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ATOMIC ENERGY
OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE
DU CANADA LIMITÉE

RADIOTRACER TECHNIQUES FOR MEASURING FLUID FLOW AND CALIBRATING FLOW METERS

TECHNIQUES DES RADIOTRACEURS POUR LA MESURE DE L'ÉCOULEMENT DE FLUIDES ET L'ÉTALONNAGE DES DÉBITMÈTRES

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RÉSUMÉ

On peut employer les techniques des radiotraceurs pour mesurer avec précision les débits de gaz et de liquides, dans des conditions de service, d'une grande variété de circuits d'écoulement. Elles conviennent parfaitement pour l'étalonnage des débitmètres ainsi que pour la mesure des écoulements non mesurés d'installations industrielles. Les applications de ces techniques s'étendent de la mesure des écoulements de combustibles et fluides industriels pour les études de bilan d'énergie et de masse à la mesure des écoulements de liquides et d'effluents en suspension dans l'air pour la limitation de la pollution.

Dans ce rapport, on décrit les diverses techniques des radiotraceurs qu'on peut employer pour mesurer les écoulements de fluides. En outre, on y examine le champ d'application et la précision inhérente de chaque technique.

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ABSTRACT

Radiotracer techniques can be used to measure accurately both gas and liquid flow rates under operating conditions in a wide range of flow systems. They are ideally suited for calibrating flow meters as well as for measuring unmetered flows in industrial plants. Applications of these techniques range from measuring the flows of fuels and process fluids for energy and mass balance studies to measuring the flows of liquid and airborne effluents for pollution control.

This report describes the various radiotracer techniques which can be used to measure fluid flows. The range of application and inherent accuracy of each technique is discussed.

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1. INTRODUCTION

Modern industries require a wide range of flow measurements in order to operate efficiently. Flow meters form an integral part of the control systems in the chemical process industries. Metering errors can lead to increased start up costs and can prolong periods of inefficient operation after start up. In addition, accurate flow measurements are needed for proper accounting and to ensure optimum efficiency in production. The general state of metering in a plant often becomes apparent when energy or mass balances are studied. Although such studies can detect the overall problem, they rarely point out which particular meter or meters are in error. Thus some means of proving individual meters is required.

Plants must purchase large amounts of raw meterials and energy to carry on production and, of course, they have to sell their products. When fluids are bought and sold custody transfer meters must be used to accumulate the charges. Since the quantities transferred are large and profit margins on bulk materials tend to be low, even small metering errors can lead to large losses which hurt overall plant profitability. When disputes arise it is often costly and disruptive to have the meters proved unless costly in-line provers have been installed. Quite clearly there is a need for a cheaper and less disruptive method to prove these meters.

Environmental protection legislation is becoming increasingly restrictive as politicians respond to the public's demands to get tough with polluters. More industries are finding that they must account for the total amount of pollutants released through their liquid effluents or airborne emissions in order to comply with government regulations. This means having to install and periodically calibrate flowmeters or to verify stack flows.

Radiotracer methods can be used to measure fluid flows under a wide range of conditions and circumstances in industrial plants. Since the measurements can be taken in situ with only minor invasions into the systems, they cause virtually no disruption of normal operations. The measurements are accurate and differ in principle from conventional meters so that they are ideal for proving existing meters. These methods can also be used to measure unmetered flows.

The use of radiotracers for flow measurements has been well established in the scientific and engineering literature. National and international standards (1 to 8) have been published covering the application of these methods. Radiotracer methods are used regularly in countries such as the U.K., the U.S.A. and the European countries.

2. Methods of Flow Measurement Using Radiotracers

2.1 Dilution Methods

2.1.1 Constant-Rate Dilution Method

In the constant-rate dilution method the tracer, with known concentration C_1, is introduced into the system at a constant rate, q, as shown schematically in Figure 1. The tracer mixes with the fluid in the pipe and is diluted to a lower concentration C_2. The concentration C_2 is then measured at a point downstream where mixing of the tracer is essentially complete (>99%). If the radiotracer emits penetrating gamma radiation, then the concentration could be measured from outside the pipe. More commonly, the concentration of tracer is determined by sampling the fluid stream and analysing the samples either on-line or later off-line.

The injection of tracer is continued until the system is saturated and the concentration C_2 reaches a steady state as shown in Figure 2a). Under steady state conditions the fluid rate Q is given by the relation:

$$Q = q \frac{C_1}{C_2}$$

The constant-rate dilution method is very versatile since the results do not depend on the channel geometry and it is not necessary to determine conditions inside the channel (such as T and P for gases) in order to calculate flow rates under standard conditions. By using suitable injection and sampling equipment this method can be used to measure gas or liquid flows in systems under either low or high pressures. It is particularly suitable for measuring flows in systems such as open channels, stacks, ventilation systems, and process systems with irregular piping or internal deposits. This method has even been used to measure the flow of large rivers.

Constant-rate dilution can also be used in systems with branches. If samples are collected at a point downstream, where the incoming flows have fully mixed, then the total flow at that point can be measured. If a single stream branches into two or more streams after the tracer is fully mixed, then the flow before the branches can be measured by sampling any of the branches provided that the fluid has not been further diluted by more incoming fluid after the branch. It is even possible to measure flow rates at several locations in the system by using a single injection of tracer.

The main disadvantage of dilution methods is the need for a second access point, since the concentration C_2 is usually measured by sampling. This may limit its application in some process systems unless the necessary ports have been installed during a shut-down. However, there is generally no such limitation in more accessible systems such as open channels or ventilation systems. In order to achieve accurate results, the fluid flow rate should remain constant during a substantial part of the injection period so that a steady state concentration can be achieved. In many cases it is possible to control the flow rates so that they remain steady during the relatively short injection period. Another limitation of the dilution method is the need for very good mixing of the tracer in the fluid. Mixing is most commonly achieved by injecting far enough upstream of the sampling point so that the natural turbulence of the system will provide adequate mixing. Where this is not possible, other techniques often can be used to enhance the mixing rate.

2.1.2 Integration Method

Another method of measuring fluid flow based on tracer dilution is the integration or sudden injection method. In this method a known amount of tracer, is injected over a short period of time. The channel is sampled at a point downstream where the tracer has mixed uniformly with the fluid across the channel cross-section. With this method a steady-state condition is not achieved and the tracer passes the sampling point as a pulse, as shown in Figure 2b. The fluid stream is sampled throughout the entire period that tracer is present at the sample point. Since all the tracer passes the sample point the equation for the flow rate can be derived from the tracer mass balance:

$$M = Q \int_{0}^{t} C_2 \, dt. \qquad (2.2)$$

where M = Volume of Tracer x tracer concentration (C_1)

Several methods can be used to sample the stream. A series of samples can be collected in sequential time periods during the passage of the tracer and the integral on the right side of equation (2.2) can be evaluated from the tracer concentrations in these samples. Alternatively, multiple grab samples or a continuous recording of C_2 could be used to define C_2 as a function t and the curve could then be integrated numerically. Perhaps the simplest method is to collect a continuous sample at a constant rate q, starting some time before t_1 and ending some time after t_2. The flowrate can then be determined from the average concentration in the entire sample. If this method is used, it is advisable to have some other measurement of C_2 as a function of t to verify that the sampling period encompassed the entire duration of the tracer pulse.

The integration method has many of the advantages of the constant rate method. In addition, less tracer is generally required and the conditions under which the tracer is injected are much less critical. However, the integration method is subject to large errors if the sampling is not done properly. It is essential that sampling is started before the tracer arrives at the sampling point and that it is stopped only after the tracer concentration has declined to background levels. Since steady state is not achieved with the integration method it is not possible to obtain replicate flow measurements by repeated sampling during the plateau in concentration and it is more difficult to detect the presence of variations in flow during the injection period.

The conditions which are necessary for accurate flow measurements using dilution methods are summarized in Table 1.

2.2 Transit Time Method

In the Transit Time method the tracer is introduced into the system as a short pulse. This pulse travels with the fluid in the pipe and is monitored at least two locations downstream with detectors mounted outside the pipe as shown in Figure 3. The computer measures the time required for the pulse to pass between the two detectors, which is called the Transit Time (t). If the volume (V) of the pipe between the detector is determined, then the volume flow rate (VF) can be calculated from the relation:

$$VF = \frac{V}{t}$$

The inside diameter (ID) of the pipe can be calculated from the outside diameter if the wall thickness is determined ultrasonically, and the length of pipe between the detectors can be measured with sufficient accuracy with a tape measure. Then the volume (V) of pipe between the detectors is calculated from the equation:

$$V = \left(\frac{ID}{2}\right)^2 \cdot \pi \cdot L$$

Ideally the length of pipe between the detectors should be straight and uniform. However, a few bends and elbows will not materially affect the accuracy of the method. Devices such as valves or orifices which will change the fluid conditions in the pipe must not be situated between the detectors. Branches ahead of the detectors lead to some loss of tracer but do not affect the measurement of flow rate between the detectors.

The Transit Time method is used to calculate the volume flow of fluids under the conditions present in the pipe. In the case of gases, the measurement of standard volume flow (SVF) is usually required. In order to convert to standard conditions, the pressure (P) and temperature (T) in the volume of pipe between the detectors must be measured. The standard volume flow is then calculated from:

$$SVF = VF \cdot \frac{P}{T} \cdot \frac{T_s}{P_s} \qquad (2.5)$$

where T_s = standard temperature
P_s = standard pressure
and T_s and T are measured in ^{o}R (Rankine) or K (Absolute)

If the mass flow rate (MF) of a liquid is desired, then the density (ρ) of the fluid within the pipe must be determined. The mass flow is calculated from the equation:

$$MF = \rho \cdot VF$$

With the Transit Time method, the amount of tracer injected is not critical and generally less tracer is required. Complete mixing usually is not essential and the detection efficiency need not be known. In addition, only a single access port is required in the system and often an existing vent or drain can be used. Because of these advantages, the Transit Time method can readily be applied in a variety of systems and it has been the most widely used method for measurements of process systems. The disadvantages are that the pipe volume between the detectors must be known accurately and the fluid conditions (P and T or ρ) must be measured.

The conditions which need to be present for the Transit Time method to be applied are summarized in Table 2.

3. Calibrating Flow Meters

In order to calibrate flow meters the meter readings are compared to the flow rate determined by a reference method. Radiotracer methods can be conveniently used as reference methods since they are accurate and can be used in situ with minimum process disruption. The meter biases (MB) are calculated from the following equation:

$$MB = \frac{(\text{meter reading} - \text{reference flow}) \times 100\%}{\text{reference flow}}$$

A negative meter bias indicates an underestimation of flow while positive bias indicates that flow is being overestimated by the meter.

The reference flows obtained with the Transient Time method are averaged over a period normally ranging from about 0.5 second to hundreds of seconds depending on the flow velocity and distance between the detectors. Repeat measurements can be taken by injecting successive tracer pulses at intervals of several minutes. Dilution methods usually give flow measurements over periods from a few minutes up to 10 or 20 minutes.

Ideally the flow rates should be steady while the meter is being calibrated so that repeated injections can be used to show the consistency of the measurements. If flows are varying rapidly or pulsing (over a few seconds or less), then the averaging times of the meter and the reference method may not be the same. Such mismatches lead to varying meter biases. Sometimes the meter averaging times can be decreased by reading the meter manually at the instant of injection. If varying readings are obtained, then a larger number of injections can be used to obtain a better average meter bias but it may be more difficult to demonstrate the consistency of the results.

4. Accuracy of Radiotracer Flow Measurements

The accuracy of radiotracer flow measurements has been tested by comparing measurements of gas flow with a primary standard method under ideal conditions (9). The results of this work demonstrated that the Transit Time method agreed with the standard method to within 0.2%, 70% of the time. Similar errors were also found for the Constant-rate Dilution method. The accuracy of the radiotracer methods under actual field conditions depends on the system being measured and the sources of these errors are discussed in more detail in Annex I. In general the ultimate accuracy of these measurements under field conditions is limited by the installation being tested. In most cases errors of 1 and 2% can be routinely achieved in the field. However, with extra care and effort even greater accuracy is possible in some cases.

5. Advantages of Radiotracers

The tracer methods described in this report were originally developed using non-radioactive tracers. Such tracers include fluorescent dyes, trace metal and halide ions and even common salt. The use of radioisotopes as tracers offers a number of distinct advantages over using non-radioactive tracers.

Radiotracers can easily be measured at extremely low mass concentrations and the background concentrations are normally zero. Thus the mass of radiotracer needed for flow measurements is very small and there is essentially no interference with the system being studied. This is in sharp contrast with non-radioactive tracers where many kilograms of tracer may be required and large volumes of tracer solution must be used.

Many radiotracers emit penetrating radiation which can readily be detected remotely, even through steel walls and insulation. The use of such radiotracers allows the Transit Time method to be applied in closed systems. This would not be practical with any other type of tracer.

Radiotracers are available in a wide variety of chemical and physical forms so they can readily be tailored to be compatible with the fluids in the system being measured. Available radiotracers include isotopes of inert gases, radioisotopes of common and trace elements, oil soluble compounds and even radio-labelled water. Because they emit ionizing photons and particles, radiotracers can be measured without the interferences encountered in measuring other types of tracers. Thus, the use of radiotracers can overcome the most frequent problems encountered with other tracers, ie. being incompatible, degraded, or absorbed by the other materials present in the system or being masked by interferences or high backgrounds.

6. Safety Considerations

All work with ionizing radiation and radioisotopes is controlled by national regulatory agencies whose regulations are based on the principles of radiation protection which have been developed by international expert bodies. In Canada the use of radioisotopes is strictly controlled by the Atomic Energy Control Board (AECB) which must be convinced that any particular use of radioisotopes is beneficial and does not pose any significant hazard to members of the public. The AECB reviews the qualifications of those who will be performing the work and maintains a staff of inspectors who review the procedures used and periodically observe the work in the field. The terms and conditions of Radioisotope licenses regulate the types and amounts of radioisotopes which can be used and sets limits on radiation and contamination levels. The licence conditions also control the disposal of waste and ensure that safe work practices are observed.

All handling of radioisotopes must be done by suitably trained personnel who are generally classified as atomic radiation workers. Every effort must be made to ensure that doses to the plant personnel and other members of the public are trivial and radiation dosimeters must be provided to any plant staff who may be exposed to radiation in the course of the work. The radioisotopes used for radiotracer studies are specifically selected for their very low radiotoxicity or short half-lives so that there will be no significant hazard from residual radioactivity at the end of the work.

The doses received by members of the public through the use of radioisotopes as industrial tracers are extremely low compared to those received from other sources such as natural background radiation, medical procedures and industrial radiography.

7. Coordination of Work Onsite

The measurement of fluid flow rates onsite requires close cooperation between plant personnel and those doing the measurements. The plant will generally designate staff to coordinate the work and to ensure that local administrative and safety procedures are followed. In order to achieve maximum efficiency and provide the lowest costs there must be a clear definition of the responsibilities of both parties beforehand and everything must be prepared before the radiotracer crew arrives at the plant site. Each installation should be examined and relevant information should be sent to the radiotracer crew for evaluation. Annex II provides some guidance on the type of information which will be required for closed piping systems.

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ANNEX I

Sources of Error

A) Sources of Error in Flow Measurements using the Transit Time Method

In the Transit Time Method flow rates are determined from the time it takes a pulse of tracer to pass through a known volume of pipe. The flow rate under the conditions present in the pipe is calculated using the equation:

$$\text{Volume flow rate (VF)} = \frac{V}{\Delta t}$$

where: Δt is the time required for the pulse to pass the detectors (transit time)
V is the volume of the pipe between the two detectors (measuring selection)

The volume, V is calculated from the equation:

$$V = L.\left(\frac{D}{2}\right)^2.\pi$$

where: L = the distance between the two detectors
D = the inside diameter of the pipe

Errors in the Calculation of Volume Flow

1. Errors in Pipe Volume

Ideally the measuring section should be in a straight section of pipe, uninterrupted by fittings. In this case the length can easily be measured with an error of <1% by using a metal tape measure. Simple pipe fittings such as couplings or elbows can be present in the measuring section without affecting the timing; however, the presence of the fittings means a number of lengths needed to be measured which could increase the overall error. Of course the volumes of the fittings themselves must also be included in the total volume. Fittings which restrict the fluid flow (valves, orifices, etc.) may change the fluid conditions (P and T for gases) significantly and must not be present in the measuring section, although they may be present ahead of the measuring section.

The pipe diameter may be determined by measuring the pipe outside diameter and measuring the wall thickness ultrasonically. It is important that the diameter and wall thickness be measured at a sufficient number of locations to ensure that the average inside diameter is truly representative.

The determination of pipe volume is also affected by the presence of any scale or other deposit inside the pipe. Likewise any dead spaces in the measuring section will lead to errors in the flow measurements. Errors in volume lead to systematic errors in the flow measurements in a given system.

2. Errors in Measurement of the Transit Time (Δt)

The measurement of the transit time is subject to a number of errors. Although the mixing of the tracer with the fluid stream is less critical for the Transit Time Method, it is still important that the tracer be adequately mixed with a short length of fluid in the pipe. This can be achieved by allowing sufficient distance between the injection point and the first detector. Ideally this distance should be on the order of 100 pipe diameters. More rapid mixing can be achieved through the use of high velocity injection jets. Likewise, pipe fittings (elbows, valves, orifices, etc.) will also promote rapid mixing.

As the pulse of radiotracer from each injection passes each detector it causes an increase followed by a decrease in the count rate. These peaks in the detector responses can be seen when the count rates from the detectors are recorded as a function of time after the injection. This recording is done with multichannel scalers which use a very stable, crystal controlled time base.

The transit time is determined from the peaks in the responses from the detectors mounted on the measuring sections. A characteristic point is found for each peak by using the methods outlined in the ISO standards. The same method is used for each peak to minimize the error in the transit time.

The detectors used for the measurements should have response which is proportional to the mean radiotracer concentration in the pipe. The effects of errors in detector response can be minimized by using matched detectors of high efficiency and adequate count-rate response. In large diameter systems several detectors may be required at each position. It is important that the electronics be quite stable because changes in detector response can lead to errors. Also sufficient tracer must be used to give a good response above the background.

Timing becomes most critical in difficult systems where the velocity is high and the measuring section is short. In such systems it is important that the injections are precise and that the mixing is rapid. The time scales which are used to record the detector responses must also be optimized. Timing errors of 1 to 2% have been achieved with transit times as low as several hundred milliseconds.

The Transit Time Method provides a measurement of fluid flow averaged over a finite period of time. Depending on the fluid velocity and the length of the measuring section this can vary from 1 second to hundreds of seconds or more. If the flow is varying then the average flow is estimated by making a number of measurements of the transit time. The mean and the random error in the measurement are then estimated from these individual measurements. However, it is not possible to distinguish random errors in the timing measurements from random fluctuations in the flow using this procedure.

Errors in the Calculations of Standard Volume or Mass Flows

The volume flows of gases determined by the transit Time Method are converted from the pipe conditions to standard conditions by using the equation:

$$\text{Standard Volume Flow (SVF)} = VF \cdot \frac{P}{T} \cdot \frac{T_s}{P_s}$$

where: VF is the volume flow under pipe conditions
P and T are the pressure and temperature respectively inside the pipe
P_s and T_s are the standard pressure and standard temperature respectively.

Thus errors in the measurement of P and T lead to errors in the standard volume flow rates. The errors in P can be particularly significant at low pressures; however, errors in temperature are less significant since the temperatures are in ^{o}R or K. In many cases the pressure can be measured at the injection point using a gauge or transducer. In some systems the fluid conditions may change between the injection point and the first detector so that the plant's pressure measurements may have to be used. The equipment used for pressure measurements must be calibrated against known pressures across its range.

Temperatures can be measured with a digital thermometer. In some situations the temperature can be measured at the injection point while in others it can be measured downstream by placing the probe under the pipe insulation or into another access point in the line.

Mass flow is calculated from the volume flow using the following equation:

$$\text{Mass flow (MF)} = VF \cdot \rho$$

where: ρ is the fluid density. The fluid density is generally based on measurements made by the plant's laboratory.

B) Sources of Error in Flow Measurements using Dilution Methods

With dilution methods the flow rate is determined from the degree of dilution of the added tracer in the fluid stream. The equation giving the flow rate for the constant rate dilution method is:

$$Q = q \frac{C_1}{C_2}$$

It can be seen from this equation that the dilution is determined by the ratio, C_1/C_2. This ratio can be measured very precisely by determining the ratio of the concentration of a standard dilution of C_1 to the concentration in the channel, C_2. With adequate care, the ratio can be determined with an error of less than 1%. The tracer flowrate q can be determined by measuring the mass or volume of tracer delivered by a very stable injector during the injection period (t). Alternatively, the delivery rate of the injector could be carefully calibrated against a reference method in the laboratory. In either case the error in q can easily be kept below 1%.

The accuracy of dilution methods also depends on the degree to which the tracer is mixed with the fluid stream. In most cases the natural turbulence in the stream will give adequate mixing provided that there is sufficient distance between the injection and sampling points. Where the natural turbulence is inadequate it may be possible to introduce additional turbulence into the system. The rate of mixing can also be enhanced by metering the tracer through several injection ports spaced across the stream. Finally, the error introduced by inadequate mixing can be corrected by collecting multiple samples across the fluid stream. In most cases, the error due to mixing can be kept to 1% or less. With the constant-rate dilution method the injection period must be long enough to reach a steady concentration of tracer in the fluid stream. The time required to reach steady state is a function of the system being tested; however, in most simple systems the time required will be 10 minutes or less. If steady state has not been reached then this will be apparent from the plot of C_2 versus time.

The greatest potential source of error in dilution gauging is due to variation of the fluid flow rate during the measurement period. In many cases it is possible to control the flow rate during the relatively short measurement period. Where this is not possible, we can often improve the chances of obtaining an accurate measurement by prolonging the injection period. A suitable period of steady flow can then be determined from the resultant plot of C_2 vs time.

With the integration method the flow rate is calculated from the basic equation:

$$M = VC_1 = Q\int_0^t C_2 \, dt.$$

The derivation of flow rate, Q from this equation will depend on the sampling method chosen; however, the flowrate will ultimately be a function of a dilution ratio which can be determined with an error of 1% or less. The integration method is also subject to errors due to poor mixing and variations in fluid flow rates. Thus, much of the discussion given above for the constant-rate method also holds for the integration method. With the integration method changes in fluid flow rate may not be readily apparent from the plot of C_2 as a function of time and caution should be used in applying this method in systems with varying flow rates.

C) Errors in Calibrating Flow Meters

Calibrating flow meters involves comparing the meter readings with flow measurements obtained by some other method such as the Transit Time Method or a dilution method. The objective is to obtain the systematic error in the meter which can be expressed as a meter bias:

$$\text{Meter Bias (MB)} = \frac{\text{Meter Reading} - \text{Reference Flow}}{\text{Reference Flow}} \times 100\%$$

If a Radiotracer Method is used to obtain the reference flow, then the meter bias obtained from individual injections will be a function of:

1. systematic meter error
2. random meter error
3. systematic errors in the Radiotracer Method
4. random errors in the Radiotracer Method
5. mismatches in the averaging times of the meter and the Radiotracer Method

Many common meters, such as orifice meters, measure fluid flow by creating a pressure drop. The flow measurement is given by the product of a coefficient and the square root of a function of the differential pressure. Because of the square root relationship the errors tend to become large in the lower portion of the normal range. The systematic meter error (1) could arise from an error in the meter coefficient in which case the meter bias would remain constant with the meter reading. Alternatively the systematic error may occur in the square root relationship and the meter bias may change with the meter reading. Part of the random meter error (2) arises from the random error in reading the pressure differential. This would lead to random errors in the meter bias which would become proportionately larger at lower readings because of the square root relationship. A similar situation exists for flumes and weirs where the flow rate is related to a level measurement.

The systematic and random errors in the Radiotracer Methods (3 and 4) are discussed earlier. Usually these errors are less than 1 to 2%.

In calculating the meter biases in system where the flow is fluctuating we must also consider the effect of mismatches in averaging times (5). This would appear as a random fluctuation in the meter bias. The averaging time of many meters can be decreased by taking instantaneous meter readings rather than the computer averaged readings. However, there still may be differences in the inherent meter averaging time and the duration of each tracer injection.

For the best meter calibrations, measurements should be taken over a range of flows up to 100% of full scale on the meter and the flows should be stable during the injections. This is difficult to achieve in practice without interrupting the process system. Thus, in most cases, a number of flow measurements must be made with the flow rate at its current operating point and the average meter bias calculated to obtain the best estimate of the systematic error. In general a significant meter bias is indicative of problems with the meter installation or the sensing instrumentation. These problems must be isolated and corrected before the meter can be properly calibrated.

ANNEX II

DATA SHEET

Identification of Installation: ______________________

Piping Characteristics:

Inside Diameter ______________________

Length of Uniform Pipe Available ______________________

Fittings ______________________

Distance from Injection Port ______________________

Accessibility ______________________

____

Injection Port:

Type ______________________

Connection - Type ______________________

- Size ______________________

Accessibility ______________________

____

Fluid:

Type ______________________

Temperature ______________________

Pressure ______________________

Density ______________________

Viscosity ______________________

Flow Rates:

Minimum ______________________

Maximum ______________________

Average ______________________

Is 115 VAC power available? ______________________

include line diagram of installation on reverse side.

TABLE 1

Conditions Necessary for Using Dilution Methods

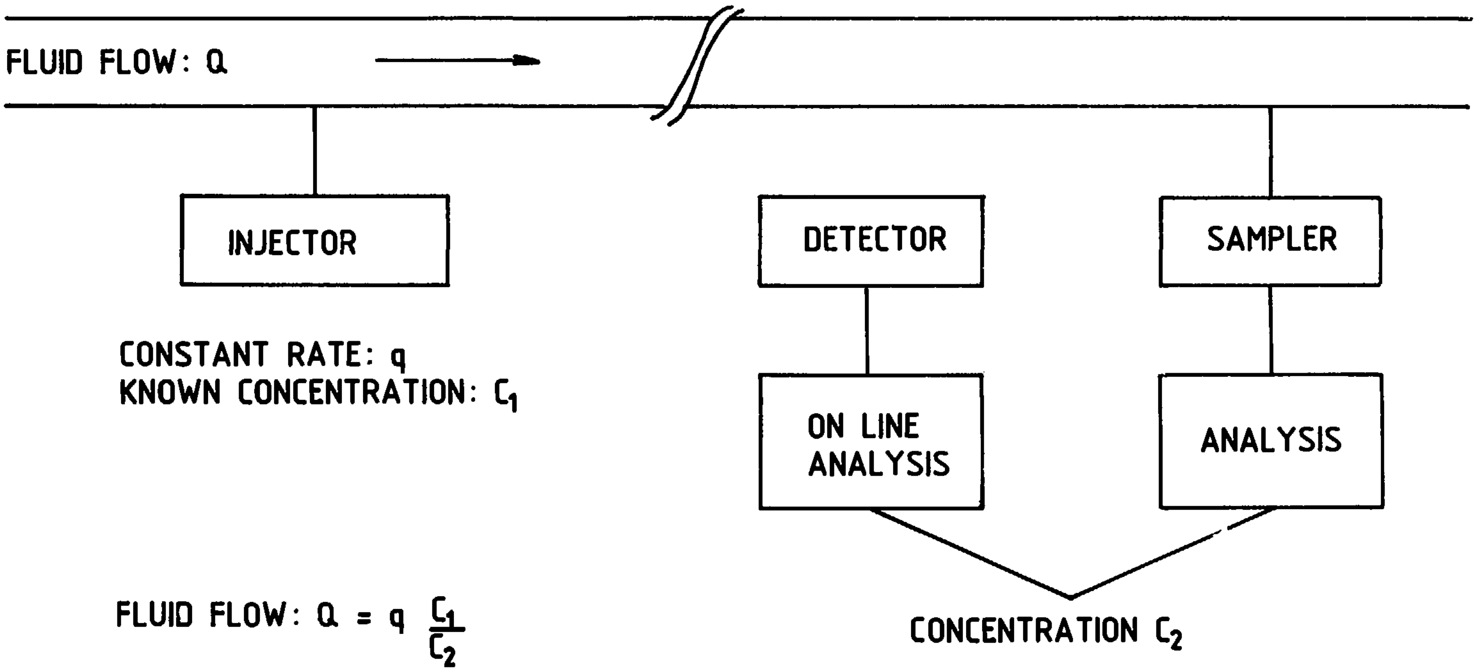
1. Suitable injection and sampling points must be present in the flow system.
2. The distance between the injection and sampling points should be sufficient for adequate mixing (usually ≈ 100 diameters for turbulent flow in pipes)
3. The flow must be turbulent or the mixing distance will be excessively long.
4. The fluid flow rate should be steady during the measurement period.

TABLE 2

Conditions for using the Transit Time Method

1. A suitable injection point must be present in the line where the measurement is to be taken.
2. A mixing distance of 50 to 100 pipe diameters should be available between the injection point and the first detector.
3. A uniform length of pipe at least 50 diameters long should be available for mounting the detectors.
4. The volume of pipe between the detectors must be known to within 1%.
5. The fluid flow should be turbulent, although in some cases it has been possible to measure laminar flow.
6. The fluid conditions within the length of pipe between the detectors must be measurable if standard volume or mass flow rates are desired.

FIGURE 1 MEASUREMENT OF FLUID FLOW USING RADIOTRACERS - DILUTION METHOD



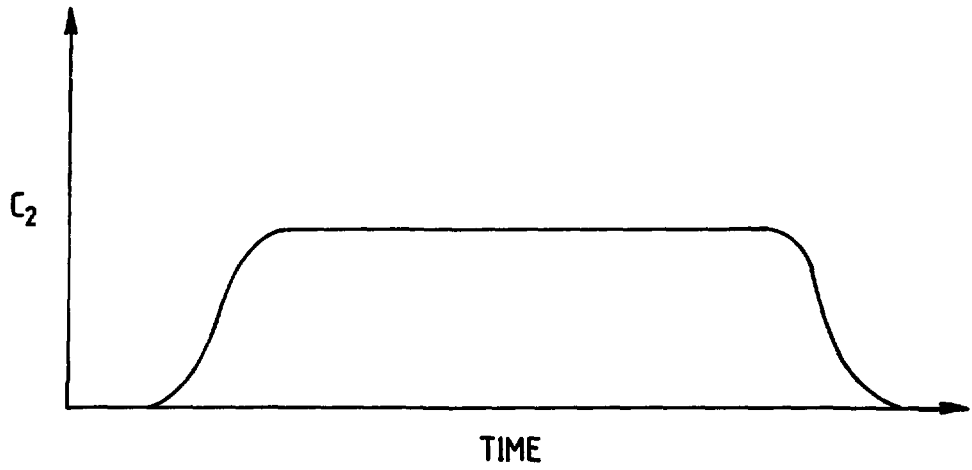


FIGURE 2a) TRACER CONCENTRATION (C_2) AS A FUNCTION OF TIME: CONSTANT-RATE DILUTION METHOD

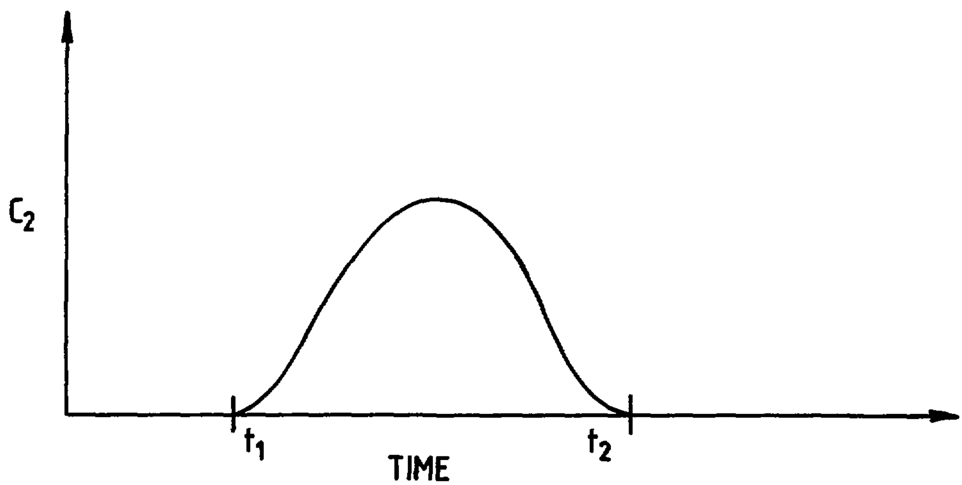
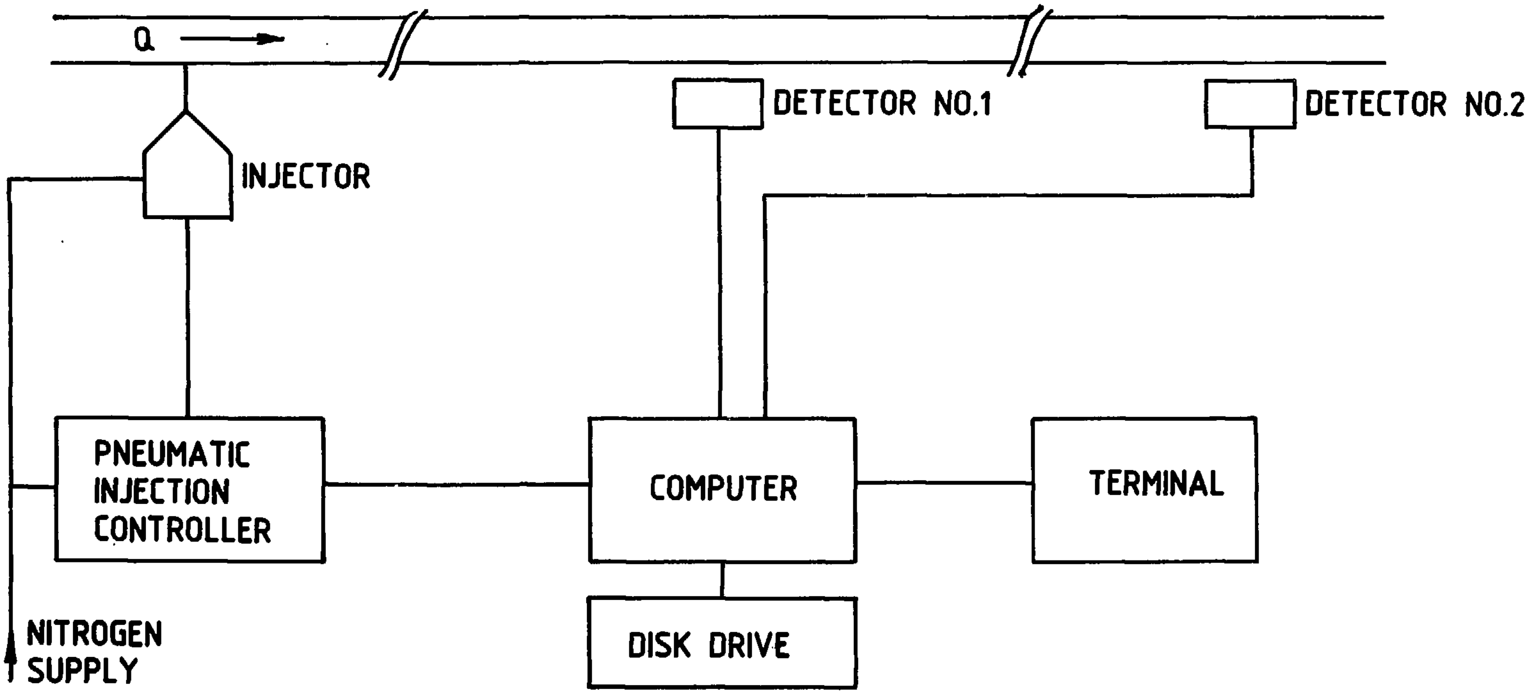


FIGURE 2b) TRACER CONCENTRATION (C_2) AS A FUNCTION OF TIME: INTEGRATION METHOD

FIGURE 3   MEASUREMENT OF FLUID FLOW USING RADIOTRACERS - TRANSIT TIME METHOD



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