

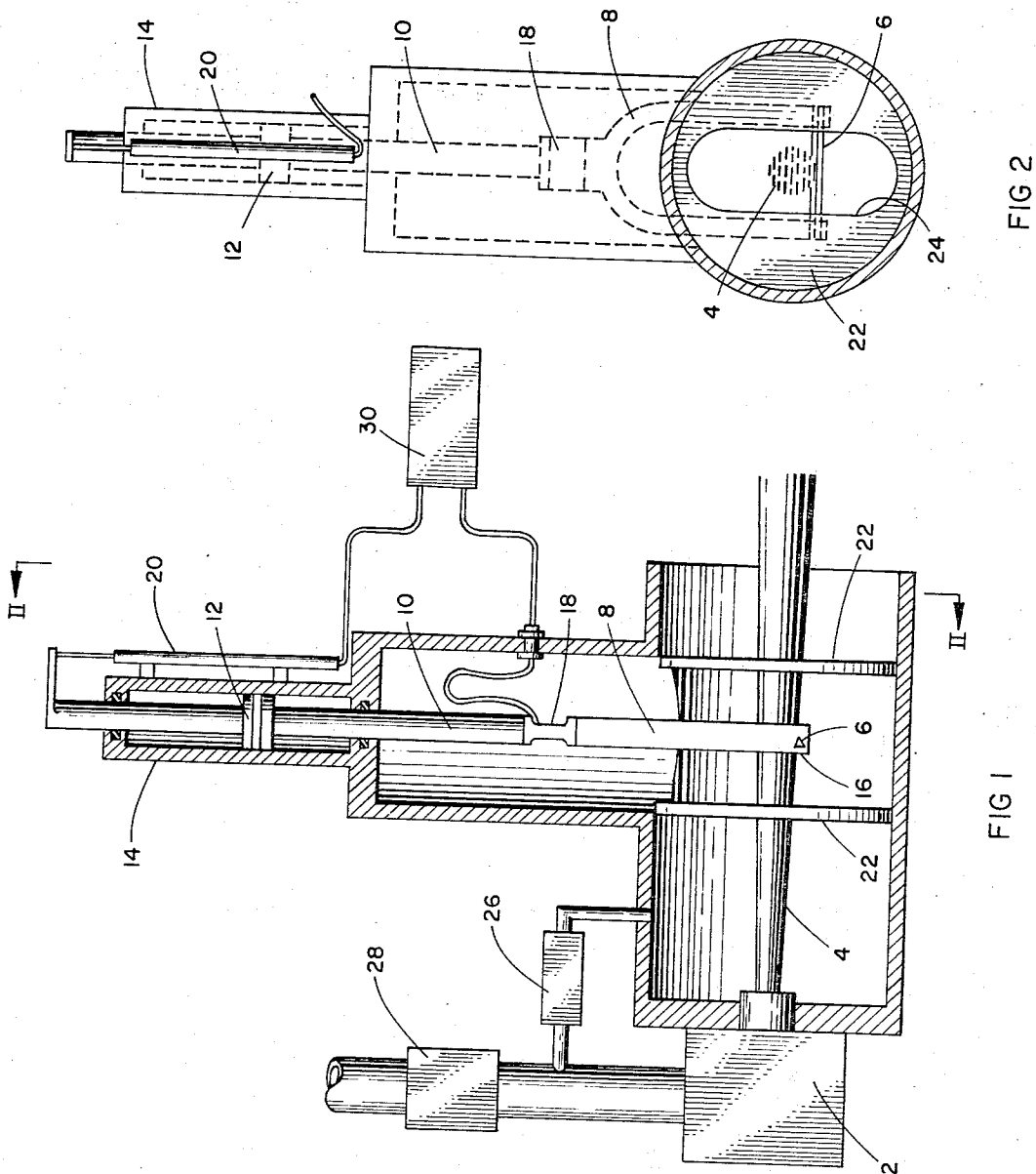
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J. D. USRY ET AL
INJECTANT STREAM ANALYZER

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2 Sheets-Sheet 1



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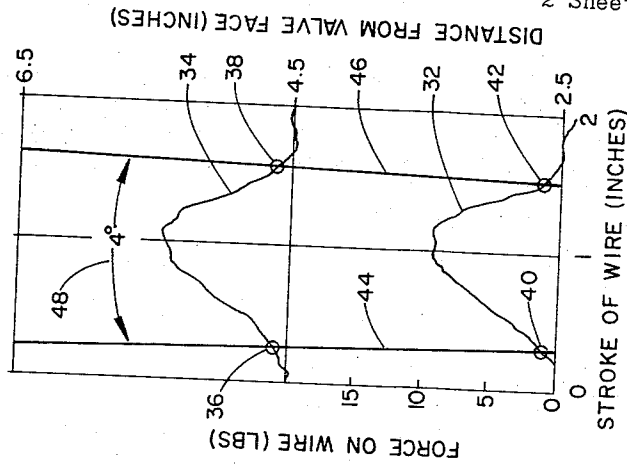


FIG 3

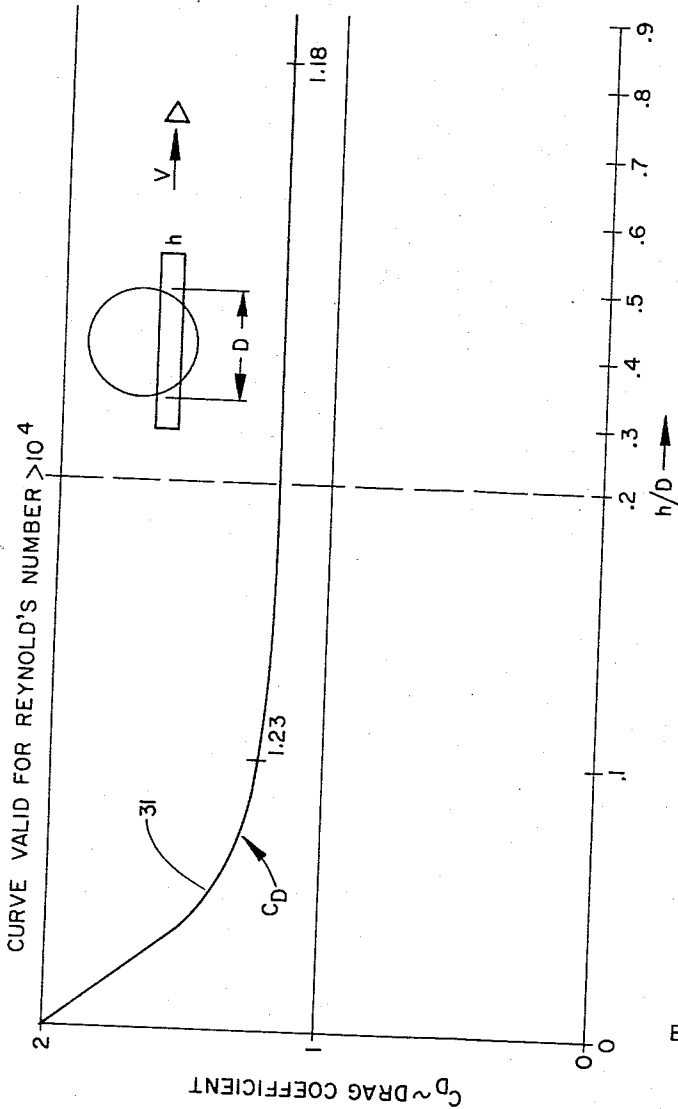


FIG 4

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INJECTANT STREAM ANALYZER

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ABSTRACT OF THE DISCLOSURE

This invention relates to device for measuring the momentum and solidity of fluid free streams from injection valves or the like by causing a wire of generally triangular cross-section to transect the stream in such a manner that the stream impinges on the base of the triangle and measuring the position of the wire and the force of the fluid impinging on the wire.

This invention relates to methods and apparatus for measuring characteristics of fluid streams and is particularly directed to novel methods and apparatus for measuring characteristics of fluid streams from secondary injection valves and the like.

In designing or evaluating injector valves and the like, two basic performance objectives must be considered. In order to obtain maximum penetration of injectant fluid into the nozzle gases for secondary injection, the injectant free stream must efficiently recover static pressure head after it leaves the valve. Secondly, the injectant fluid stream should have a solid cross section at all flow rates. Numerous methods and apparatus have been proposed heretofore for measuring the extent to which these performance objectives are attained. However, none of the prior art methods or apparatus have been entirely satisfactory.

It has been customary previously to determine recovery of static pressure head by measuring either the reaction thrust on the valve or the momentum of the stream impinging on a splash plate. However, there are decided disadvantages to either of these methods. In order to accurately measure the reaction thrust, the injector valve must be free of internal or external perturbations. Unfortunately, this is almost impossible to achieve in practice because of pressure and flow forces on the injectant supply pipe. Difficulties are also experienced with the splash plate method. Unless the stream solidity is extremely good, interaction of the stream droplets cause splash back and, since the angle of splash back is hard to determine, very erroneous readings are often obtained. The standard prior art method of measuring stream solidity has called for providing an apertured target plate upstream from the splash plate and either varying the size of the aperture or moving the target plate to shear off successive portions of the stream. However, the apparatus for accomplishing this expensive and cumbersome and performance of the method is time consuming and, often, of questionable reliability.

These disadvantages of the prior art are overcome with the present invention and novel methods and apparatus are provided for determining stream momentum and solidity. The apparatus of the present invention is simple in construction, rapid and accurate in operation, and inexpensive. Moreover, the method of the present invention is straightforward and uncomplicated.

The advantages of the present invention are preferably attained by providing a wire of wedge-shaped cross section, means supporting said wire with the flat side thereof extending perpendicular to the flow axis of the fluid free stream to be analyzed, means for causing said wire to transect said stream, means for indicating the force

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of fluid impinging on said wire, and means for indicating the position of said wire.

Accordingly, it is an object of the present invention to provide novel methods and apparatus for analyzing fluid free streams.

Another object of the present invention is to provide novel methods and apparatus for determining recovery of static pressure head and solidity of fluid free streams.

A further object of the present invention is to provide novel methods and apparatus for analyzing characteristics of secondary injection valves and the like.

A specific object of the present invention is to provide novel apparatus for measuring characteristics of a fluid free stream, said apparatus comprising a wire of wedge-shaped cross section, means supporting said wire with the flat side thereof extending perpendicular to the flow axis of said stream, means for causing said wire to transect said stream, means for indicating the force of fluid impinging on said wire and means for indicating the position of said wire.

These and other objects and features of the present invention will be apparent from the following detailed description taken with reference to the figures of the accompanying drawings.

In the drawings:

FIGURE 1 is a diagrammatic side view, partly in section, showing apparatus embodying the present invention for measuring characteristics of a fluid free stream;

FIGURE 2 is a view, partly in section, taken on the line II-II of FIG. 1;

FIGURE 3 is a diagrammatic representation of the curve drawn by the recorder of FIG. 1; and

FIGURE 4 is a curve showing drag coefficient as a function of the ratio of the dimensions of the wire and stream of FIG. 1.

In the form of the present invention chosen for purposes of illustration in the drawing, FIG. 1 shows a valve 2 emitting a free stream of fluid 4 which is to be analyzed. To analyze the stream 4, a wire 6 is tautly mounted in the ends of a yoke 8 which is formed on the free end of a piston rod 10. The opposite end of the piston rod 10 is secured to a piston 12 which is movable within a hydraulic cylinder 14. The wire 6 is preferably formed wedge-shaped or triangular in cross section, having the base 16 thereof equal to the altitude and oriented with the base 16 extending perpendicular to the flow axis of the stream 4. A strain gauge 18 or the like is provided to provide electrical signals indicative of the deflection of the yoke 8 caused by impingement of the stream 4 on the wire 6. The hydraulic cylinder 14 serves to cause the wire 6 to transect the stream 4 and suitable means 20 are connected to the piston 12 to provide electrical signals indicating the position of the wire 6. Baffles 22 formed with apertures 24 are positioned fore and aft of the yoke 8 provide a "dead" region to prevent spray reaction with the broad portion of the yoke 8. Pressure differential across valve 2 is measured conventionally by a differential pressure transducer 26 while injectant flow rate through valve 2 is measured by a flow meter 28.

To express the efficiency of an injector valve in converting the pressure head into stream velocity or momentum, a figure of merit, known as the momentum recovery, has become widely accepted. This is a ratio of the actual velocity of the stream to the ideal velocity, based on pressure head in the valve under test. From Bernoulli's equation, the ideal velocity is

$$V_I = \sqrt{\frac{2\Delta P}{\rho}} \quad (I)$$

where ΔP is the pressure differential across the valve under test, and ρ is the mass density of the fluid. To determine the actual velocity, hydraulic cylinder 14 is actuated to

move piston 12 from its extended position to its retracted position, causing the wire 6 to transect the fluid stream 4. As this is done, the signals from strain gauge 18 and position indicator 20 are supplied to a suitable recorder 30 which plots a curve, as shown at 32 in FIG. 3, displaying the force of the fluid impinging on the wire 6, indicated by the signals from strain gauge 18, as a function of the position of the wire 6, indicated by the signals from position indicator 20. It can be shown that the actual stream velocity is

$$V = \frac{FD}{1/2 C_D m} \text{ inches second} \quad (II)$$

where F_D is the integrated force on the wire 6, C_D is the drag coefficient of the wire 6 and m is the mass rate of particle flow in the stream 4. Since, as stated above, the momentum recovery is the ratio of the actual velocity to the ideal velocity, it is found that the ratio of force represented by the area under curve 32 to the ideal dynamic force of the stream 4 is equal to the product of one half the drag coefficient of wire 6 times the momentum recovery.

When curves showing drag coefficient as a function of Reynold's number are studied, for various cross sectional configurations of the wire 6, it becomes obvious that the preferred form is a wire having a wedge-shaped or triangular cross section oriented with the base of the triangle presented for impingement by the stream and extending perpendicular to the flow axis of the stream 4. It is found that the drag coefficient of a cylindrical wire varies constantly whereas the characteristics of a wire of the preferred configuration are constant for Reynold's numbers higher than 2000. It is also found that, for drag coefficient stability, the wire is preferably so dimensioned that the base of the triangle is equal to its altitude and is less than about 10 percent of the maximum expected diameter of the stream 4.

As is well known, the Reynolds number is a ratio of inertia to viscous forces for a fluid acting on a body. However, for Reynold's numbers greater than 10^4 it is found that the drag coefficient will be a function of the ratio of the dimensions of the wire 6 and stream 4, as shown in curve 31 of FIG. 4.

To perform the method of the present invention, the operator first determines the mass-density and viscosity of the injectant fluid and records the flow rate, from flow meter 28, and the differential pressure, from pressure transducer 26. From this information, he can calculate the ideal thrust and the Reynolds number for the stream 4. Next, he employs the apparatus of the present invention, as described above, to obtain a curve similar to curve 32 of FIG. 3. Having done this, he integrates the area under the curve, as with a compensating polar planimeter, and divides the result by the width of the wire 6 to determine the integrated force on the wire 6. This, added to the information noted above, enables the operator to calculate the momentum recovery of the stream 4 and, hence, the efficiency of the valve 2.

To determine the solidity of the stream 4, the apparatus of the present invention is caused to transect the stream 4 at two or more different distances from valve 2. This provides two curves corresponding to curves 32 and 34 of FIG. 3. The solidity of the stream is defined as the included angle between the stream boundaries and stream boundaries are typically considered to be the points where the curves 32 and 34 are at 10 percent of the maximum deflection, as indicated at 36, 38, 40 and 42. To determine the solidity of the stream 4, the points 36, 38, 40 and 42 are located on the curves 32 and 34 and straight lines 44 and 46 are drawn connecting the points on each side, as indicated by lines 44 and 46. Thus, the angle 48 included between these lines defines the solidity of the stream 4.

It will be apparent that the stream solidity can be determined by employing a plurality of the devices of FIG. 1

in a tandem arrangement, moreover, made without departing from the present invention. Accordingly, it should be clearly understood that the form of the invention described above and shown in the figures of the accompanying drawings is illustrative only and is not intended to limit the scope of the invention.

What is claimed is:

1. Apparatus for measuring characteristics of a fluid free stream, said apparatus comprising:

10 a wire of wedge-shaped cross-section, means supporting said wire with the flat side thereof positioned to be impinged upon by said stream and extending perpendicular to the flow axis of said stream,

15 means for causing said wire to transect said stream, means for indicating the force of fluid impinging on said wire, and means for indicating the position of said wire.

2. Apparatus for measuring characteristic of a fluid free stream, said apparatus comprising:

20 a wire of triangular cross section having the base of said triangle equal to its altitude and positioned for impingement of said stream on said base, means supporting said wire with the base of said triangle extending perpendicular to the flow axis of said stream,

25 means for causing said wire to transect said stream, means for indicating the force of fluid impinging on said wire, and means for indicating the position of said wire.

3. Apparatus for measuring characteristics of a fluid free stream, said apparatus comprising:

30 a wire of triangular cross section having the base of said triangle equal to its altitude, means supporting said wire with the base of said triangle extending perpendicular to the flow axis of said stream for impingement of said stream on said base,

35 means for causing said wire to transect said stream, means establishing a first electrical signal indicative of the force of fluid impinging on said wire, and means establishing a second electrical signal indicative of the position of said wire.

4. Apparatus for measuring characteristics of a fluid free stream, said apparatus comprising:

45 a wire of triangular cross section having the base of said triangle equal to its altitude, means supporting said wire with the base of said triangle extending perpendicular to the flow axis of said stream to cause said stream to impinge upon said base,

50 means for causing said wire to transect said stream, means establishing a first electrical signal indicative of the force of fluid impinging on said wire, means establishing a second electrical signal indicative of the position of said wire, and means for recording said first electrical signal as a function of said second electrical signal.

5. Apparatus for measuring characteristics of a fluid free stream, said apparatus comprising:

55 a cylinder, a piston movable within said cylinder between an extended position and a retracted position, a piston rod carried by said piston, a yoke formed on the outer end of said piston rod,

60 a wire of wedge-shaped cross section secured to the ends of said yoke and oriented with the flat side of said wire extending perpendicular to the direction of fluid flow to be analyzed,

65 means for indicating the force of fluid impinging on said flat side of said wire, means for moving said piston from said extended position to said retracted position to cause said wire to transect said fluid flow, and means for indicating the position of said wire.

70 means for indicating the position of said wire.

75 means for indicating the position of said wire.

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6. Apparatus for measuring characteristics of a fluid free stream, said apparatus comprising:

- a cylinder,
- a piston movable within said cylinder between an extended position and a retracted position,
- a piston rod carried by said piston,
- a yoke formed on the outer end of said piston rod,
- a wire of wedge-shaped cross section secured to the ends of said yoke and oriented with the flat side of said wire extending perpendicular to the direction of fluid flow to be analyzed,
- means establishing a first electrical signal indicative of the force of fluid impinging on said wire,
- means for moving said piston from said extended position to said retracted position to cause said wire to transect said fluid flow,

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means establishing a second electrical signal indicative of the position of said wire, and
 means for recording said first electrical signal as a function of said second electrical signal.

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