United States Patent [19]

Akashi et al.

[11] **3,840,051**

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[54] **STRAIGHTENER**

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[56]   **References Cited**

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Primary Examiner—Charles A. Ruehl
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[57]   **ABSTRACT**

A perforated-plate type straightener adapted to be fitted in a cylindrical pipe across the passage of a fluid flowing through the pipe, comprising a perforated plate having a plurality of round holes which are the same in diameter and so provided that the distances between the adjacent holes are short in the axial center of the pipe and are gradually longer near the surrounding wall.
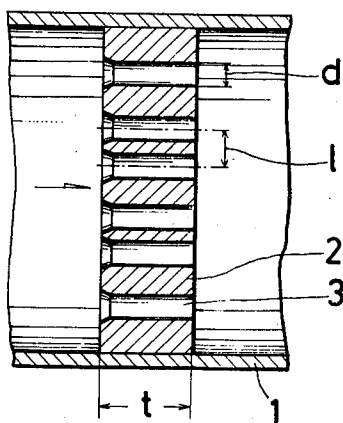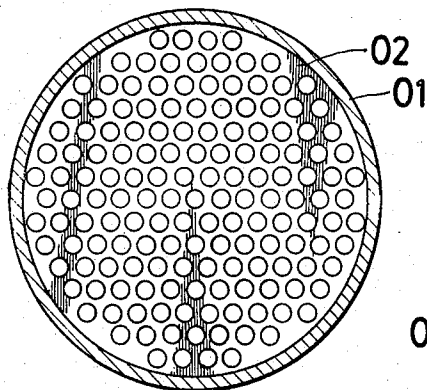
3 Claims, 16 Drawing Figures
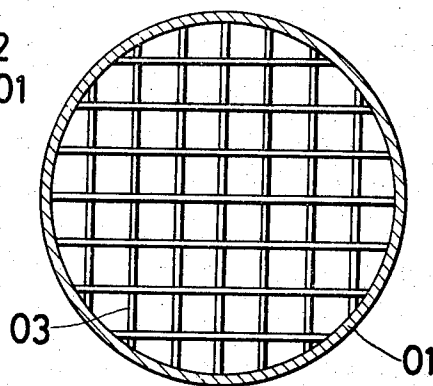
FIG. 1 PRIOR ART

FIG. 2 PRIOR ART

FIG. 3 PRIOR ART
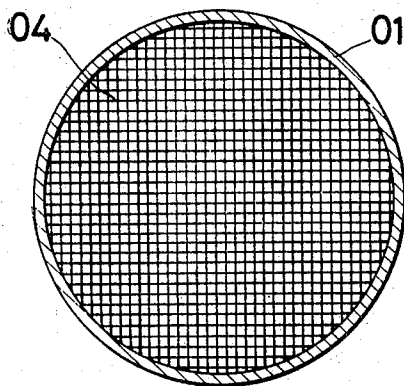
FIG. 4 PRIOR ART
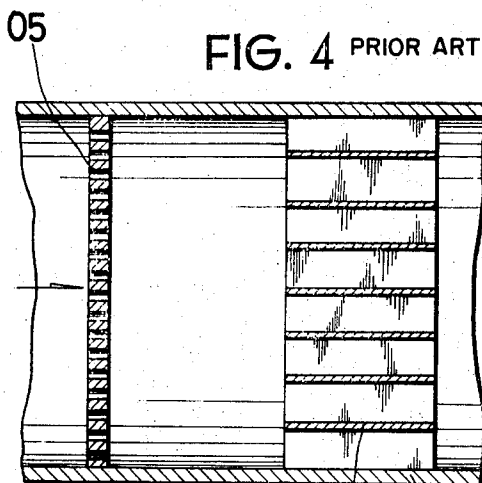
FIG. 5 PRIOR ART

FIG. 6
PRIOR ART

09

011

010

FIG. 7

FIG. 8

VIII

3

VIII

2

1

d

d

l

2

3

1

t

FIG. 9

(A)   (B)   (C)   (E)

D

012   01   014

FIG. 10

(A)   (F)

D

2   1   14

FIG. 11

1   09 2   (B)

(A)

D

D   1.5D

(C)

FIG. 12

FIG. 13

FIG. 14

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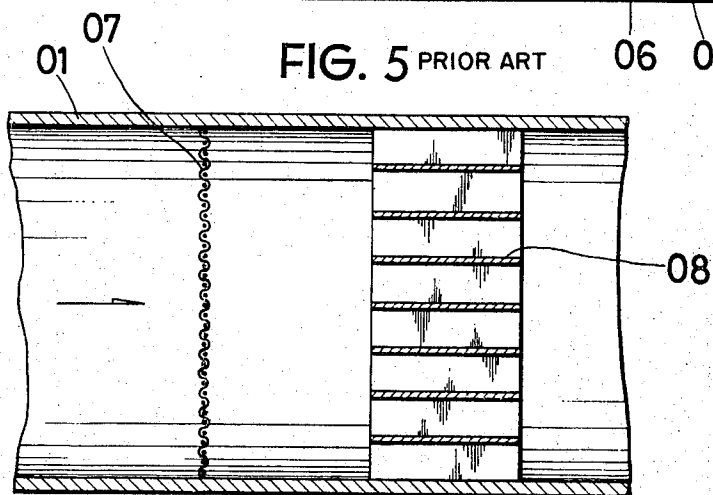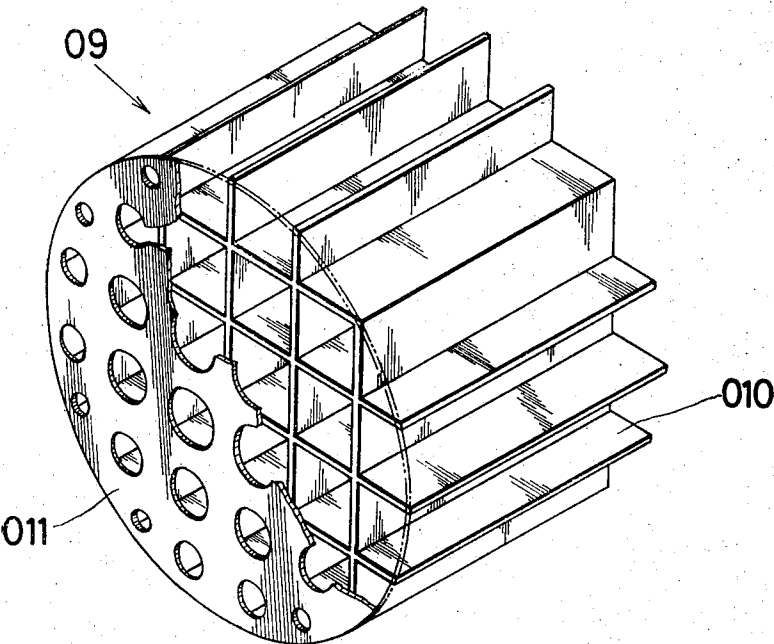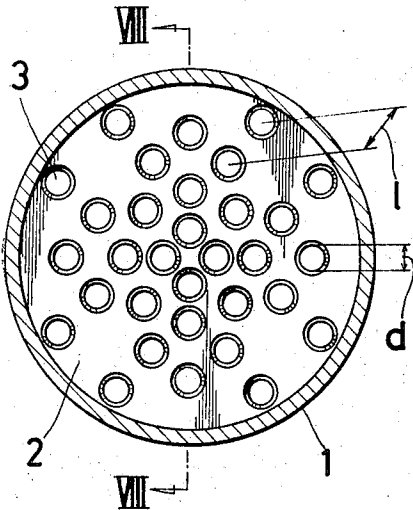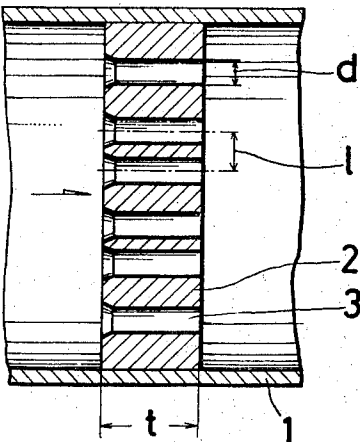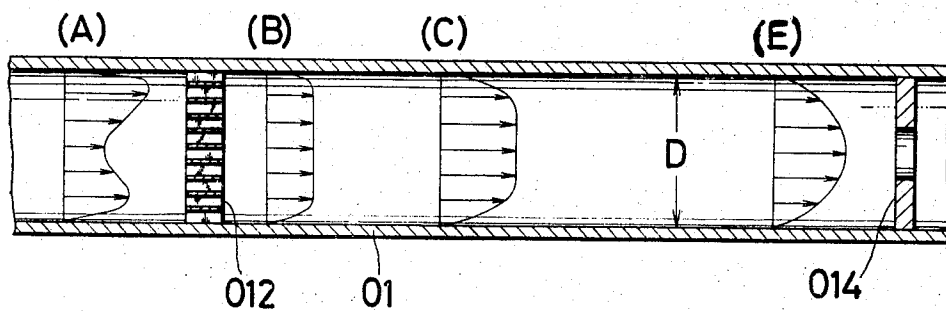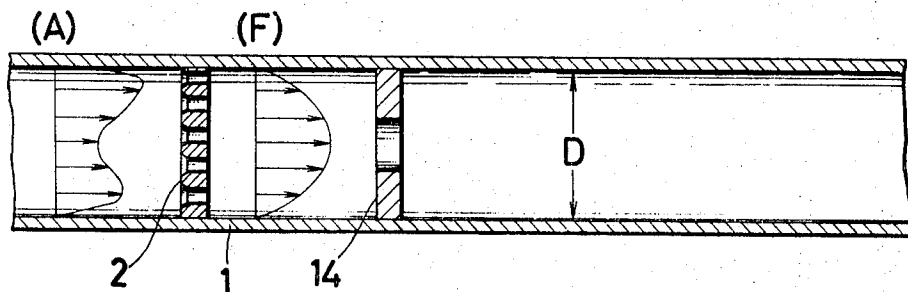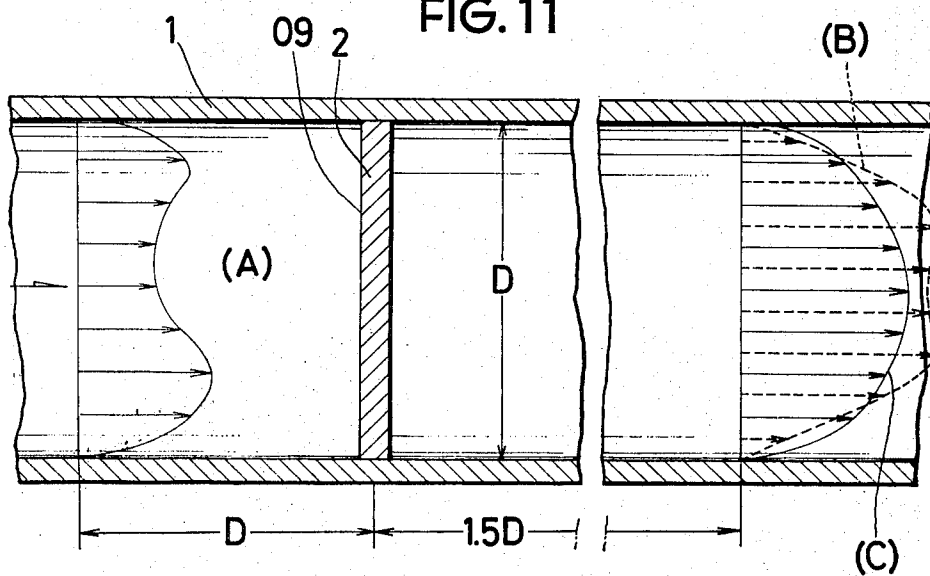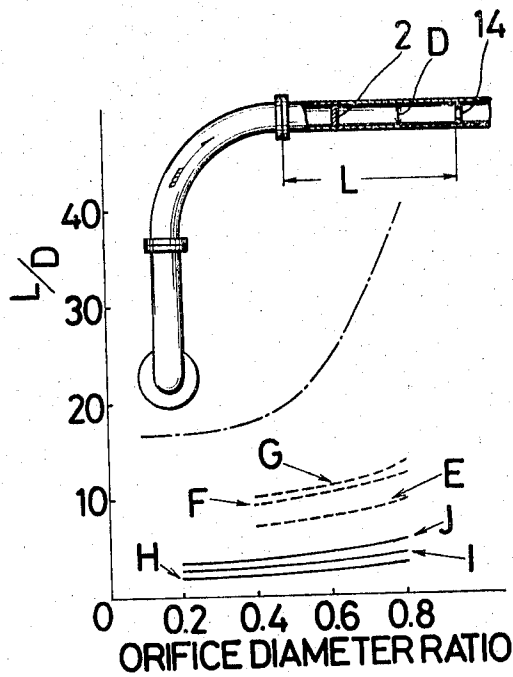
FIG.15

FIG.16

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STRAIGHTENER

This is a continuation of application Ser. No. 230,403 filed Feb. 29, 1972, now abandoned.

This invention relates to a straightener for use in the measurement of the flow rate of a single phase fluid, either gas or liquid, flowing through a pipe which is cylindrical.

Conventional straightening devices for this purpose are available in a variety of types, such as shown in FIGS. 1 to 5. Referring to the figures, the devices consist of a perforated plate 02, grid 03, wire gauge 04, perforated plate 05 plus a downstream grid 06, or wire gauge 07 plus a downstream grid 08, fitted in a pipe 01. The straighten either an upstream channeling or swirling flow or the both to ensure uniform flow velocity distribution. However, they fail to bring a trubulent-flow velocity distribution which is necessary for the measurement with a throttling flowmeter. If a proper turbulent-flow velocity distribution is to be obtained with the use of such a straightener, there is no alternative but to employ an extended straight length and take advantage of the extra friction of the fluid with the inner wall surface of the pipe.

In an effort to eliminate the foregoing disadvantage, it has been proposed to install, as shown in FIG. 6, an assembly 09 consisting of a grid 010 and a perforated plate 011 adjoining to the upstream face of the grid in a cylindrical pipe, the holes of the perforated plate 011 being gradually made larger in diameter toward the center and smaller toward the periphery. As compared wit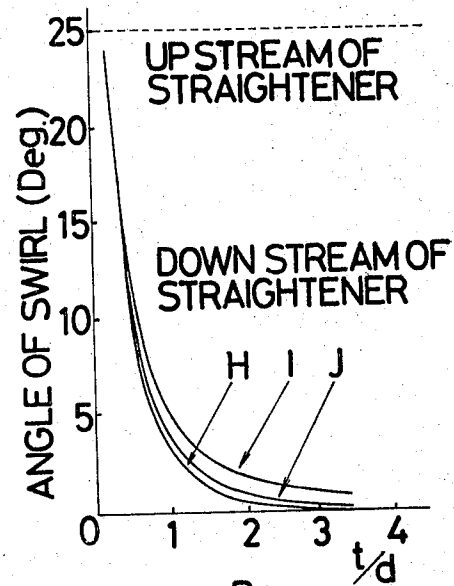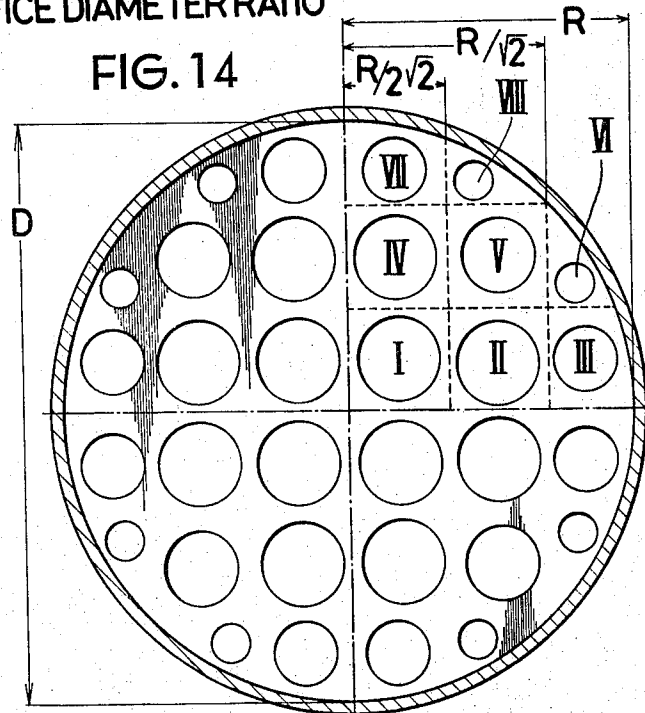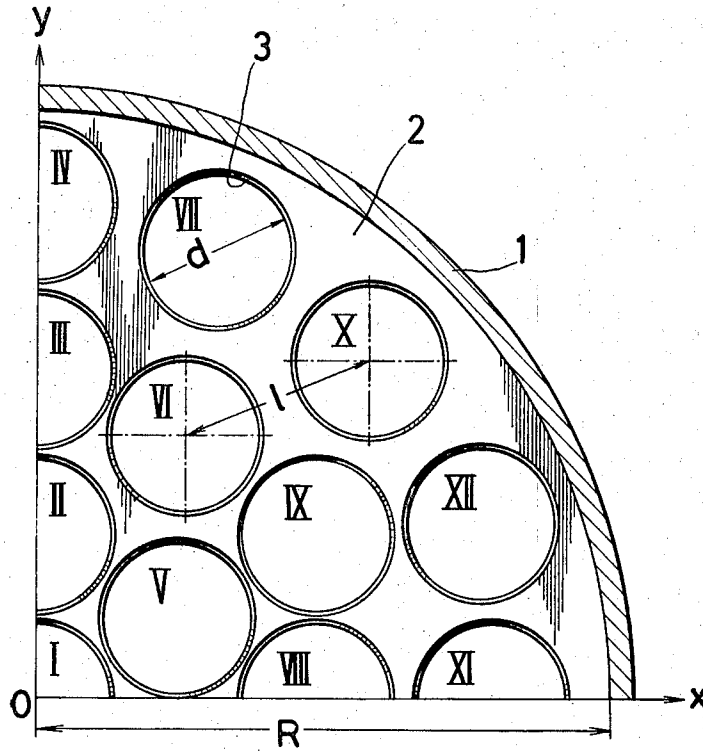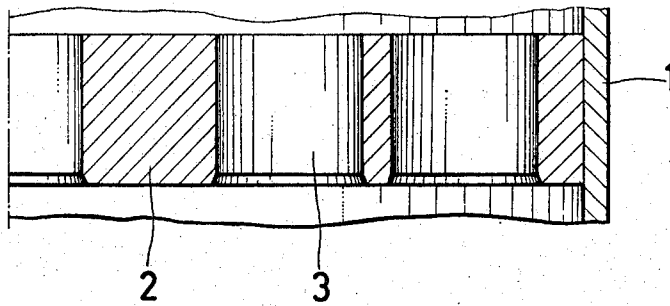h the straighteners of FIGS. 1 through 5, the device of the construction described immediately above permits the use of a relatively short straight pipe portion to obtain the necessary turbulent-flow velocity distribution. Nevertheless, the device has following drawbacks.

1. A straight pipe portion having a length about 10 times the diameter of the pipe must be provided downstream of the straightener.

2. The pressure loss is great.

3. The manufacturing cost is high.

Thus, none of the known straighteners has proved quite satisfactory as means for creating a turbulent-flow velocity distribution. In view of this and on the following additional grounds, the introduction of a straightener which can give a turbulent-flow velocity distribution with a short straight length of a pipe has been ardently called for.

a. The recent industrial tendency toward introduction of larger-capacity plants and machinery has made it no longer easy to maintain large length-to-diameter ratios for the straight lengths upstream of throttling flowmeters for the measurement of fluid flow in pipelines. On the other hand, the industry is demanding more and more enhanced accuracy of measurement and is urgently looking for the straighteners which can attain such accuracy with the shortest possible straight lengths.

b. When a throttling flowmeter which has been calibrated is to be used in actual measurement of fluid flow, there is a possibility of errors due to the lack of hydrodynamic similarity if the measuring conditions differ from those at the time of calibration because of the influence of any obstacle which may exist in the pipeline, such as a bend upstream of the primary element of the flowmeter. It has been confirmed that, par-

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ticularly when the Reynolds number is high, a throttling flowmeter will give an unusual value of flow coefficient under the influence of an ununiform upstream flow. For this reason it is most essential to install a straightener which is capable of highly efficiently counteracting the effect of such upstream obstacle as a branch pipe, bend, or valve between the primary element of the flowmeter and the particular obstacle.

c. It is clear from a number of experiments so far conducted as well as from the literature that the flow velocity distribution upstream of a throttling flowmeter can materially affect the accuracy of the measurement. This means that a straightener capable of effectively attaining a turbulent-flow velocity distribution is of absolute necessity.

d. Conventional straighteners can uniformalize the flow velocity distribution but are unable to give a turbulent-flow velocity distribution. Where the latter is to be attained a long straight length must be used.

It is therefore a fundamental object of this invention to provide a straightener which can settle all of the problems above enumerated.

Another object of the invention is to provide a highly efficient straightener capable of meeting the requirements immediately above noted.

The present invention, perfected to realize the foregoing objects, resides in a straightener characterized by the use of a perforated plate in which holes of the same diameter are scattered densely in the central portion and thinly in the peripheral portion.

These and other objects, advantages and features of the present invention will be better understood from the following detailed description taken in conjunction with the accompanying drawings showing preferred embodiments thereof.

In the drawings:

FIGS. 1 to 6 show conventional straighteners as fitted in a cylindrical pipe 01; FIG. 1 being a front view of a perforated plate 02, FIG. 2 a front view of a grid 03; FIG. 3 a front view of a wire gauze 04; FIG. 4 a longitudinal sectional view of a cylindrical pipe 01 wherein are installed a perforated plate 05 and a grid 06 downstream of the plate; FIG. 5 a longitudinal sectional view of a cylindrical pipe 01 wherein are installed a wire gauze 07 and a downstream grid 08; and FIG. 6 a perspective view of a straightener 09 which combines a grid 010 and a perforated plate 011 attached to the upstream face of the grid;

FIG. 7 is a front view of a straightener embodying the invention as fitted in a cylindrical pipe 1;

FIG. 8 is a sectional view taken on the line VIII — VIII of FIG. 7;

FIG. 9 is a view illustrating the changes of velocity distribution within a pipe 01 equipped with a known perforated-plate type straightener 012 shown in FIG. 1 (pipe size 205 mm, plate thickness 14 mm, hole diameter 7 mm, and area ratio 0.5);

FIG. 10 is a view illustrating the changes of velocity distribution within a pipe 1 equipped with the straightener 2 according to the present invention;

FIG. 11 is a view comparing the results of experiments with a conventional straightener of FIG. 6 and the straightener of the invention shown in FIGS. 7 and 8;

FIG. 12 is a graph comparing the results of experiments on the necessary straight lengths for different straighteners;

FIG. **13** is a graph illustrating the results of experiments on the straightening effects achieved by straighteners of different sizes according to the invention;

FIG. **14** is a plan view of the perforated plate of the straightener **09** shown in FIG. **6**;

FIG. **15** is a plan view of a quadrant of the perforated plate of the straightener according to the present invention; and

FIG. **16** is a sectional view of the quadrant.

Throughout FIGS. **7, 8** and **15** showing embodiments of the present invention, the hole diameter d of the plurality of holes **3** formed in the perforated plates **2** are the same. The distances l between adjacent holes **3** are gradually increased from the center of the cylindrical pipe **1** toward its surrounding wall. In other words, the number of holes **3** per unit area of the plate becomes larger towards the diametral center of the pipe and smaller towards the periphery. The upstream ends or inlets of the holes **3** are beveled. Also, the holes are so made that the ratio of the plate thickness t to the hole diameter d, or t/d, is within the range of 1.0 to 3.0.

Next, the functions of the straightener according to this invention will be described hereunder with reference to FIGS. **9** and **10** and in comparison with the functions of conventional devices. In FIG. **9** are shown the changes of velocity distribution which are caused in a cylindrical pipe **01** by a conventional straightener **012**. A fluid whose velocity distribution A is made ununiform by an obstacle not shown which is located upstream of the straightener **012** flows through the straightener **012** to attain a velocity distribution B which is an almost uniform flow. As the fluid proceeds through the straight length, a velocity distribution C is obtained, and downstream of it or at a distance of about 10 D (ten times the diameter of the pipe) from the straightener, a turbulent-flow velocity distribution E is obtained. It means that a measuring instrument, e.g., a throttling flowmeter **014**, must be installed further downstream.

FIG. **10** shows the changes of velocity distribution in a cylindrical pipe **1** with a straightener **2** of the present invention. A fluid with a velocity distribution A made uneven by an obstacle not shown upstream of the straightener **2** then obtains a turbulent-flow velocity distribution F after passage through a short straight length following the straightener **2**.

The straightener according to the present invention thus has the following advantages:

i. The straight length upstream of a throttling flowmeter can be extremely shortened.

ii. Swirl of the fluid can be reduced to almost zero.

iii. Pressure loss is negligible.

iv. Because the diameters of the holes in the perforated plate are the same, the straightener can be manufactured at low cost.

v. Fluid flow measurement is possible with a high degree of accuracy.

The velocity distribution characteristic, straight length requirements, and attenuation of swirling flow by the straightener according to this invention will be discussed hereunder in connection with the results of experiments diagrammatically represented or charted in FIGS. **11** to **13**.

I. Velocity distribution characteristic (Refer to FIG. **11**.)

1. First, devices of three different sizes E, F and G as given in Table 1 were made of perforated plates as perspectively shown in FIG. **6** and having a plane as in FIG. **14**.

Table 1

No.	E	F	G
	d/D	d/D	d/D
I	0.141	0.151	0.131
II	0.139	0.149	0.129
III	0.110	0.118	0.102
IV	0.139	0.149	0.129
V	0.136	0.146	0.126
VI	0.077	0.083	0.072
VII	0.110	0.118	0.102
VIII	0.077	0.083	0.072

Notes: d = diameter of hole
D = I.D. of pipe = 205 mm
Thickness of perforated plate = 0.02 D
Thickness of grid plate = 0.005 D
Depth of grid plate = 1.0 D

2. Next, using perforated plates having a plane as shown in FIGS. **15** and **16**, devices H, I and J with dimensions as given in Table 2 were formed.

Table 2

No.	H		I		J	
	x	y	x	y	x	y
I	0	0	0	0	0	12.0
II	0	28.5	0	29.0	12.0	38.0
III	0	57.0	0	58.0	0	63.0
IV	0	85.0	0	87.0	0	90.0
V	25.0	14.5	25.5	14.5	24.0	12.0
VI	26.5	46.0	26.0	44.5	35.0	35.0
VII	32.0	78.0	30.0	78.0	24.0	69.5
VIII	50.0	0	51.0	0	48.0	12.0
IX	50.0	28.5	51.0	29.0	56.0	48.0
X	59.0	59.0	55.5	60.0	50.0	74.0
XI	81.0	0	82.0	0	72.0	16.5
XII	79.0	31.0	80.0	33.0	79.5	40.5
Hole dia.	26.5		28.0		20.0	

Notes: Unit = mm
Perforated plate dia. R = 102.55 mm

3. The conventional device E and the device H of the invention, both adjusted in size to 200 mm in diameter, were fitted in straight pipes **1** having a inside diameter of 200 mm, and a bend was connected upstream to each pipe, and then the flow velocity distributions in the pipes were determined. The data thus obtained are diagrammatically represented in FIG. **11**. At a point 1 D (a distance equal to the pipe diameter D) upstream of each straightener, the flow velocity distribution was irregular as represented by a curve A. At a point 1.5 D downstream of the straightener, the distribution was changed as represented by the curve B in the case of a conventional straightener of FIG. **6** or by the curve B in the case of the device of the invention shown in FIGS. **15** and **16**. In either case the resulting curve was substantially symmetrical with the center axis of the pipe. Nevertheless, as will be obvious from those figures, the conventional straightener gave a distribution much different from the turbulentflow velocity distribution which is required for a throttling flowmeter, whereas the straightener of the invention produced a substantially perfect turbulentflow velocity distribution. When the pressure loss involved was determined, the loss with the straightener of the invention was several ten percent less than that with the conventional device.

II. Straight length characteristic (Refer to FIG. **12.**)

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In FIG. 12 which records the results of experiments on straight length requirements, the numbers on the abscissa indicate the diameter ratio of the orifice 14. Plotted as ordinate is the ratio of straight length L to pipe diameter D which is required for confining the error due to the effect of conditions upstream of the orifice within the tolerance value of 0.5 per cent as specified in the ISO Recommendation R541.

The curve drawn with an alternate long and short dash line in FIG. 12 indicates the straight length required upstream of an orifice, where no straightening device is employed, in accordance with the ISO Recommendation. The broken-line curves represent the results with the conventional straighteners having the contours as illustrated in FIGS. 6 and 14 and having the dimensions of E, F and G in Table 1. The solid-line curves represent the results with the straighteners according to this invention which have the contours as shown in FIGS. 15 and 16 and the dimensions of H, I and J as given in Table 2. In each experiment the test pipe was fitted with two 90° bends in different planes upstream of the flowmeter.

It will be appreciated from the graph that the straightener according to the present invention makes it possible to use by far the shorter straight length upstream of the flowmeter than the lengths usually required by the conventional devices.

III. Swirling-flow attenuation characteristic (Refer to FIG. 13.)

Using straighteners according to the invention with varied ratios of the thickness t of its perforated plate 2 to the hole diameter d and supplying a swirling flow at a certain angle of swirl to the upstream of each test straightener, the angle of swirl downstream of the device was determined. The results are given in FIG. 13. The angles were determined at points 1 D upstream and 1.5 D downstream of each test straightener. The curves H, I and J correspond to the columns H, I and J of Table 2.

As can be seen from the graph, the straightener of the present invention kills almost all of the swirl and gives out practically no swirl immediately downstream thereof provided that the ratio of its plate thickness to the hole diameter, t/d, is 1.0 or upwards. If the t/d is less than 1.0, the straightening effect will be limited with little attenuation of the swirling flow. With a t/d in excess of 3.0, the swirling flow will not be materially reduced and the accuracy of fluid flow measurement will remain practically unimproved. In addition, the thick perforated plate will be costly and inconvenient to handle.

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The straightener according to the present invention has the following advantages:

A. High precision measurement of fluid flow with a throttling flowmeter is made possible.

B. On the basis of computation of the flow velocity at one point within a pipeline (e.g., without traversing with a pilot tube), the fluid flow can be measured.

C. Fluid flow can be measured with noncontact currentmeters and flowmeters (e.g., ultrasonic currentmeter and electromagnetic flowmeter).

The straightener of the present invention is useful for the measurement of fluid flow particularly in such largediameter pipelines of large machines and plants which cannot be provided with adequate straight lengths for foreflow up to the points of measurement.

What is claimed is:

1. In apparatus for forming a turbulent-flow velocity distribution within a cylindrical pipe having fluid flowing therethrough, said apparatus including a perforated plate mounted within said pipe to extend transversely across the path of fluid flowing through said pipe, the improvement comprising, in combination:

means defining a plurality of cylindrical flow conduits extending through said plate in the direction of said fluid flow,

said conduits being of substantially equivalent diameter and disposed in said plate with the spacing between adjacent conduits increasing progressively from the inner radial portion of said plate to the outer radial portion thereof; and

means defining the upstream ends of said conduits with a beveled configuration extending from a wider diameter to a smaller diameter taken in the direction of fluid flow;

said conduits extending downstream from said beveled configuration over the major portion of their lengths with a generally uniform diameter throughout, said uniform diameter being generally coincident with said smaller diameter of said beveled configuration.

2. Apparatus according to claim 1, wherein said perforated plate comprises a thickness dimension taken in the direction of fluid flow through said pipe, with the ratio between said thickness dimension and said uniform diameter being within the range between 1 and 3.

3. Apparatus according to claim 1, wherein said beveled configuration is in the form of frusto-conical surface.

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