tatter. | |
| 2,981,057 | 4/1961 | Buttler | 181—62 X |
| 3,065,595 | 11/1962 | Gary. | |
| 3,109,715 | 11/1963 | Johnson et al. | 22—2 |
| 3,134,457 | 5/1964 | Marcellus | 181—56 |
| 3,163,256 | 12/1964 | Lanning | 181—56 |
| 3,166,895 | 1/1965 | Slayter et al. | 60—29 |
| 3,172,251 | 3/1965 | Johnson | 60—30 X |

FOREIGN PATENTS

| | | |
|---|---|---|
| 1,248,627 | 11/1960 | France. |
| 435,423 | 9/1935 | Great Britain. |
| 808,806 | 2/1959 | Great Britain. |




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