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LOW GRADE COAL UTILIZATION AND PROPERTY ANALYSIS

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Technical report: Multi-fluidized bed combustion and its suitability for burning high ash Korean anthracite

Prepared for the Government of the Republic of Korea
by the United Nations Industrial Development Organization,
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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANISATION

Visit to Korea Institute of Energy and Resources (KIER) by Göran Järvstråt, April 1987: Final Report.

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1. Summary

The visit to Korea Institute of Energy and Resources (KIER) in Daejeon, Korea was carried out during the period 1-7 April 1987. The aim was to inform KIER of the multi fluidized bed combustion (MBC) concept and to investigate its suitability for burning high ash Korean anthracite.

During the short visit two lectures were given on the MBC system and boiler design. A test burning at one of KIER's test rigs was attended and earlier test results were reviewed.

The discussions in connection with lectures, test burning and earlier test results revealed that the MBC concept seems to be a good alternative for burning Korean high ash anthracite coal. Design considerations for this special fuel were discussed and some minor design changes might be considered.

Further combustion tests with Korean anthracite are scheduled for this summer at ASEA STAL test plant in Sweden. The test programme was discussed and KIER is invited to participate in this tests.

A preliminary report was written and handed over to KIER during the visit.

2. Recommendations

- KIER is recommended to participate in combustion tests which are planned for this summer in the test plant of ASEA STAL in Linköping, Sweden. The test plant is a 2 MW (3.5 ton/h) multi bed fluidized combustion boiler and will during this test be burning high ash Korean anthracite.

- The test results of KIER and ASEA STAL should be scrutinized and evaluated and the critical design parameters laid down.

- The need for design changes when adopting the MBC-boiler for Korean anthracite should be given further consideration. Choice of performance levels will significantly affect the design solutions.

- When the two first recommendations have been carried through the need and nature of further tests at KIER and/or ASEA STAL can be established.

3. Background

Although exploration for oil and uranium is continuing, coal is the only energy resources that is present in abundance in the Republic of Korea, reserves are estimated at 1.4 billion tons, of which 600 million are recoverable with present technology.

Of the total reserves, 34% are estimated to be of low calorific value, below 3.500 kcal/kg. It is not known what percent of recoverable reserves are of this nature, and its relationship to economics in the mining process. Therefore it is anticipated that the development of new technologies will have economic impact towards industries.

The trend toward increased use of coal will continue. The Government plans to more than double the use of coal in electricity generation by 1991 (from 9.2% to 19.1%). Household consumption (90% of coal produced in 1979 was used by individual households in the form of briquettes, "yontan", for the traditional "Ondol" heating system) will rise with income and population. Last, industry is adapting its plants and equipment to burn coal as a cheaper and more readily-available fuel source. As an example, from 1979 the cement industry began to use a mixture of coal and oil in its production process; the cost of modifications to plant and equipment has been approximately Won 129 billion to date. But the cement industry manufacturer's association estimates that in 1982 alone the industry saved Won 30 billion in fuel costs.

In order for the country to make the most of what it has, and to reduce dependence on imported oil as industrialization advances, research, both technical and economic, must be undertaken into scientific and industria technologies to utilise lower grades of coal as an energy source. Preliminary results have indicated that the methods most likely to accomplish this task are fluidized bed combustion and coal slurry (coal-oil or caol-water mixing). The Korea Institute of Energy and Resources (KIER), the Government Co-operating Agency, has already begun a pilot project in fluidized-bed combustion research with a view toward the practical application of these technologies which is the principal aim of this project.

4. Objectives of visit

The UNIDO long-term objective of the project is to reduce the dependence of the Republic of Korea on foreign supplies of energy (oil and natural gas) through scientific research and experimentation into combustion techniques of lower grades of anthracite coal, a natural resource found in abundance on the Korean peninsula.

The objectives of visit were laid down by UNIDO as follows: "The expert will be assigned to Korea Institute of Energy and Resources (KIER), Ministry of Energy and Resources, and, in consultation with the Korean authorities he will be expected to assist in the development of a fluidized-bed combustion boiler for utilizing low grade Korean anthracite.

Specifically, he will be expected to perform the following taskts:

1. Investigation of multi fluidized bed boiler for utilizing high ash anthracite.

2. Design consideration for the commercial multi fluidized bed boiler.

3. Design of solid circulation systems for the load control".

5. Investigation of the suitability of the multi fluidized bed boiler (MBC) for burning high ash anthracite

5.1 MBC-Background

ASEA STAL has been developing FBC-boilers since the early seventies. An FBC pilot plant using crude oil as fuel for application as a superheater/reheater for marine steam turbine propulsion machinery was succesfully operated for 2000 hours. The development work then branched in two directions. The Pressurized Fluidized Bed Combustion (PFBC) and the atmospheric Multi Bed Combustion (MBC).
The ASEA STAL development of MBC started in 1980 with a 2 MW (3.5 ton/h) test plant in Linköping, Sweden. After thorough tests the concept was commercialized with a 100 MW (17 ton/h) district heating plant in the city Nyköping. All together ASEA STAL now have seven (not counting the test plant) MBC-boilers in operation or under construction, ranging from 10-50 MW (17-70 ton/h).
(See table 1).
The PFBC-system is more complex with gas compresser, pressurized combustor, gas turbine as well as steam turbine and the system is developed for bigger power plants. ASEA STAL has four PFBC 200-units in order, two for Stockholm, Sweden and one each for USA and Spain. All this units have a thermal output of 200 MW and a total net electrical output of 80 MWe.

5.2 TECHNICAL DESCRIPTION OF THE MBC-SYSTEM

5.2.1 MBC combustion system

Functional connections between the main components of the plant can be followed on enclosed process flow diagram (Fig. 1).

System function

The combustion system is designed for environmentally clean and efficient combustion of fuel. The heat produced by combustion is transferred to the steam system both in the combustor and the exhaust gas boiler.

MBC boiler (See fig. 2 and 3)

Presentation of the MBC technology

The MBC boiler is a development of fluidised bed technology. MBC stands for Multi Bed Combustion, indicating that combustion takes place in two fluidised beds, one above the other. Fluidised bed technology offers implicit advantages over conventional methods of solid fuel combustion. Combustion efficiency and environmental cleanliness are of a high standard. These benefits have been well utilised and developed.

Low beds in combination with a screen in the slash zone (the area just above the bed surface) minimise carryover from the beds and permit low freeboards. What is most important is that upper bed captures uncombusted fuel particles and operates as an after-burning bed. This eliminates the need for high freeboards and a compact combuster design can be achieved, together with high combustion efficiency.

The MBC boiler has excellent controllability, regarding both turndown ratio and turndown velocity. It has high fuel flexibility.

Sulphur content in the fuel can be absorbed by continously adding limestone to the beds.

Combustion in the fluidised bed

The principle of combustion in the fluidised bed is that fuel is fed to a turbulent fluidised bed at a temperature where the fuel burns spontaneously. The bed material is fluidised by the combustion air which is distributed evenly over the entire bed bottom through air nozzles. The combustion temperature is kept constant through a balance between added heat from fuel combustion and heat extracted in cooling tubes in the bed.

Lower bed

In the lower bed, the bed material is fluidised on the same principle as in a conventional bubbling bed. The bed material consists mainly (over 97%) of inert material such as ash products from the combustion process. The mean particle size is about 1 mm.

The bed is fluidised with combustion air which is distributed evenly over the bed bottom through air nozzles.

After preparation the fuel is fed into the bed above the air nozzles. Fuel feed utilises a pneumatic system. The number of feed points is chosen to achieve an even distribution of air and fuel - a condition for stable, efficient combustion.

Bed temperature varies in the range 800-900¤C. The lower temperature is the limit for stable combustion, while the upper temperature is the limit for the melting point of the ash. The temperature is regulated by balancing the heat created at combustion against the heat extracted in flue gases and an in-bed tube bundle. At full load, just about 60% of the heat generated is extracted by the in-bed tube bundle.

The combination of vigorous mixing of air and coal with a relatively long retention of the particles in the bed ensures that the largest proportion of the fuel is burnt in the bed.

The in-bed tube bundle consists of hairpin cooling tubes.

Much of the coal ash consists of fly ash and accompanies the flue gases through the distributor plate for the upper bed. Larger particles of ash remain in the lower bed and create new bed material.

Air

The bed bottom, which is also the air distribution surface, has a construction consisting of an air plenum. A number of air nozzles lead from the air plenum to the lower bed.

An insulating layer of unfluidised bed material covers the bed bottom.

Air is supplied to the air plenum via passages underneath the plenum with perforated inlets.

Upper bed

The upper bed is fluidised with flue gases from the lower bed and secondary air injected into the bed bottom. The upper bed acts as an after-burning bed and burns the coal particles that accompanied the flue gases from the lower bed. The temperature in the upper bed is about 850¤C.

The bottom of the upper bed consists of two water-cooled membrane walls. This shell constitutes the plenum for secondary air. Combustion gas from the lower bed enters the upper bed through a number of inlets connected to the inlet pipes which lead the gas through the plenum and is finally distributed through the special design nozzles into the second bed. Secondary air is injected in the fluegas from the plenum through a small hole in the inlet pipe.

Conditions for efficient output control.

One condition for efficient combustion in a fluidised bed is that the temperature is kept within fairly close limits, even with varying bed height and outputs. Bed material should be supplied to the beds at a temperature generally corresponding to their operating temperature in order to avoid undesirable cooling.

Consequently, there must be a sufficient quantity of bed material in both beds in order to run the boiler at full output when necessary.

In view of the above considerations, the following bed control system has been designed.

Bed height control

Heat transfer in the bed is considerably greater than in the freeboard. This is exploited when controling boiler output. At high outputs, the in-bed tube bundle is therefore covered by bed material in order to obtain the greatest heat extraction.

In load changes, the bed material is transferred between the upper and lower beds. When reducing load, the tube bundle in the lower bed is more or less exposed in order to adapt the transferred output to the current demand.

In the load range 100% - about 50%, the level is reduced partly by reducing the height of the lower bed since the gas flow through the bed decreases (the fluidisation rate decreases) and partly by the lower bed material being transported to the upper bed. At about 50% load, the lowest permitted fluidisation rate is reached and bed level is regulated from 50% down to lowest continuous load, 30%, through transport of bed material.

Load is increased through transfer of bed material from the upper to the lower bed.

Bed material transport utilises upcomers and downcomers. Air is used to loosen the bed material in the downcomers and this is fed via the transport pipe and the inlet pipe to the bed. The bed material consists mainly of ash.

Bed material control

The total quantity of bed material will increase with time in an MBC boiler especially with a high ash coal. When the total height of the upper beds exceeds a certain level, material is led off via ash cooler to a silo.

The bed material is fed via a downcomer to a heat exchanger with cooling tubes. The bottom of the heat exchanger is provided with a feed system which releases ash to a pneumatic transport device carrying the ash to the ash silo.

Part of the ash and part of the other bed material passes through the flue gas boiler and is separated in the flue gas filter.

Internal design

The MBC boiler is intended to operate under light overpressure and has a shell designed for this. The shell is built up from panels in which cooling tubes are welded to flat steel sections, so called membrane walls.

The side walls consists of water-cooled panels with convectional circulation. Water from the drum is passed through a downcomer and is distributed to the panel via the lower header. The water then rises in the wall as steam is generated an is collected in the upper header, after which it is carried further to the drum. Passages for bed material handling are provided in the rear wall, together with sand and limestone supply and outlet to ash cooler.

The bed bottom in the lower bed, the rear of the combustor and the roof also form a unit with convectional circulation. Water is supplied to a header at the bed bottom and a steam-water mix is collected in a header on the top.

Together with the bottom of the upper bed, the membrane wall at the front of the boiler constitutes one of the force-feed boiling circuits. The other circuit consists of the in-bed tube bundles. There are also two frames where the two tube bundles are suspended. Inspection of the upper combustion zone is enabled through two sight glasses placed in the panel wall.

Flue gas outlet is at the top.

Internallv, the boiler is lined with refractorv. This is intended to protect the walls and roof from erosion and also to avoid local cooling of the beds and flue gases.

Exhaust gas boiler (EGB)

When the flue gases leave the upper bed, thev have a temperature of about 850¤C. The temperature of the flue gases when thev finallv leave the boiler is about 170¤C.

The flue gases from the MBC boiler are passed to the exhaust gas boiler via an internallv insulated chanel.

The EGB contains two superheaters, numbered 1 and 2 in the direction of steam flow, an economiser and in certain cases an air preheater. After passing the superheaters, the flue gases are led into the economiser where feed water is preheated.

In the EGB the flue gases to are cooled about 170¤C. The flue gases are then led to a flue gas filter.

5.2.2 Auxiliary heating system

The auxiliarv heating svstem has two purposes: heating the boiler when starting up and heating the hot gas used for drving the principal fuel. The following describes the two sections individually. Gas or oil can be used as auxiliarv fuel.

Start-up system

In order for the fuel fed into the boiler to ignite and burn, the bed material must be hot. Coal should have a temperature over the ignition temperature of the fuel. This means that when the boiler is to be started up, the bed material must be preheated. An oil fired hot gas generator preheats the combustion air and thereoff the bedmaterial the specific temperature. By gas-firing the gas can be fed direct into the air nozzles if pilot burners are located in the freeboard.

Hot gas generator

Fuel is supplied to the boiler through a pneumatic feed system. If the fuel is too moist, there is a risk of the feed becoming blocked. To avoid this, the surface moisture is dried off. The drying medium is hot gas which is obtained through combusting oil or gas in the hot gas generator. The hot gas acts also as transport medium for the feed. The installation is provided with a hot gas generator which feeds the drier/crusher used.

5.2.3 Fuel handling system

External fuel handling system

System function

The external fuel handling system takes care of the fuel delivered from the main fuel storage by bulldozers to the receiving hopper. From the receiving hopper the coal is fed by a belt conveyor to a crusher station where the coal is cleaned from oversized and magnetic material, crushed to maximum 50 mm. The sized coal is then carried by another belt conveyor to the daybin.

Preparation station

The coal is screened and crushed in a preparation station consisting of:

- One roller screen where all large scale particles (over sized coal, wood boards etc.) are separated as well as magnetic material.

- One hammer crusher where the coal particles are crushed to maximum 50 mm.

Unloading tripper

The coal is discharged from the conveyor belts by unloading trippers to the fuel buffer silos (day bin).

Internal fuel handling

System function

The internal fuel system is designed for reliable input of fuel to the boiler. The system consists of a buffer silo, screw conveyor, rotary valve, crusher/drier and distributor. The fuel is fed into the pressurised system where it is dried and crushed to the correct surface moisture and size for further transport to the distributor by means of the hot gas and air. All the components are placed in a separate fuel preparation room, apart from the distributor which is located in the boilerhouse. The system has double lines apart from the distributor which is common.

Buffer silo (Day bin)

The day bin stores cleaned fuel and has an outlet for tapping fuel and an inlet for filling. The day bin is dimensioned for 4 hours' operation of the boiler at full load.

Screw conveyor

The screw conveyor transports the fuel from the buffer silo outlet to the rotary valve inlet. The screw conveyor regulates the fuel flow to the boiler.

Rotary valve

The rotary valve transports the fuel from the screw conveyor to the drier. This has six compartments. The design is self-sealing and always has four compartments engaged against the casing on the inside to withstand the pressure which is higher at the rotary valve outlet.

Drier

The drier consists of a pipe between the rotary valve and crusher with a connection for supplying hot gas. The fuel falls through the pipe and hot gas and air are used to dry the surface moisture of the fuel on the way down to the crusher. The drier contains a feed pipe for blowing in ash for recirculating and drying the coal.

Crusher

The crusher is a hammer crusher with folding, reversible jaws or roller crusher. The crusher operates by breaking down fuel fed into the grinder both indirectly by the rotating hammer system and also indirectly against the lining in the upper part of the cover. The fuel then leaves the crusher via the grate opening and is transported to the distributor. This transport takes place with the aid of the hot gas air added in the drier.

Distributor

The distributor consists of a cylinder with an internal cy-clone where most of the fuel blown in is collected and falls downwards onto a rotating distributor. Most of the air is se-parated in the upper section by the cyclone and meets the fuel again on the outside of the rotating distributor. The rotating distributor distributes the fuel evenly in the bot-tom compartments (one for each outlet pipe) from where it is forced out through eight separate pipes to a point just be-fore the bottom of the boiler. Here, each pipe is divided into four pipes which lead to the fuel nozzle through the bottom of the boiler.

5.2.4 Combustion air system

System function

The combustion air system supplies sufficient primary and secondary air for combustion and ensures fluidisation in the two beds of the boiler. At start-up, the combustion air sys-tem also supplies the oil burners with air.

Combustion air fan

The combustion air fan is a guide vane regulated fan. The air intake is placed indoors. Air is taken into the fan through a venturi and filter. A separate silencer is placed in the air intake.

Secondary air duct

To control the proportion of secondary air blown into the system the secondary air duct is provided with a control valve and actuator.

5.2.5 Flue gas system and ash handling

Flue gas cleaning

The system cleans flue gases from fly ash and transports the ash to the ash silo.

Filter, including transport device for ash

The filter cleans the flue gases from fly ash both through a pre-separator and through a filter. The ash is fed from the pre-separator via a rotary valve down into the screw conveyor which handles the ash from the electrostatic preciptator or bag-house filter.

Ash handlning

System function

Ash handling involves transporting and storing fly ash and bed ash from the process. The ash is mainly in the form of fly ash from the flue gas filter. The bed ash arrives from the combustor's upper bed through the ash cooler. Ash handling also includes feedback of ash to the process and wet feedout for deposition. The components in the system are the intermediate container, rotary valve, ash silo and feed devices.

Intermediate container

The intermediate container smoothes out the intermittent ash flow from the flue gas filter prior to transport to the rotary valve. A filter is located at the top for the surplus air outlet.

Rotary valve

The rotary valve acts as a blocking mechanism so that ash can be blown up to the ash silo.

Ash silo

The ash silo stores a mixture of fly ash and bed ash from the process. Fly ash is fed in from the intermediate container and bed ash from the ash cooler. Transport to the silo is pneumatic. A filter with intermittent compressed air purging is placed on top of the silo. The quantity of ash in the silo is measured with a load cell.

Rotary valve (ash recirculation)

The rotary valve has a blocking function to prevent transport air from travelling the wrong way into the feed device. After the rotary valve, the ash is transported pneumatically via an ejector to the drier.

Feed device (ash for deposition)

The feed device is placed at the bottom of the ash silo together with moistening equipment. The outlet opens over a container for ash deposition. The ash is subjected to a moistening process before being allowed to fall, so as to give a homogeneously moistened ash.

Abnormal operating events

With a circulation pump backed up by diesel operation, the forced circulation can be maintained for safe rundown of the boiler in a power failure or other failure in the electrically powered parallel-connected circulation pump.

The drum stores a quantity of water corresponding to a proportion of the quantity that must be taken out of the boiler to handle residual heat in fuel when water supplies are cut off.

System design

The drum is placed at such a high level that all boiling surfaces are water-filled at the lowest permitted level in the drum. All water circulation in the drum is designed to take place from the bottom to the top.

Control

Output/steam pressure control:
The pressure in the steam is adjusted so that the outlet steam pressure after superheater 2 is kept constant over the whole output range and the fuel/air quantity is regulated with impulses from the energy flow in the outlet steam and inlet feedwater respectively and the pressure in the drum.

Drum level/feedwater flow:
The drum level is controlled by regulating the feedwater flow with impulses from the outlet steam flow, inlet feedwater flow and current drum level.

Blow-off:
A special blow-off is activated to emit steam above the roof if any of the following situations arises:

- Minimum flow of outlet steam is not attained (risk of excessive temperatures in the superheated material)
- Excessive steam temperature after the superheaters. (This may occur in flows larger than the minimum flow in fault situations involving steam cooling).
- Excessive pressure in the drum (opens before the safety valves operate and resets the pressure level in a controlled manner).

Minimum limit for steam pressure.

Flue gas fan

The flue gas fan is vane-regulated fan operating synchronously with the combustion air fan. The fan ensures that the filter housing and air preheater always have under-pressure.

5.2.6 Steam/water system

The system absorbs heat from the beds, mainly the lower bed, and from the flue gases when passing through the flue gas boiler. The heat is transferred to the feedwater in the economiser, generating steam in the boiling circuits and superheated steam in the superheaters.

General description of the boiler system

The process diagram is shown in enclosed process flow diagram, fig. 4. The boiling circuits are both force-feed and convectional circuits. The force-feed circuit is divided into two parallel-connected circuits cooling the in-bed tube bundles and the upper bottom and front wall. The side walls of the boiler and the lower bottom with rear wall and roof comprise the convectional circuits. The drum is supported on two downcomers where water from the drum is led down to the bottom of the boiler, before the addition of heat from the boiler wall tubes generates steam which rises to the drum again.

The force-feed flow to the boiling circuits is taken via a downcomer to the circulation pump an id then forced through the respective circuit. Control valves allow the flow to be regulated so that the correct distribution is obtained between the circuits.

In very rapid decreases of the steam demand in the network, the boiler may not be able to keep up and reduce output sufficiently quickly. The pressure in the drum will then rise and a blow-off valve opens before the safety valves operate. This blows off surplus steam in a controlled manner through a muffler above the roof. If the pressure rises further, the safety valves operate. On the other hand, if the boiler is overloaded so that the pressure falls too low, the turbine's regulating valve, or by-pass operation is in progress, will limit the flow and the pressure level will be maintained. However, the valves cannot limit the flow more than to a certain level where the superheateers are sufficiently cooled.

The steam demand may increase faster than the boiler can manage. This causes a pressure fall in the boiler. Too rapid pressure falls can lead to temperature transients and stresses in the drum, addition to foaming and problems with drum level and steam quality.

To avoid this, the outlet steam pressure is choked if the pressure in the drum falls below a certain value.

System operation and service

Only in exceptional cases can service be performed on components during operation. When the boiler is run down, all components are accessible for service.

5.2.7 Blowers

There are two blowers. One is used for transport of fuel and ash for recirculation. The other is used for limestone feed, ash transport from the bed ash cooler to the ash silo and ash transport from the intermediate container to the ash silo.

5.2.8 Lay-out example

Fig. 5-7 shows the lay-out of the Hallsberg plant (17.3 MW) now under commissioning.

5.3 Preliminary tests with Korean anthracite in the ASEA STAL test-plant

As a result of brief preliminary tests at the 2 MW (3.5 ton/h) test plant of ASEA STAL in Linköping the following conclusions were made. The tests were made in June 1986.

Conclusions

- o Korean anthracite coal is heavier and should have a smaller particle size distribution than what is normally needed for good fluidization and combustion.
- o The bed temperature operating range is more narrow and somewhat higher than for normal bitumious coals.
- o Air preheating is beneficial for keeping an even temperature in bed 1.
- o The start up temperature in bed 1 must be higher than normal before coal can be feed into the bed.
- o Start up heating should be performed over the whole bed surface.
- o Ash recirculation is probably needed for sufficient combustion efficiency.

Test coal:

Heat value 3400 kcal/kg (14.4 MJ/kg)
Ash content 47%
Sulphur content 1.4%

Emissions:	Test result	Korean standard
SO	> 2000 ppm*	1800 ppm
NOx	180 ppm	500 ppm

* No desulphurization with limestone was carried out.

Fig. 8 and 9 shows the ASEA STAL Pilot Plant with a thermal output of 2 MW (3.5 ton/hr)

5.4. KIER tests

KIER has been running fluidized bed combustion in a smaller test rig (0.1 ton/hr, 0.3 x 0.3 m) about five years with about 1000 operation hours all together. They also have a bigger test rig (1.0 ton/hr, 0.8 x 1.0 m) that has been running in two years and the operation hours totals about 500.

Test results obtained by KIER:

"The major experimental results obtained from pilot plant operation are as follows. The combustion efficiency was 90 to 93%, 5 to 10% higher than that without recycle, indicating that the recycle effect is significant for the low grade coal combustion. The overall heat transfer coefficient for in-bed tubes was 280-320 kcal/m2 hr¤C. Carbon monoxide content in the flue gas was 100 to 300 PPM, NOx content was 100 to 200 PPM, SO2 content was 20 to 120 PPM".

Some results are also shown in the diagrams in fig. 10 and 11. As expected the combustion effiency varies with type of coal feed (inbed/over-bed), ash recycle ratio, coal particle size, fluidizing velocity and so on.
A demonstation test was run during the visit with the smaller test rig. Some datas are shown in fig. 12 and 13.

5.5 Further MBC-tests

ASEA STAL have further tests with Korean anthracite scheduled for May/June 1987. The purpose of the tests is to dermine following design data for optimizing the MBC-concept for Korean anthracite:

- Fluidization limits cold and hot
- Reliable start-up procedure
- Allowable temperature variations in bed 1 and bed 2
- Advantage of ash recycle
- Advantage of air pre-heating
- Proportions of bedash/flyash
- Heat transfer rate to in-bed tube bundle
- Effiency and emissions

The test programme was discussed with KIER and they are invited to Sweden to take part in these tests.

6. Design considerations for the commercial MBC-boiler fired with anthracite

6.1 Coal feed system

Due to the low heat value and high ash content of the anthracite the fuel feed flow and ash removal flow are very high. With this is mind the feed and drain systems should be kept as simple as possible. A simple over-bed chute feeding might be a possibility, but according to KIER's findings that means a loss of 5-10% of combustion effiency.

To bring down the cost of crushing the coal and improve the combustion effiency by not creating unnecessary fines the coal should be screened and only the big particles crushed. For availability reasons the crushing should take place off-line, that is before the day-bin. KIER are using a roller crusher with good results. The maximum coal particle size has to bee decided upon later when the ASEA STAL tests has been completed. For economical reasons these size should be as big as possible with maintained good fluidization. The bed-ash drain system also in a high degree affects the maximum feasable coal particle size.

6.2 Ash drain and cooling

Normally ASEA STAL have drained the bed-ashes from the second (upper) bed. The main reason for this is that the limestone for desulphurization is fed into this bed and that the spent limestone can mean a substantial ash flow. It is also favorable in the space requirements. But when firing high ash fuels like Korean anthracite it is better to drain the ash from the bottom of bed 1. For two reasons, the main ash flow now is coming from bed 1 and secondly the anthracite contains heavy particles that need to be removed from the bed bottom to keep the fluidization in order. The demonstration test during the visit at KIER's test facility clearly showed this fact. It might even be considered to redesign the bed bottom to a moving bed type of bottom with builtin cooling tube bundles and maybe cooling air inlets.

6.3 Ash recycle

The MBC has an advantage over the single bed in combustion effiency due to the possibility of aftercombustion in the second bed. But with high amounts of fines in the coal feed to the boiler some form of ash recycle is essential to improve the combustion effiency. The KIER tests show that the effiency can be boosted in the order of 10-15% by utilizing ash recycle.

6.4 Emissions

The Korean current standard for emission Limitations are:

SO_2	1800 ppm
NO_x	500 ppm
CO	400 ppm

Particulates:

flue gas flow

> 200.000 m3/h	400 mg/Nm2
(500-200.000 m3/h)	500 "-
< 500 m3/h	800 "-

The MBC-boiler is able to keep within these emission limitations.

7. Design of bed handling systems for load control

As described in the technical description the load control is done by changing the height of the first bed and thus increasing or decreasing the heat load of the in-bed tube bundle. The bed material is then transported between the two beds via separate upcomers and downcomers. The design is nothing but conventional L-valves wellknown from the litterature.
The capacity of the bed handling system is determined by the required turndown velocity. A normal value is about 5% load change per minute. A schematic picture of the system is shown in fig. 14.

8. Itinerary

Monday, 30 March:	11.45 departed Linköping Air Port for Stockholm, Helsinki, Bangkok, Taipei and Seoul.
Tuesday, 31 March:	10.20 arrived Seoul. Went to King Sejong Hotel.
Wednesday, 1 April:	Met Mr Jacques van Engel at UNDP in Seoul.
	15.00 departed for Daejeon.
	16.30 arrived Daejeon. Met by Ph.D. Jae-Ek Son, head of the Waste Resources Utilization Division, and taken to KIER. Stayed at Yousoung Hotel.
Thursday, 2 April:	Visited the test plant and had discussions with Jae-Ek Son and members of his staff.
Friday, 3 April:	Attended a combustion test run with Korea Anthracite in one of KIER's test rigs together with Mr Yeong Seong Park.
Saturday, 4 April:	Gave lecture on ASEA STAL's multi fluidized bed combustion concept (MBC). Departed in the afternoon for Seoul.
Sunday, 5 April:	Did some sight-seeing in Seoul. Visited Changgyonggung Palace (Palace of Bright Rejoicing), Chongmyo (Royal Shrine), Kyongbokkung Palace (Palace of Shining Happiness) and Namsan Park with Seoul Tower.
Monday, 6 April:	Gave lecture on MBC-system and boiler design. Reviewed some of KIER's test results. In the evening a tradional Korean dinner in my honour togerher with KIER staff and hosted by Jake Son.
Thuesday, 7 April:	Discussed test programme for combustion tests in Sweden. Wrote a preliminary report and handed it over to Mr. Son.
	17.37 departed for Seoul.
Wednesday, 8 April:	Visited UNDP in Seoul again for debriefing. Met Mr Subbaraman, Resident Representative, and Mr van Engel.
	20.30 departed for Anchorage, Amsterdam and Vienna.

Thursday, 9 April:	16.30 arrived Vienna. Stayed at Hotel Capri.
Friday, 10 April:	Met Mr Sugavanam at UNIDO, Vienna International Centre, for debriefing (Mr Williams, Substantive Officer, Chemical Industries Branch, was away from the office).
	17.50 departed Vienna for Copenhagen, Norrköping and Linköping.

9. Acknowledgements

I wish to thank Mr "Jake" Son and his colleagues for their co-operation and great hospitality. :stot.

Table 1

BRANDKÄRR REFERENCE PLANT (DISTRICT HEATING)

Thermal capacity	10 MW
Temperature, bed 1	920°C (1,690°F)
Temperature, bed 2	850°C (1,560°F)
Flue gas temperature	160°C (320°F)
Boiler water temperature (saturated)	170°C (340°F)
Fuel	Coal
Startup fuel	Propane 95
First operation	October 1983
Load range	110-30%
Cold startup time	30 min

TIMSFORS PLANT (PROCESS INDUSTRY)

Thermal capacity	20 MW
Temperature, bed 1	920°C (1,690°F)
Temperature, bed 2	850°C (1,560°F)
Flue gas temperature	170°C (340°F)
Steam:	
Flow rate	26.5 ton/hr (58,400 lbs/hr)
Pressure	26 bar (392 psig)
Temperature	400°C (750°F)
Fuel	Coal, peat
Startup fuel	Propane 95
First operation	July 1985

MANKATO PLANT (PROCESS INDUSTRY), Minnesota, USA

Thermal capacity	39 MW
Temperature, bed 1	920°C (1,690° F)
Temperature, bed 2	850°C (1,560°F)
Flue gas temperature	170°C (338°F)
Steam:	
Flow rate	54.4 ton/hr (120,000 lbs/hr)
Pressure	108 bar (1,552 psig)
Temperature	485°C (905°F)
Fuel	High sulphur coal
Desulphurization	Yes (limestone)
Startup fuel	Natural gas
Planned first operation	September 1986

LINCOLN PLANT (PROCESS INDUSTRY), Nebraska, USA

Thermal capacity	49 MW
Temperature, bed 1	920°C (1,690°F)
Temperature, bed 2	850°C (1,560°F)
Flue gas temperature	170°C (338°F)
Steam:	
Flow rate	68.0 ton/hr (150,000 lbs/hr)
Pressure	108 bar (1,552 psig)
Temperature	485°C (905°F)
Fuel	High sulphur coal
Desulphurization	Yes (limestone)
Startup fuel	Natural gas
Planned first operation	October 1986

GRANITE CITY (PROCESS INDUSTRY) Illinois, USA

Thermal capacity	26 MW
Temperature, bed 1	920°C (1,690°F)
Temperature, bed 2	850°C (1,560°F)
Flue gas temperature	170°C (338°F)
Steam:	
Flow rate	36.3 ton/hr (80,000 lbs/hr)
Pressure	84 bar (1,200 psig)
Temperature	485°C (905°F)
Fuel	High sulphur coal
Desulphurization	Yes (limestone)
Startup fuel	Natural gas
Planned first operation	January 1987

DES MOINES (PROCESS INDUSTRY), Iowa, USA

Thermal capacity	49 MW
Temperature, bed 1	920°C (1,690°F)
Temperature, bed 2	850°C (1,560°F)
Flue gas temperature	170°C (338°F)
Steam:	
Flow rate	68.0 ton/hr (150,000 lbs/hr)
Pressure	108 bar (1,552 psig)
Temperature	485°C (905°F)
Fuel	High sulphur coal
Desulphurization	Yes (limestone)
Startup fuel	Natural gas
Planned first operation	February 1987

HALLSBERG (DISTRICT HEATING COGENERATION)

Thermal capacity	17.3 MW
Steam pressure	65 bar
Steam temperature	512°C
Commissioning	May 1987

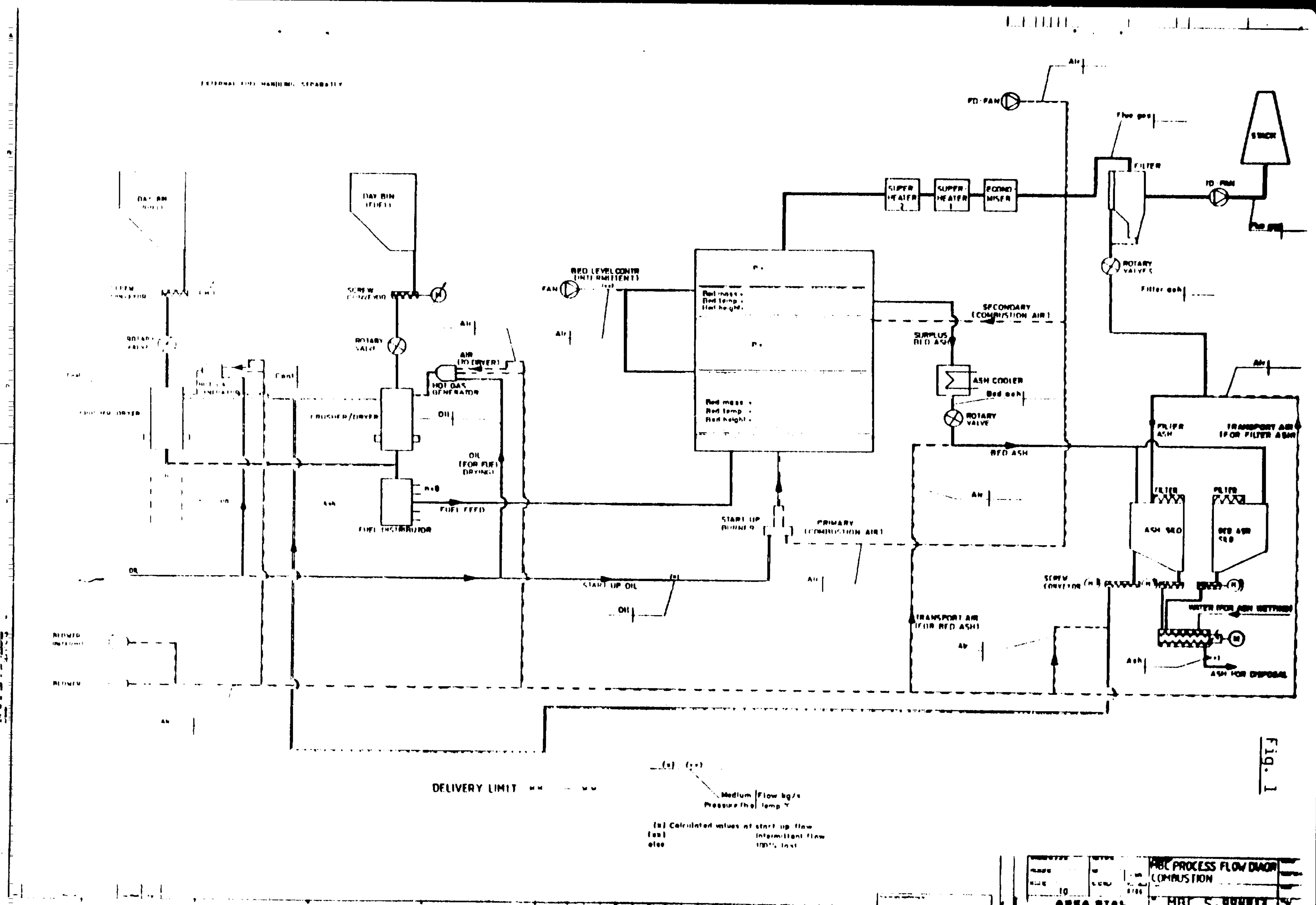

FD-FAN
Air
Flue gas
STACK
FILTER
ID-FAN
SUPER HEATER 2
SUPER HEATER 1
ECONOMISER
ROTARY VALVES
Filter ash
DAY BIN (FUEL)
SCREW CONVEYOR
ROTARY VALVE
BED LEVEL CONTR (INTERMITTENT)
FAN
Bed mass
Bed temp
Bed height
SECONDARY (COMBUSTION AIR)
SURPLUS BED ASH
ASH COOLER
Bed ash
ROTARY VALVE
FILTER ASH
TRANSPORT AIR (FOR FILTER ASH)
BED ASH
AIR (TO DRYER)
HOT GAS GENERATOR
CRUSHER/DRYER
Oil
OIL (FOR FUEL DRYING)
FUEL FEED
FUEL DISTRIBUTOR
START UP BURNER
PRIMARY (COMBUSTION AIR)
START UP OIL
FILTER
ASH SILO
BED ASH SILO
SCREW CONVEYOR
WATER (FOR ASH WETTING)
TRANSPORT AIR (FOR BED ASH)
Ash
ASH FOR DISPOSAL
DELIVERY LIMIT
Medium
Flow kg/s
Pressure
Temp
(x) Calculated values of start up flow
(xx) Intermittent flow
else 100% load
ABC PROCESS FLOW DIAGR
COMBUSTION

Fig. 1

Fig. 2

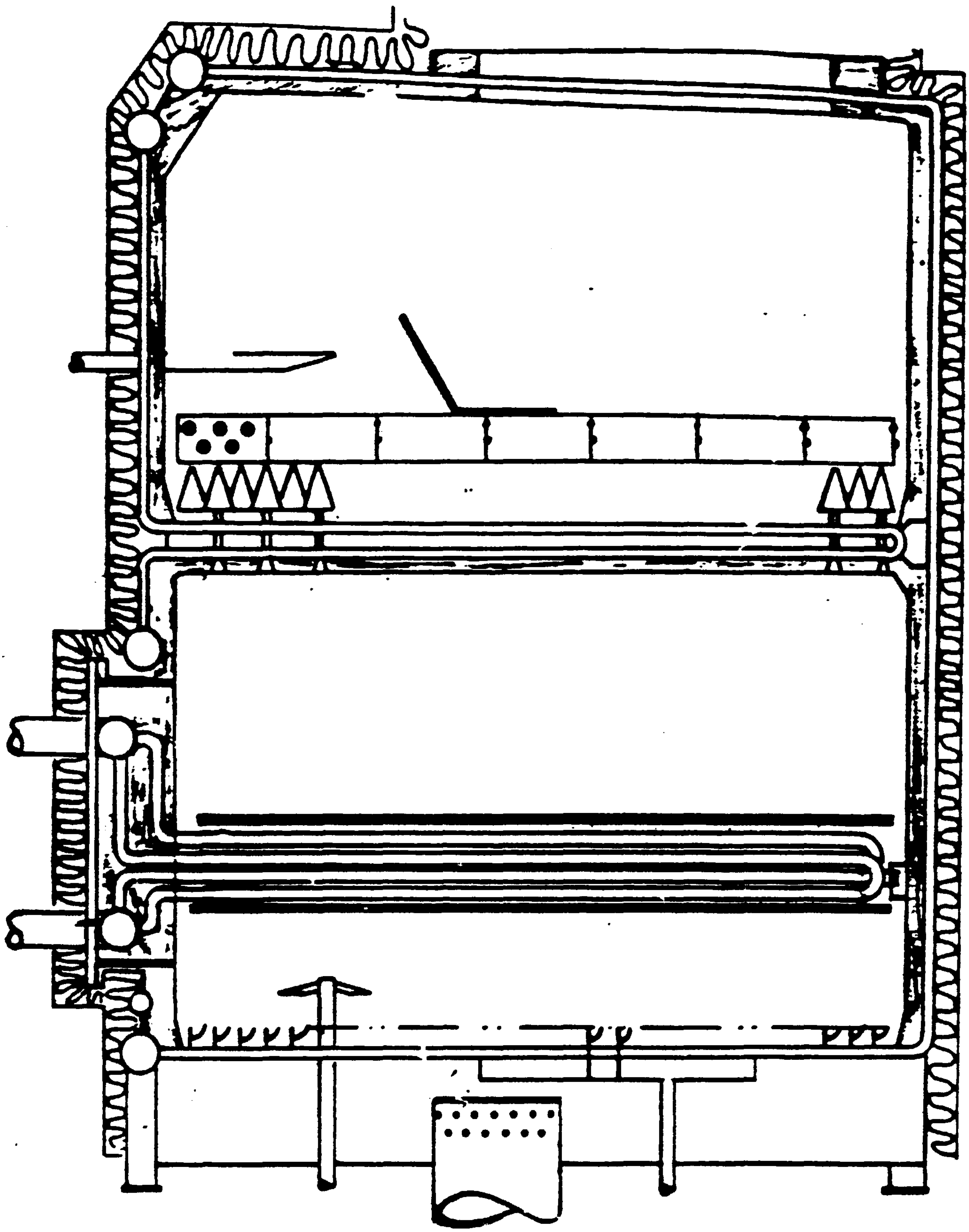


Fig. 3

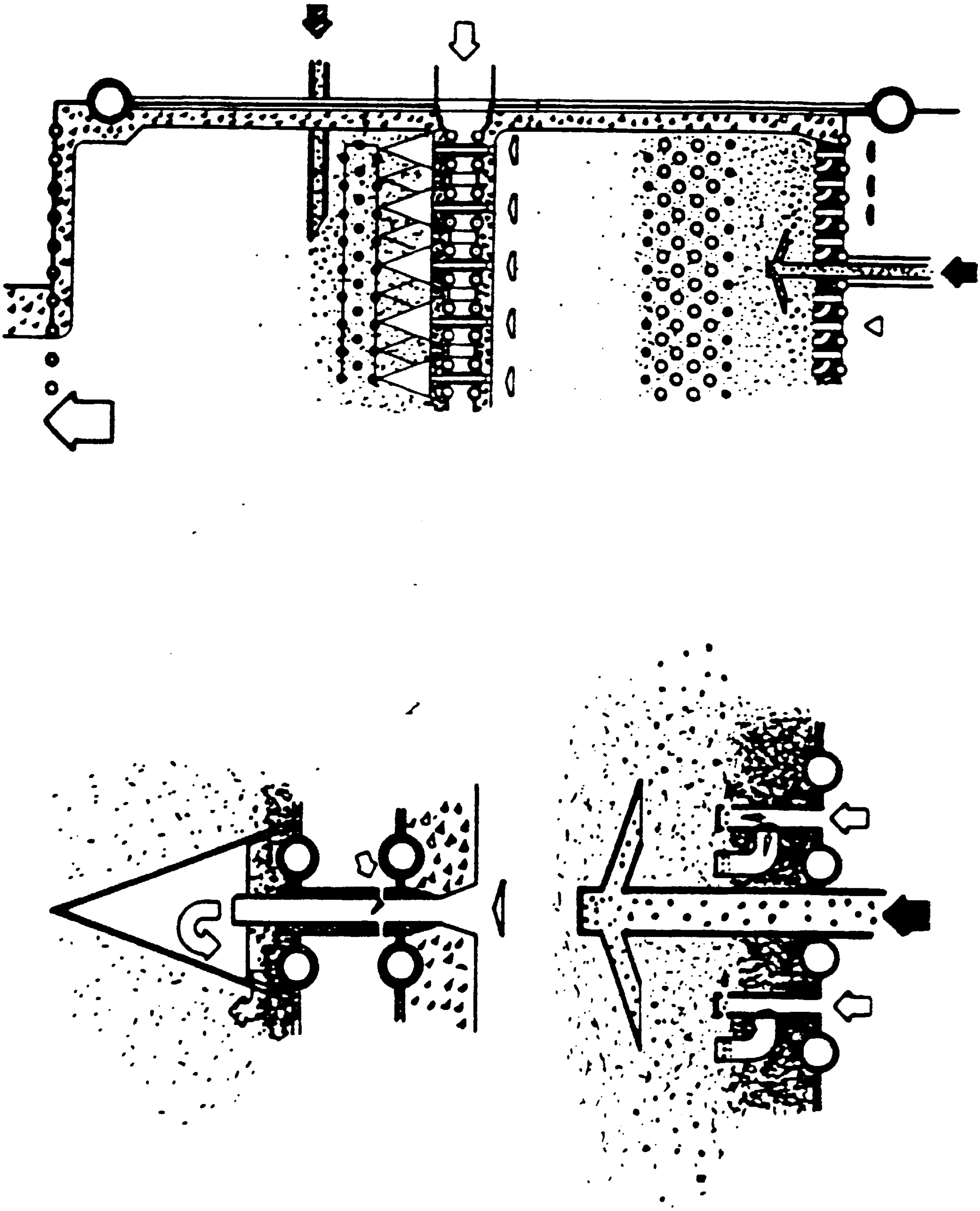
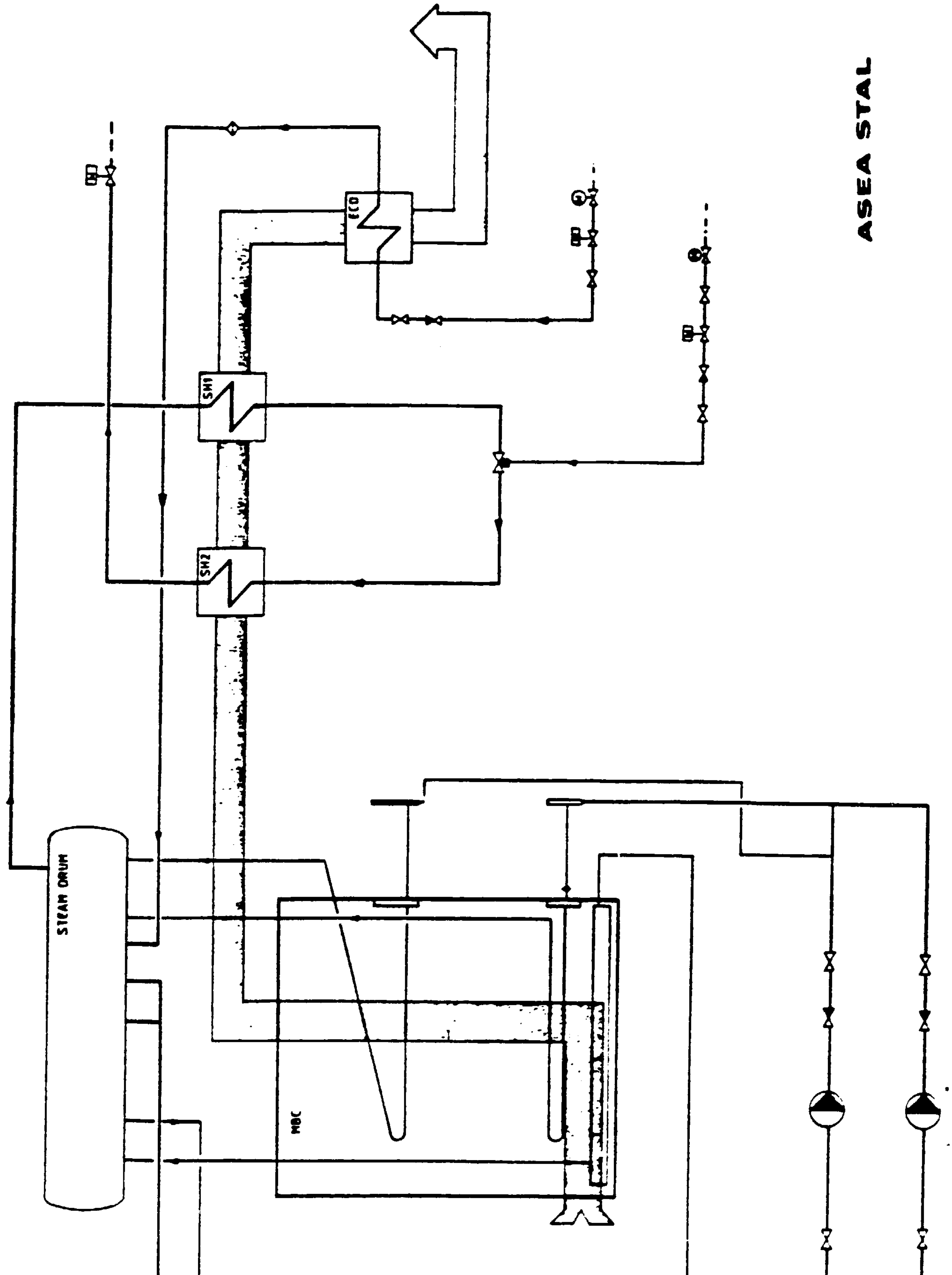


Fig. 4



ASEA STAL

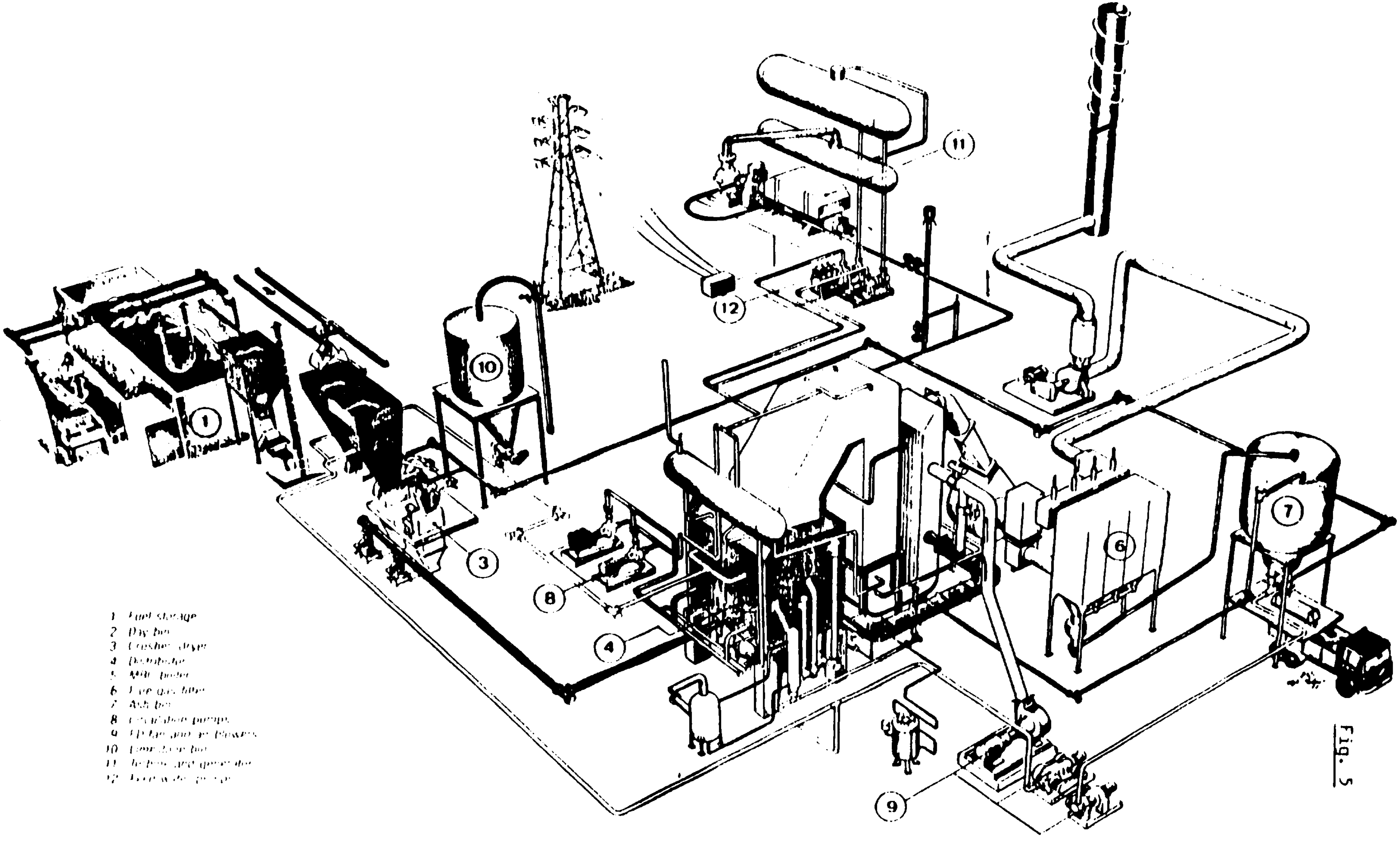
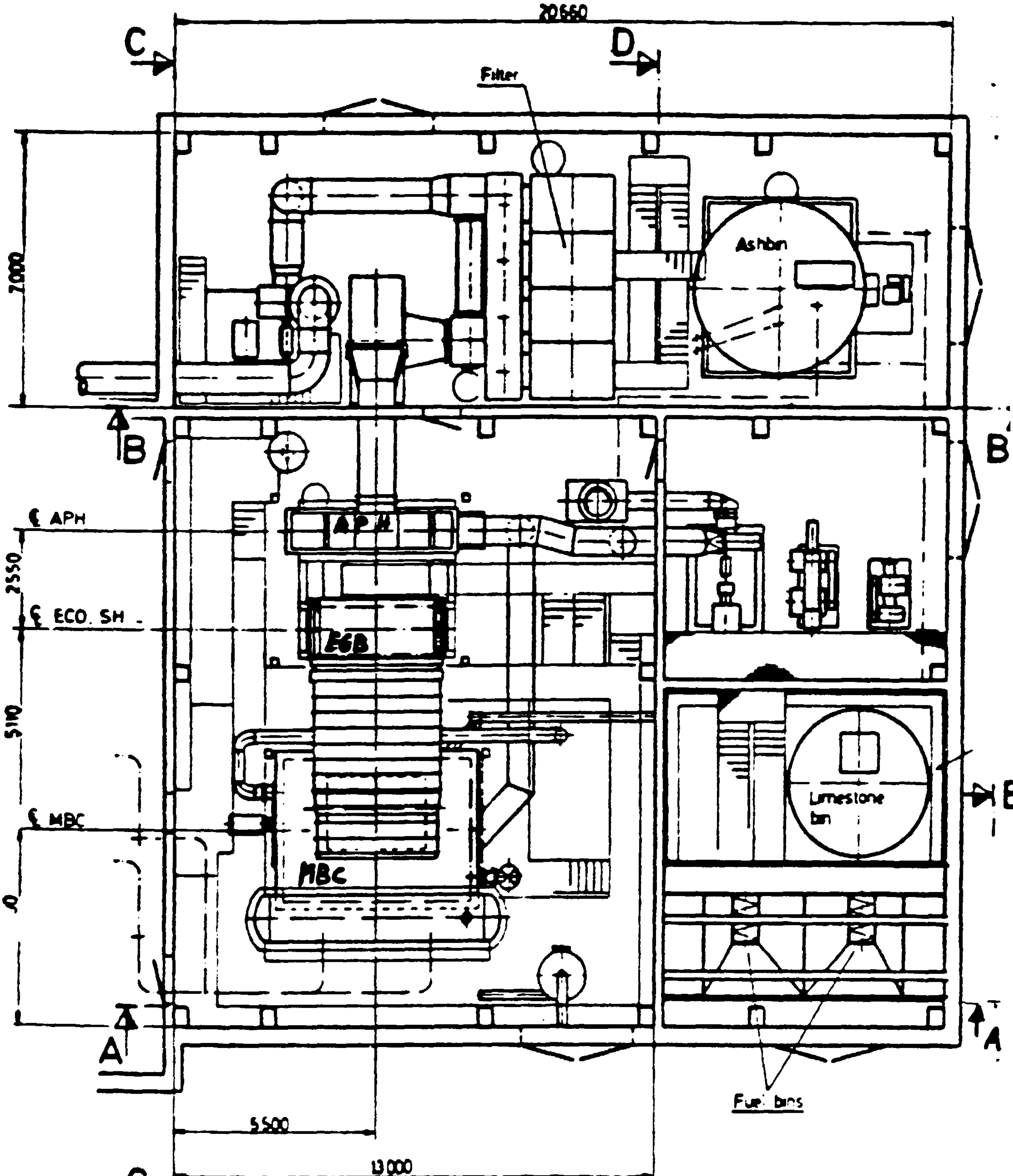

1 Fuel storage
2 Day bin
3 Crusher dryer
4 Distributor
6 Flue gas filter
7 Ash bin
8 Circulation pumps
9 FD fan and air blowers
10 Limestone bin
11 Turbine and generator

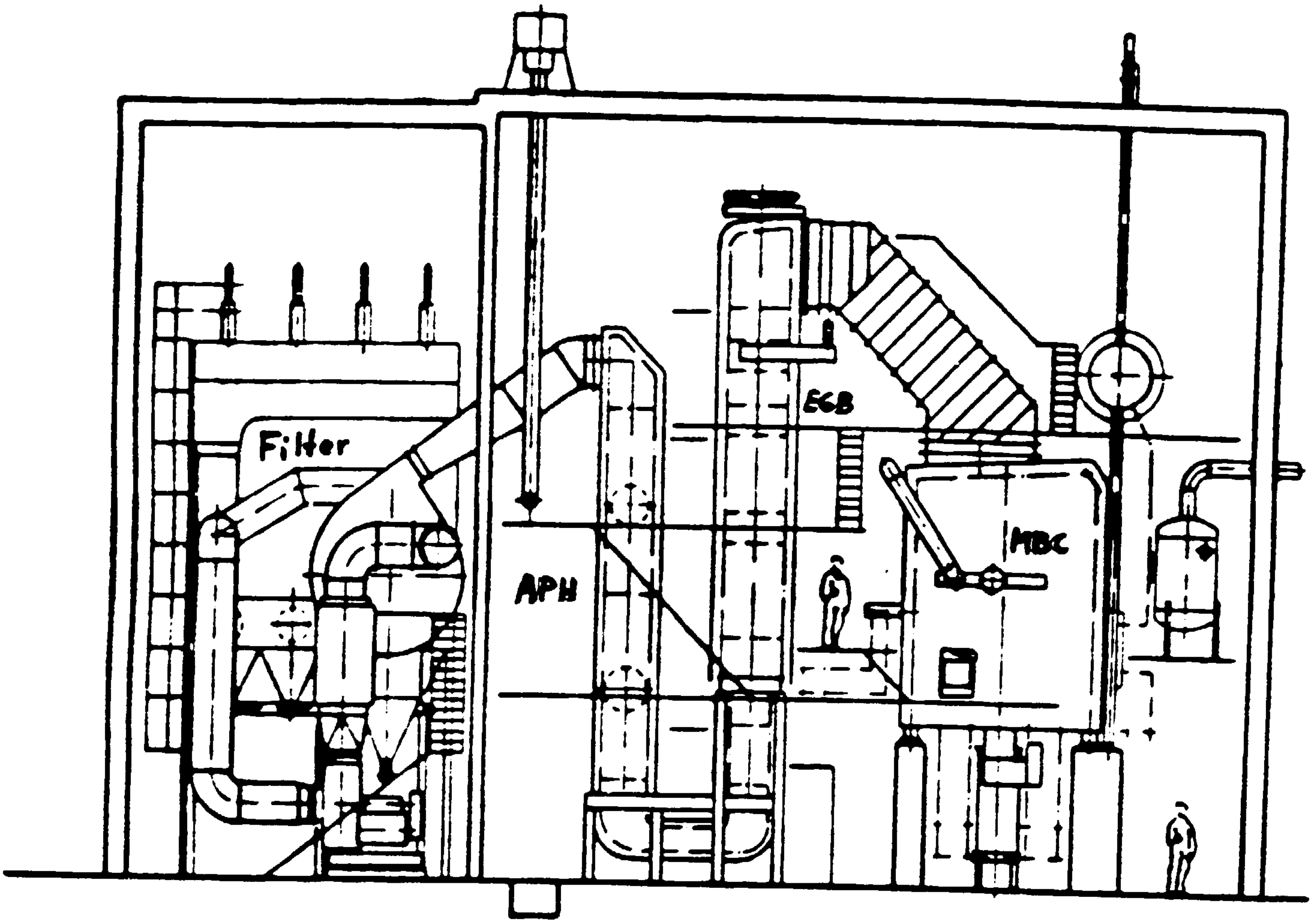
Fig. 5

Fig. 6



ASEA STAL

Fig. 7



ASEA STAL

Fig. 8

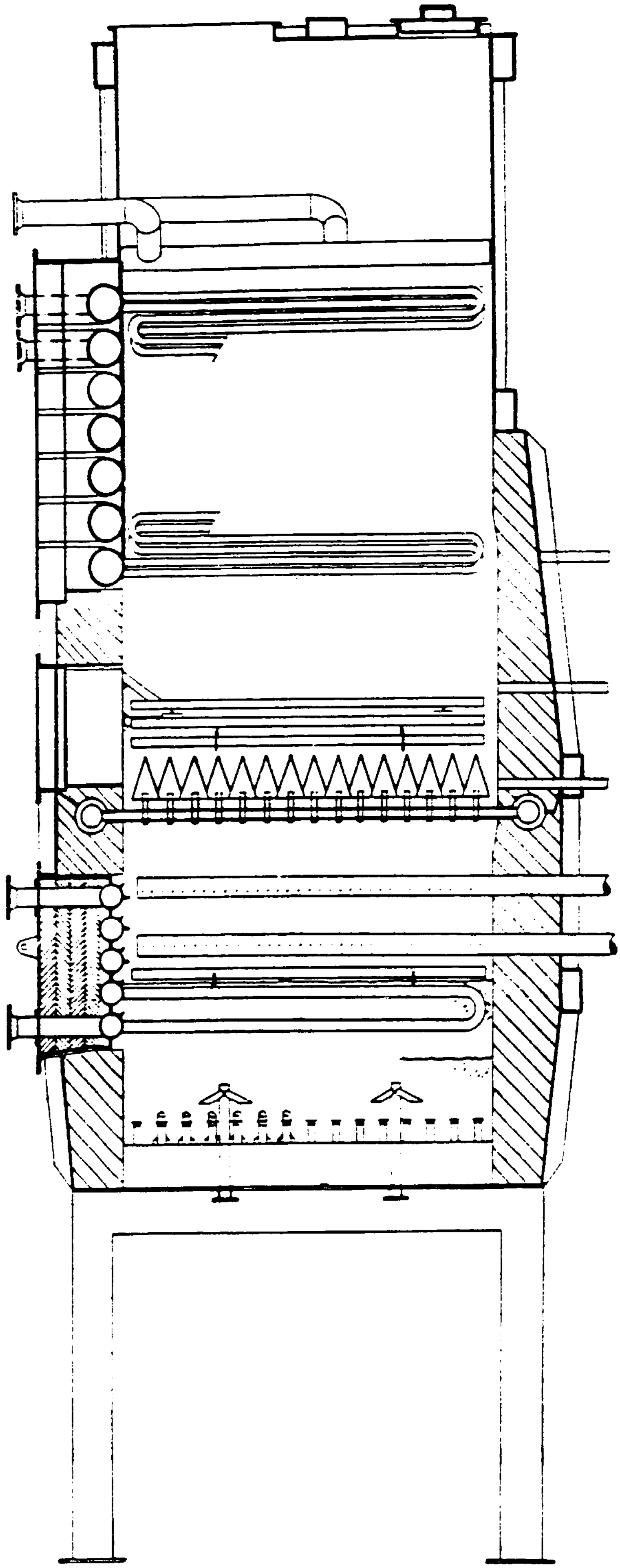
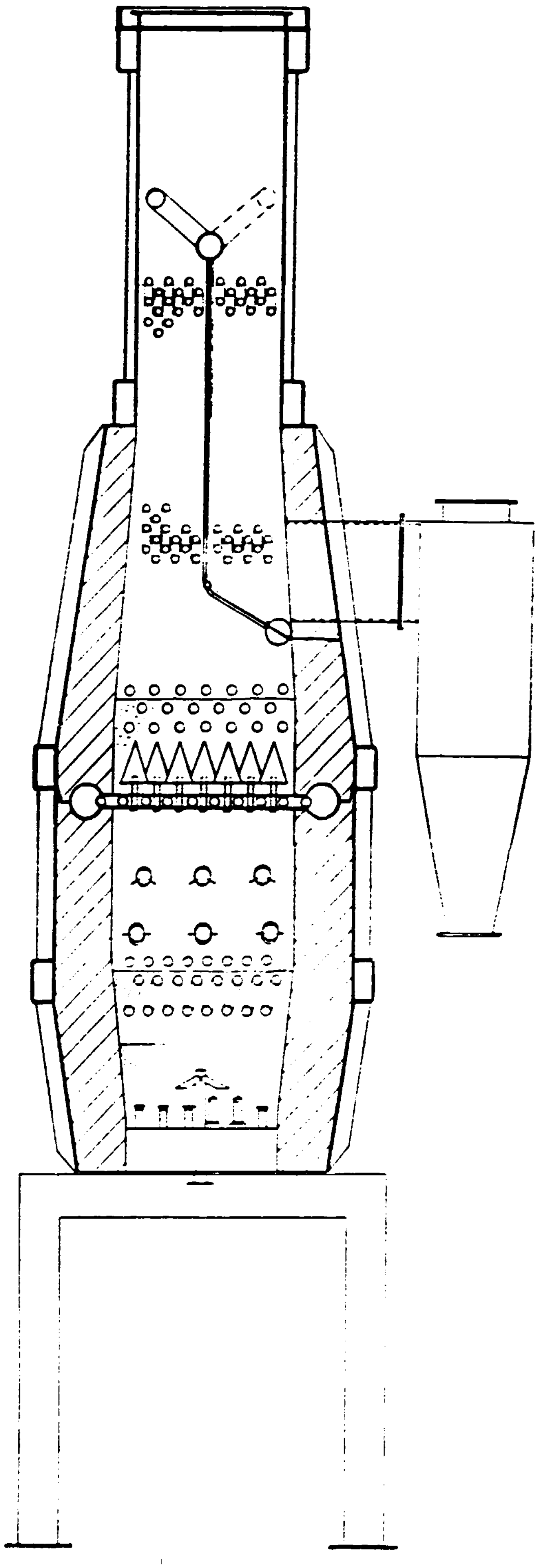
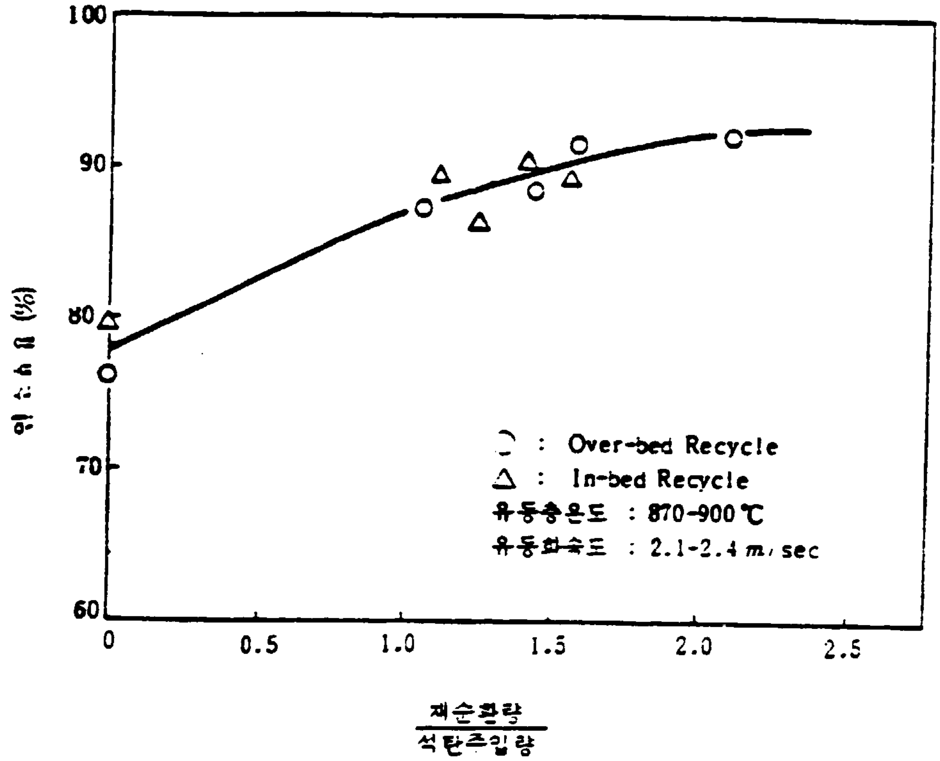


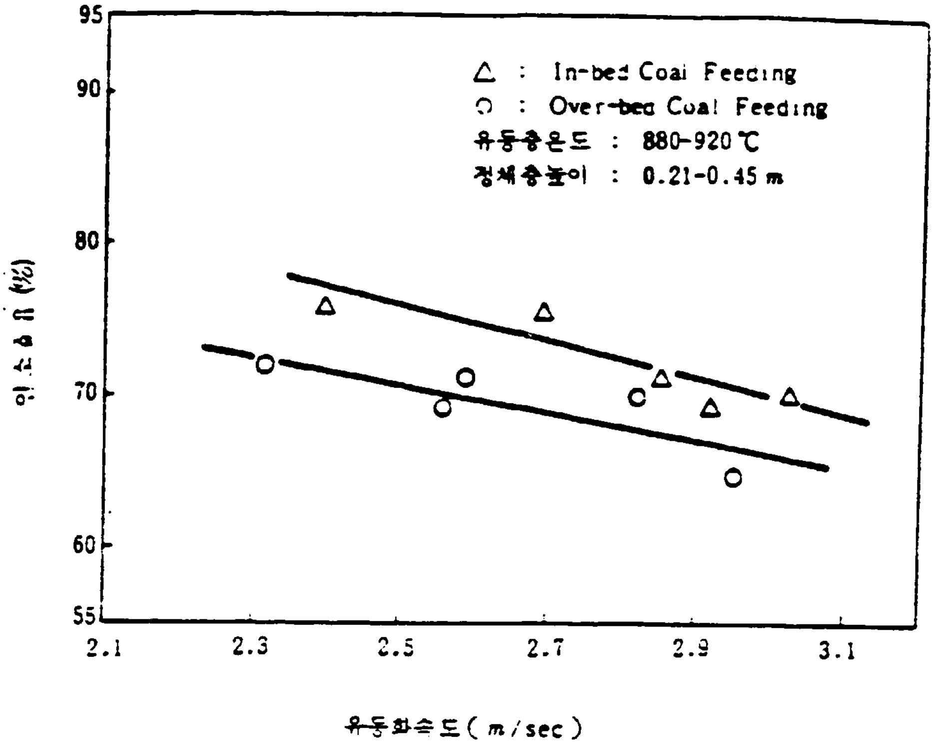
Fig. 9



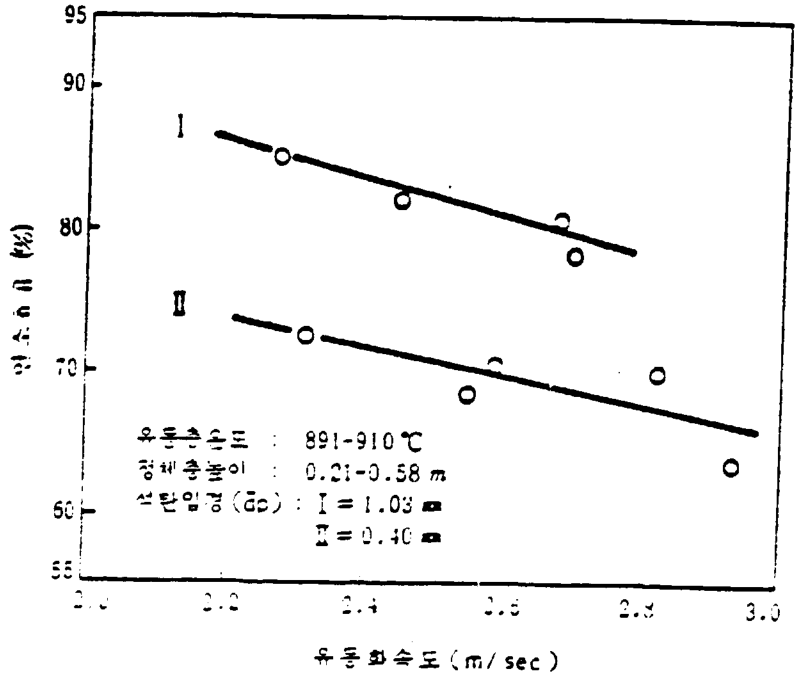


〔그림 2 — 16〕 재순환비에 따른 연소효율의 변화

Fig. 11



[그림 2-8] 유동화속도 및 석탄공급방법에 따른 연소효율변화



[그림 2-4] 유동화속도 및 시료입도에 따른 연소효율 변화

4月 3日 0.1 Ton/hr Boiler 저열량탄 연소실험 공업분석

Bottom Ash

ID *B0000000-01	DRY	AS DET
SAMPLE WEIGHT		0.879 G
MOISTURE		0.20%
VOLATILE	0.60%	0.60%
ASH	99.32%	99.12%
F.CARBON	0.09%	0.08%

ID *B0000000-02	DRY	AS DET
SAMPLE WEIGHT		1.02[illegible] G
MOISTURE		0.2[illegible]%
VOLATILE	0.98%	0.88%
ASH	99.07%	98.83%
F.CARBON	0.35%	0.05%

ID *B0000000-03	DRY	AS DET
SAMPLE WEIGHT		0.977 G
MOISTURE		0.15%
VOLATILE	0.75%	0.75%
ASH	99.23%	99.08%
F.CARBON	0.02%	0.02%

Without Recycle

1st Cyclone

ID *C1111111-01	DRY	AS DET
SAMPLE WEIGHT		1.260 G
MOISTURE		0.67%
VOLATILE	1.96%	1.95%
ASH	79.68%	79.15%
F.CARBON	18.36%	18.23%

ID *C1111111-02	DRY	AS DET
SAMPLE WEIGHT		1.161 G
MOISTURE		0.54%
VOLATILE	2.00%	1.99%
ASH	79.74%	79.31%
F.CARBON	18.26%	18.16%

ID *C1111111-03	DRY	AS DET
SAMPLE WEIGHT		0.975 G
MOISTURE		0.49%
VOLATILE	2.18%	2.17%
ASH	79.68%	79.29%
F.CARBON	18.14%	18.05%

With Recycle

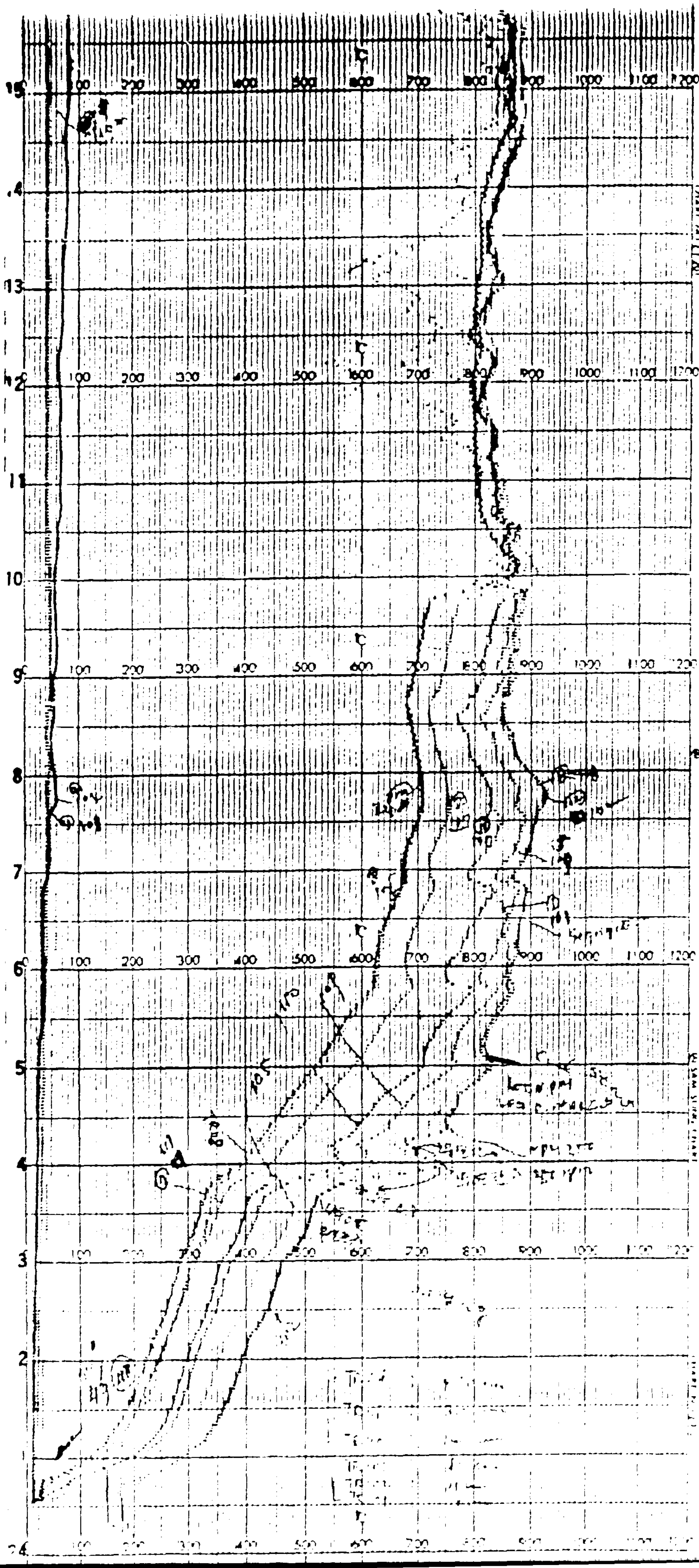
1st Cyclone

ID *C2222222-01	DRY	AS DET
SAMPLE WEIGHT		1.164 G
MOISTURE		0.04%
VOLATILE	1.38%	1.33%
ASH	95.19%	95.15%
F.CARBON	3.43%	3.43%

ID *C2222222-02	DRY	AS DET
SAMPLE WEIGHT		1.494 G
MOISTURE		0.05%
VOLATILE	1.25%	1.25%
ASH	95.20%	95.15%
F.CARBON	3.55%	3.55%

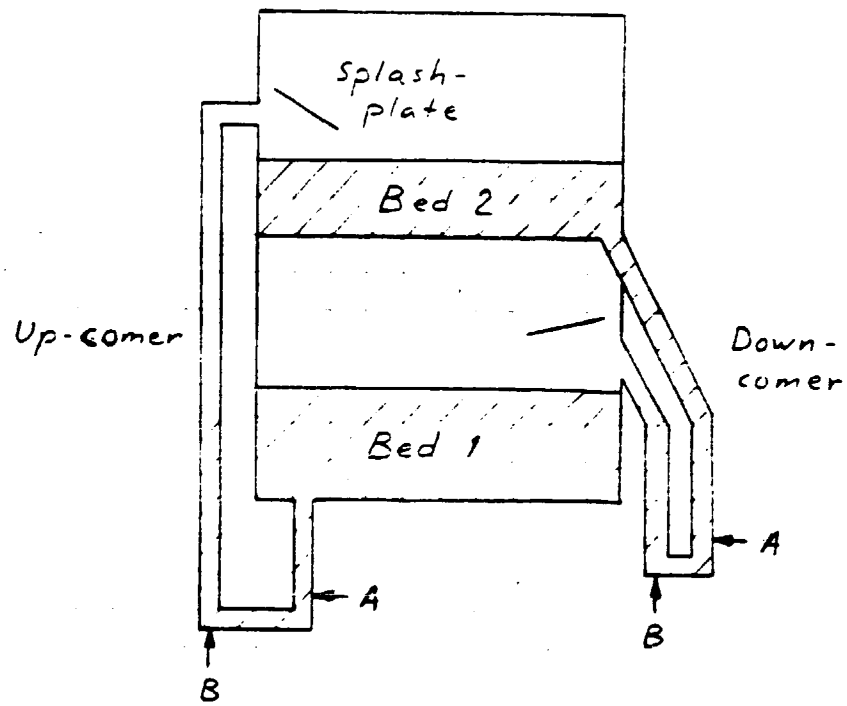
ID *C2222222-03	DRY	AS DET
SAMPLE WEIGHT		1.384 G
MOISTURE		0.00%
VOLATILE	1.26%	1.26%
ASH	95.40%	95.40%
F.CARBON	3.34%	3.34%

Fig. 13



MBC

Bed control system



A = Aeration air

B = Transport air