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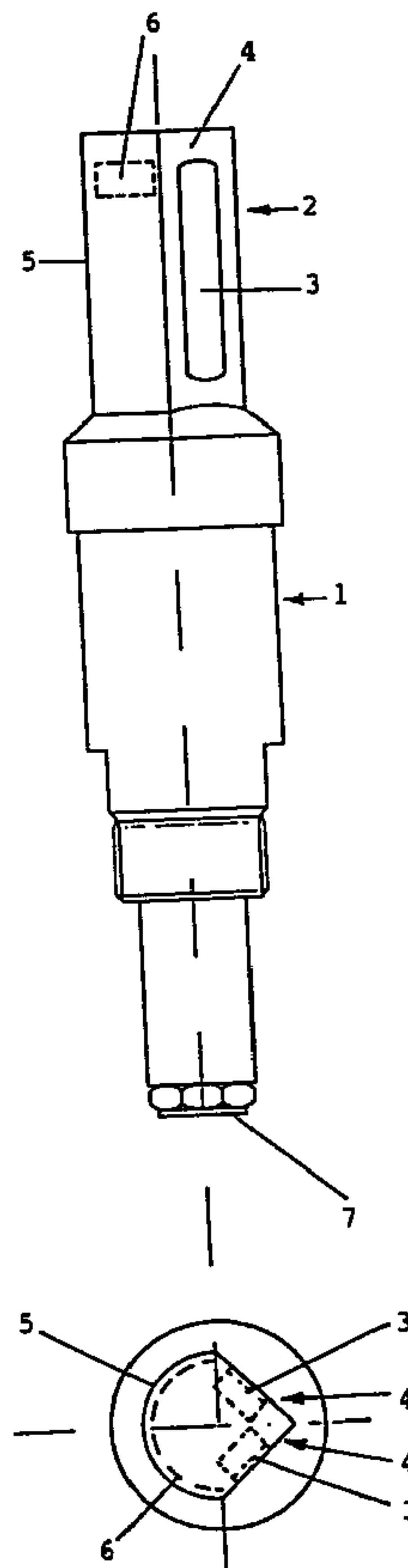
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(54) Titre : PROCEDURE ET SONDE POUR LA DETECTION DE MATIERES PARTICULAIRES DANS UN FLUX
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(54) Title: PROCEDURE AND PROBE FOR DETECTION OF PARTICULATE MATTER IN A LIQUID OR GAS STREAM



(57) Abrégé/Abstract:

A procedure for detecting particles in a fluid stream, comprising utilizing one or more probes (1) provided with at least one measuring element or erosion element (3). The probe is placed in a fluid stream, and the particle content is quantitatively



(57) **Abrégé(suite)/Abstract(continued):**

determined by measuring changes of electrical resistance as a function of erosion (r) of the measuring element by contact with particles moving in the stream. The probe may be equipped with a measuring head having a V-like shape directed upstream, and the two planar surfaces defined by the V-like shape may each be equipped with one or more measuring elements.

Abstract

A procedure for detecting particles in a fluid stream, comprising utilizing one or more probes (1) provided with at least one measuring element or erosion element (3). The probe is placed in a fluid stream, and the particle content is quantitatively determined by measuring changes of electrical resistance as a function of erosion (r) of the measuring element by contact with particles moving in the stream. The probe may be equipped with a measuring head having a V-like shape directed upstream, and the two planar surfaces defined by the V-like shape may each be equipped with one or more measuring elements.

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PROCEDURE AND PROBE FOR DETECTION OF PARTICULATE MATTER IN A
LIQUID OR GAS STREAM

The present invention concerns a process and a probe for detection of particles in a fluid stream.

Sand is often found in streams of oil and/or gas produced from underground reservoirs. The sand particles may have diameters of up to 1000 μm and may be present in quantities exceeding 25 ppm. Sand particles cause not only serious wear of production equipment, but will also potentially accumulate in the equipment, thereby causing production stoppage and serious damage.

Equipment now commercially available cannot measure with sufficient accuracy the presence of sand in fluids.

The description of this invention will analyse different types of equipment which can be used or which are suggested for use in monitoring or detecting the presence of sand in fluid streams. Disadvantages of the equipment will also be described. For example, the prior art includes a probe based on the concept that sand erodes through a thin, hollow-walled body placed in a fluid stream. The difference in pressure between the fluid stream and a reference level activates an alarm when a certain value is reached, that is when a hole is formed in the hollow body. The probe then has a significant time-delay before registering the presence of sand, and the probe cannot be used for continuous monitoring. The probe is also unable to provide a quantitative measurement of sand present in the fluid stream.

Various acoustic probes are also well known. These probes are either mounted in a conduit or on its outer side. The probes can detect the presence of sand in a otherwise pure gas or liquid. Their capacity to discriminate between sand and noise attributable to other sources is, however, unsatisfactory in intermittent streams. Calibration of the units must be performed at the actual production site and must be executed by injection of sand into the production system. However, the calibration changes when the rate of production changes or when other sources of noise alter. Also, when fine particles are produced (0 - 0.1 mm in diameter), their acoustic energy is too small to discriminate between particle and stream noise. An example of the probe described above is found in Norwegian patent no. 140838.

U.S. patent no. 3,678,273 shows a procedure for measuring wear caused by an abrasive fluid. A detector coated with radioactive material is placed in a fluid stream of, for example, oil slurry containing catalytic particles. The detector is activated by radiation from the radioactive coating as it is diminished by the particulate contents of the fluid. The detector is coupled to a monitoring and measuring unit on the outside of the conduit. This patent describes detection of particles in streams of either liquid or gas, and the detector is placed in an area of anticipated uniform current. It is stated that the particulate content in the stream can be estimated. Since the detector itself is placed in the fluid stream, the detector will partially block the stream. The detector will be unable to register fine particles since these will be deflected and will follow the flow of the fluid. This detector will not be useful for example in a high pressure hydrocarbon conduit where it is impossible to predict sand distribution. The accuracy and method of particulate content determination is not mentioned. The method requires calibration as well as a completely uniform concentration of solids.

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The applicant's Norwegian patent application no. 892819 (PCT/NO89/00112) describes a procedure for detection of particles in a production stream. The method is based on the application of activated probes giving off
5 radiation sensed by detectors placed on the outside of the stream. Each probe sends signals to one detector. The particle concentration can be determined when 0.25% of the thickness is lost.

That particular method, however, has several
10 disadvantages. Because of dependence upon use of radioactive material, special precautions must be taken both in regard to construction of the equipment and handling of the radioactive material. This means that the equipment is complicated and expensive to build and use. Although
15 measuring accuracy under ideal conditions is reasonably good, the external environment (background radiation, ambient temperature) can affect the measurements, and the statistical uncertainty for the measuring data could be high.

20 In view of the background of the prior art, the applicant has sought to provide a method of and equipment for detecting particles in an oil and/or gas stream, where the detection has high measuring accuracy, is inexpensive, is simple to build and use, and is robust and unaffected by
25 the external environment.

Surprisingly, it was found that it was possible to apply a method and a probe based on the principle that resistance of a measuring element (an erosion element or resistance element) placed in an oil/gas stream containing
30 particles will change as a consequence of erosion of the measuring element by particles in the stream.

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According to the present invention, there is provided a method for detection of sand particles in a fluid stream flowing through a conduit, wherein one or a plurality of probes are equipped with at least one corrosion-durable measuring element or corrosion-durable erosion element
5 immersed in and in contact with the fluid stream within the conduit, the element is planar and forms an angle relative to the direction of the fluid stream, and particle content is determined by measuring changes in electrical resistance
10 as a function of erosion of the measuring or erosion element.

Also according to the present invention, there is provided a probe for detecting sand particles in a fluid stream flowing through a conduit, wherein the probe has at
15 least one corrosion-durable measuring element or corrosion-durable erosion element adapted for immersion in and for contact with said fluid stream within the conduit, the element is planar and arranged to form an angle relative to the direction of the fluid stream, and by which particle
20 content is determined by measuring of the changes in electrical resistance as a function of erosion of the measuring or erosion element.

According to the present invention, there is further provided a probe for detecting sand particles in a
25 fluid stream flowing through a conduit, wherein the probe has at least one corrosion-durable measuring element or corrosion-durable erosion element adapted for immersion in and for contact with said fluid stream within the conduit, the probe has a measuring head having a circular form, said
30 measuring element is arranged on the surface of the measuring head and conformed to the surface of the measuring head, and by which a particle content is determined by

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3b

measuring changes in electrical resistance as a function of erosion of the measuring or erosion element.

Other advantageous features of embodiments of the invention are described herein.

5 The present invention has provided a solution for measuring

particles in a fluid stream without problems of handling radioactive materials. The instrumentation is simple and robust. It is possible to arrange several measuring elements on the same probe, this mean that measuring accuracy can be increased and the distribution of particles in a fluid stream can be determined over an entire cross section of a conduit. This is an essential advantage with the present invention inasmuch as previously known solutions were unable to register uneven distributions of particles in a fluid stream. The inventive probe and equipment are also not affected by the external environment, and furthermore there is no statistical uncertainty in the measuring data.

Still further, another essential advantage of the present invention is that it is unnecessary to calibrate the probe or equipment, and the measuring accuracy is very high, better than the measurement procedure described in applicant's previously mentioned patent no. 892819 (Norwegian) which represents the most effective solution in the prior art.

The present invention shall now be described in detail with examples and with reference to the drawings where:

Fig. 1 shows respectively a side view and a top plan view of an embodiment of the inventive erosion probe,

Fig. 2 shows an embodiment of the inventive probe mounted in a conduit.

Fig. 3 is a sketch of a test mounting (a test rig) for the probe shown by Fig. 1, and

Figs. 4-8 show results derived from test with the probe in the test rig shown by Fig. 3.

As stated in the preceding description, the present invention is

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based on the principle that the electrical resistance of a measuring element placed in a oil/gas stream containing particles will change as the measuring element is eroded by the particles.

Fig. 1 shows an embodiment of an erosion probe developed to test the inventive concept. The probe consists of a body part 1 with a measuring head 2. The probe is adapted for mounting to a wall in a conduit, cfr. Fig. 2 and the next paragraph. The measuring head 2 has, in the direction against the gas/liquid stream, a plow-like or V-like form, while the remaining part 5 of the measuring head 2 (located in the rearmost part of the head 2) has a semicircular form. Measuring elements 3 are arranged on each of the sides 4 of the V-shaped part of the measuring head 2. These measuring elements 3 are partially molded into the measuring head 2 such that only an outwardly facing side of each element is exposed to the ambient environment. The measuring element 3 is in this particular embodiment made of the type Monel 400 which has advantageous properties of thermal stability, electrical resistance, and wear. Monel™ 400 is also durable to corrosion; this is important in order to avoid situations where the measuring elements are affected by corrosion which consequently ruins or distorts measurements. In addition to the measuring elements 3, the probe is, as shown by broken line in Fig. 1, provided with a third element 6. This element 6 is completely molded into the measuring head 2 (element 6 thereby being unaffected by erosion) and serves thereby as a reference element.

Since the reference element 6 is located in the very front of the probe, the element 6 will simultaneously provide good temperature compensation. The measuring head 2 is made by molding with an electrically insulating insulation of the type Belzona™. All electrical connections (in addition to the elements 3 and 6) in the measuring head are molded in the insulation.

The other parts of the probe may be made of a suitable metallic material, such as stainless steel or a similar material. The

™ trademark

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probe is also equipped with an electric coupling part 7 which in a simple manner can be connected to a complementary coupling part on a conduit connected to the measuring equipment (not shown).

In some embodiments, probe's measuring head has a circular form in which one or several measuring elements are arranged on the surface of the measuring element and are adjusted to it.

Fig. 2 shows an embodiment of the inventive probe mounted in a conduit 10. As illustrated, the probe extends into the conduit 10 through a connecting piece 8 which is welded onto the conduit 10. The probe is held and secured from rotation by a hub 9 and locking screws 13. The requisite tightening between the probe and the connecting piece 8 is achieved by using gaskets 11 and 12. The probe in this embodiment is provided with four measuring elements 3, two on each of the V-shaped sides, and the measuring head with the four elements 3 extends over the entire cross section of the conduit. As previously stated, the use of a plurality of measuring elements 3 and the extension of the probe to cover the entire cross section of the conduit 10 represent an important advantage of the invention, inasmuch as it is possible to determine the distribution of sand particles in a fluid stream over an entire cross section by individually measuring wear of each of the elements. This has not been possible with any of the embodiments known to the prior art.

Fig. 3 shows a test rig in which the inventive probe was tested. Two test probes, and upper 14 and a lower 15, are mounted in a conduit 17 downstream of a descending conduit 16. A probe with two measuring elements as shown in Fig. 1 was used for the tests. Water was fed by cistern 18 to the descending conduit 16. Constant pressure in the descending conduit 16 was achieved by refilling the cistern 18 via a feeding line 19 with superfluous water being drained off through a spillway 20. The water flow through the testing section where the probes are mounted is adjusted by means of adjustment valve 21 downstream of the test section. An electromagnetic stream measurer 22 in run-off pipe 25 reads off the water flow.

Sand is added via a vibrating gutter 23 mounted over the cistern

18, and the sand is conducted through a tube 24 down through the center of descending conduit 16 in order to avoid depositing the sand in the cistern 18. The run-off pipe 25 leads to a container 26 functioning as a sand separator before the water is directed to a run-off basin. The descending conduit 16 is also equipped with a thermometer 27 for determining the temperature of the water during the tests.

The sand used during the tests was first sifted through a 0.7 mm cloth filter in order to remove fractions having a greater particle size. This resulted in a medium particle size of 0.5 mm for the coarsest type of sand used (baskarp sand 55).

Twelve tests were conducted to measure wear of the probes, that is reduction of the thickness of the measuring elements on the probes, as a function of time (wear was measured as a response "r" in nanometers/hour).

The data from the lower probe was used to adapt the following function to the response r (nm/hour):

$$r = A \cdot S \cdot F^B \cdot \sin (1.65 \alpha)^C$$

where A, B and C are estimated to be:

$$A = 2.911 \cdot 10^{-12}$$

$$B = 2.713$$

$$C = 3.488 \text{ and where}$$

S = sand concentration in ppm (weight)

F = flowthrough in liters per minute

α = angle in degrees

The factor 1.65 with which α is multiplied is chosen such that there is a maximum response at $\alpha = 55$ degrees ($1.65 \times 55 \approx 90$ degrees). This factor may also be estimated, and then one gets a value of 1.43 which gives maximum response when $\alpha = 63$ degrees.

At the same time, A, B, and C are changed to

$$A = 1.304 \cdot 10^{-12}, B = 2.849 \text{ and } C = 2.44$$

Overall, the two models give about equally good adjustment of data from the lower probe:

$$r^2 = 97.1\% \text{ with } 1.65 \text{ and } r^2 = 97.4 \text{ with } 1.43$$

This means that respectively 97.1% and 97.4% of the responses are explained by the respective models.

The function referred to above may be brought over into a more generalized form where amount of sand (P) per period of time in a fluid stream is calculated as follows:

$$P = \frac{(A \rho_m^{1.5})}{(V_m^B \cdot f \cdot d_p \cdot N)} \cdot \sum_{1}^N r$$

where r = the response (the wear)
 N = number of elements extending through the cross section.
 ρ_m = fluid mixture's density
 V_m = speed of the mixture
 d_p = particle size in nm
 f = function which is dependent on the shape and orientation of the elements in relation to the fluid stream. For the elements described above in the given inventive embodiment, $f = \sin (1.43 \times 63 \text{ degrees})$ where the optimum angle α is 63 degrees.

The parameters A, B and C are estimated constants.

As stated above, twelve tests were performed to test the probes. The test program was arranged such that these twelve tests would give sufficient data to estimate the effects of angle of the

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measuring elements, sand concentration and stream velocity in order to demonstrate the suitability of the present invention.

The measurements show in all the tests an unambiguous and linear response. Fig. 4 shows response as a function of the rate of sand. The response in nm/hour was calculated by adjusting a line between data points in accordance with the least squares method. Standard deviation in the adjustments varied from 1% for the highest wear to about 10% in the cases with the lowest rate. Stability in the measurements was found to be very good with water flowthrough up to 15 hours in some tests. Variations in measurements were here within +/- 50nm.

Fig. 5 shows the results from one of the tests where the response r in delta nanometers is shown as a function of time (in hours). The angle of the measuring element under this test was 58 degrees, the sand rate was 81 kg/hour and the flow speed was 3.9 meters per second. The erosion of the measuring elements is specified to be about 50 nm. This gives a detection limit of about 100 nm (0.1 μm) or 0.1% in the case of the measuring equipment used and with a 100 μm thick measuring element. The sensitivity is proportional to the thickness (0.1% of the thickness). This means that use of a measuring element of 10 μm will be able to increase sensitivity to 0.01 μm , but in such a case the lifetime for the element will be correspondingly reduced, that is to 1/10 of a measuring element with a 100 μm thickness. A combination of increased measuring accuracy and more frequent measurements will be able to further increase sensitivity.

Fig. 6 shows the calculation of wear as a function of the angle of the measuring element. As shown the sensitivity (the wear/the erosion of the measuring element) is greatest at an angle between 50 and 65 degrees. The optimum angle as previously stated is found to be at 63 degrees.

Fig. 7 shows calculated wear as a function of stream flow at a given angle of 55 degrees for the measuring element and with a sand rate of 125 kg per hour. The results show that the response is exponential in relation to the stream velocity, with an exponent of about 3.7.

Fig. 8 shows calculated sensitivity as a function of stream velocity. For each response, there was calculated minimum time for certain detection together with the amount of sand (kg) passing the probe for the same deflection ($0.1 \mu\text{m}$). In the best cases, a secure detection was measured (although with the limitations referred to above) even after about 20 kg of sand had passed by the test section with a stream velocity of about 6 meters per second. This shows that the inventive probe has substantially better sensitivity than the probes previously known.

Some of the test were done with sea water. The intention was to determine if the probes were affected by a moderately conductive medium. However, it was not possible to determine any difference between the two types of water.

As stated above, tests were performed with a probe having a particularly defined shape. The probe included two measuring elements and a reference element, and had a V-shaped measuring head on which the measuring elements were arranged angularly relative to each other. It should be noticed that the invention as defined by the claims is not limited to such a construction. The probe can have a different form and be provided with several measuring elements and can for example extend completely through the cross section of the conduit. Furthermore, one or a plurality of probes can be used in connection with a measuring set-up, and it may be advantageous to use other materials than those particularly given in the measuring elements, for example, nickel or stainless steel.

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CLAIMS:

1. A method for detection of sand particles in a fluid stream flowing through a conduit, wherein one or a plurality of probes are equipped with at least one
 5 corrosion-durable measuring element or corrosion-durable erosion element immersed in and in contact with the fluid stream within the conduit, the element is planar and forms an angle relative to the direction of the fluid stream, and particle content is determined by measuring changes in
 10 electrical resistance as a function of erosion of the measuring or erosion element.

2. A method according to claim 1, wherein an amount of sand, P, can be determined by

$$P = \frac{(Ag_m^{1,5})}{(Vm^B \cdot f \cdot d_p \cdot N)} \cdot \sum_1^N r$$

15 where r = the response, the wear,

N = number of elements in the cross section of a fluid stream

g_m = density of the fluid mixture

V_m = velocity of the mixture

20 d_p = particle size in nm

f = function which is dependent upon the element's shape and orientation

A and B are estimated constants.

3. A probe for detecting sand particles in a fluid
 25 stream flowing through a conduit, wherein the probe has at least one corrosion-durable measuring element or corrosion-

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5 durable erosion element adapted for immersion in and for contact with said fluid stream within the conduit, the element is planar and arranged to form an angle relative to the direction of the fluid stream, and by which particle content is determined by measuring of the changes in electrical resistance as a function of erosion of the measuring or erosion element.

10 4. The probe according to claim 3, wherein the probe has a measuring head having a V-shaped form directed upstream, and the head has two planar, flat surfaces defined by the V-shaped form each equipped with one or more measuring or erosion elements.

15 5. The probe according to claim 3 or 4, wherein at least one measuring or erosion element forms an angle, V, of between 55 and 63 degrees in relation to a direction of the current.

20 6. A probe for detecting sand particles in a fluid stream flowing through a conduit, wherein the probe has at least one corrosion-durable measuring element or corrosion-durable erosion element adapted for immersion in and for contact with said fluid stream within the conduit, the probe has a measuring head having a circular form, said measuring element is arranged on the surface of the measuring head and conformed to the surface of the measuring head, and by which a particle content is determined by measuring changes in electrical resistance as a function of erosion of the measuring or erosion element.

30 7. The probe according to any one of claims 3 to 6, wherein at least one measuring or erosion element is made of monel.

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8. A method according to claim 1 or 2, wherein the at least one measuring element or erosion element is provided on a planar surface forming an angle with the fluid stream.

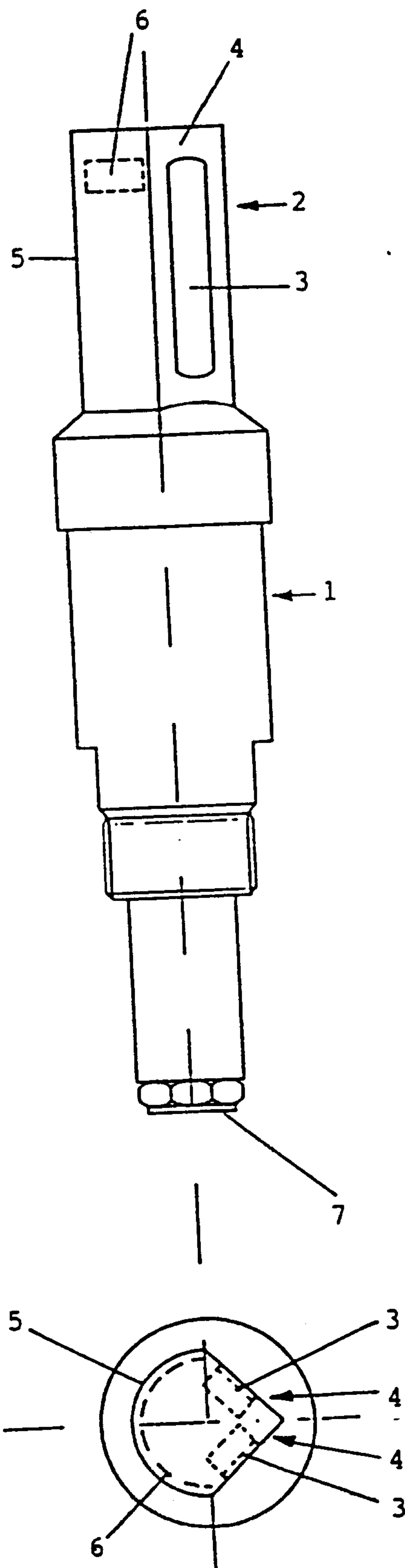
9. A probe according to any one of claims 3 to 5 or 5 7, wherein the at least one measuring element or erosion element is provided on a planar surface forming an angle with the fluid stream.

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FIG 1



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FIG 2

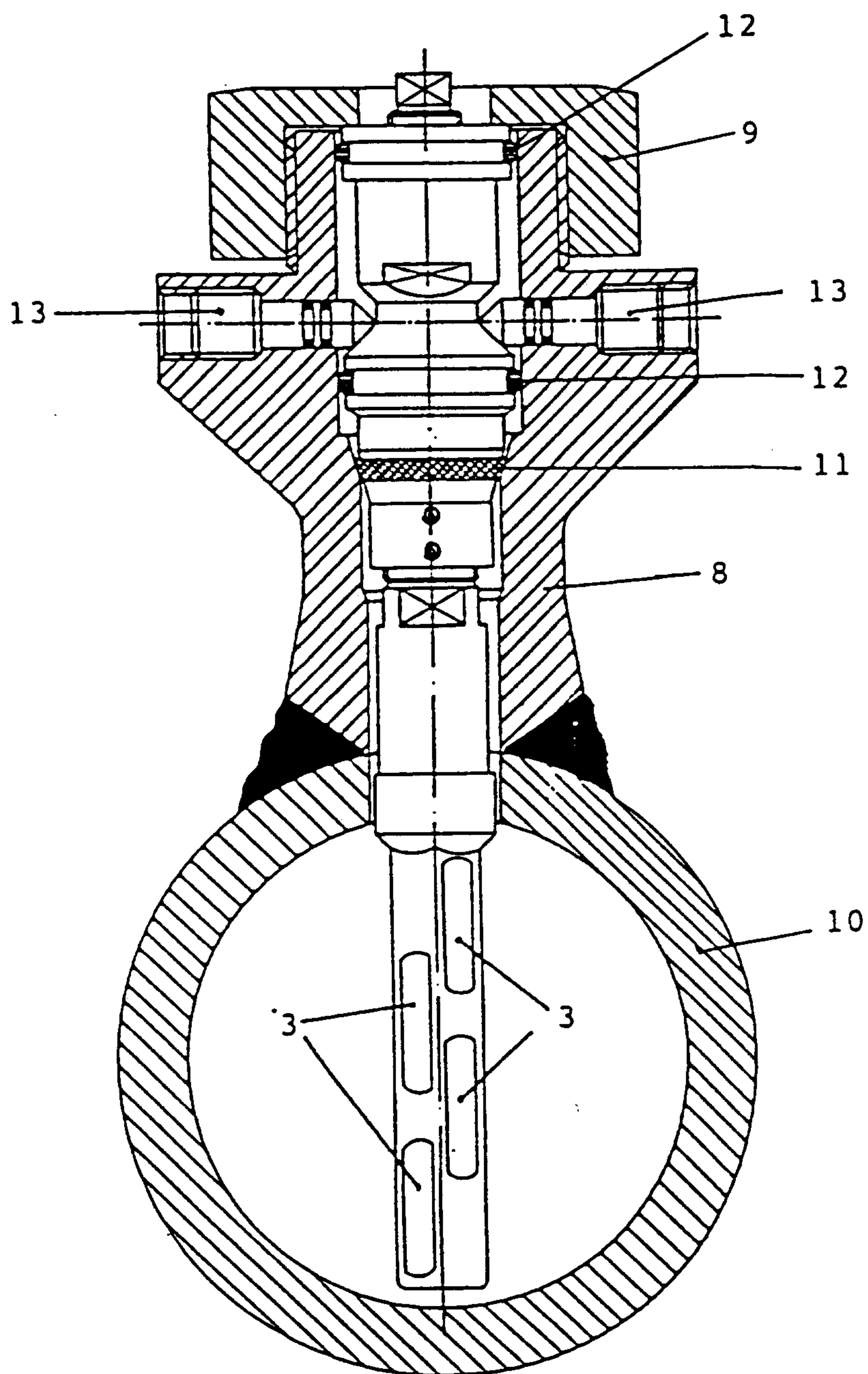
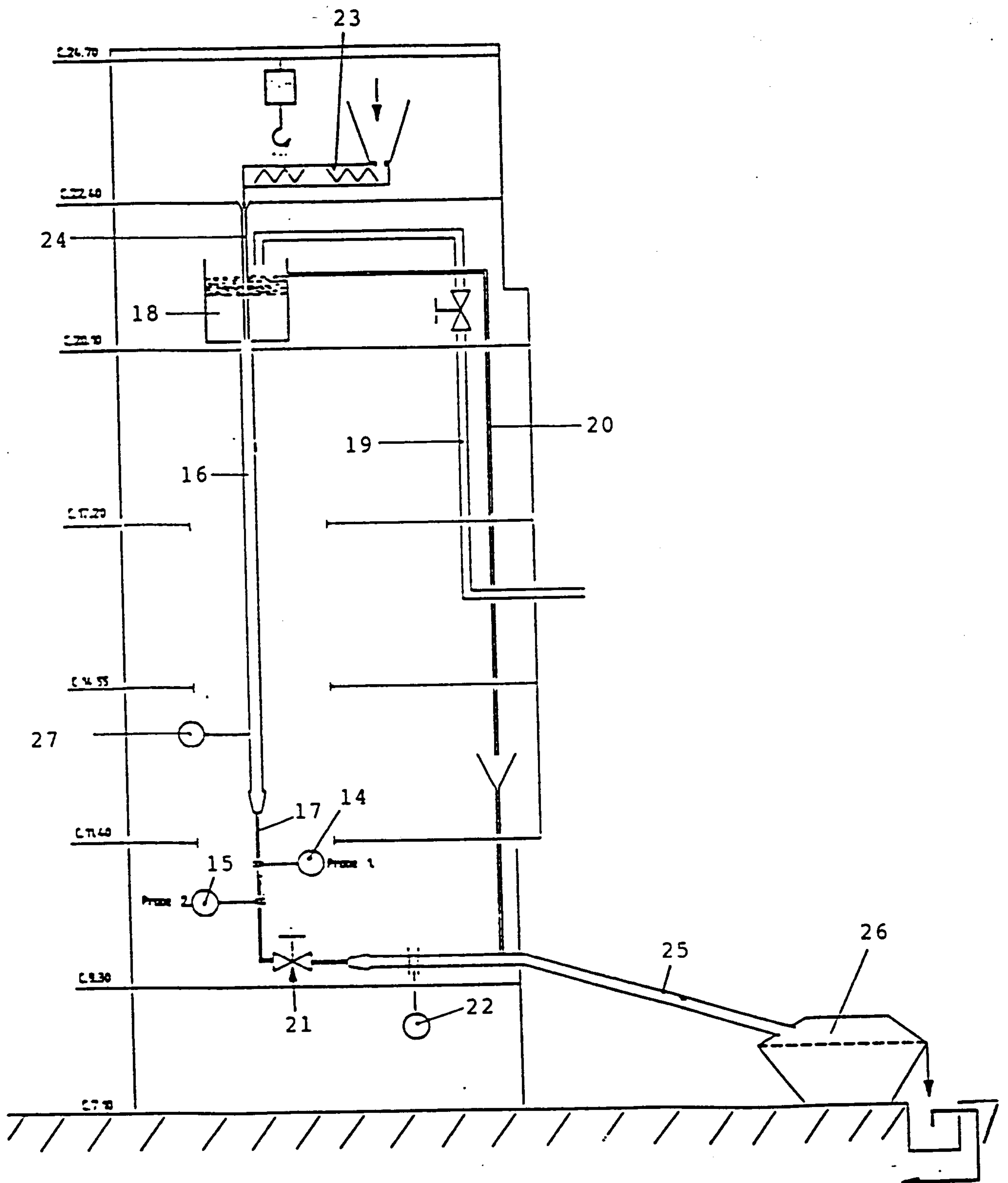


FIG 3

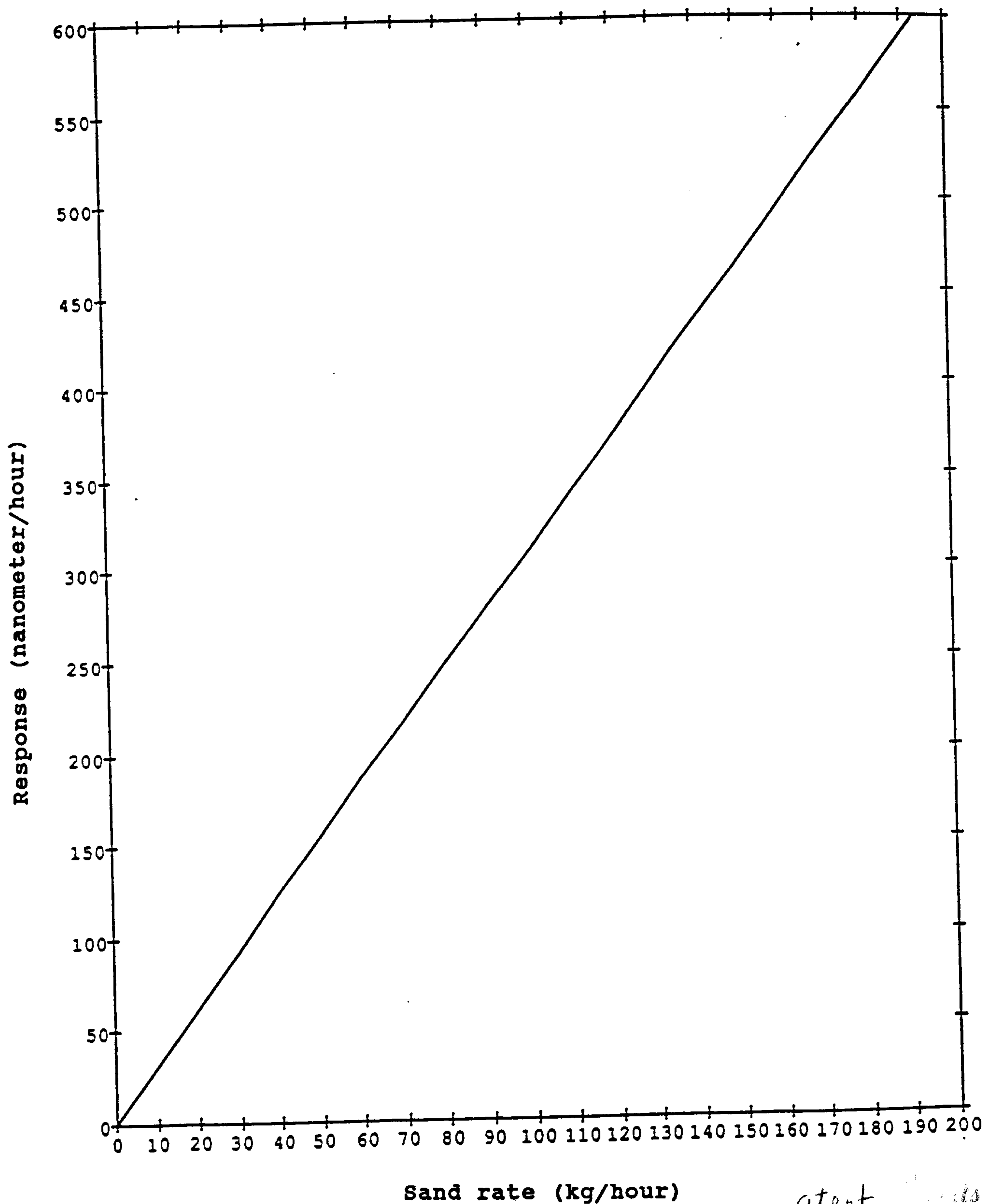
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FIG 4

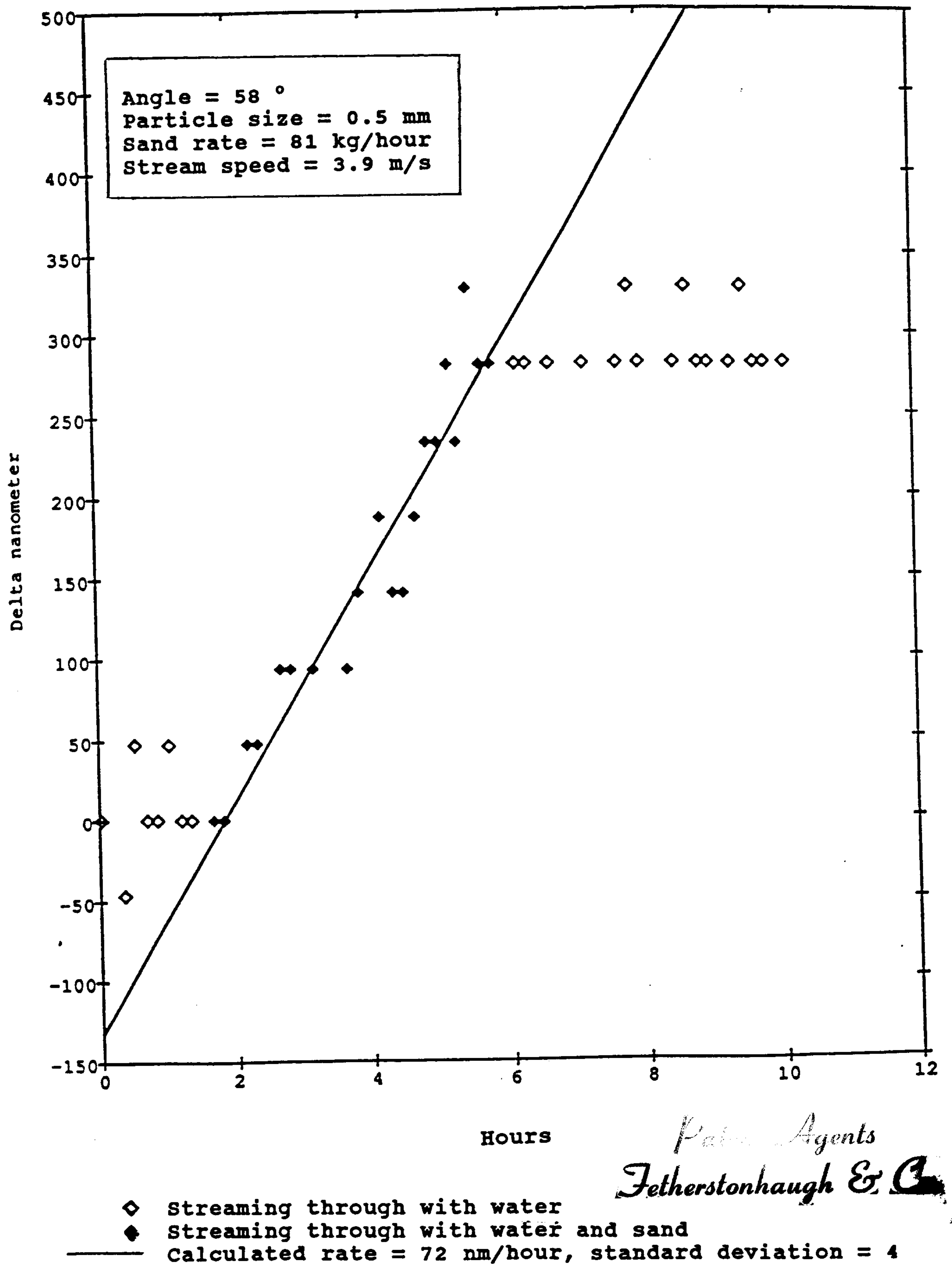
Response as a function
of
SAND RATE



— stream speed = 6 m/s, angle = 55°

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FIG 5

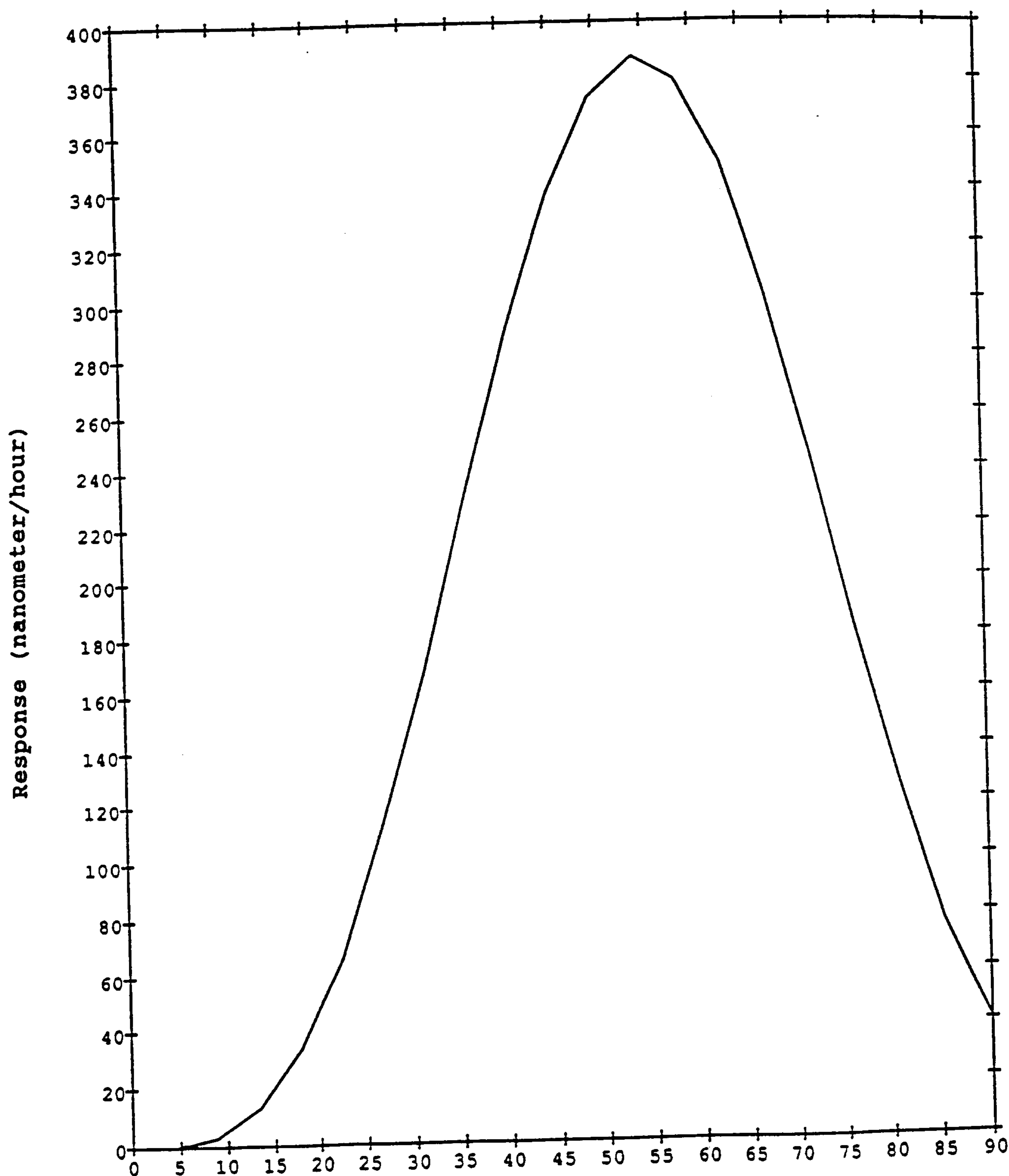


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FIG 6

Response as a function of

ANGLE



Angle (degrees)

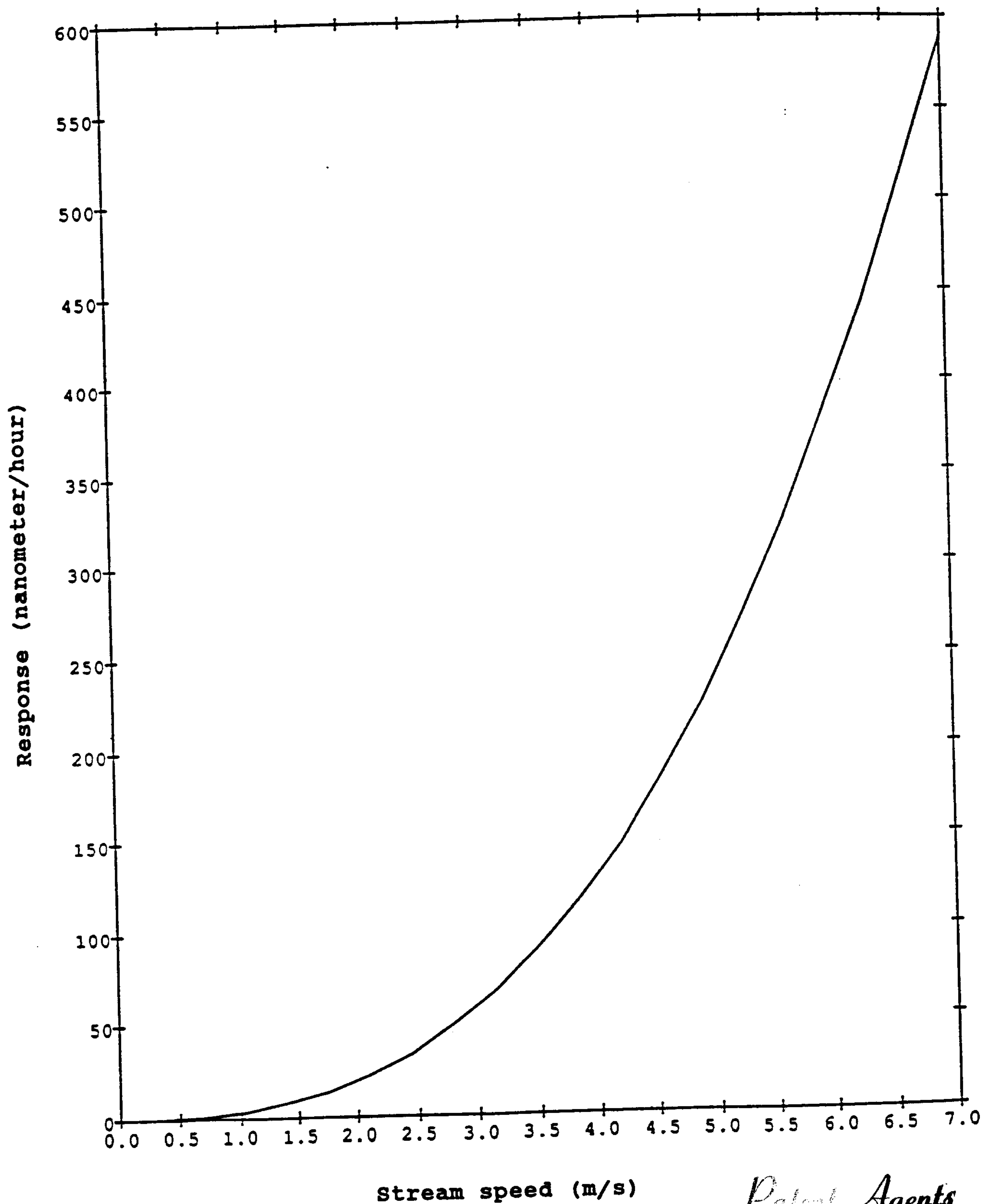
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— sand rate = 125 kg/hour, stream speed = 6 m/s

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FIG 7

Response as a function of
STREAM SPEED

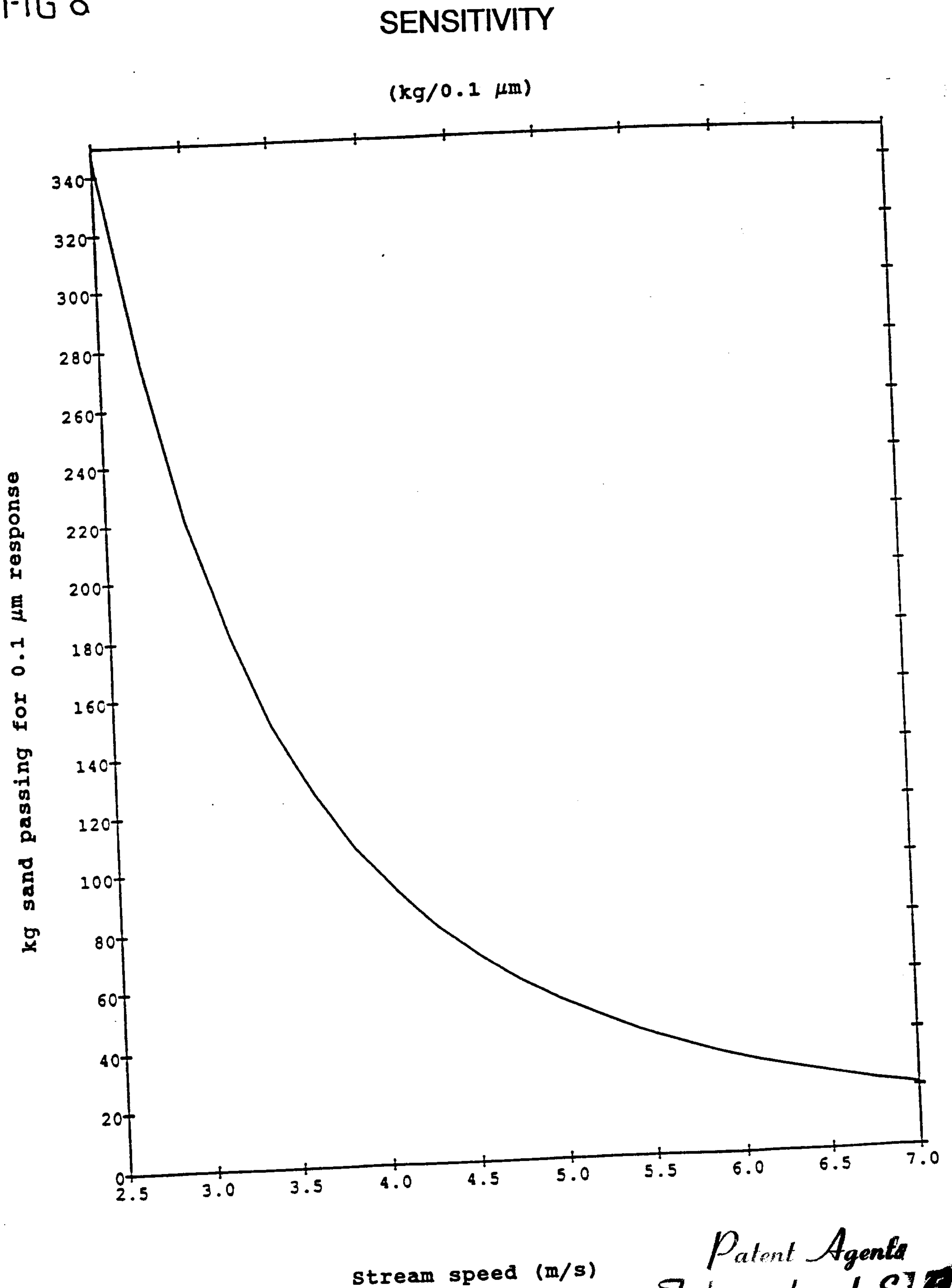


— sand rate = 125 kg/hour angle = 55 °

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FIG 8



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— detection limit at optimal angle

