FLUIDISED COMBUSTION

By H.W. Holsteyn

1. Introduction

Despite the rapid introduction of nuclear power, there will be a continued demand for fossil-fuelled generating plant, that is oil, coal and natural gas.

Unfortunately, these types of fuel have only a limited life, as shown by Fig. 1. This diagram shows the past and projected yearly production of oil and coal from the 19th to the 23rd century, the oil curve being converted to coal equivalent. It shows that sometime in the second half of the 21st century, the oil reserves will have been exhausted.

The detail of the oil production peak shown on the same diagram also shows a curve representing the yearly consumption of oil computed for a 7,5% exponential growth, as was the case until recently, and it will be seen that this indicates an inevitable shortfall.

At present, the world oil consumption has fallen off drastically, due to industrial recession and the increased prices of oil which have caused the implementation of various campaigns to save on the use of this fuel.

Nevertheless, if we would be able to contain the oil consumption per capita, to a constant figure of 1,8% exponential growth, say from the year 1980 onwards, even this would exceed the expected production.

Natural gas supply is generally expected to have just as short a life as oil.

In terms of energy content, it is estimated that the world can produce at least ten times as much coal as oil. The "coal" curve of Fig. 1. should not make us complacent, however, because much of it is difficult to produce, or of low quality. But at least this type of fuel will allow us a breathing space of a few hundred years and give time for changing over to other forms of energy.

While coal will undoubtedly save the day, it is obvious that it must be used with the maximum possible efficiency, also for low grades, and fluidised bed combustion can offer the solution with the added advantage of reduced pollution of the atmosphere.

2. The Principles of Fluidisation

If we consider, Fig. 2, a vessel with a perforated bottom on which rests a certain quantity of granular or powdery material, the fact of blowing a gas or a liquid through the bottom can have three different results; as indicated in "A", the medium simply filters through the material without it being agitated. In "B", we have increased the flow velocity sufficiently to lift the material so as to keep it in suspension and this stage is similar to a liquid condition. The now fluidised bed assumes a much higher top level, the surface of which, while being agitated, is horizontal.

In fact, if we provide an opening at this level, the material will run off as any liquid will do. Also, the bed exerts a hydrostatic pressure on the bottom of the vessel and this pressure can be measured and will indicate a value for the height of the fluidised bed.

If we increase the velocity further, the bed will become more and more fluid, it will rise higher and actual boiling will take place, due to the fact that the various gas streams collect together to form big bubbles which rise to the surface.

Eventually, the velocity can be increased to the point where the material becomes airborne, and we then have a pneumatic conveying system.

From the aforegoing, it is clear that fluidisation must take place between a well defined upper and lower velocity. These velocities can be calculated by means of very complicated methods, taking into account the variation of sizes and shapes of the particles, the varying density of the bed, its viscosity and the number of Reynolds. Table I gives formulas for minimum and maximum velocities for a Reynolds number smaller than 500.

As an example, Table II shows the wide range of calculated velocities which are able to maintain a given size of particle in suspension. In fact, such calculations are only of an indicative value because of the mix in sizes of the particles which inevitably exists in practice, and also because of the varying temperature. Therefore, it is necessary to establish these velocities by test.

Fig. 3a, shows the movement taking place in a fluidised bed. This sketch also shows that fresh material can be simply introduced anywhere in the bed and any excess can run off over a weir. As an aside, this characteristic of a fluidised bed is used for conveying powder or granular material as shown on Fig. 3b. An open- or a closed trough is divided horizontally by a porous medium through which fluidising air is blown. The material to be transported enters on one end and runs off, like a liquid, at the exit end. Although this method does not allow upwards conveying, it does permit following an intricate circuit and any number of take-off points can be provided along its path.

A conveyor of this kind, transporting cement, is capable of moving 200 tons per hour over 54 metres, the trough being 350 mm wide. The air pressure required is only about 60 Kilo Pascal (kPa) and the blower absorbs only about 10% of the power required for a screw conveyor of the same capacity.

The intense circulation shown in Fig. 3a, causes the temperature in a hot bed to be perfectly constant throughout its mass, up to a matter of centimeters above the distributor plate.

3. History

The principles and advantages of fluidisation have been known for a long time, and as early as 1879, a patent was awarded in the United States to one Charles E. Robinson. The application was for the roasting of finely ground ores, in particular gold bearing ore, in order to remove sulphur. In the words of this patent, the idea was "to keep the charge of ore in constant play like the waters of a fountain".

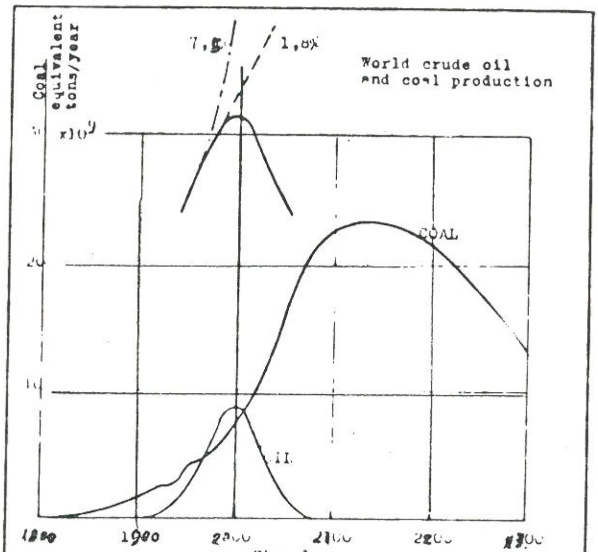


Fig. 1.

TABLE II

d (mm)	cm/sec. min. vel.	max. vel.
0,3	6,8	220
3,5	156	1400

Minimum velocity to attain fluidisation.

Maximum velocity to conveying.

Limits of fluidisation.

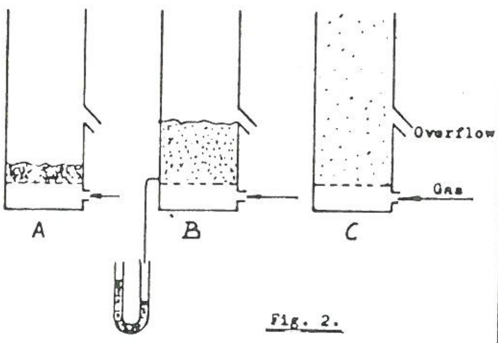
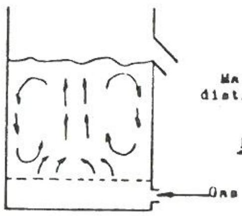


Fig. 2.



Material distribution.

Fig. 3 a.

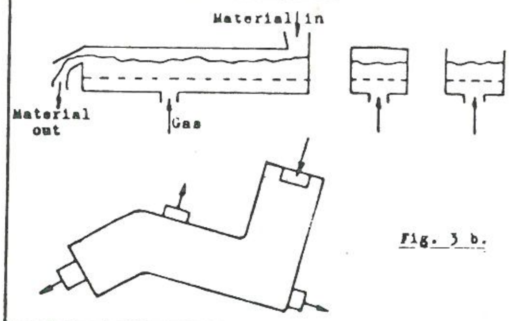


Fig. 3 b.

TABLE I

Minimum velocity to attain fluidisation.

Maximum velocity before conveying.

min. vel. =	$0{,}005 \frac{\varphi^2 d^2}{\mu} g . P . \frac{\varepsilon_m^3}{1-\varepsilon_m}$
max. vel. =	$0{,}152\, d^{1,14} \rho_f^{-0,285} P^{0,714} g^{0,714} \mu^{-0,428}$

φ = Form factor.
d = Nominal diameter of particle.
μ = Fluid viscosity.
g = Acceleration of gravity.
P = solid density - fluid density
ε_m = Fraction of voids.

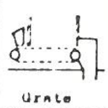
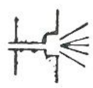
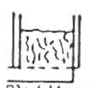
Combustion system	Contact area/mass	Contact time	Relative velocity
 Grate	Poor	High	Medium
 Pulverised	Very high costly	Poor	Poor
 Fluidised	High	High	High

Fig. 4.

It does not seem that the patent resulted in any industrial application at the time, yet the drawing accompanying the patent shows an arrangement which is practically identical to the numerous applications now in service in a wide variety of industries.

A great number of patents for the application of fluidisation were awarded since the beginning of this century and have resulted in significant improvement in efficiency and production in chemical reactors, gasification and, above all, in the cracking process of the oil industry. The latter application really came into its own only during the second world war, when it was necessary to increase the petrol yield from oil. The first intensive commercial operation of fluidisation was established only in the 1930's in Germany, for coal gasifying and roasting.

4. Fluidised Bed Combustion

From the above, it is clear that the great attraction of fluidisation is that it causes a very intimate mixing and contact between solids or liquids with other solids, liquids and gases. It is, therefore, amazing that fluidisation has not been applied earlier to combustion.

In order to ensure a good combustion intensity, it is necessary that the fuel particles during combustion:

(a) have a great surface area in relation to their mass

(b) are sufficiently long in contact with the combustion air

(c) have a great velocity relative to the combustion air.

These three conditions are met in fluidised combustion as is shown in Fig. 4, where a comparison is made with conventional combustion systems.

It is often thought that fluidised combustion requires pulverising of the coal. This is not so, as will be shown later in this paper and, in fact, it is possible to successfully burn even the dirtiest solid or liquid fuels, including oil shales and tar sands, and this with minimal atmospheric pollution.

At present, there are two distinct systems for the application of fluidisation in combustion. We, for want of a better name, call these the "hot" and "cool" systems.

4.1 The "Hot" System

To our knowledge, the very first application on a semi-industrial scale of fluidised combustion, took place in 1950 in France. Mr. A.A. Godel, inventor of the process, was well versed in the principles of fluidisation, because it was used in the manufacture of active carbon in his firm, Soc. An. Activit of Paris.

Fig. 5 shows the essential features of the application of this system, registered under the name "Ignifluid", to a watertube steam boiler.

A chain-grate inclined at about 12% acts as distributor for the primary air and for the removal of clinker. A certain number (normally six), of compartments below the chain admit the air in such a manner that an air pressure gradient from 175 mm at the front to 25 mm w.g. at the rear is maintained. This pressure gradient is required to balance the hydrostatic pressures, which are a function of the sloping bed depth. The maximum depth at the front is about 500 mm.

The primary air serves to ignite the coal and to provide the required velocity for fluidisation - secondary air is introduced from the side walls of the combustion chamber, above the coal-feed, and when this air meets the very hot gas from the fluid bed, a zone of great turbulence is created where the gases and particles are burnt out. Excess air is about 20 - 25%.

The process operates at a temperature, in the bed, of about 1 200 - 1 250°C, which is above the sintering point of coal ash. The clinker thus formed sinks through the fluid bed and is transported out of the furnace by the chain grate. Since this grate has this function only, and has to pass only a fraction of the total air requirement, it has a width of the order of 1/10th of a conventional chain grate. This, linked with the fact that no coal spreading is required, allows greater freedom in the geometry of the combustion chamber and hence the proportions of the boiler can be chosen for a more economical design.

The inclined banks which can be seen on either side of the grate, Fig. 5, are naturally formed and consist of coal. They protect the lower parts of the walls against heat and the adherence of clinker. These fuel banks play no part in the combustion as no air passes through them.

Coal is blown continuously by means of air into the bed where it mixes immediately.

Sizes are from fine to about 20 mm, ash content may be up to 50% and anthracite can be burnt as well as bituminous coal.

The large volume of hot clinker, containing up to 6% carbon, can, of course, cause substantial heat losses, when coal with an ash content in excess of 35% is fired. Post combustion equipment in the ash pit can reduce the carbon content to 2 - 3% and allows recovery of the sensible heat of the clinker.

Carry-over of fines is handled in standard cyclone systems and the fines are generally recycled with the fuel in order to burn the retained carbon.

Control of the boiler is based on maintaining a constant bed level. This is simply achieved by measuring the hydrostatic pressure of the bed which then controls the coal feed. Air requirements are controlled through steam pressure and flue gas analysis. Turn down is to 15 - 20% of maximum combustion rate (M.C.R.), but 10% can be achieved by particularly careful control and a somewhat lower bed level.

The boiler is ignited by building a wood fire for the first start-up. It is also possible to provide gas or oil burners which bring the boiler to full load and keep it there for several hours until the coal placed on the grate ignites, after which normal coal firing takes over.

To stop evaporation of the water, coal feed and air are cut off and

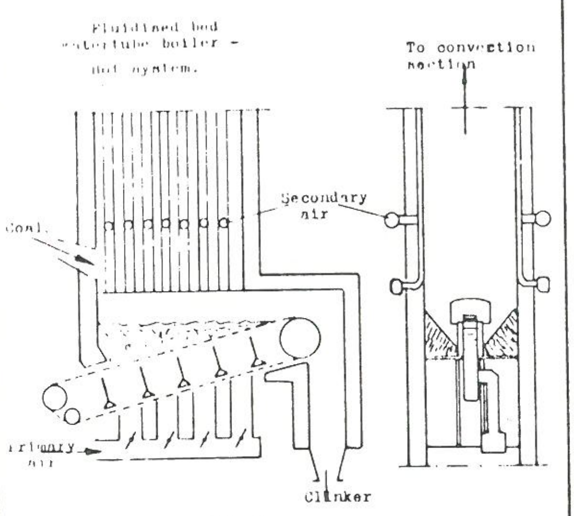


Fig. 5.

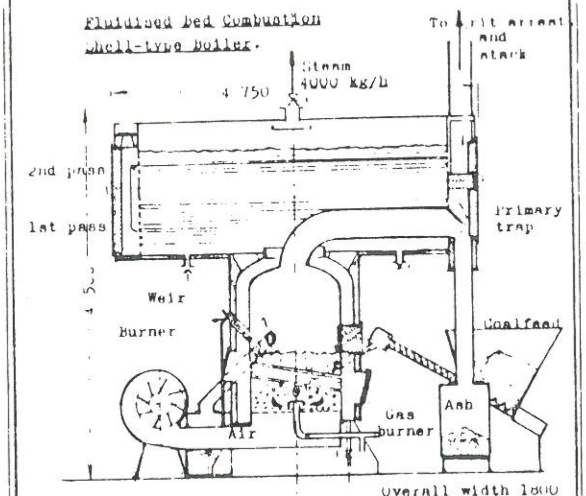


Fig. 7a.

TABLE III

Performance achieved with Leatherhead boiler.

Item.	Target	Achieved
Steam production r. & A 100°C kg/h	3690	4050
Boiler efficiency %	80	79
Combustion conditions		
Excess air %	10	5
Recycle 75 %	100	95
Combustion efficiency %	91	90-91
Turn down	4:1	2,5:1

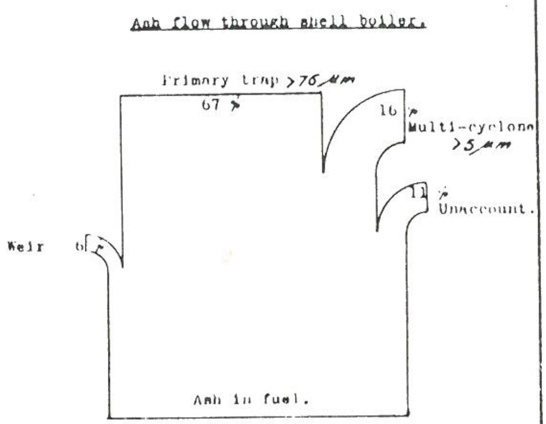


Fig. 7 b.

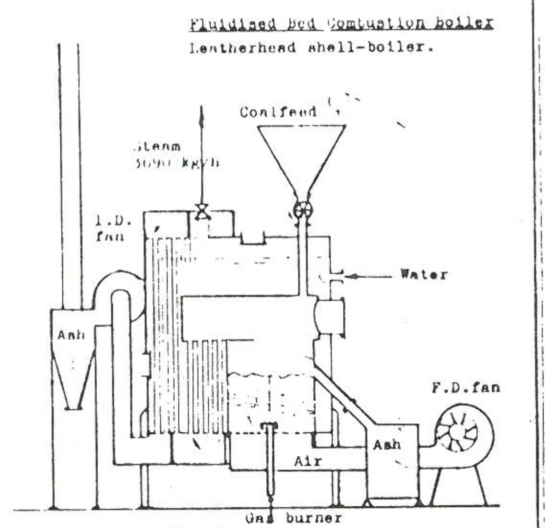


Fig 6.

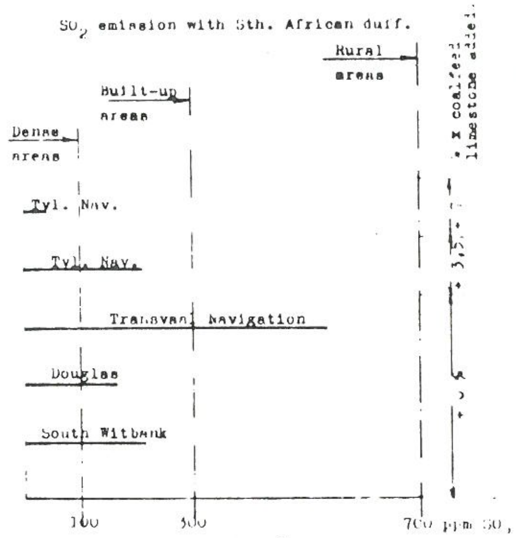


Fig. 8.

after a few hours, instantaneous start-up is obtained by re-establishing coal and air. After an evening shut-down, starting up the following morning may require 20-30 minutes.

It is claimed that the thermal efficiency of the Ignifluid system is 2 - 5% higher than for chaingrate stokers, and about the same as for pulverised fuel firing.

With regard to the cost of a boiler using the Ignifluid system, compared to a chaingrate stoker, this item is less costly and, as said above, a new boiler can be designed more economically. Compared to pulverised coal stoking, the high cost of the mills is avoided while the capacity of the grit-arresting requirement will be considerably lower.

To date 40 plants are in operation, the highest capacity being 200 tons/hour, and a 410 tons/hour boiler is now being designed for operation on 15 500 kPa and 540°C with superheat and reheat.

4.2 The "Cool" System

From 1965, the Research Establishments and the Industrial Laboratory of the British National Coal Board, together with the Central Electricity Board studied the application of fluidised combustion in both power stations and industrial plants.

The main feature which sets the system studied by these organisations apart from other systems, is the limitation of the fluidised bed temperature to about 900°C, by immersing cooling tubes in the bed. The advantages of this low temperature are that ash does not melt or clinker, since these phenomena occur only at about 1 200°C - 1 100°C. For South African coal, the melting temperature is even of the order of 1 300°C. Thus, the ash is produced in a relatively soft granular form which can be easily handled, and may be used, for instance, as additive to concrete mixes. Also, the fly-ash is not abrasive and erosion of convective surfaces will practically not take place. Another considerable advantage, is that the heat transfer, in the bed, to the immersed tubes is of the order of four times as high as in conventional boilers, so that, with about half of the total heat transfer taking place in these tubes, the boiler can be designed about 40% smaller in volume than a conventional boiler. Ash disposal being from the overflow-weir and the grit arresting equipment, no grate is required.

Encouraging results after extensive investigations, obtained with test-rigs and a pilot-scale combustor, capable of burning up to 225 kg per hour of coal led to the decision to build a 3 700 kg per hour (f. & a. 100°C) shell-type steamboiler. Table III shows the target data as well as those actually achieved since commissioning in mid 1969.

Shell-Type Boiler:-

Fig. 6 shows a section of the above mentioned boiler, installed at the British Coal Utilisation Research Association establishment in Leatherhead. The combustion and fluidising air is blown through a simple, perforated, mild steel plate into the bed which consists of any material having a maximum size in relation to the air/gas velocity in the furnace and the desired depth of the bed. It can be crushed refractory, ash or sand. Only about 0,5% in mass of the bed consists of carbon for combustion. The configuration of inclined tubes in the bed is part of the patent covering the design of this furnace. An overflow weir is provided to keep the bed at constant level. The vertical furnace is followed by a conventional three-pass set of smoke-tubes and exhaust is through a primary, coarse, cyclone, followed by a secondary, fine multi-cyclone. Coal was originally fed by means of four compressed air injectors through the bottom distribution plate, but it was later found that fuel could simply be dropped into the bed as shown on Fig. 6.

Ignition is by means of a simple gasburner situated in the centre of the distributor plate.

When my Company, as manufacturers of oil- and gas-fired boilers decided to look at coal-firing in 1970, fluidised combustion was retained as one of the possibilities and was investigated in Germany, France and Great Britain. However, the matter proceeded slowly, until the oil crisis jolted us into action and a licence agreement was signed, beginning 1975, with Combustion Systems Limited (CSL) who, in the meantime, had been incorporated to exploit commercially the patents and know-how gathered through over 22 000 hours of operation.

The design of the Leatherhead boiler having a number of practical disadvantages in respect of maintenance, tube replacement, etc., a new type of boiler was designed by our Company, as shown on Fig. 7a. Some difficulties arose due to certain design details not being covered by normal standards and it was necessary to discuss these with the British Inspecting Company, their South African office having declined to accept our design. Eventually, this was satisfactorily ironed out and, notwithstanding the delay thus incurred, compounded by manufacturing problems due to the unusual design, this boiler was completed by the middle of August, 1975.

We were fortunate in being allowed to install this 4 tons per hour boiler near our own factory to provide steam for an industrial plant.

Fig. 7a shows that the furnace design is identical to the Leatherhead boiler, except that the freeboard was increased in accordance with the recommendations from the licensor. Also, additional inspection and cleaning openings were provided which proved to be most useful, if only to allow the accommodation of various measuring instruments. From there, however, the convection section was radically modified, so that accessibility is very good and in the process, the heat transfer has been improved to the extent that it is expected to reduce the length of the top-drum appreciably for future designs.

The Leatherhead boiler, as well as the French "hot" system, operate with an induced draught, as well as a forced draught fan, in order to maintain a more or less neutral pressure in the combustion chamber. In the South African boiler, we provided only a forced draught fan, thus eliminating the expensive induced draught equipment. This requires, of course, a relatively high pressure fan, but we have been able to design this fan with a single stage.

The oil burner shown on Fig. 7a was originally planned to supply heat for ignition. This was not immediately successful and since we were pressed to produce steam, the gasburner was retained for the time being.

Ignition of the cold boiler takes about 35 minutes.

Control of the boiler under full load is very stable.

From the outset, it was decided that the coalfired boiler to be produced, should as much as possible, be controllable and operate automatically, similarly to a modern oil-fired boiler. Also, the cheapest form of coal should be burned. These two conditions, it was felt, could best be met by using fluidised bed combustion.

With regard to the fuel, it was desirable to use duff, which, at the time. was available at the mere cost of transport. Unfortunately, this is no longer so but it is still a cheap form of coal. It also has a high ash content, of the order of 20%, which is eminently suitable for use in a fluidised bed, because the ash will maintain the inert content of the bed, as it is produced. The size of duff from 0 to 6 mm is also quite adequate and this will be enlarged upon further in this paper.

It is ironical that in March, 1970, the British Government decided that, because coal was at a price comparable to oil, further development of coal-firing in the Leatherhead boiler should be discontinued. No doubt, this decision would not have been taken when the oil crisis erupted. Development was, however, continued on residual oil firing in this boiler, with successful results. As it happens, the development for coal was stopped, just when investigations on modulated turn-down control were being prepared.

Until then, on-off operation had been used and, since this is quite acceptable for the range, up to 5 tons of steam per hour at present envisaged by my Company, it was decided that turn-down and modulation would be developed for higher capacities at a later stage.

The problem of turn-down resides in the fact, that coal feed cannot be infinitely reduced, because a minimum temperature of 500°C must be maintained in the bed to avoid extinction of the coal. Also, a minimum airflow must be maintained to ensure fluidisation. At present, a turn-down to about 85% of M.C.R. can be achieved.

4.2.1 Fuel Characteristics

Before any further negotiations were undertaken, three samples of South African duff were sent to the National Coal Board through the good offices of the Transvaal Coal Owners Association.

These samples, originating from three different mines, were fully tested in fluidised bed combustion conditions at the Coal Research Establishment at Stoke Orchard and a very comprehensive report was issued on the findings of these tests. It was found that the data obtained over a wide range of operating conditions in the large pilot plants, particularly at Leatherhead, could be directly applied to the South African coals.

4.2.2 SO_2 and NO_x Emission

Due to the relatively low temperature in the furnace of the "cool" system, the formation of oxides of nitrogen, originating from the fuel and the combustion air is considerably reduced. Whereas flue gases from conventional coal fired boilers can contain some 400 - 800 ppm, this figure has been consistently as low as 60 - 120 ppm for fluidised bed combustion.

SO_2 formation is also reduced at lower temperatures, but the presence of calcium and magnesium in the fluidised bed will fix the sulphur present in the fuel to form $Ca\ SO_4$ and $Mg\ SO_4$. Both are non-toxic and can be dumped with the ash without any health hazard.

Now, calcium and magnesium are generally to be found in coal, but often in insufficient quantity to appreciably reduce SO_2 emission. In that case, lime or dolomite can be simply added to the fuel feed. Dolomite allows a reduction in SO_2 emission about 26% better than limestone. It is very fortunate that the tested South African coals have a high calcium content while the sulphur contents are relatively low, i.e. 0,41 to 1,10%, so that 53 to 77% of the sulphur can be retained.

Fig. 8 shows, in diagrammatic form, what this means. Even without additive, the emission of SO_2 from the three coals tested will probably be acceptable for most applications. The maximum allowable SO_2 emissions 100, 300 and 700 ppm for densely populated, built-up areas and rural areas respectively, are shown with vertical chain lines. As an example, it shows that the emission from Transvaal Navigation duff was reduced from 531 to 206 and 40 ppm by the addition of limestone at 3,5 and 7% of the coal feed rate respectively. It was also found that recycling of fines further reduced SO_2 emission both with and without limestone.

4.2.3 Particle Size

As was shown under the "Principles of Fluidisation", there is a definite minimum gas velocity at which a particle of a given size fluidises. Fig. 9 shows the relationship between this velocity and some particle sizes. It will be noticed that there is quite a difference between operation at atmospheric pressure and 15 °C and operation at atmospheric pressure at 800°C. This is an important factor at start-up from cold. The influence of increased furnace pressure to 1 600 kPa, an aspect which will be treated further on in this paper, is also shown on Fig. 9.

Of course, the gas velocity cannot be increased indefinitely. Even well before general conveying starts, particles of a given size in the mix of fuel will elutriate at a velocity corresponding to their density and size. Fig. 10 shows this relationship for coal and ash, again for atmospheric pressure as well as for a furnace pressure of 1 600 kPa. It is clear that in practice, particularly when using duff as at comes from the mine, some of the fines will elutriate - in particular the ash particles - and means to arrest this material must be provided. In fact, this process provides at the same time for the ash disposal.

It will be seen on Fig. 7a, that a baffle is provided where the gas stream turns to enter the first pass of smoke tubes. This baffle was the result of a rather vague idea during design that some of the coarser particles would be deflected and drop into the container provided at floor level. This turned out to be a great success because the bulk of the coarse material is retained in this location. Fig. 11 shows the general arrangement of the boiler, where it can be seen that a secondary trap was provided in the connecting duct between the boiler outlet and the multi-cyclone. This secondary trap retains the remainder of the coarse particles of which, however, very little is left in the gas stream at that point. The multi-cyclone retains fines only.

A typical account of the ash flow is shown on Fig. 7b.

In fact, the carry-over from a fluidised bed does not differ from pulverised fuel combustion, but it has the advantage that there are less fines to be trapped and the ash is generally coarser and unsintered. This latter fact, which is also an advantage over the "hot" system, is very important, because it allows higher gas velocities in the convection surfaces. Average actual velocities of 30 - 45 metres per second occur in the smoke tubes and no erosion whatsoever has been observed, only a thin coating of soot.

With regard to the combustion efficiency, this was found to be about 90%, with excess air of 7 - 10%. The combustible loss is primarily fine carbon carried over from the bed and the efficiency can be increased to about 95% by recycling these fines. It is doubtful that the added complication of a recycle system justifies a gain of only 5% in combustion efficiency for the smaller boiler capacities. The location of the primary grit trap is, in any event, ideal for the installation of a recycling device. Fig. 12 indicates the carbon loss in relation to the particle size with and without recycling.

As was mentioned earlier, the heat transfer in the bed, to the furnace wall and the cooling tubes is some 4 - 5 times higher than in conventional gas to steel transfer. Fig. 13 shows the relationship between particle size and heat transfer as well as the heat release in the bed. The astonishing figures hardly need comment. It is interesting to note that heat transfer and heat release vary in opposite directions in function of the particle size. The two curves cross at 3,7 mm size, which happens to be roughly the mean size of the duff as used.

The fluidising velocity also has a significant influence on the heat release since it determines the bed-area. Fig. 14 shows this relationship together with the particle sizes which can be at the relevant velocities.

5. Water Tube Boilers

What has been said in relation to the shell type boilers applies to the same extent to watertube boilers of any description. Such a boiler is in successful operation in the United Kingdom, producing 20 tons of steam per hour with a 3 metre square fluidised bed, designed for both solid and liquid fuels.

5.1 Supercharged Boilers

In the previous sections, mention has been made of pressurised furnaces. It will be known that heat release during combustion is intensified under increased pressure. This phenomenon can be usefully applied with fluidised combustion.

While the development of the shell-type boiler for coal was discontinued in 1970, research on a pressurised boiler continued, with American financial backing. This boiler is shown on Fig. 15. It has a rectangular bed of 1 220 x 610 mm, contained in a refractory lined combustor. This

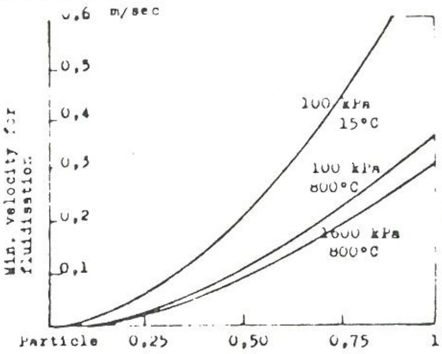


Fig. 9.

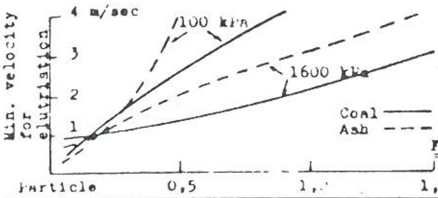


Fig. 10.

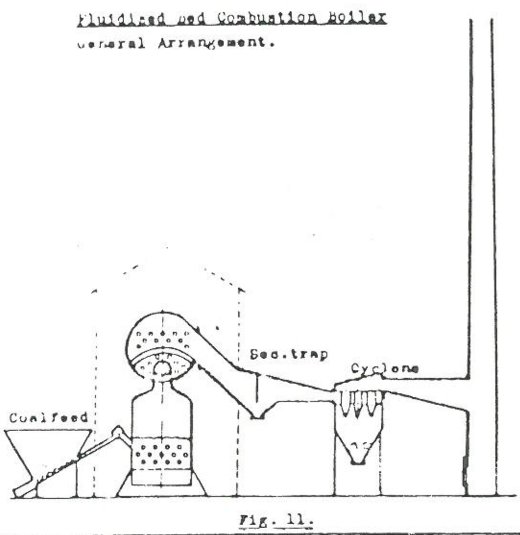


Fig. 11.

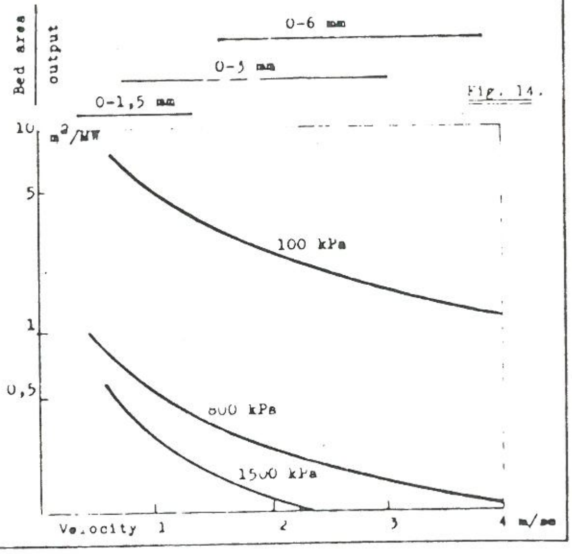


Fig. 14.

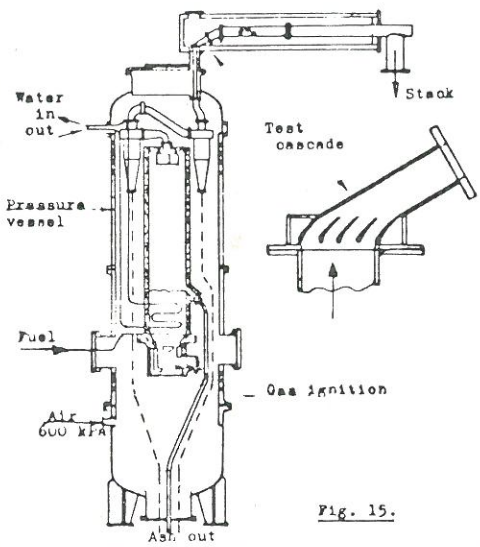


Fig. 15.

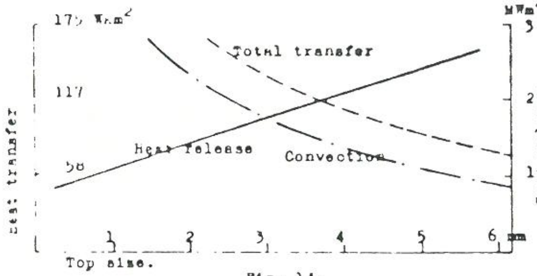


Fig. 13.

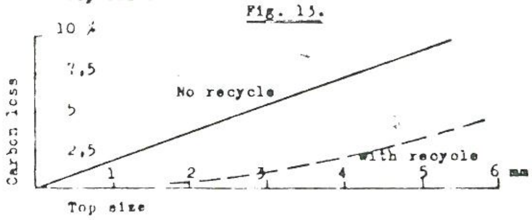


Fig. 12.

Relative volumes for 660 MW.

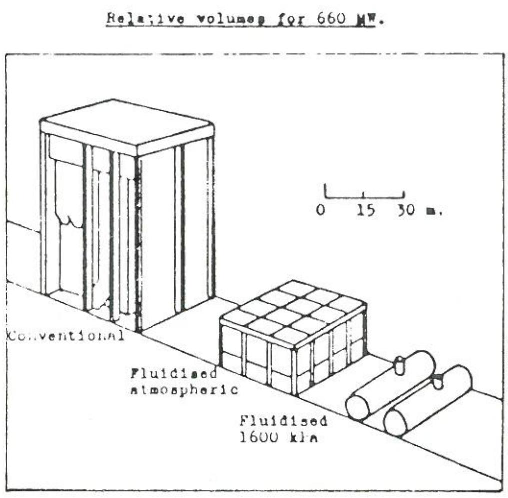


Fig. 16.

combustor, together with the grit-arresting cyclones, is located in a shell, which is pressurised to 600 kPa. A water-cooled jacket inside the shell retains the radiated heat from the combustor. Steam is raised in a coil type exchanger in the bed.

The exhaust gas passes through an assembly where various tests can be made, before it escapes through a pressure let-down valve to the stack.

A very important test-piece is shown in detail. It consists of a segment from the first stage stator row of a jet engine turbine. The approach velocity is about 120 metres per second, and the exit velocity about 600 metres per second. No erosion of the blades nor of target rods further down the gas stream has occurred, while only a small amount of easily removeable ash is deposited on the surfaces. Similar results have been obtained with other gas-turbine segments. The use of combustion gas from pulverised coal in turbines has been tried in the past, but failed due to excessive erosion and corrosion. The soft ash produced by the "cool" fluidised combustion process appears to allow some optimism with regard to the use of coal gas for gas turbines.

5.2 Applications

Fig. 16 illustrates in a rather dramatic fashion the savings which may be expected by the application of fluidised combustion. The three, outlined, boilers are for the same 660 MW capacity, but are of the conventional, atmospheric fluidised-bed and pressurised fluidised-bed types, respectively. The extraordinary reductions in size hardly need emphasizing.

Fig. 17 shows how power and process heat can be produced without raising steam. A compressor, driven by a turbine, supplies fluidising and combustion air and also cooling air for the fluid bed. The use of a gas turbine to expand the hot gas eliminates the need for a convection section and increases the generating efficiency. The hot combustion gases, mixed with the cooling air, drives the turbine, which also drives a generator. The turbine exhaust then heats a liquid or gaseous medium for process or space heating.

A rather interesting proposal is shown in Fig. 18. In order to cater for peak demands, compressed air is stored in an underground cavern, the balancing pressure being provided by water at a higher level, from a river or a lake.

In this case, there would be two cooling circuits in the fluid bed. The one circuit feeds the H.P. section of the gas turbine with air from the compressor, while the other circuit feeds the L.P. section of this turbine with a mixture of H.P. section exhaust gas and combustor exhaust gas.

In off-peak conditions, excess air is stored underground and at peak loads, this air supplements the compressor delivery.

5.2.1 Other Applications

Fluidised combustion can be applied to burning of sludge, refuse, etc., where the advantages of a high proportion of incombustibles and the reduced air pollution possible with this process, are of particular

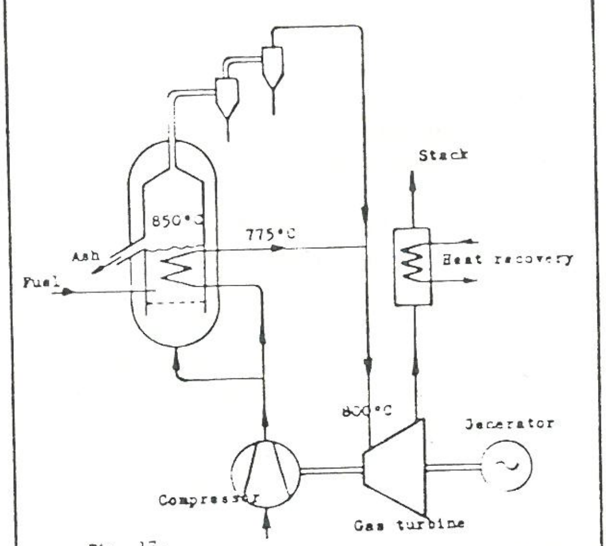


Fig. 17.

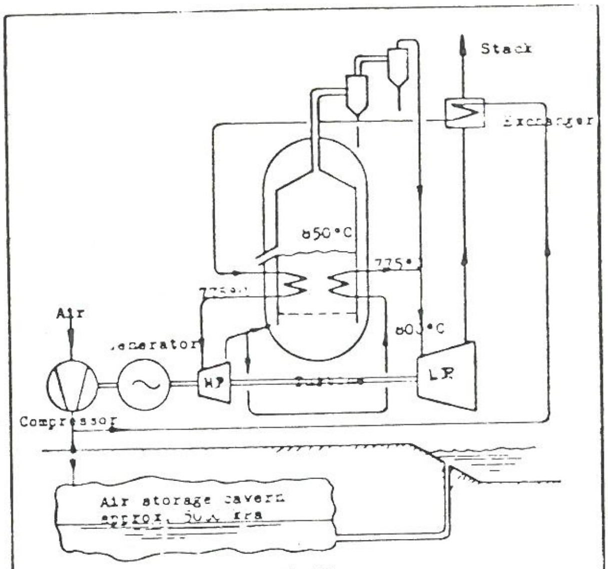


Fig. 18.

TABLE IV

Savings for Fluidised Combustion compared to conventional practice.

		Power st. 660 MW	Industr. 130 MW
Without SO_2 emission control	Capital savings	21 %	13-16 %
	Operating	10-14	8-11
With SO_2 emission control	Capital savings	21 %	13-16 %
	Operating	12-16	10-13

advantage. Refuse burning is of particular importance when it is realised that, in Europe alone, it is expected that by 1980, 275 kg of refuse will be generated per capita, per year, of which about 20% will have to be disposed of by incineration.

A further interesting development stems from the fact that in the same combustor various solid and liquid fuels can be burnt. Thus, a boiler could, say, normally run on oil but switch over to coal in case oil is not available. Also, coal combustors can be designed to be placed before an existing oil-fired boiler as a conversion unit. The output of steam can be the same or higher than for oil-firing due to the considerable heat transfer taking place in the combustor.

6. Conclusion

In the future, fluidised combustion should have an important part to play in meeting energy demands.

As mentioned several times in this paper, it seems to be the shortest, cleanest and cheapest way to generate heat. With regard to capital cost, Table IV gives an indication of the savings expected when using "cool" system as compared to conventional power generation.

Running costs for a shell-type boiler as described in this paper, based on recent cost conditions are expected to be R0,01173 per G.J. (Giga-Joule) which compares with R0,03129 for heavy oil firing and R0,01388 for conventional coal firing. In this figure, capital service, maintenance, fuel and labour are taken into consideration for a boiler of a capacity of 2 000 kg per hour, operating 2 500 hours per year at 75% load.

From what has been said in this paper, it might be concluded that "the bride is somewhat too beautiful to be real". There are, of course, as in any new engineering project, some problems of a practical nature. These, it is felt, can all be solved with common engineering sense and it would be gratifying if South Africa could significantly contribute to this. Already, enquiries have been received from overseas countries to quote for fluidised bed shell boilers, this country being the first to industrially apply this new mode of combustion.

I would like to take this opportunity to thank the Transvaal Coal Owners' Association for their valued help in providing information and putting their technical facilities at our disposal.

ACKNOWLEDGEMENTS

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