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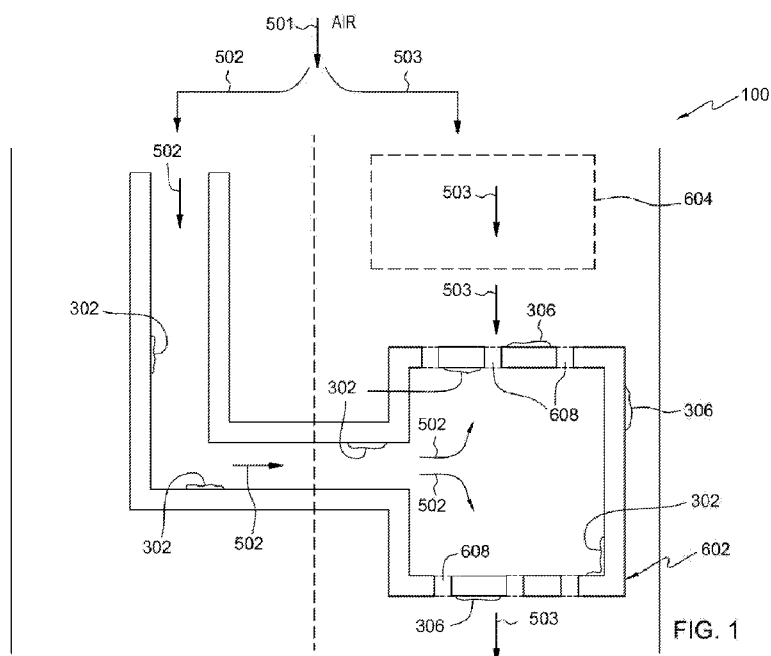
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(54) Title: DUST MIXTURES FOR ENGINE TESTING



(57) Abstract: A test dust for testing an engine under test can include a mixture representative of a dust environment that an engine in use may be exposed to. A test dust can include first mineral particles and second mineral particles.



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DUST MIXTURES FOR ENGINE TESTING

[001] This application claims the benefit of priority of U.S. Provisional Application No. 62/194,380 entitled “DUST MIXTURES FOR ENGINE TESTING” filed July 20, 2015, which is incorporated herein by reference in its entirety.

[002] The disclosure relates to test dusts in general and in particular to test dusts for testing engines.

BACKGROUND

[003] Engines such as aviation engines and vehicle engines are subject to failure or degradation due to objects that they ingest. Objects that can be ingested can range in size.

[004] Engines can be equipped with hardware to reduce a negative impact of ingested objects. Engines can be equipped with grills, filters, and self-cleaning apparatus. Aviation engines have multiple component parts, e.g., turbines, compressors, valves, fluid supply lines, and cooling system apparatus. Ingestion of an object by an aviation engine can have a negative effect on any one of the noted aviation engine components or other engine components. Prior work on particle ingestion testing for aviation engines has focused on ingestion of particles that can lead to component erosion, and on volcanic ash ingestion that can cause fouling and engine failure.

BRIEF DESCRIPTION

[005] A test dust for testing an engine under test can include a mixture representative of a dust environment that an engine in use may be exposed to. A test dust can include first mineral particles and second mineral particles.

DRAWINGS

[006] Fig. 1 is a schematic diagram of an engine having a cool air path and a hot air path;

[007] Fig. 2 is a diagram illustrating content by weight of minerals in various test dust mixtures;

[008] Fig. 3 is a diagram illustrating content by weight of the non-volatile chemical components in various melts formed from the dust mixtures as set forth in Fig. 2;

[009] Fig. 4 is an example of a particle size distribution of a set of mineral particles of a test dust in one embodiment;

[0010] Fig. 5 is an example of a particle size distribution of mineral particles of a test dust in one embodiment; and

[0011] Fig. 6 is an example of a particle size distribution of mineral particles of a test dust in one embodiment.

DETAILED DESCRIPTION

[0012] A test dust for testing an engine under test can include a mixture representative of a dust environment that an engine in use may be exposed to. A test dust can include first mineral particles and second mineral particles.

[0013] An engine under test is shown in Fig. 1. An engine under test 100 can ingest air 501 that can be separated between a cool air path 502 and a hot air path 503. Air 501 can be ingested into an engine and can be separated into a cool air path 502 and hot air path 503. Air that flows through cool air path 502 can be routed to cool an engine component 602. Air that is directed along cool air path 502 can be routed through an interior of an engine component so that air can be forced outwardly from the component via cooling holes 608. In one embodiment, a test dust on ingestion can produce cool air path accumulations 302 on component surfaces adjacent the cool air path 502 and hot air path

accumulations 306 on component surfaces adjacent the hot air path 503.

[0014] A test dust that produces accumulations 302 and 306 can be representative of a stressful dust environment that might be encountered in a field environment. A test dust that produces accumulations 302 and 306 can allow for testing of the effectiveness of new engine design adaptations that are designed to reduce accumulations on an engine. For example, a test dust that produces accumulations 302 and accumulations 306 can be used to test first and second engines to assess design changes, control changes or impact of maintenance practices (cleaning or repair). The engine that minimizes the amount of the accumulations when subject to a test dust known to produce accumulations, such as accumulations 302 and 306, can be determined to be the engine that is better adapted to reduce accumulations. Cool air path accumulations 302 as represented in Fig. 3 can include unreacted mineral particles of the mixtures of mineral particles as are summarized by the weight distributions of Fig. 1 and Table 1. Hot air path accumulations 306 on the other hand can include melt state composition products resulting from reactions occurring when mineral particles are subject to heating.

[0015] It was determined that forming a test dust having certain characteristics can encourage the production of cool air path accumulations 302 and hot air path accumulations 306. In one aspect, it was determined that providing a test dust to include first mineral particles according to a certain size distribution can encourage the production of cool air path accumulations 302. In one aspect, it was determined that providing a test dust having a melt state of relatively low viscosity can encourage the production of hot air path accumulations 306 that resemble the accumulations on fielded engines.

[0016] A weight percentage of various examples of test dusts for testing engines is shown in Fig. 2. The test dusts can include various weight percentages of the listed mineral materials. The mineral materials of the test dusts can include, e.g., minerals of the classes silicates, carbonates and/or sulfates. A silicate can be provided by, e.g., such species as quartz, feldspar (of the tectosilicate group), or mica or clays (mineral groups of the phyllosilicates mineral group). A carbonate can be provided by, e.g., calcite of the calcite mineral group or dolomite of the dolomite mineral group. A sulfate can be provided by,

e.g., anhydrite of the anhydrous sulfate mineral group or gypsum of the hydrous sulfate mineral group. The minerals and percentage content of the test dusts in their solid state (Fig. 2) determine the chemistry of the test dusts in the melt state (Fig. 3). Data of Figs. 2 and 3 is presented in table form in Tables A and B herein below.

Table A**Mineral Proportions (weight fraction)**

Sample	01	02	03
<u>Mineral</u>			
Silicates	0.48	0.65	0.84
Carbonates	0.36	0.22	0.11
Sulfates	0.09	0.1	0.05
Oxides	0.08	0.03	0.00

Table B**Chemistry (weight percent, volatile-free)**

Sample	01	02	03
<u>Oxide</u>			
SiO ₂	37.2	55.1	62.6
Al ₂ O ₃	17.8	16.3	12.9
FeO	9.8	5.1	4.6
CaO	26.5	17.7	12.2
MgO	7.8	3.9	3.2
Na ₂ O	0.8	1.1	1.9
K ₂ O	0.2	0.8	2.6
<u>CaO/SiO₂</u>	<u>0.71</u>	<u>0.32</u>	<u>0.20</u>
<u>SiO₂/CaO</u>	<u>1.40</u>	<u>3.11</u>	<u>5.13</u>
Viscosity* (Pa-S)			
@ 1300C	0.1	4.8	736

* Viscosity calculated using the model of Giordano et al., 2008, for a temperature of 1300C

D. Giordano, J.K. Russell, and D.B. Dingwell, 2008, Viscosity of magmatic liquids: A model, Earth & Planetary Science Letters, 271:123-134.

[0017] In one embodiment, to encourage formation of accumulations 302 first mineral particles of a mixture forming a test dust can be provided to include a size distribution having a peak of less than 20 μm . Referring to Fig. 4, a set of mineral particles of a mixture can be provided according to the distribution 1002.

[0018] In one embodiment, the set of mineral particles according to distribution 1002 as shown in Fig. 4 can be mineral particles of a common class of mineral particles, e.g., mineral particles of the silicate class, the carbonate class, the sulfate class, or the oxide class. In one embodiment, the set of mineral particles according to distribution 1002 can be mineral particles of a common group of mineral particles within a certain class or group, e.g., the group phyllosilicates within the class silicates, the group tectosilicates within the class silicates, the group pyroxenes within the class silicates, the group micas within the group phyllosilicates, the group clays within the group phyllosilicates, the group feldspars within the group tectosilicates, the group calcite within the class carbonates, the group dolomite within the class carbonates, the group hydrous sulfates within the class sulfates, the group anhydrous sulfates within the class sulfates, the group Fe oxides within the class oxides, or the group Fe-Ti oxides within the group oxides. In one embodiment, the set of mineral particles can be a particular mineral species within a group of a class of mineral particles, such as any species of mineral particle within a group of mineral particles identified herein, e.g., biotite within the group micas, bytownite within the group feldspars, ankerite within the group dolomite, or magnetite within the group Fe oxide. A test dust can have one or more sets of mineral particles in addition to the set of mineral particles according to distribution 1002. A set of mineral particles having the distribution 1002 can be referred to as “first mineral particles” (or Nth mineral particles herein).

[0019] Referring again to Fig. 3 and Table B, Fig. 3 and Table B illustrate the weight content of the non-volatile chemical components of melts formed from the dust mixtures as set forth in Fig. 2 and Table A. Fig. 3 and Table B illustrate the melt state (melt chemistry) of the mixtures shown in Fig. 2 and Table A. Referring to Figs. 2 and 3, and Table A and Table B, the correlation between mixtures and their respective melt state compositions can be used to design a mixture having a targeted melt state characteristic. In

some embodiments certain “target” melt state characteristics can be identified. A test dust can be designed to yield the target melt state characteristic on application of heat.

[0020] One melt state characteristic that can be useful to control is viscosity. In one aspect, it was determined that providing a test dust having a melt state of relatively low viscosity can encourage the production of hot air path accumulations 306 that resemble accumulations seen on fielded engines.

[0021] Lower viscosity melt state compositions can spread more evenly on a hot side component having a surface adjacent a hot air path 503 than higher viscosity materials. Higher viscosity materials can form larger accumulations which can be more likely to detach from an engine component. Lower viscosity materials can be more representative of stressful dust environments encountered in a field environment than higher viscosity materials.

[0022] Tabulated in Table B, it was determined that providing a test dust to exhibit a viscosity in one embodiment of about 1000 Pa-S or less at 1300 deg. C as calculated by the Giordano method (D. Giordano, J.K. Russell, and D.B. Dingwell, 2008, Viscosity of magmatic liquids: A model, Earth & Planetary Science Letters, 271:123-134) (Giordano) can feature the noted advantages. It was determined that providing a test dust to exhibit a viscosity in one embodiment of about 900 Pa-S or less at 1300 deg. C as calculated by the Giordano method can feature the noted advantages. It was determined that providing a test dust to exhibit a viscosity in one embodiment of about 800 Pa-S or less at 1300 deg. C as calculated by the Giordano method can feature the noted advantages. It was determined that providing a test dust to exhibit a viscosity in one embodiment of about 700 Pa-S or less at 1300 deg. C as calculated by the Giordano method can feature the noted advantages. It was determined that providing a test dust to exhibit a viscosity in one embodiment of about 600 Pa-S or less at 1300 deg. C as calculated by the Giordano method can feature the noted advantages. It was determined that providing a test dust to exhibit a viscosity in one embodiment of about 500 Pa-S or less at 1300 deg. C as calculated by the Giordano method can feature the noted advantages. It was determined that providing a test dust to exhibit a viscosity in one embodiment of about 400 Pa-S or less at 1300 deg. C as

calculated by the Giordano method can feature the noted advantages. It was determined that providing a test dust to exhibit a viscosity in one embodiment of about 300 Pa-S or less at 1300 deg. C as calculated by the Giordano method can feature the noted advantages. It was determined that providing a test dust to exhibit a viscosity in one embodiment of about 200 Pa-S or less at 1300 deg. C as calculated by the Giordano method can feature the noted advantages. It was determined that providing a test dust to exhibit a viscosity in one embodiment of about 100 Pa-S or less at 1300 deg. C as calculated by the Giordano method can feature the noted advantages. It was determined that providing a test dust to exhibit a viscosity in one embodiment of about 80 Pa-S or less at 1300 deg. C as calculated by the Giordano method can feature the noted advantages. It was determined that providing a test dust to exhibit a viscosity in one embodiment of about 60 Pa-S or less at 1300 deg. C as calculated by the Giordano method can feature the noted advantages. It was determined that providing a test dust to exhibit a viscosity in one embodiment of about 40 Pa-S or less at 1300 deg. C as calculated by the Giordano method can feature the noted advantages. It was determined that providing a test dust to exhibit a viscosity in one embodiment of about 20 Pa-S or less at 1300 deg. C as calculated by the Giordano method can feature the noted advantages.

[0023] Viscosity can be affected by the ratio of SiO_2/CaO . A composition having a higher SiO_2/CaO ratio can be more viscous and a composition having a lower SiO_2/CaO ratio can be less viscous. It was determined that it can be advantageous in one embodiment to provide a test dust yielding a melt state composition having an SiO_2/CaO ratio of about 3.5 or less indicative of having a relatively lower viscosity. It was determined that it can be advantageous in one embodiment to provide a test dust yielding a melt state composition having an SiO_2/CaO ratio of about 3.0 or less indicative of having a relatively lower viscosity. It was determined that it can be advantageous in one embodiment to provide a test dust yielding a melt state composition having an SiO_2/CaO ratio of about 2.5 or less indicative of having a relatively lower viscosity. It was determined that it can be advantageous in one embodiment to provide a test dust yielding a melt state composition having an SiO_2/CaO ratio of about 2.0 or less indicative of having a relatively lower viscosity. It was determined that it can be advantageous in one embodiment to provide a

test dust yielding a melt state composition having an SiO_2/CaO ratio of about 1.5 or less indicative of having a relatively lower viscosity.

[0024] Referring to Fig. 2 and Fig. 3 and to Table A and Table B various methods can be used to tune a viscosity of a melt state composition. By decreasing a quartz content of a test dust the SiO_2/CaO ratio can be decreased indicative of a lower viscosity. An SiO_2/CaO ratio can also be decreased (indicative of a lower viscosity) by increasing a content of carbonate mineral particles in a test dust, e.g., calcite or dolomite. Calcite and dolomite when melted produce calcium, leading to a higher CaO content in a melt state. An SiO_2/CaO ratio can also be decreased (indicative of a lower viscosity) by increasing a content of Ca sulfate mineral particles in a test dust, e.g., anhydrite or gypsum, which produce calcium on being melted.

[0025] The content of SiO_2 in a melt state can scale strongly with a content of quartz in a pre-melt state. For providing a lower viscosity test dust, a target SiO_2 content of a melt state can in one embodiment be about 60% by weight or less of the melt state composition, can in one embodiment, can be about 55% by weight or less of the melt state composition, and can in one embodiment, can be about 50% by weight or less of the melt state composition.

[0026] For providing a test dust representative of a dust environment, a test dust can include mineral particles of the classes silicates, carbonates and sulfates. It was determined that airborne dust environments can commonly include silicate mineral particles, carbonate mineral particles and sulfate mineral particles. Accordingly, providing a test dust to include silicate mineral particles, carbonate mineral particles and sulfate mineral particles can provide a test dust representative of a field dust of a field environment.

[0027] For providing a test dust representative of an airborne dust environment, a test dust can include silicate mineral particles. For example, a test dust can include, e.g., quartz and/or feldspar species silicate mineral particles of the tectosilicate mineral group. Quartz mineral particles can be coarse, can be of larger size, e.g., can have a size

distribution including a peak greater than 30 um, which can have less tendency to be ingested due to the design of the forward section of the engine. Accordingly, providing quartz silicate mineral particles can assure that a test dust can subject a test engine to a stressful mechanical test of a type that can be encountered in a field environment. An engine compressor can be particularly susceptible to damage by coarse mineral particles. Silicate mineral particles of a test dust can also include, e.g., mineral species of the phyllosilicate mineral group (mineral species of the clay and/or mica mineral groups).

[0028] A test dust can include between about 1% and about 90% by weight silicate mineral particles in one embodiment. Silicate mineral particle weight percentages in the specific samples of test dusts 01 through 03 (Fig. 2 and Table A) range from about 48% (test dust 01) to about 84% (test dust 03).

[0029] Carbonate mineral particles can be commonly encountered in an airborne test environment and when subjected to heat on ingestion within an engine can react with mineral particles of other types such a silicate mineral particles and sulfate mineral particles. Accordingly, providing carbonate mineral particles can increase a likelihood that a melt state content of materials that accumulate on an engine component can be representative of material that builds up on an actual engine when subject to an airborne dust environment. A test dust can include between about 1% and about 90% by weight carbonate mineral particles in one embodiment. Referring to test dusts 01 through 03 of Fig. 2 and Table A, each of the test dusts 01 through 03 has a weight percentage of between about 1% and about 90% by weight carbonate mineral particles. Carbonate mineral particle weight percentages in the specific samples of test dusts 01 through 03 (Fig. 2 and Table A) range from about 11% (test dust 03) to about 36% (test dust 01).

[0030] Sulfate mineral particles can be commonly encountered in an airborne test environment and when subjected to heat on ingestion within an engine can react with mineral particles of other types such a silicate mineral particles and carbonate mineral particles. Accordingly, providing sulfate mineral particles can increase a likelihood that a melt state content of materials that accumulate on an engine component can be representative of material that builds up on an actual engine when subject to an airborne

dust environment. A test dust can include between about 1% and about 90% by weight sulfate mineral particles in one embodiment. Referring to test dusts 01 through 03 of Fig. 1 and Table 1, each of the test dusts 01 through 03 has weight percentage of between about 1% and about 90% by weight sulfate mineral particles. Sulfate mineral particle weight percentages in the specific samples of test dusts 01 through 03 (Fig. 2 and Table A) range from about 5% (test dust 03) to about 9% (test dust 01).

[0031] In one embodiment, mineral particles of the test dust samples as summarized in Fig. 3 and Table B can have sizes less than a threshold size. It was determined in the development of methods set forth herein that aviation engines encountering a field environment can be expected to encounter both ground dust and airborne dust.

[0032] An engine can encounter ground dust on takeoff particularly when dust on a tarmac is stirred up by engine activity of takeoff. Airborne particles can be encountered when the engine is at an elevation above the ground, e.g., at elevations 10 meters or higher. In addition it was determined in the development of methods herein that airborne dust particles can have smaller sizes than ground particles. As explained with reference to the particle distribution of Fig. 4 the providing of smaller sized mineral particles in a test dust, e.g., having a peak of less than 20 μm , can encourage production of cool air path accumulations 302.

[0033] In the development of methods herein it was determined in accordance with one embodiment that a dust environment to which an engine is designated for exposure can be represented by providing a test dust having dust particles of a variety of sizes including larger sizes representative of ground particles and smaller particles representative of airborne particles. In such an embodiment, a test dust can be configured to be representative of both ground and airborne dust that an engine will be exposed to during use.

[0034] In one embodiment, as shown in Fig. 5, a test dust can be configured to have a set of mineral particles according to a size distribution 1102 with a peak of less than 20 μm , another set of mineral particles according to a size distribution 1104 having a peak

of between 20 μm and 30 μm , another set of mineral particles according to a size distribution 1106 having a peak of between 30 μm and 40 μm , another set of mineral particles according to a size distribution 1108 having a peak of between 40 μm and 50 μm , and another set of mineral particles according to a size distribution 1110 having a peak of over 50 μm . The various sets of mineral particles according to the various distributions 1102, 1104, 1106, 1108, and 1110 can be differentiated from one another in terms of one or more of species, mineral group or class.

[0035] The set of mineral particles having the different distributions 1102, 1104, 1106, 1108 and 1110 can be regarded as first through fifth mineral particles in any arbitrary order (the “first” can refer any one of the sets of mineral particles having the distributions 1102, 1104, 1106, 1108 and 1110 and so on).

[0036] In one embodiment, the set of mineral particles according to one or more or more of the distributions 1102, 1104, 1106, 1108, 1110 as shown in Fig. 5 can be mineral particles of a common class of mineral particles, e.g., mineral particles of the silicate class, the carbonate class, the sulfate class, or the oxide class. In one embodiment, the set of mineral particles according to one or more or more of the distributions 1102, 1104, 1106, 1108, 1110 as shown in Fig. 5 can be mineral particles of a common group of mineral particles within a certain class or group, e.g., the group phyllosilicates within the class silicates, the group tectosilicates within the class silicates, the group pyroxenes within the class silicates, the group micas within the group phyllosilicates, the group clays within the group phyllosilicates, the group feldspars within the group tectosilicates, the group calcite within the class carbonates, the group dolomite within the class carbonates, the group hydrous sulfates within the class sulfates, the group anhydrous sulfates within the class sulfates, the group Fe oxides within the class oxides, or the group Fe-Ti oxides within the group oxides. In one embodiment, the set of mineral particles according to one or more or more of the distributions 1102, 1104, 1106, 1108, 1110 can be a particular mineral species within a group of a class of mineral particles, such as any species of mineral particle within a group of mineral particles identified herein, e.g., biotite within the group micas, bytownite within the group feldspars, ankerite within the group dolomite, or magnetite within the

group Fe oxide. A test dust can have one or more sets of mineral particles in addition to the set of mineral particles according to distribution 1002.

[0037] In another embodiment, a test dust can be configured to be representative of airborne dust of an airborne field environment without being representative of a ground dust of a ground field environment. In such an embodiment, a test dust can be configured to include one or more set of mineral particles each set of mineral particles having a size distribution including a peak of less than 20 μm .

[0038] In one embodiment, as shown in Fig. 6, a test dust can be configured to have a set of mineral particles according to a size distribution 1202 with a peak of less than 20 μm , another set of mineral particles according to a size distribution 1204 having a peak of less than 20 μm , another set of mineral particles according to a size distribution 1206 having a peak of less than 20 μm , another set of mineral particles according to a size distribution 1208 having a peak of less than 20 μm , and another set of mineral particles according to a size distribution 1210 having a peak of less than 20 μm . The various sets of mineral particles according to the various distributions 1202, 1204, 1206, 1208, and 1210 can be differentiated from one another in terms of one or more of species, mineral group or class.

[0039] The set of mineral particles having the different distributions 1202, 1204, 1206, 1208 and 1210 can be regarded as first through fifth mineral particles in any arbitrary order (the “first” can refer any one of the sets of mineral particles having the distributions 1202, 1204, 1206, 1208 and 1210 and so on).

[0040] In one embodiment, the set of mineral particles according to one or more of the distributions 1202, 1204, 1206, 1208, 1210 as shown in Fig. 6 can be mineral particles of a common class of mineral particles, e.g., mineral particles of the silicate class, the carbonate class, the sulfate class, or the oxide class. In one embodiment, the set of mineral particles according to one or more of the distributions 1202, 1204, 1206, 1208, 1210 as shown in Fig. 6 can be mineral particles of a common group of mineral particles within a certain class or group, e.g., the group phyllosilicates within the class silicates, the group tectosilicates within the class silicates, the group pyroxenes within the class silicates, the

group micas within the group phyllosilicates, the group clays within the group phyllosilicates, the group feldspars within the group tectosilicates, the group calcite within the class carbonates, the group dolomite within the class carbonates, the group hydrous sulfates within the class sulfates, the group anhydrous sulfates within the class sulfates, the group Fe oxides within the class oxides, or the group Fe-Ti oxides within the group oxides. In one embodiment, the set of mineral particles according to one or more of the distributions 1202, 1204, 1206, 1208, 1210 as shown in Fig. 6 can be a particular mineral species within a group of a class of mineral particles, such as any species of mineral particle within a group of mineral particles identified herein, e.g., biotite within the group micas, bytownite within the group feldspars, ankerite within the group dolomite, or magnetite within the group Fe oxide.

[0041] In one embodiment, a test dust can have fewer sets of mineral particles than those depicted by the distributions 1102, 1104, 1106, 1108, 1110 of Fig. 5. In one embodiment a test dust can have fewer sets of mineral particles than those depicted by the distributions 1202, 1204, 1206, 1208, 1210 of Fig. 6.

[0042] In one embodiment, a test dust can have more sets of mineral particles than those depicted by the distribution 1002 of Fig. 4. In one embodiment a test dust can have more sets of mineral particles than those depicted by the distributions 1102, 1104, 1106, 1108, 1110 of Fig. 5. In one embodiment a test dust can have more sets of mineral particles than those depicted by the distributions 1202, 1204, 1206, 1208, 1210 of Fig. 6.

[0043] In one embodiment, a test dust can be restricted to the set of mineral particles depicted by the distribution 1002 of Fig. 4. In one embodiment, a test dust can be restricted to the sets of mineral particles depicted by the distributions 1102, 1104, 1106, 1108, 1110 of Fig. 5. In one embodiment a test dust can be restricted to the sets of mineral particles depicted by the distributions 1202, 1204, 1206, 1208, 1210 of Fig. 6.

[0044] In one embodiment, the distribution 1002 as shown in Fig. 4 can be shifted left so that a peak of distribution 1002 is lowered to any particular peak value that is less than the peak depicted in Fig. 4. In one embodiment the distribution 1002 as shown in Fig. 4

can be shifted right so that a peak of distribution 1002 is increased to any particular peak value that is greater than the peak value depicted in Fig. 4. In one embodiment, distribution 1002 can have a peak of any particular value in the range of from about 1.0 μm to about 100 μm .

[0045] In one embodiment, one or more of the distributions 1102, 1104, 1106, 1108, 1110 as shown in Fig. 5 can be shifted left so that a peak of one or more of the distributions 1102, 1104, 1106, 1108, 1110 is lowered to any particular peak value that is less than its respective peak value depicted in Fig. 5. In one embodiment one or more of the distributions 1102, 1104, 1106, 1108, 1110 as shown in Fig. 5 can be shifted right so that a peak of one or more of the distributions 1102, 1104, 1106, 1108, 1110 is increased to any particular peak value that is greater than its respective peak value depicted in Fig. 5. In one embodiment, distributions 1102, 1104, 1106, 1108, 1110 can have respective peaks of any particular value in the range of from about 1.0 μm to about 100 μm .

[0046] In one embodiment, one or more of the distributions 1202, 1204, 1206, 1208, 1210 as shown in Fig. 6 can be shifted left so that a peak of one or more of the distributions 1202, 1204, 1206, 1208, 1210 is lowered to any particular peak value that is less than its respective peak value depicted in Fig. 6. In one embodiment, one or more of the distributions 1202, 1204, 1206, 1208, 1210 as shown in Fig. 6 can be shifted right so that a peak of one or more of the distributions 1102, 1202, 1204, 1206, 1208, 1210 is increased to any particular peak value that is greater than its respective peak value depicted in Fig. 6. In one embodiment, distributions 1202, 1204, 1206, 1208, 1210 can have respective peaks of any particular value in the range of from about 1.0 μm to about 100 μm .

[0047] For any mineral particle set herein described with reference to a distribution, e.g., distribution 1002, 1102, 1104, 1106, 1108, 1110, 1202, 1204, 1206, 1208, or 1210, the set of particles can have a mean particle size. The mean particle size for a given set of particles set forth with reference to a distribution 1002, 1102, 1104, 1106, 1108, 1110, 1202, 1204, 1206, 1208, or 1210 can be equal to a value of the peak for the respective distribution 1002, 1102, 1104, 1106, 1108, 1110, 1202, 1204, 1206, 1208, or 1210 in one embodiment. A mean particle size for any given set of particles set forth herein with

reference to a distribution 1002, 1102, 1104, 1106, 1108, 1110, 1202, 1204, 1206, 1208, or 1210 can be in the range of from about 1.0 um to about 100 um in one embodiment.

[0048] For any mineral particle set herein described with reference to a distribution, e.g., distribution 1002, 1102, 1104, 1106, 1108, 1110, 1202, 1204, 1206, 1208, or 1210, the shape of the distribution can be changed, e.g., can be symmetric or asymmetric, can be wider or narrower, can be taller or shorter, can have a single peak or multiple peaks.

[0049] Test dusts as set forth herein can include a mixture of mineral particles that include mineral particles of one or more mineral particle set. Test dusts as set forth herein can have a mean particle size. A test dust as set forth herein can have a mean particle size in the range of from about 1.0 um to about 100 um in one embodiment.

[0050] It was also determined that different world geographic areas can have different dust environments. For example some world geographical areas can have dusts that are rich in silicates but not rich in carbonates or sulfates. Some geographical areas can be rich in carbonates but not rich in silicates and sulfates. Some geographical areas can be rich in carbonates and sulfates but not rich in silicates.

[0051] A plurality of test dusts can be provided, each test dust of the plurality of test dusts representative of a field environment of a particular world geographic area. According to one method first and second test dusts with first and second different mixtures can be provided. The first and second test dusts can be representative of field environment at first and second different world geographic areas. The first test dust can be used to test a first engine and the second test dust can be used to test a second engine. The first and second engines can be of common design or of different design.

[0052] Referring to Fig. 2 and Table A, there can be a first world geographic area A that is relatively rich in silicates but not relatively rich in carbonates, and a second world geographic area B that is relatively not rich in silicates but relatively rich in carbonates. Two candidate test dusts in one embodiment can be provided, test dust 01 and test dust 03. In such an embodiment, test dust 03 which more closely represents the environmental dust

at geographic area A can be selected for testing a first engine of a design designated for use in geographic area A and test dust 01 which more closely represents the environmental dust at geographic area B can be selected for testing a second engine of a design designated to use in geographic area B.

[0053] Test dusts herein can be artificial test dusts produced using one or more machine process, e.g., milling or mixing. For production of an artificial test dust, mineral particles (synthetic or naturally occurring) can initially be milled to desired sizes. Milling of particles can occur prior to any mixing of particles. Mixing of mineral particles (synthetic or naturally occurring) can be performed using a blending machine.

[0054] A method can include positioning a test dust herein in proximity with an engine and presenting the test dust to the engine. For positioning a test dust proximate to an engine under test a feed mechanism can be positioned adjacent an engine intake. For presenting a test dust to an engine under test, the feed mechanism can be activated to feed the mineral particles. The mineral particles can be preheated to dry the mineral particles.

[0055] It is to be understood that the above description is intended to be illustrative, and not restrictive. For example, the above-described embodiments (and/or aspects thereof) may be used in combination with each other. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the various embodiments without departing from their scope. While the dimensions and types of materials described herein are intended to define the parameters of the various embodiments, they are by no means limiting and are merely exemplary. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. The scope of the various embodiments should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. In the appended claims, the terms “including” and “in which” are used as the plain-English equivalents of the respective terms “comprising” and “wherein.” Moreover, in the following claims, the terms “first,” “second,” and “third,” etc. are used merely as labels, and are not intended to impose numerical requirements on their objects. Further, the limitations of the following claims are not written in means-plus-function format and are not intended to be interpreted

based on 35 U.S.C. § 112, sixth paragraph, unless and until such claim limitations expressly use the phrase “means for” followed by a statement of function void of further structure. It is to be understood that not necessarily all such objects or advantages described above may be achieved in accordance with any particular embodiment. Thus, for example, those skilled in the art will recognize that the systems and techniques described herein may be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other objects or advantages as may be taught or suggested herein.

[0056] While the invention has been described in detail in connection with only a limited number of embodiments, it should be readily understood that the invention is not limited to such disclosed embodiments. Rather, the invention can be modified to incorporate any number of variations, alterations, substitutions or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the invention. Additionally, while various embodiments of the invention have been described, it is to be understood that aspects of the disclosure may include only some of the described embodiments. Accordingly, the invention is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

[0057] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal language of the claims.

* * * * *

CLAIMS

1. A test dust comprising:

a mixture of mineral particles, wherein the mixture of mineral particles includes mineral particles of one or more of the following groups (a), (b), and (c): (a) silicate mineral particles, in an amount of from about 1% to about 90% by weight of the test dust, (b) carbonate mineral particles, in an amount of from about 1% to about 90% by weight of the test dust; and (c) sulfate mineral particles, in an amount of from about 1% to about 90% by weight of the test dust; and

wherein the mixture of mineral particles includes first mineral particles according to a size distribution having a peak of less than 20 μm .

2. The test dust of claim 1, wherein the first mineral particles are mineral particles of a common class.

3. The test dust of claim 1, wherein the first mineral particles are mineral particles of a common mineral group.

4. The test dust of claim 1, wherein the first mineral particles are mineral particles of a common mineral group, the common mineral group being selected from the group consisting of: the mineral group tectosilicates within the class silicates, the mineral group micas within the mineral group phyllosilicates, the mineral group clays within the mineral group phyllosilicates, the mineral group feldspars within the mineral group tectosilicates, the mineral group calcite within the class carbonates, the mineral group dolomite within the class carbonates, the mineral group hydrous sulfates within the class sulfates, the mineral group anhydrous sulfates within the class sulfates.

5. The test dust of claim 4, wherein the first mineral particles have a mean particle size in the range of from about 1.0 μm to about 100 μm .

6. The test dust of claim 1, wherein the first mineral particles are mineral particles of a common species.

7. The test dust of claim 1, wherein the mixture of mineral particles includes mineral particles provided by oxide mineral particles in amount of from about 1% to about 40 % by weight of the test dust.

8. The test dust of claim 1, wherein the mixture of mineral particles includes silicate mineral particles, in an amount of from about 1% to about 90% by weight of the test dust.

9. The test dust of claim 1, wherein the test dust is provided to include a corresponding melt state composition characterized by an SiO_2/CaO ratio of about 3.0 or less.

10. The test dust of claim 1, wherein the test dust is provided to include a corresponding melt state composition characterized by including SiO_2 in an amount of about 55% by weight or less of the composition.

11. The test dust of claim 1, wherein the test dust is provided to include a corresponding melt state composition characterized by an SiO_2/CaO ratio of less than about 3.0, and wherein the test dust is provided to include a corresponding melt state composition characterized by including SiO_2 in an amount of about 55% by weight or less of the composition.

12. The test dust of claim 1, wherein the test dust has a viscosity of about 500 Pa-S or less at 1300 deg. C (Giordano).

13. A method comprising:

positioning a test dust in proximity with an engine; and

presenting the test dust to the engine to test the engine, wherein the test dust includes a mixture of mineral particles, wherein the mixture of mineral particles has mineral particles of one or more of the following groups (a), (b), and (c): (a) silicate mineral particles, in an amount of from about 1% to about 90% by weight of the test dust, (b) carbonate mineral particles, in an amount of from about 1% to about 90% by weight of the test dust; and (c) sulfate mineral particles, in an amount of from about 1%

to about 90% by weight of the test dust, wherein the mixture has a viscosity of about 500 Pa-S or less at 1300 deg. C (Giordano).

14. The test dust of claim 13, wherein the mixture of mineral particles includes a corresponding melt state composition characterized by an SiO_2/CaO ratio of about 3.0 or less.

15. The method of claim 13, wherein the engine is an aviation engine.

16. The method of claim 13, wherein the test dust includes first mineral particles in a size distribution having a peak of less than 20 μm .

17. The method of claim 13, wherein the test dust includes a corresponding melt state composition characterized by including SiO_2 in an amount of about 55% by weight or less of the composition.

18. The method of claim 13, wherein the test dust includes a corresponding melt state composition characterized by including SiO_2 in an amount of about 55% by weight or less, and further includes first mineral particles in a size distribution having a peak of less than 20 μm .

19. The method of claim 13, wherein the test dust includes a corresponding melt state composition characterized by including SiO_2 in an amount of about 55% by weight or less of the composition, and further includes first mineral particles in a size distribution having a peak of less than 20 μm , wherein the first mineral particles are mineral particles of a common mineral group, the common mineral group being selected from the group consisting of: the mineral group tectosilicates within the class silicates, the mineral group micas within the mineral group phyllosilicates, the mineral group clays within the mineral group phyllosilicates, the mineral group feldspars within the mineral group tectosilicates, the mineral group calcite within the class carbonates, the mineral group dolomite within the class carbonates, the mineral group hydrous sulfates within the class sulfates, the mineral group anhydrous sulfates within the class sulfates.

20. A test dust comprising:

a mixture of mineral particles having one or more classes of mineral particles, each class selected from the group consisting of silicate mineral particles, carbonate mineral particles and sulfate mineral particles; and

wherein the mixture has a viscosity of about 500 Pa-S or less at 1300 deg. C (Giordano).

21. The test dust of claim 20, wherein the mixture of mineral particles is provided to include a corresponding melt state composition characterized by an SiO_2/CaO ratio of about 3.0 or less.

22. The test dust of claim 20, wherein the mixture of mineral particles is provided to include a corresponding melt state composition characterized by including SiO_2 in an amount of about 55% by weight or less of the composition.

23. The test dust of claim 20, wherein the mixture of mineral particles is provided to include a corresponding melt state composition characterized by including SiO_2 in an amount of about 55% by weight or less of the composition, wherein the mixture includes first mineral particles according to a size distribution having a peak of less than 20 μm .

24. The test dust of claim 20, wherein the mixture of mineral particles is provided to include a corresponding melt state composition characterized by including SiO_2 in an amount of about 55% by weight or less of the composition, wherein the mixture includes first mineral particles according to a size distribution having a peak of less than 20 μm , and second mineral particles according to a size distribution having a peak of greater than 20 μm .

25. A test dust comprising:

a mixture of mineral particles having one or more classes of mineral particles, each class selected from the group consisting of silicate mineral particles, carbonate mineral particles and sulfate mineral particles; and

wherein the mixture of mineral particles is provided to include a corresponding melt state composition characterized by including SiO_2 in an amount of about 60% by weight or less of the mixture, and wherein the mixture of mineral particles is provided to include a corresponding melt state composition characterized by an SiO_2/CaO ratio of about 3.0 or less.

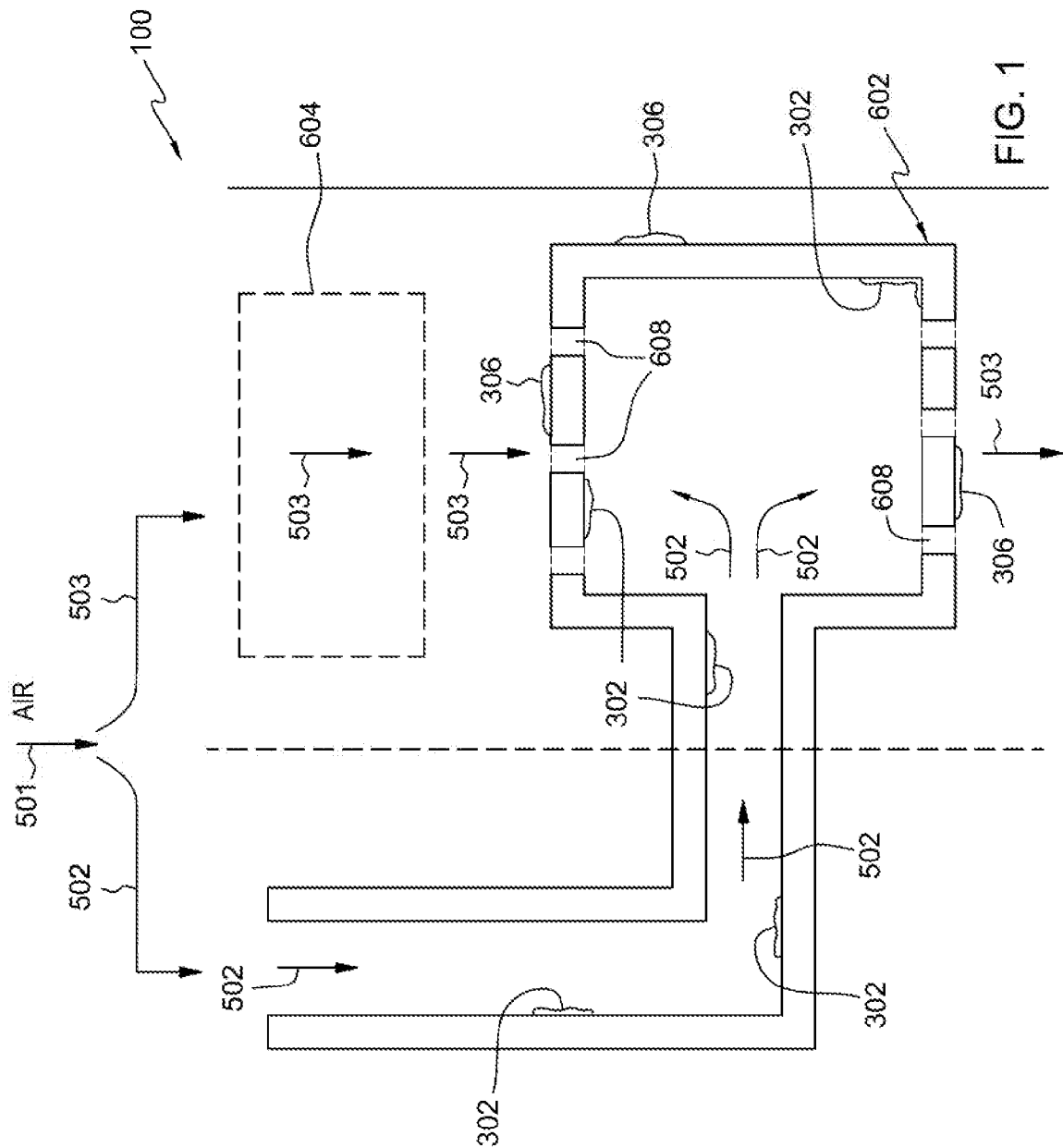
26. The test dust of claim 25, wherein the mixture includes first mineral particles according to a size distribution having a peak of less than 20 μm .

27. The test dust of claim 25, wherein the mixture includes first mineral particles according to a size distribution having a peak of less than 20 μm , and second mineral particles according to a size distribution having a peak of greater than 30 μm .

28. A method comprising:

positioning a test dust in proximity with an engine; and

presenting the test dust to the engine to test the engine, wherein the test dust includes a mixture of mineral particles, wherein the mixture of mineral particles has mineral particles of one or more of the following groups (a), (b), and (c): (a) silicate mineral particles, in an amount of from about 1% to about 90% by weight of the test dust, (b) carbonate mineral particles, in an amount of from about 1% to about 90% by weight of the test dust; and (c) sulfate mineral particles, in an amount of from about 1% to about 90% by weight of the test dust, wherein the mixture has a viscosity of about 1000 Pa-S or less at 1300 deg. C (Giordano), and wherein the mixture of mineral particles includes mineral particles selected from one or more of the following groups: the mineral group phyllosilicates within the class silicates, the mineral group anhydrous sulfates within the class sulfates, the mineral group calcite within the class carbonates, and the mineral group pyroxenes within the class silicates.



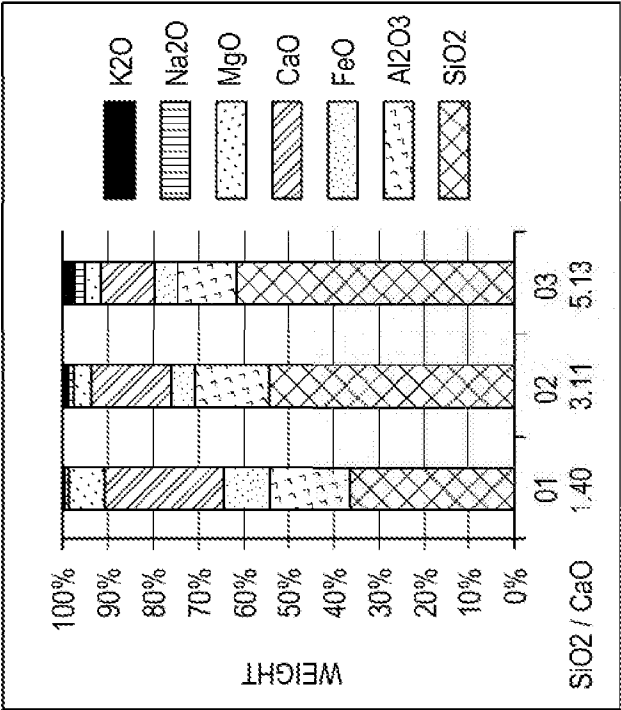


FIG. 3

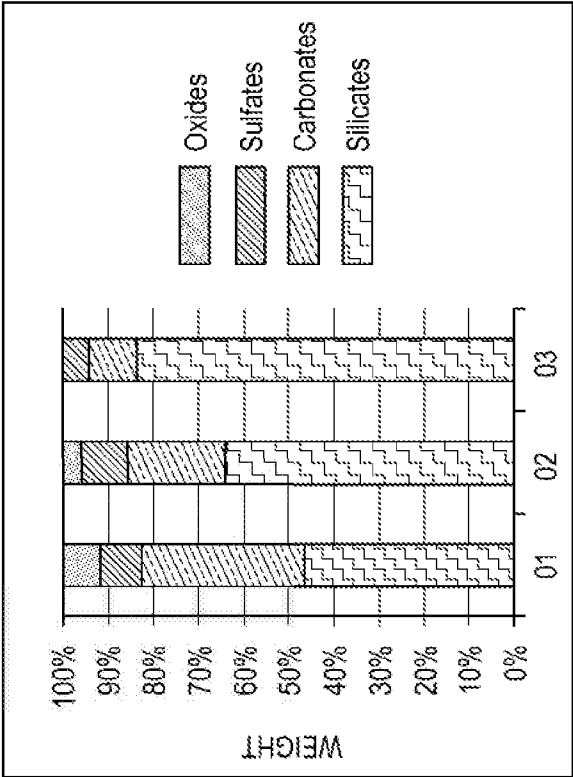
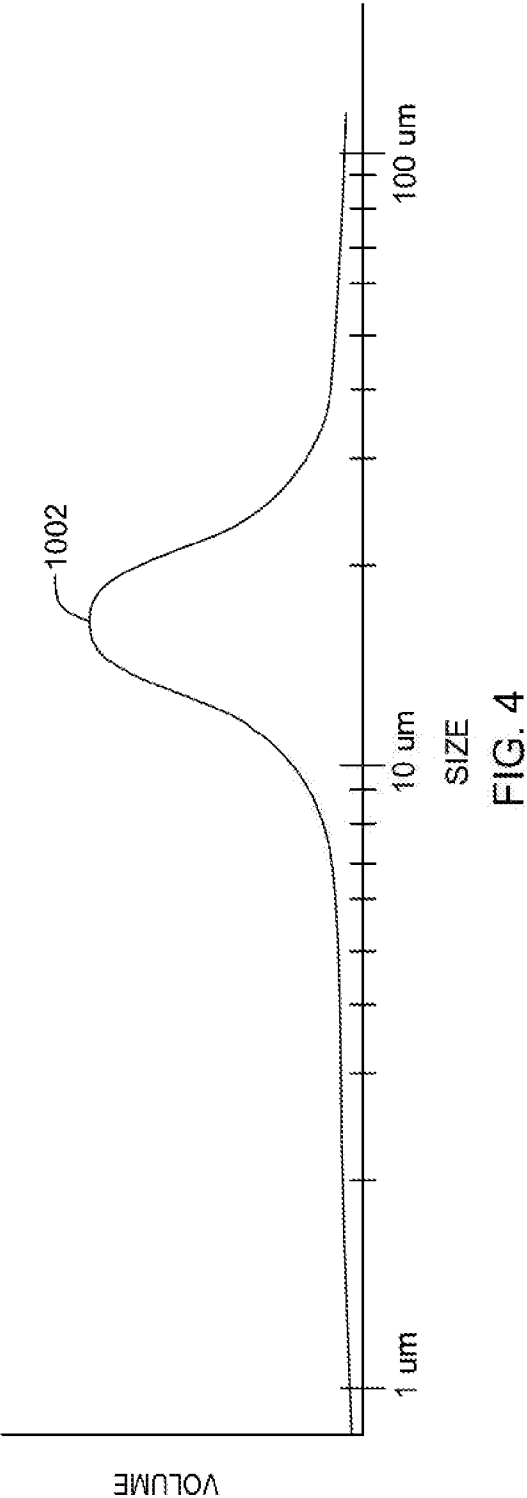


FIG. 2



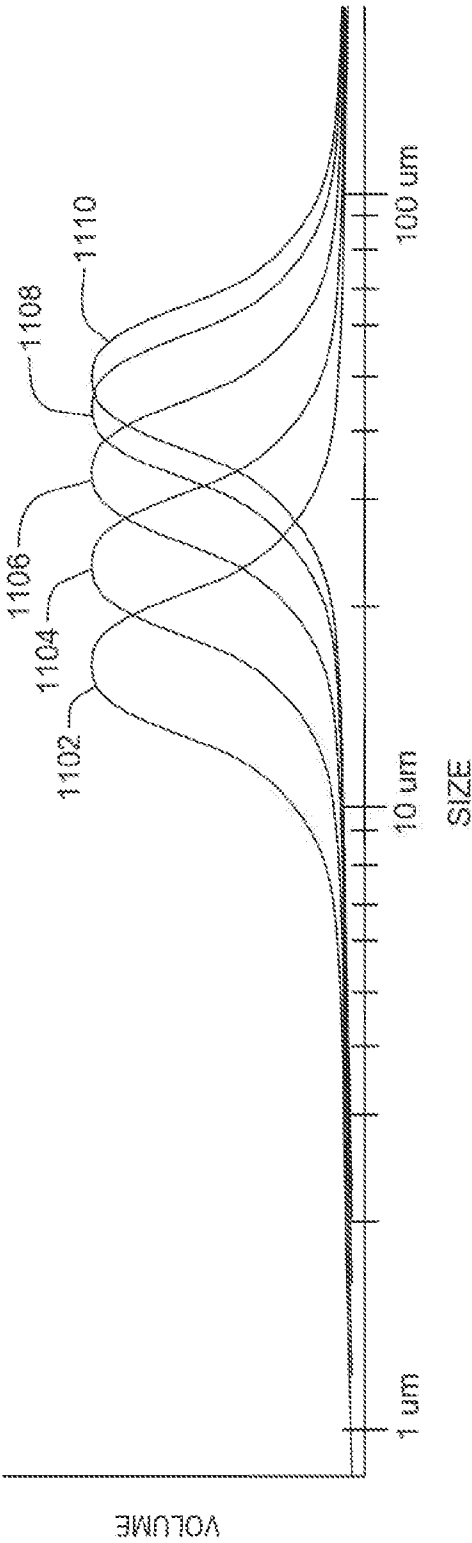
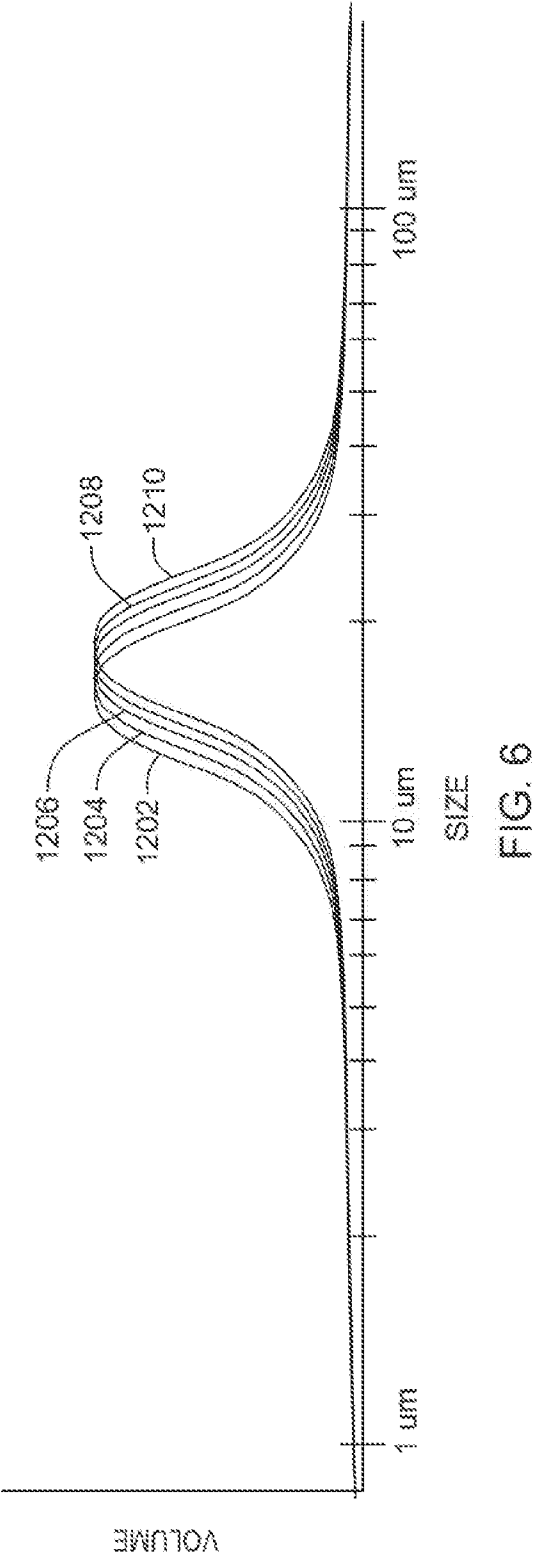


FIG. 5



INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/041890

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01M15/02 G01M15/14
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	U Teipel ET AL: "Characterization of Test Dust for Product Qualification", 31 December 2008 (2008-12-31), pages 155-161, XP055302190, Retrieved from the Internet: URL:http://portal.tpu.ru/departments/kafedra/tsnm/sotr1/Tab/BS408_teipel.pdf [retrieved on 2016-09-13] Section 1, 2, 3.4, 4; figures 4,6,7,9; tables 1-4 ----- -/--	1-3,6,8



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

15 September 2016

Date of mailing of the international search report

22/09/2016

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
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Authorized officer

Foster, Keir

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/041890

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DUNN M G ET AL: "Performance Deterioration of a Turbofan and a Turbojet Engine Upon Exposure to a Dust Environment", JOURNAL OF ENGINEERING FOR GAS TURBINES AND POWER, ASME, NEW YORK, NY, US, vol. 109, 1 July 1987 (1987-07-01), pages 336-343, XP008156888, ISSN: 0742-4795, DOI: 10.1115/1.3240045 Abstract, Table 1; page 1 - page 3; figures 4,5 -----	1-28
A	FR 2 987 124 A1 (SNECMA [FR]) 23 August 2013 (2013-08-23) page 2, line 3 - page 3, line 32; figure 1 -----	1-28
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2016/041890

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
FR 2987124	A1	23-08-2013	NONE
