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IMPROVING THE PERFORMANCE OF FLUIDIZED BED BOILERS AT CANADIAN FORCES BASE SUMMERSIDE

V.V. Razbin and F.D. Friedrich

Combustion and Carbonization Research Laboratory

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ERRATUM

Page 4 FLY ASH RECYCLE SYSTEMS

The second paragraph should read as follows:

The convection bank recycle system consists of two conventional pneumatic eductors supplied with medium-pressure air from a positive displacement blower. The multicyclone collector was supplied with a batch-type reinjection system consisting of a set of double gate valves and transfer hoppers discharging into the preferential bed through two reinjection ports. Transport air for this system was provided by a separate positive-displacement blower. Thus the entire reinjection system for one boiler consisted of two eductors, one double lock hopper system, two blowers, four reinjection ports, and associated piping and controls. This, too, was substantially modified, as will be described later.

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by

V.V. Razbin* and F.D. Friedrich**

ABSTRACT

Canada's first coal-fired fluidized bed boilers were installed in 1982 at the heating plant for Canadian Forces Base Summerside in the Atlantic province of Prince Edward Island as a demonstration project jointly funded by Defence Canada and Energy, Mines and Resources Canada. Foster Wheeler Ltd. of St. Catharines, Ontario was the prime contractor with responsibility for supplying a turnkey heating plant including two boilers rated at 18 tph (40 000 lb/h) of steam each. The boilers subsequently met all contractual requirements pertaining to capacity, efficiency and emissions, but some problems emerged with respect to boiler tube erosion and other aspects of boiler operability. The paper describes four areas of difficulty and how they are being resolved.

Evidence of boiler tube erosion appeared after only a few hundred hours of service and despite various preventative measures, resulted in a tube failure after 5600 h of operation. Subsequently studs were applied to the vertical membrane wall surfaces, and rods were welded longitudinally to the in-bed tubes. Since then, 4500 h of operation have been achieved, with no evidence of further tube wastage.

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* Combustion Engineer and ** Research Scientist, Combustion and Carbonizaton Research Laboratory, Energy Research Laboratories, CANMET, Energy, Mines and Resources Canada, Ottawa, Ontario, Canada.

A complex system for fly ash reinjection required an unacceptable level of maintenance, and in one instance failure of a minor component led indirectly to destruction of an induced draft fan. A much simpler, maintenance-free system was developed, based on the L-valve commonly used in circulating fluidized bed combustors.

An inter-bed transfer gate, installed to permit one bed to be ignited from the adjacent one, was often inoperative due to warping. It was found that the same function could be achieved with a smaller, permanent opening.

The capability of the boilers to fluidize cold material was limited, which led to difficulties in startup and frequent failure of the bed thermocouples. These problems were resolved by increasing the number of bubble caps in the distributor plate, and modifying the design of the thermocouple wells.

The Summerside boilers are now considered to be reliable and acceptable in all major respects. It is concluded that there are no insurmountable barriers to bubbling bed fluidized bed combustion becoming a mature, dependable technology.

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INTRODUCTION

Canada's first coal-fired fluidized bed boilers were installed in 1982 at the heating plant for Canadian Forces Base Summerside in the Atlantic province of Prince Edward Island, as a demonstration plant jointly funded by Defence Canada and Energy, Mines and Resources Canada. The installation was built as a turnkey heating plant comprising two boilers rated at 18 tph (40000 lb/h) of steam each, and all necessary ancilliaries.

The boilers subsequently have been subjected to a demonstration program which involved firing several Eastern Canadian coals which ranged up to 12% sulphur and 25% ash. In all cases they were able to meet contractual requirements pertaining to capacity, efficiency and emissions. They were also successfully operated with wood chips as supplementary fuel. However, some significant problems of reliability and operability became evident, which were addressed by substantial modifications to the equipment. The present report describes four main problems which seem to have been successfully resolved:

1) boiler tube erosion,
2) fly ash reinjection system,
3) inter-bed transfer gate, and
4) cold fluidization and bed thermocouple life.

It is concluded that the modifications made to the Summerside boilers can, in many cases, be successfully applied to other fluidized bed boilers.

DESCRIPTION OF THE FLUIDIZED BED BOILERS

DESIGN PARAMETERS

The design fuel analyses and key performance specifications upon which the Summerside boilers were tendered are given in Table 1. Two competitive designs were prepared, under contract, covering both boiler design and plant design. These were subsequently evaluated on the bases of technical merit and price, as a result of which the construction contract was awarded to Foster Wheeler Ltd. of St. Catharines, Ontario.

BOILER CONFIGURATION

A cross-section elevation of the fluidized bed boiler is shown in Fig. 1. This is an adaptation of a well proven two-drum water-tube design utilizing natural circulation throughout. The outside dimensions were held to limits that permitted the boilers to be shop-fabricated and shipped to the site by rail.

To provide the required level of turndown, the fluidized bed furnace is divided into two compartments parallel to the boiler drums by a vertical membrane wall. The bed closest to the drums is referred to as the preferential bed or Bed A. It is in use whenever the boiler is in operation and is designed to generate about 40% of MCR. It is the bed in which combustion is initiated by means of an overbed light-up burner using No. 2 fuel oil. It also receives all the wood chip fuel, and the fly ash recycled from the convection bank and the multiclone collector. Heat transfer surface in this bed is limited to the membrane walls which form it. Bed A is 1.23 m wide by 2.88 m long (approx. 4 ft x 9.5 ft).

The other bed, which is slightly larger, is called the secondary bed, or Bed B. It is fired with coal only, receives no fly ash, and in addition to the peripheral membrane walls it has 18 in-bed tubes passing through the bed zone, inclined at 30° and cooled by natural circulation. Bed B is 1.39 m wide x 2.88 m long (approx. 4.5 ft x 9.5 ft).

Both beds were initially built with the tubes and membrane walls bare, except that the in-bed tubes were alonized. This was later changed, as will be described.

Combustion air is introduced through a large number of alloy bubble caps penetrating uncooled distributor plates which form the floor of the furnace. Each of the two bed sections is supplied with air from a separately controlled plenum.

FUEL AND LIMESTONE FEED SYSTEMS

Fuel is fed onto each bed by means of a spreader stoker located in the end wall, thus the direction of throw is along the bed, parallel to the boiler drums. The stoker for Bed A has a paddle-wheel for coal, and pneumatic injection for wood chips. Since Bed B receives no wood chips, its stoker has a paddle-wheel only. Both beds are fired with coal having a top size of 25 mm (1 in.). Reduction from the delivered top size of 50 mm (2 in.)

The limestone required for sulphur capture is admitted to each bed by a drop pipe at the end of the bed remote from the coal feeder. The bed drains, on the other hand, are located at the fuel feeder ends of the bed. Hence the limestone must traverse the length of the bed to reach the discharge, thereby maximizing the residence time available for the sulphation reaction. Residue leaving the bed drains is cooled by means of water-cooled twin-screw conveyors, one per bed.

The furnace cavity is tall (approx. 8 m or 26 ft) which enhances sulphur capture, carbon burnout, and radiant heat transfer.

LIGHT-UP PROCEDURE

Light up of the boiler from cold conditions is accomplished as follows:

Bed A (Preferential Bed)

- The overbed oil burner in Bed A is fired over the slumped bed, to heat the surface material.
- Periodically the bed is fluidized for a few seconds, to mix the heated material into the bed.
- When the average bed temperature reaches 150 to 200°C (300 to 390°F) and the boiler is up to pressure, a small amount of coal is fed, and when it is thoroughly ignited, the bed is fluidized.
- As the bed temperature rises, coal feed rate is increased.
- When the bed temperature reaches 800°C (1470°F) the light-up burner is turned off.
- Bed A is brought up to normal operating level, by which time the boiler is operating at about half load.

Bed B (Secondary Bed)

- Bed B is fluidized in a cold condition, and established at a level lower than Bed A.
- In the as-built configuration, the inter-bed transfer gate, located at the bottom of the membrane wall dividing the beds, was opened. This allowed hot material from Bed A to flow by gravity into Bed B. This system was subsequently modified, as will be described later.
- As the temperature in Bed B rises, coal feed is initiated and increased, until the bed is at normal operating temperature and level.

FLY ASH RECYCLE SYSTEMS

Each boiler is equipped with two fly ash recycle systems, one handling material collected in the boiler convection bank, the other handling material trapped by a multiclone collector located between the convection bank and the economizer. Both systems reinject the fly ash into Bed A of the fluidized bed combustor, a short distance above the air distributor plate.

The convection bank recycle system consists of two conventional pneumatic eductors supplied with medium-pressure air from a positive displacement blower. The multiclone collector was supplied with a batch-type reinjection system consisting of two sets of double gate valves and transfer hoppers, each set terminating in one reinjection port. Transport air for both sets was provided by a single positive-displacement blower. Thus the entire reinjection system for one boiler consisted of two eductors, two double lock hopper systems, two blowers, four reinjection ports, and associated piping and controls. This, too, was substantially modified, as will be described later.

PARTICULATE REMOVAL AND ASH HANDLING SYSTEM

To achieve the required level of particulate removal, each boiler is equipped with a baghouse, located downstream from the economizer. There is no provision for recycle of the baghouse ash; it is pneumatically transported directly to the ash silo, as is the bed residue from the bed drain coolers. The composite residue from the ash silo is transported to the disposal site by means of an enclosed truck.

A more detailed description of the CFB Summerside plant has been published previously.*

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* Taylor, M.E.D. and Friedrich, F.D. "The CFB Summerside Project, Canadian State-of-the-art in FBC Boilers"
Division Report ERP/ERL 82-10(TR), Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources Canada 555 Booth St., Ottawa, Ontario, K1A 0G1, April 1982.

BOILER TUBE EROSION

BACKGROUND

In March 1983, when the boilers had logged about 600 h of operation, the contractor conducted an inspection of the furnace and observed polishing on the membrane wall tubes at a height of about 760 mm (30 in.) above the distributor plate. To prevent further wastage a belt of refractory 38 mm (1.5 in.) thick was installed around the circumference of each bed in both boilers, beginning at 530 mm (21 in.) above the distributor plate and extending upward 635 mm (24 in.), as shown in Fig. 2. An immediate negative effect of the refractory was a reduction in heat transfer; to maintain the desired bed temperature of 850°C (1550°F) it was necessary to increase the excess air level to the 80-90% range.

After a further 1000 h of operation, significant wastage of the membrane wall tubes below the refractory became evident. To counteract this, the contractor installed four rows of scalloped bars, which were welded to the fins between the tubes, angling downward at 45°, as shown in Fig. 2. Inspection after another 2000 h of operation revealed that:

- there was further polishing of the membrane wall tubes between the scalloped bars,
- a few sections of the scalloped bars had broken away,
- most of the protective alonized layer on the in-bed tubes in Bed B had spalled off, and
- there was some metal wastage of the in-bed tubes, particularly on the underside of the lower bend.

It should be noted that the secondary beds typically were operated only half as much as the preferential beds, thus at that time they had accumulated about 1800 h of operation. However, since the original wall thickness of the in-bed tubes was 7.5 mm (0.30 in.), there appeared to be an ample margin of safety, and the boilers were put back into service.

In February 1985, when Boiler No. 2 had logged 5600 h of operation, one membrane wall tube in Bed A ruptured at an exposed bend below the ignitor. Detailed inspection revealed that there were several other areas on the membrane walls, above and below the refractory, where tube thickness was less than 2.28 mm (0.090 in.) compared with the original thickness of 4.45 mm (0.176 in.). The in-bed tubes in Bed B also showed significant wastage; in localized areas wall thickness was reduced to 1.5 mm (0.060 in.) from the original 7.5 mm (0.30 in.). Undoubtedly a contributing factor to the high wastage rate was the high excess air level, which not only increased fluidizing velocities, but elutriation rate and therefore fly ash reinjection rate.

RECENT MODIFICATIONS

During the 1985 summer shutdown, after consultation with the operating personnel of the fluidized bed boilers at Georgetown University and Idaho Falls, which are of similar design, the following modifications were made to both of the Summerside boilers:

- all of the scalloped bars were removed,
- the protective refractory was removed from Bed A, but not from Bed B, because of inadequate access,
- pin studs were spot-welded to all exposed membrane wall tubes from the level of the distributor plate to a height of 1525 mm (60 in) The studs, 9.5 mm (0.375 in.) in diameter and 19 mm (0.75 in.) long were closely spaced, vertically oriented alternatively at 10, 12 and 2 o'clock or 11 and 1 o'clock, as shown in Fig. 3.
- to protect the in-bed tubes, carbon steel rods, 9.5 mm (0.375 in.) in diameter were welded to them longitudinally at the 1,4,6,8 and 11 o'clock positions, as shown in Fig. 4. The rods were welded continuously on both sides to ensure good heat transfer. At a few locations, the tubes were so thinned by erosion that they burned through during welding, and localized repairs were required.

RESULTS

Boiler No. 2 resumed service in September 1985. It was found that replacement of the refractory with the pin studs substantially improved heat transfer, as evidenced by an increase of almost 50% in boiler capacity, and a reduction in excess air to the 50-60% range. An inspection after 2500 h of operation revealed that none of the tube surfaces showed any signs of polishing; instead they were covered with a thin, black carbonaceous deposit. Some of the studs had rounded tips whereas others were capped with a partially sintered deposit of ash. Substantial quantities of gravel-sized shale particles were trapped between the studs in a band 380 to 890 mm (15 to 35 in.) above the distributor plate. The in-bed tubes likewise revealed no wastage beyond some polishing of the protective rods.

Another inspection in March 1986, after a further 2000 h of operation, showed conditions to be substantially similar.

FLY ASH REINJECTION SYSTEM

BACKGROUND

The two fly ash reinjection systems with which each boiler was originally equipped have already been described. Of these, the double lock hopper system serving the multiclone collector has required excessive maintenance, in that the lock hopper gates and their drive mechanisms had to be replaced or repaired several times because of erosion.

Furthermore, in Boiler No. 1, during the 1984/85 heating season, a solenoid valve in the vent line from one of the lock hoppers failed due to erosion, with the result that the vent line was subjected to a high-velocity flow of fly ash whenever that lock hopper was being discharged. The vent line terminated in the flue gas breeching upstream of the baghouse. Since several bags were broken, coarse fly ash penetrated to the induced draft fan, and caused sufficient erosion damage to the fan casing and impeller that both had to be replaced in the summer of 1985.

A further problem was that the noise level from the two reinjection blowers was over 100 dBa, which contributed to an unsatisfactory plant environment.

RECENT MODIFICATIONS

In the summer of 1985, the fly ash reinjection system serving the multiclone collector on Boiler No. 2 was replaced with a much simpler system employing a modified L-valve such as is commonly applied to a circulating fluidized bed combustor. The new system consists of two pipes 150 mm (6 in.) in diameter, each connecting one of the multiclone hoppers to one of the reinjection ports in the furnace wall. The pipes have a "Z" section at the lower end, as shown in Fig. 5, to form a seal against the static pressure of the fluidized bed. Fly ash flows by gravity from the multiclone hopper down the inclined pipe, is lifted over the "Z" section by small amounts of air injected at the lower elbow, and is then injected into the bed by an air nozzle located in the reinjection port. Thus, except for the reinjection nozzles the entire system operates at low velocity, with minimal potential for erosion.

Since the flow of air through the injection ports is relatively small, it is supplied from the positive displacement blower serving the convection bank reinjection system, and the blower which formerly served the double lock hopper system is no longer required.

RESULTS

At the onset of the 1985/86 heating season, it was quickly demonstrated that the new system performs well in every respect. Upon failure of the air supply it is self-sealing, and subsequently can be restarted without difficulty. Similarly, on a few occasions the boiler was operated on Bed B only, which meant that fly ash recycle had to be interrupted until Bed A was put back in service. That situation, too, was handled without difficulty. The reinjection nozzles were inspected after 2500 h and 4500 h of operation, and showed no signs of erosion.

In November 1985 the same system was installed on Boiler No. 1, and subsequently the double lock hopper systems have been dismantled. The elimination of one recirculation blower per boiler has reduced the noise level in the plant.

INTER-BED TRANSFER GATE

BACKGROUND

As already explained, the boilers were originally equipped with an inter-bed transfer gate in the membrane wall separating Beds A and B. As shown in Fig. 6, it consisted of a steel plate sliding in a simple track, operated by means of a shaft extending through the stoker end of the combustor wall. Its function was to accomplish light up of Bed B by permitting a flow of hot material from Bed A, and it was intended to be closed when either or both beds were in normal operation.

Since the gate and shaft were uncooled, substantial warping occurred, with the result that the gate was often inoperable, and Bed B could not always be brought into service when required. Furthermore, the membrane wall tubes along its path of travel could not be protected against erosion.

RECENT MODIFICATIONS

At times when the gate could not be closed, it was observed that with Bed A in operation and Bed B slumped, the opening sealed itself with a buildup of slumped material in Bed B. It was therefore decided to remove the gate and leave a smaller, permanent opening. This was accomplished by welding in a steel plate and protecting it with refractory on both sides, as shown in Fig. 6. Also, studs were applied to the previously unprotected membrane wall tubes.

Some experimentation was required to establish an optimum size for the opening. Occasionally crusting of the slumped material occurred, and prevented a free transfer of material when Bed B was subsequently fluidized. This was overcome by installing two compressed air jets in the opening, pointing from Bed A to Bed B.

RESULTS

The permanent opening has permitted trouble-free operation throughout the 1985/86 heating season. Bed B can be slumped at a low level while Bed A is operating at normal level. Ignition of Bed B is accomplished quickly and reliably when it is fluidized. The air jets were used only on a few occasions when the difference in height between the two beds was insufficient to cause the desired flow from Bed A to Bed B.

One minor disadvantage of the permanent opening is that the two beds cannot be in operation at different levels.

BUBBLE CAPS AND BED THERMOCOUPLES

BACKGROUND

The boilers were built with about 40% fewer bubble caps in Bed A than in Bed B, presumably because substantial quantities of air are introduced via the fly ash reinjection systems. Startup was difficult, because under cold conditions only a thin bed of double-screened limestone could be fluidized. Only as this was gradually heated by means of the overbed burner, periodic fluidization, and combustion of coal on the bed surface, and therefore fluidizing velocity increased due to temperature, was it possible to achieve true fluidization. Then the bed level had to be gradually built up to the normal level before ignition of Bed B could be initiated.

A consequence of the low bed level during the light-up procedure was that the bed thermocouples were exposed to the high temperatures generated by the ignition burner and the surface fire, and therefore failed frequently. Often there were one or two thermocouple failures during the light-up process. Thermocouple failure was also common due to erosion caused by impingement of air jets from the bubble caps on the base of the thermocouple well, as shown in Fig. 7.

RECENT MODIFICATIONS

During the 1985 summer shutdown, 75% more bubble caps were installed in Bed A of each boiler. Furthermore, in all beds, those bubble caps pointed at the thermocouple wells were plugged. Similarly, bubble caps around the periphery of each bed were rotated to ensure that no jets impinged on the membrane wall tubes. Finally the thermocouple wells were modified as shown in Fig. 7, by making them of heavier material, putting a protective sleeve around the base, and drilling a small hole below the upper thermocouple junction, which permits a small flow of cooling air from the plenum.

Another modification was extension of the forced draft fan inlet ducts to near the ceiling of the building, thus supplying the forced draft fans with warmer air.

RESULTS

The reduced pressure drop across the distributor plate of Bed A has made it possible to fluidize a cold slumped bed 610 mm (24 in.) in depth. Boiler startup is easier, more reliable, and quicker (typically 30 min. from the first introduction of coal to the full capacity of Bed A). More important, it is now possible to use a less expensive, single-screened limestone, 6 mm (0.25 in.) x 0 size, instead of double-screened limestone. There have been no thermocouple failures since the start of the 1985/86 heating season, and drawing the combustion air supply from the top of the building has resulted in an improved plant environment.

CONCLUSIONS

It appears that studding offers a satisfactory means of erosion protection for heat exchange surfaces exposed to the bed and splash zone, at least for vertically-oriented surfaces. Studding also offers substantial advantages in terms of heat transfer over the alternative of a refractory coating. Although more operating time is needed before unequivocal conclusions can be drawn, it is most encouraging that since the studs were applied to the Summerside boilers, one of them has operated 4500 h without any apparent wastage of the waterwall surfaces. Protecting the in-bed tubes by welding longitudinal rods to them has also given encouraging results, but because these tubes have subsequently had fewer hours of service than the membrane walls in Bed A, a longer time will be required for assessment. It should be observed that as long as the tubes or waterwalls are protected from wastage, the rods and studs can be replaced periodically at modest cost.

Fly ash reinjection into fluidized bed combustors can be accomplished by a simple, trouble-free system that has no moving parts. Its application to the Summerside boilers was made easy by a particularly fortuitous equipment layout in that the hoppers of the multiclone collectors are well above the level of the bed and there were no major impediments to straight runs of pipe. Other boiler configurations might require an intermediate fly ash storage hopper fed by a conveyor from the fly ash collector.

In boilers of a design similar to those at Summerside the function of the inter-bed transfer gate can be accomplished by a permanent opening. This is perhaps not a surprising conclusion, since other designs of fluidized bed combustors have successfully achieved turndown by slumping portions of the same bed.

The improvements in operability achieved by increasing the number of bubble caps in the distributor plate and by modifying the design of the thermocouple wells simply indicate the benefits to be gained by evolving designs on the basis of experience.

In summary, the Summerside fluidized bed boilers have been brought to a state of reliability that compares well with any coal-fired boiler. In terms of emission control and fuel flexibility they surpass conventional coal-burning technology. Whereas tube erosion has been perceived as a major problem with bubbling bed fluidized bed combustors, it appears that this can be overcome at reasonable cost, and boilers of this type are rapidly approaching the status of established technology.

TABLE 1. DESIGN FUEL ANALYSES AND KEY PERFORMANCE SPECIFICATIONS

FUEL SPECIFICATIONS

	COAL		WOOD CHIPS	
	DRY BASIS	RANGE	DRY BASIS	RANGE
Ultimate Analysis				
Carbon ....%	64.2	-	49.5	-
Hydrogen ....%	4.0	-	6.0	-
Oxygen ....%	5.5	-	42.0	-
Sulphur ....%	1.0	5-6	0.0	-
Nitrogen ....%	6.0	-	1.0	-
Ash ....%	19.3	16-22	1.5	0.5-3.0
Moisture ....%	0.0	0-10	0.0	30-60
Calorific Value				
MJ/kg, gross	26.7	23.2-27.7	20.8	8.1-14.2 (as fired)
Btu/lb, gross	11500	9970-11900	8700	3480-6090
Size Consist	50 mm (2 in.) x 0 with a maximum of 20% less than 0.6 mm (28 mesh)		25 mm (1 in.) x 0 but including twigs up to 50 cm (20 in.) long	

BOILER SPECIFICATION

Maximum continuous rating (MCR):	18 000 kg/h (40 000 lb/h)
Minimum continuous efficient capacity:	4000 kg/h (9000 lb/h)
Steam condition	99.9%, dry and saturated
Steam pressure	760 to 950 kPa (110 to 140 psig)
Feedwater temperature	165°C (221°F)
Efficiency	80% min. at MCR, based on design coal at 5% moisture
Maximum stack temperature	175°C (350°F)
Fuel flexibility	30% of heat input from wood chips at any load.

ALLOWABLE EMISSIONS

SO_2	2.96 kg/10^6 kcal heat input (1.64 lb/10^6 Btu heat input)
Particulates	0.36 kg/10^6 kcal heat input (0.20 lb/10^6 Btu heat input)
Opacity	Not to exceed 5%

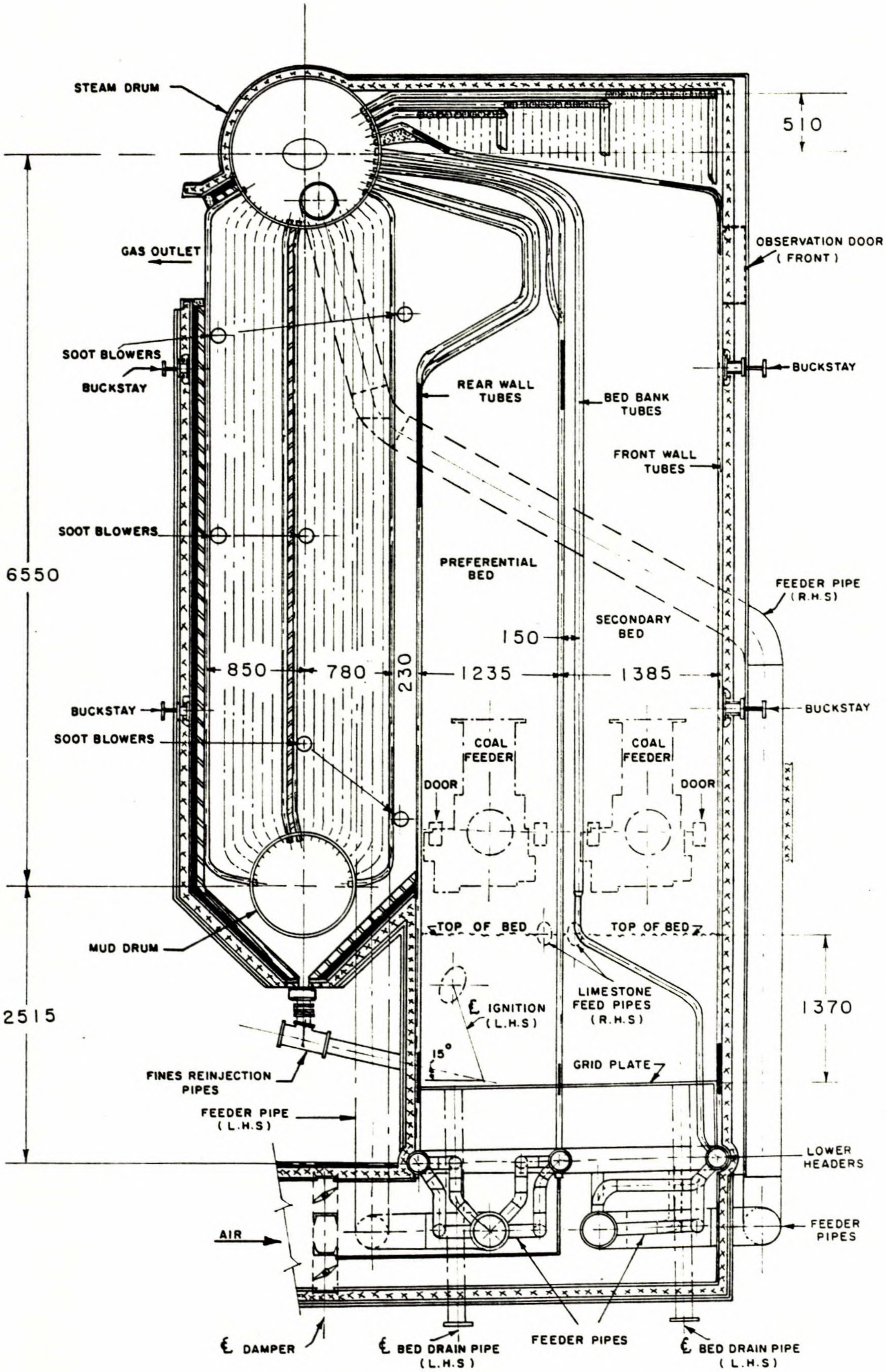

Fig.1 – Cross–sectional elevation of fluidized bed boiler

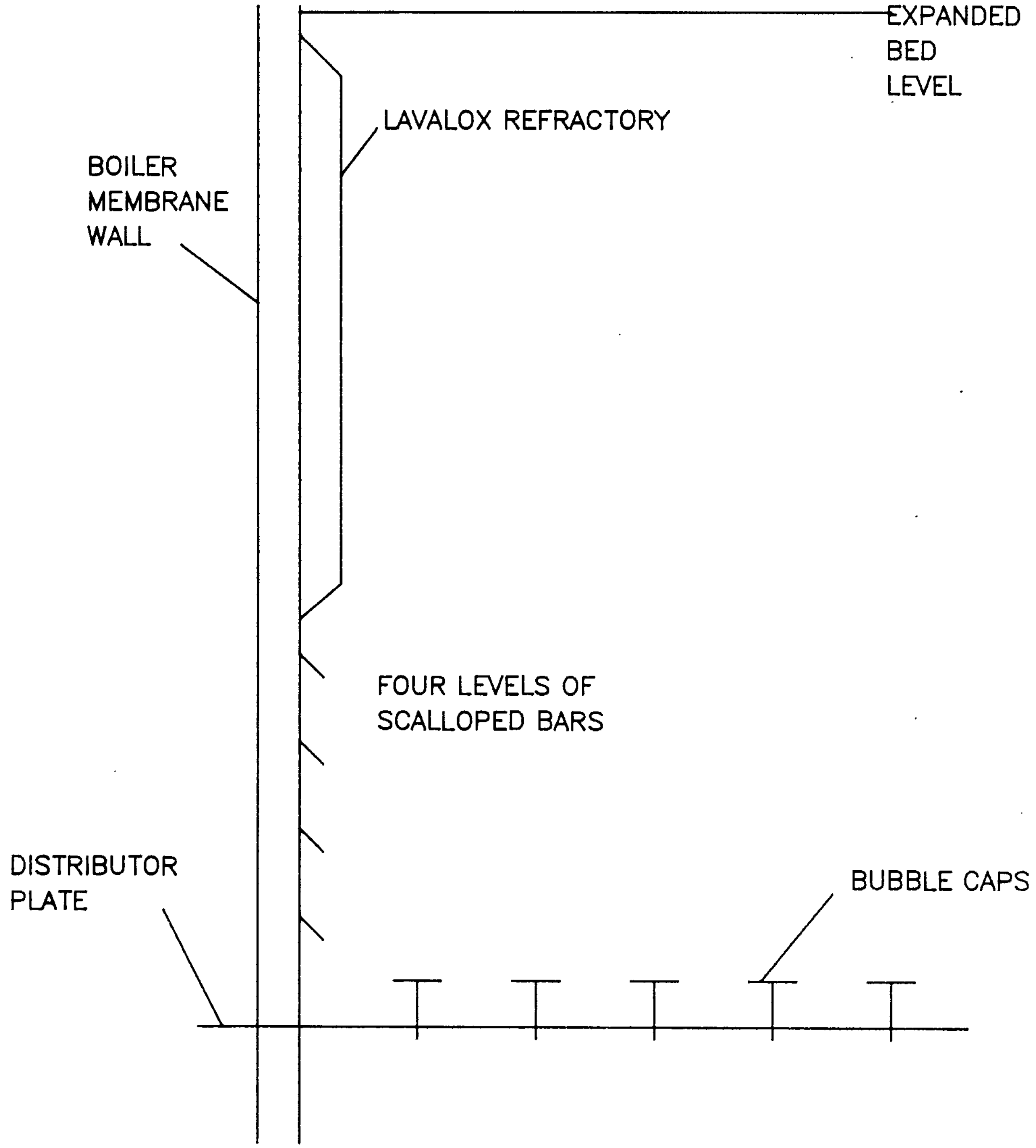

Fig.2— Schematic of refractory and scalloped bars applied to membrane walls

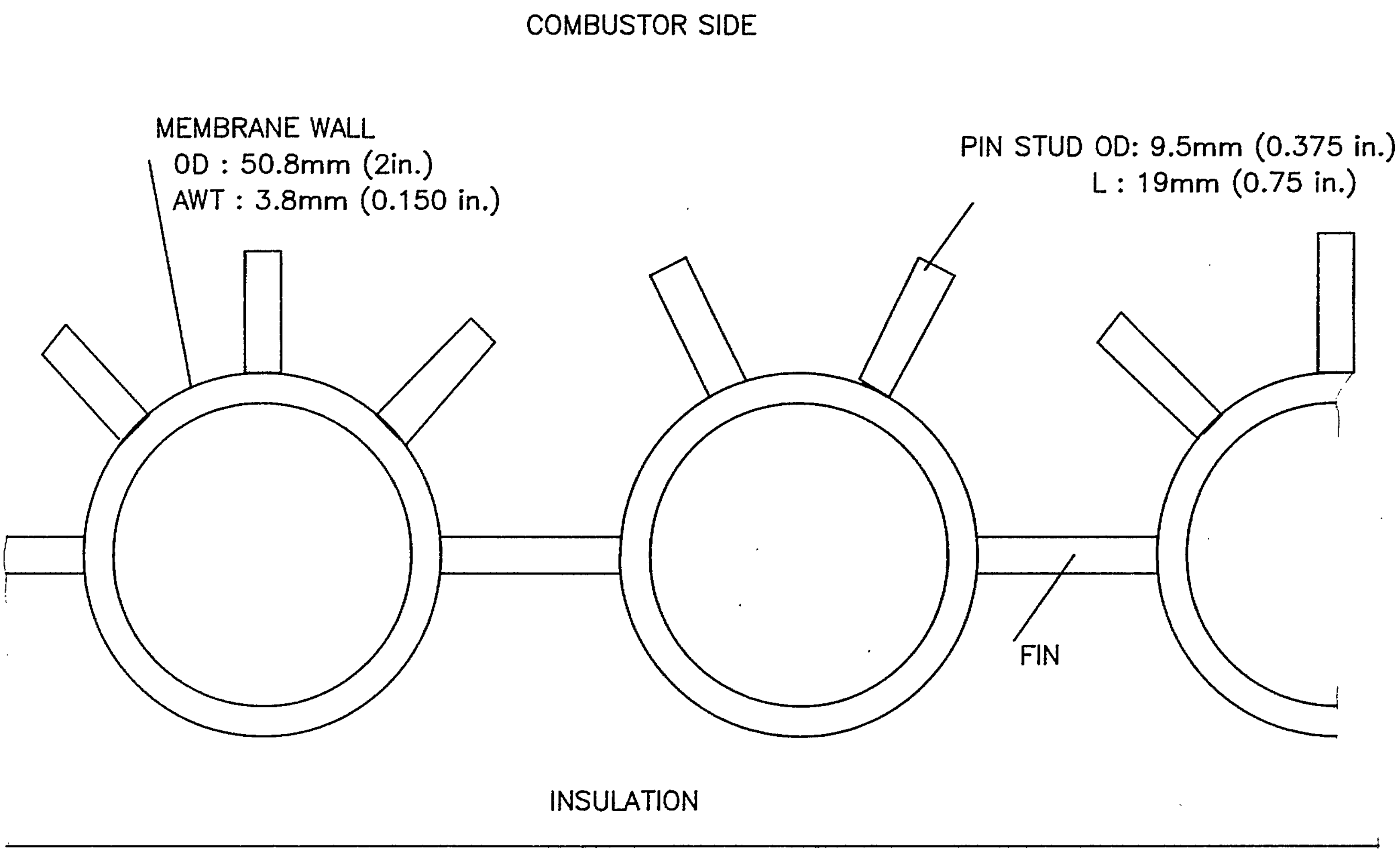

Fig.3 – Orientation of the pin studs on the membrane wall tubes

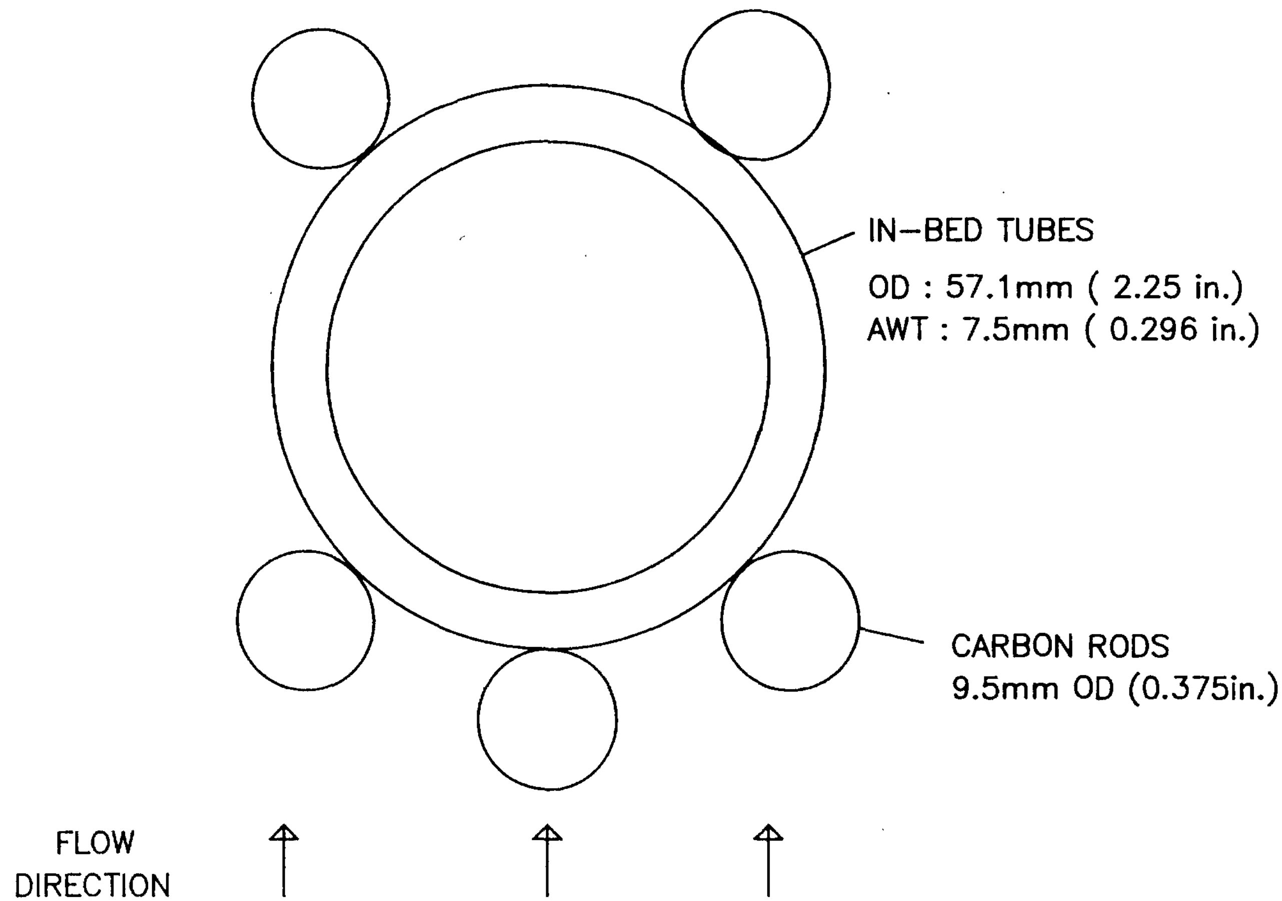

Fig.4 – Orientation of the carbon steel rods applied to the in–bed tubes

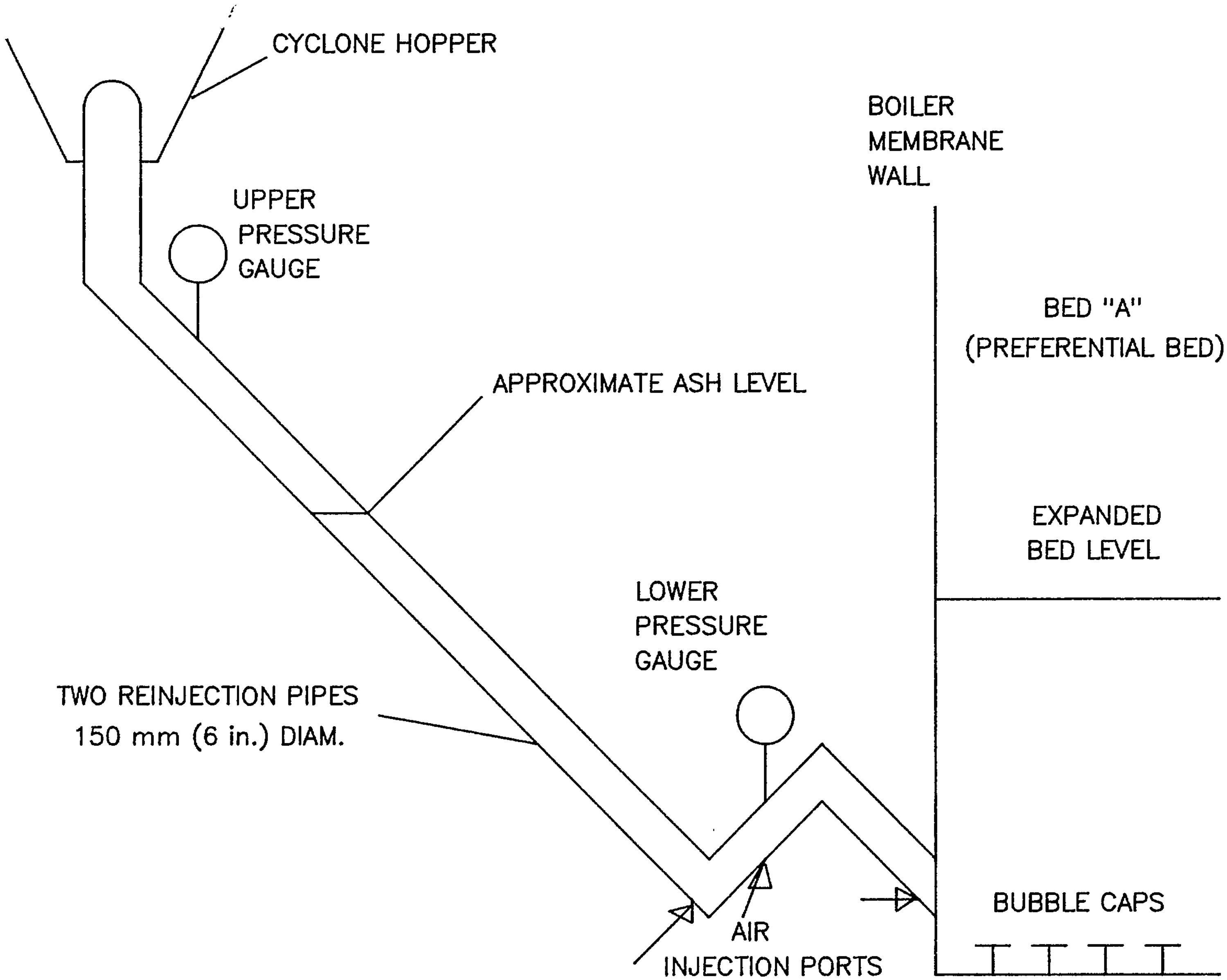

Fig.5 – Schematic of the new fly ash reinjection system

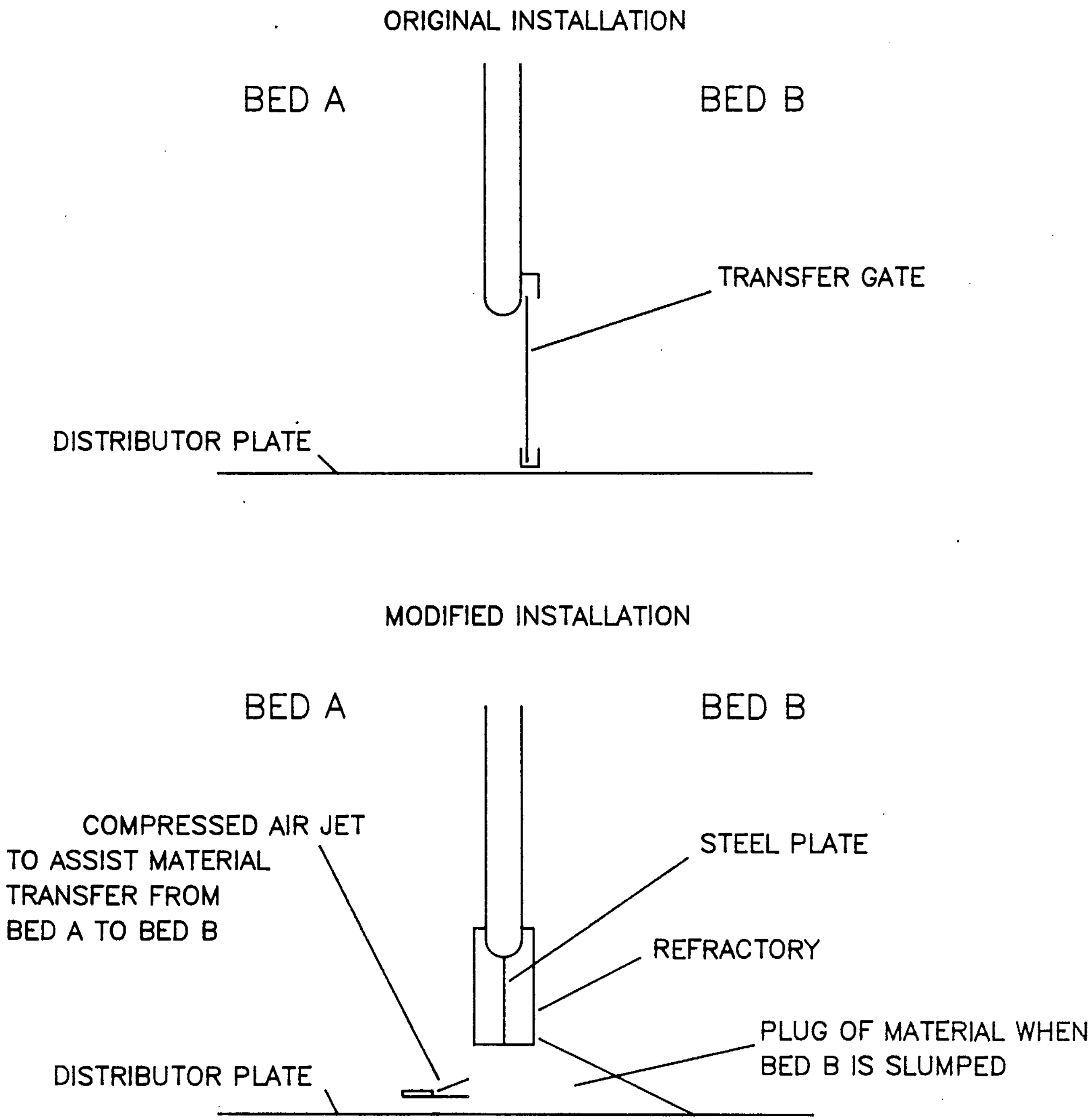

Fig.6 — Schematic of the inter—bed transfer gate as originally installed and as modified

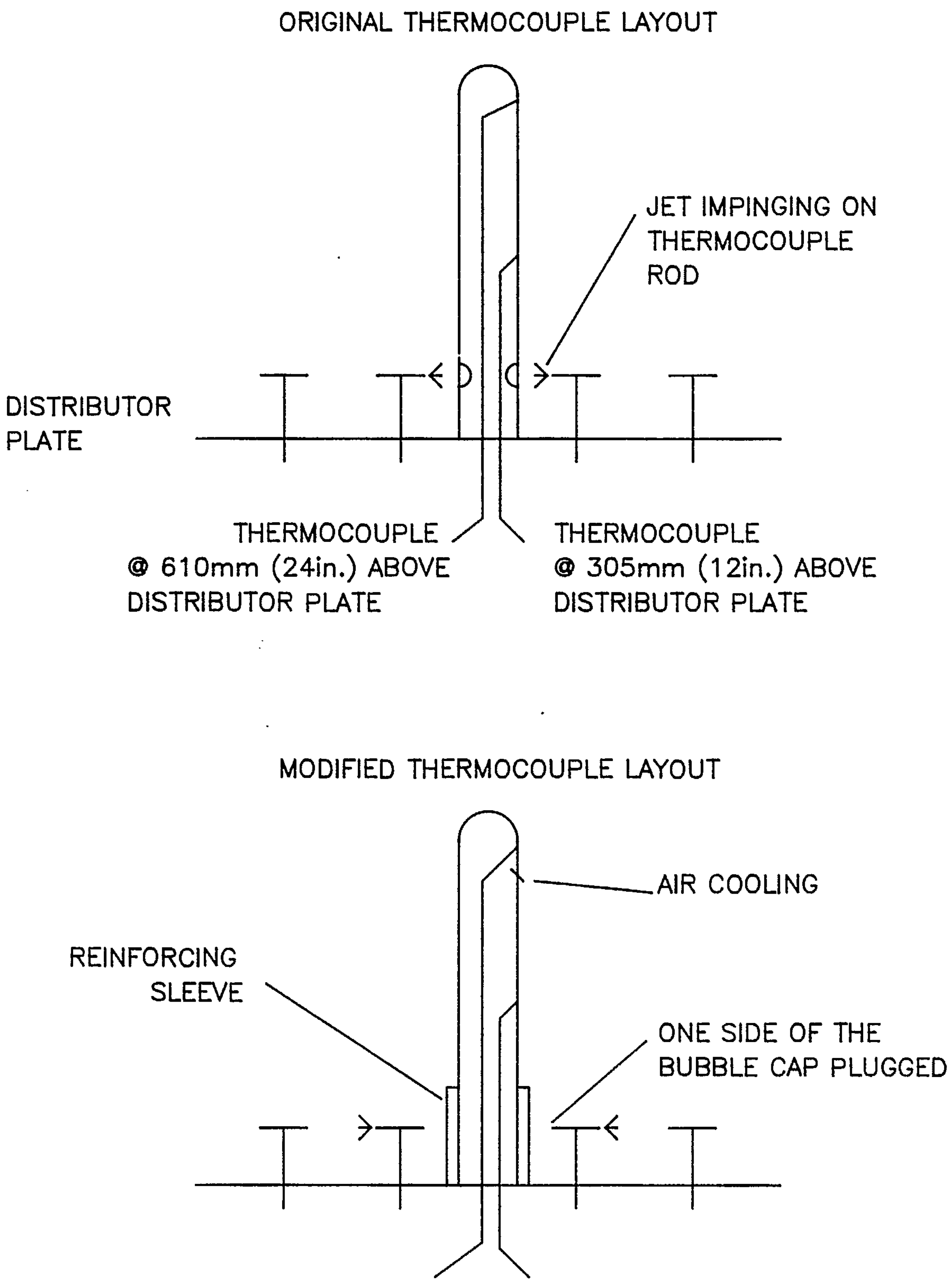

Fig.7 — Bed thermocouple installation as originally provided and as modified