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CURRENT COAL-FIRED BOILER TECHNOLOGY IN CHINA

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ABSTRACT

China, one of the world's largest energy producers, relied on coal for 70% of its primary energy demand in 1984. Coal production, which was centred around the rich deposits in the northern and northeastern provinces, reached almost 800 million tonnes and was used primarily as boiler fuel.

The widespread use of all ranks of coals in conventional equipment is being complemented by the development of large boilers to burn efficiently and cleanly coals with heating values below 12,6 MJ/kg. Pulverized-fired and fluidized-bed boilers rated at 850 and 150 t/h of steam respectively are now being demonstrated on coals containing more than 60% ash. Foreign technology for pulverized-fired boilers up to 600 MWe, automated combustion controls and pollution abatement processes will be built under joint venture agreements.

Combustion research facilities are being expanded to support the forecast growth in coal consumption with increased emphasis on the utilization of low-grade coals.

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INTRODUCTION

China has the world's third largest reserves of coal. Over the past 25 years production has risen dramatically from 32 million tonnes in 1949 to more than 700 million tonnes in 1984. By the year 2000, current forecasts indicate that coal production will escalate to about 1200 million tonnes per year, with most of this output being earmarked for domestic consumption.

Under China's national economic plan, the replacement of oil with coal in existing boilers is being accelerated, and a significant part of the nation's future energy demand will be generated by coal. Although most of the existing boiler plants are fired with high-quality coals, priority is being placed on newer designs that can burn low-calorific-value coals under automatic, environmentally acceptable conditions.

To satisfy the need for innovative boiler technology that can efficiently and cleanly burn a variety of coals, new research and manufacturing facilities are being built using a complementary mix of Chinese and foreign expertise. In addition, opportunities for participation in future energy projects, through technology transfer and joint venture agreements with industrialized countries, have rapidly increased. Numerous agreements involving purchases or licensing of production machinery, construction methods, fabrication techniques and proprietary equipment designs have been negotiated, as part of an accelerated effort to adapt off-shore energy systems to Chinese coals.

This paper, which includes data on some of the main commercial coals in China, selected technical descriptions of recently constructed or retrofitted boilers, and a list of some of the main combustion and boiler research facilities, is based on information provided by numerous universities, research institutes and industries visited by the author during invited lecture tours of China in 1983 and 1984.

COAL RESOURCES

The northeastern provinces of Heilongjiang, Kirin and Liaoning (Manchuria), the Shanxi Basin and the eastern province of Anhui contain more than 90% of China's high-rank coal resources. Substantial deposits of brown coal exist in inner Mongolia, but the southern provinces, including the Sichuan basin, have only small, widely dispersed coalfields. As shown in Fig. 1, there are 18 mines, each with an annual output of more than 7 million tonnes of coal. Two of the largest coal bases, Datong and Kailuan, each produce in excess of 20 million tonnes per year of high quality coal (1).

Most of the coals, which range from anthracite to brown coal, have moderate to high ash-fusion properties and are relatively low in sulphur. Typical analysis for the different ranks of coals is given in Table 1 (2).

Exports of coal from the north to the coal-deficient, southern provinces exceeded 50 million tonnes in 1984. However, the anticipated growth in coal utilization in this region over the next 20 years will depend on a corresponding increase in capability of the coal transportation infrastructure.

PULVERIZED-COAL COMBUSTION

GENERAL

Pulverized-firing is widely used in industrial and utility boilers with steam capacities ranging from 35 to 850 t/h. Units rated at less than 400 t/h steam largely utilize either wall- or corner-firing, although some units are roof-fired. Corner-firing is favoured on units rated at more than 400 t/h steam.

Direct firing is used almost exclusively for high-reactivity coals such as high-volatile bituminous and lignite whereas indirect firing is usually selected for low-reactivity coals such as low-volatile bituminous, high-ash bituminous and anthracite.

Since high-reactivity coals, as in the western world, are burned using established technology, this section of the paper deals only with innovative developments for low-reactivity coals and the corrective measures taken to increase boiler availability and efficiency with these fuels.

LOW-REACTIVITY COAL CHARACTERIZATION

The expanded use of low-reactivity bituminous coal for pulverized-fuel firing is an important strategy in China's plan for modernization. In 1983, more than 10% of the coal used by power stations exceeded 40% ash and less than 16,8 MJ/kg on a dry basis. However, numerous operational problems including poor ignition, poor flame stability, high carbon carryover and accelerated erosion of boiler surfaces have been experienced. Moreover, switching from high- to low-grade bituminous coal has resulted in reduced boiler efficiency, flame outs and boiler "puffs", particularly when the as-received volatile matter content dropped below 18%.

Traditionally, Chinese boiler designers have used the dry, ash-free volatile matter content of coal as the primary basis for combustion stability (3). This parameter, which has not been satisfactory when used on high-ash, high-volatile coals, has been superseded by two more realistic analytical parameters based on the thermogravimetric analysis (TGA) of the as-received coal (4, 5).

The first is the ignition temperature, Ti, which is defined as the temperature when the coal sample stops absorbing and begins releasing heat during TGA. The second is the average combustion rate, dw/dt, in mg/min during the maximum burning period. Fig. 2 shows the Ti values versus ash content and Fig. 3 shows the dw/dt values versus Ti values for a range of Chinese coals. These two figures confirm industrial experience which has shown that high-ash, high-volatile bituminous coals behave much like low-volatile bituminous or anthracite coals during combustion.

BURNER TECHNOLOGY

Most utility boilers, particularly for low-volatile or low-grade coals, are equipped with corner-firing systems (6) using burner arrays typical of those shown in Fig. 4(a). The tangential impingement circle diameter "d", shown in Figure 4(b), is normally between 0,5-0,8 m or 0,08 to 0,12 of the average furnace depth, defined as $P = (A+B)/2$.

The height to width (h/w) ratio of these burner arrays often exceeds 10 because of the narrow coal/primary air openings required to maintain ignition and the relatively large distance between the coal nozzles and the secondary air jets required to improve flame stability by delaying secondary air entrainment. In practice the h/w ratio is minimized whenever possible because the burner jets tend to migrate toward the furnace walls and produce slag deposits at h/w ratios above 10. The downward deflection of the secondary air jets is also decreased to less than 12° to improve ignition with low-reactivity coals.

As shown in Fig. 4(c) corner burners with wedge-shaped flame anchors are commonly used without oil support on boilers of 35-410 t/h steam capacity when coals containing less than 12,6 MJ/kg are to be burned. Turn-down to almost half load is achievable on most boilers.

Wall-firing with circular burner designs is used for low-volatile or high-ash coals with as received calorific values of 12,6 MJ/kg or more (Fig. 5). However, wall-firing is less popular than corner-firing because small swings in coal quality can cause a rapid deterioration in combustion performance. Burner modifications that have improved combustion performance with these coals include:

a) Increasing the cone angle of the secondary air port from 9° to 13° to increase the quantity of internally recirculated flame gases (flaring in excess of 18° caused combustion to deteriorate).

b) Changing the cone position in a cone-stabilized burner to increase the coal exit area (decrease primary air velocity).

c) Eliminating the swirl vanes in the primary air/coal pipe on an annular burner to delay coal mixing with the secondary air.

SYSTEM DESIGN CRITERIA

Some of the important design criteria developed for pulverized firing of low reactivity coals are summarized below (7):

a) Total combustion air: 125%.
b) Primary air: 25 to 30% of total combustion air.
c) Primary air speed: 20 to 25 m/s
d) Secondary air speed: 40 to 50 m/s
e) Secondary air volume below the coal/primary air stream: 25 to 30% of total secondary air.
f) Primary air temperatures above 160°C are used to transport the dry pulverized coal (160°C is the safe maximum limit for bituminous coal conveying) in order to eliminate flame instability and the need for oil support.
g) Mill off-gas volumes, injected into the furnace, are being reduced by 30% through an increase in the temperature of the gas drying medium from 250°C to 350°C.
h) Lining about 8-17% of the furnace wall in low heat transfer zones with refractory.
i) Volumetric heat release rates of 420-550 $MJ/m^3/h$ are required to keep carbon losses to less than 5% and to obtain boiler efficiencies above 90%.
j) Furnace cross-sectional heat release rates vary from 6300 to 21 000 $MJ/m^2/h$ depending on ash-softening temperature and boiler capacity, with cross-sectional heat release rates being 5000 to 8400 $MJ/m^2/h$ in the flame zone.

FLUIDIZED-BED BOILERS

Although China has more than 2200 fluidized-bed combustion (FBC) boilers in operation, many of these units are older than 20 years and fairly small.

The current designs, which can burn very high ash coals, are much larger and are equipped with both automatic and pollution controls. Since the first of the large FBC boilers became operational in 1976, a number of problems with this pioneering use of ultra-high-ash coals have been identified and successfully resolved. Ongoing studies being conducted on one retrofit and two new FBC steam plants to improve operational reliability are described.

RETROFIT INSTALLATIONS

A number of stoker-fired boilers, originally designed for medium-volatile coals, have been converted to fluidized-bed firing in order to burn stone coals, a term used for coals containing more than 70% ash. In 1976, the Yungyung Mining Co. in Sichuan Province converted a fixed, a chain and a travelling grate stoker to FBC (8). Design data for these units are given in Tables 2, 3 and 4 respectively. All three FBC retrofits, which use in-bed screw feeders for coal, required extensive water-wall modifications as well as the retrofitting of automatic boiler controls and dust collectors. The boilers, shown in Fig. 6 to 8, have each operated nearly 7000 h/a since 1976 and are designed to fire either high-volatile stone coals of 5,3 MJ/kg, medium-volatile coals of 18 MJ/kg or a 75/25 blend of the two coals. Ash contents typically average about 55% but could go as high as 80% with stone coal only.

The boiler efficiencies with stone, blended and medium-volatile coals, after conversion to FBC, are reported to be 60%, 70%, and 78% respectively with a 10% increase in steam production over stoker-firing. Boiler efficiencies for the original stoker-fired units ranged from 50% to 60% while burning medium-volatile coals.

Although vast quantities of ash are generated by FBC, particularly when fired with stone coal, the spent bed material is being fully utilized for the production of bricks and cement.

YIYANG BOILER

This unit, rated at 35 t/h, was the first Chinese FBC boiler specifically designed to burn stone coals with calorific values as low as 4,2 MJ/kg. It contains four beds, each with in-bed screw feeder for coal and operates at a bed depth of 1,2 m. The dividing walls between adjacent beds are 0,2 m high. General design information on the boiler, which was installed in 1978, is given in Fig. 9 and 10, and Tables 5 and 6 (9).

During commissionning, it was determined that many of the design assumptions relating to the combustion performance of previously uncharacterized stone coals in an operational-scale FBC were not valid. The design steam flow could not be obtained, the bed temperature was unstable and the time from cold start to steady-state steaming was excessive. Design loads and acceptable performance could, however, be obtained by using coals with a calorific value exceeding 12,6 MJ/kg.

The slow heat-up time for the bed was resolved by the following changes:

a) Replacing the wide-flame oil ignitors, which only provided intense heating in the vicinity of the coal feeder, with long-flame ignitors which blanketed the entire bed surface.
b) Decreasing the top size of the bed material to 4 mm to reduce bed cooling during start up.
c) Enriching the stone coal with a higher quality coal to provide a feed with 6,3 MJ/kg during start up (blends with a higher calorific value tended to overheat and sinter the bed).

With the above changes the procedure outlined below has resulted in all four beds reaching operating temperature within 80 min from a cold start:

a) initiate minimum fluidizing air flow to the start-up bed,
b) raise the start-up bed temperature to 800°C with the oil ignitor before increasing the fluidizing air to maximum flow,
c) start the feed of enriched coal and raise the start-up bed temperature to 1000°C,
d) fluidize the other three beds in sequence using the overflow layer of hot material from the start-up bed to initiate ignition.

Graphs showing the time-temperature profile for a cold start to steady operation and for part of an extended combustion trial are shown in Fig. 11 and 12 respectively.

The achievement of the rated boiler load with a stable bed temperature using the design coal also required significant boiler modifications. These are summarized below:

a) The area of the in-bed tubes was reduced in five stages to one third of its original value as shown in Fig. 13.
b) The hole velocity of the bubble caps was increased by about 25%.
c) The superheater area was reduced in five stages to 28% of its original value.

These changes have enabled the boiler to meet its design specifications as demonstrated by a continuous test run of 20 d when the load varied from 50% to 90% of design rating at an average boiler efficiency of 60%. Erosion of the in-bed tubes is a continuing problem, but the use of anti-erosion fins or studs on the tubes shows promise of controlling this problem. Table 7 shows the original and the final design changes.

JIXI BOILER

The largest FBC boiler in China at Jixi in Heilongjiang is designed to produce 130 t/h steam for electricity production using stone coal. Details of this boiler, which contains six beds with individual screw feeders, are shown in Fig. 14 to 16, and Tables 8 and 9 (10).

From 1981, when it was commissioned until 1983 the unit logged over 8000 h operation with one non-stop campaign of about 1350 h. However, the absence of reliable data for scaling up the FBC from 35 t/h to 130 t/h resulted in the boiler being unable to achieve its design load and in a gradual deterioration in performance over a one-year period.

A research panel, formed in 1982 to evaluate design deficiencies, recommended and then implemented the following corrective measures:

a) In-bed tube area was reduced by 25% to achieve a 60°C increase in bed temperature as shown in Fig. 17.
b) Ash overflow ports were enlarged by 100%.
c) Air ports were installed around the coal feeders and in the bed zone above the in-bed tubes to minimize reducing conditions and to improve carbon burnout.
d) Freeboard cross-sectional area was enlarged by removing the rear water wall arch to reduce velocities and increase residence time.
e) Ash hoppers were installed under the superheaters to remove some of the coarse erosive fly ash.
f) A blocking wall was installed at the rear of each combustor to reduce tube end erosion as shown in Fig.18.
g) Air preheater surface area was decreased by 50% by using fewer and smaller diameter tubes to reduce erosion severity.

Following these changes the design steam quality was met, the load increased from 90 t/h to more than 100 t/h, stable bed conditions were obtained with a 7,2 MJ/kg stone coal, combustion efficiency improved and ash erosion of convective heat exchanger tubes was reduced.

Notwithstanding these modifications, the boiler efficiency could not be increased above 66% because of the reduction in heat transfer surface, the increase in excess combustion air and the inability to raise the bed temperature above 950°C. The overall efficiency of the dust collection system was 95%, with NO_x and SO_x emissions of about 325 mg/m^3 and 480 mg/m^3 respectively.

Based on the results of the Yiyang and the Jixi boilers, and subsequent laboratory research, the research panel recommended that a number of features be considered in future bubbling-bed designs:

a) Install economizer tubes parallel to the gas flow to control erosion,
b) Increase hole velocities in the distributor and add more bubblers in the region of the coal feeder outlet,

c) Increase the bed depth, increase the horizontal spacing of the in-bed tubes, and reduce the angle of the in-bed tubes,
d) Recover heat from the hot bed material which comprises more than 50% of the total ash input,
e) Provide high-velocity, secondary air to improve turbulence in the upper zone of the bed,
f) Reduce steam load by slumping beds instead of operating all beds at part load.

COAL SLURRIES

In an effort to reduce oil consumption in steam boilers, coal/oil mixtures (COM) are being burned in many boilers originally designed for oil firing. Detailed combustion trials, with COM containing 45% weight of pulverized coal, in a 15 t/h steam boiler designed for oil have demonstrated that:

a) Ignition of COM was the same as oil,
b) Combustion efficiency decreased by only one half percent,
c) Furnace gas velocities should be limited to 22 m/s with slurries containing 5% ash to avoid erosion,
d) 30% of the COM ash was retained on the furnace bottom and required installation of an ash hopper,
e) Dust emissions of 2,6 g/m^3 exceeded Chinese emission regulations by a factor of 13 and required the installation of an electrostatic precipitator,
f) Maximum radiative heat flux valves near the side wall of the boiler at the furnace exit exceeded 24 W/cm^2 with COM and 40 W/cm^2 with oil; however, maximum values around the burner ports were reversed with the COM producing more than 4 W/cm^2 and oil producing more than 10 watts/cm^2.

Increased emphasis is now being placed on coal/water slurries (CWS) because of its potential for use directly from coal/water pipelines and for eliminating oil from the utility and industrial energy sectors. The technology for CWS is, however, still in the research and development stage.

Table 6 - Design criteria for Yiyang FBC boiler

Steam Conditions		Bed Conditions	
Load, t/h	35	Length, m	4,5
SH Press, KPa	4000	Width, m	3
SH Temp, °C	450	Height, m	1,2
Water Temp, °C	150	Sections	4
Air Preheat Temp, °C	160	Bubblers/Section	934
Flue Outlet Temp, °C	155	Feeders/Section	1
		Bed Drain/Section	1
		Dividing Wall Ht, m	0,2

Table 7 - Modified bed design criteria for Yiyang FBC boiler

Criteria	Original	Modified
Bubbler Holes		
Dia, mm	5,3	4,5
Holes/Bubbler	6	6
Cold Air Vel, m/s	0,9	0,9
Hot Air Vel, m/s	3,5	3,5
In-bed Tubes		
Number	150	48
Dia, mm	42	42
Angle, °	15	15
Area, m^2	60,2	19,7
Superheater Tubes		
High Temp Area, m^2	86,5	21,6
Low Temp Area, m^2	212	170

Table 8 - Coal specifications for Jixi FBC boiler

Analysis (As Rec'd), wt %	Original	Modified
Carbon	20,2	19,7
Hydrogen	1,5	1,5
Oxygen	4,5	2,6
Sulphur	0,1	0,1
Nitrogen	0,6	0,2
Moisture	7,0	4,1
Ash	67,2	71,7
Calorific (As Rec'd)		
LHV, MJ/Kg	6,7	7,2
Volatile (daf), wt%	25,9	35,3
Ash Fusion Temp, °C		
t_1	1500	1400

Table 9 - Design criteria for Jixi FBC boiler

Boiler Efficiency, %	73
Steam Conditions	
Load, t/h	130
Press, KPa	3800
Temp, °C	450
Bed Conditions	
Area, m x m	7,6 x 4,7
Ash Overflow Ht, m	1,2
Sections	6
Temp, °C	1000
Coal Feeders/Section	1
In-bed Tube Area, m^2	275
Superheater Area	
High Temp, m^2	328
Low Temp, m^2	449
Economizer, m^2	1863
Airpreheater, m^2	4970
Ash Overflow Port	
Area, m x m	0,5 x 0,25
Number	2

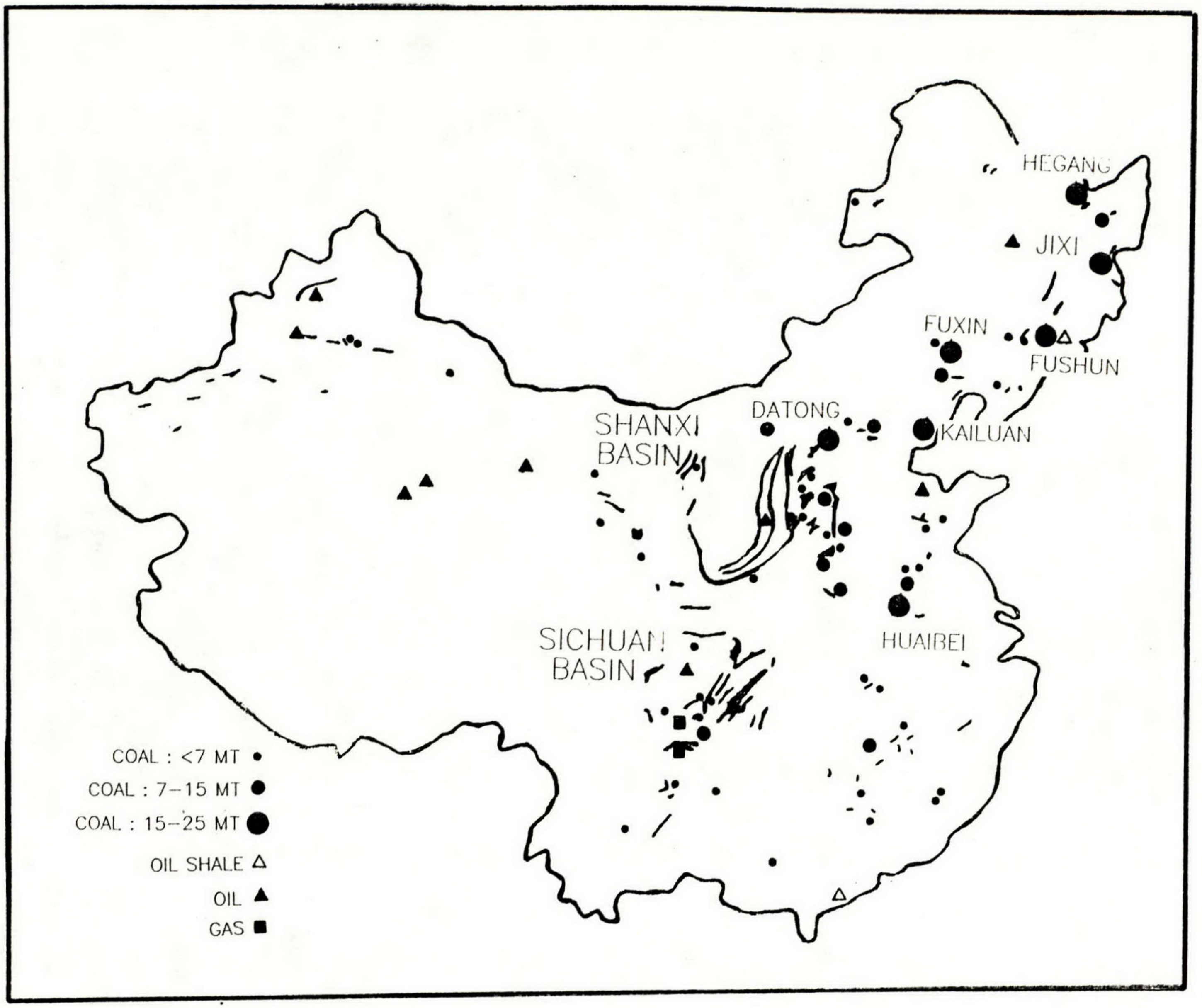


Fig. 1 - Coal resources and mines in China

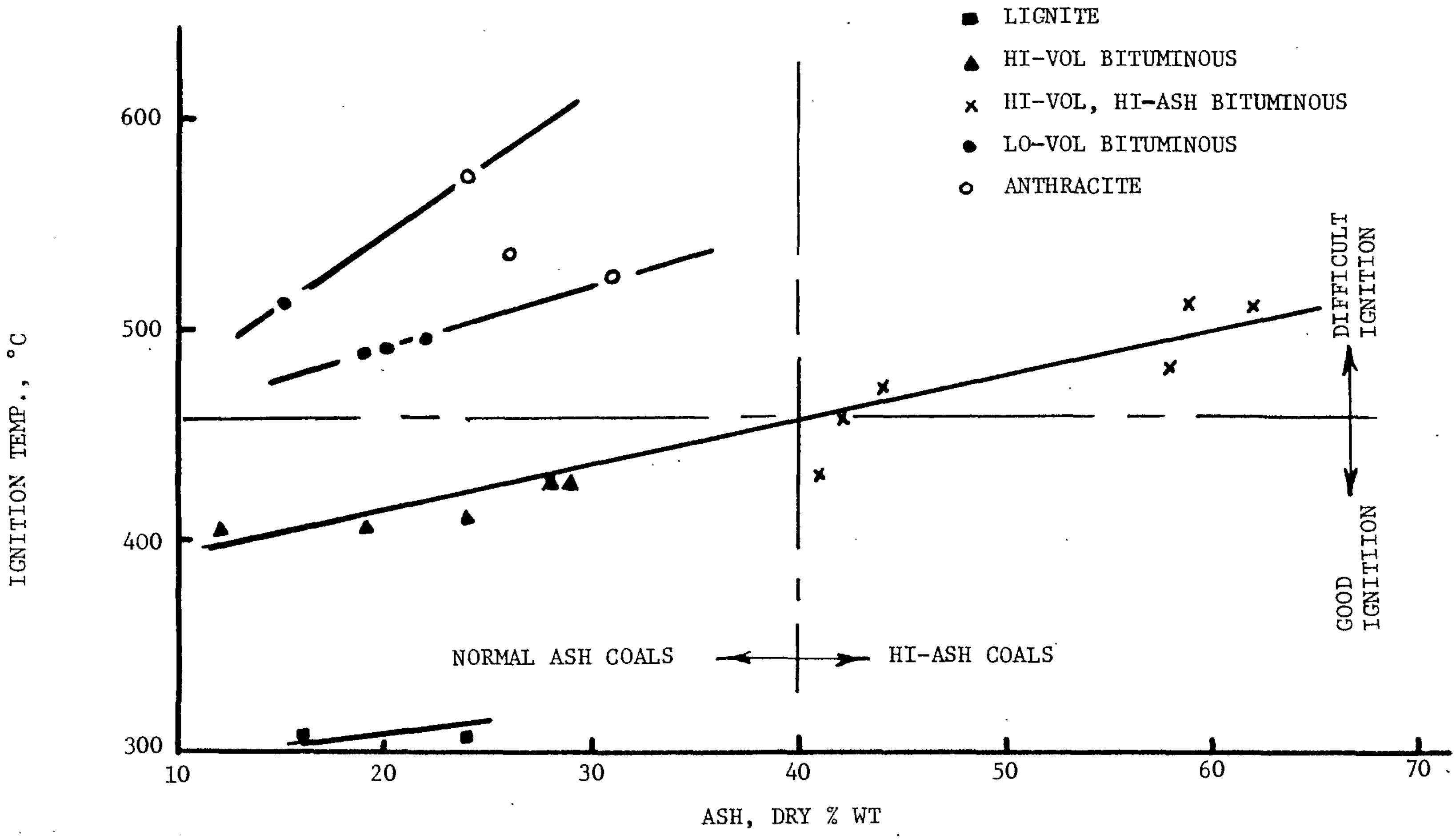


Fig. 2 - Ignition temperature variation with ash content for different coal ranks.

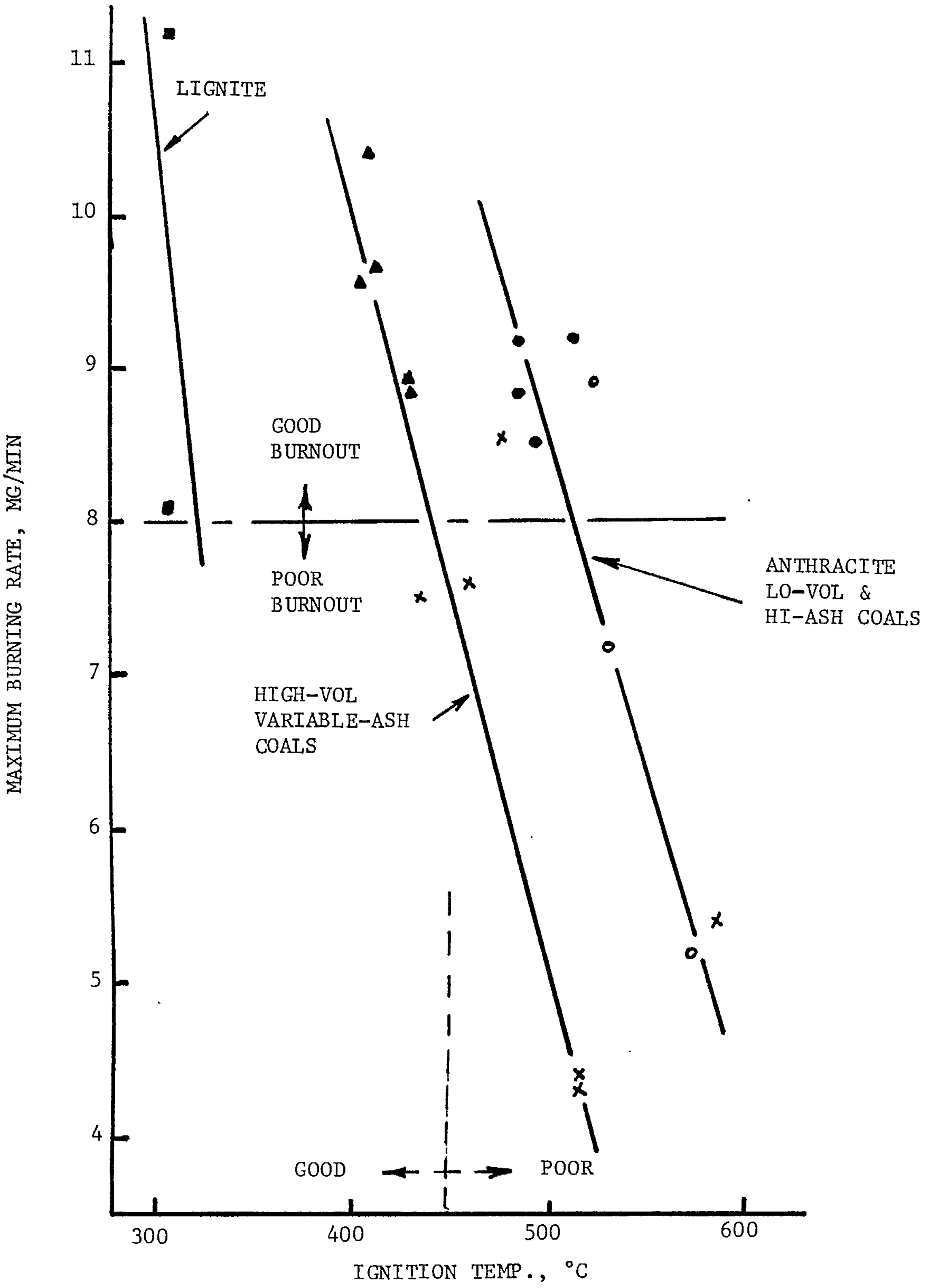
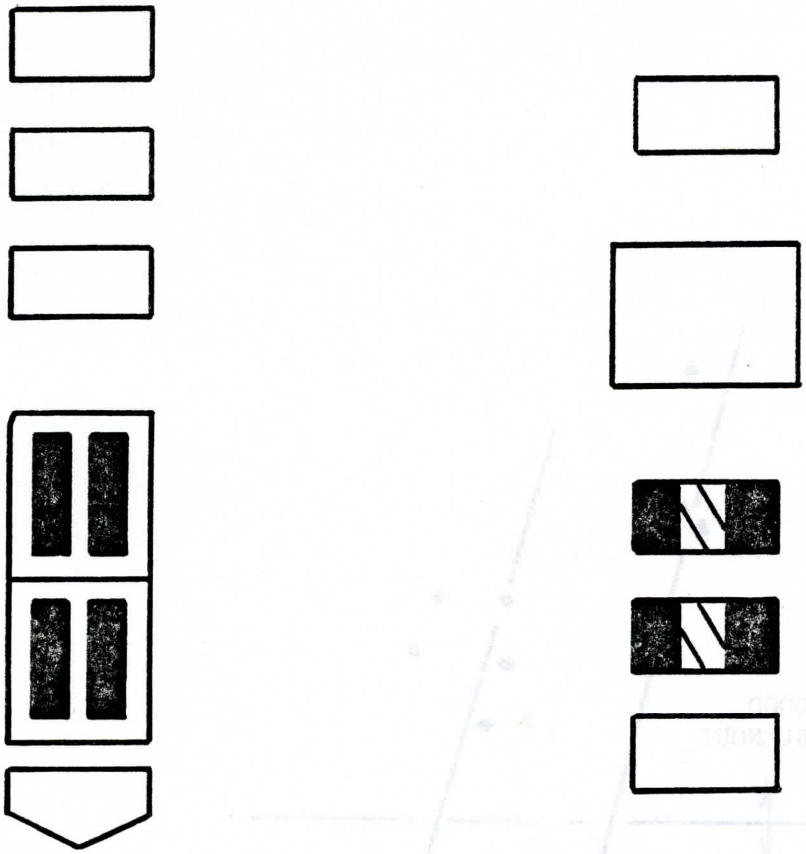
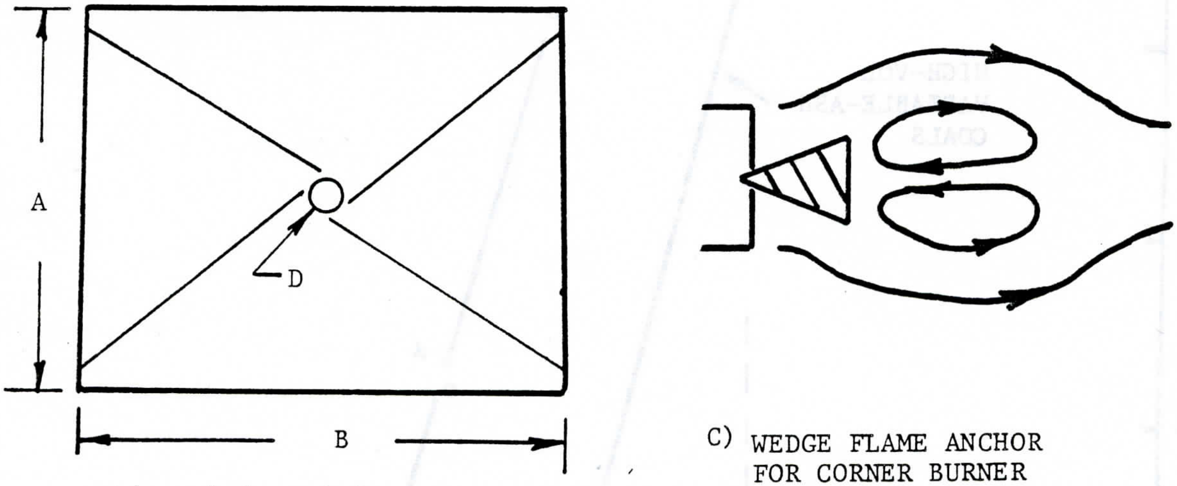


Fig. 3 - Correlation between ignition temperature and maximum burning rate for different coal ranks.



A) CORNER BURNERS FOR LOW REACTIVITY COALS



A/B = 0.8 to 1.2
D = 0.5 to 0.8 M

B) IMPINGEMENT CIRCLE
FOR CORNER-FIRING ON
LOW-REACTIVITY COALS

C) WEDGE FLAME ANCHOR
FOR CORNER BURNER

Fig. 4 - Corner burner arrays for low-reactivity coals.

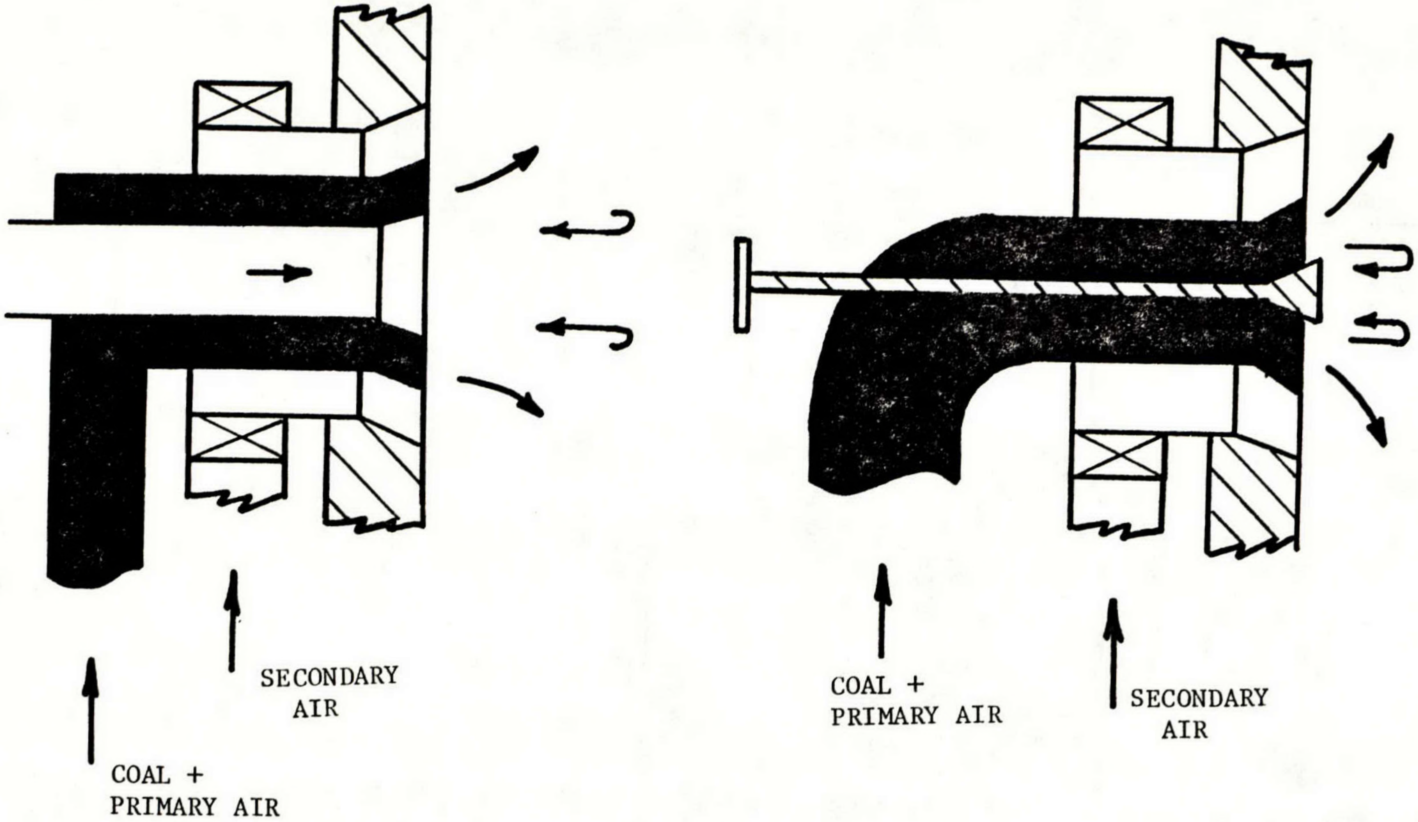


Fig. 5 - Wall burners for low-reactivity coals.

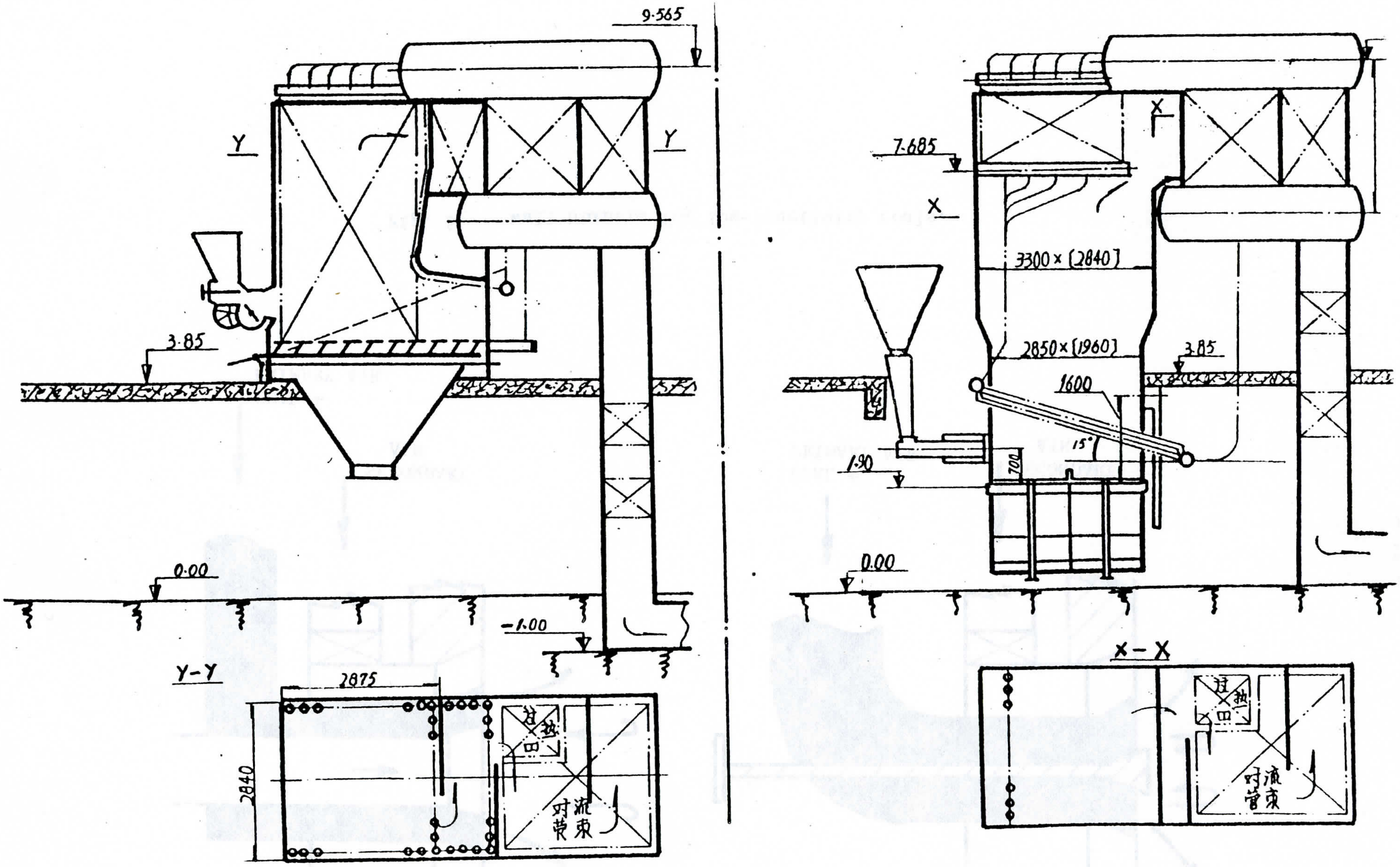


Fig. 6 - Conversion of fixed-bed stoker to fluidized-bed combustor, Sichuan.

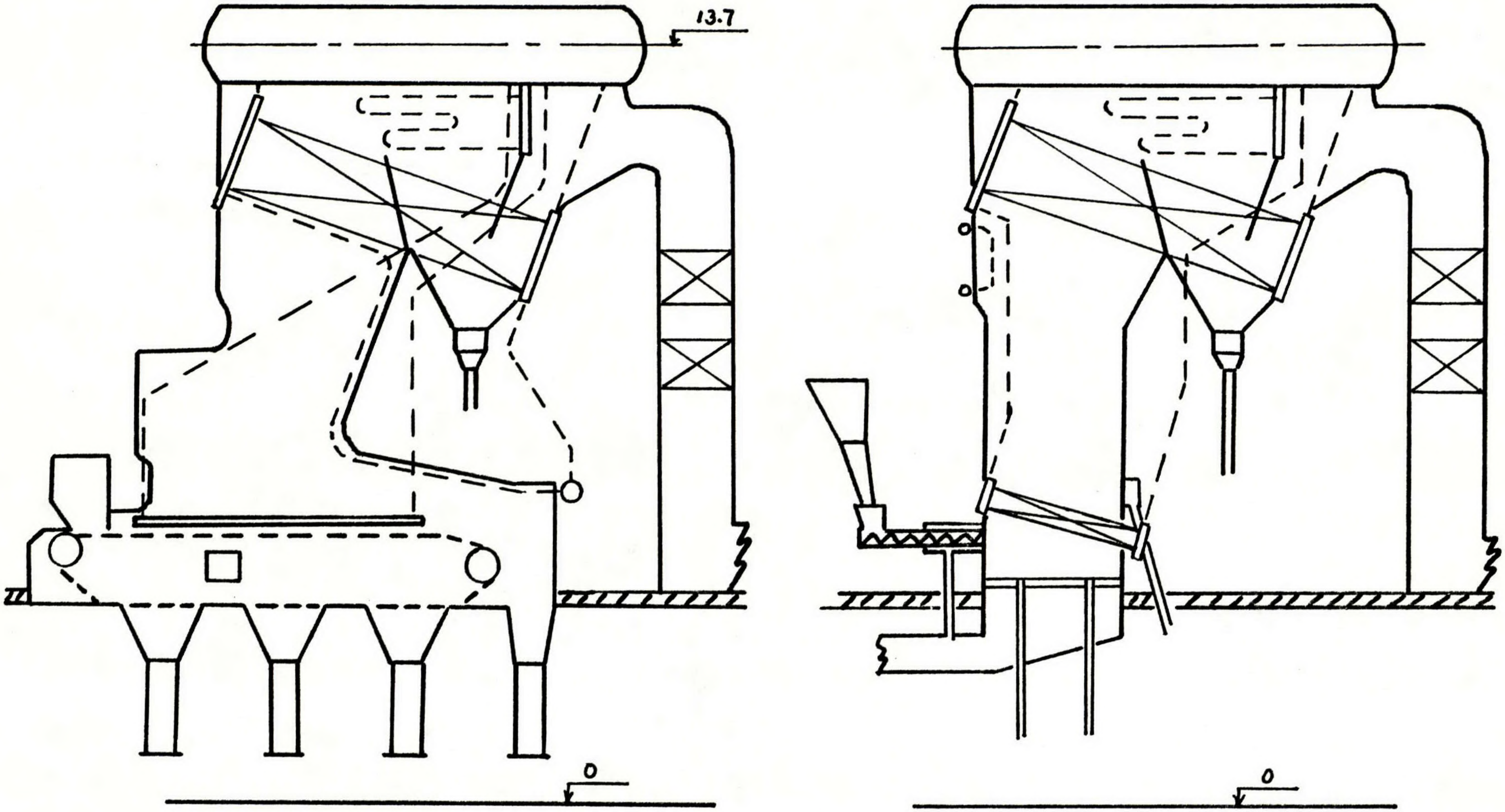


Fig. 7 - Conversion of chain-grate stoker
to fluidized-bed combustor, Sichuan.

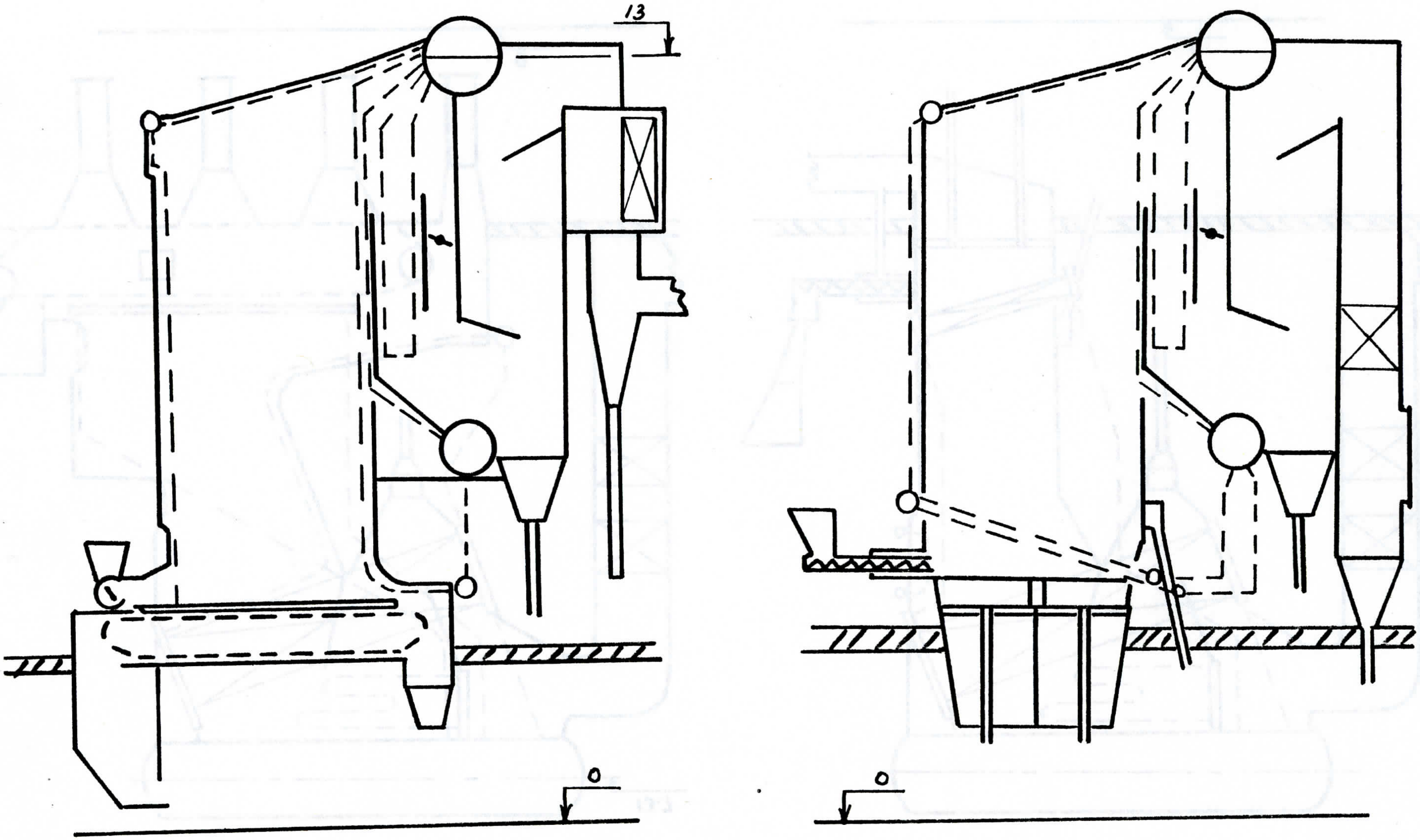


Fig. 8 - Conversion of travelling-grate stoker to fluidized-bed combustor, Sichuan.

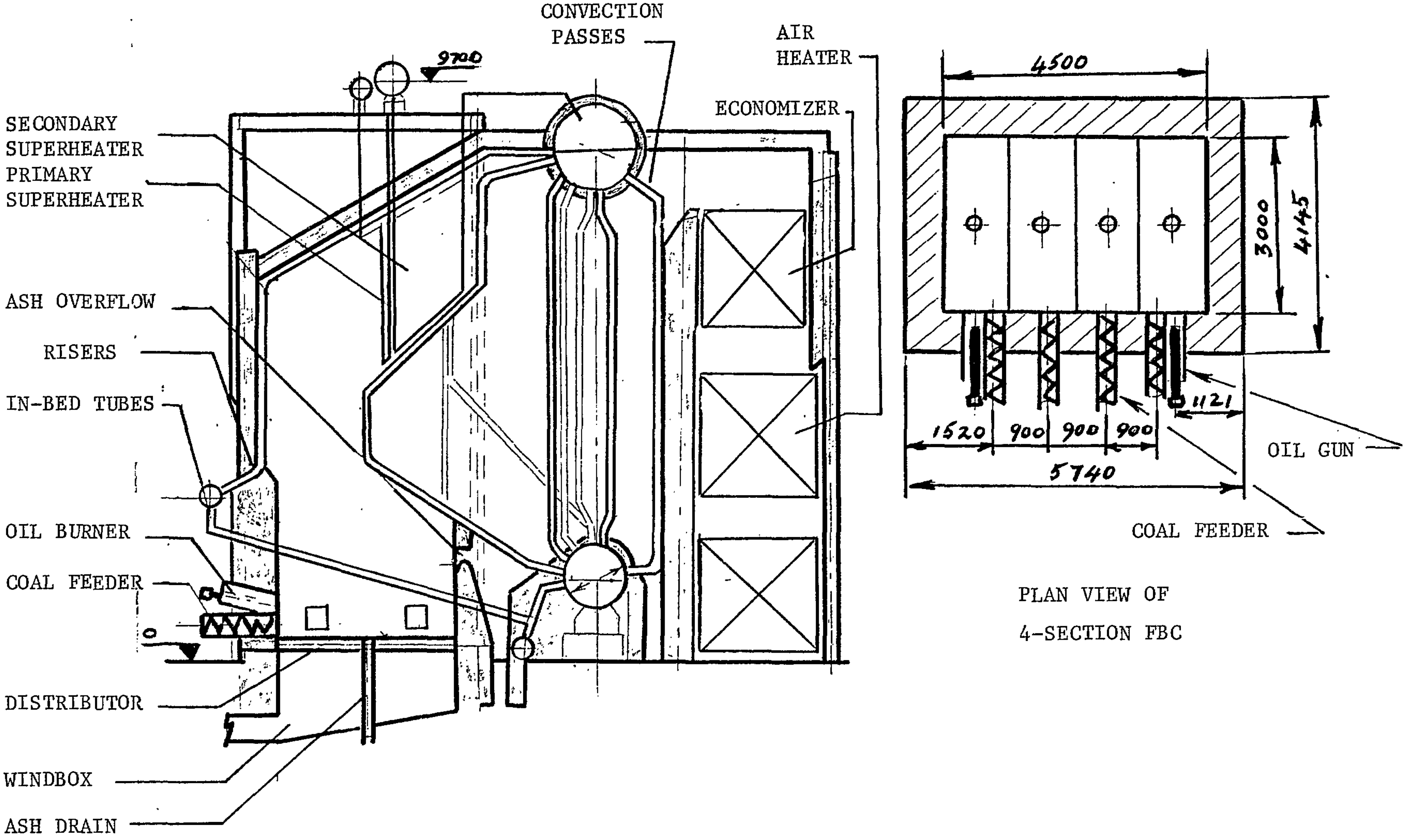
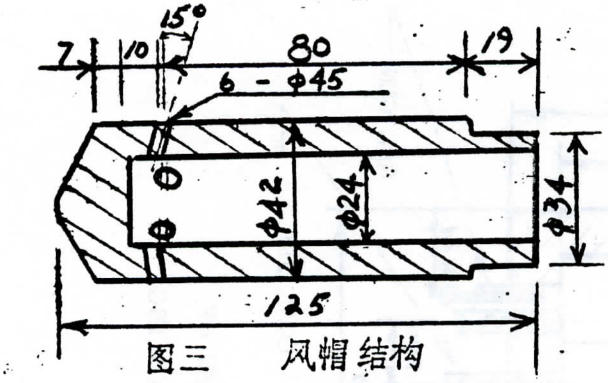
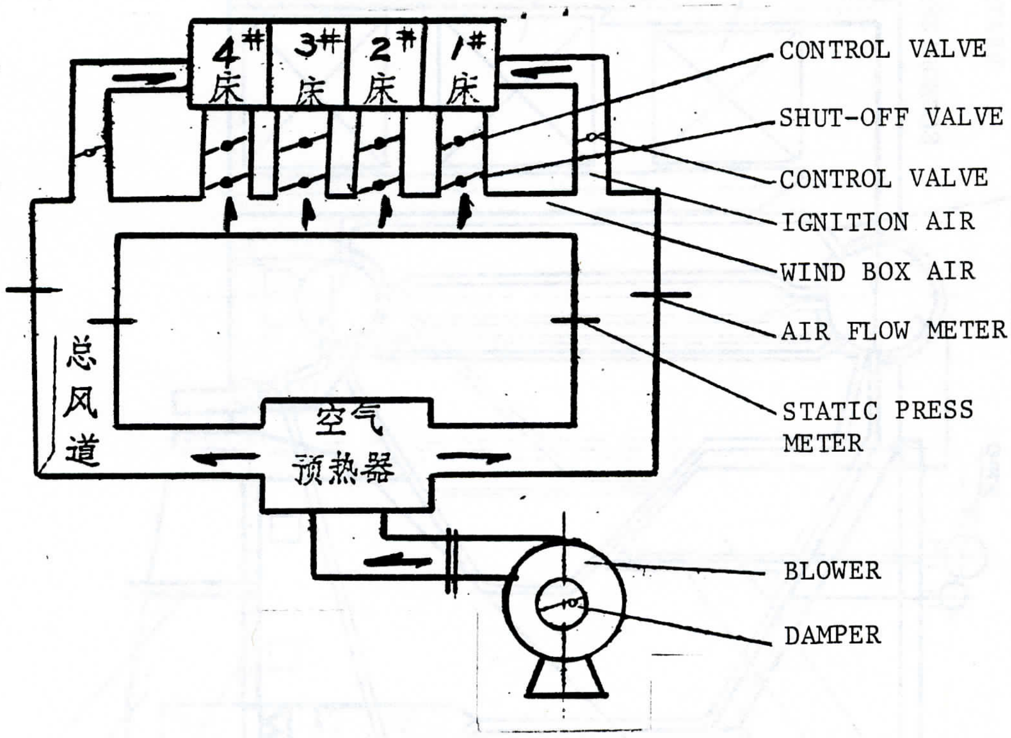


Fig. 9 - Schematic of 35t/h FBC steam boiler, Yiyang, Hunan.



a) Bubble cap design



b) Air flow circuit

Fig. 10 - Schematic of bubble cap design and air flow circuit for Yiyang FBC boiler.

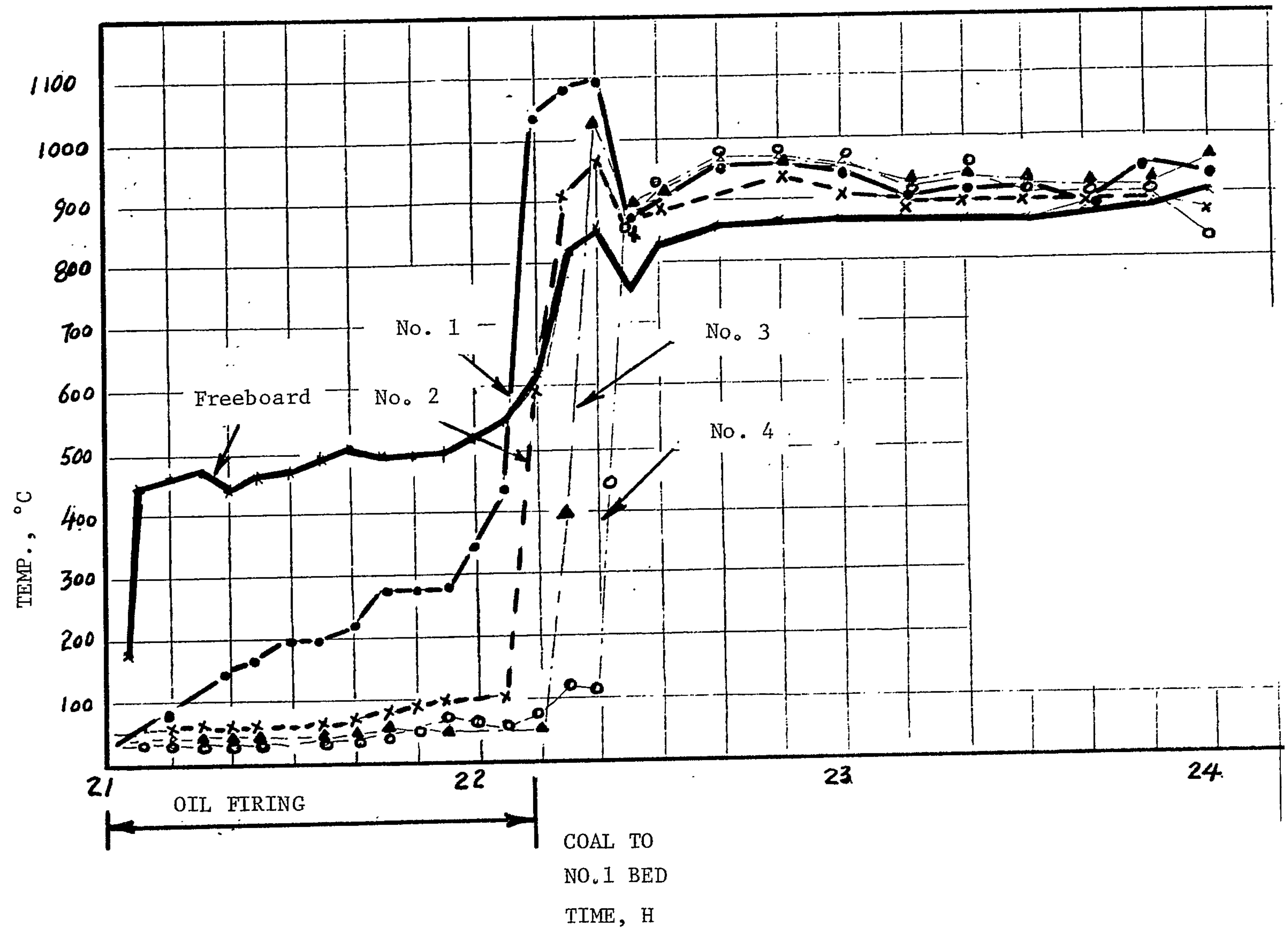


Fig. 11 - Temperature-time profile for start-up of Yiyang FBC boiler.

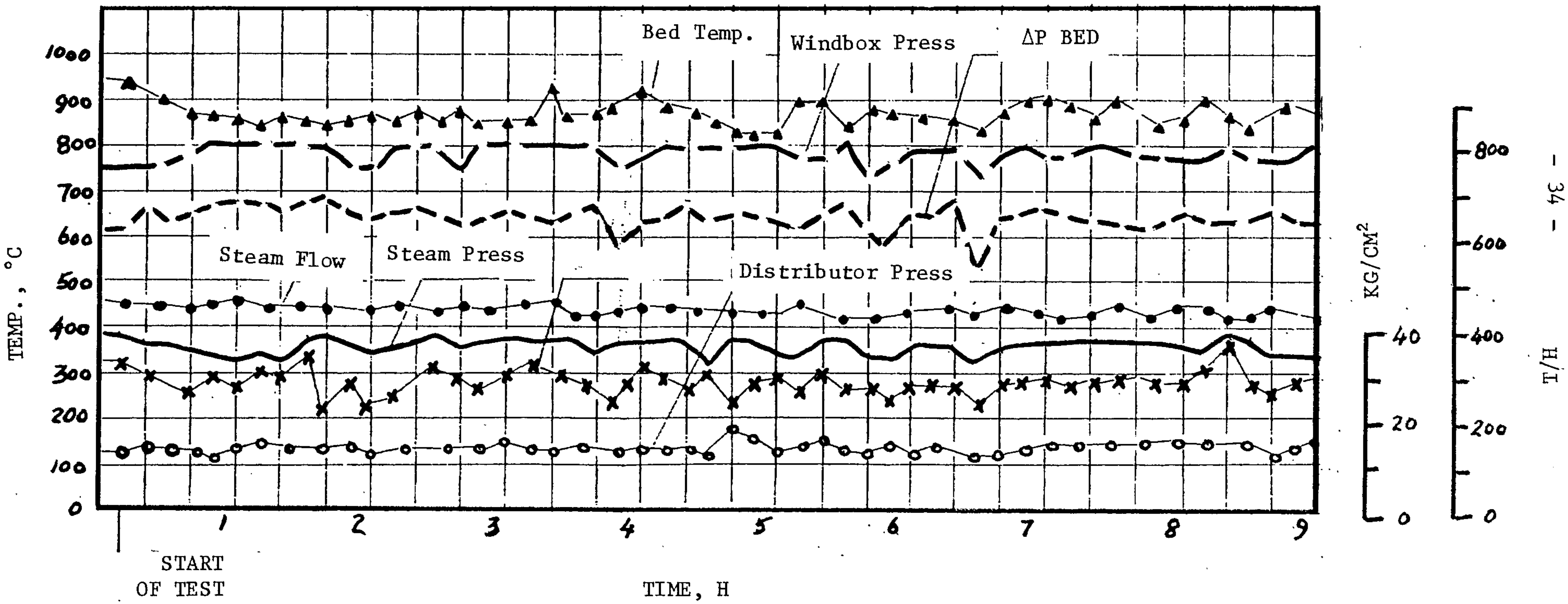


Fig. 12 - Temperature-time profile for extended combustion trial on Yiyang FBC boiler, 78-10-20.

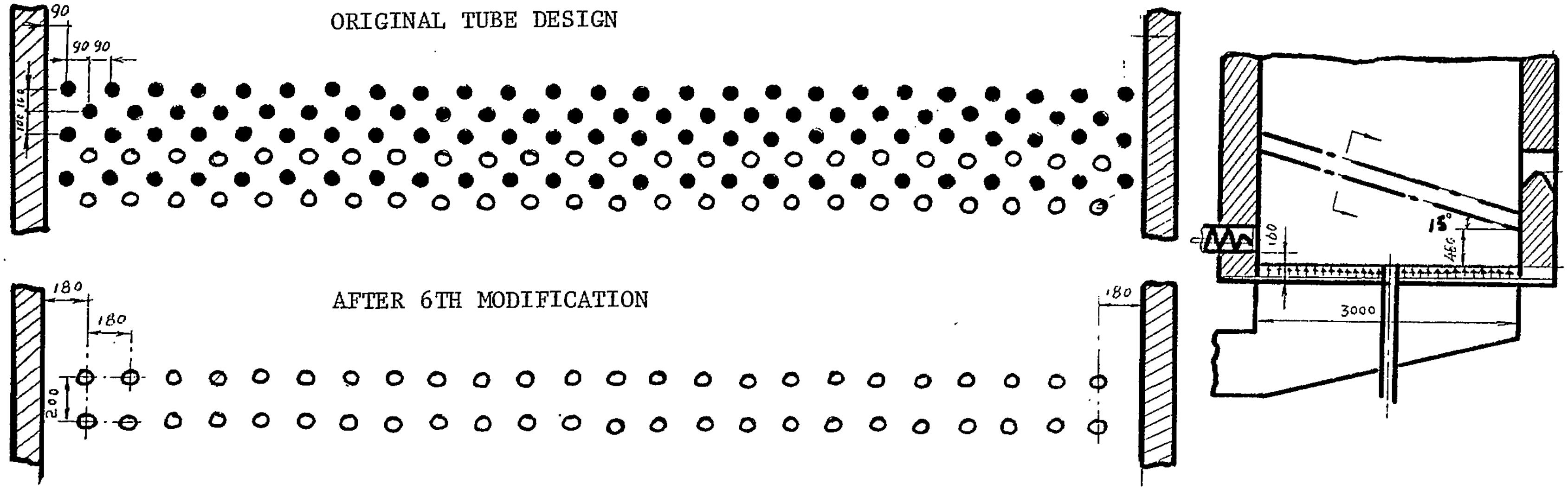


Fig. 13 - Reduction of in-bed tubes in Yiyang FBC boiler.

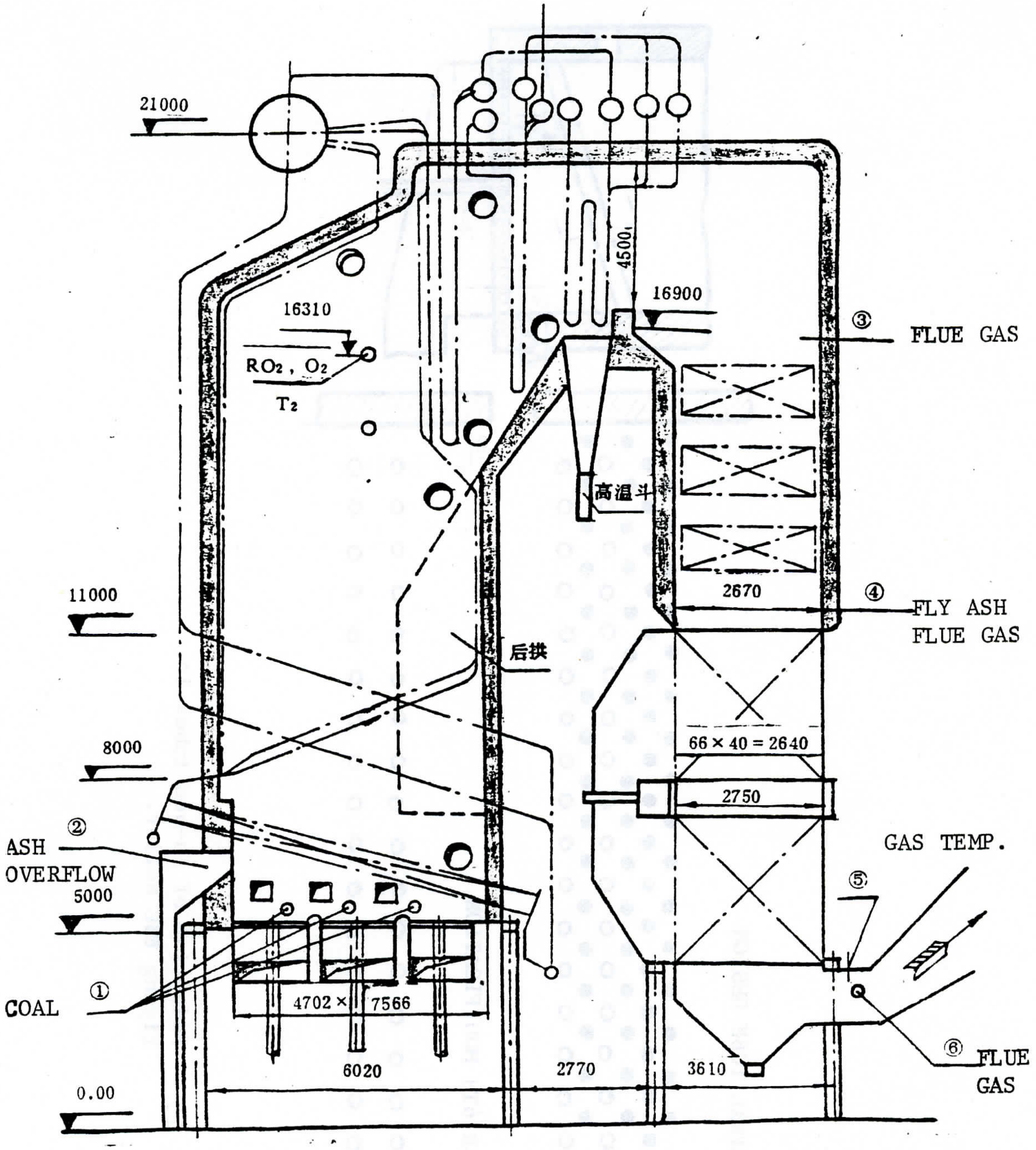


Fig. 14 - Schematic of 130t/h FBC steam boiler, Jixi, Heilongjiang.

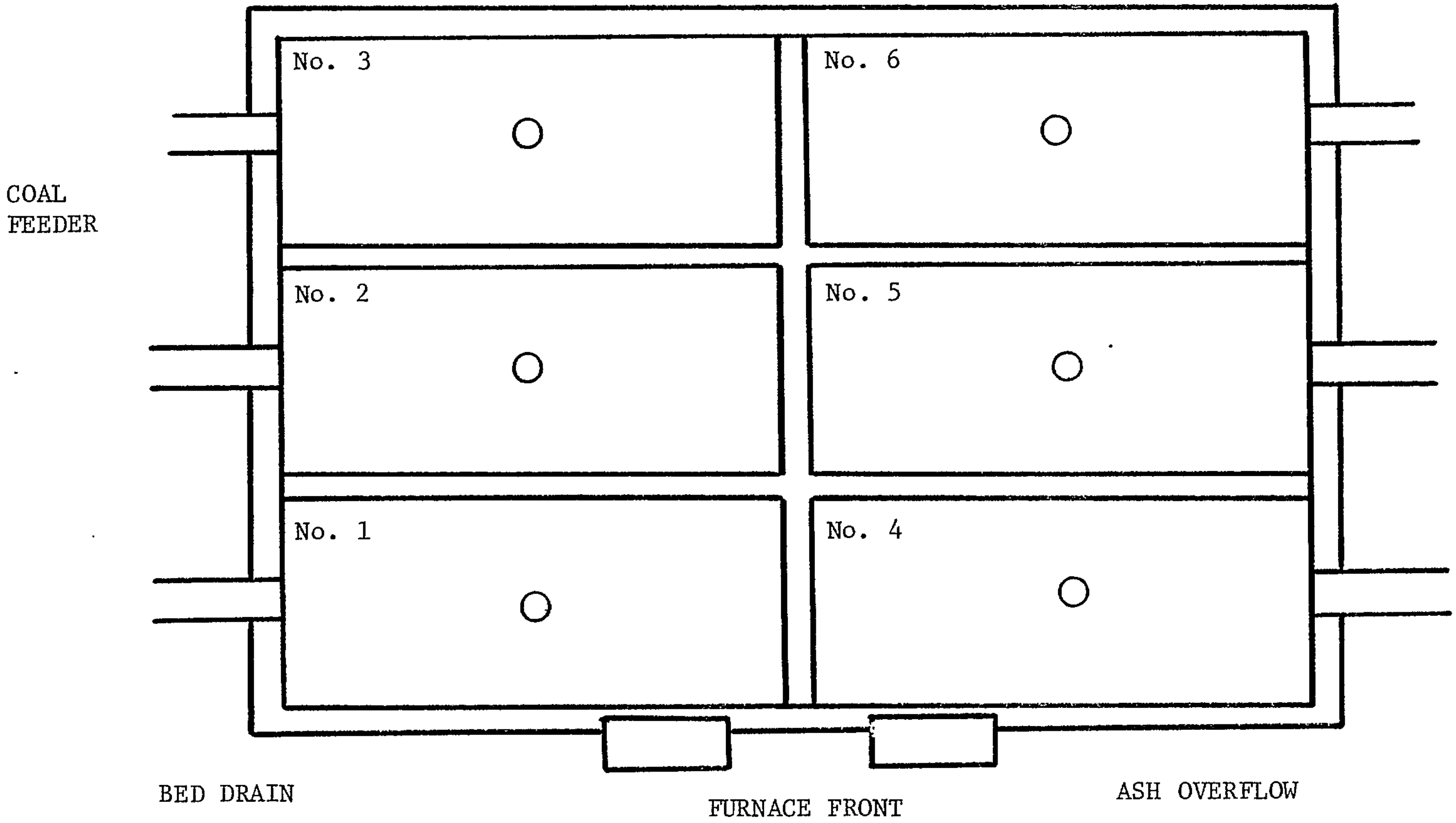


Fig. 15 - Bed layout for Jixi FBC boiler.

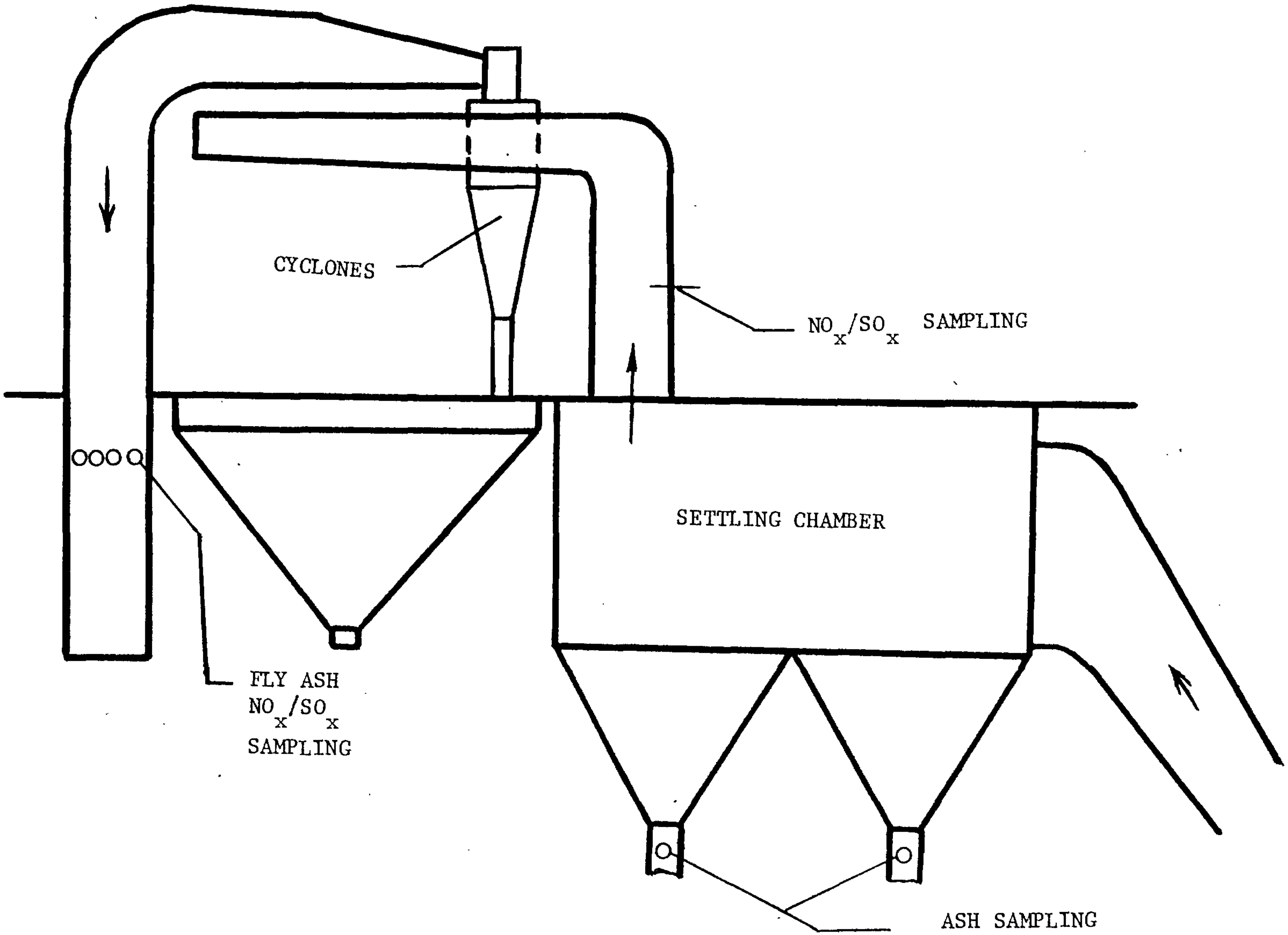


Fig. 16 - Schematic of emission monitoring and control system for the Jixi FBC boiler.

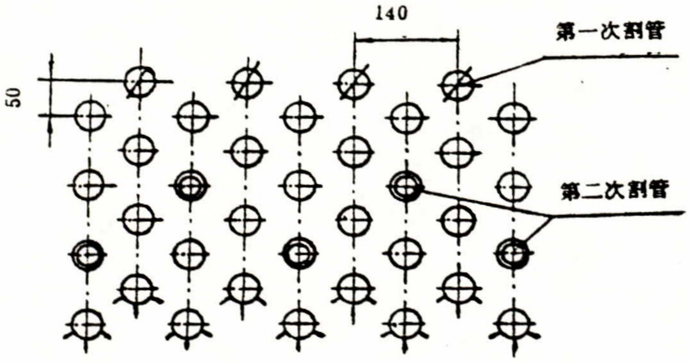


Fig. 17 - Reduction of in-bed tubes in Jixi FBC boiler.

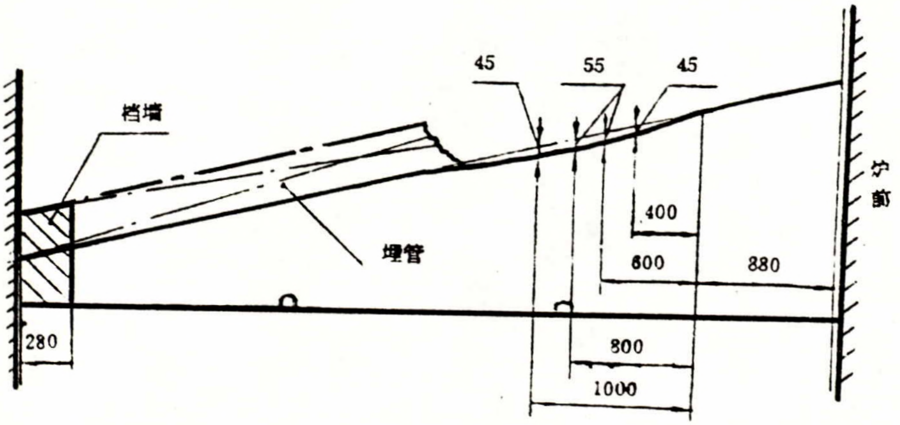


Fig. 18 - Blocking wall to reduce tube end erosion in Jixi FBC boiler.