PLENARY SESSION 3

WORLDWIDE ESP TECHNOLOGY

AN ELECTROSTATIC PRECIPITATOR DESIGNED SPECIFICALLY TO COLLECT ORIMULSION FLY ASH

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Abstract

In the late 1980's BP BITOR, a marketing company formed by a partnership between British Petroleum and Petroleos de Venezuela, introduced Orimulsion to Utility Plant Operators as a potentially cost effective replacement for heavy fuel oil in Western Europe. BITOR is also marketing the fuel in other parts of the world. Orimulsion is an emulsion of bitumen and water having broadly similar combustion properties to heavy fuel oil.

Analyses from various Orimulsion test burns are presented and compared to heavy fuel oil. This analysis indicates Orimulsion has a higher ash content and therefore produces a larger inlet loading requiring a higher efficiency for a given emission. The particle size of Orimulsion fly ash is also largely submicron and its bulk density is extremely low.

These differences are reviewed in detail with particular reference to how they impact on precipitator design. Following installation on a 500 MW unit the precipitator performance over a period in excess of 12 months is discussed. Emissions in the order of 25 mg/sm^3 wet at 12% CO_2, with a gas flow some 15% over its original design flow were recorded.

The combustion characteristics of Orimulsion are such that the heat transfer pattern in the boiler changes. This change can be load limiting unless modifications are made to the heating surfaces and soot blower installations. There was some initial conservatism about what maximum load would be sustained. The relevant modifications were implemented however, and this allowed continuous operation at a load close to the original plant MCR rating.

The results from this operational plant, not only confirm the different physical and chemical properties of Orimulsion fly ash, but produce a better understanding of how they impact on precipitator collection efficiency. The ash from Orimulsion behaves differently from, for example, coal ash and care must be taken during the design of the ash handling plant to ensure that the ash is kept warm, there is minimum water ingress and any sharp bends in the pipework are eliminated.

Introduction

The introduction of Orimulsion in the late 1980's for power generation applications was subsequently met with cries of 'Wonderfuel' to the 'Worlds Filthiest Fuel' dependent on whether you were a potential user or an objector to its use.

Orimulsion is a fuel marketed in the UK by BP BITOR, a partnership between British Petroleum and Petroleos de Venezuela. The fuel is derived from bitumen in the Orinoco basin. On extraction, the bitumen is mixed with 30% water and a surfactant to form a stable emulsion, and then transported and used as a direct cost effective replacement for heavy fuel oil.

The main advantage of Orimulsion lies in its combustion characteristics which are superior to heavy fuel oil. The improvement is a result of a nominal median 20 micron bitumen particle suspension, giving lower carbon carryover without resorting to high excess air combustion. The 30% moisture however reduces the calorific value (CV) and gives a higher moisture in the boiler exit gases. In addition, the fuel has a constant quality as it is extracted from a large homogeneous deposit of natural bitumen. This means that is possible to optimize combustion and precipitator conditions for good environmental performance.

Its disadvantages relating to emissions are: - a) Orimulsion contains more ash than heavy fuel oil, around 0.3%, compared to less than 0.1%, giving rise to higher particulate carryover particularly of the heavy metal oxides, vanadium and nickel, b) Its sulphur content, which, although no higher than HFO and some coals, could with the vanadium acting as a catalyst, potentially give rise to the formation of SO_3 and relatively high acid dew point temperatures. In practice it has been found that the good combustion characteristics of the fuel mean that it can be burned with very low excess air. This, together with the effects of the magnesium which is added at source, means that very low levels of SO_3 are measured.

In the UK, there are a number of oil fired utility installations which, because of the variable and often high price of oil, have a relatively low utilization factor. The introduction of Orimulsion has produced interest from the power companies as a means of improving their plant utilization.

Various test burns have been conducted world wide with a number of existing plants fitted with electrostatic precipitators, these being originally supplied as a means of controlling coal fly ash emissions. These test burns proved Orimulsion as a technically and potentially commercially viable alternate to both coal and heavy fuel oil as a means of power generation. Analysis of the fly ash characteristics identified major differences between the Orimulsion fly ash and other types of fuel derived particulates as regards potential collection problems.

The paper describes how the different characteristics of Orimulsion fly ash have been resolved with a precipitator designed specifically to produce low and acceptable particulate emissions.

Orimulsion Fly Ash Characteristics

As indicated earlier Orimulsion differs from heavy fuel oil in many respects, for example, handling, combustion and ash characteristics. These differences are compared in Table 1 for the typical fuels.

The particulate carryover varies in many aspects both in terms of composition and particle size. These differences are identified in Table 2 which lists the chemical analyses. It should be noted that the chemical composition can vary. Careful control of excess air can result in much less of the ash being sulphated and a resulting higher concentration of Vanadium Pentoxide. Figure 2 compares the particle sizing.

Orimulsion produces a higher dust burden than the combustion of most heavy fuel oils. It therefore requires a higher removal efficiency to comply with legislation. Recent worldwide environmental pressures particularly, as regards heavy metals, means even lower emissions are necessary to satisfy environmental restrictions. Achieving high collection efficiency is made even more onerous since the heavy metals are probably condensed from a vapor phase resulting in sub micron particle sizing.

Chimney Emission Requirements

With the increasing world wide attention to the environment, concern was uppermost in deciding the emission requirement for any new plant firing Orimulsion. In the EC the proposed particulate emission from oil fired installations is 50mg/Nm^3, but it was decided that as 70% of the Orimulsion fly ash was sub micron, the chimney discharge at 50mg/Nm^3 would be fairly visible, an average emission of 35mg/Nm^3 was therefore chosen to form the basis of the precipitator design. (Normal is expressed as 0°C and 1.013 bar dry corrected to 3% oxygen).

The impact of mass concentration on stack opacity is illustrated in Figure 1. Generally a stack opacity of 20% (Ringlemann 1) or less is considered acceptable for power plant. Note that as the opacity meter output depends on path length the results must be corrected for the chimney diameter.

Plant Design Characteristics

Efficiency

From Tables 1 and 2, assuming a maximum ash content of 0.34% and 100% carryover from the furnace, an inlet concentration of 250mg/Sm^3 is produced at the MCR boiler flow rate of 670.8 Am^3/s at 175°C. An emission of 25mg/Sm^3, (15°C 1 bar pressure, wet, corrected to 12% CO_2) equivalent to the above 35 mg/Nm^3, produces an efficiency of 90%.

Gas Temperature

Typical of furnaces firing high sulphur fuels, the amount of sulphur trioxide converted from the sulphur dioxide is dependent on a number of factors, such as, flame length, flame temperature, excess air, the presence of catalysts etc. However, at normal full load conditions the exit gas temperature from the air heater is usually well above the acid dew point temperature thus avoiding any corrosion and fouling.

Fly Ash Properties

Unlike other fuels, the fly ash produced from Orimulsion has a fairly narrow size spectrum and an extremely low bulk density of 80 - 160 kg/m^3 as measured on the collectors. This low bulk density, which is exacerbated by retained electrostatic charges can give rise to rapping re-entrainment problems. It is therefore important to give due consideration to the precipitator velocity, rapping frequency and intensity, together with aspect ratio when designing the precipitator.

With the total mass of dust decreasing as the gas passes from the inlet to the outlet fields, the elapsed time between consecutive field rapping blows must be lengthened in order to provide sufficient time to produce a layer sufficiently thick, to form an agglomerate large enough to fall and drop into the hoppers. Unfortunately, with time, the charge on the particle decreases and the agglomeration strength of the layer increases, because of increased Van de Waal forces. This change requires a higher impact load to remove the dust from the collectors. It is important therefore that both rapping frequency and intensity are optimized under operating conditions to reduce possible re-entrainment, whilst ensuring that the plant stays free of buildup.

In a hot dry condition the fly ash behaves like a fluid. It is important to maintain these conditions as a drop in temperature below the water dew point could result in the ash absorbing water and being more difficult to remove.

Precipitator Design Features

To meet the requirements associated with Orimulsion fly ash collection the precipitator was designed having the following characteristics:

1. 3 electrical precipitation zones in series.
2. A gas velocity of around 4 ft/s (1.3m/s).
3. An aspect ratio, field length to field height of around unity.

Based on experience, the particle sizing of the fly ash suggested that corona suppression could be a problem for the precipitator to achieve high collection efficiency. Corona suppression arises as a result of the formation of a significant particulate space charge in the inter electrode area. The phenomenon exhibits itself as a low corona discharge current at a fairly high kV. Although the particles are charged by the corona, the resultant large number of very small slow moving particles having a low negative charge, produces a masking effect which reduces further corona current flow.

To ensure that sufficient current is available to overcome the worst effects of corona suppression, a high emission type electrode was used on the inlet field. This has an emission characteristic some 3 times higher than a standard electrode under non-space charge conditions. As a consequence of the inlet fields reducing the concentration and number of particles, the subsequent fields do not exhibit corona suppression. To limit power consumption, standard cruciform shaped wire electrodes are used. The two types of discharge electrode are illustrated in Figure 3a together with the electrode support mast arrangement.

To minimize reentrainment, with the low bulk density ash, the collecting electrodes are of the well proven catch space type. They have vertical stiffening channel sections which act as mechanical collectors by forming a quiescent zone in front of the flat collecting surface. The collector design is illustrated in Figure 3b.

To maintain cleanliness of the discharge electrodes these are rapped using the standard tumble hammer system, Figure 4a. The dust from the collectors is removed by drop rod rapping, Figure 4b, whose frequency is controlled by a microprocessor PLC. Intensity can be varied by changing the position of the cam lifter, situated in the 'rapping house' above the field area. (Figure 5). The advantage of this feature is that the adjustments can be made without contact with the fly ash and outside of the gas stream.

To minimize equipment cost, the collectors are spaced at 400mm throughout the plant. The discharge electrodes are energized from transformer rectifiers rated at 111kV peak having a current equivalent to 0.3 mA/m^2 of collector plate. Each TR is controlled by a microprocessor based AVC unit sensing and optimizing on peak kV.

Evacuation of fly ash from the hoppers is by means of a lean phase vacuum system. Each of the 8 hoppers of each precipitator is connected to the vacuum system via a pneumatically operated slide valve. This allows the dust to drop vertically into the evacuation system prior to transporting the dust to a storage silo.

Precipitator Arrangement

The precipitation plant, although designed to handle Orimulsion fly ash is retrofitted onto an existing oil fired utility installation not equipped with precipitators. Similar to most retrofit applications the distance and space between the air heater outlet, ID fans and chimney is strictly limited. This particular plant was not exception and a novel approach was used to minimize disruption to plant operation during erection and optimizing space availability. The ductwork design was complicated since the ID fans had limited spare capacity and although only one twin flow precipitator was involved, it was required to handle the gases from either of the two boiler units.

Examination of the site revealed that by positioning the new precipitator directly alongside one of the units, using a side inlet and outlet configuration, the ducting runs were simplified for ease of connecting into either boiler outlet. This approach enabled the complete precipitator and ducting to be installed with only a 3 day outage being necessary on each boiler to facilitate the final gas pass connections.

The plant layout is shown in Figure 6. The proprietary and patented side inlet and outlet duct arrangement, although minimizing space requirements, requires a full height inlet and outlet duct with a splitter arrangement designed to turn the gases through 90°. This approach is only suitable for low inlet loadings since gas distribution is critical on having a duct free of dust deposits. Some idea of the <20% RMS can be appreciated from Figure 6, where the ratio of precipitator length to width is 1:3.

Operating Experiences

The precipitator installation was commissioned and put into service in November 1991 following the scheduled outage to connect up the duct work. Like other plants which change fuels, the unit took some time to achieve load and consequently a great deal of moisture condensed within the precipitator because of low back and temperatures. Some 40 liters of liquid was drained off the hoppers prior to energization.

When energized, once the temperature reached 140°C, the chimney emission cleared indicating successful collection was being achieved. Initially, the TR's ran at maximum current input on all fields, however as the internals became coated with fly ash, the inlet field current began to decrease with increasing kV as the space charge developed. Although this was anticipated, the inclusion of the high emission electrodes minimized the effect. Following some 12 months operation, the precipitator has stabilized and the corona current on the inlet field, at approximately 50% of the TR rating, is considered satisfactory as evidenced by the low emission and the high first and second field hopper catches.

In February 1992 after adjustments to collector rapping frequency and intensity, full scale acceptance tests were carried out to compare plant performance against specification. The results of these tests are presented in Table 3. The acceptance tests were carried out with a gas flow rate equivalent to the maximum boiler output, following modifications to the superheater and evaporative surfaces of the boiler and the addition of soot blowers in the convection pass to control fouling. The results, although being carried out at some 15% above the precipitator design volume were still satisfactory and meet the corrected emission values. In fact as an average of the 2 tests the emission was still only 25mg/Sm^3 wet in spite of the volume increase.

The test results from the precipitator confirm the original design concept of ash precipitability. Once in the hopper, fly ash handling proved problematic. Initially, the down legs from the hoppers terminated in a transfer box, where the dust tended to lodge and solidify as it absorbed moisture. Leaking hopper isolation valves, enabled air to enter into the hoppers cooling the fly ash thereby worsening the transfer box situation. These areas were modified after gaining operating experience following commissioning of the plant.

Figure 6, shows the position of the storage silo, which collects the vacuum conveyed dust from the precipitator hoppers. In a fluidized dry state the dust is relatively easy to handle. However, storage in the silo resulted in settling and dust 'hold up', such that the operation of the vibratory bin discharger caused severe compaction. This limited evacuation, at the required steady rate for the conditioner/mixer, resulting in the dust leaving the mixer being either too dry or too wet. To resolve these, the diameter of the discharger was reduced to give larger clearance and aeration pads fitted to the bottom of the silo. Further proving time will be necessary to ensure satisfactory fly ash evacuation.

Conclusions

Analysis of fly ash obtained from the Orimulsion test burns at various sites, identified differences when compared with other fuels. These differences were assessed and built into a precipitator designed to successfully handle this fly ash in terms of low emission and high precipitator availability.

Results are presented which confirm the precipitator can deliver the required performance levels. The handling of the dust collected in the hoppers, by means of a lean phase vacuum system is not entirely satisfactory and has required a number of significant modifications which still have to be proven.

Acknowledgements

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Table 1

Comparison of Heavy Fuel Oil and Orimulsion

Ultimate Analysis

	Typical HFO	Orimulsion
Carbon	85.0 %	60.10%
Hydrogen	10.70%	7.42%
Sulphur	3.26%	2.70%
Oxygen	0.50%	0.21%
Nitrogen	0.46%	0.50%
Ash	0.08%	0.30%
Vanadium	240 ppm	300 ppm
Sodium	31 ppm	40 ppm
Moisture	<1.0 %	29.30%

Table 2

Comparison of Fly Ashes Produced by Heavy Fuel Oil and Orimulsion

	HFO	Orimulsion
Loss of Ignition	53.5%	18.8 %
Carbon*	42.8%	0.71%
Fe_2O_3	12.2%	1.56%
Ni O	0.4%	2.14%
V_2O_5	2.3%	14.63%
CuO	0.1%	NA
Cr_3O_3	0.1%	NA
Na_2O	2.3%	2.13%
SiO_2	0.4%	0.37%
SO_3	25.7%	37.07%
TiO_2	NA	0.25%
MgO**	NA	20.33%
AI_2O^3	NA	0.09%

* Carbon in HFO fly ash is extremely variable, figures of 20-80% can be found.

** Magnesium Oxide used to limit SO_3 emissions - separate additive with HFO, present in orimulsion as an emulsion stabilizer.

Table 3

DESIGN DATA

Summary of Actual Test Data

	Specification	
Gas flow rate	670.82	Am^3/s
Gas temperature	175	°C
Inlet dust loading	250	mg/Sm^3
Emission	25	mg/Sm^3
Efficiency	90.0	%

Correction curves for gas flows, temperature, moisture in gas, inlet dust loading.

Results

	Prelim Test	Acceptance Test	
Gas flow rate	747.9	739.4	Am^3/s
Gas temperature	181.9	189.3	°C
Inlet dust loading	229.4	227.4	mg/Sm^3
Emission	30.5	19.0	mg/Sm^3
Efficiency	86.7	91.6	%
Corrected Design Effic.	(84.8)	(85.4)	%

(Figures in brackets are design conditions corrected for actual test conditions)

Electrical Readings

A1	kV/mA	61/365	62/392	
A2	kV/mA	73/661	73/601	
A3	kV/mA	64/1017	64/1014	
A4	kV/mA	64/1070	64/1052	) Outlet field
B1	kV/mA	64/295	65/663	
B2	kV/mA	68/554	69/517	
B3	kV/mA	66/1012	67/1019	
B4	kV/mA	64/1045	64/1037	) Outlet field

N.B. Standard conditions 15°C 1 Bar wet corrected 12% CO_2

FIGURE 1

EMISSION v PARTICLE SIZE FOR 20% OPACITY

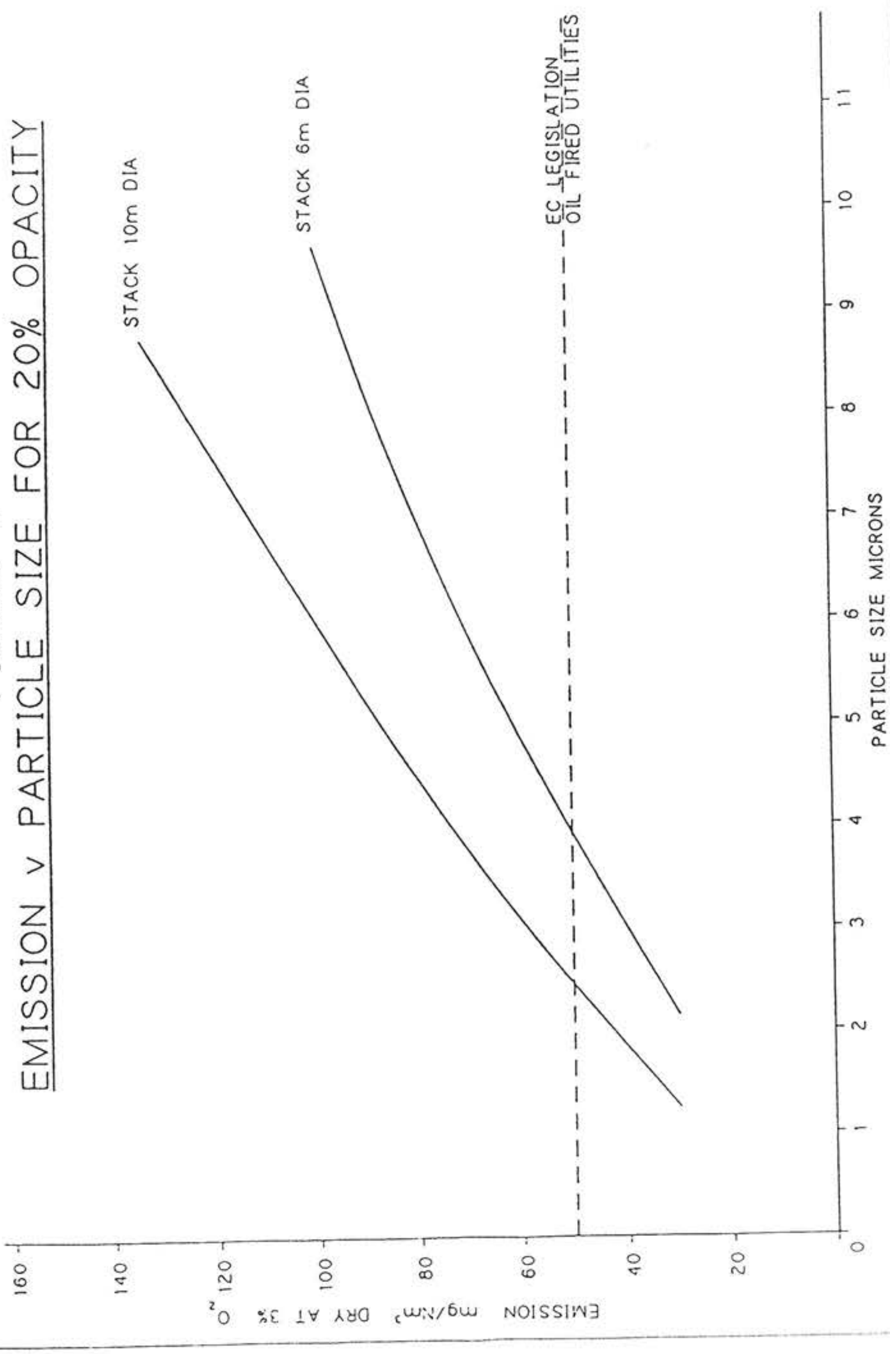


FIG 2 FLY ASH PARTICLE SIZE DISTRIBUTION

COMPARISON OF ORIMULSION vs No.6 FUEL OIL

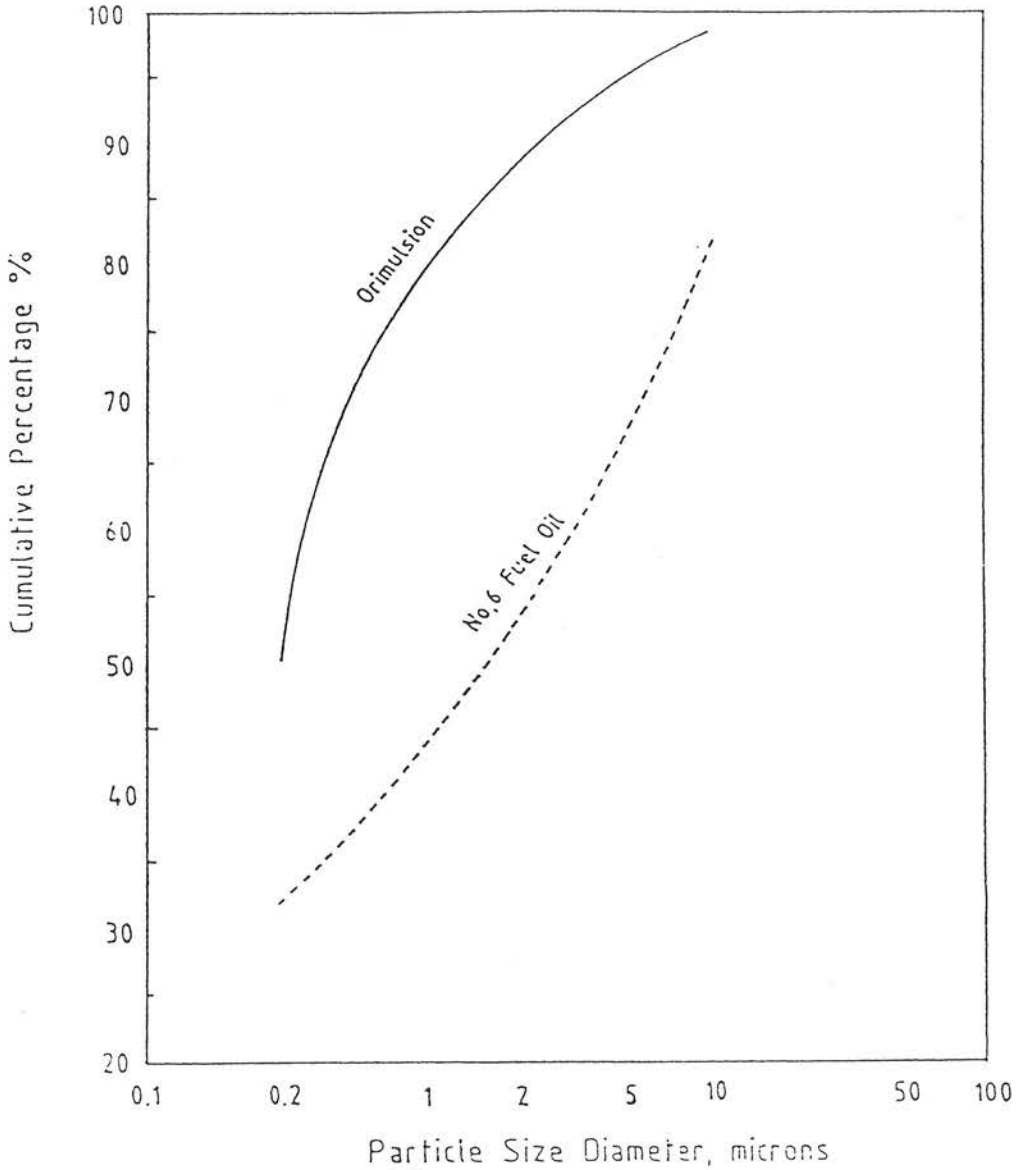
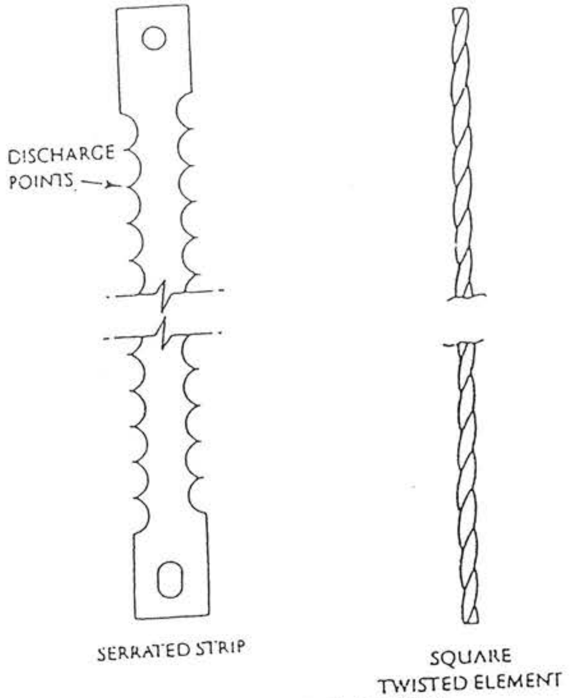


FIG 3A TYPICAL DISCHARGE ELECTRODES AND ARRANGEMENT



TYPICAL DISCHARGE ELECTRODE EMITTING ELEMENTS

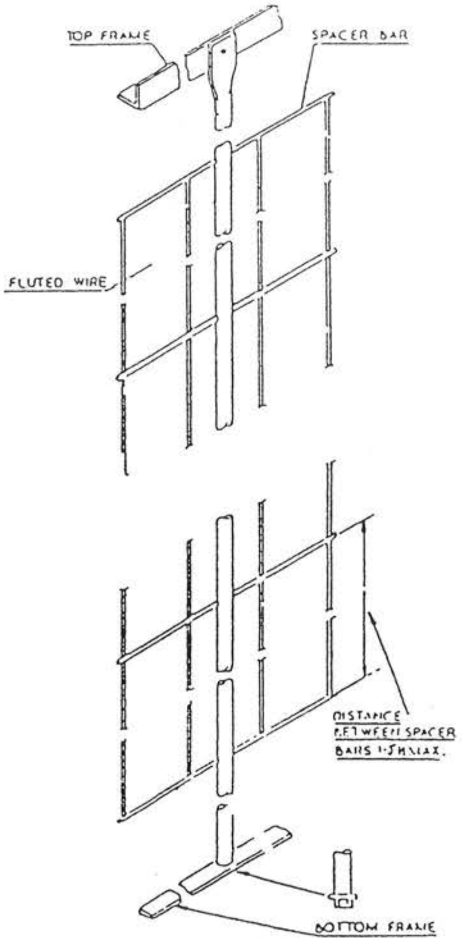
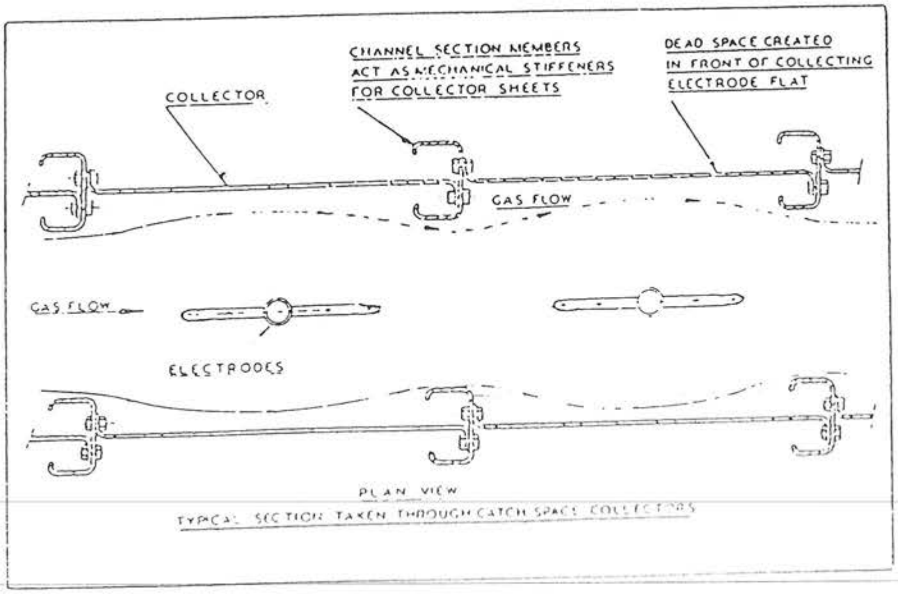


FIG 3B ARRANGEMENT OF CATCH SPACE COLLECTOR ELECTRODE



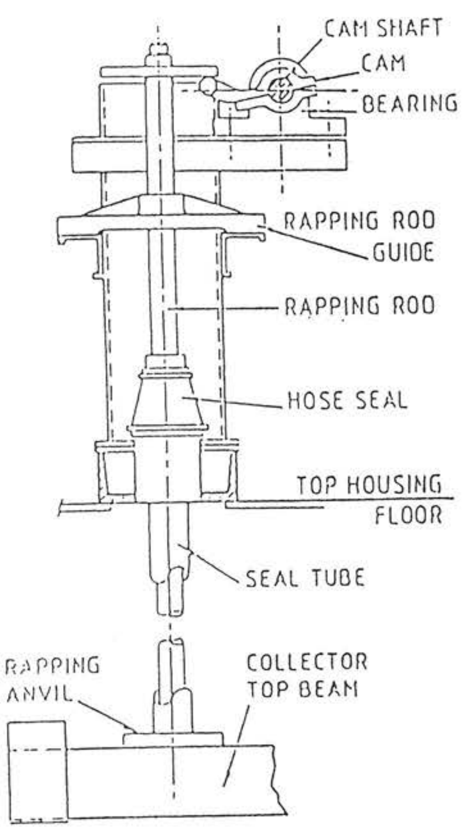


FIG 4B DROP ROD COLLECTOR RAPPING

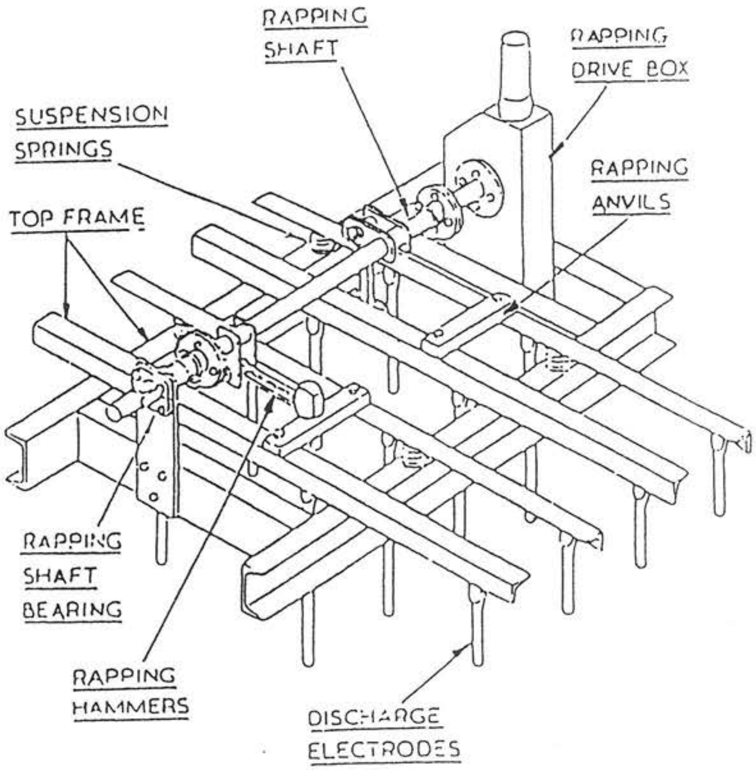
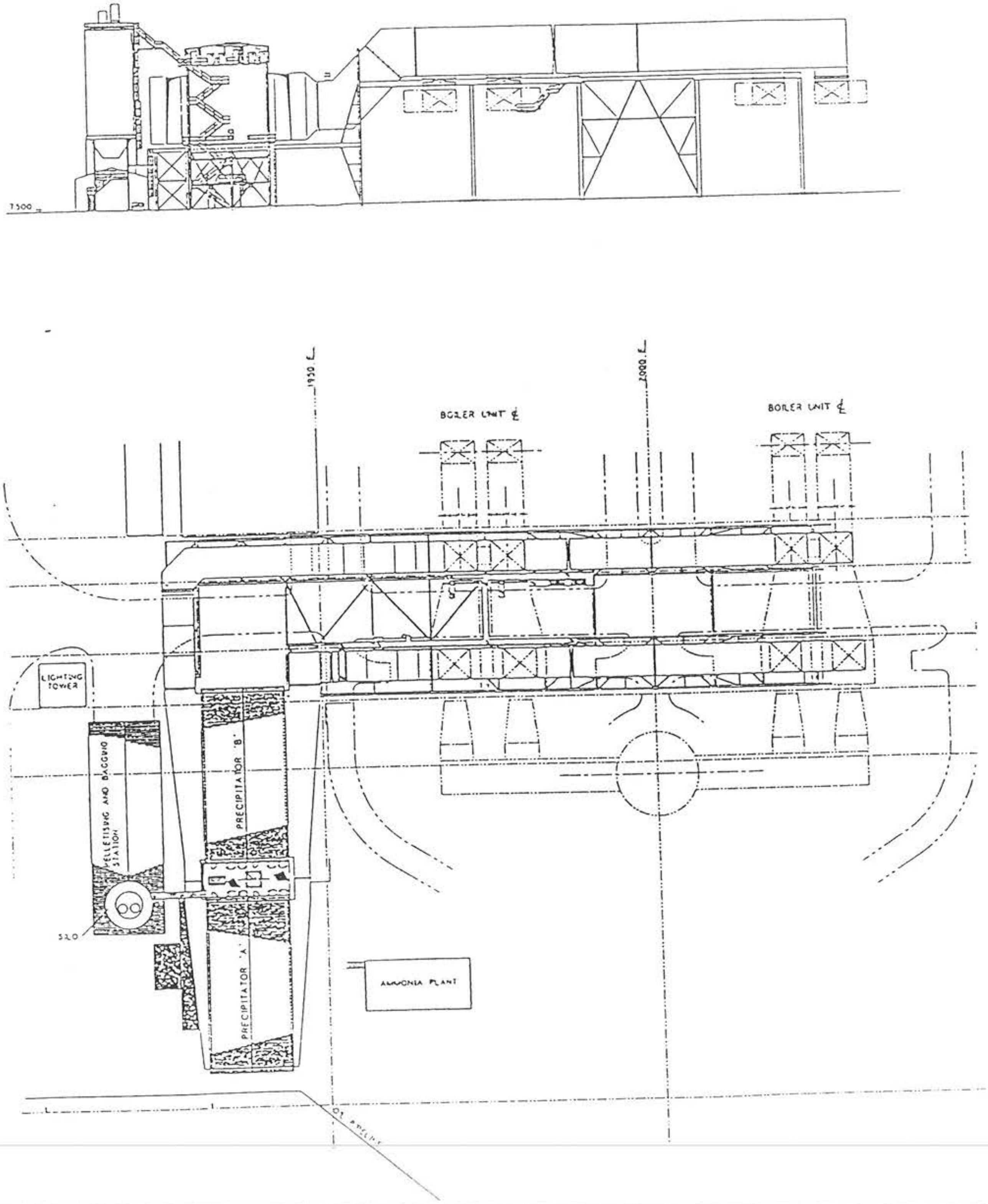


FIG 4A TUMBLING HAMMER RAPPING FOR DISCHARGE ELECTRODES

FIG. 6 PRECIPITATOR AND DUCTING ARRANGEMENT



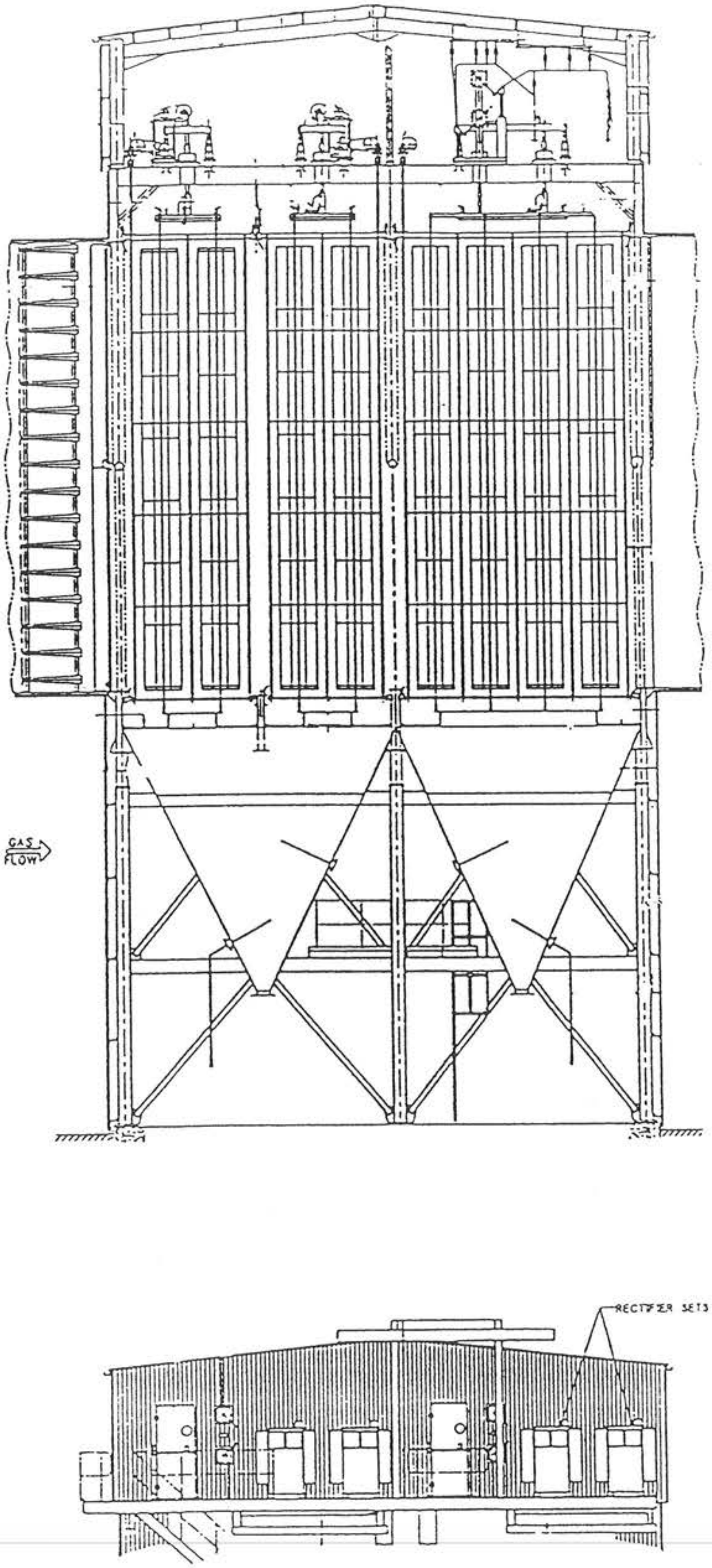


FIG. 5 SIDE ELEVATION OF PRECIPITATOR