

# ISOKINETIC TESTING FOR AIR POLLUTION CONTROL IN SOUTH AFRICAN INDUSTRY

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## SUMMARY:

This is an exposition of the practical issues raised when isokinetic sampling is attempted on industrial stacks and deals with problems raised by: very large flues; very hot flues; very wet gases.

## OPSOMMING:

Hierdie referaat gee 'n voorbeeld van die moeilikhede wat teegewerk moet word wanneer 'n mens te doen het met die meet van stofdeeltjie digtheid binne in groot industriële pype en skoorstene.

## INTRODUCTION

The paper attempts to illustrate test procedures and methods necessary to facilitate isokinetic sampling in industry generally. However, whilst the well known concept of "to measure is to know" is often quoted, physical measurements in the field are difficult to perform. In this latter regard it is relatively easy to discuss sampling in the lecture room or laboratory, however to carry out such sampling on-site is no mean feat, being an arduous task and requiring both considerable experience and tenacity. The first need for carrying out isokinetic sampling is to assemble a test team which must be prepared to work through meal periods, expect to be subject to the wrath of the elements, have a good head for heights and "asbestos hands", i.e. be prepared for handling hot sampling probes. Whilst in my experience it is not necessary for every member of the test team to be employed in the disciplines of physics or chemistry, it is necessary that they have a good working knowledge of sampling techniques or alternatively prior experience on sampling projects. The ease with which an isokinetic sampling project is carried out is mainly dependent upon the ability of test personnel to work as a team and to be attentive at all times. This latter aspect is important because one can expect to be testing on-site for more than eight consecutive hours, depending upon the nature of the sampling project. Finally, by way of an introduction, I would point out that to facilitate isokinetic sampling it is important to have good liaison between plant operating personnel and the test team, in order to ensure that the required optimum plant conditions prevail during testing. It is painful experience to learn, after spending considerable time and energy on performing an isokinetic test, (possibly in inclement weather) that plant operating staff either switched out the plant, reduced loading or adjusted parameters, which directly affected the gas cleaning plant.

## ISOKINETIC SAMPLING

I think it necessary for the benefit of the layman to define the term "isokinetic sampling" and to digress on the need to sample isokinetically (where possible) on all industrial sources. The term isokinetic simply means to sample at the same velocity at the sampling probe nozzle, as that of the stack gas velocity at the point of measurement. Failure to observe this condition results in sampling which is termed anisokinetic and, except in the case of very fine particles, this results in an inaccurate collected mass determination,

(coarse grit particles tend to persist in their direction of motion and are not easily diverted by either a converging or diverging gas stream). Whether the sample is collected isokinetically or anisokinetically is solely dependent upon the suction applied at the sampling apparatus.

If the suction is too high, resulting in a high nozzle inlet velocity, then due to inertia of the larger particles these will not follow the gas stream flow lines and therefore be deflected around the nozzle. These sampling conditions will be responsible for the mass of particulate matter collected being lower than true mass. Alternatively if the suction is too low, resulting in a low inlet velocity, then the lighter particles will be deflected around the nozzle whilst the heavier particles flow directly into the nozzle. This latter sampling condition will result in the mass of particulate collected being in excess of the mass actually present at the point of sampling.

It has been found that inertia directly effects larger particles, this becomes more significant when particle size exceeds 3 microns. Therefore if a goodly proportion of particles in a gas stream exceed 3 microns in size it is important to sample isokinetically. Whilst a number of authorities give formulae and expressions for converting the mass of particulate collected, or the resultant concentrations (mass/volume of gas sampled), from anisokinetic to isokinetic conditions, I believe that results that obtained are not a true reflection of actual concentrations. This is because most of these expressions tend to correct the nozzle velocity and stack gas velocity to suit the mass collected, when in actual fact what is required is a detailed study of the homogeneity of the material being sampled and its characteristics of collection.

I do however believe that repetitive sampling on an individual test basis could result in a value being obtained for a true concentration of a specific material, providing that plant loadings and gas cleaning conditions were consistent for all tests. However to obtain repeatable results the material sampled and conveying gas constituents would have to be such as to enable accurate collected mass determinations. In this latter regard the material should not be hygroscopic and matrix forming, whilst the gases should be relatively dry and low in sulphur content.

Finally to conclude on Sampling, I would advocate the maintenance of isokinetic flow rates wherever possible (normally on dry particulate emissions this is very feasible).

However difficulties do arise on wet particulate emissions, either due to extremely low dynamic heads and their interpretation, or alternatively very high velocities (up to 44 m/s have been experienced). In this case, pressure drop across the sampling train inhibits the maintenance of the required sampling rate across the control orifice of flowmeter.

#### TYPE OF EMISSIONS AND CLASSIFICATION

Every emission from industry which contributes to atmospheric pollution can be classified and ultimately referred to as a specific type. Further; the diversity of industry necessitates that different types of gas cleaning plant be deployed. For example certain emissions are best controlled by electrostatic precipitation, whilst other necessitate dry collection with cyclones or bag filters. Further the nature of certain other particulate matter necessitates some form of wet scrubbing. Hence the type of gas cleaning plant deployed varies with the requirements of a specific industry and the capital investment available in that industry, for expenditure on gas cleaning equipment. Often two or more different types of gas cleaning plant will be deployed on a single installation or industrial site.

Therefore from the point of view of measurement, one cannot expect that an emission will be the same from a similar or even a related industry. Hence the first requirement before agreeing to undertake isokinetic sampling is to ascertain the source e.g. Power Generation Industry – ash and dust, Pulp & Paper Industry – wet scrubbed particulates and gases, and the metallurgical industry – dry hot dust before spray towers and bag filter units. The second requirement is to plan accordingly, to sample either a wet or dry emission, or ones which border on the molecular.

Finally in my experience it has often been found that the most difficult types of emissions to classify have been those emanating from the Fertilizer and chemical Industries. For these industries it has been prudent to evaluate the suitability of different types of sampling apparatus before actual testing.

#### ISOKINETIC TESTING LOCATIONS

The correct sighting of a location from which to conduct isokinetic testing is of extreme importance from the point of:

- a) finding a suitable ducting stack cross-section conforming to laid down Test Standards.
- b) the accessibility of such a location.

Regarding a) there are a number of such laid down standards available which emanate from Germany, U.S.A. and Britain. Possibly the most widely used of these standards is BS 3405 "Simplified Methods for measurement of grit and dust emission" or the later BS 893 "Method for the measurement of the Concentration of Particulate Material in Ducts Carrying Gases", subcript 6.2 Selections of sampling position. However, more often than not plant ducting configurations

do not conform to laid down standards. Then certain deviations must be followed (the use of such deviations usually involves sampling at a greater number of test points). The correct number of ducting diameters downstream of bends, expansion joints and dampers often results in scaffolding having to be erected to gain access to the sampling plane, although the performing of testing from scaffolds and galleries can sometimes be precarious.

I have found in practice that it is often more secure and practical to position the bulk of the test apparatus at ground level or some intermediate level, hereby retaining only the probe pushers on the scaffold or gallery. What often appears to be a simple downward traverse can sometimes give problems, particularly if the traverse depth is over 3 metres and the gas therein about 150° C. Obviously side access traverses are better (horizontal plane). However they are not always feasible due to the length of traverse and the width of access galleries. With regard to circular ductings these are by far the less difficult, until one encounters diameters of over 6 metres. Then, usually, test tapping bosses should be diametrically opposed, to afford access from either side of the traverses. This latter aspect is important when considering testing large circular wet scrubber stacks, as above 2 metres it is not feasible to heat sample probes and to guarantee that they remain above dewpoint.

Further, I would point out that whilst personally conducting traverses of over 6 metres, great problems have existed with sampling-probe weights, lengths and droop. Finally, I would categorically state that in practice text book traverses very rarely exist within industry and therefore whilst isokinetic testing locations must be positioned as accurately as possible in accordance with Standards, practicability must also be considered in such siteing

#### TRAVERSE POSITIONS

The number of sample points on a traverse and the positioning of the traverses within the cross section of the sampling plane are also required to conform to a Standard Work. With regard to circular ducts the number of points and the positioning of these points usually conforms to what is termed the tangential rule for circular ducts (ref BS 893), or alternatively from an analysis using logarithmic law equations for velocity profile (ref BS 848). The positioning of points on rectangular or parallel sided ducts usually involves dividing the ducting into a number of equal areas and positioning traverse sample points at the centroids of these areas.

In my experience, at least sixteen points should be traversed in a rectangular ducting to a maximum of forty eight, depending upon the ducting dimensions. However, a guide to the maximum number of sample points can be obtained from BS 893 subcript table 2 Determination of Sampling Points. The norm per circular ducting is two traverses of six points each interdispersed at 90°. However, a third traverse at 45° is recommended if the ducting diameter exceeds 2,2 metres.

## ISOKINETIC SAMPLING OF DRY PARTICULATE EMISSIONS

The term dry particulate emissions can be used for particulate matter conveyed in gas streams consisting of less than twenty percent moisture by volume. In practice a sample of this particulate matter can be collected without any special provision being made to retain the sampling train above dewpoint. The two most common methods of collecting dry particulate matter entail the positioning of the sampling media either in or out of the gas stream. Obviously here again different authorities and bodies associated with particulate emission control and gas cleaning plant performance testing, advocate one or other of the two methods. I personally prefer the in-stack method, as it has proven less cumbersome to operate and control, returning precise and accurate collection of particulates, depending upon the type of filter media used. Further, this method obviates the deposition of particulates on the probe and sampling line surfaces, and the possibility of dewpoint conditions occurring in the said sampling line. This latter aspect of the possibility of condensation taking place within the sampling line often necessitates the use of a heated line, when operating with an external collection (filter) device. However it is to be pointed out that providing ambient temperatures are somewhat high, and sampling lines are kept above dewpoint, it is possible to collect a far larger particulate sample (mass) by use of an external heated filter unit. Further the collection of a large sample is also dependant upon the use of 15 to 25 mm diameter sampling nozzles and high rate metering orifices or rotameters.

Regarding filter media, this is an aspect which must be studied carefully, before embarking upon dry particulate sampling, irrespective of whether the stack or out-of-stack method is used. In-stack the use of pulped paper thimbles is satisfactory, providing temperatures are not above 160°C and that acid and oil vapours are not present, and that the particulate is not too hygroscopic by nature.

At elevated gas temperatures glass fibre and cellulose pulp thimbles should be used for in-stack collection, bearing in mind that with regard to the latter thimbles they cannot withstand large pressure drops. Further alternatives are cotton bags for low temperature, and fibreglass bags for high temperature. However, care must be taken when weighing and emptying such bags due to loss of material i.e. threads and stitching. For acid mists and very hygroscopic particulates it is suggested that super-fine glassfibre or silica wool be used in-stack, but care must be taken with filter packing and weighing.

Regarding an external heated filter unit, cotton collection bags are suitable up to 120°C, thereafter fibreglass filter bags should be used to avoid charring.

The assembly of a dry particulate train for in-stack use usually conforms to the following design:

- i) A filter or thimble holder in which the sampling medium is held and upon which interchangeable

sampling nozzles can be fitted, the thimble holder being so designed as to enable its insertion onto the hot gas stream at the point of measurement (access in this regard is usually facilitated by a 100 mm diameter tapping boss).

- ii) A condenser unit used for condensing the sampled gas moisture before the metering or control device.
- iii) A gas metering and control device which incorporates both a means of regulating gas flow through the whole apparatus (i.e. for maintenance of isokinetic conditions at the sampling nozzle) and a measuring unit, usually either an orifice plate or a rotameter.
- iv) Finally, located completely downstream is the gas aspirating device, in this regard the most suitable and reliable device has been found to be an industrial rotary vane type pump.
- v) In addition to the sampling train described above, other supporting equipment and instrumentation are necessary, such as an appropriate sized pitot static tube, a thermocouple and temperature recorder, a manometer (preferably of the inclined design) and a calculator preferably with programme facilities. An orsat apparatus for gas analysis and a wet and dry bulb device.

Finally, with regard to the necessary requisites for a dry particulate sampling train one must have the use of, or alternatively access to, both drying and accurate weighing apparatus. Such apparatus is necessary, to both condition and determine mass of the sampling media before and upon completion of testing.

## ISOKINETIC SAMPLING OF WET PARTICULATE EMISSIONS

Wet particulate emissions can aptly be described as either a) particulate and gaseous emissions emanating from the outlet of a wet scrubber or saturated stream (normally  $\pm 40\%$  moisture by volume) or b) an emission which is below the conveying gas dewpoint (acid or water). To sample such an emission isokinetically is probably the most difficult of all emission source testing. This testing often entails the carrying out of diametrically opposed traverses across the stack or scrubber outlet, with a need to continuously rotate the sampling apparatus around the stack to facilitate these opposed traverses. Such traverses (i.e. diametrically opposed) are necessary on large diameters (up to 3.5 metres have been encountered), because the need to heat the sampling probe effectively inhibits the operational length of the probe. The heating of the sampling probe is essential to retain the probe above the dewpoint of the gas stream, as is the heating of the flexible sampling line and thereafter the particulate collection filter. An alternative method is to use an in-stack heated catchpot as recommended by certain authorities. However, from experience, I would advocate the use of an externally heated collection filter. Here again there are advantages and disadvantages to the use of external

and in-stack collection devices. However, I do believe it is easier to maintain and control the sampling train temperature out of stack than it is with an in-stack heated collection device, although it is necessary to wash out with acetone both the sampling probe and flexible line (before an external filter) upon completion of sampling, thereby ensuring that no particles are still adhering to the respective surfaces. In this latter regard experience has shown a need to use acetone from glass bottles and to check its suitability against a blank. The secondary part of any wet particulate sampling train is the condenser section, which is located immediately downstream of the heated collection device. The condenser usually takes the form of a series of glass impingers which are located within an ice bath.

The American Environmental Protection Agency's Method 5 - "Determination of Particulate Emissions from Stationary Sources" describes in detail the proposed lay out and requirements for a wet particulate sampling train. Whilst a number of different manufacturers in the U.S.A. produce wet particulate sampling trains, they usually have special application for a specific plant. For example they are of finite length in regard to pitot static sampling probes, and sometimes the construction inhibits traversing in any other plane but the horizontal.

In practice I have found it more convenient to assemble a wet particulate sampling train, which will cater for and accommodate sampling on all types of installations. In this regard I have utilized 316 stainless steel probes and teflon flexible sampling lines, both heated with glass fibre heating tapes, which in turn are temperature regulated by Iron/Constantan thermocouples and controllers. The dry collection device also 316 stainless steel is housed within a heated glass fibre enclosure (also temperature controlled). Commercially available glass fibre or cotton filter bags are used with this collection device. The impingers used in the wet train are 500 ml, with number two/three porosity discs fitted or alternatively round (blown) restricters. The connection between the impingers and the rest of the sampling train is facilitated with glass B 19/26 connectors. Regarding operation of this wet train, the first two impingers in the train contain 100 ml of distilled water respectively and here experience has shown a need to use high purity deionized water. The third impinger is operated dry and this in turn is followed by one containing 200 to 300 g of pre-weighed silica gel. The gas metering and control is facilitated by using a combined control/measuring unit, with differential pressures being recorded on a manometer tube connected across a 9.525 mm square edge orifice plate. The gas is aspirated through the train with a rotary vane type pump. Regarding the ancillary apparatus, this is the same as for dry particulate sampling, excepting that certain of the methods of operation have to be adapted for a wet gas stream. In this latter regard a water trap should be positioned upstream of the Orsat Apparatus, and an in-stack determination of psychrometric values has been found to be more suitable than using an aspirated hygrometer (reference BS 1339 "Definitions, Formulae Relating to Humidity of the Air").

The magnitude and direction of gas dynamic heads in a wet gas stream can only be deduced from experience, as can the problems of sampling-train pressure drops and sampling nozzle selection. In this latter regard the norm tends to favour the use of either a 6 or 8 mm diameter nozzle, however at times due to very high stream velocities a 4 mm nozzle has been used. Finally when operating any wet sampling trains, care must be exercised to ensure:

- a) Pressure drops across the various components of the train do not prevent the maintenance of an isokinetic sampling rate at the control and measuring device.
- b) The flow rate through the train does not result in carry-over of water from one impinger to the next and subsequent ones.
- c) That flow rate through the apparatus is not causing temperature depletion of the probe and hot collection device.
- d) That the temperature of the ice bath be kept to a minimum in order to fully condense the gaseous and fine particulate matter.
- e) That when pressure testing for leakage on the fully assembled wet sampling train, the blockage or restriction placed at the nozzle inlet is removed carefully with the suction pump running, in order to avoid backward suction and carry-over within the impinger assembly.
- f) Where particulate emission rates are thought to be less than  $150 \text{ mg/Nm}^3$  then filter bags should be substituted for filter discs. This change is in order to ensure the correct mass determinations after testing.

#### ISOKINETIC TESTING PROCEDURE

The procedure for successfully performing isokinetic testing is basically the same no matter what type of emission i.e., the criterion is the maintenance of isokinetic conditions at the sampling nozzle inlet. Therefore a description of the testing procedure to be followed when testing a dry particulate emission with an in-stack filter train aptly describes testing on any other source, (with the exception of the prescribed variation in sampling train components and assembly).

- i) In all instances it is advisable to carry out a pre-test temperature and pressure exploratory search (traverse) across the proposed sampling plane. The object is to ascertain both the magnitude of the gas dynamic head for sampling nozzle selection, and the suitability of the proposed plane for conducting isokinetic sampling. In this latter regard the presence of gas reverse or null flows must be recognised, and large temperature and dynamic head differences across the sampling plane identified. It is to be fully understood that one cannot sample at positions where reverse flows or null

velocities exist. This means therefore that either the chosen plane be rejected as unsuitable, or in the absence of another accessible plane, that standard on such sampling be studied for guidance e.g. 3405 Appendix B. Selection of Alternative Sampling Positions "or EPA Test Method 1" Sampling Points. Upon satisfactory completion of the exploratory traverse and the fitting of both the sampling nozzle and media onto the in-stack catchpot, the probes and pitot tubes should be marked off in accordance with the stipulation in BS 893 Appendix B 'Methods and Rules for determining the position of sampling points in circular and rectangular ducts'.

ii) The pitot static tube should be connected across the manometer, assuming that this unit has been zero checked and adjusted accordingly, thus compensating for ambient temperature in relation to the specific gravity of the indicating fluid. The pitot static tube should be inserted into the stack, at a position corresponding to the first sampling point of the first traverse, and a measurement of temperature and pressure made. These measurements will form the basis for the commencing velocity to be applied through the sampling train (suggested method of rapid calculation is to use a programmable calculator). The sampling probe complete with nozzle and media should now be positioned alongside the pitot static tube (in the gas stream), with the sampling nozzle directed downstream of the gas flow.

iii) At the appropriate time (commencement of sampling period usually between three and five minutes per point) the sampling probe should be turned to face squarely upstream of the flow. The sampling rate should be at all times commensurate with the velocity being measured by the pitot static tube. In this latter regard the rapid conversion of gas dynamic head from the pitot static tube plus gas temperature measurement from the thermocouple into a velocity requirement through the sampling nozzle, can only satisfactorily be facilitated by using a programmable calculator. The use of nomographs and pre-calculated data curves are considered too time-intensive for facilitating true isokinetic sampling.

Upon completion of the sampling period at this first point and depending upon the requirement, the sampling probe can either be turned downstream of the flow and removed from the ducting, or advanced to the next sampling position of this first traverse. The removal of the sampling probe, after completion of sampling at each point, would only be observed where either a) determination of individual point particulate emission rates in g/s were required. b) where the particulate emission rate was too high for the measurement of more than a single point. In this latter regard any attempt to sample a second position without changing the media would result in stratification across the media. However, normally,

increment point sampling is possible for a complete traverse, without having to change sampling media.

iv) Upon completion of sampling at all points on the first traverse, second and subsequent traverses are to be performed in a like manner as quickly as possible. In this latter regard test continuity should be the criterion to ensure that plant conditions through-out the test remain stable and constant. In cases where large fluctuations in gas flow are experienced it is advisable to set up a continuous gas monitoring analyser and, to use reference pitot static tubes to ascertain the magnitude of gas component variations throughout the sampling period and correct data statistically.

v) Upon completion of the actual test sampling it is advisable to take gas analysis constituent readings. These readings are to be from separate tapping points located outside the line of traverse, but within a short distance either upstream or downstream of the sampling plane. Alternatively if it is feasible to make continuous analysis throughout the test period, this is ideal. Further, with regard to wet sampling trains it is essential that in addition to an exploratory temperature and pressure traverse, a series of exploratory gas analysis constituent readings be taken. This is in order to enable compensation to be made for percentage moisture by volume, to gas relative density at the sampling point. However, it is worth noting that this correction is not necessary at the measuring and control unit, as theoretically the gas there should be dry. Finally, it is important that a wet sampling train be brought up to temperature and stabilized at  $120 \pm 14^{\circ}\text{C}$  before sampling commences.

#### TREATMENT OF TEST SAMPLING MEDIA

The results obtained from isokinetic particulate matter sampling will only be as good as the effort and expertise put into the actual testing and the prior and post test treatment of the sampling media. In this latter regard most sampling media tend to have hygroscopic properties and certain media such as ashes, pulped paper and cellulose can be stated to be extremely hygroscopic. Therefore the need to dry, desiccate and weigh meticulously before and after testing is of the utmost importance. Normal procedure is to dry the media at  $105^{\circ}\text{C}$  to  $110^{\circ}\text{C}$  for a period of one hour, with regard to cotton/terelene bags and pulped paper thimbles it is not advisable to exceed these temperatures. Regarding glass wool, silica or mineral wool the ideal temperature for stability before weighing is in the order of  $180^{\circ}\text{C}$ . The treatment of filters generally, and their suitability for use on various emissions, can be cross-referenced with an excellent work on the subject entitled "Sampling of Dust Laden Gases" section Sampling Filters by C.J. Stairmand. It is often advisable to consider taking to site, a standard filter, in order to enable the mass of the other filters (used during the testing) to be corrected before final mass determinations are made. Further, correct identification markings

on individual filters are essential, but such markings should be added to the filters before initial drying and weighing takes place.

In practice it has been found practical to deposit the filters into plastic bags for transport to and from site (the bags having the same number ascribed as on the filters). It would obviously be better to transport filters to and from site in glass weighing bottles, but this could prove to be an expensive proposition for certain tests, due to the considerable number of filters required.

With regard to filters (used in-stack) and packed with glass or silica wool etc., the ideal mass of such wool and its collection characteristics should preferably be known, in order to prevent stratification and poor collection efficiency. In this regard these aforesaid filter units, usually constructed of stainless steel, should be first packed then dried and weighed.

Finally, regarding the correct determination of mass of particulate matter collected from a wet sampling train, certain controversy exists whether the particulate matter mass collected dry should in fact be added to that collected from the wet impinged train (condenser). In this latter regard total solids, obtained in the form of dissolved and suspended solids, often are condensable gases. For example, when using impingement into distilled water there is a possibility of interference by soluble acidic gases, which dissolve into solution thereby influencing total solid determinations. It is therefore recommended (as sulphur dioxide and sulphur trioxide in flue gas forms sulfide and sulfate ions) that before adding the solids collected in the wet impinger train to those collected dry pH analysis or ionic balances be performed on the solution collected. However, I believe that solids collected in the wet impinger train be considered in the final analysis (suspended solids). In this latter regard it is often possible for very fine particulate matter to pass the dry (heated) collection device. Obviously some attempt should be made to determine what constitutes the dissolved and suspended matter in the samples, collected from the wet impinger train.

#### DETERMINATION OF RESULTS

The determination of results after completing isokinetic sampling revolves around a number of standard calculations and methods. All calculations are based upon the derivation of density, velocity, volume and mass flows encountered during the testing. Here again various authoritative bodies give guide lines as to the format of such calculations, which are all basically the same with only the units of expression differing and the degree of accuracy entered into. Regarding (a) Velocity the formula  $V = \sqrt{2gh}$  must be transposed to bring in all factors and can be used in the form:

$$V = 14,15 \frac{h_o}{d_o} \text{ where } V = \text{velocity in m/s}$$

$h_o = \text{gas dynamic head in millibars}$   
 $\text{and } d_o = \text{density in kg/m}^3$

- b) Volume flows  $\text{m}^3/\text{s}$  in all incidences is equal to the velocity in  $\text{m/s}$  multiplied by the cross-sectional area of the sampling plane in  $\text{m}^2$ .
- c) Mass flow  $\text{kg/s}$  is equal to the volume flow  $\text{m}^3/\text{s}$  Multiplied by the gas density in  $\text{kg/m}^3$ .
- d) The concentration of solids in the flue gas or stream is the product of the mass of particulate matter collected in grammes divided by the total volume of gas sampled in the total sampling time (in seconds). This latter value is determined from the formula:-

$$0.7854 \frac{Vd^2t}{10}$$

where  $V$  = the gas velocity in  $\text{m/s}$   
 $d$  = the diameter of the sampling nozzle in  $\text{mm}$   
 $t$  = the total sampling time in seconds

- e) The rate of emission in  $\text{g/s}$  can be calculated from:

$$\frac{A W}{a t} \times 10^6$$

where  $A$  = the  $\text{c/s}$  area of the sampling plane  $\text{m}^2$   
 $W$  = the mass of particulate collection in  $\text{gm}$   
 $a$  = the  $\text{c/s}$  area of the sampling nozzle  $\text{mm}^2$   
 $t$  = the total sampling time

- f) Alternatively the rate of solid emission in  $\text{g/s}$  can be calculated from:-

$$\frac{\text{Particulate matter concentration mg/m}^3 \times \text{gas volume flow m}^3/\text{s}}{106}$$

Variation and elaboration to the above formulas can be made to take into consideration gas relative densities and corrections for moisture by volume to dry gas analysis.

Corrections to gas volume flow rates can be made for conversion from actual conditions to any given reference condition e.g. s.t.p. and percentage  $\text{CO}_2$  "Conversion of volume rate of flow from working conditions to any given reference conditions" and "Measurements of Solids in Flue Gases" by Hawksley, Badzioch and Blackett table 3 conversion between actual concentration and concentration at 7,10 and 12% standard  $\text{CO}_2$ .

#### GASEOUS EMISSION SAMPLING

Whilst gaseous emissions do not necessarily fall into the category of emissions which must be sampled isokinetically, they are never the less worth mentioning. In this regard it is normal to follow a Standard work with regard to maintaining ideal flow rates through the sampling trains. For example it is recommended (BS 1756) that a flow rate of between 700 ml to 800 ml per minute be maintained through an apparatus to determine sulphur oxides. The type of apparatus

suitable for determination of gaseous emissions can be used for a number of diverse gases e.g. sulphur dioxide, chlorine dioxide, ammonia or nitrogen oxides. The apparatus consists basically of two impingers (250 ml) in which various reagents can be contained, two glass U tubes containing desiccants, a drying tower with thermometer, a vacuum gauge, calibrated rotameter and diaphragm type pump. Provision is made to vary flow rates and reagents can be readily observed for end-Point determination. Further, where required, a heated inlet probe (stainless steel or glass) can be attached to the apparatus, and a particulate collection filter inserted where necessary.

#### CONCLUSION

I have attempted in the paper to give a general insight

into the difficulties as well as the methods of conducting isokinetic sampling on industrial sources. Obviously I cannot cover every aspect of the subject in such a brief review of techniques, as every emission or source requires some considerable forethought on how the sampling is to be conducted and with what type apparatus. This is tantamount to stating that there is no single sampling train available for all applications i.e. each emission should be evaluated separately and apparatus adapted to suit the specific application. Finally, I firmly believe that a quality assessment (visual observation) of an emission is hypothetical and only by performing measurements can an accurate assessment of the true emission be made. Therefore the well known adage "To measure is to Know" has much merit.

#### ADDENDUM

##### REFERENCES USED FOR ISOKINETIC SAMPLING

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