Nov. 3, 1959 **R. E. OPDYKE** **2,910,865**

METHOD OF VISUALIZING FLOW PATTERNS

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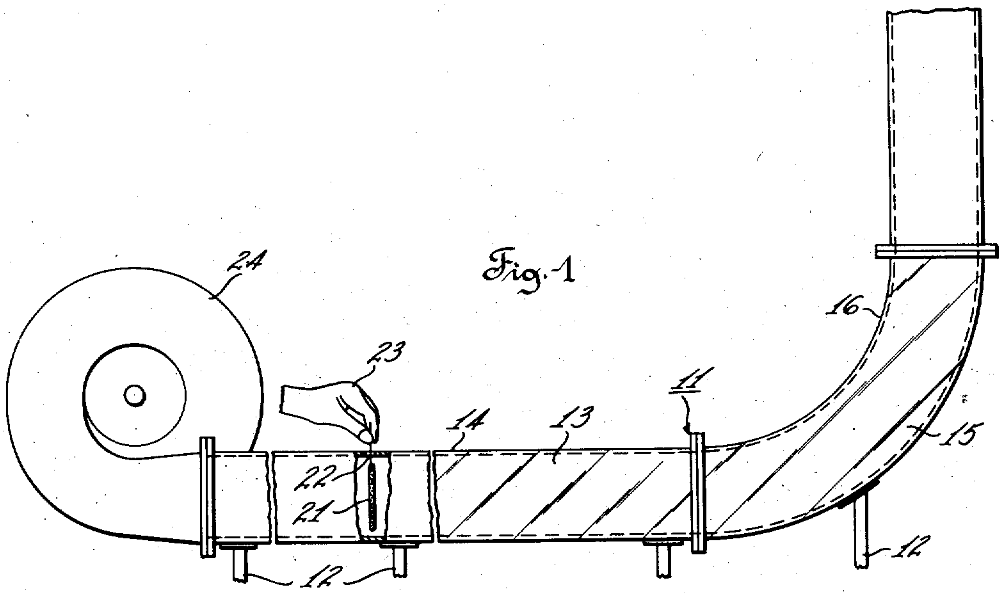

Fig. 1

Fig. 2

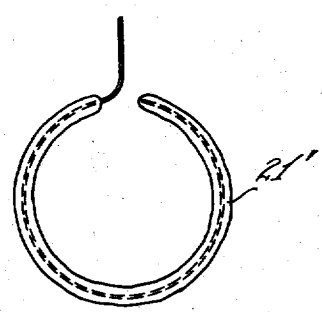

Fig. 3

Inventor
Richard E. Opdyke
by Richard R. Mybeck
Attorney

United States Patent Office

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METHOD OF VISUALIZING FLOW PATTERNS

Richard E. Opdyke, West Allis, Wis., assignor to Allis-Chalmers Manufacturing Company, Milwaukee, Wis.

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The present invention relates to a method of analysis and more particularly to a method of visualizing the flow patterns of noncombustible combustion supporting gas streams.

In the selection of conduit for containing a desired flow of gaseous fluids, it is frequently vital that the characteristics of gaseous flow through conduit of various geometric configurations be determined to permit the utilization of conduit most properly suited to the desired flow. The characteristics can best be determined by creating flow through a prototype and analyzing its flow pattern provided that pattern is true.

A further area in which knowledge of the characteristics of gaseous flow is vital is in the design of articles, such as aircraft, which operate in gas streams under flow conditions assimilated by the stream induced in the prototype. Again, it is essential that the flow pattern be true.

The problem of creating true gas flow patterns in prototypes of conduit and other aerodynamic apparatus has perplexed men in that art for many years. The problem is particularly aggravated in regions of flow having Reynolds numbers in excess of about 3,000 because the flow become turbulent in character.

Basically, the prior art techniques or methods of visualizing gas flow fall into three categories, namely: (1) the contamination of the gaseous fluid with foreign matter; (2) the utilization of optical effects; and (3) especially prepared flow passage boundaries.

The present invention relates to the first of these categories, to wit, the contamination of the gaseous fluid with foreign matter. The prior are methods in this category include the introduction of balsa wood dust, elongated ribbons and strings, cotton tufts, and smoke trails. Of these, the introduction of smoke is perhaps the most successful but even it is limited to streamline or laminar flow, i.e., flows having a Reynolds number of less than 3000 and most generally less than 2100. These methods are further limited in that they are not adaptable to flow through rotating machine elements, such as blower impellers.

The smoke method specifically comprises introducing smoke into a conduit through which a gas flow has been created and observing, through a transparent wall in the conduit, the path followed by the smoke as it is carried by the gas. With streamline flow, the smoke provides a decent laminar flow pattern having discrete paths. With turbulent flow, the smoke, in response to the turbulence, diffuses into a single cloud and no discrete paths are observable. Consequently with respect to turbulent flow, the smoke technique is virtually useless.

The other foreign particles enumerated above are subject to the same general limitations as the smoke in varying degrees, i.e., independent paths cannot be observed. Furthermore, use of all of these foreign particles to achieve results usually requires costly and complicated equipment.

In addition to teaching the introduction of the aforementioned foreign matter into the gaseous fluid flow as a usual means for visualizing subsonic flow having low Reynolds numbers, the prior art teaches using especially prepared boundary patterns as another means for determining the characteristics of subsonic flow and optical effects as the usual means for visualizing transonic and supersonic flow. Inasmuch as the present invention does not relate to the concept of either especially prepared boundaries or optical effects, these techniques will not be further discussed.

In all the know prior art, there is no teaching of a method for accurately representing for visualization and/or otherwise recording the flow pattern of gases in the subsonic range at Reynolds numbers in excess of about 3000 and through moving or rotating machine elements. A need for such a method is very real and very much present.

The present invention proposes to satisfy that need by a method comprising the introduction of low mass self-illuminating tracer particles into a gas stream for observing and/or otherwise recording the paths of the particles as they are borne by the stream and by various compositions of matter of which the particles are made, each of said compositions consisting of carbon, admixed with an oxidizing agent and a binder. A reducing agent may also be incorporated into the admixture when certain flow conditions exist as will be more fully explained.

Accordingly, one of the primary objects of the present invention is to provide an improved method for visualizing flow patterns of gaseous fluids which is not limited to any particular range of Reynolds numbers and which provides equally satisfactory results regardless of the velocity of the fluid flow.

Another object of the present invention is to provide a method of visualizing flow patterns of gaseous fluids in which the flow pattern is accurately reflected by self-illuminating tracer particles which are introduced into and borne by the fluid stream.

Another object of the present invention is to provide an improved method for visualizing gas flow patterns in curved conduit by introducing into the gas flow particles having a sufficiently low mass to be carried by the fluid stream without being detoured by centrifugal action as would be characteristic of particles of larger mass.

A still further object of the present invention is to provide an improved method for visualizing flow patterns which is easily and simply performed and which does not require costly and elaborate setups and equipment.

An even further object of the present invention is the provision of an improved method for visualizing flow patterns utilizing a self-illuminating tracer particle having sufficiently low mass to respond to the velocity component of the fluid flow in the direction of flow to reflect a true pattern of that flow and to resist forces which might otherwise distort the pattern of flow.

A still further object of the present invention is the provision of an improved method for visualizing flow patterns by which subsonic turbulent flow through moving or rotating machine elements may be easily and readily determined.

These and still further objects will become apparent from the following detailed description when read in conjunction with the accompanying drawing in which:

Fig. 1 is a view in elevation of apparatus by which the present invention may be utilized; and

Figs. 2 and 3 are elevations of various sparkler configurations.

In Fig. 1, a typical aerodynamic prototype **11** is supported by suitable supports **12**. A transparent plate **13** is disposed in the outer wall of a longitudinal portion **14** of prototype **11** and a transparent plate **15** is disposed in the outer wall of elbow **16**. Transparent plates **13, 15** may be disposed in the outer wall of any portion of the prototype to observe the flow pattern in that portion since the position of plates **13**, **15** in Fig. 1 is merely exemplary. Or the entire prototype may be made of transparent material when test conditions dictate that it be so made.

To analyze and observe the flow pattern through the longitudinal portion **14** of the protoype **11**, a sparkler **21** is inserted in the prototype as at **22** and is supported by any suitable manner, such as by hand **23**. The gaseous stream is created through the prototype in any suitable manner such as by running a blower **24** having its outlet in register with prototype **11**. Sparkler **21** is here shown unignited.

The method of the present invention specifically comprises the introduction into a gaseous stream of burning or glowing particles of sufficiently small mass that they are carried by the fluid flow and are not adversely influenced by inertia or centrifugal forces. By either visual or photographic analysis of the luminous particle traces or paths through a wholly or partly transparent prototype, the gas flow pattern may be studied precisely and may be the subject of photographic analysis.

In addition to the utilization of sparklers in an improved method of visualizing gas flow by burning the sparklers and introducing the resulting sparks into a flowing gaseous stream, the present invention further embraces certain compositions of pyrotechnic matter from which the sparklers are made.

Certain characteristics are desired for a sparkler comprising a composition conforming to the present invention. They are that the sparkler shall: burn and emit sparks; be self-propagating; not flame; not smoke excessively; not burn too rapidly; not emit ash or other residue; and have a physical configuration which is adaptable to prototypes of many geometric configurations. Further, the emitted spark shall be characterized in that it shall: be self-illuminating; have a mass which is sufficiently low to create a balance between the drag, $3\pi\mu Dv_r$ (where $\pi=3.14$; μ=viscosity of the gas; D=diameter of particle; and v_r=radial velocity of particle), and the centrifugal force, mv_t^2/r (where m=mass of particle; v_t=tangential velocity of particle; and r=radius of curved section), acting on the particle in curved sections, and between the drag and the forces acting on the particle in straight sections; have a long life; and have a visible brilliance.

The sparklers utilized may be of any suitable configuration such as will give a maximum dispersion of sparks into the fluid stream and are preferably limited only by the geometry of the prototype to be analyzed. For example, in the analyzation of fluid flow through the cylindrical tube of Fig. 1, a straight sparkler **21** (shown enlarged as sparkler **21** in Fig. 2) gives the most desirable results since it traverses the flow profile. Other prototypes may be better suited to a sparkler hoop (shown as **21'** in Fig. 3).

The sparklers may be prepared by any suitable method such as that by which commercial "Fourth of July" sparklers are made, to wit, mix the dry ingredients, add sufficient water to form a viscous paste, deposit the paste on a wire and dry the coating on the wire. The paste can be deposited on the wire by molding, dipping or other suitable means. It is preferred that the wire be shaped before coating since the dry coating has a tendency to chip when bent.

While the methods of preparation are similar, commercial sparklers do not particularly lend themselves to the present invention because the mass of the iron particles they use is generally too great to permit burning iron particles to freely follow the gas flow. Comparative tests were conducted utilizing as the source of sparks, first, the so-called "Fourth of July" or commercial sparkler and, then, the sparklers of the present invention. In both runs, the sparks were introduced into an air stream passing through an elbow at 60–80 f.p.s. with a Reynolds number of about 45,000. It was readily observed that the commercial sparks, because of the inertia resulting from their larger mass, ricochet off the inner walls of the elbow instead of following the air stream; whereas the carbon sparks of the present invention, because of their smaller mass, follow the air stream.

The importance of the sparks having a low mass is further apparent, both in the detection of vortices and in the location of leaks in the conduit.

Accordingly, the present invention further includes various sparkler compositions which provide all of the characteristics desired for use with the present method. The particles of these compositions are characterized by being self-illuminating and having sufficiently low mass to be carried by the fluid stream.

Sparkler compositions which give most satisfactory results when employed in the method of the present invention contain carbon, sugar, dextrine, potassium chlorate, barium nitrate and aluminum. Of these ingredients, the carbon is the source of the sparks which are carried by the gas stream. Sugar ($C_{12}H_{22}O_{11}$) and dextrine ($C_6H_{10}O_5$) act as binders and as a source of readily oxidizable carbon. Care should be exercised not to use more dextrine than sugar because excessive dextrine causes the occurrence of a liquid phase during burning which deters satisfactory combustion. On the other hand, excessive sugar, i.e., in proportion to the total ingredients in the mixture, results in inadequate binding and combustion residue is introduced into the gas stream. As a secondary effect, it is noted that the rate of combustion can be varied by altering the sugar-to-dextrine ratio since sugar increases the rate of combustion and dextrine reduces it.

Both potassium chlorate ($KClO_3$) and barium nitrate ($Ba(NO_3)_2$) act as oxidants and supply oxygen to support combustion. It is noted that the rate of combustion may also be controlled by varying the potassium-to-barium ratio in the mixture since potassium chlorate increases the burning rate and barium nitrate reduces it.

Aluminum is used to increase the temperature of combustion and, though only optional in sparklers to be used to visualize streams of low velocity, it is a highly desirable ingredient for sparklers which will be used to visualize streams of high velocity. The passage of high velocity flow over a sparkler which contains no aluminum transfers heat from the burning sparkler so rapidly that soon the sparkler is unable to kindle the unburned portion of the sparkler as it attempts to self-propagate. Consequently, when flow conditions are to be analyzed which will effect a rapid heat transfer, the aluminum offsets the effect of the rapid flow by providing additional heat. Thus even though the heat transfer continues, there is sufficient residual heat at the sparkler to keep the burning particles kindling the unburned particles to effect the desired self-propagation.

Thus, the compositions used in the practice of the present invention may be altered by the skilled artisan to fit the particular flow conditions desired for study. If an increased burning rate is desired, the sugar:dextrine ratio may be increased to a point where dextrine is eliminated completely so long as the ratio of sugar to the total composition remains substantially in the range disclosed by the examples set forth below. And the burning rate may likewise be increased by increasing the potassium:barium ratio to a point where barium is eliminated. Conversely, the burning rate may be retarded by reducing the sugar:dextrine and potassium:barium ratios although it is preferable that the sugar:dextrine ratio be not less than 1:1.

Further, if high heat is desired, aluminum may be included. In all of the compositions, however, it is essential that they include a binder, such as sugar, an oxidant, such as potassium chlorate, and a quantity of carbon in excess of that amount required for a complete stoichiometric combustion balance.

Specific sparkler compositions which give most satisfactory results when employed in the method of the present invention are set forth in the examples below. Each sparkler was prepared by grinding the dry ingredients to a fine particle size, thoroughly mixing the dry ground ingredients, adding sufficient water to the mixture to form a thick paste, coating a wire form with the thick paste, and drying the coated wire for approximately twenty-four hours at room temperature.

Example 1

The following ingredients comprise Mix No. 1:

	Grams
$KClO_3$	6.5
$Ba(NO_3)_2$	7.5
Aluminum	0.84
$C_6H_{10}O_5$	2.33
$C_{12}H_{22}O_{11}$	3.66
Carbon	2.46

Example 2

The following ingredients comprise Mix No. 2:

	Grams
$KClO_3$	0.5
$Ba(NO_3)_2$	3.5
Aluminum	1.0
$C_{12}H_{22}O_{11}$	0.5
Carbon	1.0

Example 3

The following ingredients comprise Mix No. 3:

	Grams
$KClO_3$	1.0
$Ba(NO_3)_2$	1.0
Aluminum	1.0
$C_6H_{10}O^5$	0.5
$C_{12}H_{22}O_{11}$	0.5
Carbon	1.0

Example 4

The following ingredients comprise Mix No. 4:

	Grams
$KClO_3$	1.0
$C_{12}H_{22}O_{11}$	1.0
Carbon	1.0

The carbon of all four mixes may be either finely powdered wood charcoal or graphite, and preferably less than forty microns in diameter. Bone charcoal is not satisfactory because of its low carbon and high phosphate content.

Although the sparkler may be of any desired shape or form so long as it does not disturb the flow pattern (see Figs. 2 and 3), a one-fourth inch diameter sparkler has been found satisfactory in practicing the method with respect to most conventional prototypes having diameters of two and one-half inches or larger.

When the sparkler has been prepared and after the gas stream is initiated through the desired prototype, the sparkler is strategically placed in the stream and ignited. The sparks which are emitted from the sparkler then provide a brilliantly accurate and dramatic trace pattern of the flow through the prototype and may be readily photographed, if desired, to provide a permanent record. Incidentally, excellent results are obtained using both motion picture and still picture cameras, and, if an immediate picture is needed, the Polaroid Land Camera (manufactured by the Polaroid Corporation, Cambridge, Massachusetts) provides pleasing results. Several photographic records have been made of the particle paths in ranges of turbulent flow and all provided discrete particle paths such as have not been obtainable heretofore. It is to be noted that, in the flow patterns analyzed by the practice of the present invention, there is no diffused blending of the particles into a single cloud mass as was characteristic of the smoke technique.

The terms "gas," "gaseous fluid" and "fluid" are used interchangeably herein to define a gas, such as air, which will support combustion but which is not itself combustible.

It is understood that the foregoing description of one embodiment of the method and several exemplary sparkler compositions is for illustrative purposes only and that the present invention is not intended to be limited thereto. Rather, it is intended that such obvious modifications and equivalents as may readily occur to one skilled in the art from knowledge of this disclosure are likewise embraced by the present invention which is to be limited only by the scope of the appended claims.

What is claimed is:

1. The improvement in the art of visualizing the flow patterns of a stream of combustion supporting noncombustible gas passing through an aerodynamic prototype comprising introducing a burning tracer particle into the stream, and releasing said particle into the stream to be carried by the stream, said particle having sufficiently low mass to follow the velocity component of the stream in the direction of flow and to accurately reflect by its physical movement the pattern assumed by the flow.

2. The improvement in the art of visualizing the flow pattern of a stream of combustion supporting noncombustible gas passing through an aerodynamic prototype comprising introducing discrete incandescent tracer particles to the stream, and releasing said particles into the stream to be carried by the stream, said particles being characterized by a mass sufficiently low and a size sufficiently small to enable it to resist the influence of forces acting thereupon to deter it from reflecting the true flow pattern of the stream.

3. A method of visualizing the flow pattern of a gas combustion supporting noncombustible gas stream passing through an aerodynamic prototype comprising presenting to the gas stream a sparkler comprising a sparking composition of pyrotechnic matter; burning said sparkler to create sparks; and causing said sparks to be emitted from the sparkler into the stream to be carried by the stream.

4. The method of visualizing gas flow patterns in conduit comprising initiating gas flow through a conduit; introducing self-illuminating pyrotechnic tracer particles into said flow, and releasing said particles into the stream to be carried by the stream, each of said particles having sufficiently low mass to effect a balance between the drag of the particle and the inertia and centrifugal forces acting on the particle, to enable the particles to follow the velocity component of the gas flow in the direction of the flow thereby accurately reflecting by their physical movement the pattern assumed by said flow.

5. The method of visualizing gas flow patterns in conduit comprising: initiating gas flow through a conduit; introducing discrete incandescent tracer particles into said flow, and releasing said particles into the stream to be carried by the stream, said particles being characterized by a mass sufficiently low to resist the influence of inertia and centrifugal forces acting thereupon; and recording the paths of said particles in said flow.

6. The method of visualizing the flow pattern of an air stream passing through an aerodynamic prototype comprising creating an air stream through an aerodynamic prototype; and causing burning sparks consisting essentially of carbon to be introduced into and carried by the air stream to accurately reflect the flow pattern of the air stream.

7. The method of visualizing the flow pattern of an air stream passing through an aerodynamic prototype comprising creating an air stream through an aerodynamic prototype; and causing burning sparks consisting essentially of carbon to be introduced into and carried by the

air stream, said carbon sparks being characterized by a critical diameter of not more than 40 microns.

8. The improvement in the art of visualizing the flow pattern of a stream of combustion supporting noncombustible gas passing through an aerodynamic prototype comprising: preparing a sparkler comprising carbon particles having a diameter of 40 microns or less; initiating a stream of combustion supporting noncombustible gas through an aerodynamic prototype; presenting said sparkler to said stream; burning said sparkler to liberate said carbon particles in a burning state; and utilizing said stream to prolong the burning of said particles which have entered into and are carried by said stream and cause visible recognition of the flow pattern of said stream.

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