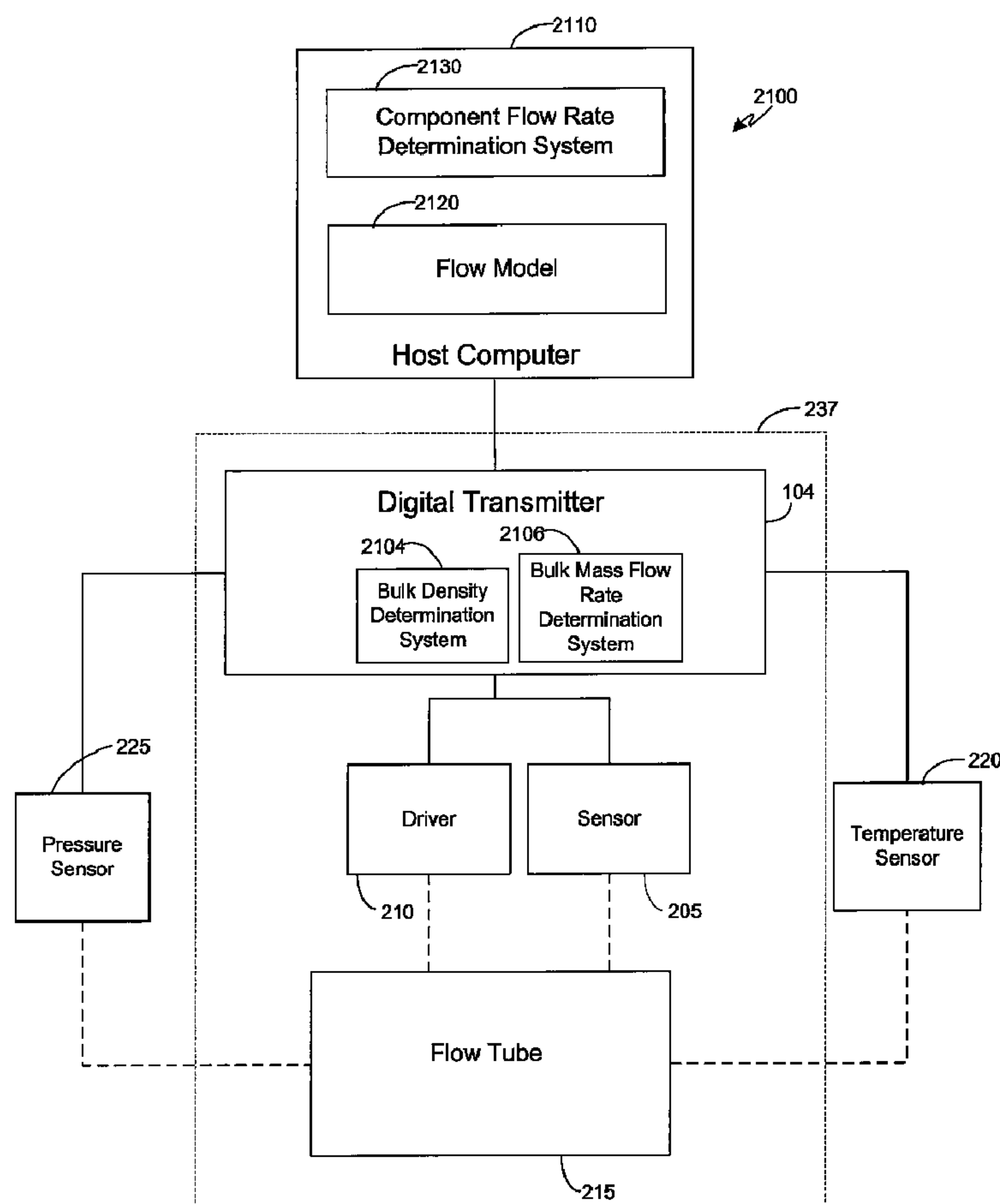




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(54) Title: MULTI-PHASE CORIOLIS FLOWMETER



(57) Abrégé/Abstract:

A Coriolis flowmeter determines a property of a multi-phase fluid. A flow model determines another property of the fluid. A determination system determines a third property of the fluid based, on the first two properties. A flow rate of a component of the



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

multi-phase fluid based on the bulk density, the bulk mass flow rate, and the pressure may include determining a water-cut or gas void fraction of the multi-phase fluid based, on the pressure; and determining a flow rate of a component of the fluid based on the bulk density, the bulk mass flow rate, and the water-cut or gas void fraction. Determining the water-cut or gas void fraction of the fluid based on pressure may include using a flow model to determine the water-cut or gas void fraction based on pressure.

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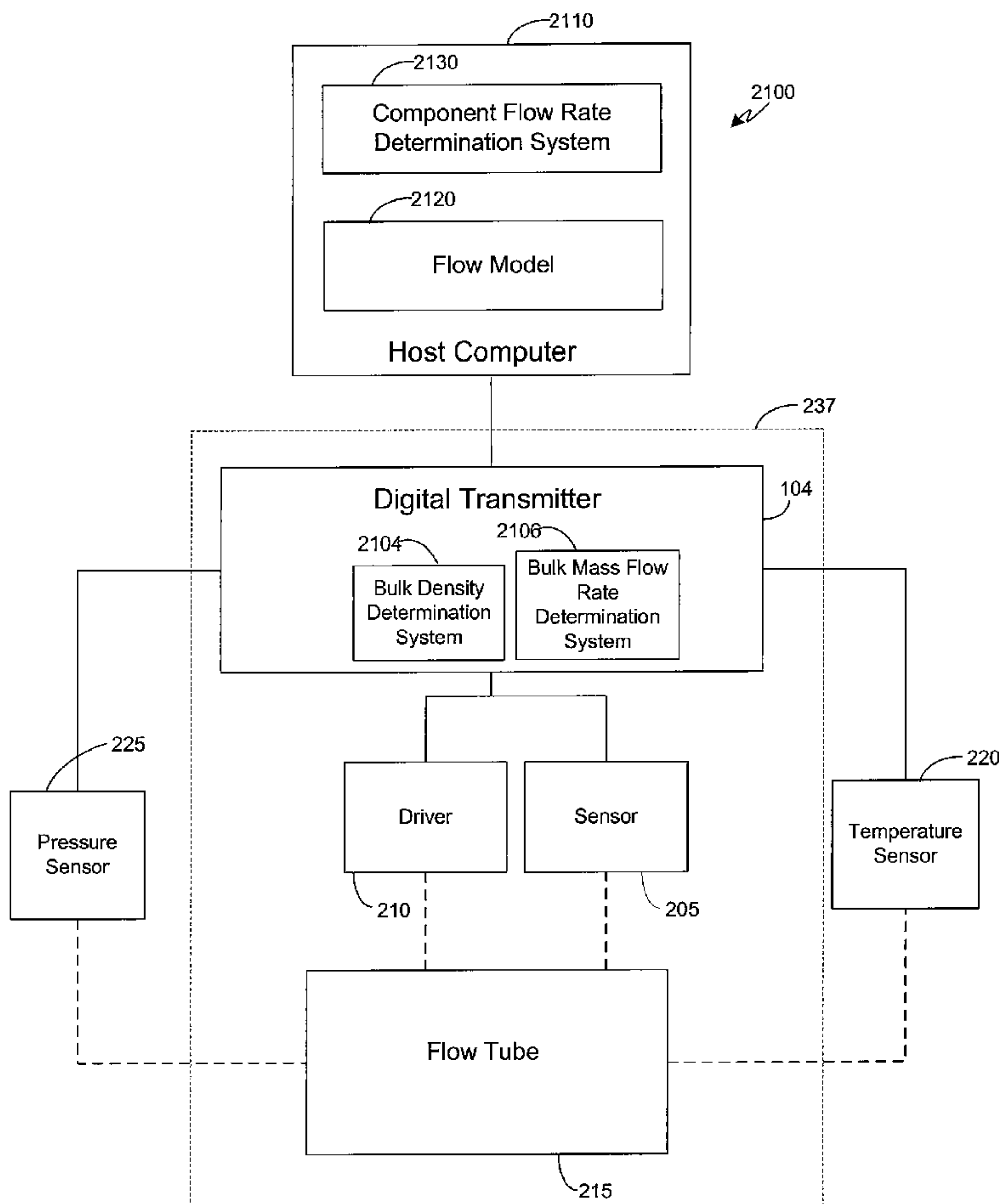
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(54) Title: MULTI-PHASE CORIOLIS FLOWMETER



(57) Abstract: A Coriolis flowmeter determines a property of a multi-phase fluid. A flow model determines another property of the fluid. A determination system determines a third property of the fluid based, on the first two properties. A flow rate of a component of the multi-phase fluid based on the bulk density, the bulk mass flow rate, and the pressure may include determining a water-cut or gas void fraction of the multi-phase fluid based, on the pressure; and determining a flow rate of a component of the fluid based on the bulk density, the bulk mass flow rate, and the water-cut or gas void fraction. Determining the water-cut or gas void fraction of the fluid based on pressure may include using a flow model to determine the water-cut or gas void fraction based on pressure.

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MULTI-PHASE CORIOLIS FLOWMETER

CLAIM OF PRIORITY

This application claims priority under 35 USC §119(e) to U.S. Patent Application Serial No. 60/820,032, filed on July 21, 2006, the entire contents of which are hereby
5 incorporated by reference.

TECHNICAL FIELD

This description relates to flowmeters.

BACKGROUND

Flowmeters provide information about materials being transferred through a conduit,
10 or flowtube. For example, mass flowmeters provide an indication of the mass of material being transferred through a conduit. Mass flowmeters also may provide an indication of the density of the material.

For example, Coriolis-type mass flowmeters are based on the Coriolis effect, in which material flowing through a conduit is affected by a Coriolis force and therefore experiences
15 an acceleration. Many Coriolis-type mass flowmeters induce a Coriolis force by sinusoidally oscillating a conduit about a pivot axis orthogonal to the length of the conduit. In such mass flowmeters, the Coriolis reaction force experienced by the traveling fluid mass is transferred to the conduit itself and is manifested as a deflection or offset of the conduit in the direction of the Coriolis force vector in the plane of rotation.

20

SUMMARY

In one aspect, a Coriolis flowmeter is configured to determine a first property of a multi-phase fluid. A flow model is configured to determine a second property of the multi-phase fluid. A determination system is configured to determine a third property of the multi-phase fluid based, at least in part, on the first property and the second property.

25

Implementations may include one or more of the following features. For example, a sensor may be configured to sense a fourth property associated with the multi-phase fluid, and the flow model may be configured to determine the second property based on the fourth property. The fourth property may be a pressure or temperature associated with the multi-phase fluid.

The Coriolis flowmeter may be configured to determine a fourth property of the multi-phase fluid. The determination system may be configured to determine the third property of the multi-phase fluid based, at least in part, on the first property, the second property, and the fourth property. The first property may be a bulk density of the multi-phase fluid, the second property may be a water-cut or gas void fraction of the multi-phase fluid, and the fourth property may be a bulk mass flow rate of the multi-phase fluid. The third property may be a mass flow rate or a volumetric flow rate of a component of the multi-phase fluid.

In another aspect, a bulk density determination system determines a bulk density of a multi-phase fluid. A mass flow rate determination system determines a bulk mass flow rate of the multi-phase fluid. A pressure sensor is configured to determine a pressure associated with the multi-phase fluid. A flow model is configured to determine water-cut or gas void fraction of the multi-phase fluid based, at least in part, on the sensed pressure. A flow rate determination system determines a flow rate of at least one component of the multi-phase fluid based on the bulk density, the bulk mass flow rate, and the water-cut or gas void fraction.

In another aspect, a first property of a multi-phase fluid is determined using a Coriolis flowmeter. A second property of the multi-phase fluid is determined using a mathematical model of a flow of the multi-phase fluid through a conduit. A third property of the multi-phase fluid based is determined, at least in part, on the first property and the second property.

Implementations may include one or more of the following features. A fourth property associated with the multi-phase fluid may be determined and the second property may be determined by inputting the fourth property into the mathematical model. The fourth property may be a pressure or temperature associated with the multi-phase fluid.

A fourth property of the multi-phase fluid may be determined and the third property of the multi-phase fluid may be determined based, at least in part, on the first property, the second property, and the fourth property. The first property may be a bulk density of the multi-phase fluid, the second property may be a water-cut or gas void fraction of the multi-phase fluid, and the fourth property may be a bulk mass flow rate of the multi-phase fluid. The third property may be a mass flow rate or a volumetric flow rate of a component of the multi-phase fluid.

In another aspect, a bulk density of a multi-phase fluid is determined. A bulk mass flow rate of the multi-phase fluid is determined. A pressure associated with the multi-phase

fluid is determined. A flow rate of at least one component of the multi-phase fluid based on the bulk density, the bulk mass flow rate, and the pressure.

Implementations may include one or more of the following features. For example, determining a flow rate of at least one component of the multi-phase fluid based on the bulk density, the bulk mass flow rate, and the pressure may include determining a water-cut or gas void fraction of the multi-phase fluid based, at least in part, on the pressure; and determining a flow rate of at least one component of the multi-phase fluid based on the bulk density, the bulk mass flow rate, and the water-cut or gas void fraction. Determining the water-cut or gas void fraction of the multi-phase fluid based, at least in part, on the pressure may include using a flow model to determine the water-cut or gas void fraction based on the pressure.

In another aspect, a bulk density of a multi-phase fluid is determined using a Coriolis flowmeter that includes a flowtube. A bulk mass flow rate of the multi-phase fluid is determined using the Coriolis flowmeter. An inlet and outlet pressure of the multi-phase fluid is determined at an inlet and outlet, respectively, of the flowtube. An inlet and outlet temperature of the multi-phase fluid is determined at the inlet and outlet, respectively, of the flowtube. A water-cut or gas void fraction of the multi-phase fluid is determined based on the bulk density, the bulk mass flow rate, the inlet pressure, the outlet pressure, and the inlet temperature. A flow rate of at least one component of the multi-phase fluid is determined based on the bulk density, the bulk mass flow rate, and the water-cut or gas void fraction.

Implementations may include one or more of the following features. For example, determining the water-cut or gas void fraction of the multi-phase fluid may include using a mathematical model of a flow of the multi-phase fluid through the flowtube to determine the water-cut or gas void fraction of the multi-phase fluid based on the bulk density, the bulk mass flow rate, the inlet pressure, the outlet pressure, and the inlet temperature.

25

DESCRIPTION OF DRAWINGS

FIG. 1A is an illustration of a Coriolis flowmeter using a bent flowtube.

FIG. 1B is an illustration of a Coriolis flowmeter using a straight flowtube.

FIG. 2 is a block diagram of a flowmeter system.

FIG. 3A illustrates a interpolated water-cut vs. outlet pressure curve.

30

FIG. 3B shows the curve of FIG. 3A with indications of the data points calculated by a flow model and an indication of the point on the interpolated curve where the actual outlet pressure is located.

FIG. 4 shows a flowchart illustrating one implementation of a process for determining properties of individual components of a three-phase fluid flow.

FIG. 5 illustrates a sample nodal plot 500 illustrating a coriolis meter's pressure sensitivity to water-cut.

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DETAILED DESCRIPTION

Types of flowmeters include digital flowmeters. For example, U.S. Patent 6,311,136, which is hereby incorporated by reference, discloses the use of a digital flowmeter and related technology including signal processing and measurement techniques. Such digital flowmeters may be very precise in their measurements, with little or negligible noise, and may be capable of enabling a wide range of positive and negative gains at the driver circuitry for driving the conduit. Such digital flowmeters are thus advantageous in a variety of settings. For example, commonly-assigned U.S. Patent 6,505,519, which is incorporated by reference, discloses the use of a wide gain range, and/or the use of negative gain, to prevent stalling and to more accurately exercise control of the flowtube, even during difficult conditions such as two-phase flow (e.g., a flow containing a mixture of liquid and gas) or three-phase flow (e.g., a gas and two different liquids).

Although digital flowmeters are specifically discussed below with respect to, for example, FIGS. 1 and 2, it should be understood that analog flowmeters also exist. Although such analog flowmeters may be prone to typical shortcomings of analog circuitry, e.g., low precision and high noise measurements relative to digital flowmeters, they also may be compatible with the various techniques and implementations discussed herein. Thus, in the following discussion, the term "flowmeter" or "meter" is used to refer to any type of device and/or system in which a Coriolis flowmeter system uses various control systems and related elements to measure a mass flow, density, and/or other parameters of a material(s) moving through a flowtube or other conduit.

FIG. 1A is an illustration of a digital flowmeter using a bent flowtube 102. Specifically, the bent flowtube 102 may be used to measure one or more physical characteristics of, for example, a (traveling) fluid, as referred to above. In FIG. 1A, a digital transmitter 104 exchanges sensor and drive signals with the bent flowtube 102, so as to both sense an oscillation of the bent flowtube 102, and to drive the oscillation of the bent flowtube 102 accordingly. By quickly and accurately determining the sensor and drive signals, the digital transmitter 104, as referred to above, provides for fast and accurate operation of the

bent flowtube 102. Examples of the digital transmitter 104 being used with a bent flowtube are provided in, for example, commonly-assigned U.S. Patent 6,311,136.

FIG. 1B is an illustration of a digital flowmeter using a straight flowtube 106. More specifically, in FIG. 1B, the straight flowtube 106 interacts with the digital transmitter 104.

5 Such a straight flowtube operates similarly to the bent flowtube 102 on a conceptual level, and has various advantages/disadvantages relative to the bent flowtube 102. For example, the straight flowtube 106 may be easier to (completely) fill and empty than the bent flowtube 102, simply due to the geometry of its construction. In operation, the bent flowtube 102 may operate at a frequency of, for example, 50-110 Hz, while the straight flowtube 106 may
10 operate at a frequency of, for example, 300-1,000Hz. The bent flowtube 102 represents flowtubes having a variety of diameters, and may be operated in multiple orientations, such as, for example, in a vertical or horizontal orientation.

FIG. 2 is a block diagram of a flowmeter system 2100. Flowmeter system 2100 may be used to measure properties of the individual components in mixed flows. For example, a
15 “three-phase” flow or “mixed two-phase flow” refers to a situation in which two types of liquid are mixed with a gas. For example, a flowing mixture of oil and water may contain air (or another gas), thus forming a “three-phase flow,” where the terminology refers to the three components of the flow, and does not generally imply that a solid material is included in the flow. In such a situation, it may be useful to determine properties (e.g., the mass or
20 volumetric flow rates) of the individual components of the fluid.

To determine the properties of the individual components in a three-phase flow, three independent properties of the bulk fluid may be needed. In general, a Coriolis flowmeter can provide accurate measurements of the bulk density and the bulk mass flow rate of a three-phase fluid. However, these two independent properties of the bulk fluid may not be enough
25 information to determine properties of the three individual components of the fluid. Thus, one implementation of the flowmeter system 2100 uses the pressure drop across the Coriolis flowmeter, and specifically the pressure drop across the flowtube 215, as an additional property of the bulk fluid to enable the determination of the properties of the three individual components.

30 In particular, the following description describes an implementation of flowmeter system 2100 that is used to determine individual component flow rates (mass and/or volumetric) within a three-phase flow. Specifically, the implementation described determines the flow rates of the individual components in an oil-water-gas three phase flow. However, other implementations may determine different properties of the individual components of the

fluid flow, and the individual components may include materials other than oil, water, and gas.

Furthermore, the implementation described uses the inlet pressure of the Coriolis flowtube 215, the outlet pressure of the Coriolis flowtube 215, and inlet temperature as inputs into a mathematical model of the fluid flow through the Coriolis flowtube 215 so that the mathematical model can determine the water-cut, which is then used to determine the flow rates of the individual components. Other implementations, however, may determine the water-cut using a mathematical flow model that relies on other inputs (and, hence, an independent property of the bulk flow other than the pressure drop across the Coriolis flowtube). Similarly, other implementations may use the mathematical model to determine a property other than water-cut (based on pressure or other types of inputs), which is then used to determine the desired property or properties of the individual components. For instance, the gas void fraction may be determined instead of, or in addition to, the water-cut.

In general, the flowmeter system 2100 uses properties of the fluid determined by a Coriolis meter plus a mathematical model of the fluid flow through the Coriolis flowtube. As described, a Coriolis flowmeter can generally provide accurate measurements of the bulk density and the bulk mass flow rate of a three-phase fluid. The mathematical model uses the pressure drop across the Coriolis flowtube to determine an additional property of the fluid, such as the water-cut (percentage of water in the oil-water mixture) or gas void fraction. This additional property is then used in conjunction with the properties determined by the Coriolis flowmeter to determine the flow rates of the individual components of the fluid.

In particular, the flowmeter system 2100 includes a digital mass flowmeter (e.g., Coriolis flowmeter) 237, a pressure sensor 225, a temperature sensor 220, and a host computer 2110. The digital mass flowmeter 237 includes the digital transmitter 104, one or more motion sensors 205, one or more drivers 210, and a flowtube 215 (which also may be referred to as a conduit, and which may represent either the bent flowtube 102, the straight flowtube 106, or some other type of flowtube).

The digital transmitter 104 may be implemented using one or more of, for example, a processor, a Digital Signal Processor (DSP), a field-programmable gate array (FPGA), an ASIC, other programmable logic or gate arrays, or programmable logic with a processor core. It should be understood that, as described in U.S. 6,311,136, associated digital-to-analog converters may be included for operation of the drivers 210, while analog-to-digital converters may be used to convert sensor signals from the sensors 205 for use by the digital transmitter 104.

The digital transmitter 104 includes a bulk density determination system 2104, and a bulk mass flow rate determination system 2106 to generate measurements of bulk density and bulk mass flow rate of a material flowing through the flowtube 215, based at least on signals received from the motion sensors 205. The digital transmitter 104 also controls the drivers 210 to induce motion in the flowtube 215. This motion is sensed by the motion sensors 205.

Density measurements of the material flowing through the flowtube are related to, for example, the frequency of the motion of the flowtube 215 that is induced in the flowtube 215 by a driving force supplied by the drivers 210, and/or to the temperature of the flowtube 215. Similarly, mass flow through the flowtube 215 is related to the phase and frequency of the motion of the flowtube 215, as well as to the temperature of the flowtube 215. Generally, under multi-phase flow conditions (e.g., three-phase flow), the bulk density refers to the density of the flowing material as a whole, as opposed to the density of the individual components making up the multi-phase material. Similarly, under such conditions, the bulk mass flow rate refers to the mass flow rate of the material as a whole, as opposed to the mass flow rates of the individual components.

In FIG. 2, it should be understood that the various components of the digital transmitter 104 are in communication with one another, although communication links are not explicitly illustrated, for the sake of clarity. Further, it should be understood that conventional components of the digital transmitter 104 are not illustrated in FIG. 2, but are assumed to exist within, or be accessible to, the digital transmitter 104. For example, the digital transmitter 104 will typically include the drive circuitry for generating and supplying a drive signal to the driver 210.

The temperature sensor 220 is in communication with the transmitter 104 and measures the temperature of the flowing material at the inlet of the flowtube 215. The pressure sensor 225 is in communication with the transmitter 104, and is connected to the flowtube 215 so as to be operable to sense a pressure of a material flowing through the flowtube 215 at the inlet and the outlet of flow tube 215 (either by measuring the pressure at both the inlet and outlet, or by measuring the pressure at one or the other in addition to the differential pressure). If the inlet and outlet pressures are explicitly measured, pressure sensor 225 may actually be composed of two sensors – one at the inlet, and one at the outlet.

The temperature and pressure may be used by transmitter 104, and specifically by bulk density determination system 2104 and bulk mass flow rate determination system 2106, to more accurately determine the bulk density and bulk mass flow rate. For instance, the temperature of the fluid in the flowtube 215 may affect certain properties of the flowtube,

such as its stiffness and dimensions. The digital transmitter 104 may compensate for these temperature effects.

A host computer 2110 is coupled to the digital transmitter 104 and may read the bulk density, the bulk mass flow rate, the inlet pressure, the outlet pressure and the inlet
5 temperature from the transmitter 104. Host computer 2110 executes a flow model 2120 and a component flow rate determination system 2130.

The flow model 2120 is a mathematical model of the flow of fluid through flowtube 215. Flow model 2120 may be implemented using a software system that provides for the modeling of fluid flow through a conduit or a series of conduits and connecting components.
10 Generally, such flow modeling software systems are commercially available. Examples of commercially available flow modeling software systems include Pipephase® from SIMSCI-ESSCOR, Pipesim from Schlumberger, and Flowmaster2 from Flowmaster, Ltd. Flow model 2120 may be developed for a given Coriolis flowtube geometry and expected fluid composition.

For instance, flow model 2120 may include a pipe network that represents the Coriolis
15 flowtube 215 and that models the fluid as a three-phase flow of oil, water, and gas. If flowtube 215 has the geometry shown in FIG. 1A, the pipe network may include two parallel links that include bends and straight pipe sections that correspond to the geometry of the flowtube shown in FIG. 1A.

The host computer 2110 reads the bulk mass flow rate, the bulk density, the inlet
20 pressure, the outlet pressure, and the inlet temperature from the digital transmitter 104 (or a storage which stores the information from the transmitter 104). The flow model 2120 then uses the inlet pressure and inlet temperature to determine the water cut of the fluid (or, alternatively, in other implementations the flow model may determine the gas void fraction).
25 To that end, the flow model may use the densities of the individual components, the inlet pressure, inlet temperature, the bulk density, and the bulk mass flow rate to determine a water-cut vs. outlet pressure curve. The densities of the individual components may be known beforehand and assumed to be constant, or the flow model 2120 may calculate these densities based on the inlet temperature, the inlet pressure, and the specific gravity of the gas
30 (which is typically known). The water-cut vs. outlet pressure curve and the actual outlet pressure is then used to determine the actual water-cut of the fluid.

To determine the water-cut vs. outlet pressure curve, the flow model 2120 may vary the mole fraction of the components to vary the water-cut and the gas void fraction in a way that keeps constant the measured bulk density and bulk mass flow rate. For example, the

flow model 2120 may determine the mole fractions of the components for the water-cut equal to 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100%. For each percentage of water-cut, the flow model 2120 then may use the mole fractions of the components, with the inlet temperature and inlet pressure, to calculate the corresponding outlet pressure.

5 The component flow rate determination system 2130 then interpolates these points and uses the actual, measured outlet pressure to determine the actual water-cut of the fluid. That is, the determination system 2130 determines the point on the interpolated curve corresponding to the actual, measured pressure, with the corresponding water-cut value being accepted as the actual water-cut. Based on the water-cut, the bulk mass density, the bulk
10 mass flow rate, and the densities of the individual components, the component flow rate determination system 2130 then calculates the mass and/or volumetric flowrates of the individual components. To do so, the component flow rate determination system 2130 may use the following equations:

	Mixture volumetric-flow-rate:	q_T	$= WT/DENTP$
15	Liquid density:	$DENL$	$= DENO*(1.0 - WC) + DENW*WC$
	Gas-void-fraction:	GVF	$= (DENL - DENTP)/(DENL - DENG)$
	Gas-volumetric flow rate:	q_G	$= GVF * q_T$
	Gas-mass flow rate:	w_G	$= q_G * DENG$
	Liquid-volumetric flow rate:	q_L	$= (1 - GVF)*q_T$
20	Oil-volumetric flow rate:	q_O	$= (1.0 - WC)*q_L$
	Oil-mass flow rate:	w_O	$= q_O * DENO$
	Water-volumetric flow rate:	q_W	$= WC * q_L$
	Water mass flow rate:	w_W	$= q_W * DENW$

where:

25	w_G :	In-situ gas mass-flow rate
	w_O :	In-situ oil mass-flow rate
	w_W :	In-situ water mass-flow rate
	q_G :	In-situ gas volumetric-flow rate
	q_O :	In-situ oil volumetric -flow rate
30	q_W :	In-situ water volumetric -flow rate
	q_L	In-situ liquid volumetric flowrate
	GVF :	In-situ gas-volume-fraction
	q_T	Bulk volumetric flowrate
	WT	Bulk mass flow rate

DENTP	Bulk density
DENL	Density of liquid
DENO	Density of oil
DENW	Desnity of water
DENG	Density of gas
WC	Water-cut

Some commercially available flow modeling software systems, such as Pipephase®, have an open architecture that enables the development of a main-driver program in a programming language such as Fortran or C++ or Visual Basic (VB). Pipephase®, for example, provides an API that allows such a driver program to make custom automatic calls to Pipephase, manipulate Pipephase model variables as desired, and access the desired results of the model. As a result, the component flow rate determination system 2130 may be implemented as a driver program that uses the APIs of the software implementing the flow model 2120 to determine the water-cut vs. outlet pressure points for the fluid. For example, the driver program may be implemented to access the data from the transmitter 104 (or, in other implementations, a storage of the data, such as a historian), to provide the data to the flow model 2120, and initiate the flow model 2120 to determine the water-cut vs. outlet pressure points. The driver program then may access these points from the flow model 2120, interpolate these points, use the actual outlet pressure to determine the actual water-cut, and then calculate the flow rates as described above.

While not described explicitly, the bulk density and bulk mass flow rate measurements performed by the bulk density determination system 2104 and the bulk mass flow rate determination system 2106 may be corrected bulk density measurements and corrected mass flow rate measurements. In general, the presence of gas in the fluid flow may affect both an actual and a measured value of a density of the fluid flow, resulting in the density measurement to be, and to read, lower than if the fluid flow contained only the liquid component. Thus, the apparent bulk density may be different from the actual bulk density. Similarly, the apparent mass flow rate may be different from the actual mass flow rate. Thus, the bulk density determination system 2104 and the bulk mass flow rate determination system 2106 may correct the initial/apparent measurements of bulk density and mass flow rate, respectively, so that these items are closer to the true density and true mass flow rate.

Also, while the flowmeter system 2100 is described as using a host computer 2110 that implements the flow model 2120 and component flow rate determination system 2130, one or both of these items may be implemented in the digital transmitter 104. For instance, if

the processing power of the transmitter is sufficient, the flow model 2120 and determination system 2130 may be implemented on the transmitter 104 with analytical flow modeling software such as Pipephase®. However, if processing power is limited, other techniques may be used to obtain properties such as water-cut from the inlet temperature, inlet pressure, outlet pressure, and densities of the components. For example, a neural network may be implemented in the transmitter 104. The neural network would be trained with training data that includes various values of inlet temperature, inlet pressure, and outlet pressure and the corresponding water-cut values. The inputs may also include various densities of the components, or the neural network may be trained for a particular set of density values of the components (and, hence, density is not specifically needed because the other training data is only valid for the particular set of density values). A component flow rate determination system implemented in the transmitter 104 (or, e.g., on host computer 2110) then uses the water-cut output by the neural network, along with the bulk density and bulk mass flow rate, to determine the flow rates of the individual components.

As implicated above, in some implementations, the data from the Coriolis meter 237 may be output to a historian database, and then accessed from the historian by the host computer 2110 (rather than the host computer 2110 accessing or receiving it directly from the transmitter 104). This may be particularly advantageous when the flow model 2120 is implemented on the host computer 2110 using an analytical flow model software system. In such a situation, the transmitter 104 may produce data at a much more frequent rate than the flow model 2120 and determination system 2130 can process the data to determine the flow rates. For instance, flow model 2120 and determination system 2130 may take a second or two to process the data to determine the flow rates, while the transmitter 104 may output data every few milliseconds. Thus, the transmitter 104 may output data much faster than the flow model 2120 and determination system 2130 can handle. Using the historian database allows this data to be stored until the flow model 2120 and determination system 2130 can access it.

Furthermore, in such situations, it may be advantageous to average the data produced by the transmitter 104 over a period of time, such as a second or two, and to use the averaged data as the inputs to the flow model 2120 and the determination system 2130. Alternatively, the host computer 2110 could just read the data points that occur every second or two (rather than averaging over the period).

In general, it should be appreciated that the system 2100 and the various implementations thereof may allow for all or substantially all of the three-phase fluid flow to flow continuously through the flowtube 215 and through an associated pipe or other conduit

for transporting the three-phase flow material. As a result, determinations of individual component flow rates do not require separation of the three-phase fluid flow into separate flows containing one or more of the constituent components. For example, when the three-phase flow contains oil, water, and gas, it is not necessary to separate the gas from the oil/water liquid combination in order to perform measurements (e.g., mass flow rate) on the oil portion of the resulting oil/liquid flow. Accordingly, reliable measurements of an amount of oil produced, for example, at an oil production facility, may be made easily, quickly, inexpensively, and reliably.

FIG. 3A illustrates a interpolated water-cut vs. outlet pressure curve that may be generated, for example, by component flow rate determination system 2130. FIG. 3B shows the curve with indications of the data points calculated by the flow model 2120 shown as triangles, and an indication of the point on the interpolated curve where the actual outlet pressure is located shown as a square. The point on the interpolated curve where the actual outlet pressure is located corresponds to a water-cut of 0.24.

FIG. 4 shows a flowchart illustrating one implementation of a process 400 for determining properties of individual components of a three-phase fluid flow. The implementation determines the mass flow rates of the individual components of a oil-water-gas fluid based on the bulk mass flow rate, the bulk density, the inlet temperature, and the inlet and outlet pressure of the fluid as it passes through a conduit. The process may be performed by, or in conjunction with the flowmeter system 2100, or the process 300 may be adapted to a different system.

A three-phase fluid, such as an oil-water-air mixture, is passed through a conduit (402). The temperature of the fluid at the inlet of the conduit is determined (404). The pressure of the fluid at the inlet and at the outlet of the conduit is determined (406). In addition, the bulk density and the bulk mass flowrate of the three-phase fluid is determined (408). The water-cut or gas void fraction of the fluid is determined based on the inlet pressure, the outlet pressure, the bulk density, and the bulk mass flow rate (410). For example, a mathematical model of the flow of the fluid through the conduit or a trained neural network may be used to determine the water-cut or gas void fraction. When the mathematical model is used, known values of the densities of the individual components also may be used in the model to determine the water-cut or gas void fraction. The flow rates of the individual components of the three-phase flow are then determined based on the water-cut or gas void fraction, the bulk density, and the bulk mass flow rate (412).

For example, when used in conjunction with flowmeter system 2100, the conduit is the Coriolis flowtube such that the three-phase fluid is passed through the Coriolis flowtube. The temperature sensor 220 is used to sense the temperature of the fluid at the inlet of the flowtube 215 and the pressure sensor or sensors 225 may be used to sense the inlet and outlet pressures of the flowtube 215. The Coriolis meter 237 measures the bulk density and the bulk mass flow rate of the fluid passing through the flowtube. The component flow rate determination system 2130, in conjunction with the flow model 2120, then determines the actual water-cut of the fluid based on the inlet pressure, the outlet pressure, the bulk density, and the bulk mass flow rate and determines the mass flow rates of the individual components of the three-phase flow based on the water-cut or gas void fraction, the bulk density, and the bulk mass flow rate.

FIG. 5 illustrates a sample nodal plot 500 illustrating a coriolis meter's pressure sensitivity to water-cut. The plot shows the change in outlet pressure as a function of flow rate, with water-cut as the parameter that varies with each curve. Based on the plot, it can be noted that near the lower ranges of flow rate, for a given coriolis flowtube size, the curves become much closer and it may be harder to distinguish between different water-cuts. Therefore, an appropriately sized coriolis flowtube should be used for the expected ranges of flow, so that sufficient pressure differentiation can be obtained for changing water-cut.

The foregoing techniques were tested by developing a Pipephase-network model to model the flow through the a CFT50-3 Coriolis meter from Invensys Systems, Inc. The 'coriolis-meter-network' included a flow through two identical parallel paths (loop) representing the coriolis-meter-flow tubes. These parallel links consisted of bends and pipe-sections, which correspond to the flow geometry of the meter. Specifically, the model included short pipe segments interspersed with BEND devices. The KMULs (described below, and used for the Pipephase simulation) for each bend were implicitly restricted to be of equal value for the lack of any discriminating information to justify any other KMUL value distribution and to make it easier/tractable to analyze the results.

KMUL is in calculations related to pressure drop across a bend. Pressure drop across a bend can be generally represented as:

$$DP = K_{mul} * f_1(w, \rho, d, \mu) * f_2(\text{multi-phase flow effects})$$

K_{mul} is L/D , which is a characteristic of a bend and can be obtained from a single-phase flow test pressure drop data. f_1 is the term that depends on mass flow rate w , fluid

density ρ , flow diameter d and viscosity μ . This data is available from thermodynamic property calculations in Pipephase. f_2 is the term that accounts for multi-phase flow effects including flow pattern, and slip and compressibility. The Chisolm or Homogeneous model is used to calculate this term in Pipephase.

5 The fluid was modeled with a 3-component model of water, air and a pseudo-component oil-component. The model of the fluid assumed, with little loss in rigor, that the water component was in the water phase, the air component was in the vapor phase and the oil component was in the oil-phase (laboratory conditions were assumed). For modeling field conditions, a more rigorous model/algorithm may reflect a more accurate phase behavior.

10 The Pipephase model file for modeling the CFT50 flowtube and fluid is provided in Appendix B.

 Two-phase air-water lab data was used to check the model fidelity and calibrate the model. Standard Pipephase case-study feature was used to run a large number of Pipephase case studies using the measured data.

15 Data over a wide range was fed into the model and the Bend KMUL (L/D) value was manually varied to match the pressure drop and flow rate for the given pressure drop. For modeling the pipes the BBMhV and Lockart-Martinelli models were tried. For the bends the HOMOGENEOUS model and the CHISOLM model were tried.

 As described above, it was assumed that all bends have the same value of KMUL to
20 simplify the model. For the Chisolm-bmhv combination a KMUL of 14 was found appropriate. For the Homogeneous-bbmhv combination a KMUL of 12 was found appropriate. Specifically, the Chisolm model with a KMUL=12 gave good results (average 1.18% error in flow) for the lower flow range (15 kg/s flow rates). The error was -6.6 % for KMUL=14.35 and the homogeneous model gave better predictions for the higher flow
25 ranges using a KMUL=14.375. So the KMUL value for each bend is expected to be in the 12 to 14 range overall.

 This manual calibration can be easily automated in Pipephase by exposing BEND
input data KMUL as an optimization (decision, constraint and objective variable). This data
may be exposed in 3 ways (a) Individual Bend Variable for KMUL (b) KMUL for all bends in
30 a link (KMUL_BEND_IN_LINK and (c) KMUL for all bends in a network
(KMUL_BEND_IN_NETW). If this enhanced feature is developed in Pipephase, more
accurate, faster automatic calibration to lab- measured data may be possible.

 The simulation trials indicated that (a) the Chisolm model in combination with the BBMhV pipe model has the highest fidelity for lower range flow rates when slip is more

present or dominant and (b) the Homogeneous Bend model in combination with the BBM HV pipe model has the highest fidelity for higher range flow rates when slip becomes insignificant. This observation is consistent with expected behavior.

The following table summarizes the flow results generated so far for specified pressure drops.

Flow ranges -->	15 kg/s	19 kg/s	23 kg/s
KMUL	12	12	12
Chisolm model average flow error %	6.617%	4.34%	1.18%
Homogeneous model average flow error %	=	=	=
KMUL	14.35	14.35	14.35
Chisolm model error %	-1.67%	-3.77%	-6.63%
Homogeneous model average flow error %	+6.42%	1.40%	-2.01%

A FORTRAN driver routine was developed to call Pipephase via the Pipephase API so as to implement an algorithm to implement the component flow rate determination system 2130, with Pipephase implementing the flow model 2120. The driver program is included in Appendix A.

The driver program was developed to reflect a Laboratory/Field Coriolis meter measurement scenario. The Coriolis meter outputs 5 quantities (a) the bulk mass flow rate, (b) the bulk density, (c) the inlet pressure (d) the outlet pressure, and (e) the inlet temperature. Three additional constants are also used: (1) in-situ gas density (2) in-situ water density (3) in-situ oil density. The driver program reads the Coriolis measured data from an *.csv file, sends the data to the underlying coriolis network model, and calculates the outlet pressure Pout as a function of a fine grid of water-cut values that vary from 0% water cut to 100% water cut while keeping the bulk mass flow rate and bulk density constant. The curve of Pout vs. Wcut is then interpolated for water-cut for the measured value of outlet pressure.

The algorithm was tested for the underlying Chisolm model. The generated results revealed that the curve generated was not a smooth and monotonically changing curve. So a straight line interpolation scheme between data points should be used to get reasonable results. A higher order interpolating scheme may yield erratic results.

The algorithm also was tested for the underlying HOMOGENEOUS model. The Pout vs Wcut curve generated was smooth. From this it can be concluded that the HOMOGENEOUS model has more desirable mathematical properties in comparison to the

Chisolm model even though the latter may reflect the conditions that actually occur, especially in the lower ranges of meter flow when the slip may be significant.

Appendix A

3-phase Coriolis-meter-Fortran-Driver-Program

5 External Files:

- The Coriolis-meter-data measured data resides in a csv file in the same directory where the Pipephase coriolis-meter-keyword-input file resides
- Current implementation of the Coriolis-meter-pipephase run generates an output csv file containing the complete 3-phase flow calculated results for one data set. The output file resides in the same directory where the Pipephase coriolis-meter-keyword-input file resides

input coriolis-meter data file name : **CORIOLIS_INP.CSV**

15 Sample:

WT(1)	DENTP	PRES(1)	PRES(2)	TEMP(1)	DENO	DENW	DENG
17594.78	820	9.7816	9.71	40	833.6	1001.3	12.909

output coriolis-meter data file name : **CORIOLIS_OUT.CSV**

20 Sample:

WT(1)	wG	wO	wW	qG	qO
kg/hr	kg/hr	kg/hr	kg/hr	m3/hr	m3/hr
1.76E+04	1.73E+01	1.27E+04	4.84E+03	1.34E+00	1.53E+01
WUT ARRAY(FRAC)					
0.00E+00	1.00E-01	2.00E-01	3.00E-01	4.00E-01	5.00E-01
CALCULATED OUTLET PRESSURE ARRAY (Bara)					
9.70E+00	9.70E+00	9.71E+00	9.71E+00	9.71E+00	9.71E+00
qW		WCUT_CLC	GVF	Pout-measured bara	
m3/hr		frac	frac	bara	
4.83E+00		2.40E-01	6.26E-02	9.71E+00	
WUT ARRAY(FRAC)					
6.00E-01		7.00E-01	8.00E-01	9.00E-01	1.00E+00
CALCULATED OUTLET PRESSURE ARRAY (Bara)					
9.71E+00		9.72E+00	9.72E+00	9.72E+00	9.73E+00

Pipephase-Coriolis-meter-Fortran-Driver-Program

```

5      C MAINS-MAINONE
      C NOTRANS
      C
      C $Archive:: V:/cc/ff/src/mains/mainone.for!v          $
      C $Workfile:: mainone.for                             $
10     C $Revision:: 1.16                                     $
      C
      C $Author:: thald                                       $
      C $Modtime:: 24 Oct 2002 17:28:56                       $
      C $Date:: 24 Oct 2002 17:31:24                         $
15     C
      C PROGRAM MAINONE
      C
      C *****
      C SAMPLE FORTRAN DRIVER
      C *****
20     C
      C This is the main driver for the PIPEPHASE simulation program. It
      C also demonstrates the use of the PIPEPHASE API that is available
      C for users who wish to link PIPEPHASE into their own in-house
25     C FORTRAN or C applications. The below calls are resolved by linking
      C with a SIMSCI provided user added subroutine library, which on the PC
      C is named D_MAINONE.LIB.
      C IMPLICIT DOUBLE PRECISION(A-H,O-Z), INTEGER(I-N)
      C
30     C -----
      C-L LOCAL VARIABLES
      C -----
      C
      C CHARACTER*2 CDUM
35     C CHARACTER*256 INPNAME, INPDIR, CFGNAME, CWORK
      C CHARACTER*256 CORIOLIS_OUT_FILNAM,CORIOLIS_INPUT_FILNAM
      C-SB-Start
      C Character*20 cClass,cName,cItem,cBuff(5000),
      C 1 c2Buff(250), c3Buff(250),cComponentName(50),
40     C 2 cBuff_TON(5000),cBuff_FRMN(5000),cBuff_shrt(5000)
      C DIMENSION DBUFF(100),IBUFF(10)
      C DIMENSION XMOLWT(50)
      C DIMENSION ZGAS(50), ZOIL(50), ZWAT(50)
      C EQUIVALENCE ( ZGAS(1),ZOIL(1),ZWAT(1) )
45     C DIMENSION ZCOMP(50), ZNEW(50)
      C DIMENSION WT(1),PRES(2), TEMP(2)
      C DIMENSION POUT_ARR(100), WCUT(100)
      C CHARACTER SRCNAM(1)*20, SNKNAM(1)*20
      C CHARACTER COMPNAMS(50)*20
50     C CHARACTER HEADING*132
      C
      C-SB-End
      C
      C -----
55     C-C CODE BEGINS HERE
      C -----
      C
      C RETRIEVE COMMAND LINE ARGUMENTS
      C CALL PARSECMDLINEARGS(INPNAME, INPDIR, CFGNAME)
60     C
      C Initialize Local Variables
      C IDUM = -1
      C RDUM = -1
      C IRET = -1
65     C CDUM = ' '
      C
      C Setup Simulation Data
      C CALL FF_VALS(IDUM, 'Quiet',IDUM,RDUM,CDUM)
      C CALL FF_EXEC('Quiet',' ', IRET)
70     C
      C CALL FF_VALS(IDUM, 'Initialize', IDUM,RDUM,CDUM)
      C CALL FF_VALS(IDUM, 'Activate Standard Code', IDUM,RDUM,CDUM)
      C CALL FF_VALS(IDUM, 'Standard Output', IDUM,RDUM,CDUM)
      C SB change to manual termination

```

```

C      CALL FF_VALS(IDUM, 'Automatic Termination', IDUM, RDUM, CDUM)
C      CALL FF_VALS(IDUM, 'MANUAL TERMINATION', IDUM, RDUM, CDUM)
C      CALL FF_VALS(IDUM, 'Main Control FORTRAN', IDUM, RDUM, CDUM)
5  C
C      Setup problem information before initializing
C      CALL FF_VALS(IDUM, 'Input File Name', IDUM, RDUM, INPNAME)
C      CALL FF_VALS(IDUM, 'Input File Directory', IDUM, RDUM, INPDIR)
C      CALL FF_VALS(IDUM, 'Configuration File Name', IDUM, RDUM, CFGNAME)
10 C
C      Initialize and clean directory before running.
C      CALL FF_EXEC('Initialize', ' ', IRET)
C      IF (IRET.LT.0) GOTO 999
C      CALL FF_EXEC('Clean Start', ' ', IRET)
C      IF (IRET.LT.0) GOTO 999
15 C
C      Run Simulation
C      CALL FF_EXEC('Run Preprocessor', ' ', IRET)
C      IF (IRET.LT.0) GOTO 999
C      CALL FF_EXEC('Run Thermo Module', ' ', IRET)
20 C      IF (IRET.LT.0) GOTO 999
C      CALL FF_EXEC('Run Cross Checker', ' ', IRET)
C      IF (IRET.LT.0) GOTO 999
C      CALL FF_EXEC('Run Calculations', ' ', IRET)
25 C-SB-start
C
C      =====
C      Start of the special Coriolis meter project modifications
C      =====
30 C
C      Open 3ph-CORIOIS-Meter Output file
C      ITMP1 = LEN_TRIM(INPDIR)
C      CORIOIS_OUT_FILNAM = INPDIR(1:ITMP1)//'\CORIOIS_OUT.CSV'
C      OPEN(UNIT=129, FILE=CORIOIS_OUT_FILNAM, STATUS='UNKNOWN')
35 C      Open 3ph-CORIOIS-meter input file
C      CORIOIS_INPUT_FILNAM=INPDIR(1:ITMP1)//'\CORIOIS_INP.CSV'
C      OPEN(UNIT=130, FILE=CORIOIS_INPUT_FILNAM, STATUS='UNKNOWN')
C
C      WRITE(129,*)
40 C      1'WT(1), wG, wO, wW, qG, qO, qW, WCUT_CLC, GVF, Pout-measured'
C      WRITE(129,*)
C      1'kg/hr,kg/hr,kg/hr,kg/hr,m3/hr,m3/hr,m3/hr,frac,frac,bara'
C
C      NWCS is the number of water-cut grid points. The water-cut range is divided equally from
C      0.0 to 1.0.
45 C      NWCS =10
C      DWAT = 1.0/NWCS
C      NWCS = NWCS + 1
C      WC = 0.0
50 C
C      =====
C      The component list in the network file must be listed in order such that
C      contiguous components are nominated to be gas or oil or water.
C      =====
55 C
C      ISTRT_GAS is the starting component number of the gas-component
C      ISTRT_GAS = 2
C      IEND_GAS is the ending component number of the gas-component
C      IEND_GAS = 2
60 C
C      ISTRT_OIL is the starting component number of the oil-component
C      ISTRT_OIL = 3
C      IEND_OIL is the ending component number of the oil-component
C      IEND_OIL = 3
65 C
C      ISTRT_WAT is the starting component number of the water-component
C      ISTRT_WAT = 1
C      IEND_WAT is the ending component number of the water-component
C      IEND_WAT = 1
70 C
C
C      *****
C      Get Coriolis meter Source Name
C      *****
C      CHARACTER SRCNAM(1)*16, SNKNAM(1)*16
75 C
C      iPutGet = 1

```

```

        cClass = 'NAMES'
        cName  = 'SOURCE NODES'
        CALL PPDATC (iPutGet,cClass,cName,cItem,SRCNAM,iSize,iCount,
5         1 iReturnCode)
C
C *****
C         Get Coriolis meter Sink Name
C *****
C
10         iPutGet = 1
        cClass = 'NAMES'
        cName  = 'SINK NODES'
        CALL PPDATC (iPutGet,cClass,cName,cItem,SNKNAM,iSize,iCount,
15         1 iReturnCode)
C
C *****
C         Get Coriolis meter model COMPONENT Names
C *****
C
20         iPutGet = 1
        cClass = 'NAMES'
        cName  = 'COMPONENTS'
        CALL PPDATC (iPutGet,cClass,cName,cItem,cBuff,iSize,iCount,
25         1 iReturnCode)
C
C         DIMENSION COMPNAMS(50)
        NOC = iCount !number of components
        DO 1020 JC = 1,NOC
            COMPNAMS(JC)=CBUFF(JC)
30         1020 CONTINUE
C
C         DIMENSION XMOLWT(50)
        IF(iReturnCode.EQ.0) THEN
C
35         C *****
C         Get the Coriolis meter molecular weights
C *****
C
        iPutGet = 1
40         cClass = 'NODE'
        cName  = 'FEED(MW)'
        cItem   = SRCNAM(1)
        cComponentName = ' '
        CALL PPDATR(iPutGet,cClass,cName,cItem,iItemID,          cComponentName,
45         & dBuff,iBuff,KUOM,IUOM,iReturnCode )
C
        DO 1030 JC = 1, NOC
            XMOLWT(JC) = DBUFF(JC)
50         1030 CONTINUE
C
C *****
C         Get the molar composition array of the source
C *****
C
55         iPutGet = 1
        cClass = 'NODE'
        cName  = 'FEED(M)'
        cItem   = SRCNAM(1)
        cComponentName = ' '
60         CALL PPDATR(iPutGet,cClass,cName,cItem,iItemID, cComponentName,
        & dBuff,iBuff,KUOM,IUOM,iReturnCode )
C
        DO 1010 JC = 1, NOC
            ZCOMP(JC) = DBUFF(JC)
65         1010 CONTINUE
C
C *****
C         Set pressure tolerance for Coriolis network
C *****
C
70         iPutGet = 2
        cClass = 'NETWORK'
        cName  = 'PRES TOLER'
        cComponentName = ' '
75         dbuff=1.0E-5
        KUOM = 9 ! Pressure

```

```

        IUOM = 6 ! Bara
        CALL PPDATR(iPutGet,cClass,cName,cItem,iItemID, cComponentName,
        & dBuff,iBuff,KUOM,IUOM,iReturnCode )
C
5  C *****
C      Calculate the molecular weightb of lumped gas
C *****
C      DIMENSION ZGAS(50), ZOIL(50), ZWAT(50)
C      EQUIVALENCE ( ZGAS(1),ZOIL(1),ZWAT(1) )
10 C
C      xmwLG = 0.0
C      SUMG = 0.0
C      DO 1040 J= ISTRT_GAS, IEND_GAS
C      xmwLG= xmwLG + ZCOMP(J)*XMOLWT(J)
15 SUMG = SUMG + ZCOMP(J)
C 1040 CONTINUE
C
C      xmwLG = xmwLG / SUMG
C      DO 2040 J= ISTRT_GAS, IEND_GAS
20 IF(SUMG.GT.0.0) THEN
C      ZGAS(J) = ZCOMP(J)/SUMG
C      ELSEIF(ISTRT_GAS.EQ.IEND_GAS) THEN
C      ZGAS(J)=1.0
C      ELSE
25 ZGAS(J) = 0.0
C      ENDIF
C 2040 CONTINUE
C
C *****
30 C      Calculate the molecular weight of lumped oil
C *****
C
C      xmwLO = 0.0
C      SUMO = 0.0
35 DO 1050 J= ISTRT_OIL, IEND_OIL
C      xmwLO= xmwLO + ZCOMP(J)*XMOLWT(J)
C      SUMO = SUMO + ZCOMP(J)
C 1050 CONTINUE
C
40 IF(SUMO.GT.0.0) THEN
C      xmwLO = xmwLO / SUMO
C      ELSE
C      xmwLO = XMOLWT(ISTRT_OIL)
C      ENDIF
45 C
C      DO 2050 J= ISTRT_OIL, IEND_OIL
C      IF(SUMO.GT.0.0) THEN
C      ZOIL(J) = ZCOMP(J)/SUMO
50 ELSEIF(ISTRT_OIL.EQ.IEND_OIL) THEN
C      ZOIL(J)=1.0
C      ELSE
C      ZOIL(J) = 0.0
C      ENDIF
C 2050 CONTINUE
55 C
C *****
C      Calculate the molecular weight of lumped water
C *****
C
60 C      xmwLW = 0.0
C      SUMW = 0.0
C      DO 1060 J= ISTRT_WAT, IEND_WAT
C      xmwLW= xmwLW + ZCOMP(J)*XMOLWT(J)
C      SUMW = SUMW + ZCOMP(J)
65 1060 CONTINUE
C
C      IF(SUMW.GT.0.0) THEN
C      xmwLW = xmwLW / SUMW
C      ELSE
70 xmwLW = XMOLWT(ISTRT_WAT)
C      ENDIF
C
C      DO 2060 J= ISTRT_WAT, IEND_WAT
C      IF(SUMW.GT.0.0) THEN
75 ZWAT(J) = ZCOMP(J)/SUMW
C      ELSEIF(ISTRT_WAT.EQ.IEND_WAT) THEN

```

```

        ZWAT(J)=1.0
    ELSE
        ZWAT(J) = 0.0
    ENDIF
5   2060 CONTINUE
C
C *****
C   We should read the Coriolis meter data here
C   (a) The Total weight rate,
10  C   (b) The Two phase density
C   (c) The inlet Pressure
C   (d) The outlet pressure
C   (e) Inlet temperature
C
15  C   Meter Constant data we should read are
C   (a) In-situ oil density at the meter (DENO),
C   (b) In-situ Water density at the meter DENW,
C   (c) In-situ Gas density at the meter (DENG
C *****
20  C
C   Below are some fictitious data
C   DIMENSION WT(1)82811.08914
C   WT(1)   = 85139.88 !KG/HR
C
25  C =====
C   3-phase meter SWRI data set from 3000-00-025 MST
C   total rate 645.1419067 lb/min 17594.78 kg/hr
C   Inlet pressure 141.8707733 psig = 9.7816 bar
C   Temperature: 103.263031 F = 40 C
30  C   oil density 833.6 kg/m3
C   Water density: 1001.3 kg/m3
C   Gas density: 0.805544317 lb/ft3 = 12.909 kg/m3
C   WT(1)   = 17594.78 !KG/HR
C   PRES(1) = 9.7816 !Bar-abs inlet pressure
35  C   PRES(2) = 7.7816 !Bar-abs outlet pressure (fictitious)
C   TEMP(1) = 40.0 ! degrees C
C   DENO = 833.6 ! kg/m3
C   DENW = 1001.3 ! kg/m3
C   DENG = 12.909 ! kg/m3
40  C =====
C
C =====
C   Data set
C   WT(1)   = 82811.08914 !KG/HR
45  C   PRES(1) = 2.51268335 !Bar-abs inlet pressure
C   PRES(2) = 1.646795786 !Bar-abs outlet pressure
C
C   TEMP(1) = 31.68140366 ! degrees C
C
50  C   qT = qG + qO + qW
C   qT = 0.436781609 + 0 + 82.977043226 !m3/hr
C   DENTP= WT(1)/qT
C
C   DENO = 750.0 ! kg/m3
55  C   DENW = 998.0 ! kg/m3
C   DENG = 2.61 ! kg/m3
C =====
C
C *****
60  C   Manufacture missing data for testing the model
C *****
C
C   GVF_dum = 5.511579543 * 1.0E-2
C   wc_dum = 0.15
65  C   DENL_dum = wc_dum*DENW + (1.0 - WC_dum)*DENO
C   DENTP = DENL_dum - GVF_dum * (DENL_dum - DENG)
C
C   Read coriolis-meter data from a csv input file
70  C   WT(1) = Total mass flow rate KG/HR
C   DENTP = Mixture density kg/m3
C   PRES(1) = Coriolis-meter Inlet pressure (coriolis network source pressure, bara)
C   PRES(2) = Coriolis-meter Outlet pressure (coriolis network sink pressure, bara)
C   TEMP(1) = Coriolis-meter Inlet temperature (source temperature)
C   DENO = Oil phase density (kg/m3, usually a nominated value for a particular data
75  set or installation)

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WO 2008/011587

PCT/US2007/074011

```

C      DENW      = Water density (kg/m3, usually a nominated value for a particular data set
or installation)
C      DENG      = Gas density (kg/m3, usually a nominated value for a particular data set or
installation)
5      C
      READ(130,6030) HEADING
      6030 FORMAT(A132)
      READ(130,*) WT(1), DENTP, PRES(1), PRES(2), TEMP(1), DENO,
10      1          DENW , DENG
      C
      qT = WT(1)/DENTP
      C
      NVAL_WCS = NWCS
15      JVAL_WCS = 0
      C
      C *****
      C      Start of loop of Outlet pressure calculations for a range of watercuts
      C *****
20      C
      DO 1000 JWAT = 1, NWCS
      C
      C      WC = WC + DWAT
      C      DENL = DENO*(1.0 - WC) + DENW*WC
25      C      GVF = (DENL - DENTP)/(DENL - DENG)
      C      IF(GVF.LT.0.0) THEN
      C      NVAL_WCS = NVAL_WCS - 1
      C      WC = WC + DWAT
      C      GO TO 1000
30      C      ENDIF
      C      qG = GVF * qT
      C      wG = qG * DENG
      C
      C      qL = (1 - GVF)*qT
35      C      qO = (1.0 - WC)*qL
      C      wO = qO * DENO
      C
      C      qW = WC * qL
      C      wW = qW * DENW
40      C
      C *****
      C      Calculate mole fractions for lumped gas, oil and water components
      C *****
45      C
      XMOLGAS_LMP = wG/xmwLG !Moles of lumped gas
      XMOLOIL_LMP = wO/xmwLO !Moles of lumped oil
      XMOLWAT_LMP = wW/xmwLW !Moles of lumped water
      TOTAL_MOLES = XMOLGAS_LMP + XMOLOIL_LMP + XMOLWAT_LMP
      C
50      C
      C *****
      C *****
      C      Calculate the total stream composition mole fraction data back, based on the lumped
      C      component mole rates.
55      C
      C *****
      C *****
      C
      DO 3040 J= ISTRT_GAS, IEND_GAS
60      C      ZNEW(J) = ZGAS(J)*XMOLGAS_LMP / TOTAL_MOLES
      C      3040 CONTINUE
      C
      DO 3050 J= ISTRT_OIL, IEND_OIL
      C      ZNEW(J) = ZOIL(J)*XMOLOIL_LMP / TOTAL_MOLES
65      C      3050 CONTINUE
      C
      DO 3060 J= ISTRT_WAT, IEND_WAT
      C      ZNEW(J) = ZWAT(J)*XMOLWAT_LMP / TOTAL_MOLES
70      C      3060 CONTINUE
      C
      C
      =====
      =====
      C      Set the new source weight rate and the new source pressure &
75      C      Calculate by calling Pipephase the new outlet pressure and store Poutlet versus WC for a
      C      range of WC's

```

```

C
=====
C
5 C *****
C   Set the source flow compositions
C *****
C
    iPutGet = 2
10   cClass = 'NODE'
    cName = 'FEED(M)'
    cItem = SRCNAM(1)
    cComponentName = ' '
C
15 C   Need to tell how many elements are being sent (this needs to be documented)
    iBuff(1)=NOC
    CALL PPDATR(iPutGet,cClass,cName,cItem,iItemID,      cComponentName,
& ZNEW,iBuff,KUOM,IUOM,iReturnCode )
C
20 C *****
C   Set the source weight flow rate
C *****
    iPutGet = 2
25   cClass = 'NODE'
    cName = 'RATE(WT)'
    cItem = SRCNAM(1)
    cComponentName = ' '
    KUOM = 2 ! Weight Rate
    IUOM = 9 ! kg/hr
30   CALL PPDATR(iPutGet,cClass,cName,cItem,iItemID, cComponentName,
& WT(1),iBuff,KUOM,IUOM,iReturnCode )
C
C *****
C   Set the Inlet Pressure and Temperature
35 C *****
C
    iPutGet = 2
C   cClass = 'NODE'
    cName = 'PRESSURE'
40   cItem = SRCNAM(1)
    cComponentName = ' '
    KUOM = 9 ! Pressure
    IUOM = 6 ! Bara
    CALL PPDATR(iPutGet,cClass,cName,cItem,iItemID,cComponentName,
45   & PRES(1),iBuff,KUOM,IUOM,iReturnCode )
C
C   Set the Inlet Temperature
C   DIMENSION TEMP(2)
C   iPutGet = 2
50   cClass = 'NODE'
    cName = 'TEMPERATURE'
C   cItem = SRCNAM(1)
    cComponentName = ' '
    KUOM = 7 ! temperature
55   IUOM = 3 ! Centigrade
    CALL PPDATR(iPutGet,cClass,cName,cItem,iItemID,cComponentName,
& TEMP(1),iBuff,KUOM,IUOM,iReturnCode )
C
C
60 C   =====
C   Calculate Coriolis-meter network
C   =====
C
    CALL FF_EXEC('Rerun Calculations', ' ', IRET)
C
65 C   IF(IRET.NE.2) THEN
C
    NVAL_WCS = NVAL_WCS - 1
    WC = WC + DWAT
    GO TO 1000
70   ENDIF
C
C *****
C   Get the outlet pressure
C *****
75 C
    iPutGet = 1

```

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```

C      cClass = 'NODE'
      cName = 'PRESSURE'
      cItem = SNKNAM(1)
      cComponentName = ' '
5      KUOM = 9 ! Pressure
      IUOM = 6 ! Bara
      JVAL_WCS = JVAL_WCS + 1
      CALL PPDATR(iPutGet,cClass,cName,cItem,iItemID,cComponentName,
10      & POUT_ARR(JVAL_WCS),iBuff,KUOM,IUOM,iReturnCode )
C
C      POUT_ARR(JWAT) = PRES(2)
      WCUT(JVAL_WCS) = WC
C
C      Calculate next water cut
15      WC = WC + DWAT
      1000 CONTINUE
C
C *****
C      Interpolate for water cut
20 C *****
C
      NVAL_WCS = JVAL_WCS
      IF(NVAL_WCS.EQ.0) THEN
25      WRITE(129,*) 'FAILED TO CALCULATE WATER-CUT and GVF'
      GO TO 4060
      ELSEIF(NVAL_WCS.EQ.1) THEN
      WCUT_CLC = WCUT(1)
      ELSEIF(NVAL_WCS.EQ.2) THEN
30      CALL SRTVAR (NVAL_WCS, POUT_ARR, WCUT)
      WCUT_CLC= FLAGRR(POUT_ARR, WCUT,PRES(2),1,NVAL_WCS)
      ELSEIF(NVAL_WCS.GT.2) THEN
      CALL SRTVAR (NVAL_WCS, POUT_ARR, WCUT)
      WCUT_CLC= FLAGRR(POUT_ARR, WCUT,PRES(2),1,NVAL_WCS)
35      ENDF
C
      IF(WCUT_CLC.GT.1.0) THEN
      WC = 1.0
      ELSEIF(WCUT_CLC.LT.0.0) THEN
40      WC = 0.0
      ELSE
      WC = WCUT_CLC
      ENDF
      DENL = DENO*(1.0 - WC) + DENW*WC
      GVF = (DENL - DENTP)/(DENL - DENG)
45      qG = GVF * qT
      wG = qG * DENG
C
      qL = (1 - GVF)*qT
      qO = (1.0 - WC)*qL
50      wO = qO * DENO
C
      qW = WC * qL
      wW = qW * DENW
      WCUT_CLC = WC
55 C
C *****
C      Write out the coriolis meter results and watercut vs pout curve results
C *****
C
60      WRITE(129,6010) WT(1), wG, wO, wW, qG,qO,qW,WCUT_CLC,GVF, PRES(2)
      6010 FORMAT(20(1X,E16.5,', '))
      WRITE(129,*) ' WUT ARRAY(FRAC) '
      WRITE(129,6010) (WCUT(I),I=1,NVAL_WCS)
      WRITE(129,*) 'CALCULATED OUTLET PRESSURE ARRAY (Bara) '
65      WRITE(129,6010) (POUT_ARR(I),I=1,NVAL_WCS)
      ENDF
C
      4060 CONTINUE
      CLOSE(129)
70      CLOSE(130)
C-SB-end
      IF (IRET.LT.0) GOTO 999
      GOTO 998
C
75 C
C      ERRORS - IF AUTOMATIC TERMINATION IS SELECTED,
C      THE CODE BELOW WILL NEVER BE REACHED SINCE THE CALL

```

```

C          TO FF_EXEC WILL STOP WITH AN EXIT CODE WHEN THE
C          SIMULATION HAS COMPLETED.
C
5      999 CONTINUE
      CALL FFGETMESSAGE(IRET,CWORK)
      WRITE(*,*) ' '
      WRITE(*,'(A,I6,2A)') '*** ERROR: ',IRET, ' ',CWORK(1:60)
C
10     998 CONTINUE
      CALL FF_EXEC('End',      ' ', IRET)
      CALL FF_EXEC('Clean End', ' ', IRET)
      CALL FF_EXEC('Stop',     ' ', IRET)
C
C -----
15  C-E  END OF ROUTINE
C -----
C
      STOP
      END
20  C
C      THIS IS A COMPAQ VISUAL FORTRAN SPECIFIC COMMAND LINE PARSER.
C
      SUBROUTINE PARSECMDLINEARGS(FNAME,FPATH,CNAME)
25  C-A
      CHARACTER*(*) FNAME,FPATH,CNAME
C-L
      CHARACTER*256 ARG(3),CWORK
      LOGICAL EXISTS
C-C
30  FNAME='NONE'
      *-IF IBMPC
      FPATH='.\'
      *-ELSEIF UNIX
      *- FPATH='./'
35  *-ENDIF
      CNAME='pipephase.ini'
      ARG(1)=' '
      ARG(2)=' '
      ARG(3)=' '
40  C
      I=NARGS()
      IF (I.GT.3) I=3
      DO J=1,I
          CALL GETARG(J,ARG(J))
45  ENDDO
C
      DO WHILE (I>0)
          IF (ARG(I)(1:3).EQ. '/F=' ) FNAME=ARG(I)(4:)
          IF (ARG(I)(1:3).EQ. '/D=' ) FPATH=ARG(I)(4:)
50  IF (ARG(I)(1:3).EQ. '/I=' ) CNAME=ARG(I)(4:)
          IF (ARG(I)(1:3).EQ. '/f=' ) FNAME=ARG(I)(4:)
          IF (ARG(I)(1:3).EQ. '/d=' ) FPATH=ARG(I)(4:)
          IF (ARG(I)(1:3).EQ. '/i=' ) CNAME=ARG(I)(4:)
          I=I-1
55  ENDDO
C
      ITMP1 = LEN_TRIM(FPATH)
      ITMP2 = LEN_TRIM(FNAME)
      *-IF IBMPC
60  IF (FPATH(ITMP1:ITMP1).NE. '\') THEN
          CWORK=FPATH(1:ITMP1)//'\ '//FNAME(1:ITMP2)//'.INP'
      ELSE
          CWORK=FPATH(1:ITMP1)//FNAME(1:ITMP2)//'.INP'
      ENDIF
65  *-ELSEIF UNIX
      *- IF (FPATH(ITMP1:ITMP1).NE. '/') THEN
      *- CWORK=FPATH(1:ITMP1)//' '//FNAME(1:ITMP2)//'.INP'
      *- ELSE
      *- CWORK=FPATH(1:ITMP1)//FNAME(1:ITMP2)//'.INP'
70  *- ENDIF
      *-ENDIF
C
C      CHECK FOR INPUT FILE
      INQUIRE (FILE = CWORK, EXIST=EXISTS)
75  IF (.NOT. EXISTS) THEN
      WRITE(*,*) ' '

```

```

        WRITE(*,*) 'INPUT FILE NOT FOUND: ',CWORK(1:50)
        GOTO 998
    ENDIF
C
5  C    CHECK FOR CONFIG FILE
    INQUIRE (FILE = CNAME, EXIST=EXISTS)
    IF (.NOT. EXISTS) THEN
        WRITE(*,*) ' '
10     WRITE(*,*) 'CONFIGURATION FILE NOT FOUND: ',CNAME(1:40)
        GOTO 998
    ENDIF
C
    GOTO 999
C
15  998 CONTINUE
    WRITE(*,*) ' '
    WRITE(*,*)
    1  'PROPER SYNTAX: MAINONE /F=INPNAME /D=INPDIR /I=CFGNAME'
*-IF IBMPC
20     WRITE(*,*)
    1  '          IE: MAINONE /F=TEST /D=''.\' ' /I=PIPEPHASE.INI'
*-ELSEIF UNIX
*-    WRITE(*,*)
*-    1  '          IE: MAINONE /F=TEST /D=''./' ' /I=PIPEPHASE.INI'
25 *-ENDIF
    WRITE(*,*) ' '
    STOP
    999 CONTINUE
C-E
30     RETURN
    END
C FFLIB-FLAGR
C
C $Archive:: V:/cc/ff/src/fflib/FLAGR.FOV $
35 C $Workfile:: FLAGR.FOR $
C $Revision:: 1.7 $
C
C $Author:: thald $
C $Modtime:: Oct 20 1999 09:16:00 $
40 C $Date:: Oct 25 1999 09:42:32 $
C
C +-----+
C !
C !          MAINTENANCE AND ENHANCEMENT RECORD
45 C !          =====
C !
C !   D A T E      WHO      BRIEF DESCRIPTION OF CHANGES
C !   -----      -
C !
50 C +-----+
C !
C !   PURPOSE:
C !
C !   AUTHOR(S):
55 C !
C !   COMPLETION DATE:
C !
C +-----+
C !
60 C !          MAJOR LOCAL VARIABLES USED
C !          =====
C !
C !   IN ARGUMENT LIST
C !   -----
65 C !   NAME      TYPE      I/O      BRIEF DESCRIPTION
C !   -----
C !
C !   LOCAL VARIABLES
C !   -----
70 C !   NAME      TYPE      BRIEF DESCRIPTION
C !   -----
C !
C +-----+
C
75 C
    FUNCTION FLAGRR(X,Y,XARG, IDEG,N2)

```

```

C
C   FLAGR USES THE LAGRANGE FORMULA TO EVALUATE THE INTERPOLATING
C   POLYNOMIAL OF DEGREE 'IDEG' FOR ARGUMENT XARG USING THE DATA VALUE
C   X(1) . . . . .X(N) AND Y(N) . . . . .Y(N). SUBSCRIPTS MIN AND
5  C   SELECTED BY THE FUNCTION TO BRACKET XARG.  X(1) . . . . .X(N)
C   ASSUMED TO BE IN ASCENDING ORDER BUT NOT NECESSARILY EVENLY SPACED
C
C       X = VECTOR OF INDEPENDENT VARIABLE DATA POINTS.
C       Y = VECTOR OF CORRESPONDING DEPENDENT VARIABLE DATA POINTS.
10  C   XARG=VALUE IN THE X VECTOR FOR WHICH Y EQUIVALENT IS DESIRED.
C   IDEG= DEGREE OF INTERPOLATING POLYNOMIAL - 1 IS LINEAR, 2 IS
C       QUADRATIC, ETC.
C   N = NUMBER OF DATA POINTS IN X AND Y
C
15  C   INCLUDE 'PRECIS.CMN'
C       IMPLICIT      DOUBLE PRECISION(A-H,O-Z), INTEGER(I-N)
C       DIMENSION X(N2),Y(N2)
C
C   PROTECT CONSTANT ARGUMENTS THAT MAY HAVE BEEN PASSED IN.
20  C   N=N2
C
C       NDEG=IDEG
C       L=1
C       IF(N.LT.0) L=2
25  C       IF(N.LT.0) N=-N
C       IF(N-2) 6,7,8
6   FLAGRR=Y(1)
C       RETURN
7   NDEG=1
30  C   8 CONTINUE
C       SXARG=XARG
C       N1=NDEG+1
C       GO TO (191,192),L
35  191 DO 11 MAX= N1, N
C       IF(XARG.LT.X(MAX))GO TO 12
11  CONTINUE
C       MAX=N
C       GO TO 12
40  192 DO 21 MAX= N1, N
C       IF(XARG.GT.X(MAX))GO TO 12
21  CONTINUE
C       MAX=N
12  MIN=MAX-IDEG
C       FACTOR=1.
45  DO 2 I= MIN, MAX
C       IF(XARG.NE.X(I)) GO TO 2
C       FLAGRR=Y(I)
C       RETURN
50  2 FACTOR=FACTOR*(XARG-X(I))
C       YEST=0.
C       DO 5 I= MIN, MAX
C       TERM=Y(I)*FACTOR/(XARG-X(I))
C       DO 4 J= MIN, MAX
55  4 IF(I.NE.J)TERM=TERM/(X(I)-X(J))
C       5 YEST=YEST+TERM
C       XARG=SXARG
C       FLAGRR=YEST
C       RETURN
C       END
60
C FFLIB-SRTVAR
C
C $Archive:: V:/cc/ff/src/fflib/srtvar.fov $
C $Workfile:: srtvar.for $
65 C $Revision:: 1.1 $
C
C $Author:: thald $
C $Modtime:: Sep 13 1996 11:28:16 $
C $Date:: Sep 13 1996 11:28:26 $
70 C
C       SUBROUTINE SRTVAR (SETSIZ, VAR1, VAR2)
C
C +-----+
C !
75 C ! MAINTENANCE AND ENHANCEMENT RECORD !
C ! ===== !

```

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```

C !
C !  D A T E      WHO      BRIEF DESCRIPTION OF CHANGES      !
C ! -----      - - - - -      - - - - -      - - - - -      !
5  C !  09-09-96   DTT     INITIAL IMPLEMENTATION.             !
C !
C +-----+
C !
C !  PURPOSE:              SORT CURVE DATA FOR VAR2 BASED ON VAR1      !
C !
10 C !  AUTHOR :              R.F. (Bob) Schaettle                 !
C !
C +-----+
C !
C !              MAJOR LOCAL VARIABLES USED                          !
15 C !              =====
C !
C !  IN ARGUMENT LIST
C !  -----
C !  NAME      TYPE      I/O      BRIEF DESCRIPTION              !
20 C !  -----      - - - - -      - - - - -      - - - - -      !
C !
C !  IN COMMON BLOCKS
C !  -----
25 C !  NAME      COMMON      TYPE      I/O      BRIEF DESCRIPTION      !
C !  -----      - - - - -      - - - - -      - - - - -      - - - - -      !
C !
C !  LOCAL VARIABLES
C !  -----
30 C !  NAME      TYPE              BRIEF DESCRIPTION              !
C !  -----      - - - - -      - - - - -      - - - - -      !
C !
C !  SETSIZ      IA      Number of points in CURVe                !
C !
35 C !  VAR1      RA      Holds CURVe data for first variable        !
C !  VAR2      RA      Holds CURVe data for second variable        !
C !
C +-----+
C
40 C=====
C-
C=====
C
C      INCLUDE 'PRECIS.CMN'
45 C      INCLUDE 'KCONS.CMN'
C      INCLUDE 'DEFUNT.CMN'
C      INCLUDE 'CDUMP.CMN'
C      INCLUDE 'CINOUT.CMN'
C
50 C=====
C-L
C=====
C
C      IMPLICIT      DOUBLE PRECISION(A-H,O-Z) , INTEGER(I-N)
55 C      CHARACTER*6 MYNAME
C      PARAMETER (MYNAME='SRTVAR')
C      INTEGER SETSIZ,DEBUG,P1,P2
C      DIMENSION VAR1(SETSIZ), VAR2(SETSIZ)
C
60 C      EQUIVALENCE (IIDMP(1,53),DEBUG)
C
C=====
C-F
C=====
65 C
C
C      9001 FORMAT (2X, '*** ', A8, 1X, A6)
C
C=====
70 C-C
C=====
C
C      IF (DEBUG.GT.0) THEN
C      WRITE (KUPPOT, 9001) 'ENTERING', MYNAME
75 C      ENDIF
C

```

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```

      IF (SETSIZE.GT.1) THEN
C      Bubble Up
      DO 1300 I= 1, (SETSIZE-1)
        P1 = 1 + (I-1)
5      1000      CONTINUE
        JMARK = 0
      DO 1100 J= (I+1), SETSIZE
        P2 = 1 + (J-1)
      10      C      IF (VAR1(P1).GT.VAR1(P2)) THEN
          Mark this set
          JMARK = J
          ENDIF
      1100      CONTINUE
      C
      15      IF (JMARK.GT.0) THEN
      C      Swap the current data and the marked data
          TEMP = VAR1(P1)
          VAR1(P1) = VAR1(JMARK)
          VAR1(JMARK) = TEMP
      20      TEMP = VAR2(P1)
          VAR2(P1) = VAR2(JMARK)
          VAR2(JMARK) = TEMP
      C
      C      Now go back and bubble the new value that
      25      C      has been swapped into this slot.
      C
          GO TO 1000
      ENDIF
      1300      CONTINUE
      C
      30      Bubble Down
      DO 2300 I= SETSIZE, 2, -1
        P1 = 1 + (I-1)
      C
      35      2000      CONTINUE
          JMARK = 0
      DO 2100 J= (I-1), 1, -1
        P2 = 1 + (J-1)
      C
      40      IF (VAR1(P1).LT.VAR1(P2)) THEN
      C      Mark this spot
          JMARK = J
          ENDIF
      2100      CONTINUE
      45      IF (JMARK.GT.0) THEN
      C      Swap the current data and the marked data
          TEMP = VAR1(P1)
          VAR1(P1) = VAR1(JMARK)
          VAR1(JMARK) = TEMP
      50      TEMP = VAR2(P1)
          VAR2(P1) = VAR2(JMARK)
          VAR2(JMARK) = TEMP
      C
          GO TO 2000
      55      ENDIF
      2300      CONTINUE
      ENDIF
      C
      C      -----
      60      C      -----  END OF ROUTINE SRTCRV  -----
      C      -----
      C
      C      IF (DEBUG.GT.0) THEN
      C      WRITE (KUPPOT, 9001) 'LEAVING ', MYNAME
      65      C      ENDIF
      RETURN
      END

```

Appendix B:
Sample Pipephase keyword input model files of CFT50 Coriolis-
meter-network

5 **Coriolis-Meter-Pipephase-Model-Keyword-input File:**

Homogeneous-model:

Keyword-file name: **TRIAL3_ACT_DATA_HOMOG_BMHV_K12meter.inp**

```

10 $ SIMSCI PIPEPHASE Version 9.1 keyword file...
$
$      General Data Section
$
15 TITLE DATE=06/07/06
$
$
DIMENSION SI, TEMPERATURE=C, PRESSURE=BAR, *
LENGTH=FT,IN
20 $
CALCULATION NETWORK, Compositional, PRANDTL
$
FCODE PIPE=BBHV
$
25 DEFAULT IDPIPE=4.026, IDTUBING=4.026, IDRISER=4.026, *
IDANNULUS=6.065, ROUGH(IN)=1.8000e-005, *
HAUSEN
$
PRINT INPUT=FULL, DEVICE=PART, CONNECT=NONE, *
30 MERGESUB, ITER, DATABASE=NONE, PROPERTY=FULL, *
SIMULATOR=PART
$
SEGMENT AUTO=OFF, DLHORIZ(FT)=1, DLVERT(FT)=500, *
MAXSTEPS=2000
35 $
LIMITS PRES(MIN)=1.000e-003
$
$      Component Data Section
$
40 COMPONENT DATA
$
LIBID 1, H2O / *
2, AIR
PETRO(KGM3) 3, c7+,300, 833.6 $750.0
45 $
PHASE VL=1,2

$
$      Network Data Section
50 $
NETWORK DATA
$
SOLUTION PBALANCE, FLOWAL=2, STEP=1, *
QDAMP=10, HALVINGS=1
55 $

```

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```

TOLERANCE PRESSURE=1.000e-005
$
$      Thermodynamic Data Section
$
5  THERMODYNAMIC DATA
$
METHOD SET=SET01, SYSTEM=SRK
$
10 WATER PROPERTY=Super
$
KVALUE BANK=SimSci
$
$      PVT Data Section
$
15 PVT PROPERTY DATA
$
SET SETNO=1, SET=SET01
$
$      Structure Data Section
20
$
$      STRUCTURE DATA
25 $
$SOURCE NAME=S000, PRIORITY=0, SETNO=1, *
$ SET=SET01, PRES=2.51268335, TEMP=31.37, *
$ RATE(est,W)=82811.08914, XCORD=0, YCORD=-688, * $85139.88
$ COMP(M)=1, 0.999895572 / 2, 0.000104428/3,0
30 $
$SINK NAME=D000, PRES=1.646795786, RATE(ESTI)=1000, *
$ XCORD=1769, YCORD=-719
$
SOURCE NAME=S000, PRIORITY=0, SETNO=1, *
35 SET=SET01, PRES=2.51268335, TEMP=31.37, *
RATE(W)=17587.4654352121, XCORD=0, YCORD=-688, * $85139.88
COMP(M)=1, 0.999895572 / 2, 0.000104428/3,0
$
SINK NAME=D000, PRES(est)=1.646795786, RATE(ESTI)=1000, *
40 XCORD=1769, YCORD=-719
$
JUNCTION NAME=J001, XCORD=791, YCORD=-704
JUNCTION NAME=J002, XCORD=1294, YCORD=-706
$
45 $
LINK NAME=L000, FROM=S000, TO=J001, *
XCOR=583,380,266, YCOR=-641,-650,-647
PIPE NAME=P000, LENGTH(FT)=0.87, ID=3.02, *
U=1
50 $D~CONTRACTION NAME=C001, IDIN=3.02, IDOUT=1.744, *
$D~ ANGLE=7.30103
$
LINK NAME=L001, FROM=J001, TO=J002, *
XCOR=1146,1003,909, YCOR=-604,-604,-615
55 $D~TEE NAME=T002, IDPIPE=1.744, KMUL=16
REGULATOR NAME=R002, PRES=999
PIPE NAME=P007, LENGTH(FT)=0.2738, ECHG=0.2738, *
ID=1.744, U=1
BEND NAME=B009, ID=1.744, NONSTANDARD, *
60 ANGLE=180, RADIUS=5.99936, KMUL=12, *

```

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ROUGH(IN)=2.000e-004,HOMOG
 PIPE NAME=P008, LENGTH(FT)=0.3333, ECHG=-0.3333, *
 ID=1.744, U=1
 BEND NAME=B010, ID=1.744, NONSTANDARD, *
 5 ANGLE=90, RADIUS=5.99936, KMUL=12, *
 ROUGH(IN)=2.000e-004,HOMOG
 PIPE NAME=P009, LENGTH(FT)=1.275, ID=1.744, *
 U=1
 BEND NAME=B011, ID=1.744, NONSTANDARD, *
 10 ANGLE=90, RADIUS=5.99936, KMUL=12, *
 ROUGH(IN)=2.000e-004,HOMOG
 PIPE NAME=P010, LENGTH(FT)=0.3333, ECHG=0.3333, *
 ID=1.744, U=1
 BEND NAME=B012, ID=1.744, KMUL=12, *
 15 ROUGH(IN)=2.000e-004,HOMOG
 BEND NAME=B013, ID=1.744, NONSTANDARD, *
 ANGLE=180, RADIUS=5.99936, KMUL=12, *
 ROUGH(IN)=2.000e-004, HOMOGENEOUS
 PIPE NAME=P011, LENGTH(FT)=0.2738, ECHG=-0.2738, *
 20 ID=1.744, U=1, FCODE=BMHV
 \$D~TEE NAME=T003, IDPIPE=1.744, KMUL=16
 \$D~TEE NAME=T004, IDPIPE=1.744, KMUL=16
 PIPE NAME=P012, LENGTH(FT)=0.2738, ECHG=0.2738, *
 ID=1.744, U=1
 25 BEND NAME=B014, ID=1.744, KMUL=12, *
 ROUGH(IN)=2.000e-004,HOMOG
 PIPE NAME=P013, LENGTH(FT)=0.3333, ECHG=-0.3333, *
 ID=1.744, U=1
 BEND NAME=B015, ID=1.744, NONSTANDARD, *
 30 ANGLE=90, RADIUS=5.99936, KMUL=12, *
 ROUGH(IN)=2.000e-004,HOMOG
 PIPE NAME=P014, LENGTH(FT)=1.275, ID=1.744, *
 U=1
 BEND NAME=B016, ID=1.744, NONSTANDARD, *
 35 ANGLE=90, RADIUS=5.99936, KMUL=12, *
 ROUGH(IN)=2.000e-004,HOMOG
 PIPE NAME=P015, LENGTH(FT)=0.3333, ECHG=0.3333, *
 ID=1.744, U=1
 BEND NAME=B017, ID=1.744, NONSTANDARD, *
 40 ANGLE=180, RADIUS=5.99936, KMUL=12, *
 ROUGH(IN)=2.000e-004,HOMOG
 PIPE NAME=P016, LENGTH(FT)=0.2738, ECHG=-0.2738, *
 ID=1.744, U=1
 \$D~TEE NAME=T005, IDPIPE=1.744, KMUL=16
 45 \$
 LINK NAME=L002, FROM=J001, TO=J002
 \$D~TEE NAME=T006, IDPIPE=1.744, KMUL=16
 REGULATOR NAME=R001, PRES=999
 PIPE NAME=P019, LENGTH(FT)=0.2738, ECHG=0.2738, *
 50 ID=1.744, U=1
 BEND NAME=B020, ID=1.744, NONSTANDARD, *
 ANGLE=180, RADIUS=5.99936, KMUL=12, *
 ROUGH(IN)=2.000e-004,HOMOG
 PIPE NAME=P020, LENGTH(FT)=0.3333, ECHG=-0.3333, *
 55 ID=1.744, U=1
 BEND NAME=B021, ID=1.744, NONSTANDARD, *
 ANGLE=90, RADIUS=5.99936, KMUL=12, *
 ROUGH(IN)=2.000e-004,HOMOG
 PIPE NAME=P021, LENGTH(FT)=1.275, ID=1.744, *
 60 U=1

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BEND NAME=B022, ID=1.744, NONSTANDARD, *
  ANGLE=90, RADIUS=5.99936, KMUL=12, *
  ROUGH(IN)=2.000e-004,HOMOG
5  PIPE NAME=P022, LENGTH(FT)=0.3333, ECHG=0.3333, *
  ID=1.744, U=1
  BEND NAME=B023, ID=1.744, KMUL=12, *
  ROUGH(IN)=2.000e-004,HOMOG
  BEND NAME=B024, ID=1.744, NONSTANDARD, *
10  ANGLE=180, RADIUS=5.99936, KMUL=12, *
  ROUGH(IN)=2.000e-004,HOMOG
  PIPE NAME=P023, LENGTH(FT)=0.2738, ECHG=-0.2738, *
  ID=1.744, U=1, FCODE=BMHV
  $D~TEE NAME=T007, IDPIPE=1.744, KMUL=16
  $D~TEE NAME=T008, IDPIPE=1.744, KMUL=16
15  PIPE NAME=P024, LENGTH(FT)=0.2738, ECHG=0.2738, *
  ID=1.744, U=1
  BEND NAME=B025, ID=1.744, KMUL=12, *
  ROUGH(IN)=2.000e-004,HOMOG
20  PIPE NAME=P025, LENGTH(FT)=0.3333, ECHG=-0.3333, *
  ID=1.744, U=1
  BEND NAME=B026, ID=1.744, NONSTANDARD, *
  ANGLE=90, RADIUS=5.99936, KMUL=12, *
  ROUGH(IN)=2.000e-004,HOMOG
  PIPE NAME=P026, LENGTH(FT)=1.275, ID=1.744, *
25  U=1
  BEND NAME=B027, ID=1.744, NONSTANDARD, *
  ANGLE=90, RADIUS=5.99936, KMUL=12, *
  ROUGH(IN)=2.000e-004,HOMOG
  PIPE NAME=P027, LENGTH(FT)=0.3333, ECHG=0.3333, *
30  ID=1.744, U=1
  BEND NAME=B028, ID=1.744, NONSTANDARD, *
  ANGLE=180, RADIUS=5.99936, KMUL=12, *
  ROUGH(IN)=2.000e-004,HOMOG
  PIPE NAME=P028, LENGTH(FT)=0.2738, ECHG=-0.2738, *
35  ID=1.744, U=1
  $D~TEE NAME=T009, IDPIPE=1.744, KMUL=16
  $
  LINK NAME=L003, FROM=J002, TO=D000
  $D~EXPANSION NAME=E003, IDIN=1.744, IDOUT=3.02
40  PIPE NAME=P030, LENGTH(FT)=0.87, ID=3.02, *
  ISOTHERMAL
  $ End of keyword file...
  END

```

Chisolm Model:Keyword File Name: **TRIAL3_ACT_DATA_CHIS_BMHV_K14meter.inp**

```

5      $ SIMSCI PIPEPHASE Version 9.1 keyword file...
      $
      $      General Data Section
      $
10     TITLE DATE=06/07/06
      $
      $
      DIMENSION SI, TEMPERATURE=C, PRESSURE=BAR, *
      LENGTH=FT,IN
15     $
      CALCULATION NETWORK, Compositional, PRANDTL
      $
      FCODE PIPE=BBHV
      $
20     DEFAULT IDPIPE=4.026, IDTUBING=4.026, IDRISER=4.026, *
      IDANNULUS=6.065, ROUGH(IN)=1.8000e-005, *
      HAUSEN
      $
      PRINT INPUT=FULL, DEVICE=PART, CONNECT=NONE, *
25     MERGESUB, ITER, DATABASE=NONE,PROPERTY=FULL, *
      SIMULATOR=PART
      $
      SEGMENT AUTO=OFF, DLHORIZ(FT)=1, DLVERT(FT)=500, *
      MAXSTEPS=2000
30     $
      LIMITS PRES(MIN)=1.000e-003
      $
      $      Component Data Section
      $
35     COMPONENT DATA
      $
      LIBID 1, H2O / *
      2, AIR
      PETRO(KGM3) 3, c7+,300,750.0
40     $
      PHASE VL=1,2

      $
      $      Network Data Section
45     $
      NETWORK DATA
      $
      SOLUTION PBALANCE, FLOWAL=2, STEP=1, *
      QDAMP=10, HALVINGS=1
50     $
      TOLERANCE PRESSURE=1.000e-005
      $
      $      Thermodynamic Data Section
      $
55     THERMODYNAMIC DATA
      $
      METHOD SET=SET01, SYSTEM=SRK
      $

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WATER PROPERTY=Super
 \$
 KVALUE BANK=SimSci
 \$
 5 \$ PVT Data Section
 \$
 PVT PROPERTY DATA
 \$
 SET SETNO=1, SET=SET01
 10 \$
 \$ Structure Data Section

 15 \$
 STRUCTURE DATA
 \$
 SOURCE NAME=S000, PRIORITY=0, SETNO=1, *
 20 \$SET=SET01, PRES=2.285677266, TEMP=31.37, * \$23kgs/line 2
 \$RATE(est, W)=82811.08914, XCORD=0, YCORD=-688, * \$23kgs/line 2
 \$COMP(M)=1, 0.999999808 / 2, 1.91884E-07/3, 0 \$23kgs/line 2
 \$
 \$SET=SET01, PRES=1.631911817, TEMP=31.5756866, * \$15kgs/line 2
 25 \$RATE(est, W)=53952.91437, XCORD=0, YCORD=-688, * \$15kgs/line 2
 \$COMP(M)=1, 0.999999678 / 2, 3.22461E-07/3, 0 \$15kgs/line 2

 SET=SET01, PRES=1.942586675, TEMP=31.5756866, * \$19kgs/line 2
 RATE=53952.91437, XCORD=0, YCORD=-688, * \$19kgs/line 2
 30 COMP(M)=1, 0.999999856 / 2, 1.43789E-07/3, 0 \$19kgs/line 2
 \$
 SINK NAME=D000, *
 \$PRES=1.537303089, RATE(ESTI)=1000, * \$23kgs/line 2
 \$PRES=1.248341963, RATE(ESTI)=1000, * \$15kgs/line 2
 35 PRES(est, W)=1.377834393, RATE(ESTI)=1000, * \$19kgs/line 2
 XCORD=1769, YCORD=-719
 \$
 JUNCTION NAME=J001, XCORD=791, YCORD=-704
 JUNCTION NAME=J002, XCORD=1294, YCORD=-706
 40 \$
 \$
 LINK NAME=L000, FROM=S000, TO=J001, *
 XCOR=583,380,266, YCOR=-641,-650,-647
 PIPE NAME=P000, LENGTH(FT)=0.87, ID=3.02, *
 45 U=1
 \$D~CONTRACTION NAME=C001, IDIN=3.02, IDOUT=1.744, *
 \$D~ ANGLE=7.30103
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 LINK NAME=L001, FROM=J001, TO=J002, *
 50 XCOR=1146,1003,909, YCOR=-604,-604,-615
 \$D~TEE NAME=T002, IDPIPE=1.744, KMUL=16
 REGULATOR NAME=R002, PRES=999
 PIPE NAME=P007, LENGTH(FT)=0.2738, ECHG=0.2738, *
 ID=1.744, U=1
 55 BEND NAME=B009, ID=1.744, NONSTANDARD, *
 ANGLE=180, RADIUS=5.99936, KMUL=14.35347, * \$16, * \$12, *
 ROUGH(IN)=2.000e-004 \$, HOMOG
 PIPE NAME=P008, LENGTH(FT)=0.3333, ECHG=-0.3333, *
 ID=1.744, U=1
 60 BEND NAME=B010, ID=1.744, NONSTANDARD, *

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ANGLE=90, RADIUS=5.99936, KMUL=14.35347,* \$16,* \$12, *
ROUGH(IN)=2.000e-004 \$,HOMOG
PIPE NAME=P009, LENGTH(FT)=1.275, ID=1.744, *
U=1
5 BEND NAME=B011, ID=1.744, NONSTANDARD, *
ANGLE=90, RADIUS=5.99936, KMUL=14.35347,* \$16,* \$12, *
ROUGH(IN)=2.000e-004 \$,HOMOG
PIPE NAME=P010, LENGTH(FT)=0.3333, ECHG=0.3333, *
ID=1.744, U=1
10 BEND NAME=B012, ID=1.744, KMUL=14.35347,* \$16,* \$12, *
ROUGH(IN)=2.000e-004 \$,HOMOG
BEND NAME=B013, ID=1.744, NONSTANDARD, *
ANGLE=180, RADIUS=5.99936, KMUL=14.35347,* \$16,* \$12, *
ROUGH(IN)=2.000e-004 \$, HOMOGENEOUS
15 PIPE NAME=P011, LENGTH(FT)=0.2738, ECHG=-0.2738, *
ID=1.744, U=1, FCODE=BMHV
SD~TEE NAME=T003, IDPIPE=1.744, KMUL=16
SD~TEE NAME=T004, IDPIPE=1.744, KMUL=16
PIPE NAME=P012, LENGTH(FT)=0.2738, ECHG=0.2738, *
20 ID=1.744, U=1
BEND NAME=B014, ID=1.744, KMUL=14.35347,* \$16,* \$12, *
ROUGH(IN)=2.000e-004 \$,HOMOG
PIPE NAME=P013, LENGTH(FT)=0.3333, ECHG=-0.3333, *
ID=1.744, U=1
25 BEND NAME=B015, ID=1.744, NONSTANDARD, *
ANGLE=90, RADIUS=5.99936, KMUL=14.35347,* \$16,* \$12, *
ROUGH(IN)=2.000e-004 \$,HOMOG
PIPE NAME=P014, LENGTH(FT)=1.275, ID=1.744, *
U=1
30 BEND NAME=B016, ID=1.744, NONSTANDARD, *
ANGLE=90, RADIUS=5.99936, KMUL=14.35347,* \$16,* \$12, *
ROUGH(IN)=2.000e-004 \$,HOMOG
PIPE NAME=P015, LENGTH(FT)=0.3333, ECHG=0.3333, *
ID=1.744, U=1
35 BEND NAME=B017, ID=1.744, NONSTANDARD, *
ANGLE=180, RADIUS=5.99936, KMUL=14.35347,* \$16,* \$12, *
ROUGH(IN)=2.000e-004 \$,HOMOG
PIPE NAME=P016, LENGTH(FT)=0.2738, ECHG=-0.2738, *
ID=1.744, U=1
40 SD~TEE NAME=T005, IDPIPE=1.744, KMUL=16
\$
LINK NAME=L002, FROM=J001, TO=J002
SD~TEE NAME=T006, IDPIPE=1.744, KMUL=16
REGULATOR NAME=R001, PRES=999
45 PIPE NAME=P019, LENGTH(FT)=0.2738, ECHG=0.2738, *
ID=1.744, U=1
BEND NAME=B020, ID=1.744, NONSTANDARD, *
ANGLE=180, RADIUS=5.99936, KMUL=14.35347,* \$16,* \$12, *
ROUGH(IN)=2.000e-004 \$,HOMOG
50 PIPE NAME=P020, LENGTH(FT)=0.3333, ECHG=-0.3333, *
ID=1.744, U=1
BEND NAME=B021, ID=1.744, NONSTANDARD, *
ANGLE=90, RADIUS=5.99936, KMUL=14.35347,* \$16,* \$12, *
ROUGH(IN)=2.000e-004 \$,HOMOG
55 PIPE NAME=P021, LENGTH(FT)=1.275, ID=1.744, *
U=1
BEND NAME=B022, ID=1.744, NONSTANDARD, *
ANGLE=90, RADIUS=5.99936, KMUL=14.35347,* \$16,* \$12, *
ROUGH(IN)=2.000e-004 \$,HOMOG
60 PIPE NAME=P022, LENGTH(FT)=0.3333, ECHG=0.3333, *

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ID=1.744, U=1
 BEND NAME=B023, ID=1.744, KMUL=14.35347,* \$16,* \$12, *
 ROUGH(IN)=2.000e-004 \$,HOMOG
 BEND NAME=B024, ID=1.744, NONSTANDARD, *
 5 ANGLE=180, RADIUS=5.99936, KMUL=14.35347,* \$16,* \$12, *
 ROUGH(IN)=2.000e-004 \$,HOMOG
 PIPE NAME=P023, LENGTH(FT)=0.2738, ECHG=-0.2738, *
 ID=1.744, U=1, FCODE=BMHV
 \$D~TEE NAME=T007, IDPIPE=1.744, KMUL=16
 10 \$D~TEE NAME=T008, IDPIPE=1.744, KMUL=16
 PIPE NAME=P024, LENGTH(FT)=0.2738, ECHG=0.2738, *
 ID=1.744, U=1
 BEND NAME=B025, ID=1.744, KMUL=14.35347,* \$16,* \$8, *
 ROUGH(IN)=2.000e-004 \$,HOMOG
 15 PIPE NAME=P025, LENGTH(FT)=0.3333, ECHG=-0.3333, *
 ID=1.744, U=1
 BEND NAME=B026, ID=1.744, NONSTANDARD, *
 ANGLE=90, RADIUS=5.99936, KMUL=14.35347,* \$16,* \$12, *
 ROUGH(IN)=2.000e-004 \$,HOMOG
 20 PIPE NAME=P026, LENGTH(FT)=1.275, ID=1.744, *
 U=1
 BEND NAME=B027, ID=1.744, NONSTANDARD, *
 ANGLE=90, RADIUS=5.99936, KMUL=14.35347,* \$16,* \$12, *
 ROUGH(IN)=2.000e-004 \$,HOMOG
 25 PIPE NAME=P027, LENGTH(FT)=0.3333, ECHG=0.3333, *
 ID=1.744, U=1
 BEND NAME=B028, ID=1.744, NONSTANDARD, *
 ANGLE=180, RADIUS=5.99936, KMUL=14.35347,* \$16,* \$12, *
 ROUGH(IN)=2.000e-004 \$,HOMOG
 30 PIPE NAME=P028, LENGTH(FT)=0.2738, ECHG=-0.2738, *
 ID=1.744, U=1
 \$D~TEE NAME=T009, IDPIPE=1.744, KMUL=16
 \$
 LINK NAME=L003, FROM=J002, TO=D000
 35 \$D~EXPANSION NAME=E003, IDIN=1.744, IDOUT=3.02
 PIPE NAME=P030, LENGTH(FT)=0.87, ID=3.02, *
 ISOTHERMAL

 \$ End of keyword file...
 40 \$
 END

WHAT IS CLAIMED IS:

1. A system comprising:
a Coriolis flowmeter configured to determine a first property of a multi-phase fluid;
a flow model configured to determine a second property of the multi-phase fluid; and
5 a determination system configured to determine a third property of the multi-phase fluid based, at least in part, on the first property and the second property.
2. The system of claim 1 further comprising a sensor configured to sense a fourth property associated with the multi-phase fluid, wherein the flow model is configured to
10 determine the second property based on the fourth property.
3. The system of claim 2 wherein the fourth property is a pressure associated with the multi-phase fluid.
- 15 4. The system of claim 2 wherein the fourth property is a temperature associated with the multi-phase fluid.
5. The system of claim 1 wherein:
the Coriolis flowmeter is configured to determine a fourth property of the multi-phase
20 fluid; and
the determination system is configured to determine the third property of the multi-phase fluid based, at least in part, on the first property, the second property, and the fourth property.
- 25 6. The system of claim 1 wherein the first property is a bulk density of the multi-phase fluid, the second property is a water-cut or gas void fraction of the multi-phase fluid, and the fourth property is a bulk mass flow rate of the multi-phase fluid.
7. The system of claim 1 wherein the third property is a mass flow rate or a
30 volumetric flow rate of a component of the multi-phase fluid.
8. A system comprising:

a bulk density determination system to determine a bulk density of a multi-phase fluid;

a mass flow rate determination system to determine a bulk mass flow rate of the multi-phase fluid;

5 a pressure sensor configured to determine a pressure associated with the multi-phase fluid;

a flow model configured to determine water-cut or gas void fraction of the multi-phase fluid based, at least in part, on the sensed pressure;

10 a flow rate determination system to determine a flow rate of at least one component of the multi-phase fluid based on the bulk density, the bulk mass flow rate, and the water-cut or gas void fraction.

9. A method comprising:

determining a first property of a multi-phase fluid using a Coriolis flowmeter;

15 determining a second property of the multi-phase fluid using a mathematical model of a flow of the multi-phase fluid through a conduit; and

determining a third property of the multi-phase fluid based, at least in part, on the first property and the second property.

20 10. The method of claim 9 further comprising determining a fourth property associated with the multi-phase fluid, wherein determining the second property comprises inputting the fourth property into the mathematical model.

25 11. The method of claim 10 wherein the fourth property is a pressure associated with the multi-phase fluid.

12. The method of claim 10 wherein the fourth property is a temperature associated with the multi-phase fluid.

30 13. The method of claim 9 further comprising determining a fourth property of the multi-phase fluid, wherein determining the third property of the multi-phase fluid comprises determining the third property based, at least in part, on the first property, the second property, and the fourth property.

14. The method of claim 9 wherein the first property is a bulk density of the multi-phase fluid, the second property is a water-cut or gas void fraction of the multi-phase fluid, and the fourth property is a bulk mass flow rate of the multi-phase fluid.

5 15. The method of claim 9 wherein the third property is a mass flow rate or a volumetric flow rate of a component of the multi-phase fluid.

16. A method comprising:
determining a bulk density of a multi-phase fluid;
10 determining a bulk mass flow rate of the multi-phase fluid;
determining a pressure associated with the multi-phase fluid; and
determining a flow rate of at least one component of the multi-phase fluid based on the bulk density, the bulk mass flow rate, and the pressure.

15 17. The method of claim 16 wherein determining a flow rate of at least one component of the multi-phase fluid based on the bulk density, the bulk mass flow rate, and the pressure comprises:

determining a water-cut or gas void fraction of the multi-phase fluid based, at least in part, on the pressure; and

20 determining a flow rate of at least one component of the multi-phase fluid based on the bulk density, the bulk mass flow rate, and the water-cut or gas void fraction.

18. The method of claim 17 wherein determining the water-cut or gas void fraction of the multi-phase fluid based, at least in part, on the pressure comprises using a flow
25 model to determine the water-cut or gas void fraction based on the pressure.

19. A method comprising:
determining a bulk density of a multi-phase fluid using a Coriolis flowmeter, the Coriolis flowmeter including a flowtube;
30 determining a bulk mass flow rate of the multi-phase fluid using a Coriolis flowmeter;
determining an inlet pressure of the multi-phase fluid at an inlet of the flowtube;
determining an outlet pressure of the multi-phase fluid at an outlet of the flowtube;
determining an inlet temperature of the multi-phase fluid at the inlet of the flowtube;

determining a water-cut or gas void fraction of the multi-phase fluid based on the bulk density, the bulk mass flow rate, the inlet pressure, the outlet pressure, and the inlet temperature; and

5 determining a flow rate of at least one component of the multi-phase fluid based on the bulk density, the bulk mass flow rate, and the water-cut or gas void fraction.

20. The method of claim 19 wherein determining the water-cut or gas void fraction of the multi-phase fluid comprises using a mathematical model of a flow of the multi-phase fluid through the flowtube to determine the water-cut or gas void fraction of the multi-phase fluid based on the bulk density, the bulk mass flow rate, the inlet pressure, the
10 outlet pressure, and the inlet temperature.

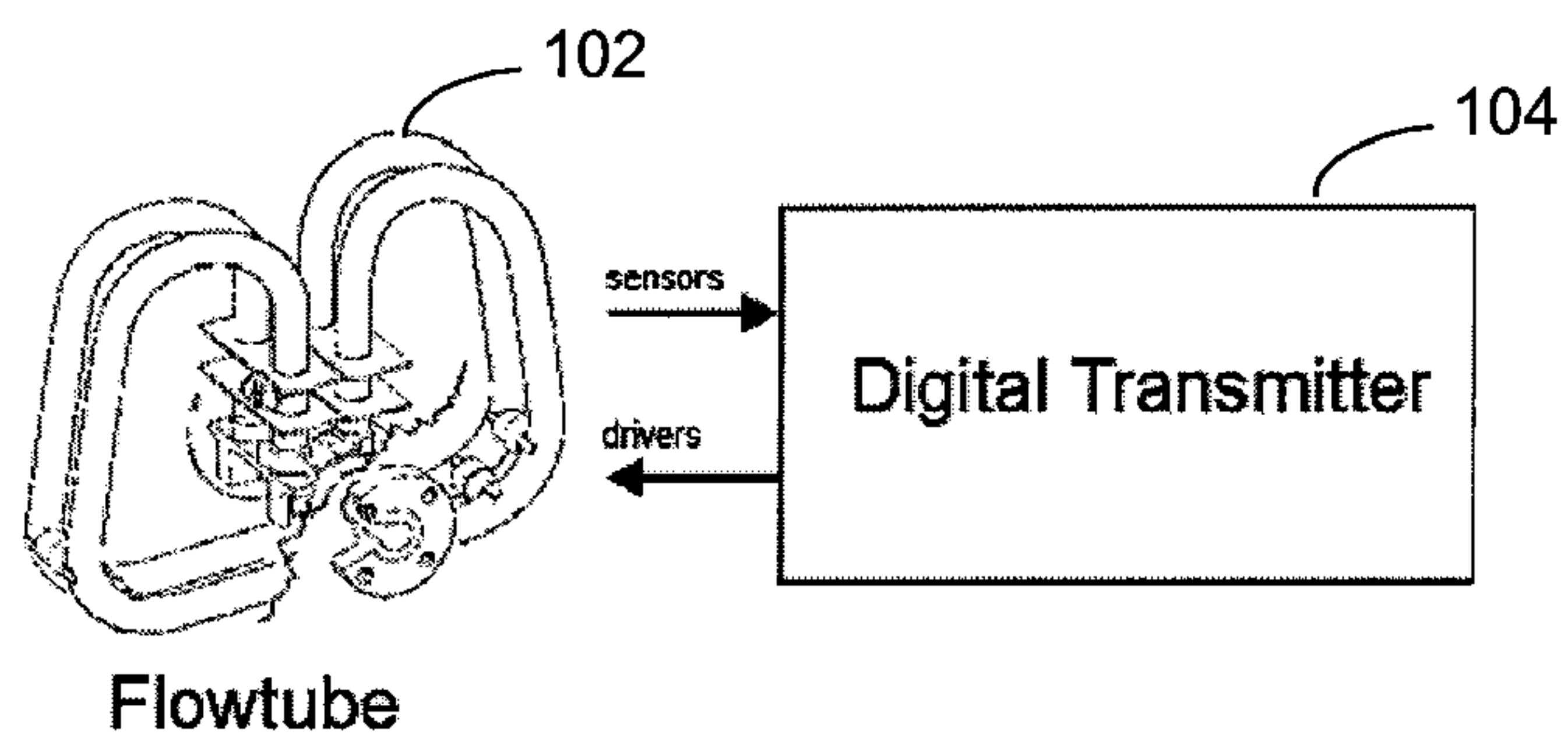


FIG. 1A

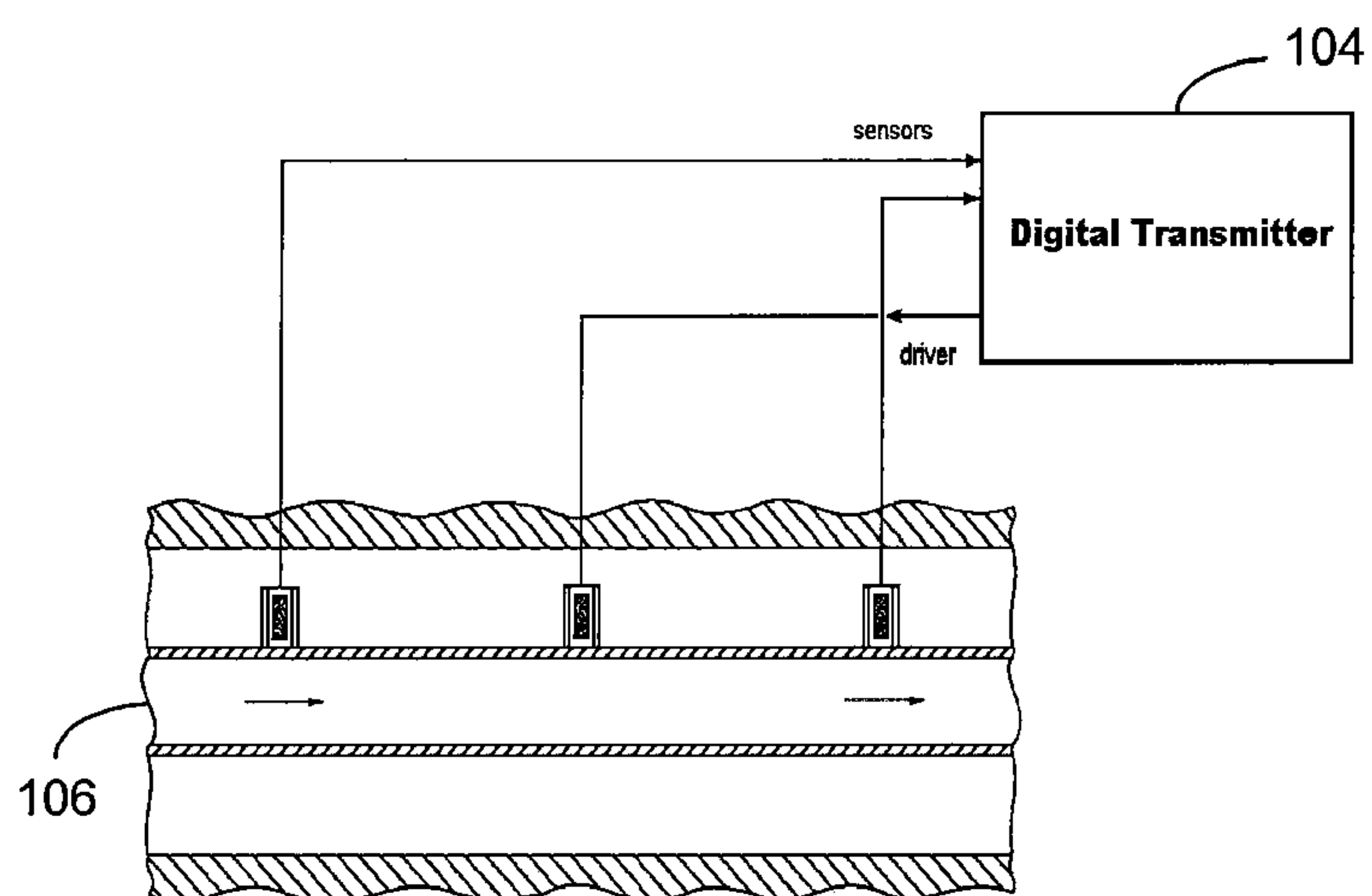


FIG. 1B

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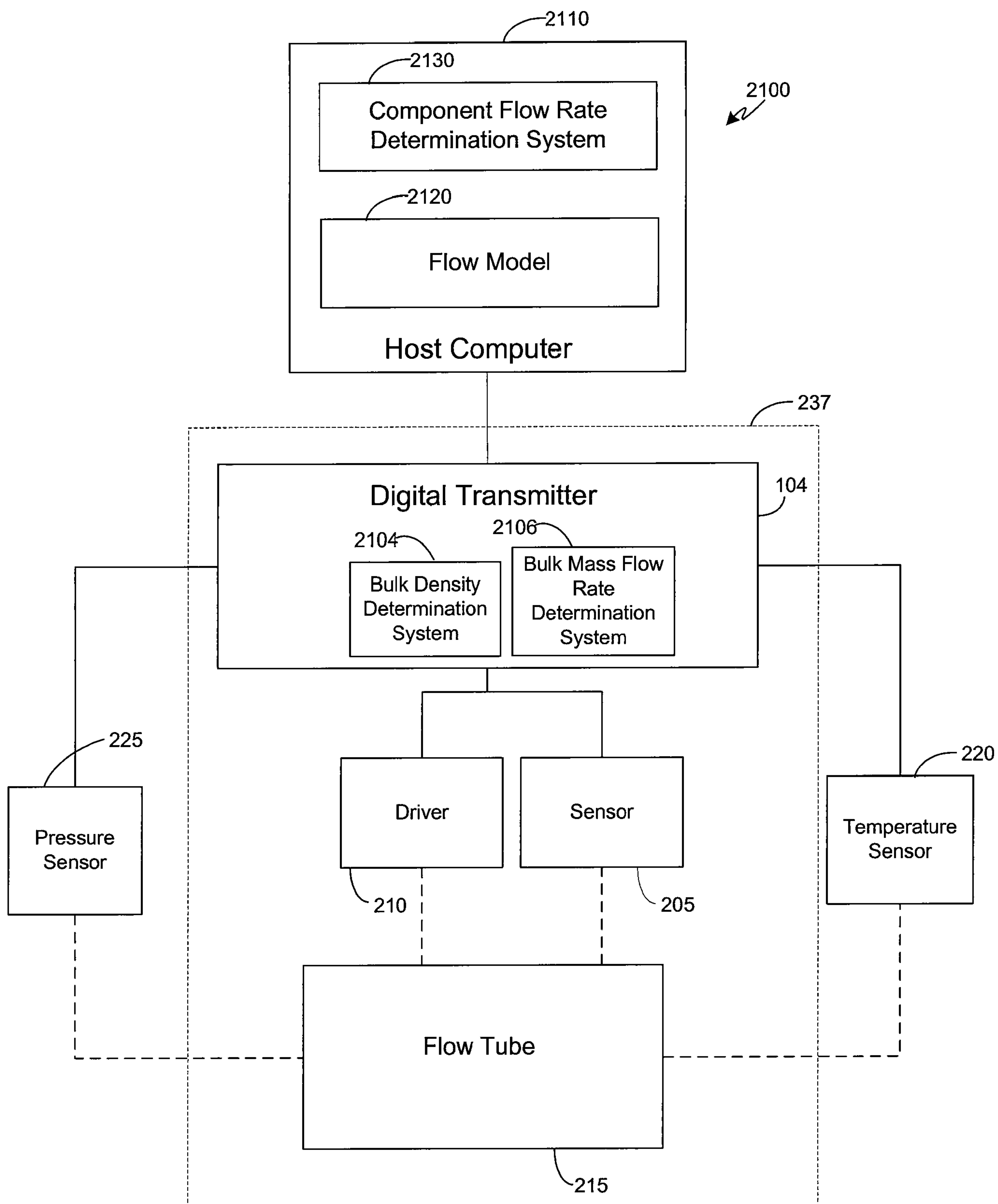


FIG. 2

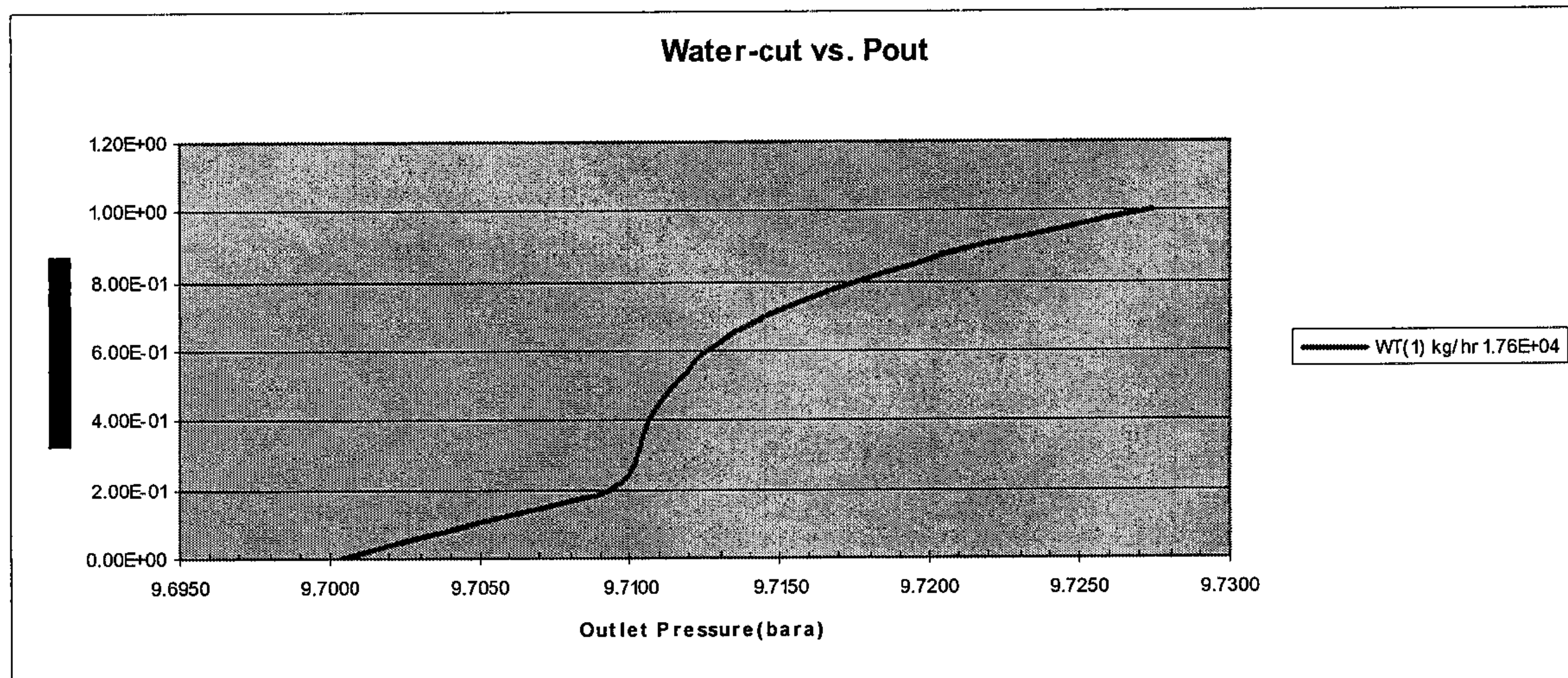


FIG. 3A

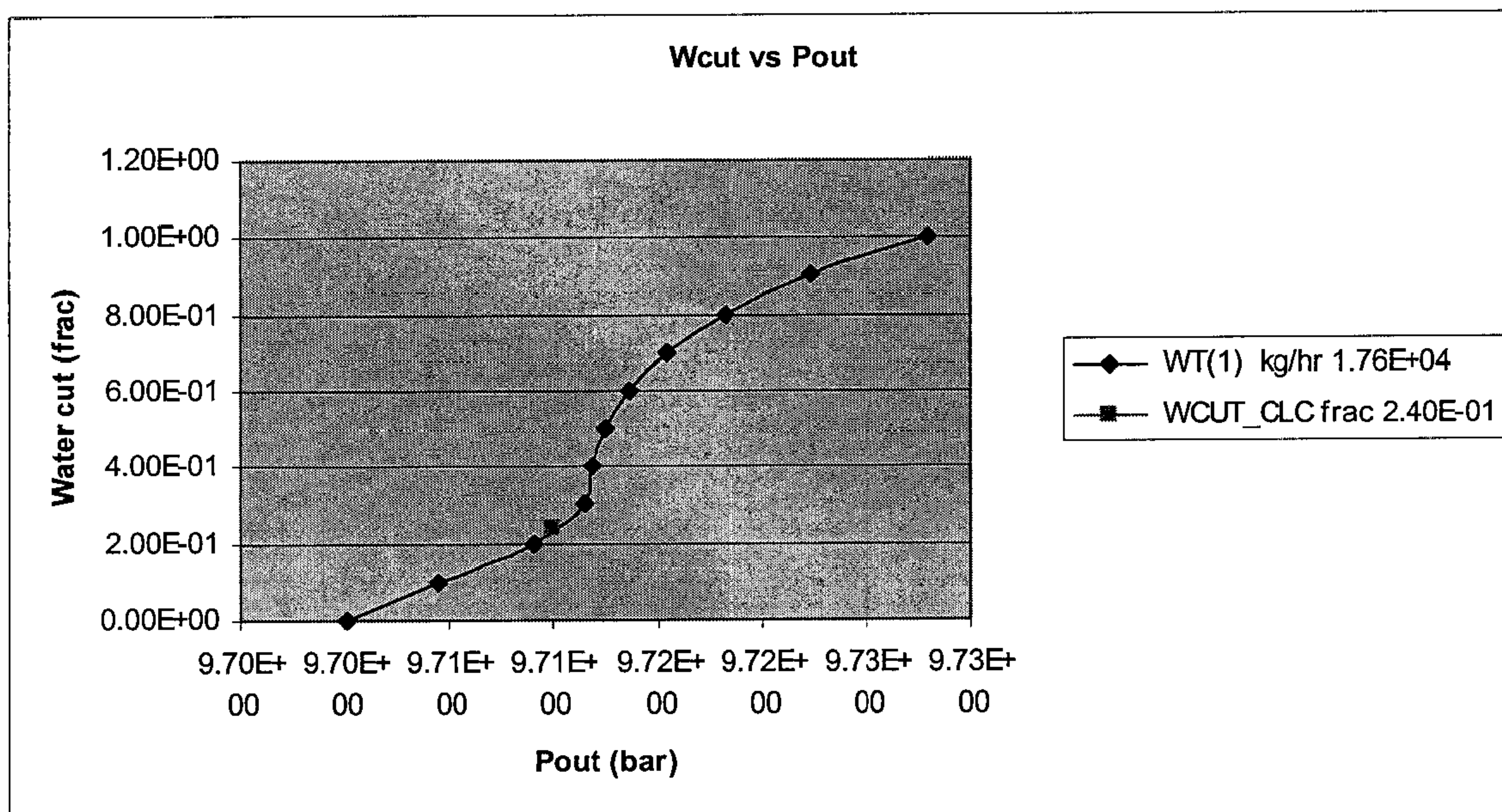


FIG. 3B

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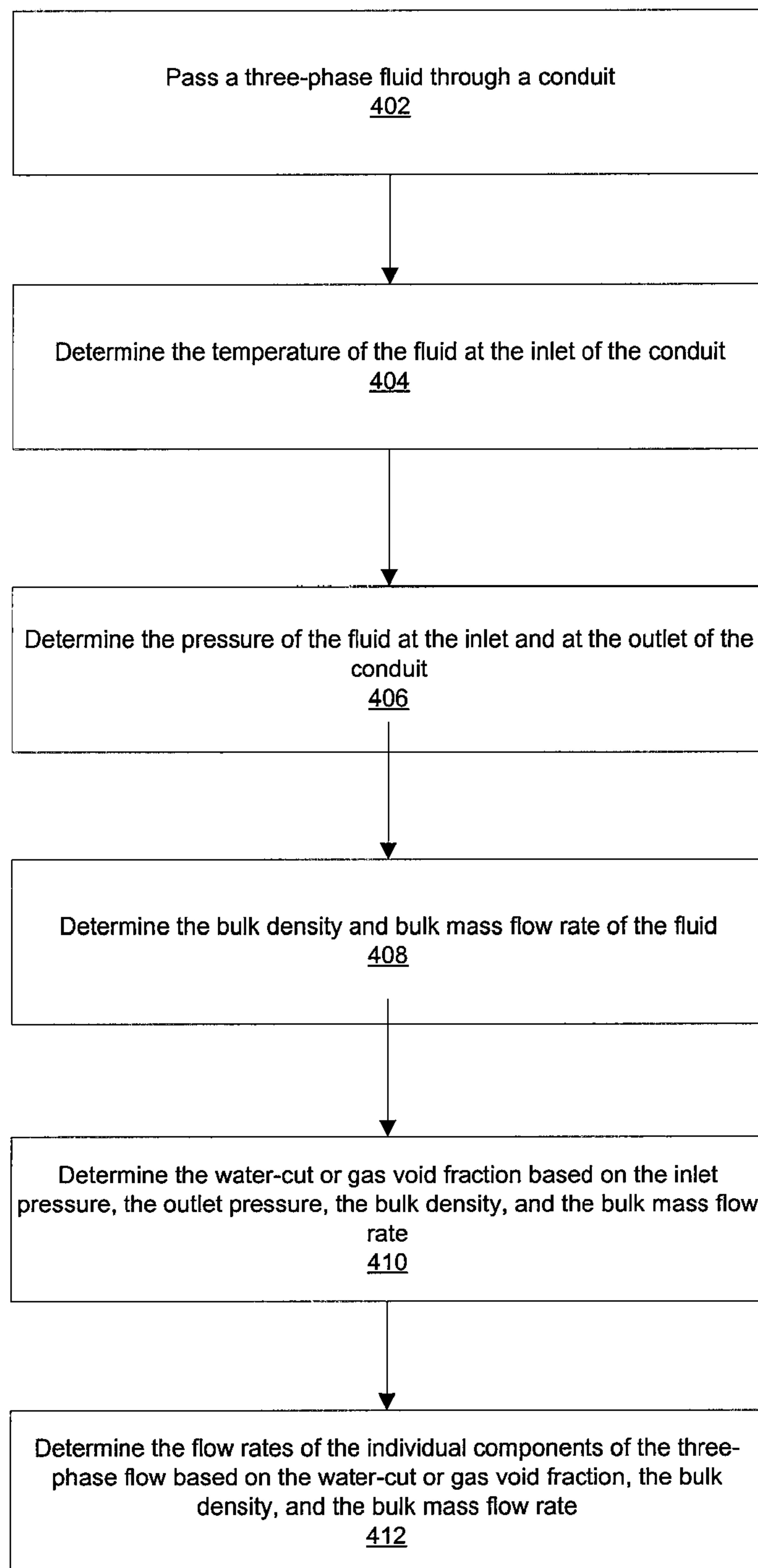
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FIG. 4

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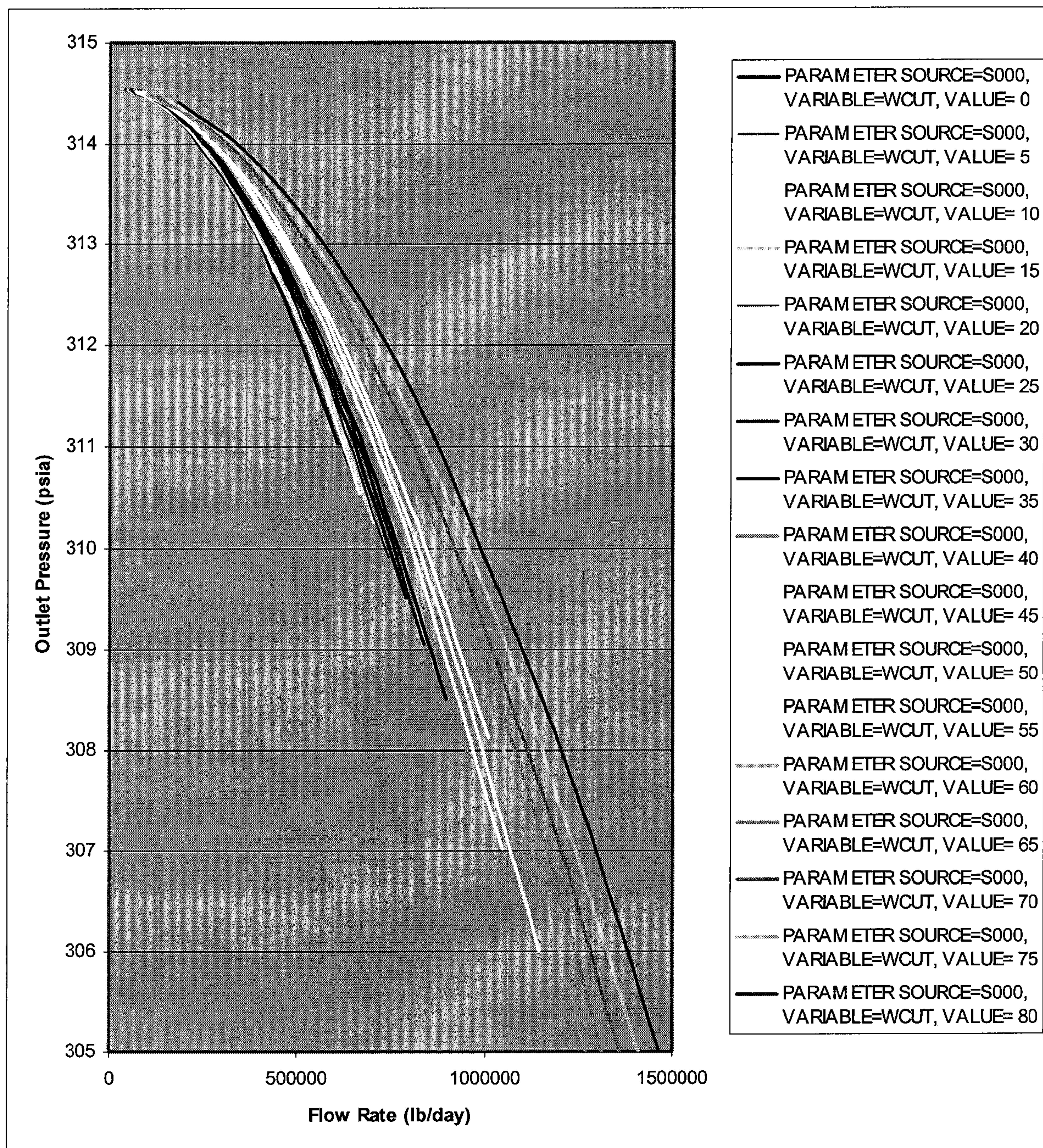
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FIG. 5

