ITEM	11
MANAGER'S REPORT NO.	14
COUNCIL MEETING	85/02/18

RE: LETTER FROM MR. HARVEY ELDER, PRESIDENT - EAST BURNABY RATEPAYERS ASSOCIATION, 8251 - 14TH AVENUE, BURNABY, B.C. V3N 2C1
PROVISION OF SCRUBBERS FOR PROPOSED GVS&DD INCINERATION FACILITY IN BURNABY'S BIG BEND INDUSTRIAL AREA

MUNICIPAL MANAGER'S RECOMMENDATION:

1. *THAT the recommendation of the Director Planning & Building Inspection be adopted*

* * * * * * * * *

TO: MUNICIPAL MANAGER — 1985 February 14

FROM: DIRECTOR PLANNING & BUILDING INSPECTION — Our File: 15.601.1

SUBJECT: PROVISION OF SCRUBBERS FOR PROPOSED GVS&DD INCINERATION FACILITY IN BURNABY'S BIG BEND INDUSTRIAL AREA

==

RECOMMENDATION:

1. THAT a copy of this report be forwarded to:

   Mr. Harvey Elder
   President
   East Burnaby Ratepayers' Association
   8251 - 14th Avenue
   Burnaby, B.C. V3N 2C1

R E P O R T

Appearing on the 1985 February 18 Council agenda is a letter from the East Burnaby Ratepayers' Association stating their opposition to the construction of the proposed GVS&DD incineration facility without the additional protection of scrubbers to reduce flue gas emissions.

They have also expressed the view that any decision in this regard should await the results of the Lower Mainland Refuse Projects' review of air pollution control requirements for refuse incinerators.

In this regard staff would report as follows:

1.0 PROVISION OF SCRUBBERS

A report on this subject ws submitted to the GVS&DD Waste Management Committee on 1985 February 13.

As this report is quite lengthy, copies have only been made available to Council members with their agendas. Additional copies are available in the Manager's Office for review by other parties as required.

ITEM	11
MANAGER'S REPORT NO.	14
COUNCIL MEETING	85/02/18

The Committee will be recommending to the GVRD Board that scrubbers be provided in the initial construction of the proposed incinerator.

2.0 LOWER MAINLAND REFUSE PROJECT

It is the intention of the GVRD Board to also consider the recommendations of the Lower Mainland Refuse Project. Once these recommendations are known this information will be transmitted to Council.

A.L. Parr
DIRECTOR PLANNING &
BUILDING INSPECTION

PB/mcb

cc: Chief Public Health Inspector
Director Engineering

GREATER VANCOUVER SEWERAGE AND DRAINAGE DISTRICT

ITEM	11
MANAGER'S REPORT NO.	14
COUNCIL MEETING	85/02/18

MEMO

TO: A.D. Purdon

FROM: W.A. Mechler

RE: **Acid Flue Gas Scrubbing at Refuse Incineration Plants; Stack Emissions and Provision for Scrubbing at the Proposed Plant in Burnaby**

DATE: February 7, 1985

Introduction and Summary

This report is to answer questions that have been raised or are anticipated with regard to stack emissions from the proposed refuse incineration plant[1], in particular the reduction of acid gases by scrubbing. The section headings of the detailed report are phrased as the following principal questions.

(1) What are acid gases and what quantities are emitted?

(2) What is scrubbing and what technologies are used?

(3) Which type of scrubber is best and what are the costs?

(4) Why wasn't an acid gas scrubbing system included in the design and tender?

(5) Don't we know from experience at RIPs in other cities what amounts of acid gases will be emitted? Is our garbage so different from that in other North American cities?

---

1 This lengthy term is herein abbreviated as "RIP", or sometimes briefly put as "plant". Other long technical or institutional terms are for convenience herein also replaced by capital letter abbreviations which are introduced in brackets following the first use of the particular term.

2/13 M

(6) If ambient air concentration limits can be met without scrubbing, why do many agencies specify emission limits which make scrubbing necessary?

(7) How would air quality control recommendations by the Incinerator Emissions Committee (IEC) of the Lower Mainland Refuse Project (LMRP) affect the RIP proposed in Burnaby?

(8) How should a scrubbing system be selected, and would installation of a system affect the timing of the RIP project.

In summary, the interrelated set of questions is answered as follows:
(A more detailed response to each of the questions follows on Page 9.)

- The chemical compounds hydrogen chloride (HCl), hydrogen fluoride (HF) and sulphur dioxide (SO_2) formed during combustion of refuse are referred to as "acid gases". They are emitted in concentrations of milligrammes per standard cubic metre (mg/m^3) of flue gas in the order of
  - (i) a few hundred to about 1500 mg of HCl per m^3
  - (ii) around 10 mg of HF per m^3
  - (iii) in the low hundreds mg of SO_2 per m^3.

  These "emission concentrations" can be converted to "emission factors" in terms of kilogrammes emitted per tonne of refuse burned, using the specific gas volume (m^3 per tonne of refuse burned, which is normally around 6000 m^3). The acid gas of primary concern is HCl.

- The acid gases, when sufficiently concentrated, affect the respiratory organs of people, damage plants and cause corrosion. No actual damages attributable to RIPs have been reported, and because ambient concentration limits are rarely reached, many countries are not requiring reduction of emissions.

- Some European countries control ambient air concentrations -- i.e. concentrations in the air around us, in the air we breathe -- to assure safety against health risks and against general damage under their protection principle. On that basis, most RIPs, except large ones in areas with prior elevated ambient concentrations from other sources would not have to reduce acid gas emissions.

- In 1974, West Germany adopted regulations on the basis of a further principle which also limits the emission concentrations (referred to standard gas conditions), i.e. the concentration of pollutants in the flue gas as it is leaving the stack. This additional so-called precaution principle, says, simply put, that emissions should not only be as low as necessary to prevent damage (under the protection principle), but should be as low as possible within reasonable technical and economic means. This applies regardless of the size of the source (above a certain small size), and requires that scrubbers must be installed on new plants, or existing plants, when they are altered. By now, 25 of the 46 RIPs in West Germany have scrubbers.

- Some other European countries and Japan have followed the West German example of limiting emission concentrations. More recently, the regulatory agencies of some states in the USA and of Ontario also have established emission limits and others are about to do so. The guiding philosophy in the USA is "prevention of significant deterioration (PSD)" of air quality, and this calls for application of the "best available control technology (BACT)" or achievement of the "lowest achievable emission rate (LAER)". In effect, PSD is similar to the precaution principle. This development in North America is fairly recent, and at this time there are no RIPs with recovery of energy which have scrubbers, but some plants that are planned will have them. A few plants in Switzerland, France and Sweden and many plants in Japan are equipped with scrubbers.

- Scrubbing is the cleansing of a gas of impurities. Other languages use the equivalent of "washing (out)". Scrubbing of acid gases can be accomplished by mixing the flue gases with water or a slightly alkaline solution, which is called wet scrubbing (WS). Alternatively, scrubbing can be effected by introducing a dry alkaline reagent such as lime, into the gas stream, which leads to chemisorption of the acid gases with formation of dry crystalline neutral salts as the products of the reactions and hence is called dry scrubbing (DS). The reactions are more rapid and complete at lower gas temperatures and in the presence of moisture. To achieve both, a third type of system has been developed, in which the reagent[2] is added in a watery suspension. When that is injected or sprayed into the hot gas stream as a mist, the water immediately evaporates, and dry salts result. Hence, this is called quasi-dry scrubbing (QDS). To avoid treatment of the spent scrubbing liquid from WS, the latent heat of the flue gases may be used to evaporate the liquid, so that dry salt products result. This type of process may be indicated by the letters WS/DP.

- WS and WS/DP systems require the highest capital and general operating cost, but the lowest amount of lime, viz. at or near the "stoichiometric rate", i.e. the amount theoretically required under ideal conditions for complete neutralization of the acids, symbolized by α factor = 1. In general, DS systems have the lowest capital costs, but require much more lime, (α factor about 3), whereas QDS systems are intermediate in both respects. (See Fig 8 re. costs). With DS and QDS, the amount of lime may be reduced by recirculating particulates captured by the subsequent particulate removal equipment, either an electrostatic precipitator (ESP) or a fabric filter (FF), sometimes referred to as baghouse. With WS systems most of the particulates are removed prior to scrubbing by means of ESP, FF, or at least an efficient multicyclone. (See App. C for general information and illustration of particulate removal equipment.) In general, all combinations of scrubbing systems and particulate collection devices can achieve adequate removal, except if very low limits are required, when DS + ESP may not be adequate unless a coarse-dust precollector and multiple product recycling, or a fluidized bed absorption reactor are used. Representative examples of the three major types of scrubbers are shown on Figs. 1 to 5. Figs. 6 and 7 show that the acid gas removal efficiencies in a given system and at a given rate of lime addition (α factor) are different for the three gases, and further show the dependencies of removal efficiency on some other variable parameters such as temperature and product recycle.

---

2 Usually lime, as quicklime or hydrated (slaked) lime, is used, because it is the cheapest chemical. Lime may therefore herein stand for any of the alkaline reagents. Slaked lime -- $Ca(OH)_2$ -- is most frequently used in a watery suspension which is called "milk of lime ".

- Some regulatory agencies have preferences for certain scrubbing systems. The Swiss, for instance, prefer WS systems with waste water treatment because of overall air and water pollution control considerations. These are related to the fact that the salts from dry product systems are readily soluble when deposited in landfills with the other residues, and may leach into small water courses. Hydroxide sludges from treatment of waste scrubbing liquid are not soluble and can be landfilled without concern. The California Air Resources Board (CARB) prefers DS or QDS followed by FF because of more removal of fine particulates, in which trace metals etc. occur in greater mass concentration. The Incinerator Emissions Committee (IEC) established under the Lower Mainland Refuse Project (LMRP) followed this view. However, newer data show that the differences in this regard between ESP and FF are not substantial. In view of the fact that there are as yet few installations of FF in RIPs (most of them recent), and in view of the well-known potential problems with FF, declaring the QDS + FF combination as BACT is at least premature. The newer test data collected by Mechler of the GVSDD staff in a memorandum with comments on the IEC Report (dated January 22, 1985) indicate that quite adequate results can be achieved with DS or, better, QDS + ESP, let alone the excellence of WS systems.

- Selection of a scrubbing system for the Burnaby RIP project should be made with expert advice and in consultation with the selected contractor and combustion system vendor, as well as the operator, all of whom can contribute to the most suitable choice. The system vendor associated with the lowest bid has access to experience with various systems, and District staff have contacts with the operators of some of the newest systems, and with regulatory agencies which carry out the testing of these systems.

- Ambient air concentration of contaminants anticipated from a new source can be estimated by mathematical modelling using as input, atmospheric and terrain data, stack height and flue gas exit velocity, and an expected mass emission rate. The latter is determined from an assumed emission concentration. Such modelling of HCl dispersal was carried out for the proposed RIP in Burnaby, using a raw gas concentration considered to be normal for RIPs in North America. For the worst short-term conditions, this resulted in calculated ambient concentrations below the limit established by several regulatory agencies as safe for long-term exposure. The modelling procedure tends to be conservative, but recent publications of test data from other RIPs indicate higher concentrations at some RIPs than heretofore were found and used in the modelling as normal for North America.

- In the absense of specific regulations, and considering the philosophical nature of a decision on scrubbing, it was considered a reasonable approach to build the RIP with provision (space) for insertion of a QDS system, and determine on the basis of actual emission testing and ambient air quality monitoring whether a scrubbing system should be added. If yes, this approach would have the advantage of allowing the system to be designed for known emissions and desired reductions. If need be, temporary measures such as addition of lime to the refuse (as in regular operation at RIP Montreal) could be taken to allow the RIP to operate while an appropriate scrubbing system is selected, designed, fabricated and installed.

- From the inception of the LMRP it was understood that specific pollution control requirements for RIPs would be set by that process or the path to environmental approval would be prescribed, and that the RIP project would have to comply. No definite regulations appeared before the return of tenders. In any case, inclusion of a scrubbing system in a tender on the basis of performance specifications is not practical at the present state of technical development and market. As noted before, a suitable scrubbing system would best be selected in consultation and negotiation with the successful tenderer.

- There is no North American cost experience with scrubbers, and even in Europe no definite market prices have been established. Guided by the range of values given in a West German publication and by some cost information from the vendor of the Teller QDS system (USA), it is estimated that a QDS system for the basic 70 000 t/a plant would cost about $1.5 million, and that such scrubbers for the large plant of 140 000 t/a capacity would add about $2.4 million to the cost. The capital costs for a WS system would be about twice as much, while those for a DS system might be somewhat lower than for QDS. The additional units cost ($/tonne of garbage burned) with the QDS system would be around \$7.0/t and \$6.0/t for the small and large plants respectively, half of it being the amortization cost which would effectively drop with the rate of inflation. The remainder is for operation, maintenance, and chemicals.

- If definite regulations were adopted soon and selection of a system were pursued without delay, an understanding with the contractor-to-be could be reached before final award of a contract, and addition of a scrubbing system could be accommodated within the scheduled construction period.

- Recent information from testing carried out during the last 4 years at RIPs in North America indicates that at some plants concentrations of HCl in the raw gas are much higher than earlier measured at other plants. This may be due to a general increase in the plastics content of domestic refuse, but more likely is related to the type of refuse being burned (possibly to a high proportion of industrial/commercial solid waste). Conservative assumptions would need to be made in designing a system that is to be installed during general plant construction.

- In November 1984, the IEC submitted to the Project Manager of the LMRP its report with recommendations for air pollution control requirements for refuse incinerators. The recommendations applicable to RIPs in or near urban areas suggest specific limits for

total particulates	-	viz. 50 mg/m^3,
HCl	-	viz. 70 mg/m$_3$,
HF	-	viz. 5 mg/m^3,
SO_2	-	viz. 250 mg/m^3, and
Nitrogen Oxides (NO_x)	-	viz. 300 mg/m^3.

Hydrocarbons (H_mC_n), carbon monoxide (CO), and trace organics would be controlled in a general way by specifying a minimum temperature and residence time for the combustion gases, as has been a requirement of some European regulations for some time.

- The limits for the gaseous pollutants are lower than many of the European limits and apparently were influenced more by the limits promulgated in California. The proposed limits for HCl and SO_2 seem overly stringent.

NO_x, which are emitted by RIPs at relatively low levels, are not amenable to reduction, except to some extent by judicious control of well designed combustion air systems. A note in the recommendations pertaining to trace metals suggests that emission levels would be sufficiently controlled if the preferred particular removal technology, viz. FF, is adopted. This preference also follows the California example. As noted above, declaring the (Q)DS + FF combination as BACT is at least premature. The drastically lowered new European limits for trace metal (heavy metal) emissions can be maintained with efficient ESP also, particularly when combined with scrubbing systems. This conclusion is supported by data in Mechler's memorandum to the Chairman of the IEC. In any case, adoption of acid gas emission limits at or near the recommended levels would require acid gas scrubbing.

- The IEC Report recommendations imply that H_mC_n, CO, and trace organics (which include the dioxins and furans) will be kept at acceptable levels by proper design and operation, with particular emphasis on combustion control so as to maintain a minimum temperature and residence time. This is supported by the additional recent data and information in Mechler's memorandum of January 22, 1985 on the IEC Report. West Germany and Switzerland have set specific limits for these parameters (excepting dioxins and furans which cannot directly be regulated because of sampling and analysis difficulties), and measurements indicate that RIPs can comply with these limits. Conditions which favour generation of dioxins and furans and prevent their subsequent destruction in a high temperature zone can be indirectly monitored by related parameters, such as the previously mentioned temperature and residence time, the CO and O_2 content and the total emission of organic compounds expressed as carbon. (The new West German regulations will limit the sum of all organic emissions to 50 mg total carbon per m^3.) Compliance with such limits can be achieved by proper operations.

DETAILED DISCUSSION -- QUESTIONS AND ANSWERS

(1) **What are acid gases and what amounts are emitted?**

Chlorine (Cl), fluorine (F) and sulphur (S), which are chemically bound in refuse components, are partly released during combustion in the form of the acid gases

- hydrogen chloride (HCl),
- hydrogen fluoride (HF), and
- sulphur dioxide (SO_2)

  plus a small amount of sulphur trioxide (SO_3) which is considered in measurements as an equivalent amount of SO_2.

The source of HCl is mostly in the plastics, predominantly PVC; a smaller source is table salt in food wastes.

Fluorine is for instance contained in Teflon and in the propellant gas used in spray cans.

Sulphur is contained in many refuse components. In comparison with some other fuels, refuse is a low sulphur fuel. However, recently some regulatory agencies are lowering the emission limits for SO_2 so that it becomes a factor in scrubbing. Before, only HCl and HF were the targets of scrubbing requirements, primarily the HCl. The acid gases, in sufficient concentration, affect the human respiratory organs, damage plants, and may cause corrosion.

For protection against adverse effects, some regulatory agencies have specified safe limits of the ambient air concentrations at or near ground level in an area around a source (the air we breathe), typically 100 ug/m^3 for long durations and sometimes higher for short peaks, occurring for an hour or so.[3] Values under these limits satisfy the protection principle. Effective flue gas dispersal through a high stack leads to concentrations below the limits in most

---

3 ug stands for microgramme = 1/1000 of a gramme; m^3 stands for cubic metre. ug/m^3 means microgramme(s) per cubic metre.

cases when the prior existing concentrations are nil or low as they generally are except perhaps in some areas with industrial emission sources. Ambient concentration monitoring over extended periods around two refuse incineration plants (RIPs) in Switzerland, for instance, have shown very low ambient concentrations.

Before a plant goes into operation, the acid gas concentration in the flue gas is not exactly known. With emission concentration values (milligramme of acid gas per m^3 of flue gas at standard conditions of a reference gas, or short mg/m^3) assumed as experienced at other sources, dispersal modelling calculations can be carried out using atmospheric and terrain data as further input to the model. Such modelling for the proposed RIP in Burnaby has shown that ambient limits as established in other jurisdictions would not be exceeded.

In 1974 West Germany adopted an additional principle or philosophy in its air quality regulations, referred to as "precaution principle". It says that over and above what is necessary for <u>protection</u> of health and for prevention of damage, the emissions should be reduced to a degree that can be achieved technically with a reasonable effort. Hence the emission concentrations were limited to

(i) 100 mg/m^3 std. adjusted to 11% O_2 for HCl, and
(ii) 5 mg/m^3 std. adjusted to 11% O_2 for HF,

and now well over half of the 46 RIPs in that country are equipped with scrubbers. The present limit for SO_2 is above the raw gas values experienced at RIPs, but the presently proposed revision of the regulations which is still under discussion, would set a limit of 200 mg/m^3 for SO_2.

Some other jurisdictions in Europe have followed the West German (D) example in recent years, notably Switzerland (CH), France (F) and on a case basis, Sweden (S). Only a few RIPs in these countries have been retrofitted with scrubbers, e.g. 2 of 48 in CH. The U.K., Denmark, the Netherlands, Italy and Belgium, all with many RIP's, at this time have no emission limits for HCl and HF. In Japan (J), local jurisdictions also have imposed limits, in some cases lower than the German limit. Recently several state air pollution control agencies in the USA also have established limits or will do so. Canadian provincial agencies are following suit. At present, no RIP's with energy recovery in North America have scrubbing systems, but at RIP Montreal some agricultural lime is fed into the furnaces with the refuse and this simple device accomplished a reduction of the HCl emission by about 50%.

The raw gas concentrations for HCl are typically considerably higher than the limits,

viz.,	D	400-1500 (average 780) mg HCl/m^3
	CH	average 950
	J	most reported values between 300 and 800
	USA	most earlier reported values around 350; several recently reported values considerably higher.

(Note: An alternative way of measuring emissions is as "emission factors" of kg of a pollutant per tonne of refuse burned.)

Therefore, to meet the emission concentration limits, much of the HCl has to be scrubbed out.

The raw gas concentrations of HF in Europe normally range 2-20 mg/m^3 and alone probably would not have led to requirements for scrubbing. Those for SO_2 are reported by various sources to average (for MBG RIPs)

46 RIPs in D	660 mg/m^3
11 RIPs in Bavaria	250 mg/m^3
48 RIPs in CH	195 mg/m^3
10 RIPs in USA	227 mg/m^3, ranging from 102 to 454.

(2) **What is scrubbing and what technologies are used?**

The description will concentrate on HCl, which is of most concern. The same methods and chemicals used for absorption work very well on HF but not quite as effectively on SO_2.

Plain water is an excellent solvent for HCl. So, water can be used to scrub or wash the acid gas out of the flue gas. However, usually an alkaline solution is added to enhance the removal of the acid gases. In the wet scrubbing systems (WS), the wash water is recirculated until it becomes very acidic. A pH balance is held by adding fresh water and drawing off some wash water (approx. 0.5-0.8 m^3 per tonne of refuse burned). Before this waste water can be discharged, it must be neutralized by addition of an alkaline chemical. Certain metals such as mercury, may be precipitated. The wet scrubbing lowers the gas temperature so much that dew point corrosion problems can occur and the gas buoyancy in the stack is reduced. Unless the stack is designed for these conditions, the gas must be reheated or other measures taken.

To avoid the said difficulties and the expense of liquid waste treatment and sludge disposal associated with wet scrubbing, some systems are offered in which the excess scrubbing liquid is evaporated using the latent heat of the flue gases. The remaining dry salts are readily soluble in water when they are deposited on land. In this respect, the wet systems with dry product are similar to dry scrubbing systems which also produce soluble salts. From overall environmental considerations, the Swiss regulatory agencies prefer wet systems with water treatment and effluent discharge to larger water courses which can absorb the residual salt load. The hydroxide sludge from neutralization with calciumhydroxide, $Ca(OH)_2$, is dewatered. Its deposition in landfills is considered non-problematic because the chemical compounds are not soluble.

A variety of washer types are used for wet systems. Fig. 1 shows the diagram of a wet system with waste water treatment as used at RIP Lausanne (CH). Citizens have been made to understand that the vapour plume above the stack is a sign that the system is working properly. Fig. 2 shows the diagram of a wet system with dry products. Wet scrubbing systems are installed downstream of a particulate removal device, usually an electrostatic precipitator (ESP) or at least an efficient cyclone. The WS systems are the most effective, at least as far as heavy metals removal is concerned, and they are the most expensive to build. However, WS requires only a small amount of chemicals in comparison with dry systems and this lowers the operating cost.

To avoid certain difficulties and early problems (corrosion) with wet systems and to lower the capital costs, dry and quasi-dry scrubbing systems have been developed. They are placed between the boiler and a particulate removal device, either an ESP or a fabric filter (FF). If an alkaline reagent -- usually quick lime, CaO, or hydrated (slaked) lime, $Ca(OH)_2$, because lime is cheaper than other reagents -- is well mixed in dry powder form or slurry form with the flue gas stream, neutralizing reactions with the acid gases take place and dry crystalline salt particulates are formed. A portion of the particles drops to the bottom of the reactor and is withdrawn from there. The remaining salt particles are carried with the flue gas stream into the ESP or FF where they are collected and withdrawn together with the fly ash.

In dry scrubbing (DS) systems, the lime (or other reagent) powder is blown or centrifugally dispersed into a reactor through which the flue gas exiting from the boiler is passed. An expanded fluidized bed of reagent is used in another system. Because the reactions in the dry state and at the prevailing gas temperature are slow, a much larger amount of lime is needed than theoretically necessary for complete reaction under ideal conditions (the stoichiometric ratio). The multiple of this ideal rate that is actually used to achieve reduction of the acid gases to the required limit or for a certain percent reduction is usually called the stoichiometric or alpha (α) factor. In dry systems it may range 2.5-3.5. For comparison, a near stoichiometric ratio (α factor = 1) is achieved in wet scrubbing.

Absorption of the acid gases by the alkaline reagent is enhanced by the presence of water and lowering of the temperature. Both are achieved in the quasi-dry scrubbing (QDS) systems in which the lime (or other reagent) is suspended or dissolved in water. The slurry or solution is distributed as fine droplets or mist in the reactor vessel through which the flue gas is passed. Good distribution can be achieved by means of rapidly rotating sprayers or by atomizing injection nozzles using compressed air to propel and "atomize" the slurry. The art of reactor design is in achieving good distribution throughout the gas stream and preventing caking on the reactor walls which is a potential problem with QDS. The α factor for QDS systems may range 1.5-2.5. For the beneficial effect of moisture and lower temperature explained above, some DS systems have a conditioning vessel upstream of the reactor where water is sprayed into the gas stream (evaporation cooler).

Fig. 3 shows in diagramatic form a dry scrubbing system and Figs. 4a and 4b depict a quasi-dry system. The systems depicted on Figs. 1 to 4 were developed in Europe. Fig. 5 shows a QDS system developed by Teller in the USA and used as shown on Fig. 5 with FF in two Japanese RIPs. The Teller QD quench reactor with ESP is installed in a fairly large number (14 or so) of RIPs in Japan.

If a fabric filter (FF) is used for particulate removal, a further reaction takes place in the dust layer which builds up on the bags, resulting in somewhat reduced reagent requirement. With both FF and electrostatic precipitators (ESP), the collected particulates are usually recycled into the reactor so that the unreacted lime will be exposed again for reaction. Multiple recycling (perhaps 10 times) will achieve good utilization also with ESP. To avoid burdening the recycling system and the ESP with too much fly ash, a precollector cyclone is sometimes inserted ahead of the scrubbing reactor, or with upflow reactors the bottom portion is designed as a cyclonic precollector. The capital cost of QDS systems lies between the wet and dry scrubbing systems.

The principal chemical reactions in DS or QDS systems with hydrated lime are as follows:

$$Ca(OH)_2 + 2HF \longrightarrow CaF_2 + 2\,H_2O$$
$$Ca(OH)_2 + 2\,HCl \longrightarrow CaCl_2 + 2\,H_2O$$
$$Ca(OH)_2 + SO_2 \longrightarrow CaSO_3 + H_2O$$

Fig. 6 shows the removal efficiency (the percentage removed) for the three acid gases vs. α factor for a dry scrubbing system + FF. The graph demonstrates that (1) the reaction with HF is rapid and near complete at a low α, (2) with HCl a high removal rate is achieved with $\alpha > 2$, and (3) with SO_2 the reaction is relatively slow and therefore may determine the reagent requirement if a relative low emission limit is specified for SO_2.

Figs. 7a and 7b illustrate in diagrams the relationship of some of the other parameters that were mentioned above with the reagent requirement (α factor).

(3) **Which type of scrubber is best and what are the costs?**

All types of scrubbers (wet, dry and quasi-dry) can achieve adequate removal efficiencies. However, with QDS and particularly DS systems, the amounts of reagent (lime or other) required to meet the low emission concentration limits specified by some regulatory agencies (e.g. in CH; special cases in D; local jurisdictions in J; State of California) may become inordinantly high if the raw gas concentrations are high (as typically in Europe). The adequacy of a DS system also depends on the particular particle collection device. Aside from costs, the selection should consider relative simplicity, robustness, and dependability of the systems under consideration, as proven by experience in other installations. Because there are many vendors of systems and relatively few installations of some of the makes exist (none as yet at RIPs with energy recovery in North America), at this time predictable market prices are not available from the published information. A graph showing the range of investment costs in West Germany has been published in a paper (1983) by a principal of a consulting firm which has been involved in the selection and evaluation of many systems. Fig. 8 renders this graph. An approximate scale of $ costs equivalent to the DM figures has been added. These costs cover the combined cost of the scrubbing and particulate removal devices. Costs given for the American Teller QDS system, that has been used in a number of Japanese RIPs fall into the range for QDS on the graph. The maintenance and general operating cost of the WS systems is probably higher than for the QDS and DS systems, particularly when water treatment is required. This is partly offset by considerably lower cost for the chemicals (lime or other). When the available data are applied to the proposed RIP in Burnaby, we expect roughly the following capital costs in million dollars (M$) additional to the ESP which is included in the tender price.

	Small Plant	Large Plant
No. of Units	1	2
Capacity (t/d)	228	456
Annual Throughput (t/a)	70 000	140 000
Wet Scrubbing (M$)	3.0	4.8
Quasi-Dry Scrubbing (M$)	1.5	2.4
Dry Scrubbing (M$)	1.0	1.6

The capital cost difference between QDS and DS indicated by the graph does not appear quite plausible. If it is assumed (1) that a QDS system is selected, (2) that interim finance charges amount to 15% of capital cost, and (3) that the annual amortization cost can be taken as 15% of capital cost, the additional amortization cost per tonne processed would be $3.70 per tonne ($/t) for the small plant and $2.96/t for the large plant. With costs for the reagent chemical as stated in the report by the Thermal Reduction Committee of the Lower Mainland Refuse Project and an allowance for operation and maintenance, the overall unit costs are estimated as approximately $7.0/t and $6.0/t for the small and the large plant respectively. These unit costs are higher than costs claimed by the vendor of the North American Teller QDS system, but they seem in line with some cost data from Europe, and represent a prudent estimate. With any increase in inflation the amortization portion, which is about one half of the total unit cost, will effectively become a decreasing burden as it will be paid in inflated dollars, while the O&M costs will rise approximately with the inflation rate.

(4) **Why wasn't an acid gas scrubbing system included in the design and tender?**

When the project was initiated, there were no applicable regulations in B.C. or, for that matter, anywhere in North America. While it was known that some regulatory agencies in Europe and local jurisdictions in Japan required scrubbing, many others had not moved to control acid gas emission. However, the possibility that scrubbing might become necessary was anticipated, and tenderers were asked to provide space for addition of a QDS system.

Acid gas dispersal modelling was carried out for the atmospheric conditions prevailing at the site and the local terrain. With emission concentrations then considered typical for North America used as input to the model, the results indicated that the highest ambient air concentrations occurring rarely under unfavourable atmospheric conditions would be under the limit established by some European agencies and latterly also in some North American jurisdictions. These limits, which are all nearly identical, are set so as to prevent adverse health effects and damage to the general environment. Actual long term monitoring around two Swiss RIPs with similar mass emission rates had shown much lower ambient concentrations than the limits that would be expected from dispersal studies for which, usually, quite conservative assumptions are made. No actual experience of specific ill effects from acid gas emitted by RIPs has become known from anywhere.

A possible approach considered as reasonable was to start operating the RIP, to measure the actual emissions and to monitor ambient air quality in a wide area around the plant. If necessary, a scrubbing system could then be designed for known raw gas conditions and to achieved a required reduction. If such an approach were followed, the monitoring might be carried out for several months unless emission concentrations were found from the beginning to be appreciably higher than anticipated. Even if they were, the plant could be operated until the retrofit of a scrubbing system is arranged. If need be, an interim measure such as adding some lime to the refuse could be taken, which is proving fairly effective at RIP Montreal as a regular measure that reduces HCl emissions by about 50%. A scrubber could be prefabricated and then installed fairly quickly during a shutdown of the plant or each individual unit in case of the larger plant, lasting perhaps a few weeks.

It may be questioned if such a 'wait and see' approach was justified, and a number of corollary questions may be asked, such as

-- Don't we know from experience at RIPs in other cities what amounts of acid gases will be emitted?
   Is our garbage so different from that in other North American cities?
-- If ambient concentration limits can be met without scrubbing, why do many agencies additionally or exclusively specify emission limits which make scrubbing necessary?

Before going into these questions, the response to the present question should be completed.

It was understood from the inception of the LMRP that the project would establish air pollution control standards or set out procedures for environmental approval, and that the project would have to meet whatever requirements would be imposed. If these were not in place before the tenders were received, the necessary adjustments could be negotiated as an extra to the accepted tender. Aside from the uncertainty on specific performance requirements which made it premature to make a decision on a scrubbing system, it is not practical at the present state of the market in North America to expect receiving a proven satisfactory system on the basis of general performance specifications. A proposed approach to scrubbing system selection will be outlined later herein. To complete the response to the present question (why a scrubber was not included in the tender), it should be added that the time required for the District alone to select and specify a particular system for inclusion in the bidding (which, we think, is not the best way) would have delayed the tenders considerably when firm information on the cost of a RIP was desired as input to the final recommendations and decision-making for a waste management plan under the Lower Mainland Refuse Project. Also, in fairness to the bidders, who were otherwise ready to submit their designs and prices, the already lengthly tendering process should not have been further extended. Before discussing the general selection process for a scrubbing system that is envisaged once specific requirements are established, the subsidiary questions posed in this section will be answered, and the impact on the proposed RIP in Burnaby of recommendations for air quality controls made by a special committee to the Project Manager of the Lower Mainland Refuse Project will be noted.

(5) **Don't we know from experience at RIPs in other cities what amounts of acid gases will be emitted?**
Is our garbage so different from that in other North American cities?

The HCl emission data available at the time indicated 200 ppmv (parts per million by volume) = 322 mg/m^3 as an average at comparable plants in the USA, i.e., plants which do not have scrubbing systems. Yet it was known that RIP Montreal had HCl emissions around 500 ppmv (800 mg/m^3). From very recent publications, some additional data have become known. These additional average HCl emission data now available are listed below:

HCl in the Raw Gas		ppmv	mg/m3	Emission Factor (kg/t burned)
RIP East Hamilton				2.7
RIP Chicago Northwest*		232	374	
RIP Harrisburg	PA*			4.24
RIP Nashville	TE*	110	177	
RIP Babylon	NY*	207	334	
RIP Galatin	TE	509	821	2.44
RIP Saugus	MA	605	976	
1979 Tests by USEPA				
2 unnamed RIPs		237	382	
RIP Montreal		ca. 500	ca. 800	before lime addition
RIP Quebec		950	1530	

* Tests between 1970 and 1978. Unmarked, tests later.
Note: In cases where repeated tests were run, the individual results did not differ much from the overall averages given in the table.

One can see great variations from place to place, and markedly higher values from many of the more recently conducted tests. How can the differences be explained? The earlier reported values are generally lower, so an increase in the use of plastics, primarily PVC, could be the cause. It is interesting to note that West German raw gas HCl concentrations are reported to have generally decreased in recent years due to lower consumption of plastics.

Differences in the composition of the wastes, in particular the proportion of commerical/industrial wastes could be a bigger factor. RIP Chicago NW, although a large plant in a big industrial city, burns almost exclusively refuse from domestic collections and has relatively low HCl emissions.

The RIP in Burnaby also would primarily burn domestic wastes and incidental pickup from small businesses. But we do not exactly know the composition and being able to base the design of a scrubbing system on measured data would be an advantage. In the absence of exact information, conservative assumptions would have to be made.

(6) If ambient air concentration limits can be met without scrubbing, why do many agencies specify emission limits which make scrubbing necessary?

The establishing of emission limits first in West Germany was based on a further principle, the precaution principle. It calls for lowering of all emissions to the extent that is technically achievable with a reasonable effort. Under this philosophy (As little emission as possible!), the emission limits are not related to a specifically defined danger level. Many other jurisdictions have since adopted similar emission limits on similar grounds, or are about to do so. The Incinerator Emissions Committee (IEC) of the Lower Mainland Refuse Project (LMRP) has made recommendations in line with this trend, and gone as far as declaring dry scrubbing plus fabric filtration as "best available control technology (BACT)". BACT or "lowest achievable emission rates (LAER)" are American concepts tied to the philosophy of "prevention of significant deterioration (PSD)" which is in effect roughly similar to the European precaution principle.

Whether the emission control philosophy (as low as possible, in keeping with reasonable technical feasibility) should be adopted, which pollutants should be regulated and to what limits they should be reduced, are questions now to be decided by the Lower Mainland Refuse Project. The next section discusses how adoption of the air quality control recommendations made by a special committee under the Project would affect the RIP in Burnaby. It mentions the limits proposed for the key parameters and makes some comments on these, and on the declaring of a BACT.

(7) How would air quality control recommendations by the Incinerator Emissions Committee (IEC) of the Lower Mainland Refuse Project affect the RIP proposed in Burnaby?

The recommendations for emission limits (extract from IEC report) are attached as Appendix A. The key controlled parameters applicable to this project are

(a)	Total Particulate		50	mg/m^3)	
(b)		HCl	70	")	All adjusted to standard
(c)		HF	5	")	
(d)	Sulphur Oxides	SO_x	250	")	at 12% CO_2.
(e)	Nitrogen Oxides	NO_x	300	")	

These values are oriented on the average or consensus of emission limits specified by regulatory agencies in the USA (some states), Europe (CH, D, S) and Japan, as summarized in Table C.5 of the IEC report, which is appended as Appendix B. Some of these are proposed revisions of existing regulations (CH, D) which are presently tabled for discussion but not yet adopted. The table (Table C.5) contains some inaccuracies, which have been pointed out in Mechler's memorandum to the IEC Chairman.

In addition to particulates and the four gaseous contaminants with specific limits in the IEC recommendations, some European regulations set specific limits also for groups of other contaminants, such as trace metals (heavy metals; see Table C.5 of IEC Report = App. B), hydrocarbons (H_mC_n), organics etc. However, the European regulations are general, i.e. applicable for all industries. The IEC recommendations, which are specifically meant for RIPs, imply that (1) adequate combustion control, which maintains a specified minimum temperature and gas residence time at that temperature, and (2) the specified particulate emission control will reduce emissions from RIPs to levels at which there is no concern. So, there is no need to set specific limits for these other contaminants. The treatment of these other emissions is somewhat related to BACT on which comments will be made later. The newer test data show, indeed, that RIPs can keep emissions of these other contaminants below specific limits set in the European regulations, which are levels that do not pose a risk.

The following discusses the impact of the IEC recommendations on the design of the proposed RIP in Burnaby.

Re (a) - Particulates: The previous and still existing requirement in B.C. is 0.1 gr/sdcf = 230 mg/m^3. The West German limit prior to the proposed revisions was 100 mg/m^3. The maximum specified for the Burnaby RIP is 0.025 gr/sdcf = 58 mg/m^3. It was set at this level to provide some margin for increased particulate load, if a scrubbing system were installed, between the increased particulate loading and a limit of 100 mg/m^3, which was considered an acceptable level. The new limit for all the countries mentioned and proposed for B.C. is now lower, viz., 50 mg/m^3. If this is to be met by the ESP, its design would have to be improved or a coarse dust precollector (separate or integral with a scrubbing reactor) would have to be installed.

Re (b) - HCl: The limit under the revised West German regulations will remain at 100 mg/m^3. The proposed Swedish limit is 200 mg/m^3. The new Swiss limit is to be 30 mg/m^3. The Swiss regulatory agency strongly favours wet scrubbing with discharge of treated waste water for overall (air and water pollution) considerations. Low residual emissions under the specified limits are regularly achieved by WS systems. It is felt that if a limit as low as 70 mg/m^3 is to be applied in B.C. some leeway for averaging over time (say a 2- or 4-hour average should be allowed. In any case, scrubbing would be required and the recommended limit could be maintained with a good and proven system of any of the three types.

Re (c) - HF: Raw gas concentrations are usually close to the limit specified. If scrubbing is done, emissions will be reduced to perhaps 1/10 of the raw gas concentration.

Re (d) - SO_x: As noted this is primarily SO_2. The proposed limit for West Germany of 200 mg/m^3 is being contested by plant owners, because RIPs contribute only a very small portion of the total SO_2 emissions, and such a low limit could lead to much increased use of reagents with DS and QDS systems and require an additional washing stage in wet systems. That is perhaps why the new Swiss limit is set at 500 mg/m^3. It is felt that a limit of 250mg/m^3 as proposed for B.C. should be reviewed and perhaps revised upward in the light of these considerations.

Re (e) - NO_x: Nitrogen oxides are not directly controllable in refuse combustion by add-on devices. They can be controlled to some extent by judicious control of the operation of well-designed combustion air systems. Emissions are typically around the limit proposed for B.C. Experiments have been made in Europe and Japan with NO_x reduction at RIPs by flue gas recirculation, but such measures have not been introduced into general practice except apparently at two RIPs in Denmark. It is considered doubtful whether this parameter needs to be regulated for RIPs.

Re BACT: The aforementioned memorandum by Mechler contains recent information on emissions of trace metals, trace organics (carcinogenic compounds), and dioxins and furans. The data indicate that, in RIPs of the type proposed here, the emissions can be held below the levels considered not to pose a risk by appropriate combustion system design and proper operation at the plants. Excepting dioxins and furans, which for practical reasons explained in the said memorandum cannot be regulated to specific limits, the new West German and Swiss regulations contain specific limits for trace metals and trace organic compounds, many of these drastically lowered from the previous permitted levels. Test data from numerous plants indicate that the new limits can be met by all three types of systems.

The test data also show somewhat lower trace metal emissions for plants equipped with scrubbing systems and having newer or augmented particulate removal devices, as compared to RIPs with particulate removal by ESP only. They also show that the differences in performance between ESP and FF with respect to particulate and trace metal removal are relatively minor and certainly not as great as the IEC Report suggests. Brief descriptions and some illustrations of ESP and FF, as well as cyclones, will be found in Appendix C.

Contrary to the impression given in the IEC Report, world-wide there are not more than a dozen RIPs equipped with FF and most of these are recent installations. There are some potential problems with FF which a recent paper by authors associated with American Air Filter Company (which supplies both types of particulate control devices and is a licensee for the Teller QD scrubbing system) lists as "fabric burning, blinding, degradation, ... (sensitivity to) low temperatures, excursions through the acid dew point, sparks" [4]. Also, filter bags have to be renewed periodically which adds to the operating cost. It is felt that the IEC Committee was not sufficiently informed when declaring dry scrubbing + FF as BACT, and that it is at least premature to do so. In fact, system selection should not be part of the regulations that may be adopted.

Further information on the experience at the relatively few and recent installations with FF should be obtained before considering a switch to fabric filtration for the Burnaby RIP. It would be prudent to obtain experienced advice and question the operators of systems, rather than rely on claims by the vendors and the opinion of the staff of regulatory agencies which have no practical experience with applications at RIPs.

(8) How should a scrubbing system be selected, and would installation of a system affect the timing of the RIP project?

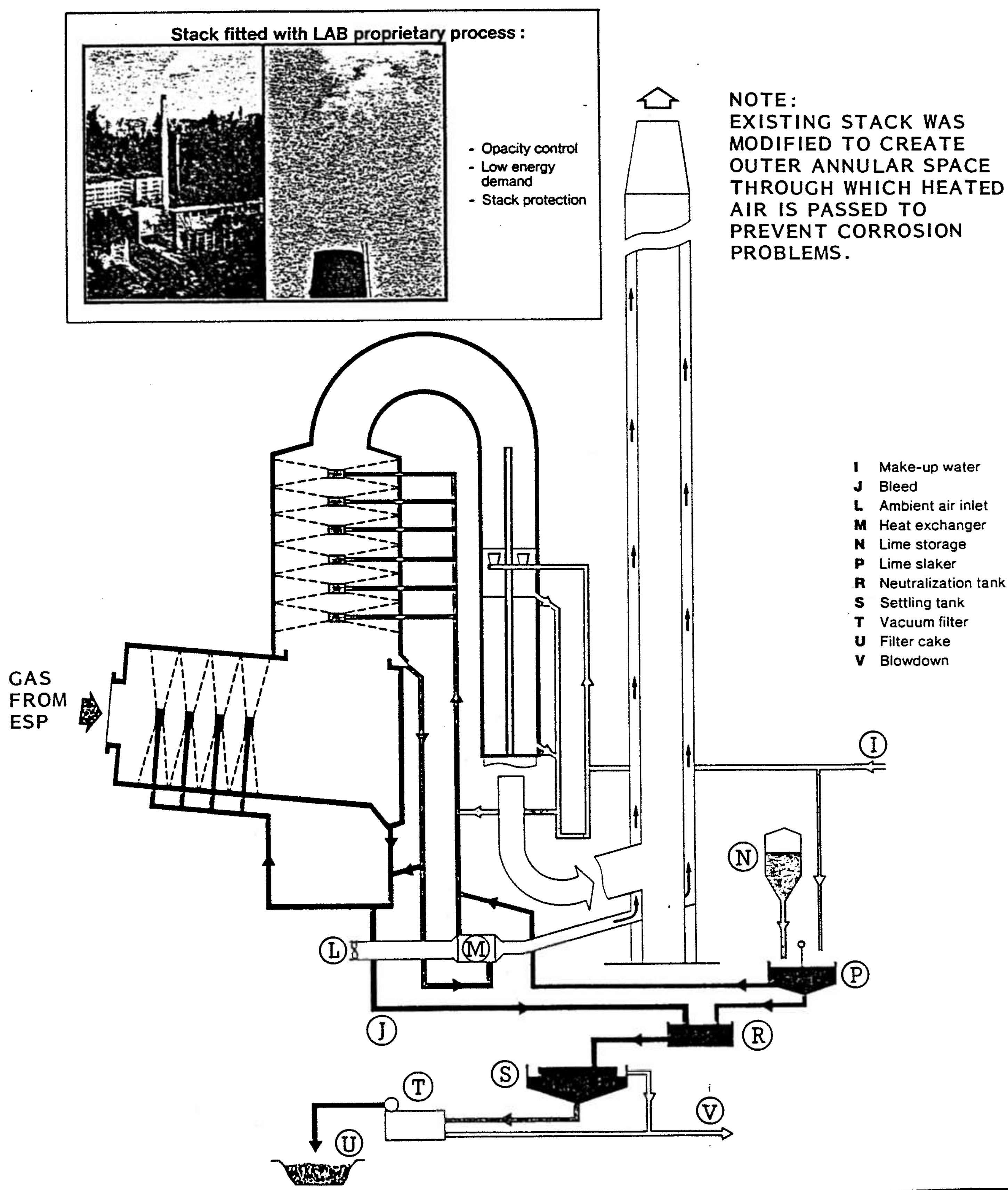
If it is decided, that a scrubbing system is to be installed as part of the RIP construction in order to have it operative from the start of plant operation, the following procedure could be used. GVSDD staff is already prepared for this by having gathered recent information on scrubbing systems and particulate control devices. During the selection process, staff could obtain advice from their contacts with operators of some of the newest systems and with regulatory agencies which carry out emission testing of these systems and are also familiar with them. This may be supplemented with expert advice from an experienced consultant. Staff would thus be prepared to choose a system in consultation with the selected contractor, its combustion system vendor, and its operating partner. In this way, the experience and preference of the members of the contracting group would be taken into account. If such a process were initiated early and specific air emission control performance criteria were established soon, an agreement in principle with the selected contractor on the erection cost and operating fee for a scrubbing system could

---

4 A full quotation from the paper on this matter is contained in Mechler's memo to the IEC.

be concluded without appreciably delaying award of a contract. The procurement could then proceed while site preparation work is carried out, and thus the addition of a scrubbing system would not appreciably affect the construction period required for the RIP.

It may be added that the vendor of the combustion system associated with the low bidder has recently built a plant in West Germany for which a QD + FF system was selected, and further that a plant soon to be constructed in Oregon for which this vendor is supplying the combustion system also will be equipped with FF. Moreover, that company has supplied technology for many operating plants in Japan and is involved in a number of new projects there, so that it is familiar with the status of technology in that country. So, well informed advice would be available from that source as input to the selection of a suitable system.



LAB WET SCRUBBING SYSTEM WITH WASTE SCRUBBING WATER TREATMENT AT RIP LAUSANNE (CH).

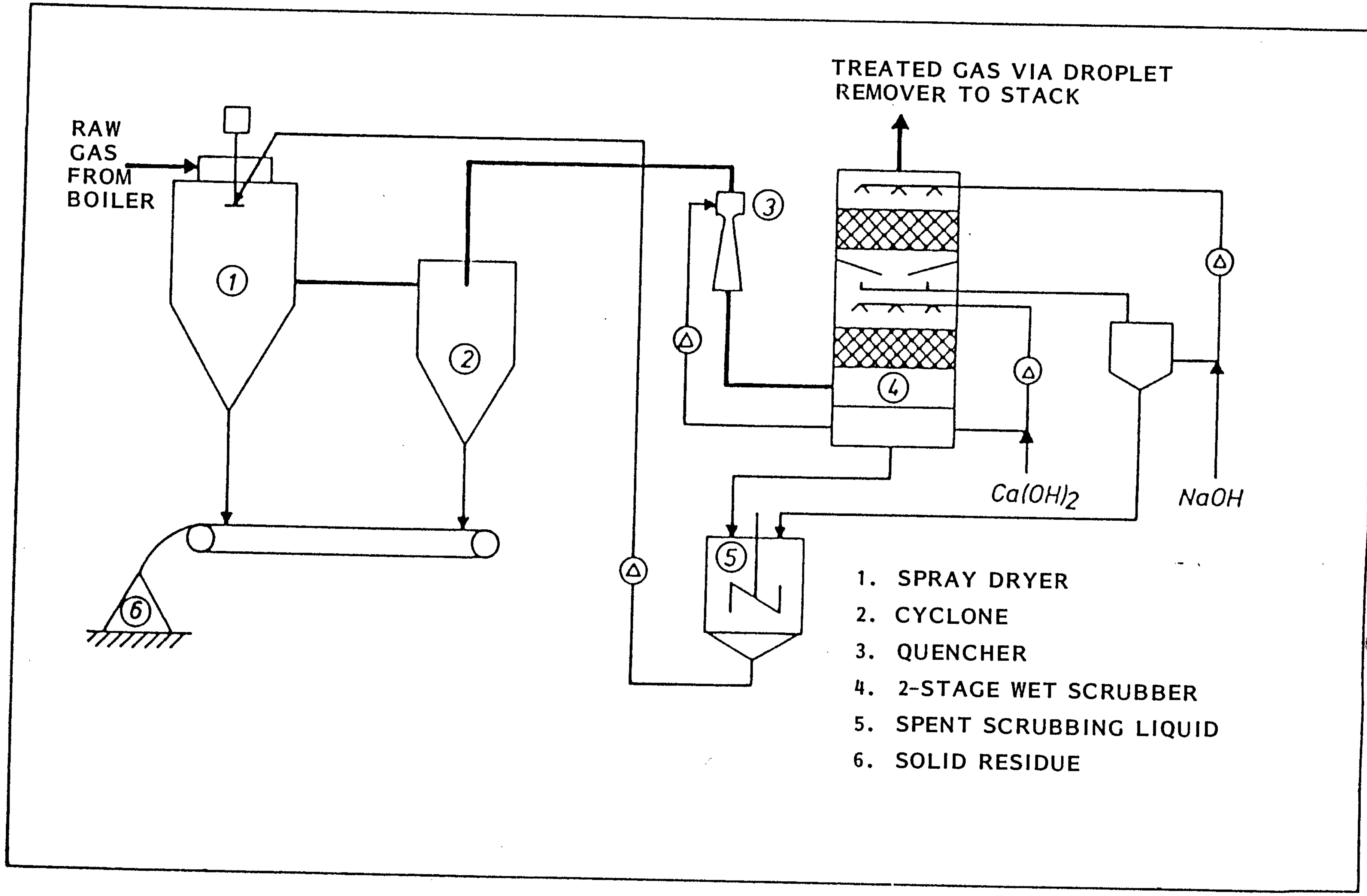


FIG. 2 - CIBA GEIGY WET SCRUBBING SYSTEM WITH EVAPORATION OF SPENT SCRUBBING LIQUID IN SPRAY DRYER (1) AND RESULTING DRY PRODUCT

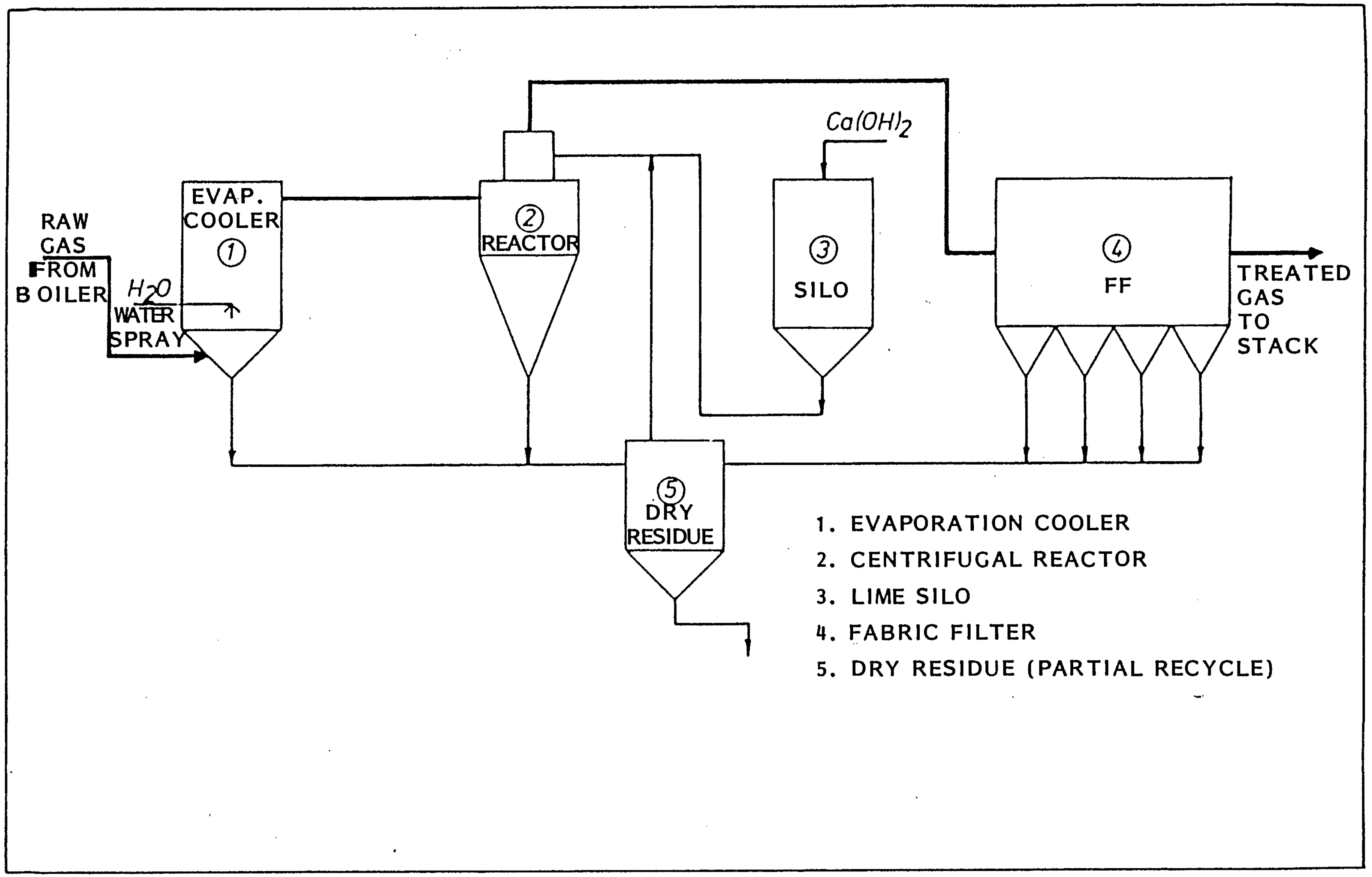


FIG. 3 - STEINMUELLER DRY SCRUBBING SYSTEM + FABRIC FILTER

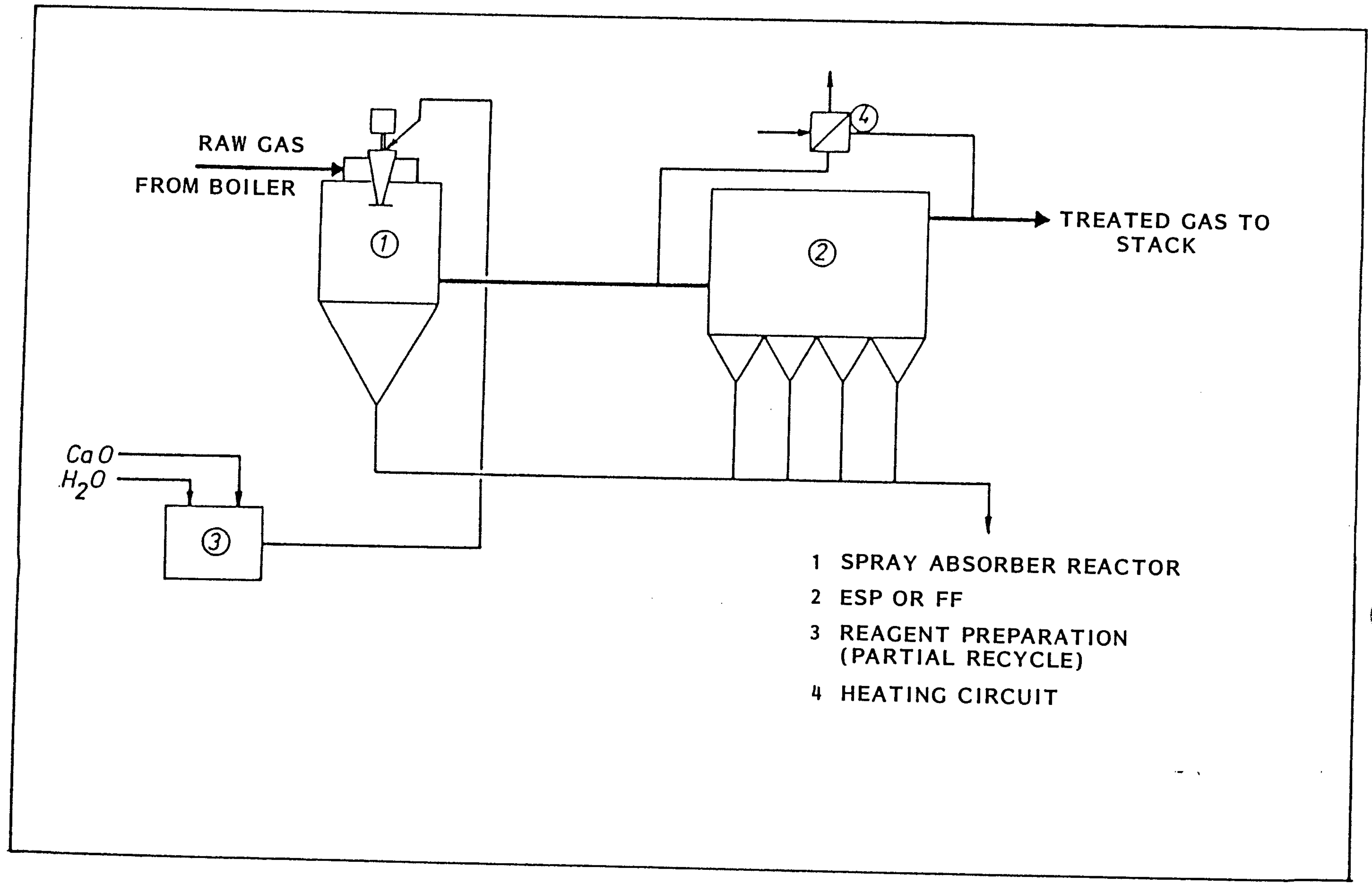
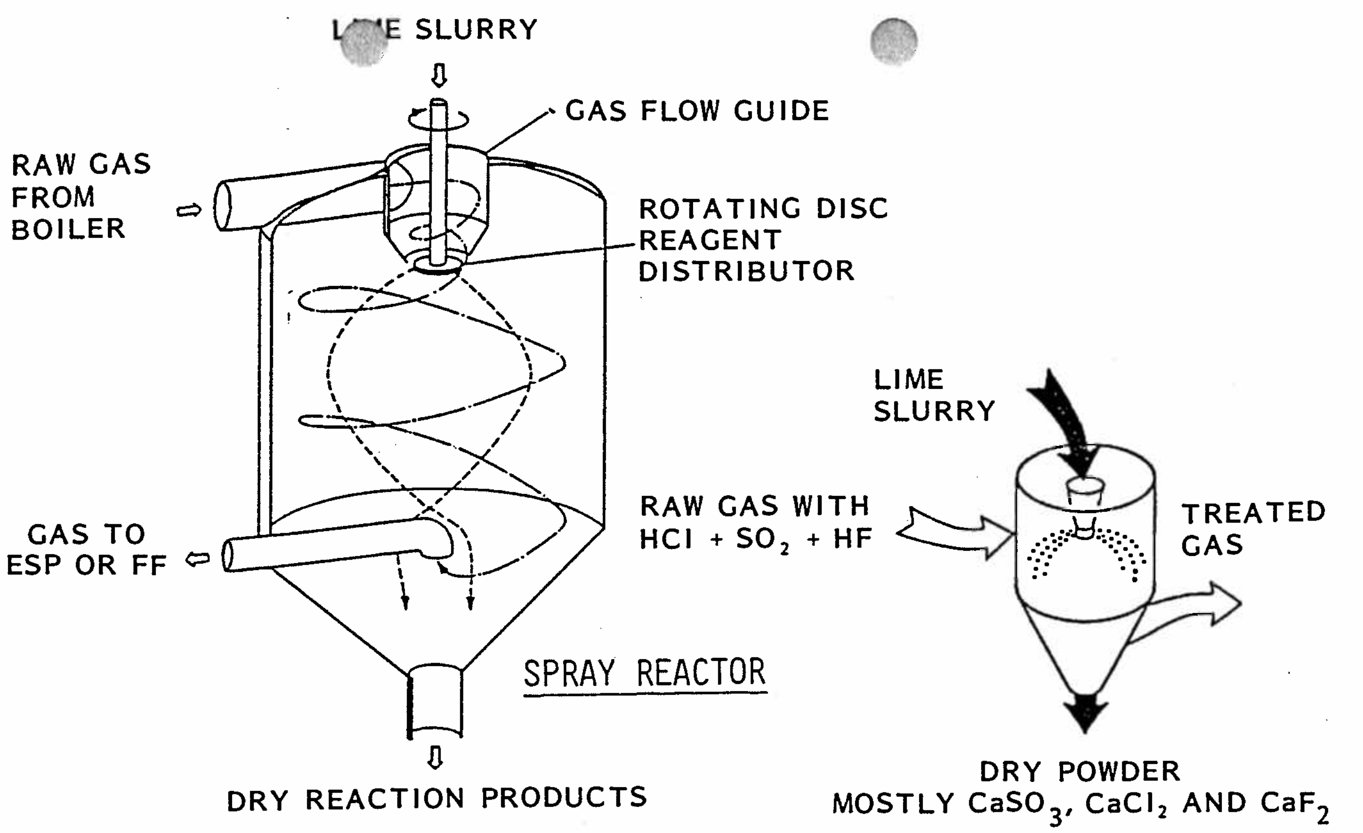
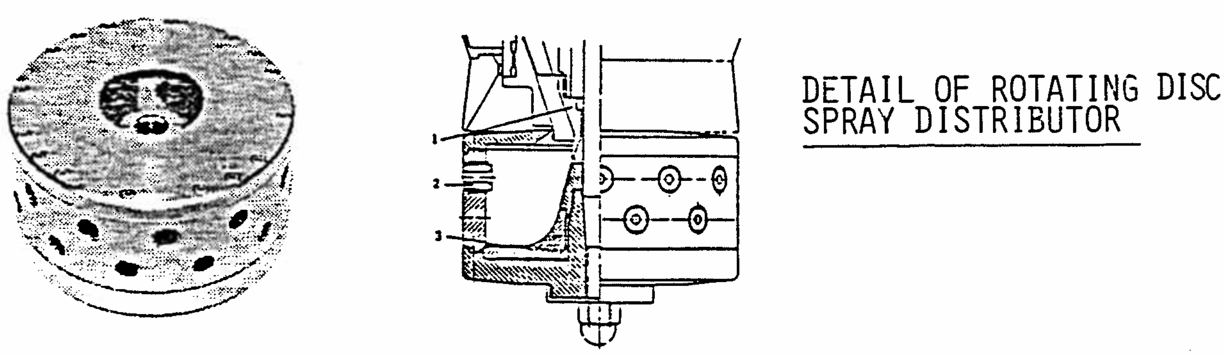


FIG. 4A - NIRO ATOMIZER QUASI-DRY SCRUBBING SYSTEM


SLURRY
GAS FLOW GUIDE
RAW GAS
FROM
BOILER
ROTATING DISC
REAGENT
DISTRIBUTOR
LIME
SLURRY
GAS TO
ESP OR FF
RAW GAS WITH
HCI + SO2 + HF
TREATED
GAS
SPRAY REACTOR
DRY REACTION PRODUCTS
DRY POWDER
MOSTLY CaSO3, CaCl2 AND CaF2


1
2
3
DETAIL OF ROTATING DISC
SPRAY DISTRIBUTOR

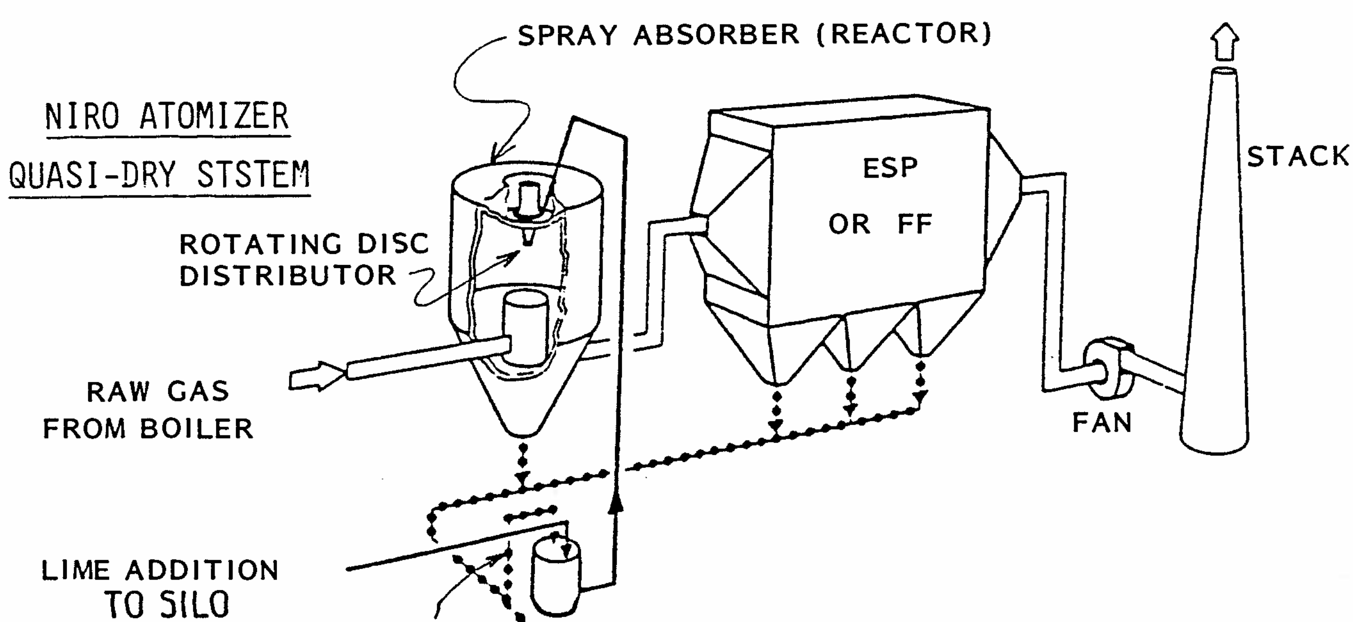
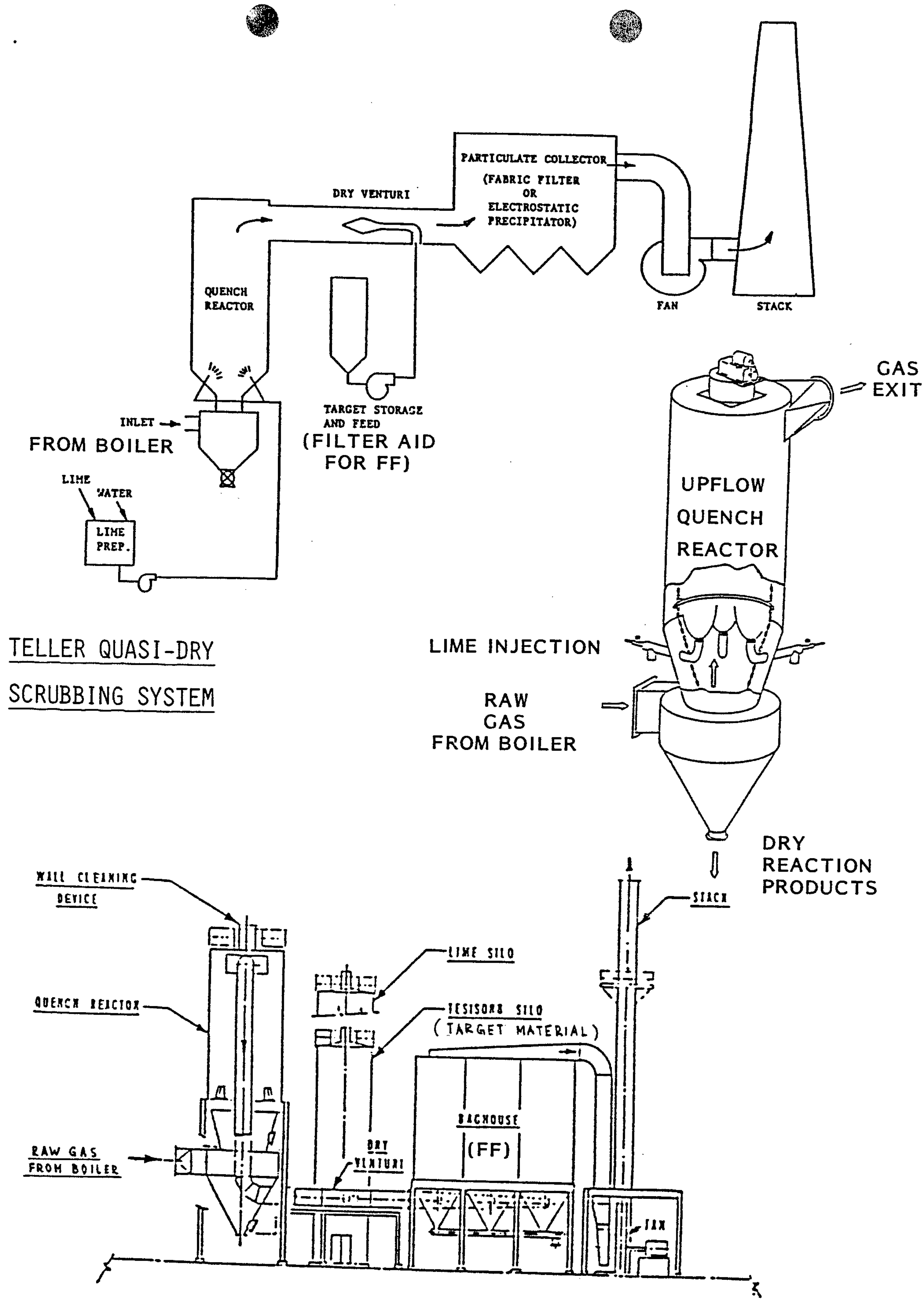

SPRAY ABSORBER (REACTOR)
NIRO ATOMIZER
QUASI-DRY STSTEM
ROTATING DISC
DISTRIBUTOR
ESP
OR FF
STACK
RAW GAS
FROM BOILER
FAN
LIME ADDITION
TO SILO
PARTIAL
RECYCLE
TO LANDFILL

FIG. 4B



TELLER QUASI-DRY
SCRUBBING SYSTEM

FIG. 5

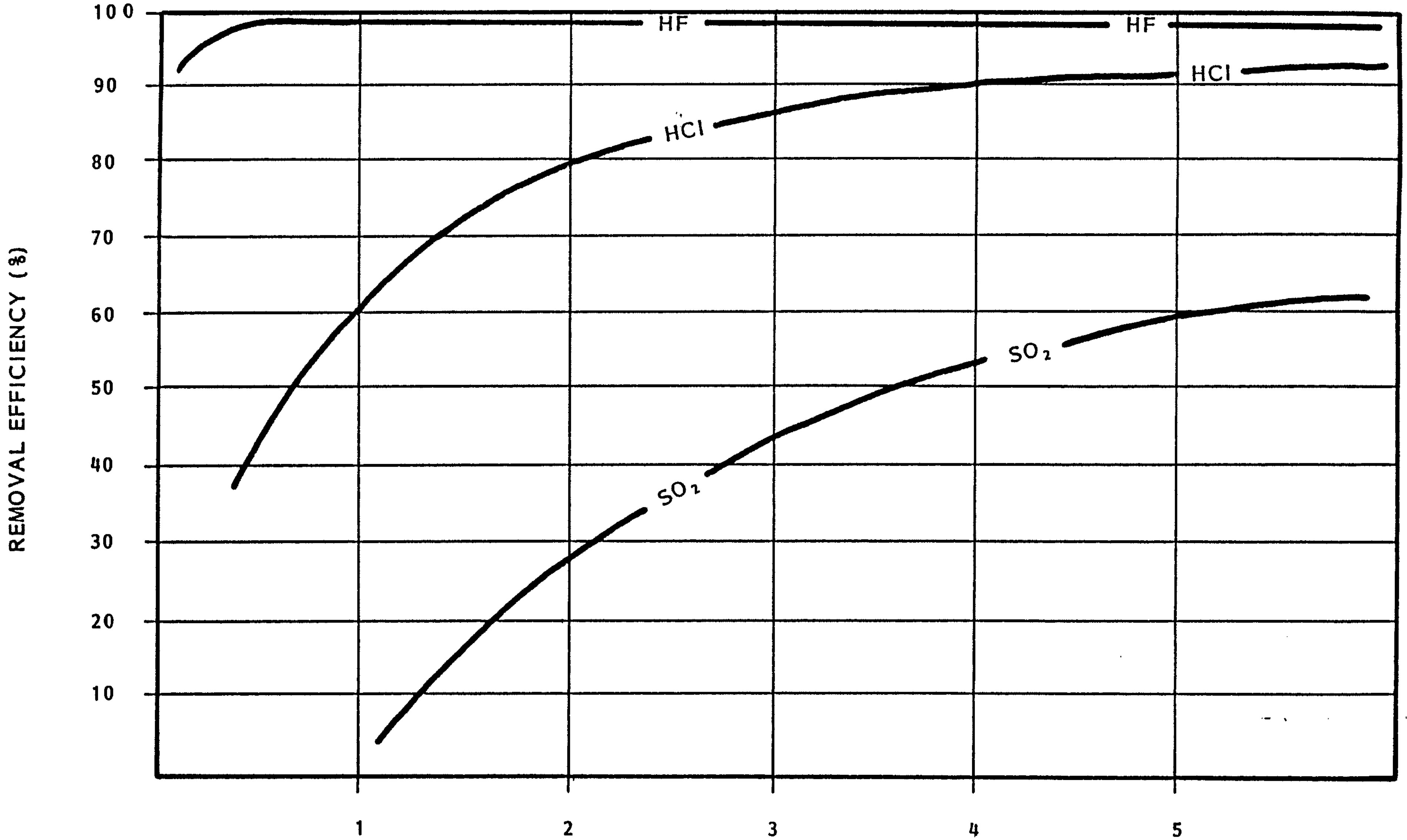
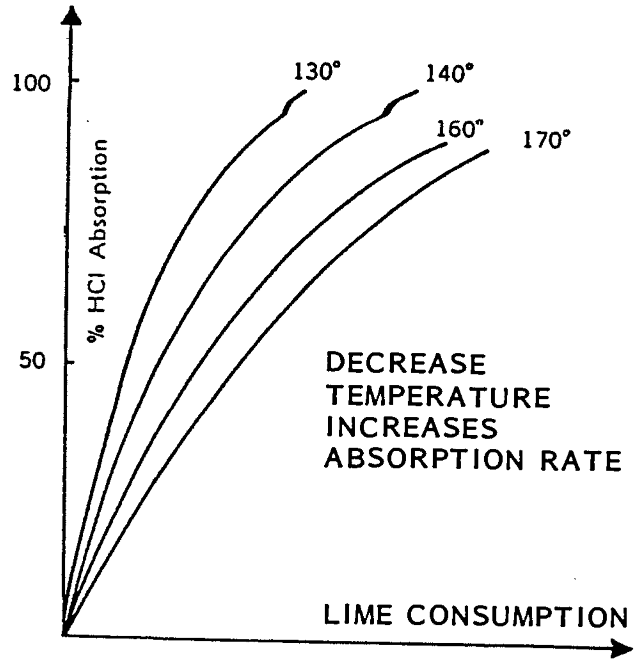
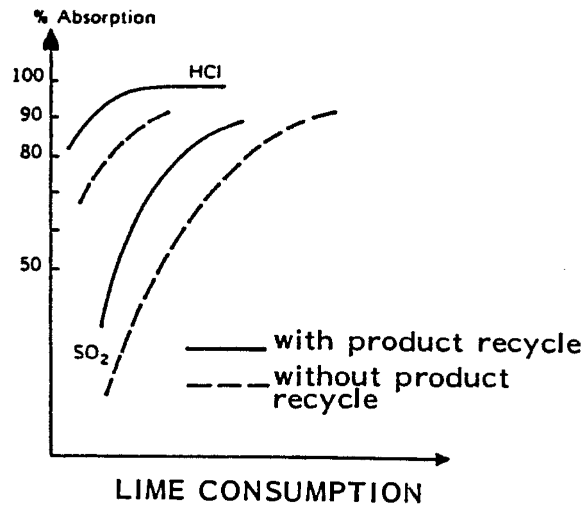


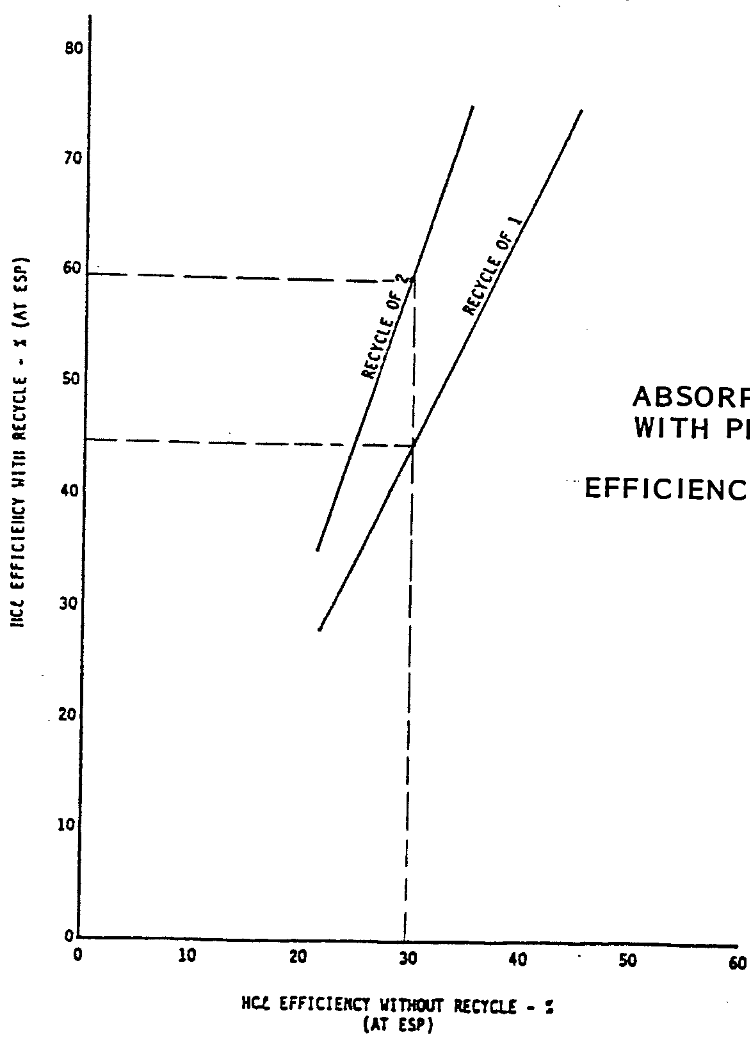
FIG. 6: Ca $(OH)_2$ ALKALINE REAGENT USE - STOICHIOMETRIC FACTOR α FOR A DRY SCRUBBING SYSTEM + FABRIC FILTER



EFFECT OF GAS TEMPERATURE ON LIME CONSUMPTION AND ABSORPTION EFFICIENCY

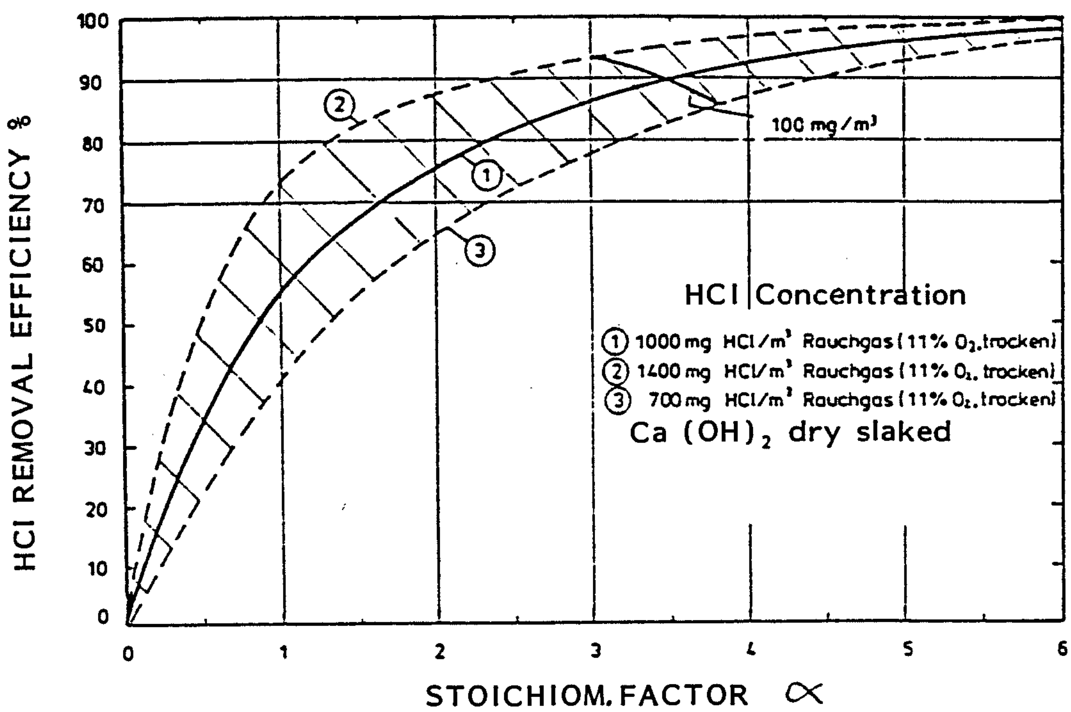


EFFECT OF PRODUCT RECYCLE ON LIME CONSUMPTION AND ABSORPTION EFFICIENCY

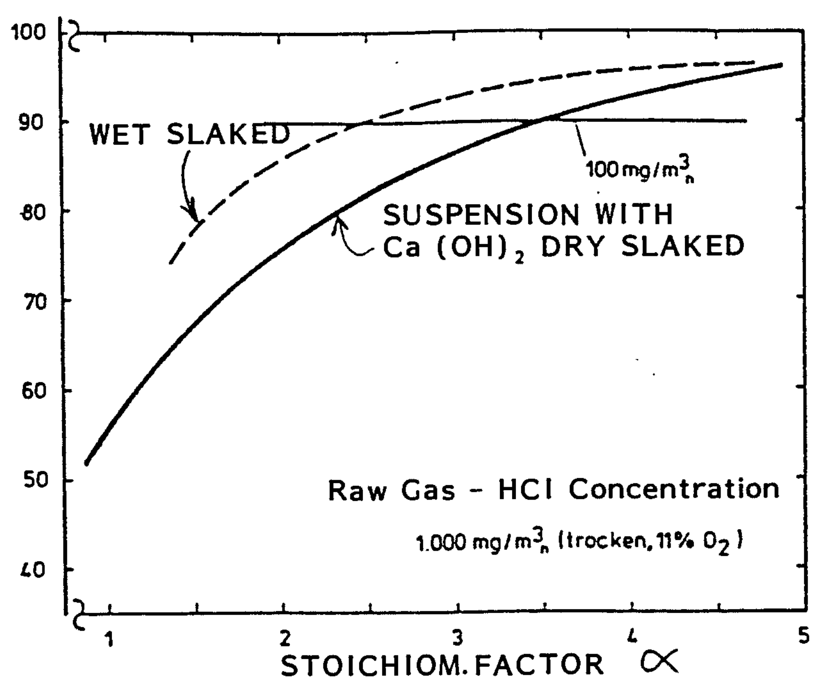


HCl ABSORPTION EFFICIENCY WITH PRODUCT RECYCLE VS. EFFICIENCY WITHOUT RECYCLE

FIG. 7A



REMOVAL EFFICIENCY AND AMOUNT OF LIME REQUIRED TO ACHIEVE ≤ 100 mg/m³ EMISSION AT VARIOUS HCl RAW GAS CONCENTRATIONS WITH A QD SYSTEM + ESP



REMOVAL EFFICIENCY AND AMOUNT OF LIME AS A FUNCTION OF LIME QUALITY

FIG. 7B

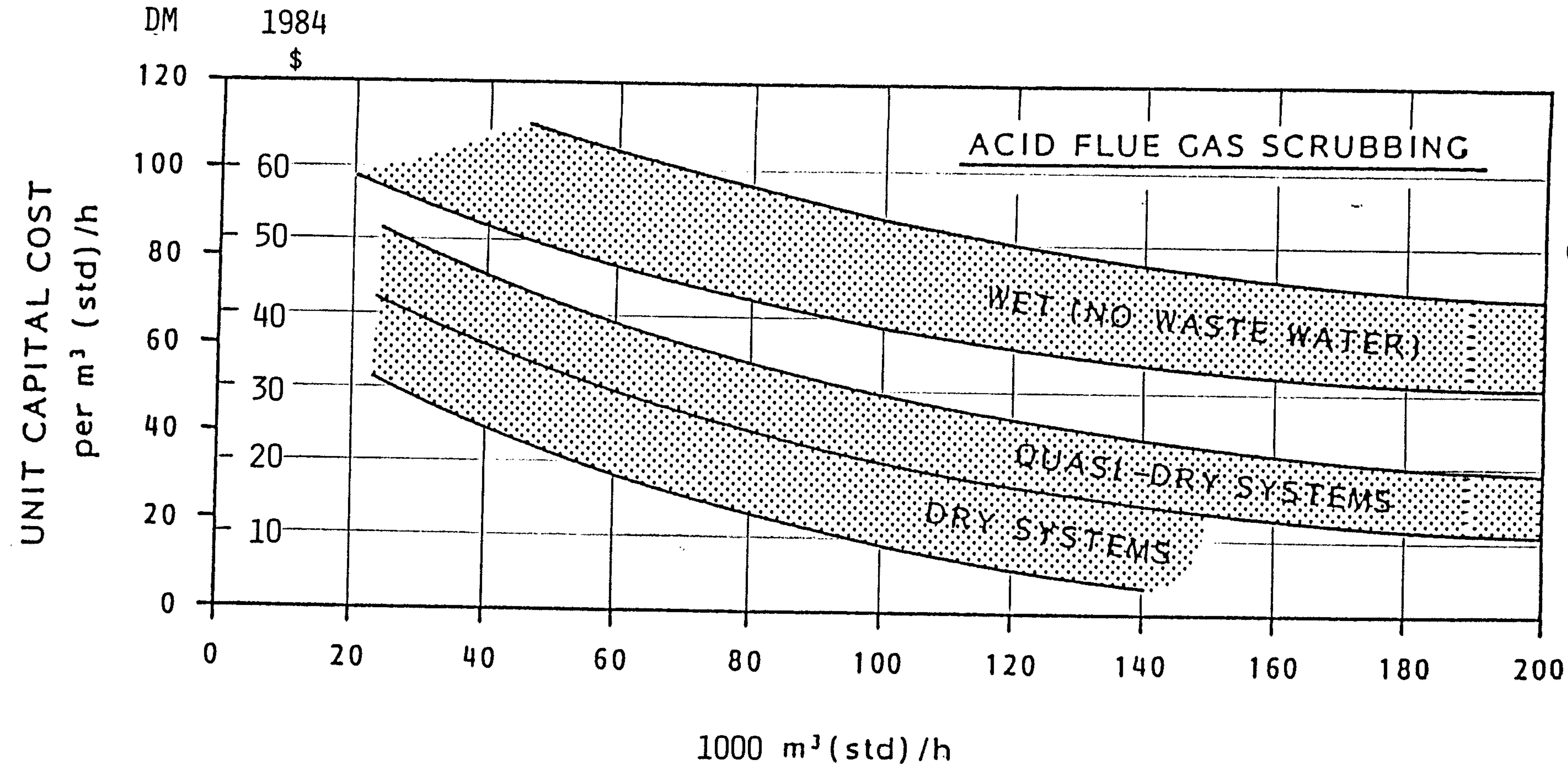


FIG. 8 Capital Costs of Acid Flue Gas Scrubbing Systems in West Germany (1983)

(from Report by Thermal Reduction Committee of LMRP, June 1984)

TABLE I

RECOMMENDED EMISSION LIMITS FOR MUNICIPAL REFUSE INCINERATORS WITHIN THE LOWER MAINLAND

PARAMETER	EMISSION RANGE (mg/m^3)	REMARKS
Total Particulate	50-230	1,3,4
Hydrogen Chloride (HCL)	70-a	1,3
Hydrogen Fluoride (HF)	5-a	1,3
Sulphur Oxides (SO_X)	250-a	1,3
Nitrogen Oxides (NO_X)	300-a	1,3
Hydrocarbons (HC)	See note "b" below	
Carbon Monoxide (CO)	See note "b" below	
Trace Organics	See note "b" below	2
Trace Metals	See note "c" below	2

Notes

a) Normal emissions from an efficiently operated incinerator burning typical municipal refuse.
b) The incinerator shall be designed to maintain the combustion gases at minimum temperature of 980°C with a residence time of at least one second.
c) Emission levels based upon particulate emission control technology.

Remarks

1. Concentrations corrected to 12% Carbon Dioxide (CO_2).
2. Emissions of trace organics and trace metals will be minimized by fabric filtration.
3. Compliance with these numbers should be based upon single measurements.
4. On most restrictive end annual average of 30 mg/m^3 should be achieved.

TABLE C.5

Summary of Emission Limits for Municipal Refuse Incinerators

CONTAMINANT	EMISSION LIMIT (mg/m^3)				
	USA (a)	West Germany (c)	Switzerland (b)	Sweden (b)	Japan (c)
Particulates	25-75	50-75	50	50	35
HCl	50	30-100	30	200	80
HF		5	5	5	
SO_2	75-200	200	500	-	
Zn			5		
Pb			5		
Sb,Cu,Mn,V		5			
As,Cr,Co, Ni,Se,Te		1	(Refer to Table C.3)		
Tl					
Cd		0.2	0.2		
Hg			0.2		0.1
Basis: Dry gas at:	12%CO_2	11%O2	11%O2	10%CO2	

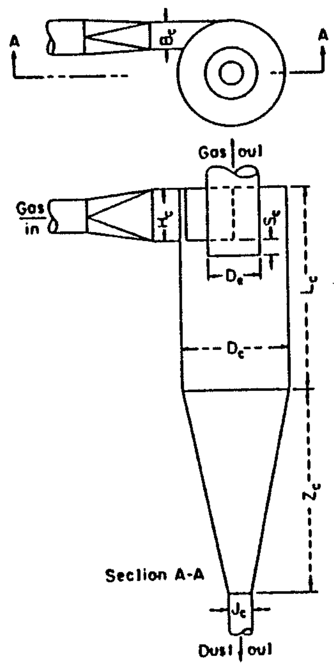
a) No nationwide standards, however many states, including Washington, Oregon, California, New Jersey, Connecticut, and New Hampshire, have guidelines which call for BACT control technology capable of meeting these emission limits.

b) Newly proposed.

c) Local regulations might be stricter and include trace toxic elements in gas phase.

Cyclone

The cyclone is one of the commonly used devices for separating solids from gases because of its relatively low capital and operating costs. Generally a cyclone consists of a vertical cylinder provided with a tangential entry positioned above a conical reducing section that leads to a hopper for the solids. Gas and entrained solids flow in a vortex path, with the larger particles separated by the centrifugal forces as already described. The clean gas leaves the cyclone at the top through the centrally located outlet that projects into the cylindrical section.

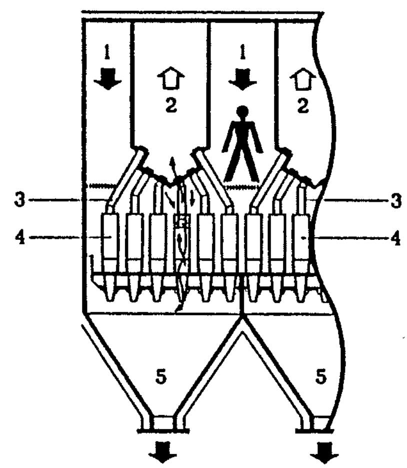


NOTE: CYCLONES ARE SOMETIMES USED AT RIPs AS PRECOLLECTORS FOR COARSE PARTICLES

Multiclones

A multiclone takes up less space than a large-size cyclone for the same gas throughput. The type of construction and the arrangement of the gas inlet and outlet can be varied within wide limits, enabling multiclones to be easily incorporated into existing plants.

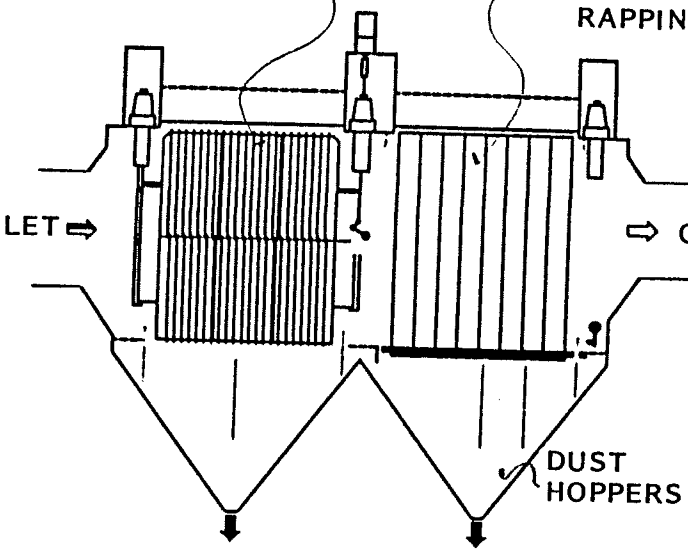
Multiclones consist of a large number of collecting tubes arranged in parallel (diameter 230 mm), with internal vane rings which force the dust-laden gas to rotate. The cleaned gas flows up through the centre of the collecting tubes into the clean gas manifolds. The inclination of these tubes makes the multiclone easily accessible for inspection. The multiclone tubes are smaller in diameter than a large-size cyclone, and therefore higher centrifugal forces can be obtained.

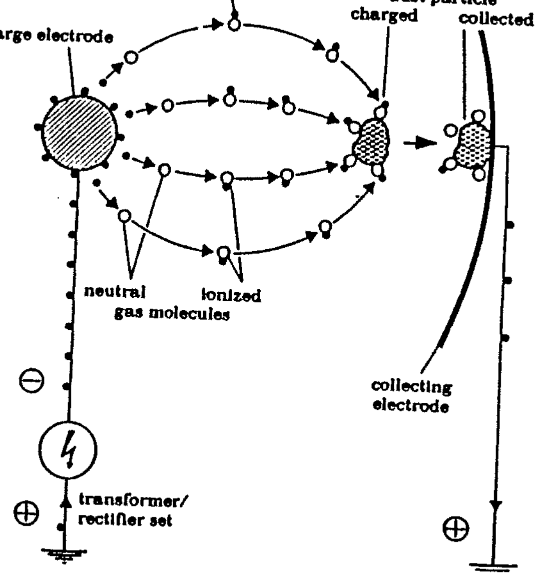


Multiclone Installation

1 Raw gas duct, accessible for inspection
2 Clean gas manifold
3 Clean gas tube
4 Collecting element
5 Dust hopper

APPENDIX C — PARTICULAR REMOVAL DEVICES: CYCLONES





Types

Electrostatic precipitators may be of either the tube or the plate design. Both types can be used for dry gases and for wet, mist-laden gases.

Tube precipitators

consist of parallel, vertical tubes with a circular or honeycomb cross-section, in the centre of which are suspended the high-voltage discharge electrodes. The tubes, which form the collecting electrodes, are earthed.

Plate precipitators

Here, the collecting electrodes are in the form of parallel, vertical plates, between which the high-voltage discharge electrodes are arranged. The plates are shaped to provide quiescent zones to prevent the collected dust from being re-entrained by the gas stream.

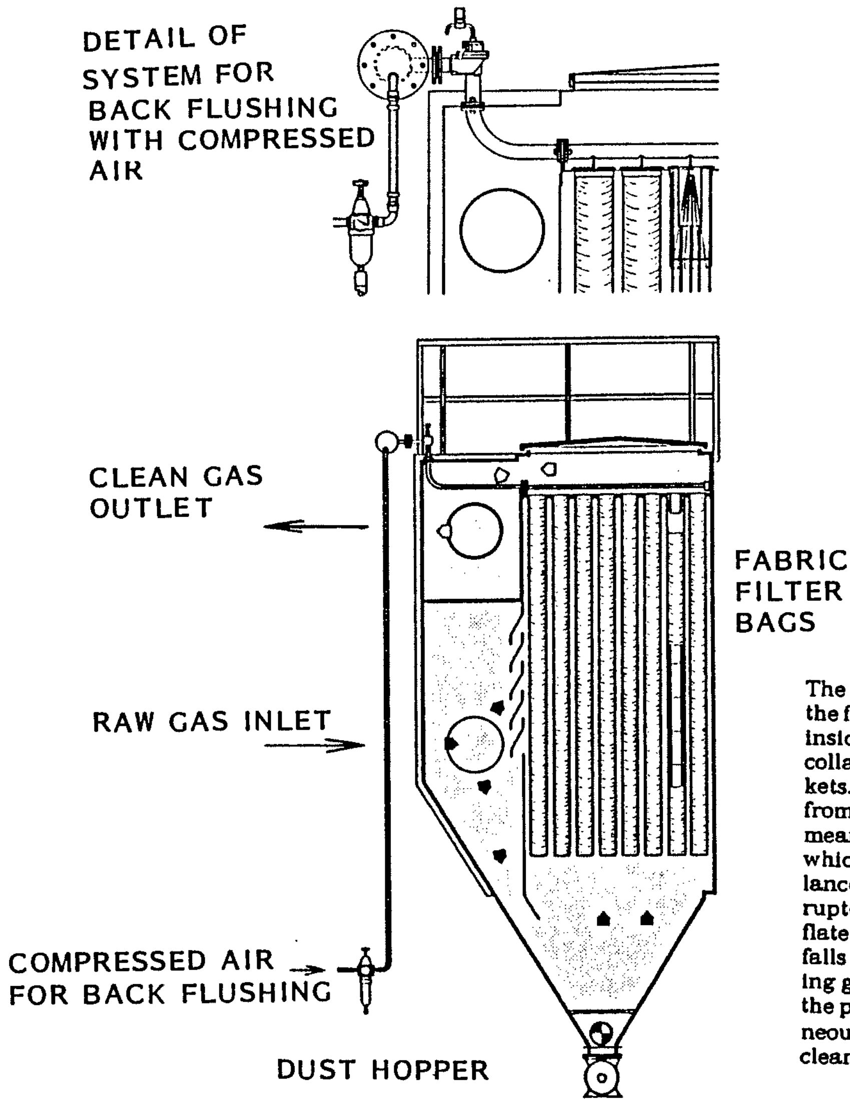
The precipitator casings are constructed of sheet steel, brick, concrete or plastic, depending on the properties of the gas to be cleaned.

Collection principle

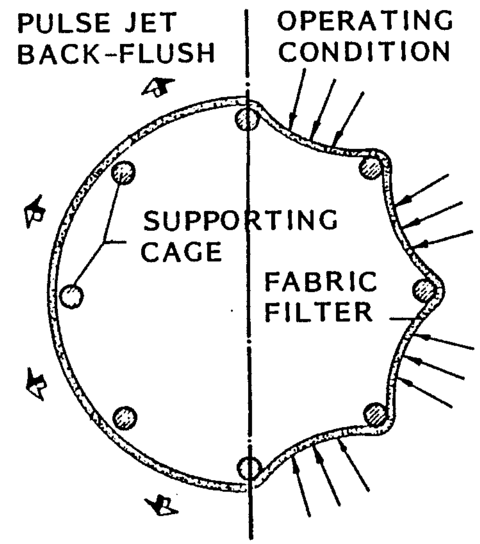
The dust or mist particles suspended in the gas are electrically charged, conveyed to the collecting electrodes under the influence of a strong electrical field and deposited there.

The collecting electrodes are earthed together with the precipitator casing, while the discharge electrodes (thin wires or barbed strips) have negative polarity and are suspended from insulators.

A d.c. field prevails between the electrodes, the voltage of which ranges from 20 kV to over 100 kV depending on the type of precipitator and the application. In the immediate vicinity of the discharge electrodes, corona discharges take place due to the high field strength. This releases electrons; the resulting negatively-charged gas ions attach themselves to the dust particles. The latter migrate under the influence of the electrical field to the collecting electrode, where they lose their charge.



The dust-laden gases pass through the filter bags from the outside to the inside. The bags are prevented from collapsing by interior support baskets. The collected dust is removed from the surface of the filter bag by means of a pulse of compressed air, which is injected into the bag via a lance. The gas flow is briefly interrupted, the filter bags suddenly inflate and the dust cake breaks up and falls into the hopper. The scavenging gas stream injected by means of the pulse of compressed air simultaneously brings about thorough cleaning of the filter medium.



Collection principle

When dust-laden gases flow through a porous fabric, the dust is separated from the carrier gas and deposited on the filter cloth. It is removed periodically and falls into the dust hopper.