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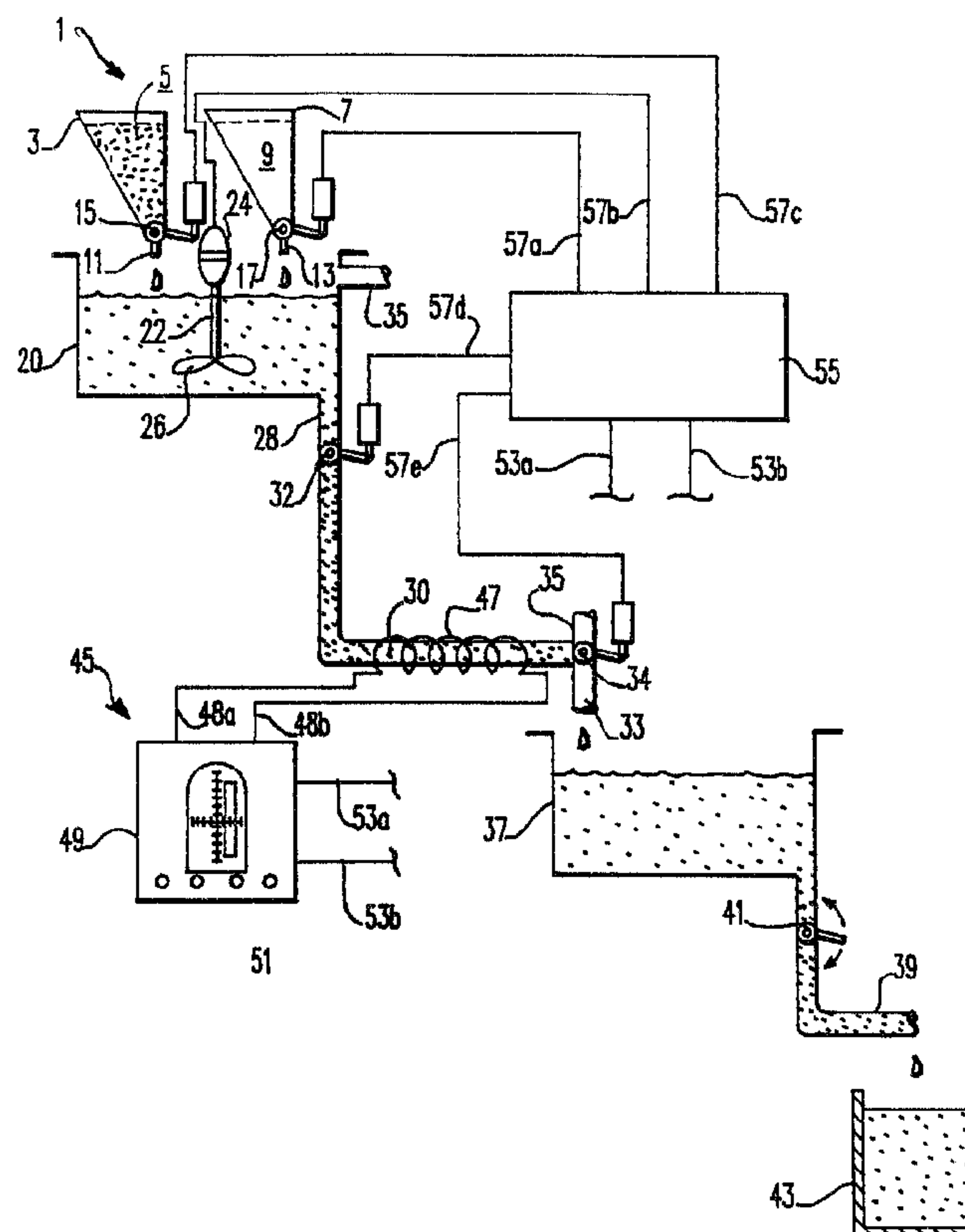
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(54) Titre : METHODE ET SYSTEME POUR CONTROLER LE MELANGE DE PRODUITS FLUIDES

(54) Title: METHOD AND SYSTEM FOR MONITORING THE ADMIXING OF FLUENT MATERIALS



(57) Abrégé/Abstract:

A method and system for monitoring the admixing of first and second fluent materials that ultimately harden into a solid structure is provided wherein a selected quantity of a particulate tagging substance, whose presence is detectable by a fluctuating electromagnetic field is uniformly dispersed throughout the first fluent material. The system of the invention comprises a means for mixing together the first and second fluent materials, a conduit for conducting a flow of the resulting admixture, a tagged particle detector for detecting the concentration and distribution of the tagged particles in the mixture, and a recycling conduit and valve for



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

recycling the admixture back to the mixing means if the admixture is in any way defective. The method comprises the steps of mixing together the first and second fluent materials, and then monitoring the distribution of the detectable particulate tagging substance throughout the admixture by transmitting the fluctuating magnetic field through it in order to determine the extent to which the materials are uniformly mixed together, as well as their relative ratios. When the admixture of fluent materials hardens into a solid structure, the uniform distribution of the particulate tagging substance throughout the structure advantageously allows it to be inspected for the presence of voids, cracks and discontinuities by the transmission of a fluctuating electromagnetic field through the structure.

Abstract of the Disclosure

A method and system for monitoring the admixing of first and second fluent materials that ultimately harden into a solid structure is provided wherein a selected quantity of a particulate tagging substance, whose presence is detectable by a fluctuating electromagnetic field is uniformly dispersed throughout the first fluent material. The system of the invention comprises a means for mixing together the first and second fluent materials, a conduit for conducting a flow of the resulting admixture, a tagged particle detector for detecting the concentration and distribution of the tagged particles in the mixture, and a recycling conduit and valve for recycling the admixture back to the mixing means if the admixture is in any way defective. The method comprises the steps of mixing together the first and second fluent materials, and then monitoring the distribution of the detectable particulate tagging substance throughout the admixture by transmitting the fluctuating magnetic field through it in order to determine the extent to which the materials are uniformly mixed together, as well as their relative ratios. When the admixture of fluent materials hardens into a solid structure, the uniform distribution of the particulate tagging substance throughout the structure advantageously allows it to be inspected for the presence of voids, cracks and discontinuities by the transmission of a fluctuating electromagnetic field through the structure.

1 METHOD AND SYSTEM
2 FOR MONITORING THE ADMIXING
3 OF FLUENT MATERIALS
4

5 Background of the Invention
6

7 This invention generally relates to a method and
8 system for monitoring the admixing of fluent materials
9 in order to determine not only the extent to which the
10 materials are uniformly mixed together, but also the
11 ratio of the fluent materials in the admixture.

12 Sampling methods for monitoring the admixing of
13 fluent materials to determine both the thoroughness of
14 the mixing operation and the ratio of the fluent
15 materials are known in the prior art. Such methods
16 find application in such diverse fields as the mixing
17 of concrete, the manufacture of plastic articles (where
18 monomers and curing agents are mixed together to form
19 hardened polymeric materials), the manufacture of
20 pressed wood articles (where glue and sawdust are mixed
21 together to form pressed wood), and even in the
22 manufacture of explosives and rocket propellants, where
23 organic binders are used to bind together small
24 particles of reactive metal and oxidizers into certain
25 shapes to achieve desired burning rates.

26 The prior art techniques for monitoring the
27 progress of the mixing operation in such diverse
28 industrial fields generally involves periodically
29 capturing and inspecting a sample of the admixture
30 during the mixing operation. For example, in the case
31 of concrete mixing, a sample of the concrete being
32 mixed is removed for the admixture and the water
33 content of the concrete is indirectly determined by
34 measuring the "slump" of the sample of concrete. If
35 the slump measurements are too high (which indicates
36 that the concrete mixture is too stiff), more water is
37 added. Conversely, if the slump measurements are too
38

1 low (indicating that the concrete mixture is too
2 runny), additional cement, gravel and sand are added to
3 the mixture.

4 Unfortunately, there are a number of drawbacks
5 associated with such sampling methods. For example, of
6 the periodic (as opposed to continuous) nature of the
7 sampling, and the time it takes to perform each
8 sampling operation, a significant amount of end product
9 of unacceptable quality might be produced before such
10 periodic sampling and inspection indicated a flaw in
11 either the thoroughness of mixing, or the ratio of the
12 fluent materials forming the end product. This problem
13 is exacerbated in situations where the inspection
14 operation does not yield the desired quality control
15 information instantaneously, but only after significant
16 amounts of time. For example, in the case of concrete,
17 it takes a significant amount of time to perform the
18 aforementioned "slump" test after a sample is
19 withdrawn. Finally, such sampling methods cannot be
20 used to test the structural integrity of the final
21 product of the fluent materials after they harden into
22 a solid shape. Any such structural tests will involve
23 an entirely separate testing operation, which in many
24 instances is not available in any practical form. For
25 example, when concrete is poured into forms to create
26 structural columns and beams, it is absolutely
27 essential that the poured concrete be substantially
28 free of air bubbles or other voids (known as
29 "honeycombing" in this art) or the resulting structure
30 may not be able to support its required load.
31 Similarly, the presence of air bubbles or voids in
32 finished plastic articles, or pressed wood products can
33 seriously jeopardize the quality of these articles. In
34 the case of explosives or rocket propellants, the
35 presence of air bubbles or voids can render the end
36 products highly dangerous, as the presence of any such
37
38

1 bubbles or voids can dangerously accelerate the burning
2 rate of the explosive or propellant matrix by
3 increasing the combustible surface area of the matrix.

4 Clearly, there is a need for a method for
5 continuously and accurately monitoring the admixing of
6 fluent materials which ultimately harden into final
7 products in order to determine both the thoroughness of
8 the mixing step, and the ratio of the fluent materials
9 within the admixture. Such a continuous monitoring
10 method would provide the manufacturers of such diverse
11 products as concrete, plastic articles, pressed wood
12 articles and rocket propellants with a technique for
13 insuring the final quality of their products, as such a
14 method would provide continuous feedback signals which
15 could instantaneously be used to correct any errors in
16 either the thoroughness of mixing or the ratio of the
17 materials used in the end products as soon as they
18 occur. It would further be desirable if the monitoring
19 method could be extended to inspect the structural
20 integrity of the end products formed from the admixing
21 operation so that voids, cracks, or discontinuities
22 within the final products could be easily detected and
23 the defective products either repaired or discarded.

24 Summary of the Invention

25
26
27 Generally speaking, the invention is a method and
28 system for monitoring the admixing of first and second
29 fluent materials that ultimately harden into a solid
30 structure which overcomes the deficiencies associated
31 with the prior art. The method comprises the steps of
32 uniformly dispersing a selected quantity of a
33 particulate tagging substance into the first fluent
34 material whose presence is detectable by radiant energy
35 transmittable through the first fluent material; mixing
36 the first fluent material with the second fluent
37 material, and continuously monitoring the distribution
38

1 of the detectable particulate tagging substance
2 throughout the mixture by transmitting radiant energy
3 through it to determine the extent to which the
4 materials are uniformly mixed together, as well as the
5 ratio of first and second fluent materials in the
6 admixture.

7 The method may further include the step of
8 uniformly dispersing a selected quantity of a second
9 particulate tagging substance whose presence is also
10 detectable by radiant energy transmitted through the
11 first and second fluent materials, but whose character-
12 istics upon such detection are different from the
13 detectable characteristics of the first particulate
14 tagging substance. The use of such a second
15 particulate tagging substance allows the operator of
16 the method to immediately detect the presence of any
17 voids in the admixture of the first and second fluent
18 materials. Further, the method may include the steps
19 of allowing the mixture to harden into a solid
20 structure, and then inspecting the integrity of the
21 structure by transmitting radiant energy through it in
22 order to detect the presence of voids, cracks and
23 discontinuities. The method of the invention finds
24 particular application in the quality control of
25 industrial processes where thoroughness of mixing, the
26 ratio of the fluent materials admixed, and the presence
27 or absence of voids in the admixture are important
28 criteria. Advantageously, the same particulate tagging
29 substances which allow the monitoring of the mixing
30 operation may further be used to inspect the integrity
31 of the resulting solid structure.

32 The particulate tagging substance may be particles
33 of a ferromagnetic material, or a piezo-electric
34 material, a material that effects the acoustical
35 impedance of the fluent materials (such as fine
36 particles of silicon dioxide), or particles that effect
37 the optical properties of the fluent materials (such as
38

1 vanadium dioxide, potassium di-hydrogen phosphate, and
2 lithium niobate). The radiant energy used for the
3 monitoring step of the method may include a fluctuating
4 electromagnetic field (in the case of ferromagnetic
5 material), a fluctuating electric field (in the case of
6 piezo-electric material, ultrasound in the case of
7 materials effecting the acoustical impedance of the
8 fluent materials), or light (either visible or
9 invisible) in the case of particles that effect the
10 optical properties of the fluent materials.

11 The system of the invention generally comprises
12 means for mixing together at least two different fluent
13 materials, at least one of which includes a particulate
14 tagging substance, a conduit for conducting a flow of
15 the admixture, and a tagged particle detect or for
16 transmitting said radiant energy through the admixture
17 flowing through the conduit to detect the presence and
18 concentration of the particulate tagging substance in
19 order to determine the extent to which the fluent
20 materials are mixed together, as well as their relative
21 ratio.

22 The means for mixing said fluent materials
23 together may include a blending vessel whose outlet
24 communicates with the aforementioned conduit, and a
25 mixing device, and the system may further include
26 reservoirs of the first and second fluent materials
27 having valve-operated outlets for supplying a separate
28 flow of each fluent material into the blending vessel.
29 Finally, the particle detector may generate a signal
30 indicative of the ratio of the fluent materials and the
31 thoroughness with which they are mixed, and this signal
32 may communicate with both the valves of the fluent
33 material reservoirs and the mixing device so that the
34 ratio of the fluent materials and the thoroughness with
35 which they are mixed may be maintained within selected
36 parameters.
37
38

Both the method and the system of the invention may be applied to the mixing of common structure concrete, the mixing of Polysil® concrete, the mixing of urethane monomers with a curing agent of the type applied to the hulls of naval vessels, and the mixing of binding agents to explosive mixtures of metal particles and oxidizers in the manufacture of shaped charges used in military ordnance, as well as the mixing of glue and particulate wood in the manufacture of particle board. The method provides a convenient means of inspecting not only the structural integrity of the resulting structure (as may be the case with concrete or particle board), but also the presence of areas of disbonding in instances where the fluent structure hardens over a surface in order to bind the structure thereto (as in the case of polyurethane over the hull of a naval vessel).

Brief Description of the Several Figures

Figure 1 is a schematic view of a system for monitoring the admixing of two fluent materials which incorporates the invention, wherein only one of the two fluent materials mixed contains tagged particles;

Figure 2 is a perspective view which illustrates how the finished products that result from the admixture of the fluent materials illustrated in Figure 1 may be inspected by, for example, an eddy current probe in order to determine the presence of any bubbles or cracks within the product;

Figure 3 is a schematic view of a system for monitoring the admixing of fluent materials that incorporates a second embodiment of the invention, wherein each of the fluent materials mixed includes a different type of tagging particle;

Figure 4 illustrates how a finished product created by the mixing system illustrated in Figure 3

1 might be inspected not only for bubbles, but for non-
2 homogeneities in mixing, and for regions of disbonding
3 when the finished product is a bonding coating;

4 Figure 5 is a graph illustrating how the eddy
5 current response increases as a weight percentage of
6 the content of the tagged particles (which in this
7 example is particulate ferrite), and how this response
8 varies at frequencies of 100 hertz, 500 hertz and 1
9 kilohertz, and

10 Figure 6 is a graph illustrating how the eddy
11 current response varies as a function of the weight
12 percentage of the tagged particles for a variety of
13 fluent mediums, such as water, cement, plaster and
14 adhesive.

15
16 Detailed Description of the Preferred Embodiment
17

18 With reference now to Figure 1, wherein like
19 components are designated by like numerals throughout
20 all the several figures, the system 1 of the invention
21 comprises a hopper 3 filled with a first fluent
22 material 5 into which a quantity of a particulate
23 tagging substance has been dispersed (as is indicated
24 by the dots), and another hopper 7 which contains
25 untagged fluent material 9. In this particular example
26 of the system 1, the tagged fluent material 5 is an
27 aqueous solution of ferromagnetic iron lignosulfonate
28 which contains about one percent by weight of very
29 fine, spinel ferrite particles having diameters of
30 about 50 to 150 Angstroms. Such a solution of
31 ferromagnetic iron lignosulfonate is available from the
32 Georgia Pacific Corporation, located in Bellingham,
33 Washington. The untagged fluent material 9 is a dry
34 concrete mixture of Portland cement, sand and gravel.
35 While in this example the fluent materials 5 and 9 are
36 water and concrete, both the system and method of the
37 invention are applicable to mixtures of virtually any
38

1 two fluent materials which ultimately harden into a
2 solid structure.

3 Each of the hoppers 3,7 includes an outlet 11,13
4 through which the fluent materials 5,9 may flow, either
5 continuously or intermittently. The flow of such
6 materials through the outlets 11,13 is modulated by
7 motor operated valves 15,17. The system 1 of the
8 invention also has a mixing vessel 20 for receiving the
9 fluent materials 5,9 which flow through the outlets
10 11,13 of the hoppers 3,7. An electric mixer 22 is
11 provided for admixing the fluent materials 5,9 to form
12 a homogeneous admixture of these materials. For this
13 purpose, the mixer 22 includes a motor 24 which turns a
14 propeller 26 by way of a shaft as shown to mix and
15 agitate the fluent materials 5,9. The mixing vessel 20
16 has an outlet 28 for discharging the admixture of the
17 fluent materials 5,9 created by the electric mixer 22.

18 The system 1 further includes an inspection and
19 drain conduit 30 which conducts a flow of the admixture
20 generated within the mixing vessel 20 and permits it to
21 be inspected by a source of radiant energy capable of
22 detecting both the concentration and distribution of
23 the particulate tagging material dispersed throughout
24 the admixture. To these ends, it is important that the
25 walls of the inspection drain conduit 30 be formed from
26 a material which is substantially transparent to
27 whatever type of radiant energy is used to detect both
28 the concentration and distribution of the tagged
29 particulate material. In this example, since a
30 fluctuating, high frequency electromagnetic field is
31 used to detect both the concentration and the
32 distribution of the ferrite particles distributed
33 throughout the concrete mix created in mixing vessel
34 20, the walls of the inspection and drain conduit 30
35 are preferably formed from a plastic material such as
36 polyvinyl chloride. Additionally, the inspection and
37 drain conduit 30 should be dimensioned so that it
38

1 easily accommodates whatever structural form the source
2 of particle-detecting radiant energy may take. In the
3 instant invention, since the source of the high
4 frequency fluctuating electromagnetic field may
5 conveniently be a simple electrical coil, the conduit
6 30 is tubular in shape with its outer diameter being
7 less than the inner diameter of the coil used to
8 generate the detecting radiant energy.

9 The upstream end of the inspection and drain
10 conduit 30 is connected to the outlet 28 of the mixing
11 vessel 20 through a motor operated discharge valve 32
12 as shown, while the downstream end of the conduit 30
13 includes both an outlet 35 which is disposed over a
14 reservoir vessel 37, a motor operated diverter valve
15 34, and a recycling conduit 35 which is connected back
16 to the mixing vessel 20. Under normal operating
17 conditions, the admixture flowing through the conduit
18 30 will be discharged into the reservoir vessel 37.
19 However, should the admixture prove defective, the
20 diverter valve 34 will shift position to recycle the
21 admixture back to the mixing vessel 20 via conduit 35
22 for correction.

23 The purpose of the reservoir vessel 37 is to hold
24 an inventory of the admixture of the fluent materials
25 5,7 created within the mixing vessel 20 for final use
26 in creating a finished product. Like the previously
27 described mixing vessel 20, the reservoir vessel 37
28 also includes an outlet 39 whose output is modulated by
29 means of a final discharge valve 41. In this example
30 of the system 1 of the invention, the outlet 39 is
31 disposed over a mold 43 which molds the fluent
32 admixture created in the mixing vessel 20 to a final
33 desired shape. The provision of the reservoir vessel
34 37 within the system 1 advantageously accommodates
35 short-term variations in the rate at which an admixture
36 is created within the mixing vessel 20 and the rate at
37 which this admixture is applied to a final purpose,
38

1 such as the creation of a solid structure within the
2 mold 43.

3 The system 1 of the invention further includes a
4 tagged particle detector 45. In this example of the
5 invention, the tagged particle detector 45 includes a
6 sensing coil 47 looped around the inspection and drain
7 conduit 30 as shown. The leads 48a,b of the sensing
8 coil 47 are connected to a multi-frequency generator 49
9 of the type used in eddy current probe inspections. In
10 the preferred embodiment, the multi-frequency generator
11 49 is preferably part of Miz-18 eddy current inspection
12 system manufactured by Zetec located in Isaquah,
13 Washington. Such commercially available inspection
14 systems operate by generating and conducting a high
15 frequency alternating current through a sensing coil
16 such as coil 47 so that the coil radiates a fluctuating
17 electromagnetic field, and further by measuring the
18 amount of impedance that this electromagnetic field
19 incurs as the result of electromagnetic coupling
20 between the field and the ferrite tagging particles
21 distributed throughout the admixture flowing through
22 the conduit 30. From the magnitude and location of
23 this measurable impedance, both the concentration and
24 the distribution of the ferrite tagging particles
25 within the admixture flowing through the conduit 30 may
26 be measured. From these measurements, both the
27 relative concentration of the fluent materials 5,9 and
28 the thoroughness by which they were mixed within the
29 vessel 20 may also be inferred, and displayed on a CRT
30 readout screen 51. The multi-frequency generator
31 measurements of both the concentration and distribution
32 of the ferrite tagging particles may be reduced to
33 electrical signals which may be transmitted outside of
34 the multi-frequency generator 49 via output cables
35 53a,b.

36 Finally, the system 1 of the invention includes a
37 microprocessor control circuit 55 whose input is
38

1 connected to the output cables 53a,b of the multi-
2 frequency generator 49, and whose output is connected
3 to control cables 57a,b,c,d,e which are connected to
4 the motor operated valve of the hopper 5, the electric
5 motor 24 of the mixer 22, the motor operated valve 17
6 of the hopper 7, and the motor operated discharge valve
7 32 disposed on the outlet 28 of the mixing vessel 20,
8 and the motor operated diverter valve 34 disposed
9 upstream of the outlet 33 of the inspection and drain
10 conduit 30. One of the functions of the microprocessor
11 control circuit 55 is to modulate the flow of both
12 tagged and untagged fluent material 5,9 from the
13 hoppers 3,7 into the mixing vessel 20 so that the ratio
14 of these materials 5,9 in the final admixture flowing
15 out through the outlet 28 continuously remains within a
16 range corresponding to a selected manufacturing
17 tolerance. Another function of the microprocessor
18 control circuit 55 is to operate the electric mixer 22
19 at a speed and over a sufficient length of time with
20 the discharge valve 32 closed such that the tagged and
21 untagged fluent materials 5,9 are thoroughly and
22 homogeneously admixed at the time that the admixture is
23 finally discharged through the motor operated discharge
24 valve 32. In the event that the signal generated by
25 the tagged particle detector 45 indicate that the ratio
26 of the mixture is no longer within the preselected
27 range or that the fluent materials 5,9 are
28 insufficiently mixed, the microprocessor control
29 circuit 55 changes the position of the diverter valve
30 34 to recycle the defective admixture back to the
31 mixing vessel 20 via conduit 35 for correction, either
32 by adding more or less of the fluent materials 5,9, or
33 by varying the speed of the mixer motor 24, or by
34 increasing the mixing time within the vessel 20 by
35 keeping the discharge valve 32 closed for longer
36 lengths of time. The continuous monitoring of both the
37 concentration and distribution of the ferrite tagging
38

1 particle in the admixture by the tagged particle
2 detector 45, and the continuous transmission of this
3 information into the input of the microprocessor
4 control circuit via cables 53a,b provide in effect a
5 continuous feedback signal to the microprocess or
6 control circuit 55 which allows it to quickly and
7 advantageously manipulate the motor operated valves
8 15,17 of the hoppers 3,7, the motor 24 of the electric
9 mixer 22, the discharge valve 32 of the mixing vessel
10 20 and the diverter valve 34 of the conduit outlet 33
11 to continuously and automatically create an admixture
12 whose fluent components stay within a desired ratio and
13 whose components are homogeneously intermixed to
14 virtually any preselected degree of thoroughness before
15 being discharged through conduit outlet 33 into the
16 reservoir vessel 37.

17 While in this example of the tagged fluent
18 material 5 is water that has been tagged with fine
19 particles of spinel ferrite and the untagged fluent
20 material 9 is a dry concrete mixture, it should be
21 noted that the invention is not confined to the use of
22 these particular tagging particles in fluent materials.
23 For example, the tagging particles may be formed from a
24 piezo-electric material such as quartz, or a material
25 which measurably changes the acoustic impedance of the
26 surrounding fluent material (which again may be fine
27 particles of quartz). If piezo-electric or acoustical-
28 impedance type tagging particles are used, then the
29 tagged particle detector 45 should radiate either a
30 fluctuating electric field or ultrasound through the
31 inspection and drain conduit 30. Alternatively, the
32 tagging particles may be formed from a substance that
33 effects the optical properties of the fluent materials
34 with which it is admixed, such as particles of vanadium
35 dioxide, potassium di-hydrogen phosphate, and lithium
36 niobate. In such an instance, the tagged particle
37 detector 45 should generate a form of light (which may
38

1 be either visible or invisible) which easily penetrates
2 the fluent materials forming the admixture and the
3 material forming the walls of the inspection and drain
4 conduit 30, but which is absorbed by (or otherwise
5 measurably interacts with) the particulate tagging
6 substance. Other examples of admixtures of fluent
7 materials which can be effectively monitored by the
8 system 1 of the invention include the admixing of
9 monomers with curing agents to create polymer plastics,
10 the admixture of glue with particulate wood to form
11 particle board, the admixture of polymerizable resin with
12 fillers of silica and alumina to form Polysil® concrete,
13 and the admixture of organic binding agents with fine
14 particles of active metals and oxidizers to form shaped
15 charges used in explosives and rocket propellants that
16 burn at controlled rates.

17 Figure 2 illustrates how the structural
18 integrity of a finished product 60 formed from the
19 hardened admixture created in the mixing vessel 20 might
20 be inspected by a "pancake" type eddy current probe
21 assembly 62. Such probe assemblies 62 include an annular
22 coil (not shown) which radiates a fluctuating magnetic
23 field 64 capable of penetrating deeply into a non-
24 metallic solid structure. For example, such a finished
25 product 60 may be inspected by a means of a model SPO
26 air-core "pancake" eddy current probe that is connected
27 to a model NDT No. 25 L programmable test instrument,
28 both of which are manufactured by Nortec located in
29 Kennewick, Washington. The scanning may be performed by
30 means of a model STC 460 X-Y scanner manufactured by the
31 Daedal Corporation located in Harrison City,
32 Pennsylvania, and the results may be interpreted by means
33 of a model LSI 11/23 computer manufactured by the Digital
34 Equipment Corporation located in Maynard, Massachusetts,

1 and displayed on a model 4695 plotter manufacturer by the
2 Tektronix Corporation located in Beaverton, Oregon. Such

1 commercially available instrumentation would be easily
2 capable of detecting any voids or "bubbles" 66 present
3 within the walls of the finished product 60 that might
4 seriously jeopardize its ability to perform its intended
5 function (i.e., such as the bearing of a specified load
6 in the case of concrete formed into the structural
7 component of a building). Such an inspection may also be
8 used to detect the presence of other discontinuities,
9 such as cracks 68. Fortunately, in the case where the
10 spinel ferrite particles present in lignosulfonate are
11 used as the tagging particles, the extremely small size
12 of these particles allows an extremely large number of
13 such particles to be distributed throughout the solid
14 matrix resulting from the hardening of the fluent
15 materials containing such ferrite tagging particles, even
16 when particles form only a small weight percent (such as
17 one percent) of the admixture. The large number of
18 particles present in even a very small weight percent in
19 turn allows a very fine resolution picture of the
20 internal structure of the finished product 60 to be made
21 by means of the aforementioned commercially-available
22 eddy current probes and related scanning equipment. A
23 further advantage of the extremely small particle size of
24 the spinel ferrite contained within lignosulfonate is
25 that it forms a colloidal suspension in even relatively
26 non-viscous liquids, such as water, and hence will not
27 tend to either settle to the bottom of the admixture, or
28 buoyantly float to the top of it.

29 Figure 3 illustrates a modified system 70 of
30 the invention which is exactly the same in all respects
31 as the previously discussed system 1 of the invention,
32 with the exception that a second type of particulate
33 tagging substance (schematically illustrated by small
34 crosses) is distributed throughout the second fluent
35 material 72. In this embodiment 70 of the system of the

1 invention, radiant energy is transmittable through both
2 the first and second fluent materials, and the
3 particulate tagging material

1 uniformly distributed through the second fluent
2 material 72 is a spinel ferrite having measurably
3 different absorption characteristics with respect to
4 the fluctuating electromagnetic field emanated by the
5 sensing coil 47 of the tagged particle detector 45. In
6 operation, the multi-frequency generator 49 of the
7 tagged particle detector 45 would alternately generate
8 alternating currents having different frequencies so
9 that the frequency of the alternating magnetic field
10 generated by the sensing coil 47 would periodically
11 change from a higher frequency to a lower one and then
12 back to the higher frequency. By rapidly multiplexing
13 the frequency of the alternating current it generates,
14 the multifrequency generator 49 of the tagged particle
15 detector 45 could be made to "see" two separate images
16 of the fluent material flowing through the inspection
17 and drain conduit 30, as is schematically illustrated
18 on the CRT readout screen 51. Such alternate sensing
19 of the different tagging particles used in the first
20 and second fluent materials 5,72 allows the
21 microprocessor control circuit 55 of this embodiment 70
22 of the system to unambiguously interpret a space in the
23 admixture which is entirely devoid of either type of
24 tagging particle as a bubble or air space in the
25 admixture flow. By contrast, in the first described
26 system 1, such a space might indicate an area of
27 incomplete mixing that is entirely filled up by the
28 untagged fluent material 9. This embodiment 70 of the
29 system advantageously allows the microprocessor control
30 circuit 55 to correctly interpret areas in the
31 admixture wherein only one of the two types of tagging
32 particles is present as being an area wherein
33 insufficient mixing has taken place. In such
34 instances, the microprocessor control circuit 55 may
35 take corrective action by either increasing the speed
36 of the electric motor 24 of the mixer 22, or by
37 increasing the time of the mixing operation within the
38

1 mixing vessel 20 by keeping the motor operated
2 discharge valve 32 closed for longer lengths of time
3 between discharges. Hence, the use of separately
4 detectable types of tagging particles in the two fluent
5 materials forming the admixture within the mixing
6 vessel 20 creates new information which may be
7 advantageously used for tighter and more comprehensive
8 quality control.

9 Figure 4 illustrates how the presence of two
10 different types of tagging particles in the finished
11 product 74 created by the alternate embodiment of the
12 system 70 may be used to effect an even more detailed
13 inspection of such products. In this particular
14 example, the finished product 74 is a coating of
15 polyurethane 77 which is applied over the hull 78 of a
16 naval vessel to muffle the reflection of enemy sonar.
17 When this coating 77 is inspected by means of the
18 previously-described eddy current probe assembly 62
19 (which in this case is operated by multiplexing
20 different frequency alternating currents through the
21 annular coil disposed in the probe head), the probe
22 assembly 62 is capable of resolving the difference
23 between a bubble 66 in which neither of the tagged
24 particles is present, and an area 82 of incomplete
25 admixing wherein only one type of tagged particle is
26 predominantly present. Additionally, in this
27 particular finished product 74, the probe assembly 62
28 is capable of detecting an area 83 of disbonding
29 between the ship hull 78 and the sonar adsorbing
30 plastic coating 77, as such an area 83 will, like the
31 bubble 66, be characterized by the total absence of
32 either type of tagged particle. The ability to
33 unambiguously detect such unbonded areas 83, and to
34 distinguish them from unmixed areas 83 is of particular
35 importance with respect to sonar absorbing coatings 77,
36 as a disbonded area 83 substantially impairs the
37 ability of such coating to perform its intended
38

1 function, while a small local area 82 of insufficient
2 admixing of the components forming the polyurethane would
3 not significantly effect such sonar absorbing
4 characteristics.

5 Figure 5 is a graph illustrating how the
6 response of the eddy current probe used in both the
7 tagged particle detector 45 and in the probe assembly 62
8 illustrated in Figures 1 through 4 changes with respect
9 to the content of the ferrite particles present in the
10 admixture. As is evident from this graph, the eddy
11 current response is essentially a linear function of the
12 weight percent of ferrite content within the admixture.
13 Specifically, Figure 5 shows a favourable eddy current
14 response is obtained over a range of 0.5 to 10.0 weight
15 percent of ferrite content within the admixture, and a
16 most favourable response is obtained in the range of 0.5
17 to 3.0 weight percent of ferrite content within the
18 admixture. Moreover, the eddy current response remains
19 substantially unchanged over a fairly broad spectrum of
20 alternating current frequencies ranging from 100 hertz,
21 to 1 kilohertz.

22 Figure 6 illustrates how the eddy current
23 response increases with the weight percent of ferrite in
24 various fluent materials, including water, cement,
25 plaster and a polymer adhesive (represented by circles,
26 square, triangles and hexagons, respectively).
27 Essentially, this graph indicates that the eddy current
28 response increases linearly with the weight percent of
29 ferrite in almost exactly the same manner for each of
30 these four different types of fluent materials. While
31 the data represented by the graphs of Figures 5 and 6 are
32 by no means a complete picture, they do suggest that the
33 eddy current response of a tagged admixture may be easily
34 and simply predicted for a broad range of materials on
35 the basis of the weight percent of the amount of spinel

1 ferrite particles distributed throughout the admixture,
2 and that the eddy current response will remain
3 substantially unchanged over a broad range of detection
4 frequencies.

5 The method of the invention may be understood
6 in the context of the operation of either of the systems
7 1,70 of the invention. In the first step of the method

1 of the invention, a selected quantity of a particulate
2 tagging substance (such as the fine spinel ferrite
3 particles present in ferromagnetic iron lignosulfonate)
4 is dispersed throughout one of the fluent materials 5
5 of the admixture. The two fluent materials 5,9 are
6 then admitted out of the outlets 11,13 of their
7 respective hoppers 3,7 into the mixing vessel 20, and
8 mixed by means of the mixer 22. After the mixer 22 has
9 been operated for a long enough time to thoroughly
10 admix the two fluent materials, the motor operated
11 discharge valve 32 which is mounted over the outlet 28
12 of the mixing vessel 20 is opened to start a flow of
13 the completed admixture to be conducted through the
14 inspection and drain conduit 30.

15 At this juncture, the tagged particle detector 45
16 is actuated in order to determine both the
17 concentration and the distribution of the tagged
18 particles within the admixture. In both embodiments of
19 the system 1,70, the tagged particle detector 45
20 includes a sensing coil 47 and a multi-frequency
21 generator 49 for generating a high frequency
22 alternating electromagnetic field which penetrates
23 completely through the admixture flowing through the
24 inspection and drain conduit 30. At this juncture in
25 the method of the invention, the tagged particle
26 detector 45 continuously generates electric signals
27 indicative of both the concentration and distribution
28 of the tagged particles, and transmits these signals to
29 the microprocessor control circuit 55 via cables 53a,b.
30 From this information, the microprocessor control
31 circuit 55 infers both the ratio of each of the fluent
32 material within the admixture flowing through the
33 conduit 30, as well as the thoroughness of the mixing
34 operation. The microprocessor control circuit
35 continuously compares these readings with a preselected
36 range of desired ratios, and a desired mixing level.
37 Whenever the measured ratios and mixing level varies
38

1 from these preselected ranges and values, the
2 microprocessor control circuit 55 shunts the flow of
3 admixture from the conduit outlet 33 to the recycle
4 conduit 35 by changing the position of the diverter
5 valve 34, adjusts the motor operated valves 15,17 of
6 the fluent material hoppers 5,9, and/or adjusts the
7 speed of the motor 24 of the electric mixer 22 and the
8 position of the mixing vessel discharge valve 32 to
9 bring these values back into conformance with the
10 desired values. In the final step of the method of the
11 invention, the structural integrity of the finished
12 product 60,74 produced by the systems 1,70 may be
13 inspected in the aforementioned manner by means of an
14 eddy current probe assembly 62.

EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A method for monitoring the admixing of first and second fluent materials that ultimately harden into a solid structure, comprising the steps of:
selecting a detectable particulate tagging substance including particles or ferromagnetic material;
uniformly dispersing a selected quantity of the particulate tagging substance into said first fluent material whose presence is detectable by a fluctuating electromagnetic field transmittable through said first fluent material;
mixing said first and second fluent materials to form a mixture, and
monitoring the distribution of said detectable particulate tagging substance throughout said mixture by transmitting said fluctuating electromagnetic field through said mixture to determine the extent to which said materials are uniformly mixed together.
2. A method as defined in claim 1, further including the step of remixing said mixture if said fluent materials are not admixed to a desired extent.
3. A method as defined in claim 1, further comprising the steps of allowing said mixture to harden into a solid structure, and then inspecting the integrity of said structure by transmitting said fluctuating electromagnetic field through said structure to detect the presence of voids, cracks and discontinuities.
4. A method as defined in claim 1, wherein said detectable particulate substance includes particles of a piezo-electric material.

5. A method for monitoring the admixing of first and second fluent materials that ultimately harden into a solid structure, comprising the steps of:

selecting a detectable particulate tagging substance including particles of a material that effect the optical properties of said first fluent material;

uniformly dispersing a selected quantity of the particulate tagging substance into said first fluent material whose presence is detected by light transmittable through the first fluent material;

mixing the first and second fluent materials to form a mixture, and

monitoring the distribution of said detectable particulate tagging substance throughout said mixture by shining said light through said mixture to determine the extent to which said materials are uniformly mixed together.

6. A method as defined in claim 5, wherein said detectable particulate tagging substance comprises particles of at least one of the group consisting of vanadium dioxide, potassium di-hydrogen phosphate, and lithium niobate.

7. A method as defined in any of claims 1 to 6, further including the step of uniformly dispersing a selected quantity of a second particulate tagging substance whose presence is detectable by radiant energy transmitted through said second fluent material.

8. A method as defined in any one of claims 1 to 6, further comprising the steps of applying the resulting mixture over a surface in order to bond the resulting solid structure to said surface, and then inspecting the interface between the solid structure and the surface by transmitting said radiant energy through said interface to detect the presence of any disbanding.

9. A method as defined in claim 8, wherein said first fluent material is unpolymerized urethane, said second fluent material is a curing agent that cures said fluent urethane into solid polyurethane, and said surface is the exterior surface of the hull of a water vessel.

10. A method as defined in claim 1, wherein the first fluent material is water, and said second fluent material is a particulate concrete mix, and wherein the monitoring of the distribution of said detectable particulate tagging substance throughout said mixture is used both to determine the ratio of water to said particulate concrete mix, and to determine the thoroughness of the mixing of said water and concrete mix prior to the hardening of said mixture.

11. A method as defined in claim 10, wherein the distribution of said particulate tagging substance is continuously monitored in said mixture of water and particulate concrete to continuously measure the extent to which the water and concrete mix were admixed and the ratio of the water to the concrete mix.

12. A method as defined in claim 11, wherein said particulate ferromagnetic particles constitute between about 0.5 and 10 weight percent of said water.

13. A method as defined in claim 11, wherein said particulate ferromagnetic particles constitute between about 0.5 and 3 weight percent of said water.

14. A method as defined in any one of claims 1 to 6, wherein said first fluent material is a polymerizable resin, and said second fluent material is a particulate ceramic filler material.

15. A method as defined in claim 14, wherein said ceramic filler material comprises at least one of the group consisting of silica and alumina.

16. A method as defined in any one of claims 1 to 6, wherein said first fluent material is glue, and said second fluent material is particulate wood, and said solid structure is particle board.

17. A method as defined in claim 16, further including the steps of allowing said mixture of glue and particulate wood to harden into particle board, and further including the step of inspecting the integrity of said particle board by transmitting said radiant energy through said board to detect the presence of voids, cracks and discontinuities.

18. A method as defined in any one of claims 1 to 6, wherein said first fluent material is an organic binder, and said second fluent material is a mixture of reactive metal particles and oxidizer particles, and said structure is a solid ordinance propellant, and further including the step of inspecting the integrity of said solid ordinance propellant by said transmission of radiant energy through said propellant to detect the presence of voids, cracks and discontinuities.

19. A method for monitoring the admixing of first and second fluent materials that ultimately harden into a solid structure, comprising the steps of:

uniformly dispersing a selected quantity of a particulate tagging substance into said first fluent material whose presence and concentration is detectable by radiant energy transmittable through said first fluent material,

mixing said first and second fluent materials in a mixing vessel to form a mixture;

discharging said mixture from said mixing vessel;

monitoring the distribution of said detectable particulate tagging substance throughout said mixture by transmitting said radiant energy through said mixture to determine both the ratio of said first and second fluent materials in said admixture, as well as the progress of the mixing step; and

returning the mixture to the mixing vessel if said measured ratio of materials or said progress of admixing does not conform to preselected values.

20. A method for monitoring as defined in claim 19, further including the step of uniformly dispersing a selected quantity of a second particulate tagging substance through said second fluent material whose presence and concentration is detectable by radiant energy transmittable through said second fluent material and whose detectable characteristics are different from the detectable characteristics of the first particulate tagging substance.

21. A method for monitoring as defined in claim 20, further including the step of simultaneously monitoring the distribution of both said first and second particulate tagging substances in both said first and second fluent materials of said mixture to detect the presence of any void spaces in the mixture, and to further more positively determine the ratio of said first and second fluent materials in said mixture, as well as

the thoroughness to which said materials are uniformly mixed together.

22. A method for monitoring as defined in claim 19, 20 or 21, wherein said simultaneous monitoring is continuous.

23. A system for monitoring the admixing of first and second fluent materials that ultimately harden into a solid structure after mixing, wherein a selected quantity of a particulate tagging substance has been uniformly dispersed throughout said first fluent material whose presence and concentration is detectable by radiant energy transmittable through said fluent materials, comprising

a means for mixing together the fluent materials including a mixing vessel for receiving said fluent materials, and a mixing device for mixing said fluent materials together in said vessel,

a conduit for conducting a flow of said mixture,

a tagged particle detector for measuring the distribution of said particulate tagging substance by transmitting said radiant energy through said mixture flowing through said conduit in order to determine the extent to which said fluent materials are uniformly mixed together, and for measuring the concentration of the fluent materials in the mixture so that the ratio of the fluent materials in the mixture may be computed.

24. A system as defined in claim 23, wherein said mixing vessel has an outlet for discharging said fluent materials after said mixing device has mixed them together, and wherein said outlet communicates with said

conduit, and further comprising a conduit means for selectively returning the mixture of fluent materials back to the mixing vessel.

25. A system as defined in claim 24, further comprising first and second reservoirs for supplying separate flows of said first and second fluent materials into the mixing vessel, respectively, wherein each reservoir has an outlet, and valve means for modulating a flow of fluent material through said outlet.

26. A system as defined in claim 25, wherein said tagged particle detector generates a signal indicative of the extent to which said fluent materials are admixed together, and further comprising a control circuit electrically connected to the mixing device for receiving said signal and for generating a control signal for controlling the operation of the mixing device.

27. A system as defined in claim 26, wherein said tagged particle detector generates a signal indicative of the ratio of the fluent materials in the admixture, and further comprising a control circuit operatively connected to said valve means of each of said fluent material reservoirs for receiving said signal and for controlling the modulation of said flow of fluent material to maintain the ratio of said fluent materials within a selected range.

28. A system for monitoring the admixing of first and second fluent materials that ultimately harden into a solid structure after mixing, wherein a selected quantity of a particulate tagging substance has been uniformly dispersed throughout said first fluent material whose presence and concentration is detectable by radiant

energy transmittable through said fluent materials, comprising

means for mixing together the fluent materials including a mixing vessel for receiving said fluent materials and an electrically operated mixing device for mixing said materials together, wherein said mixing vessel includes an outlet;

first and second reservoirs for supplying separate flows of said first and second fluent materials into said mixing vessel, wherein each reservoir has a reservoir outlet, and an electronically operated valve means for modulating a flow of fluent material through said reservoir outlet and into said mixing vessel;

a drain conduit connected to the outlet of said mixing vessel for conducting a flow of the resulting mixture of said first and second fluent materials out of said mixing vessel;

a tagged particle detector for transmitting said radiant energy through said flow out of said vessel and through said conduit and generating an electrical signal indicative of the extent to which said fluent materials are mixed and the ratio of said materials;

a recycling conduit selectively connectable to the outlet conduit by an electrically operated valve means for returning the mixture to the mixing vessel if the ratio of fluent materials or extent of admixing measured by the tagged particle detector is outside of preselected limits, and

a control circuit electronically connected to said tagged particle detector and to said mixing device and said valve means of said reservoirs and said drain conduit for receiving said detector signals and for generating electrical control signals for controlling the operation of said mixing device and the modulation of said valve means to control the extent to which said

fluent materials are admixed and the ratio of said materials in said mixture.

29. A system as defined in claim 28, wherein said control circuit includes a microprocessor.

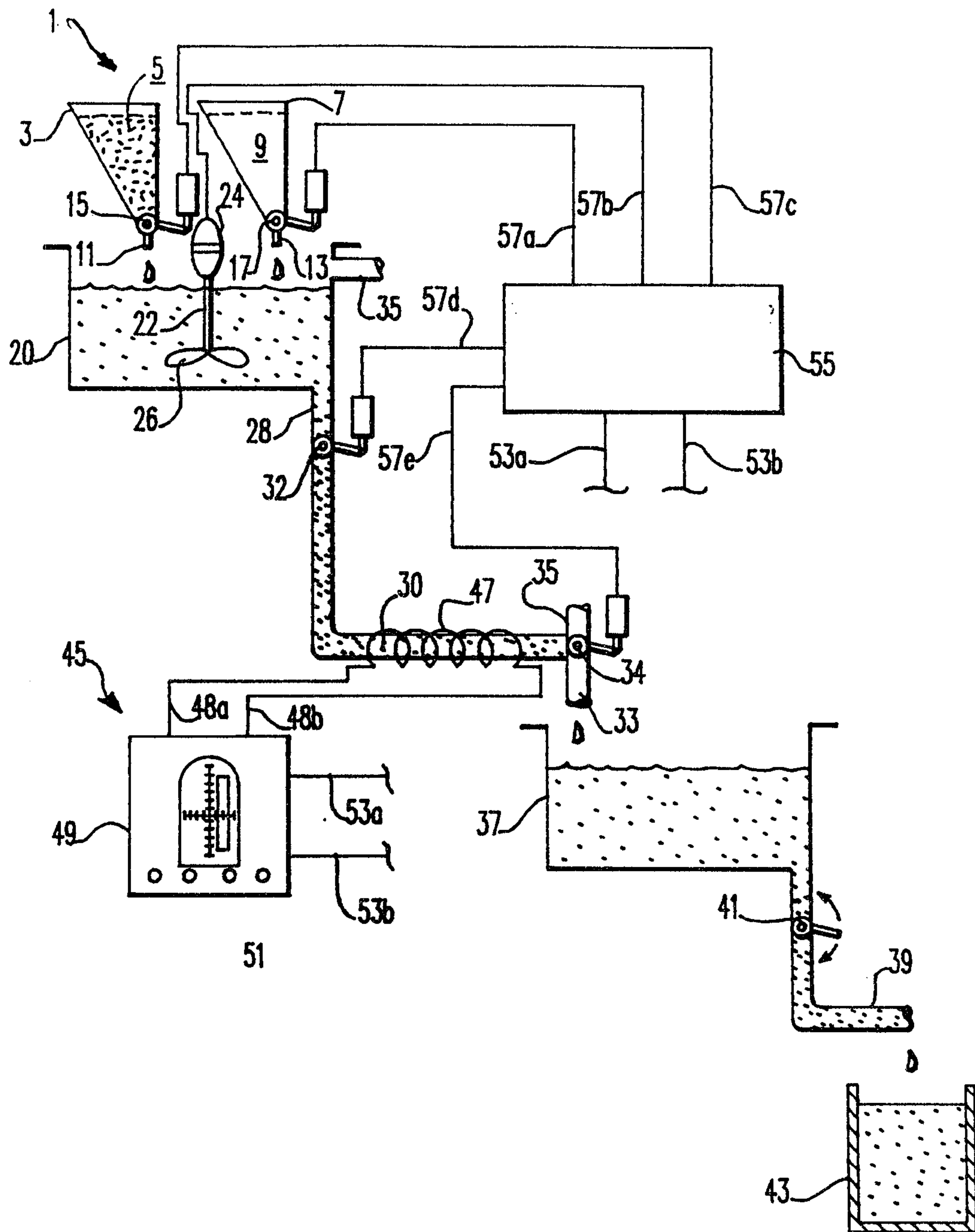


FIG. 1

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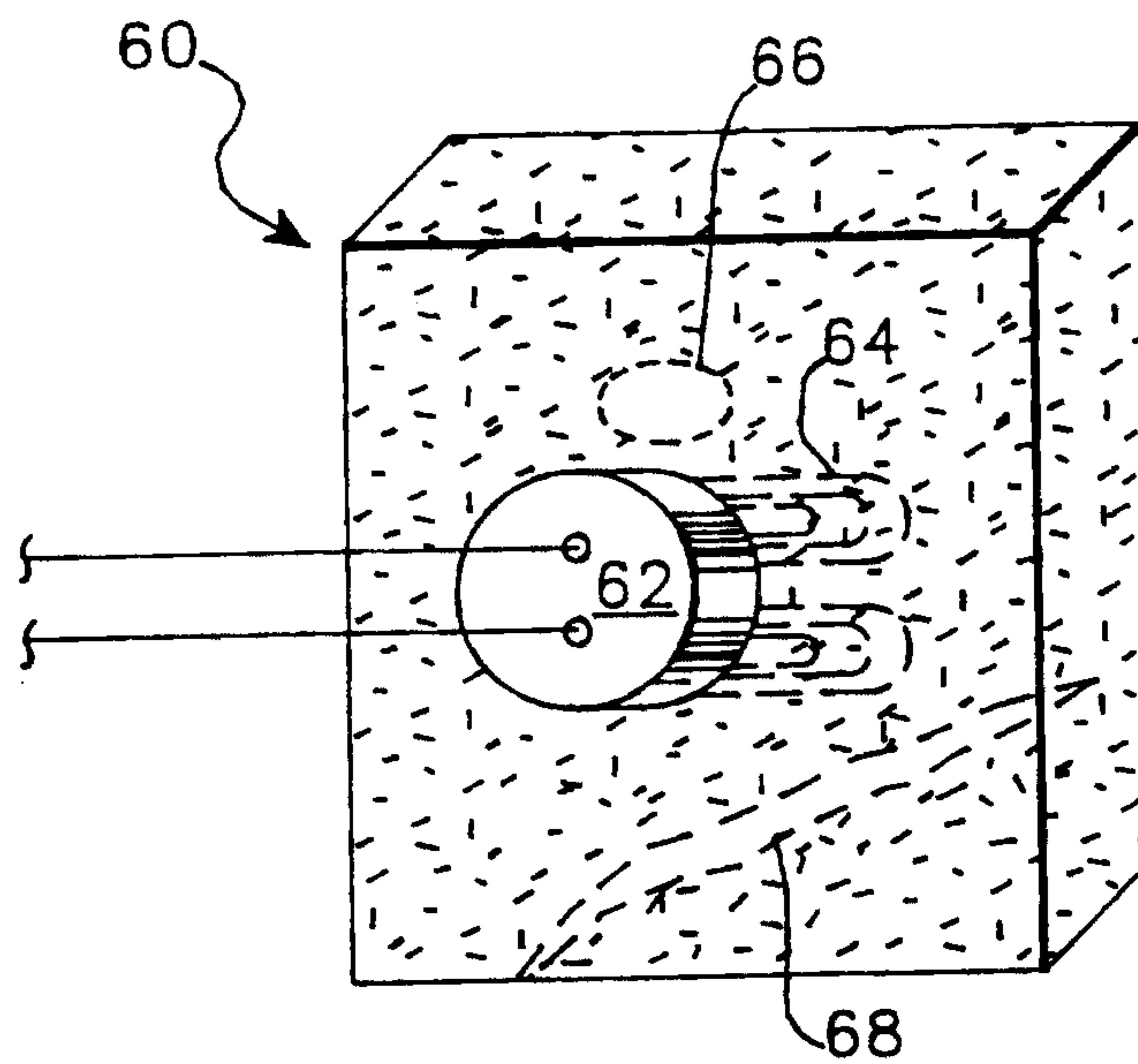


FIG. 2

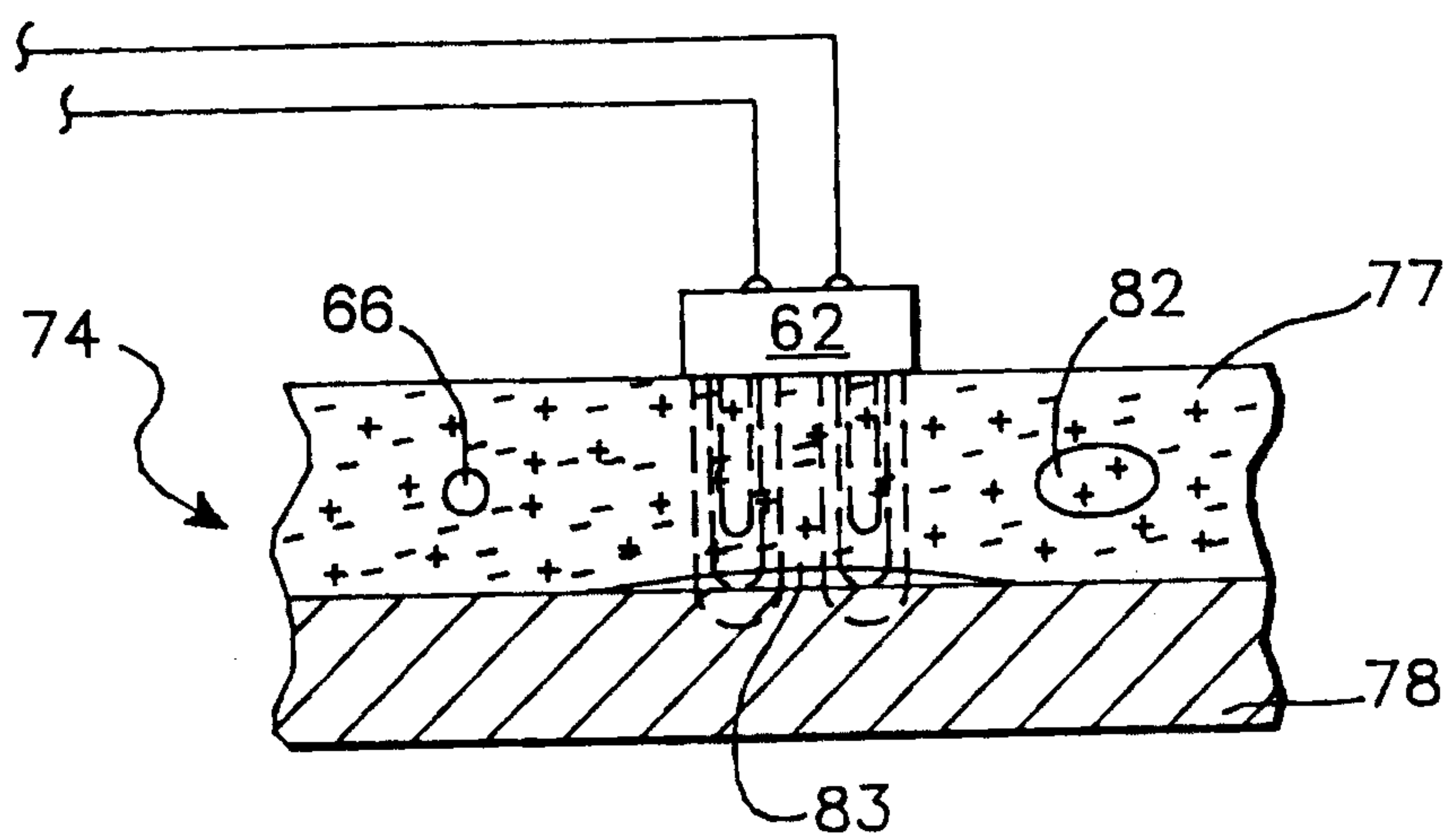
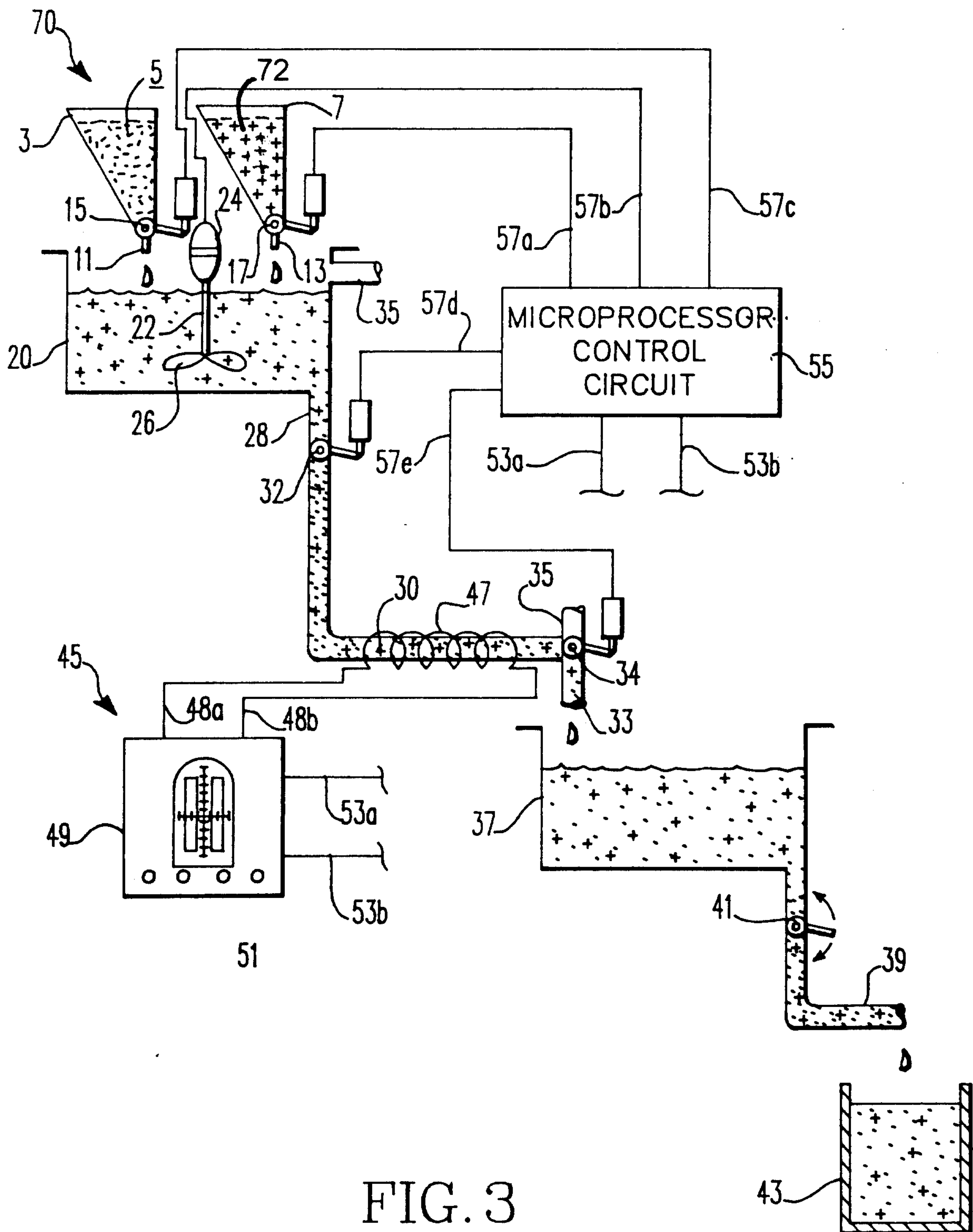


FIG. 4



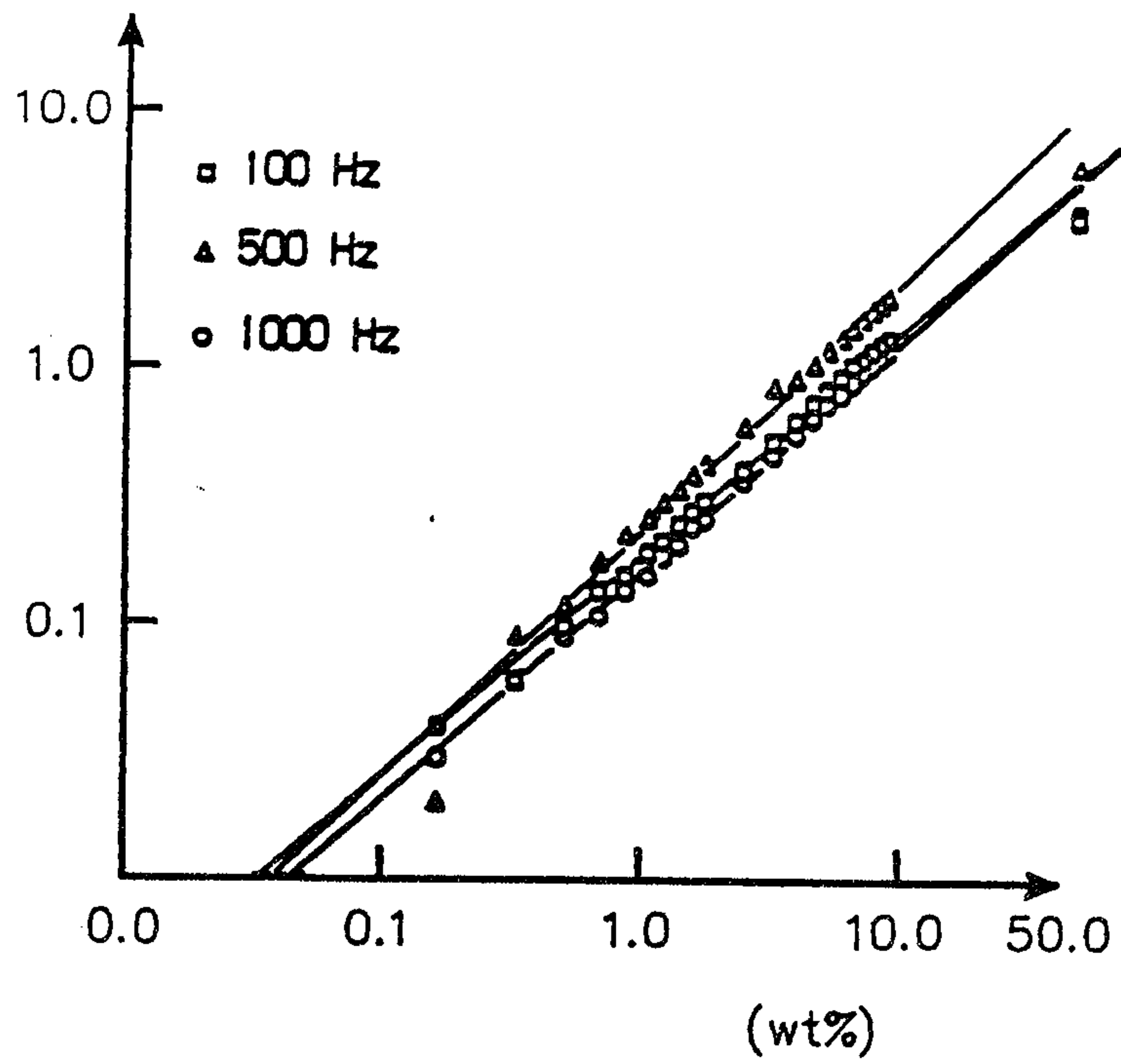


FIG. 5

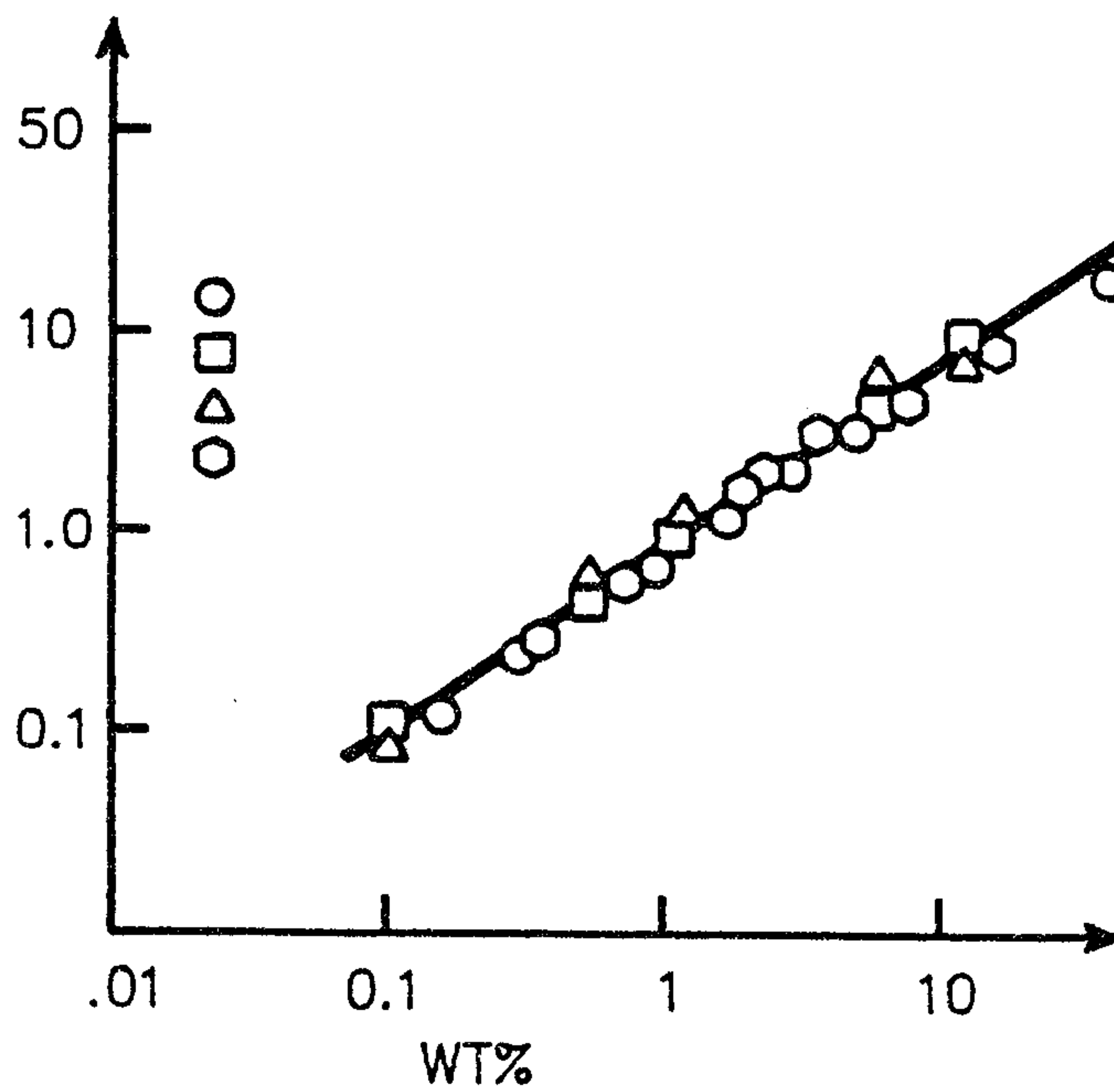


FIG. 6

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