

CHARACTERISING A PARTICULATE EMISSION

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INTRODUCTION

The term "particulate emission" may be defined as the setting free of particulate matter into the atmosphere by a man made process. There are naturally occurring processes which also are contaminating the atmosphere with particulate matter, such as wind erosion, vulcanic eruptions etc. but these are not the subject of this paper.

In this paper emissions and their characteristics are briefly discussed while the main part deals with the sampling of particulate emissions as practiced by the Chemical Engineering Research Group of the CSIR. Factors affecting sampling such as representativity, isokineticity, equipment, manpower and costs are looked at. It is hoped that by emphasising some of the difficulties involved plant management will more seriously consider the merits of requesting sampling tests and, in cases where measurements are required, assist the sampling teams to ensure that the results obtained are meaningful.

WHERE DO MAN MADE PARTICULATE EMISSIONS OCCUR?

Mostly they are found where materials are processed. As all man made goods are derived by processing some kind of raw materials the emissions are encountered in areas where the process industry is active. The major South African processes are concerned with minerals and ores, and agricultural products, but the generation of electricity from coal is a major source.

The processing of agricultural products is mainly done on a relatively small scale in rural areas while the generation of electricity takes place on a large scale, although predominantly in rural areas. The processing of minerals and ores is usually accomplished on a large scale and often in the vicinity of similar operations in an industrial complex and in the vicinity of urban areas.

We thus find that the emissions from the large scale combustion of coal and from the processing of minerals and ores are more likely to give rise to significant air pollution problems than do the emissions from the processing of agricultural products. This aspect is also evident from the activities of the Department of Health in applying the Clean Air Act.

WHAT IS THE PURPOSE OF CHARACTERISING A PARTICULATE EMISSION?

As indicated above the emissions from a process or a conglomerate of processes may create pollution problems in the atmosphere. In order to remedy such a situation the approach of the medical doctor may have to be followed, who, when confronted with a patient, is required to make a diagnosis before treatment can be administered. Thus the characterisation of the emission is required in order to arrive at remedial action.

Some information on the emission may be obtained by measuring the quality of the ambient air. This type of diagnosis is done by the Air Pollution Research Group of the CSIR and the Medical Research Council, but only in certain cases will this produce the data required for effective pollution abatement.

The particulate emissions generated by the process industry require measurements at the source if emission data is not available from the literature, from operating characteristics of similar plant or from equipment manufacturers. One of the activities of the Chemical Engineering Research Group of the CSIR is concerned with the prevention of air pollution which amongst others comprises the measurement of particulate emissions.

WHAT PARAMETERS ARE INVOLVED IN CHARACTERISING A PARTICULATE EMISSION?

They may be grouped into two sections:

- (a) Stack conditions
- (b) Particle characteristics.

- (a) Stack Conditions

These are mainly concerned with the characteristics of the gas carrying the particulate material - information on temperature, pressure, flow profile in the sampling plane, flow rate and whether the flow is steady or is subject to sporadic or cyclic fluctuations, humidity, presence of gaseous substances other than air, and, of course, the emission rate of particles.

- (b) Particle characteristics

These comprise: the size or shape of the particulate material
the size distribution
the composition
physical characteristics like solubility and hygroscopicity.

EMISSION SAMPLING

The approach followed by our sampling team usually consists of three phases.

PHASE I

When an enquiry is received concerning the measurement of a particulate emission an initial plant visit will take place. This serves to assess the problem on hand and to collect factual information inherent to the particular plant, its locality and operation. It also serves to establish personal contacts with plant personnel whose co-operation is vital in the actual measurements. If technically feasible and warranted a proposal will be prepared on the basis of the knowledge gained during this visit and bearing in mind the requirements of plant management - such as timing, detail of information required. The proposal will

stipulate the type of equipment to be used in the measurement, the expected duration and timing of the tests and the costs. It will also contain details as to the facilities, required by the sampling team, which have to be provided by plant management.

PHASE II

On acceptance of the proposals put forward, this phase is concerned with the actual measurements. This requires selection and assembly of the equipment required for the particular needs of the measurements to be made; transportation of the equipment and sampling team from Scientia, Pretoria to the factory and ultimately to the sampling platform; measurements in the stack with - as far as possible - surveillance of the operating conditions of the plant during the period of tests; and after completion, dismantling of the equipment and return of equipment and team to Pretoria.

PHASE III

Analysis of the particulate material collected, i.e. determination of mass and perhaps particle characterisation. This is followed by evaluation of the laboratory and test data and the compilation of a confidential report which is submitted to the firm requesting the measurements.

EQUIPMENT

The method of measuring particulate emissions comprises the withdrawal and analysis of a small but representative fraction of the total stack emission.

Typical sampling equipment is illustrated in Figure I. Basic equipment consists of a Pitot tube/inclined manometer for determining stack gas velocities, a sampling probe and vacuum pump for withdrawing the gas sample, a filter for collecting the particles, and a flow rate meter for determining the gas sampling rate. Ancillary equipment includes temperature probes, pressure gauges, psychrometers, gas meter, etc. Special purpose equipment is required for very hot or very humid emissions and for low gas velocities^{1,2}.

A drying oven and an accurate chemical balance are essential in the laboratory. In addition, equipment for qualitative/quantitative chemical analysis and particle size determinations may be required.

SAMPLING ACCURACY

The accuracy of a sampling test is determined, in part, by the number and location of the sampling points in the duct cross section, and the method of integrating the data to obtain the total stack emission. The simplest procedure is the cumulative sampling technique with sampling points selected according to the equal area principle³. The total dust collected is divided by the total gas volume sampled to give a mean solids concentration and hence the total emission rate. This method is acceptable for sampling steady emissions at a sampling station where the velocity and concentration distributions are uniform.

Circumstances often dictate that the sampling station be located in a region where the flow is not uniform, e.g. close to a bend, a junction or obstruction in the duct. Multipoint sampling, in which the dust concentration at a number of sampling points distributed randomly over the duct cross section is determined, will then be used. Velocity and concentration "surfaces" are fitted through the point data and used to calculate the emission rate. High speed digital computation facilities are expedient⁴.

Unsteady emissions require that an additional reference sample be taken simultaneously with each point measurement. Equipment efficiency tests thus require the use of four complete sampling sets if conditions are not steady, i.e. two upstream and two downstream of the dust arrestor. The point measurements are normalised to a mean emission rate prior to surface fitting.

The greater the number of sampling points and the longer the time of sampling, the higher the accuracy of a sampling test. Some errors are, however, inherent in the sampling equipment or in the procedure being followed. They may be related to the emission characteristics, and cannot be reduced by extending the sampling period. An appreciation of all the sources of error is essential if sampling is to be executed with the least costly procedure compatible with the desired accuracy^{5,6}.

ISOKINETICITY

To withdraw a gas sample that is representative of the stack gas at the sampling point it is essential that, inter alia, the sampling velocity equals the local stack gas velocity - see Figure 2. To illustrate the method of ensuring isokineticity, consider the case where a rotameter is used to indicate the flow rate in the sampling nozzle, and a Pitot tube is used to determine the flow rate at the sampling point.

If the Pitot differential is Δh Pa and the stack gas density is ρ_s kg/m³, then the stack velocity is given by:

$$V_s = \sqrt{2 \Delta h / \rho_s} \quad \dots\dots\dots(1)$$

Isokineticity will be achieved if the rotameter is adjusted to a mass flow rate:

$$M = V_s A_n \rho_s \quad \dots\dots\dots(2)$$

where A_n is the cross sectional area of the sampling nozzle. The rotameter equation may be written simply in terms of the scale reading R , the mass flow rate M , the gas density at rotameter conditions ρ_R and a constant k :

$$R = k M \sqrt{\frac{1}{\rho_R}} \quad \dots\dots\dots(3)$$

Substituting (1) and (2) in (3) yields:

$$R = k A_n \sqrt{2} \sqrt{\Delta h} \sqrt{\frac{\rho_s}{\rho_R}} \dots\dots\dots(4)$$

Rewriting in terms of gas densities at normal temperature and pressure (subscript o):

$$R = k A_n \sqrt{2} \sqrt{\Delta h} \sqrt{\frac{\rho_{s,o}}{\rho_{R,o}}} \sqrt{\frac{P_s \cdot T_R}{P_R \cdot T_s}} \dots\dots\dots(5)$$

P_s , P_R are the pressures, and T_s , T_R , the temperatures in the stack and rotameter respectively. Provided there is no condensation between stack and rotameter, $\rho_{s,o} = \rho_{R,o}$ and equation (5) may be simplified to:

$$R \sim A_n \sqrt{\Delta h} \sqrt{\frac{P_s \cdot T_R}{P_R \cdot T_s}} \dots\dots\dots(6)$$

Equation (6) has normally to be evaluated repeatedly while sampling because P_R changes as dust builds up on the filter. Changes in temperature and Δh velocity may occur as well, and have to be incorporated in the periodic recalculation of the sampling rate.

Even under isokinetic conditions it is possible that the flow streamlines will be distorted by the presence of the sampling probe, and result in the collection of a non-representative sample. It has been shown⁷ that the degree to which the streamlines are obstructed is related to the amount of obstruction presented to the flow by the probe. Negligible disturbance under isokinetic conditions may be achieved with a thin-walled, sharp-edged nozzle with the chamfer on the inside, and the stem of the probe at least 11 diameters downstream from the nozzle inlet. Sampling accessories in the vicinity of the nozzle, e.g. internal filters, must be avoided.

MANPOWER

The characterising of particulate emissions not only requires the necessary equipment but also suitably trained staff. The staff must be competent in operating the equipment and must also have adequate formal training to be fully aware of the significance of the readings taken during emission measurements. Furthermore the staff should also have sufficient background to understand the operation of the particle emitting plant. This is required in assessing the feasibility, need and scope of the sampling operation and is also required in the meaningful evaluation of the test data.

Unfortunately the supply of such staff is rather limited in South Africa, as is the case with technically trained staff in general. Another aspect

having a bearing on staff scarcity is that the conditions under which sampling takes place are usually hazardous. Hazards encountered are amongst others dusty atmospheres, fumes, heat and the ills of changing weather conditions, plus altitude and cat ladders.

COSTS

The costs of sampling emissions are high. In part this is due to the investment in equipment but by and large the manpower intensive nature of the equipment is the major contributing factor to costs. The replacement value of the CERG's equipment for sampling particulate and gaseous emissions is estimated at R30 000. Without charging clients for depreciation the costs for sampling a particulate emission are between R2 000 and R3 000. To this must be added the cost to provide sampling openings and platforms.

RESULTS

Experience gleaned over 15 years sampling in the South African process industry has shown that one or more of the following will occur on the day the consulting team commences measurements:

- (a) there will be a power failure
- (b) the plant will have to shut down or operate at abnormal loads due to equipment malfunction
- (c) the pollution control equipment will become inoperative
- (d) fans will break down
- (e) key plant personnel will be unavailable, and
- (f) it will rain.

Having gone through the process of sampling and characterising a particulate emission the gist of the result may read as follows:

"At the time of sampling the dust concentration was $0,5 \text{ g/m}^3$ corresponding to an emission rate of 35 kg/h. 20% of the dust was less than $10 \mu\text{m}$, and 80% less than $50 \mu\text{m}$ in size. The SO_3 concentration was 10 ppm and the acid dew point 160°C ."

From information available on similar plant elsewhere it was probably known beforehand that the particle size distribution was such as to make the use of a cyclone for emission control dubious. This leaves electrostatic precipitators, bag filters and venturi scrubbers. If there is sulphur in the fuel, there is bound to be SO_3 in the effluent gases. The acid dew point for a wide range of SO_3 concentrations and humidities falls in the range $150\text{-}180^\circ\text{C}$. Thus there is a good chance of acid condensation in stagnant regions in a bag filter if the emission temperature is below 200°C , while high temperature acid resistant bags are an obvious consideration for hot emissions. The choice between electrostatic precipitation and venturi scrubbing may be dictated by costs, availability of power and water, space considerations and waste disposal problems. None of these factors were determined in the sampling tests. Finally

the dust loading can often be estimated with sufficient accuracy for determining hopper sizes by studying material balances.

Admittedly, no problem is in practice as clear cut as suggested above, and there frequently are cases where information obtainable by sampling is essential. It is hoped that this indication of the type of information obtainable will help management to decide when sampling is necessary, and the discussion of difficulties involved will alert them to the need for co-operation in the interests of obtaining meaningful results.

Furthermore, suppliers of abatement equipment should ensure, prior to giving guarantees on the performance of their equipment, that these guarantees can be substantiated by measurements. In the interest of air pollution prevention, it does not matter whether a piece of equipment is 98% or 99,5% efficient in controlling an emission, but what is important is whether the relevant emission level is not exceeded.

NEW DEVELOPMENTS

There is a continuous effort by equipment manufacturers and research organisations to develop new equipment for the measurement of particulate emissions. The main aim of these new developments is to produce more reliable equipment which is less demanding on the skill and training of the technician. This is achieved by improving existing equipment, by automating certain operations and also by utilising new technologies.

"NULL" PROBES

At the CSIR under grant from the Department of Health a design for a sampling probe is currently being developed which aims at utilising the null principle to achieve isokineticity. The need for isokineticity in sampling was given earlier. At isokinetic flow rates the static pressure inside the sample nozzle should, ideally, equal the stack static pressure. Thus it may be argued that isokineticity may be achieved by simply matching two pressure readings, without the need for any calculations (as with equation (6)). Unfortunately, pressure losses - due to the development of the nozzle velocity profile, skin friction on the nozzle walls, eddy shedding, etc - are such that the internal and external static pressures are not equal under isokinetic conditions.

A further problem is that the introduction of pressure taps in the vicinity of the nozzle mouth requires thick-walled probes. This is contrary to the conditions stipulated on page 15 so that even if the null principle were to correctly achieve isokineticity, it is doubtful whether the sample so obtained would be representative.

It remains to be seen whether the new design, which constitutes a compromise between the null principle and practical consideration, will stand up to mathematical modelling and tests in the wind tunnel.

CONCLUSIONS

- (1) Considerable computation is necessary to maintain isokineticity while sampling. This may so engross unpractised operators that developments which may have a significant bearing on the results are not observed.
- (2) Some commercially available sampling probes cause sufficient obstruction to the flow to significantly distort the streamlines even under isokinetic conditions.
- (3) Developments in the design of sampling equipment should aim at reducing the demands made on sampling personnel. Established criteria for reducing streamline distortion should be heeded.
- (4) Sampling is costly and should only be requested if the limited information resulting is essential for taking necessary action. Stack sampling should not be regarded as a panacea for pollution transgressions.
- (5) Failure to accurately supply all relevant information to sampling personnel may lead to erroneous results and the selection of inadequate control equipment.

REFERENCES

- (1) BRENCHLEY, D.L. et al, Industrial source sampling. Ann Arbor Science Publishers, Inc. (1973).
- (2) CSIR Brochure B44. Industrial dust sampling. Chemical Engineering Research Group - CSIR, Pretoria (1974).
- (3) British Standards Institution. Simplified methods for measurement of grit and dust emission from chimneys. British Standard 3405 (1971).
- (4) PAULSEN, J.P. and HICKS, R.E., Computation of gas and dust flow rates from point measurements in a duct, using surface fitting. CSIR Special Report CHEM 149, CSIR, Pretoria (1971).
- (5) ROUILLARD, E.E.A., Experimental errors in sampling dust laden gas streams. CSIR Special Report CHEM 189, CSIR, Pretoria (1971).
- (6) HICKS, R.E., Measurement technique and systematic errors in sampling dust laden gas streams. CSIR Special Report CHEM 188, CSIR, Pretoria (1971).
- (7) ROUILLARD, E.E.A. and VALVONA, P.J., Flow patterns upstream of isokinetic dust sampling probes. CSIR Report CENG 019, CSIR, Pretoria (1974).

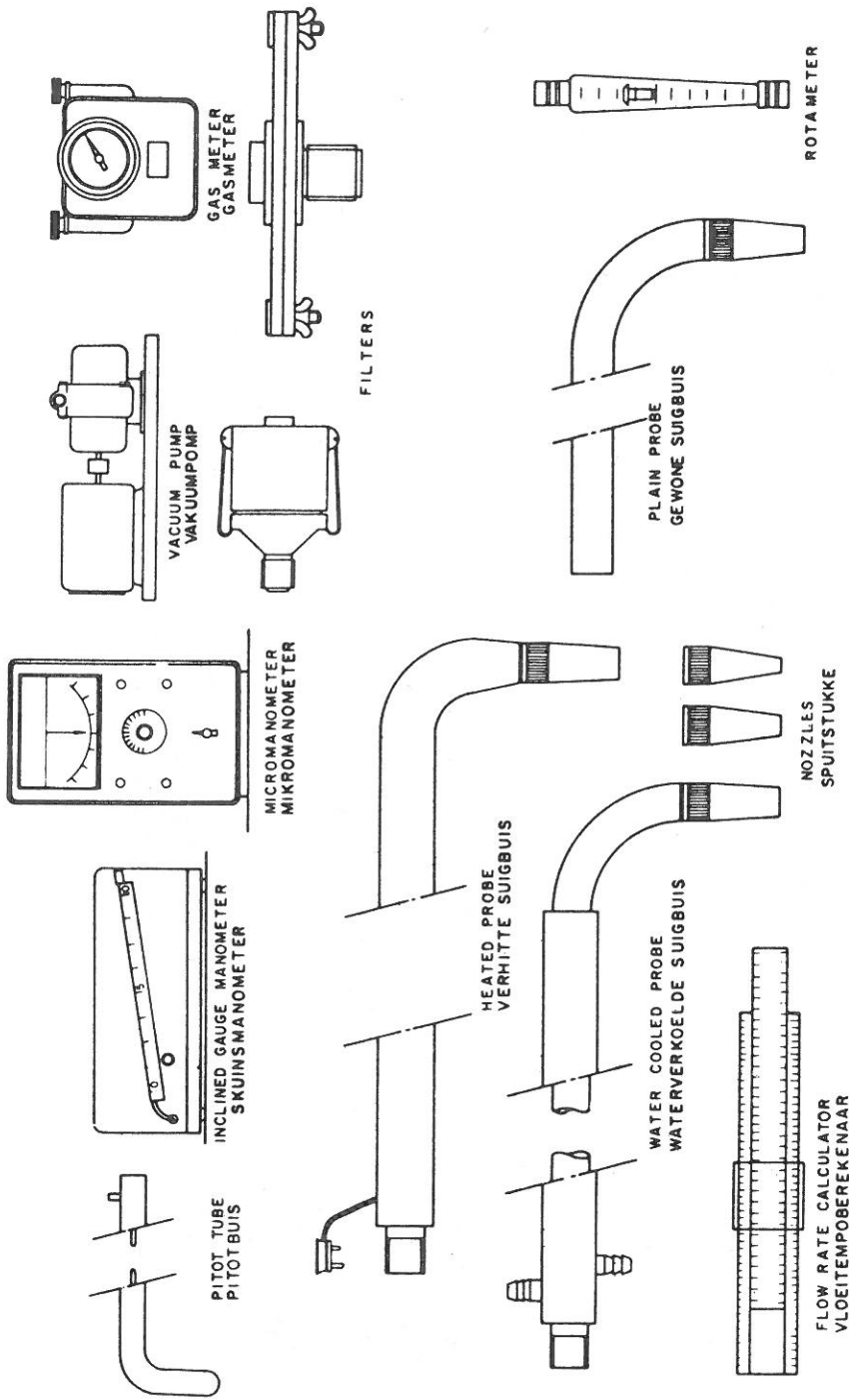


FIGURE I SAMPLING EQUIPMENT

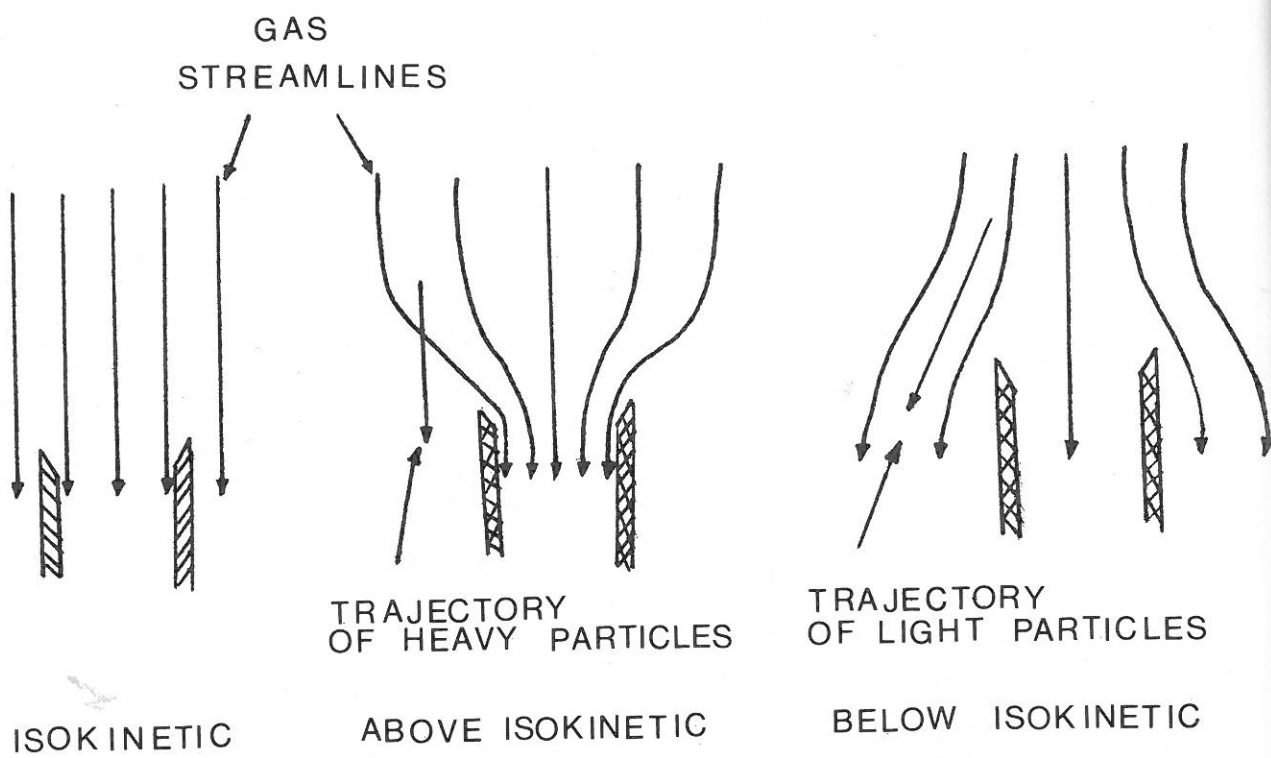


FIGURE 2

ILLUSTRATION OF PRINCIPLE OF ISOKINETIC SAMPLING