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ENGLISH

POLLUTION CONTROL RESEARCH INSTITUTE, HARDWAR

DP/IND/83/008/11-06

INDIA

Technical report: Pollution control in boilers*

Prepared for the Government of India by the
United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of Mr. J.G. Wain
expert on pollution control in boilers

Backstopping officer: S. P. Maltezou, Chemical Industries Branch

United Nations Industrial Development Organization
Vienna

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V.87-88307

ABSTRACT

This four-week assignment was arranged for the Expert to guide the national staff carrying out in-house research programmes on the control of air/water pollution with respect to the steam boilers. During the course of the assignment the Expert was requested to extend the scope of work to include environmental impact assessment, analytical chemistry, air pollution dispersion and water pollution topics.

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RECOMMENDATIONS

1. That UNIDO give favourable consideration to the Govt of India's request for U.N. Fellowships for the 5 nominated members of PCRI. The Fellowship to consist of a 3 months tour of Austria, UK, USA, to include training and visits associated with the work of PCRI.

2. In view of PCRI interest in air dispersion, it is felt this work could easily be extended to cover the environmental impact assessment of large projects (eg. power stations, airports, dams, reservoirs, indistrial complexes, oil refineries etc). The Expert provided an outline plan for baseline studies and methodology. It is essential that PCRI obtain copies of the UNEP Guidelines to E.I.A. Vol 1 & 2). In addition, it is for consideration whether one or two members of staff could attend one of the UNEP workshops on Environmental Impact Assessment (eg. of the type organised by the University of Aberdeen, Scotland).

3. PCRI is anxious to commence a modest programme of research and development in methods of waste water treatment. The aim is to confirm the existing process design parameters are applicable to local conditions and to make adjustments where necessary. The topics to be examined are:-

   (a) Anaerobic Digestion of Molasses
   (b) The Treatment of Electroplating wastes
   (c) Treatment of effluents arising from the production of producer gas (carbonisation of coal)

   The Expert has had discussions on the preliminary requirements for (a) and (c) and has agreed to provide information on existing processes for (b). The Purchase of small laboratory items (eg. glassware, glass blowing equipment, flowmeters, pumps, "nuts and bolts") is recommended, together with the installation of the usual laboratory services (water, compressed air, vacuum).

4. It is the view of the Author that there is a need in PCRI for a person with a financial/marketing background with experience of cost estimation of proposals and projects. He would also be required to market the services offered by PCRI. It would be useful if UNIDO could help, when assistance is requested.

5. It would be advantageous if some way could be found to make the existing constraints on the use of funds, more flexible. It has been necessary to purchase several items which weren't originally budgeted for and this is causing a short-fall in some of the categories.

6. It is suggested that PCRI should consider offering an instrument calibration and pollution control equipment maintenance service as a method of fund raising. The suggestion is made because the additional outlay for tools and equipment would be small.

7. The Director requested information on the outcome of the request for a computer system and its probable delivery date. The following order of priorities for equipment purchase is suggested.

   (1) Computer (including terminals and personal)
   (2) Copying machine (xerox) including collator.
   (3) Remainder.

8. It is considered advisable that the following books should be purchased when funds are available.

1. Encyclopaedia of General Chemical Technology, Kirk Othmer, 3rd Edition (25 volumes), J. Wiley.
2. Safety in Laboratories, Bretherton (or CRC Handbook of Lab Safety)
3. Handbook of Chemistry and Physics, CRC Press.
4. Environmental Exposure from Chemicals, Neely & Blau, CRC Press.
5. CRC Handbook of CHEMICAL SYNONYMS and TRADE NAMES

(approximate cost $US 6,000 including class D. air cargo charges)

INTRODUCTION

The original job specification limited the assignment to studying the water and air pollution control problems associated with steam boilers. (see annex 3)

It became apparent that the Director wished to widen the scope of the assignment, to include other topics which the Expert was competent to deal with. The following list of topics was agreed and drawn up as follows.

1. AIR POLLUTION GROUP - to discuss the following:-

   (a) Present work being carried out by the Group with the ground concentration level model.
   (b) Monitoring of Black Smoke
   (c) Estimation of chimney height, plume rise and effective chimney height by various methods
   (d) Grit Arrestment Processes
   (e) Sulphur dioxide removal processes
   (f) Environmental impact assessment.

2. TECHNICAL LABORATORY GROUP _ to discuss the following:-

   (A) Boiler Water Treatment Processes

      (i) Demineralisation
      (ii) Reverse Osmosis
      (iii) Deaeration
      (iv) Boiler Water Additives
      (v) The behaviour of Silica in boilers
      (vi) Condensate polishing
      (vii) Cooling water circuits

         (a) Once through method
         (b) Closed Circuit

(B) Methods of Analysis.

(i) Langelier Saturation Index
(ii) Free carbon dioxide in water
(iii) Biochemical Oxygen Demand
(iv) Chemical Oxygen Demand
(v) Sulphates - Barium Chloranilate Method

(C) Laboratory Quality Assurance

(D) Environmental Impact Assessment

3. Discussion on ways and means of dealing with the disposal of solid wastes (eg. fly ash)

(i) Ash-handling and dewatering
(ii) coal preparation
(iii) possible uses of fly ash.

4. The Expert was also requested to give a few lectures to all senior staff to pass on his experience and to link it with the project in hand wherever possible. (see annex 1)

ADMINSTRATIVE MATTERS

At our first meeting good wishes were conveyed from Dr Maltesou to Professor Mahajan, and a collection of documents from UNIDO, Vienna were delivered.

In addition, the following suggestions were passed on for Professor Mahajan's consideration.

1. A request from Dr Maltesou for a list of preferred priorities for acquisition of the remaining equipment

2. To consider the inclusion of safety aspects including assessment risk in the training programme together with the possible establishment of a safety team

3. To consider involvement with environmental impact assesment

The Director explained that PCRI had been successful in acquiring three projects as follows:-

1. Assessment of air pollution from foundries in Agra

2. Estimation of plume rise and maximum ground level concentration of particulate matter and sulphur dioxide, for inclusion in BHEL proposal to the Government of Mudel Pradesh, in respect of Birsinghpur Power Station

3. Environmental Impact Assessment for the proposed extension to Baetinda Power Station (2 x 500 MW)

It is his intention to increase staff and buy additional equipment (including technical book/publications etc) as funds accrue from the acquisition of more projects.

During the course of the assignment regular meetings took place between the Director and Expert during which progress reports were presented and ideas/ suggestions were discussed. The following are some of the items mentioned.

Cost Estimation/Marketing

It was suggested that as PCRI had now reached the stage of tendering for porjects it was important that some professional help be engaged to consider financial matters. It seemed appropriate that this help should be in the form of someone experienced in cost estimation of projects and their presentation. It also seemed reasonable that the same person could become involved in marketing the services offered by PCRI. Other duties could include the pricing of recommendations made as a result of R&D investigations carried out by PCRI.

Dust Generation around PCRI

The author soon became aware of the dust generated around the PRC1 complex and suggested possible ways in which this could be alleviated to some extent. These included the covering of all flower beds in the vicinity of the buildings with a layer of gravel or pebbles to prevent the wind dispersing dust. Another procedure is to spray dusty areas with a suitable coal/petroleum distillate preparation specially prepared for this purpose.

Additional Services

A suggestion was made that PCRI might care to consider the establishment of an instrument calibration and pollution control equipment maintenance service. The intention being that in offering this service additional revenue could be obtained without the need for extra capital expenditure. In addition it would provide an additional point of contact with Industrialists and with it access to current working practices and possible projects associated with them. The Director expressed interest in this suggestion but was anxious not to enroach on work presently being undertaken by other government bodies e.g. the Indian Standards Organisation.

Apportionment of Effort

Mention was made of the advisability of Section Heads to produce, say on a weekly basis, a record of the time spent by each member of staff on the various projects. This information could then be studied by the Cost Estimator to check that the time spent remains within the period allocated when the project proposal was prepared and accepted. The Author was pleased to learn from the Director that such a system was just about to be implemented.

Wastewater Treatment/Solid Wastes disposal Processes

This topic was raised to enquire of the PCRI view. It seems that there are a number of consultants already in the field of solid wastes disposal, so it was thought that it would be difficult for PCRI to enter this field at this stage. The Director however was very anxious to extend the present PCRI effort into the investigation of three types of liquid wastes which were local problems. These were:-

(a) Molasses
(b) Electro planting wastes
(c) Producer gas effluents (and coke oven wastes)

The investigations would confirm that the existing technology and design parameters were applicable to Indian conditions and, if necessary, to carry out additional experimental work to improve the processes.

The author was able to make a contribution in this field and also agreed to supply further information on his return to U.K. A range of small laboratory items and equipment (including services) is required in the water pollution research laboratory.

UN Fellowships

The Director enquired whether UNIDO could arrange such fellowships for a 3-month period, whereby the 5-nominees could spend one month in Austria, one month in U.K. and one month in U.S.? In order to expedite matters further information was obtained from the nominees as to their particulars disciplines and areas of interest. These are given in Annex 4. In this connection, the opinion of the Deputy Director were sought, in view of his recent visits to Europe and the United States of America. Two U.N. fellows returned from the U.S. (on 26th May) so their views were also obtained.

TECHNICAL MATTERS

1. GENERAL

The Director requested a series of informal lecture/discussion groups for the senior staff of the PCRI. These proved to be quite useful events as they tended to develop into questions and answer sessions. The following topics were discussed:-

(a) Pollution Control procedures including ways in which these could be linked with existing industrial licencing arrangements. It also suggested that control systems should be capable of being practical (based on plant performance), flexible and mindful of cost considerations.
In addition various technical processes were mentioned, for the control of gaseous emissions and liquid discharges. Information was also provided on the efficiency of the processes discussed.

(b) The second session covered technical processes available for the treatment of solid wastes. These included dewatering techniques, controlled tipping procedures for landfill sites and incineration methods for the degradation of hazardous wastes.
Also discussed were the controls necessary for monitoring working atmospheres and plant safety. They were discussed under the following headings:-

Indentification	- International arrangements for labelling chemicals, packaging pipelines and the transport of chemicals.
Safety equipment	- protective clothing, fire appliances, sprinkler systems.
Safety training	- to follow recommendations of suppliers of equipment and manufacturers of chemicals.
Storage	- Fire protection arrangements in warehouses and drainage systems to cope with accidental spillages.

Working Conditions - including the monitoring of factory atmospheres for toxic gases, ventilation of hazardous operations (eg. paint spray operations and grit blasting), noise and temperature control.

It was emphasised that the monitoring of manufacturing processes was essential to ensure that pollution control equipment was being used correctly and that all safety devices were in place and serviceable.

(c) A short talk was delivered to a party of engineers from Rookee University, led by Professor Panesar, Head of Chemical Engineering Department and Mr Bagbie of the Central Pollution Board, Delhi. It provided current information on commercial desulphurisation processes presently in use in Europe and the United States.

(d) The talk on desulphurisation processes was also given to the senior staff together with a discussion on ash handling problems (especially those associated with the high ash content of local coal) including possible uses for pulverised fuel ash. These included use as an additive for concrete and possible use as an inert cover in the procedure for the controlled tipping of municipal refuse.

2. AIR POLLUTION GROUP

At the first meeting of the air pollution group information was provided on the projects presently under investigation. These included:-

(1) Agra Foundries' Emissions - This project is jointly funded by UNDP and PPDC, and was commenced with the help of Dr Graber. There are approximately 200 foundries with small cupola furnaces operating on a batch basis. The emissions are discharged dirctly to atmosphere and as these foundries are located within 12 km of the Taj Mahal there is concern about possible damage to its fabric. This project is at an advanced stage but some difficulty had been experienced with the carbon monoxide determination. A precipitate had formed in the ammoniacal cuprous chloride solution and unreliable results had been obtained. It was suggested that ammoniacal cuprous chloride solution had become exhausted and that a fresh supply should be prepared. Care needs to be taken to obtain a clear solution of cuprous chloride (by reducing with sulphur dioxide).

2. Birsinghpur Power Station - PCRI was requested to provide data on plume rise and maximum ground level concentrations for particulates and sulphur dioxide for BHEL. This information is to be included in BHEL'S proposal to the Government of Mudel Pradesh for the construction of an extension to this station. Some doubts had been expressed as the accuracy of the formulae used to calculate plume rise and these were discussed on several occasions during the assignment.

3. Baetinda Power Station - PCRI had just been awarded a contract to carry out an environmental impact assessment for the proposed 500 MW extension to this power station. Environmental Impact Assessment method and programme was discussed.

LECTURES

Black Smoke - considered the Rigelmann method for measuring black smoke and presented calculating to equate plume gas analysis with efficient combustion (annex 5).

Air Emission Dispersion - The Indian Standard. (IS 8229) and Brigg's equation (from Cheremissinov) for estimation of plume rise were compared with several simplified methods used in the U.K. These are shown in annex 6.

Air pollution control equipment - included discussion of dry and wet processes for removal of particulate matter and sulphur dioxide.

Environmental Impact Assessment - discussed and devised practical ways of initiating an environmental impact assessment programe covering air emissions, liquid discharges, solid wastes and effect on existing community. Also discussed possible ways in which the monsoons could affect the dispersal pattern of particulate matter and sulphur dioxide by "washout".

1. Initial Baseline Studies (i.e. conditions existing prior to construction of project) should include:-

   Water Quality - composition and quality

   Ambient air quality

   Biological Survey - including soil and vegetation conditions, ecology of water course and geology of site.

   Social Affairs - present population, population groupings, infrastructure, existing roads, railways, airports, housing, shops, schools etc., refuse disposal and other local government services.

   Ambient Noise Levels

2. Requirements of Project to include

Water consumption
Land required, together with any additional infrastructure
Additional transport required
Proposals for dealing with disposal of gaseous, liquid and solid wastes.
Show how possible adverse impacts can be overcome.

3. Assessment - It is necessary to satisfy the existing community and State government administration that the impact of the project will not have an adverse effect. It will be necessary to carry out a public relation exercise to inform the local population of the proposed project and to discuss it with them. It would be helpful to obtain no-objection statements from local organisations so that these can be submitted along with the E.I.A.

Calculation of Effective Height, Plume Rise and Maximum Ground Level Concentration of Particulates and Sulphur Dioxide

There were two possible areas in which doubts as to the accuracy of the calculations existed. In the case of Birsinghpur the mean wind speed was given as 2 kph (0.44 m/sec). In the UK, formulae are simplified to a mean wind speed of 6 m/sec, an efflux velocity of 15 m/sec and an exit temperature of 150^{o} C. The two equations presently in use (IS 8229 and Briggs') produced, what was considered to be, a wide divergence of results when the mean wind speed was taken as 0.55 m/sec. However when the ranges of results for different wind speeds were examined it was shown (see annex 6) that percentage deviation from the mean was the same in each case.

Comparison of the results obtained from all the methods (annex 7) revealed another source of discrepancy. It transpired that from the version of Brigg's equation given in Cheremissinov's book it was possible to construe the Qh term was calculated in Kcals. This was in contradiction with the IS 8229 version which expressed Qh in calories. This variation, taking into consideration the cube root terms in Briggs' equation produced a result one tenth that of IS 8229. Eventually, it was possible to show that Cheremissinov intended the Qh term to be expressed in calories/g (see equation 18 page 208).

Further work on this topic included the calculation of maximum ground level concentrations of particulate matter and sulphur dioxide, together with its location.

Environmental Impact Assessment - Baetinda Power Station

A scheme was evolved, based on the lecture/discussion, which required the taking of samples on a grid pattern downwind of a chimney. In the case of Baetinda Power Station, there are two chimneys proposed (275 m high) and 100 metres apart. The effects from these two plumes, therefore, are likely to be cumulative. Other information collected during the assignment was that there is no surface water available and that there is very little rainfall. It was, therefore, unlikely that water samples would be available and the biological survey would be limited to soil analysis and vegetation counts. For the measurement of sulphur dioxide from the existing power station use could be made of lead dioxide candles, to provide a check for results obtained with the mobile laboratory.

Visits

Three visits were made to the BHEL Thermal Power Station (TPS), where the Air Pollution Group carried out measurements on the flue gases. Information on this emission proved to be valuable during the discussions on plume rise etc (it was visible from the lecture room) when it could be associated with the calculations for the Birsinghpur and Baetinda Projects. The observations suggested the plume from BHEL TPS had very little momentum or buoyancy . These observations were confirmed from the design data obtained and measurements carried out.

A visit was also made to another investigation being carried out in the turbine-blade grinding workshop. This is a study of the working atmosphere associated with the grinding operation. From observations made the following points require investigation.

(1) Determination of noise levels at operators' position

(2) Analysis of working atmosphere using gas detector tubes

(3) Check air velocities in region of operator(s) and at extraction vent

(4) Check temperature of work place

Possible Remedies

Provision of ear protectors and mouth/nose masks. Experiment with piece of magnetised iron/steel to collect ferro-magnetic particulate matter.

Fit extractor systems to each piece of machinery. Extend extract hood and improve air velocity around the blade slot-cutting machine.

3. Technical Laboratory Group

At the first meeting staff were invited to describe the project presently under investigation. These included:

(i) Routine testing of effluents from BHEL and other factories

(ii) Evaluation of a scheme for the re-use of water at BHEL, Hardwar

(iii) Analysis of soils contaminated with flyash

(iv) Involvement with the environmental impact assessment for the proposed extension to Baetinda Power Station. This to include the analysis of underground water supply, soils and biological survey of vegetation.

During the course of this discussion it became clear that copies of volumes I and II of the U.N.E.P. Guidelines on Environmental Impact Assessment should be obtained. It was hoped that Dr Hussein might have a copy at the UNDP Office in Delhi and a request would be made as soon as possible.

Lectures

Water Treatment Processes in Power Stations - this lecture covered the following topics:

Boiler Feed Water - Demineralisation of raw water by ion exchange and reverse osmosis

Deaeration

Boiler additives
- Phosphates
- Hydrazine/sodium sulphite
- Morpholine
- Silica carryover
- Condensate 'polishing"

Cooling Water Circuit - Chemical conditioning including

- Descalants
- Dispersants
- Biocides (excluding those containing mercury, arsenic, tin and other persistent poisons).
- control of legionnaires disease

Methods of Analysis - The following tests were discussed.

Langelier Saturation Index - a nomogram was provided and the method of use described. It will be useful to determine the scaling/corrosive characteristics of waters, especially as at BHEL the some scaling of pipelines occurs.

Free Carbon Dioxide - a nomogram for determination of free carbon dioxide in waters was provided and this could be helpful if it is necessary to adjust the Langelier Index.

Biochemical Oxygen Demand - standard method described including instructions on the preparation of standard dilution water and specific points of technique.

Chemical Oxygen Demand - description of standard method and discussion of technique involved.

Laboratory Quality Control - discussed procedures for sustaining a high level of reliability in laboratory work. Subjects covered included:

Use of accepted standard methods
Internal laboratory controls
External laboratory controls
Storage of certified standards and reagents
Replicate determinations
Good housekeeping, including use of protective clothing etc
Laboratory conditions

Environmental Impact Assessment - discussed the analytical work required in connection with E.I.A. of Baetinda Project.

Discussion of Specific Problems

Biochemical Demand Test - Analysts were interested to discuss the procedures involved with this test and it seemed more appropriate to demonstrate these in the laboratory. Particular interest centred on the preparation of fully saturated dilution water, the removal of entrained air bubbles from diluted samples, and the mixing required at the oxygen absorption stage.

Determination of organic carbon - some difficulty was being experienced with one particular soil sample which contained a quantity of fine coal dust. The digestion stage did not appear to go to completion so one or two suggestions were made to overcome this (e.g. reduction in sample size). Analysis of Soils - this discussion was concerned with a programme of soil analysis associated with the E.I.A. for Baetinda Power Station extension. Possible analysis considered included heavy metals (especially cumulative poisons i.e. Arsenic, Antimony, Cadwich, Lead and Mercury) and fluorides (cause of fluorosis in cattle). Other elements which could be examined were plant nutrients (N & P, & K) and an indicator metal (e.g. Cr or V) to show the presence of fly-ash. However, it was agreed that the extent of the programme had to be designed to fit into the project timetable.

A discussion on a programme for studying the anaerobic digestion of molasses took place at the request of a staff member. A sketch of a flow diagram for a laboratory experimental unit was drawn. In addition an initial programme was suggested (pending the acquisition of minor items of laboratory equipment) to ascertain the composition of molasses in respect of BOD, COD and nutrients (at varying dilutions). It was also suggested that a quantity of domestic sewage sludge should be subjected to anaerobic digestion to provide a source of suitable micro-organisms.

Visits

BHEL Water Treatment Plant

Following the determination of free chlorine in a sample of tap water taken from the Shivalik Guest House (0.01 ppm), the expert requested a meeting with the Engineer in Charge (Mr S N Mishrah). He explained that the Guest House was at the end of a distribution some distance away from the clorine closing point, but that he could try to increase the dosing to bring the residential chlorine level to a more acceptable value (0.3 ppm).

Information was given on the use of calcium hypochlorite granules (as a better alternative to the bleaching powder presently being used). It was emphasised that the use of granules (with an available chlorine content of 65% min, compared with 30% - 35% in bleaching powder) had certain advantages. These included the preparation of a clear solution without the need to dispose of unwanted lime, no dust generated when preparing dosing solution and better storage life without loss of chlorine (granules are supplied in 50 kg sealed drums).

BHEL Central Plant Laboratory

I met Dr Chabbia, deputy general manager in charge of Laboratories and he kindly explained their scope of work and took me on a tour of inspection. The Laboratories are primarily concerned with metalurgical investigations, the monitoring of materials used in insulation and the calibration of all instruments used in the works. The laboratories are air conditioned (by an integrated duct system) and although 20 years old they contain a wide range of the latest equipment (i.e. electron microscope, x-ray fluorescence spectophotometer etc).

ANNEX 1

TIMETABLE OF MISSION

3 May 1987		Departed Coulsdon, UK	1215 hrs
3 May 1987		Arrived Vienna, Nordbahn Hotel	1930 hrs
4 May 1987		Attended UNIDO for briefing	0825/1700 hrs
5 May 1987		Departed Nordbahn Hotel	0800 hrs
6 May 1987		Arrived Ashok Hotel, New Delhi	0145 hrs
6 May 1987		Attended UNDP office and had discussions with Dr Hussein, Mr Sat Pal and Professor Kempa who was completing his assignment	
7 May 1987		Departed Ashok Hotel	0915 hrs
		Arrived BHEL Guest House	1700 hrs
8 May 1987		PCRI, Hardwar	
	am	Discussion with Professor Mahajan in morning	
	pm	Programme preparation	
9 May 1987	am	Lecture to senior staff on Pollution Control including aspects of air pollution and water pollution processes.	
	pm	Taken on tour of complex to meet staff.	
Sun 10 May 87		Preparation of lectures	
11 May 1987	am	Met Dr Trehen and the Technical Lab Group; discussed present project and invited staff to discuss any problems.	
	pm	Met the Air Pollution Group to obtain information on present project and to encourage open discussion of any problems.	
12 May 1987	am	Met Technical Lab. Group and lectured on various methods of water treatment required in power stations.	
	pm	Met Air Pollution Group and found that some discrepancy was occuring between methods used for calculation of plume height. Carried out calculations using Baetinda Power Station data. Discussed possible fallout pattern in monsoon conditions.	
13 May 1987	am	Discussed methods of analysis including B.O.D. with Technical Lab. Group and carried out practical demonstration.	
	pm	Air Group interested in E.I.A. so discussed possible baseline studies. Also mentioned existence of U.N.E.P. Guidelines (2 volumes)	

14 May 1987	am	Spoke to Gen. Laboratory Group about Quality Assurance and the need to build up a strong reputation for producing reliable results.
	pm	Had discussion with Professor Mahajan to make suggestions on cost estimating for proposals and project, development of information centre for industrialists, possible need for extra help in biological survey team.
15 May	am	Explained to Tech. Lab Group the role of analysis in E.I.A. and also discussed with Dr Mrs Srivastava possible ways of overcoming a problem which had occurred with the acid digestion stage of a soil analysis sample.
	pm	Produced a range of results obtained from Baetinda Power Station data using seven different methods, to estimate effective chimney height, plume rise and chimney height. As a result of discussion a further discrepancy was revealed.
16/17 May		Joined Professor Mahajan, at his invitation, on a visit to Massouri.
18 May	am	Gave lecture to senior staff on processes available for treatment of solid wastes working atmospheres and plant safety.
	pm	At request of Air Pollution group had discussion on discrepancy between IS 8229.1978 method and Briggs' equation. Was able to resolve the problem to the satisfaction of group.
19 May	am	Had discussion with Dr Mrs Ramini on the analysis of heavy metals in soils and the type of analysis required for E.I.A.
	pm	Spoke to a visiting party headed by Professor Panesar, Head of Chemical Engineering, Rookee and Mr Bagbie, Central Pollution Control Board, Delhi. Described latest processes being used industrially in Europe for the removal of SO_2 from flue gases.
20 May	am	Visited Mr S N Mishral, Engineer in charge of Waterworks BHEL, to try to resolve the lack of residual chlorine in the water at the Guest House. Also visited Dr Chabbia, Deputy General Manager in charge of BHEL Central Plant Laboratories, who kindly took me on a tour of inspection.
	pm	Had discussion with Professor Mahajan to obtain his views and problems and to discuss his requirements.

26 May Preparation of draft terminal report continued together with summary report for SIDFA, Delhi. Further visit to BHEL Thermal Power Station to observe gas flow measurements.

27 May Final lectures on desulphurisation of flue gas, solid wastes handling and report writing.

28 May Left BHEL for UNDP Delhi.

29 May Departed Delhi 0230 hrs for UNIDO, Vienna.

ANNEX 2

Papers, Documents etc. Provided During Assignment

1 B.S. 2486:1978 - Recommendations for the treatment of water for Land Boilers

2 Nomogram for Determination of Langelier Index

3 Nomogram for Determination of free CO_2 in water

4 Copy of the Harwell Waste Management Bulletin

5 Copy of ENDS Report No 140 (including paper on desulphurisation of flue gas)

6 Technical Memorandum on Chimney Heights

7 Chimney heights - simplified plume rise calculation

8 Note on the calculation of chimney heights

9 Notes on best practical means for electricity works

10 Diagram of Ringlemann smoke charts

11 Chimney Heights - Second Edition of the 1956 Clean Air Act Memorandum

12 Plume Rise Estimation - graphical method based on stack gas emission rate

13 Total effective height - graphical method based on pollutant emission rate

14 Downwind G.L.C (3 min mean) - graphical method for max G.L.C

15 Removal of particulate matter from air

16 Environmental aspects of particulates

17 Removal of particulate matter from air by the use of wet scrubbers

18 Electrostatic Precipitators - operation, design, criteria, applications

19 Fabric Filters - precoating and injection for improved performance

20 SO_2 - Sulphur Dioxide - an air pollutant

21 Water Quality Classification - BEWA : DS 02.86

22 Metal finishing effluent - Degremont Process

23 BS 1756 : Part 2 : 1971 - Methods for the sampling and analysis of flue gases - by Orsat Apparatus

24 BS 1956 : Part 1 : 1971 - Methods and sampling for analysis of flue gases

25 BS 3892 : Part 1 : 1982 - Pulverised - fuel ash - for use as a cementitous component in structural concrete

26 BS 3892 : Part 2 : 1984 - Pulverised - fuel ash - for use in grouts and for miscellaneous uses in concrete

27 CRC Press - Chemistry Book List - Winter 1987

ANNEX 3

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

UNIDO

JOB DESCRIPTION

DP/IND/83/008/11-06/32.1.J.

Post title Expert for Reduction/Control of Pollution from Boiler

Duration 4.0 m/m

Date required ASAP

Duty station Hardwar, India

Purpose of project The immediate objective of this project is to establish a Pollution Conti Research Institute with capabilities to a) develop industrial pollution co itrol technologies with respect to air, water, noise and solid wastes; b) develop practical methods for recovery and re-use of industrial waste: c) evolve processes and control procedures for minimising pollution generation; d) advise industry on how to introduce and maintain pollutio control levels and technical standards and scientific knowledge on pollution control technologies.

Duties The expert will be required to work under the general directives of the project head of the institute and will co-operate and co-ordinate with UNIDO, the Government of India, UNDP and BHEL.

The expert will be required to guide the national staff in carrying out the following duties:

1) In-house research programmes on control of air/water pollution with respect to steam boilers.

2) He will train the national staff (in a methodological manner- - classes struction material) in their respective duties in the laboratory and advise in the formulation of future programmes.

3) He will also help in writing and finalizing the technical reports on t activity.

4) He will assist in the selection and evaluation of equipment for the reduction/control of pollution from boiler.

5) He will provide a comprehensive report on his assignment.

..../..

ANNEX 4

Personnel Nominated by the Government of India for UN Fellowships

NAME	DISCIPLINE	AREAS OF INTERESTS
Dr N C TREHEN (Chief Chemist)	Chemistry	Sampling Techniques River Monitoring Methods of wastewater treatment
A GOEL	Chem Eng	Air Sampling, Stack Monitoring Air Dispersion Modelling Fugitive emissions Industrial Chemical Processes
G N GHOSH	Mech Eng	Air Pollution Control Equipment Experience in Foundries Fertilizer Plants
Dr Keshav	Chem Eng	Wastewater Treament (molasses, electroplating, carbonisation wastes) On-line methods of analysis
S N SAH	Electronic/ Communication Eng	Microprocessors for air/water pollution control Environmental Impact Models for large industrial complexes and cities Mathematical models for air/water/solids pollution control

ANNEX 5

COMBUSTION AND

FLUE GAS ANALYSIS

EXAMPLE

GIVEN THAT PROPANE IS BURNT WITH EXCESS OXYGEN OF 25%.

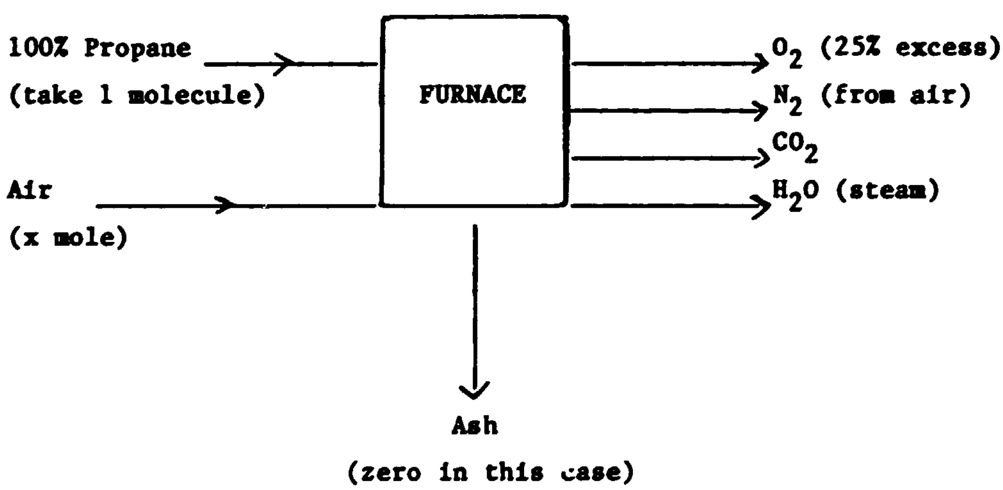
CALCULATE THE COMPOSITION OF FLUE GAS.

EQUATION

$$\underset{\text{PROPANE}}{C_3H_8} + \underset{\text{(Source of oxygen)}}{\text{AIR}} \xrightarrow{\text{25\% excess } O_2} CO_2 + H_2O$$

So,

$$C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$$



IN THEORY ONE MOLECULE OF PROPANE PRODUCES $3CO_2 + 4H_2O$ AND THESE REQUIRE $5O_2$. AND AS 25% excess WAS USED

$$\text{TOTAL OXYGEN} = 5 \times \frac{125}{100} = \underline{6.25 \text{ mole.}}\ O_2$$

AS AIR IS THE SOURCE OF OXYGEN THEN THERE ARE THE FOLLOWING NUMBER OF NITROGEN MOLECULES ASOCIATED

(<u>NOTE</u> - COMPOSITION OF AIR 21% O_2 (by volume) + 79%N_2 (by volume)

and if ratio of molecules = ratio by volume

THEN AMOUNT OF $N_2 = 6.25 \times \frac{79}{21} = 23.25$ mole N_2

∴ ON MOLECULAR BASIS FLUE GAS CONTAINS

$O_2 = 6.25 - 5$	= 1.25
N_2	= 23.25
CO_2	= 3.00
H_2O	= 4.00

∴ 1 mole Propane produce 31.5 mole flue gas

TO CONVERT TO % COMPOSITION

$$O_2 = \frac{1.25}{31.50} = 3.94\%$$

$$N_2 = \frac{23.25}{31.50} = 74\%$$

$$CO_2 = \frac{3}{31.50} = 9.52\%$$

$$H_2O = \frac{4}{31.50} = 12.70\%$$

IF PROPANE FLOW IS 1kg/HR

THE NUMBER OF GM MOLECULES USED IS $\frac{1000}{44}$ = 22.73 mole

(So $C_3H_8 + 5O_2 \longrightarrow 3\ CO_2 + 4H_2O) + 1.25O_2$

44 160 132 72 40

AMOUNT FOR 22.73 mole 25% excess air

22.73 x 44	22.73 x 160	$\longrightarrow$	22.73 x 132 +	22.73 x 72 +	40 x 22.75
1000	3367		3000	1637	909.2

MOLECULES OF NITROGEN 23.25 x 22.73 x 28 = 15,677g

<u>WEIGHT OF FLUE GAS</u>			% weight
CO_2	3000	$\frac{3000}{21223}$	14.3
H_2O	1637	$\frac{1637}{21223}$	80%
N_2	15677	$\frac{15766}{21223}$	71
O_2	909	$\frac{909}{21223}$	5
	21,223g/h		

FOR LIQUID OR SOLID FUEL

EXAMPLE - Given fuel combustion with 25% excess air

$$C + H + O \xrightarrow{25\%\ \text{excess}\ O_2} H_2O + CO_2 + O$$

Equation

Assume complete combustion and fuel composition

90% C by wt 10% H_2 (take 1g)

Have to convert % wt to mole basis

thus if 1 mole C = 12g

then 0.9g $= \frac{0.9}{12} = 0.075$ mole

1 mole H = 2

then 0.1g = 0.05 mole

So ratio of C /H_2 is 1.5/1

so molecular equation

$$1.5\ C + H_2 + 2O_2 \xrightarrow{25\%\ \text{excess air}} 1.5\ CO_2 + H_2O + \tfrac{1}{2}O_2$$

∴ Flue gas contains $N_2 = 4.5 \times \frac{79}{21} = \frac{355.5}{21} = 17$ mole

			% vol	
O_2	=	0.5	2.5	1
N_2	=	17.0	85	34
CO_2	=	1.5	7.5	3
H_2O	=	1.0	5	2
		20.0 mole /gas	100	

At 50% excess 1 mole O_2 present in flue gas

∴ O_2	1.0	4.4%
$N_2 = 5 \times \frac{79}{21} = \frac{395}{21} =$	18.8	84.5%
CO_2	1.5	6.7%
$H2^O$	1.0	4.4%
	22.3 mole/gas	19.0

To obtain fuel composition from flue gas composition

Flue Gas analysis in % by vol

	% vol			
O_2	2.5	Calculate Ratio	$\frac{2.5}{2.5}$	= 1
N_2	8.5	by dividing	$\frac{8.5}{2.5}$	= 34
CO_2	7.5	by lowest % value	$\frac{7.5}{2.5}$	= 3
H_2O	5		$\frac{5}{2.5}$	= 2
	100%			

So flue gas contains

$\longrightarrow 3CO_2 + 2H_2O + O_2 + 34N_2$

therefore original material

$+ O_2$ **ie 25% excess**

$3C + 2H_2 + 4O_2 \longrightarrow$

therefore $3C \times 12 = 36$

$2H_2 \times 1 = 4$

wt of is 40g and % composition 90% C 10% H

Note

Theoretical CO_2 content of flue gases, with no excess air, in range 18 - 18.8% depending in rank of coal & hydrogen content

can only react 18.4% on average in pulverised fuel installation

Max figures

Water tube boilers - pulverised fuel -	16.5%	CO_2 in flue gas
- retort stokers	16.0	
- chain grate	15.0	

ANNEX 6

PLUME RISE VARIATION WITH DIFFERING WIND SPEEDS

$\bar{U}$ m/sec	PLUME RISE(m) IS 8829	Briggs	Mean	Range	% of mean
0.5	4176	5772	4974	±798	±16
1	2088	2886	2487	±399	±15.8
2	1044	1443	1243	±200	±16.1
4	522	721	621	±100	±16.1
6	348	481	414	±67	±16.2
8	261	361	311	±50	±16.1

This shows the values of plume rise at a wind speed of 0.5 m/sec are consistent (on a percentage of mean basis), with those obtained for other wind speeds.

ANNEX 7

DETERMINATION OF EFFECTIVE HEIGHT, PLUME RISE AND CHIMNEY HEIGHT

COMPARISON OF RESULTS

GIVEN WIND SPEED 6m/sec CHIMNEY HEIGHT (FIXED) - 275m

EFFLUX VEL 15m/sec EXIT TEMP 150°C

	1	2	3	4	5	6	7	8
	IS829	Briggs	Flow/ Temp Graph	9M 4p	glc/ SO_2Emm Graph	Fuel consump Graph	Stack Emm Graph	SO_2/day Graph
EFFECTIVE HEIGHT	-	-	-	533	500	-	-	-
PLUME RISE	348	481	257	-	-	383	267	-
CHIMNEY HEIGHT	-	-	-	-	-	-	-	119

MEAN EFF HEIGHT m 516 ± 16 = ±30% (all methods)

PLUME RISE 347 + 133 = +38%

- 90 -26%

CHIMNEY(m) (by diff) 169

METHODS 1 & 2 ONLY

MEAN PLUME RISE(m) 415 ± 67 = ± 16%

CHIMNEY (GIVEN)(m) 275

EFF HEIGHT (m) 690

Conversion of Mean (Methods 1 & 2) to 2kph wind speed.

$$\text{PLUME RISE at 0.55 m/sec} = \frac{415 \times 6}{0.55} = 4527\text{m}$$

ANNEX 8

CHIMNEY HEIGHT/SO_2 EMMISION RELATIONSHIP

ref BOSANQUET AND PEARSON (TRANS.FARADAY SOC., 1936, No 184)

SO_2 EMISSION (Tons/DAY)	3.6	7.5	13	21	30	40
MINIMUM HEIGHT OF CHIMNEY (FEET)	100	150	200	250	300	350

POSITION OF MAXIMUM GROUND LEVEL CONCENTRATION

ref. "Recommendations on Heights for New Industrial Chimneys"
G. NONHEBEL, J. INST FUEL, 1960, MAY

$$X\ max = 4.5\ H^{1.14}\ \text{feet}$$

where X = maximum distance from chimney
H = Effective Height of Chimney

MAXIMUM CONCENTRATION AT GROUND LEVEL (ppm) P

1. $P = 3.9 \times \frac{J}{UH^2} \times 10^3$ ppm

2. $P = 1.7 \times \frac{FS}{UH_2} \times 10^4$ ppm

where J = Volume rate of emission of offensive gas at STP (f^3/min)
U = Wind Speed (ft/sec)
H = Effective Height of Emission(feet)

F = Rate of fuel Consumption (tons/hour)
S = SULPHUR IN FUEL, AS RECEIVED, per cent.

Use 1 when volume rate is known

2 Use for fuel burning installation

Note 1 cuft SO_2 = 0.17 lb 1 cuft any gas = $\frac{\text{Molecular weight}}{360}$ lb

ANNEX 9

PLUME RISE CALCULATION

INDIAN STANDARD 8829 : 1978

$$\Delta h = 0.84\ (12.4 + 0.09h)\ \frac{QH^{\frac{1}{4}}}{\bar{U}}$$

Where h = 275 m (fixed)

$\bar{U}$ = wind speed in m/sec = 6m/sec.

QH = heat content of flue gas in calories/g/sec.

$$\text{GAS FLOW} = \frac{3{,}016{,}544}{3600}\ m^3/sec$$

$$\text{WEIGHT OF GAS} = \frac{3{,}016{,}544}{3600} \times 0.816$$

$$= 678\ kg/sec$$

$$QH = 678 \times 1000g \times (140 - 15^{o}C) \times 0.24\ cal./g/^{o}C.$$

$$= \underline{20{,}340 \times 10^3\ cal}/sec.$$

$$= 0.84\ (12.4 + 0.09 \times 275) \times \frac{\sqrt[4]{20.34 \times 10^6}}{6}$$

$$= \frac{31.15 \times 67.16}{6}$$

$$= \underline{348m}$$

Note height due to momentum only

$$\Delta h = \frac{3\ Wo\ D}{U} = \frac{3 \times 25 \times 6.5}{6}\ (diam) = \underline{81.25m}$$

Where Wo = efflux vel. in metres

ANN! contd.

<u>BRIGGS' FORMULA</u> (as given in Cheremissinov)

$$\Delta h = \frac{0.25\ Qh^{1/3}\ h^{2/3}}{\bar{U}}$$

Where Qh is in calories/g

$$= \frac{0.25 \times \sqrt[3]{20.34 \times 10^6} \times \sqrt[3]{275^2}}{6}$$

= <u>481 metres</u>

ANNEX 10

PLUME RISE VERSUS FUEL CONSUMPTION

COAL (TONS/HOUR)	OIL (TONS/HOUR)	RISE OF PLUME (Feet)
50	35	400
100	70	680
200	140	1025
300	210	1300
400	280	1500
500	350	1630
600	420	1740

DATA CONSIDERED

AIR TEMPERATURE - 10°C

MEAN WIND SPEED - 20 fps (at 400 ft above ground)

TEMPERATURE GRADIENT - 1°C per 1000 ft altitude

GAS TEMPERATURE - 150°C

EFFLUX VELOCITY - 50 fps

DENSITY OF FLUE GAS = DENSITY OF AIR

ANNEX 11

SIMPLIFIED PLUME HEIGHT CALCULATION

Ref. BOSANQUET - PEARSON FORMULA (AS REPORTED BY NOHEBEL),
APPLYING FOLLOWING CONDITIONS - DENSITY OF AIR = GAS DENSITY
WIND SPEED = 20 ft/sec.
EFFLUX VELOCITY AT TWO VALUES.

(1) Calculate Product (p)

$$\frac{\text{(Gas flow rate cfm/STP) x (gas temperature } ^{o}\text{C - 15)}}{1 \times 10^{6}} = P$$

(2) ESTIMATE P FROM FOLLOWING PLOT.

P	Efflux Vel 30ft/sec.	Efflux Vel 50ft/sec.
1	17	20
2	30	35
3	42	47
4	53	59
5	63	69
6	73	79
7	82	89
8	91	98
9	100	107
10	108	115
11	115	123
12	123	131
13	131	138
14	138	144
15	145	151
16	151	158
17	157	164
18	163	171
19	169	176
20	175	183

ANNEX 11 contd

SIMPLIFIED PLUME HEIGHT CALCULATION

25	220
30	250
35	280
40	310
45	340
50	365
60	420
70	465
80	510
90	555
100	600
110	640
120	680

PLUME RISE BASE ON FLOW RATE/TEMPERATURE GRAPH

$$P = \frac{(\text{gas flow rate cfm/STP}) \times (\text{gas temp. } ^{o}C - 15)}{10^6}$$

gas flow STP (760 mm 273) = 1,990,919 m^3/h

= 331,819.8 m^3/min

= 331,820 x 35.9/cfm

So $\frac{331,820 \times 35.9 \times 125}{10^6} = 148.9$

P = 149

From graph (estimated) - PLUME RISE - 770 feet.

- 257 m^3

ANNEX 12

EFFECTIVE CHIMNEY HEIGHT CALCULATION

Ref - E.A.J. MAHLER, INTERNATIONAL CLEAN AIR CONGRESS, LONDON, OCTOBER 1966

(Effective Height in feet) $H^2 = \frac{9M}{4P}$ 9M (mass of emission in lb/day); P (Max permitted 3-min mean ground level concentration in mg/m^3)

Note - Wind Speed taken as 20 feet/second.
- If no information is available for P use a value of 1/30th that quoted for occupational exposure (limit for 8 hr working day)

(to be used as a first assesment)

FOR BAETINDA POWER STATION

GIVEN INDIAN POLLUTION BOARD LIMIT FOR SO_2 - $120\mu g/m^3$
WIND SPEED 6m/sec
EFFLUX VELOCITY 15m/sec
EXIT GAS TEMP. 150 °C

$$H^2 = 9 \times \frac{(3.016 \times 10^6 \times 0.816 \times 24 \times 2.2 \times (0.1\%)}{4 \times 0.120\ (mg/m^3)}$$

$$H^2 = \frac{9 \times 129,990}{0.48} = \frac{1,169,910}{0.48} = 2,437,310$$

H = approx. 1600 feet
= 533 metres

ANNEX 13

CONVERSION OF VOLUME COMPOSITION (ppm) (ml/m^3) TO WEIGHT mg/m^3 OF GASES

GIVEN

1 gram molecule of gas occupies 22.4 litres at NTP.

In 1 m^3 there are 1000 litres

So a 1ppm concentration of a gas ($1ml/m^3$) means there is 1 ml present.

$$\therefore \text{Weight of 1 ml gas} = \frac{\text{Molecular Weight} \times 10^3}{22.4} \times \frac{1000}{1 \times 10^6} \quad mg/m^3$$

$$\text{So} \quad \text{Weight of gas} = \text{Vol. of gas (ppm)} \times \frac{\text{Molecular Wt.}}{22.4} \quad mg/m^3$$

CONVERSE

$$1\ mg/m^3 \text{ of a gas occupies } \frac{22.4 \times 1 \times 10^6}{\text{Mol Wt.} \times 10^3 \times 1000} \quad ml/m^3$$

$$\text{Volume of gas} = \text{Wt. of gas} = \text{Wt. of gas } (mg/m^3) \times \frac{22.4}{\text{Mol Wt.}} \quad ml/m^3 \text{ (ppm)}$$

EXAMPLE

Convert 120 $\mu g/m^3$ SO_2 into ml/m^3 (ppm) SO_2

$$\text{ppm} = 0.12 \times \frac{22.4}{64} = \underline{0.042}$$

ANNEX 14

SULPHUR DIOXIDE/EFFECTIVE HEIGHT RELATIONSHIP

CONVERSION OF WEIGHT OF SO_2(kg) TO VOLUME (scf)

VOL OF FLUE GAS/SEC = $\frac{3.106,544}{3600}$ M^3/h.

WT OF FLUE GAS/SEC = $\frac{3.106 \times 10^6}{3600} \times 0.816$

WT OF SO_2/SEC = $\frac{3.106 \times 10^6}{600} \times 0.816 \times \frac{0.1}{100}$ kg

CONVERT TO VOLUME = $\frac{3.106 \times 10^6}{3600} \times 0.816 \times \frac{0.1}{100} \times \frac{22.4}{64}$

= WT OF SO_2 x 1000g x $\frac{22.4}{64}$ litres

CONVERT TO F^3/SEC = WT OF SO_2 (kg) x 1000 x $\frac{22.4}{64}$ litres = 246.4 litres

(27 litres = $1f^3$)

so $\frac{246.4}{27}$ = $\underline{9.1\ f^3/sec}$

DETERMINATION OF H

Plot. H on graph using Pollution Emission Rate of 9.1 f^3/sec SO_2
and glc (3 min mean) 0.042

H approx 1500 feet. (ca $500m^3$) (at wind 6m/sec)
efflux 15m/sec
temp 150°C

From Plot of stack emission rate scf/sec
Plume rise = 800 ft.
= $\underline{267\ m^3}$

ANNEX 15

STACK EMMISION/PLUME RISE RELATIONSHIP

CORRECTION OF GAS FLOW FROM BAETINDA POWER STATION (to cfm)

Given GAS FLOW 3,016,544 m^3/h
Temp of exit gas 140^oC

Assume pressure constant

Then $\frac{P1\ V1}{T1} = \frac{P2\ V2}{T2}$

So $\frac{760 \times 3,016,544}{413} = \frac{760 \times V2}{273}$

thus $V2 = \frac{760 \times 3,016,544 \times 273}{413 \times 760}$

$= \underline{1,990,919\ m^3/h\ STP}$

CONVERT FROM m^3/h to f^3min STP
$1\ m^3 = 35.9\ f^3$

$\therefore \frac{1,990,919 \times 35.9}{60} = 1,191,233 \quad f^3/min$

and $\frac{1,990,919 \times 35.9}{60 \times 60} = 19,854\ f^3/sec$

Calculate Plume rise Stack gas emission 5 ^{3}/sec versus temperature

267 metres.

ANNEX 16

PLUME RISE BASED ON FUEL CONSUMPTION

TAKE FUEL CONSUMPTION AS 250 MT/h

(based on 6m/sec wind speed 15m /sec efflux vel, exit temp 150°C)

then (from graph plume rise is approx 1150 ft

383m^3

ANNEX 17

MAXIMUM CONCENTRATION AT GROUND LEVEL (ppm) P.

FORMULA - $P = 3.9 \times \frac{J}{\bar{U}H^2} \times 10^3$

Where J - Volume rate of SO_2 at STP (f^3/min) - 9.1 x60 = 546 ^{3}/m

$\bar{U}$ = wind speed (ft/sec) - 20 ft/sec

H^2 = effective height (feet) - 2,437,310

$$P = 3.9 \times \frac{546 \times 10^3}{20 \times 2,437,310} \text{ ppm}$$

$$= \frac{2,129,400}{48,746,200}$$

P = 0.04368 ppm

or $0.0437 \times \frac{64}{22.4} =$

= 0.0437 x 2.86 = 0.125 mg/m^3

Note GLC ppm per scf/sec.

$$= \frac{0.04368}{9.1} = .0048$$

Plot of Downwind Cume at H = 1600 ft
provides two points where max consentration occurs

Two points 6000 ft and 9000 ft
approx 2 km and 3.0 km

ANNEX 17 contd.

POSITION OF MAX GROUND LEVEL CONCENTRATION

$$X_{max} = 4.5\,H^{1.14} \text{ feet.}$$

Where X = max distance from chimney

H = Effective height of chimney (feet)

$$= 4.5 \times (275 \times 3.1)^{1.14} \text{ feet.} = (852.5)^{1.14} = 2193$$

= 9,567 feet = 3,183 m

or taking calculated chimney height

$$= 4.5 \times (177 \times 3.1)^{1.14} \text{ feet} = (548.7)^{1.14} = 1327$$

= 5971 feet from source

= 1,926 m