Conclusions

- Erosion-corrosion effects begun as soon as the plant started operating and they were very significants during the first three years with material losses of order 70% in about 300 to 400 bends.

- The decrease in the number of leaks since 1976 was fundamentably due to the change in vaporization zone.

- At lower rate, corrosion continued after 1976, decreassing slightly when ammonia was sustituted by morpholine.

- Significant erosion-corrosion reduction was obtained when AMP has been used, and this were constate not only by the leaks rate reduction but also by the gammagraphies analysis of wear.

DESIGN, CONSTRUCTION AND OPERATING EXPERIENCE OF BOILERS AT WYLFA POWER STATION

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Abstract

The report will describe the boilers, but will emphasise the problems encountered and the solutions.

DESIGN

The boilers are 'once through' with start up drums. Some redunancy was provided but this advantage was lost due to downrating of gas temperature.

CONSTRUCTION

The boilers are carbon steel suspended plattens (992 per reactor) tightly packed in the annular space between the core shielding and the spherical wall of the pressure vessel.

This construction denies access to repair tube leaks. When a leak occurs the faulty platten has to be plugged off. This is done with the reactor at 60% power. The process will be described.

OPERATION

Reactor 1 commenced operation in 1971, Reactor 2 in June 1971. Between 1972 and May 1984 21 leaks occurred which resulted in a major shutdown for investigation. This revealed the leaks were caused by gas flow induced vibration resulting in fretting of tubes in clips.

Restraints and additional clamps were fitted. This has been successful but the modifications were extensive and in very difficult working conditions, the Reactor being shut down until May 1976.

A family of leaks adjacent to personnel access ways commenced in Reactor 1 in 1975 which was later identified as erosion/corrosion on the water/steam side caused by the feed flow instability. This problem is common to both Reactors. Various modifications have been applied. Redistribution of feed flow using orifice plates and ferrules was only temporarily successful.

Following extensive rig testing the feed water has been dosed with amino methyl proponal (AMP) since September 1983 with an immediate and sustained reduction in the leak rate. The amine provides protection through the steam/water phase.

Rig testing continues to attain a better understanding of the erosion/corrosion.

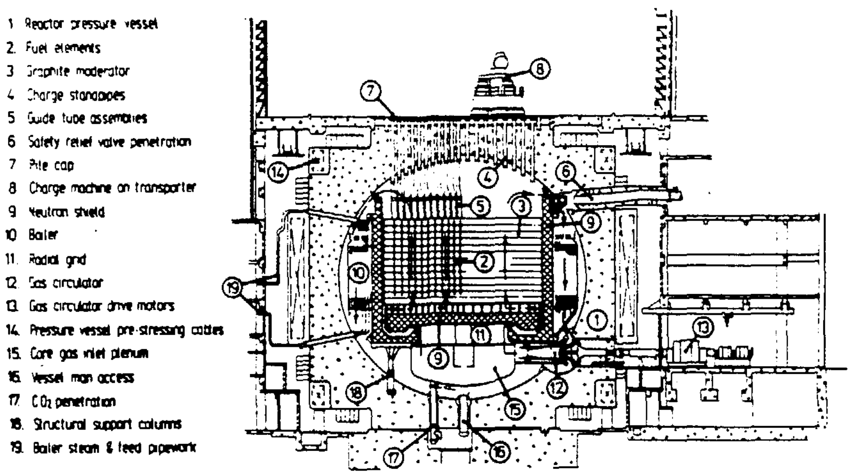
INTRODUCTION

The reactors at Wylfa Power Station are the largest, most technically advanced and last of the 'Magnox' type reactors built by the CEGB. The 'Magnox' type reactors have graphite moderator, magnesium oxide encased natural uranium fuel elements and are carbon dioxide gas cooled. The pressure vessel is steel tendon stressed concrete, mild steel lined with the boilers contained within the pressure vessel.

The steel liner of the pressure vessel is 96 feet diameter and the concrete biological shield is 11 feet thick at the bottom and sides and 12 feet thick at the top. The graphite core is approximately 61 feet diameter and 30 feet high, the boilers filling the annular space between the core and pressure vessel liner, see diagram below.

The reactor design conditions are as follows:

Thermal Output	-	1540MW (590MW electrical)
Gas Pressure	-	385 lb/in^2
Gas Temperature	-	Core outlet - 360°C
		Core inlet - 240°C
Gas Flow	-	26,000 lb/sec



ARROWS SHOW THE FLOW OF CARBON DIOXIDE THROUGH REACTOR AND BOILERS

FIG.1. Sectional diagram of the reactor.

BOILER DESIGN

The decision to opt for a prestressed concrete pressure vessel to contain the reactor-boiler arrangement has influenced the choice of design of the boiler. In earlier nuclear stations where the boilers are external to the pressure vessel, use has been made of the forced circulation boiler. In this type of boiler, the economiser, evaporator and superheater sections are separate sections each with their own connections to the gas circuit. This results in a large boiler size with numerous penetrations through the pressure vessel wall.

The alternative to this is to use the 'once-through' type boiler. In this type of boiler, the functions of economising, evaporating and superheating are carried out in one continuous length of tube, the tube diameter increasing at each stage to allow for the increase in fluid volume. This has the effect of reducing the overall size of the boiler and also reduces the number of penetrations through the pressure vessel. See Fig. 2.

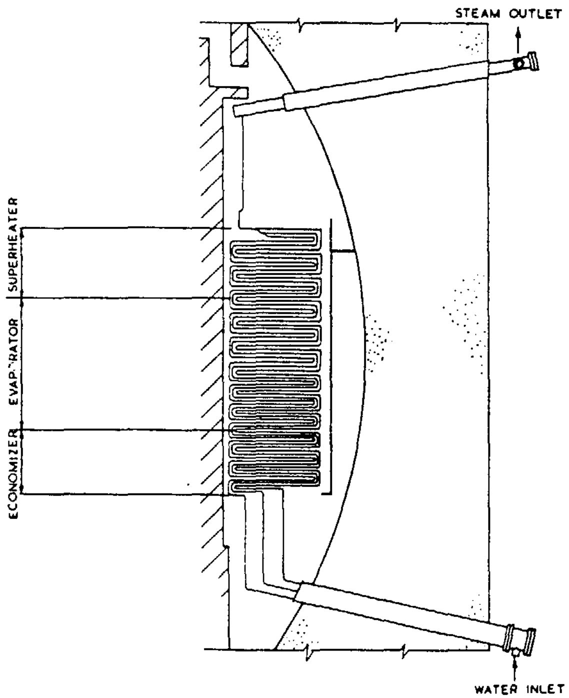


FIG.2. Tube arrangement in pressure vessel.

Since the decision to use a prestressed concrete pressure vessel with integral boiler had been made, to keep the physical size of the boiler and number of penetrations through the pressure vessel to a minimum the 'once through' type of boiler was chosen.

To enable acceptable steam conditions to be obtained at start up of the boiler, a steam/water drum with recirculating pumps was designed into the system. This enables the feed water to be recirculated around the boiler until acceptable conditions are obtained at the superheater outlet. The drum is then isolated from the system and the boiler operates in its once though mode. See Fig. 3.

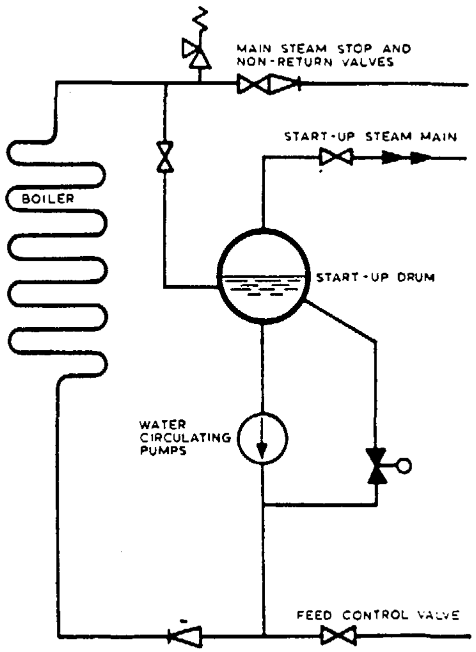


FIG.3. Simplified diagram of boiler start-up system.

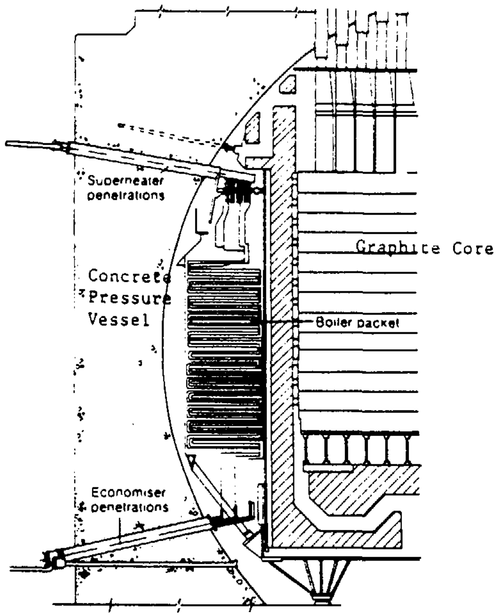


FIG.4.

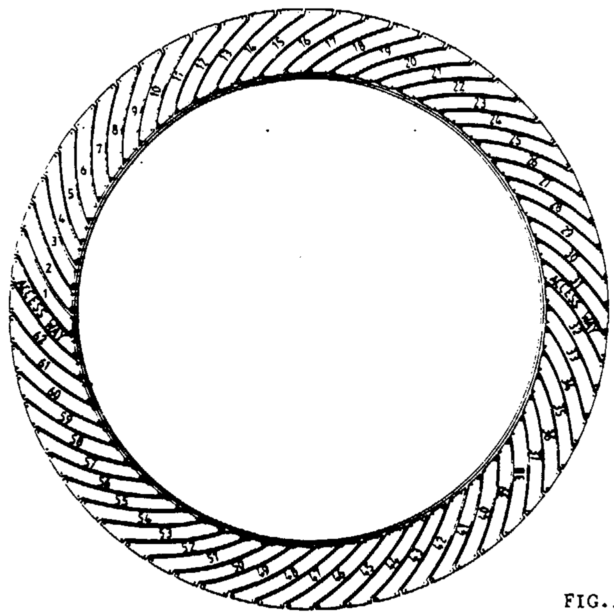


FIG.5. Plan of boiler packets.

BOILER, CONSTRUCTION AND SPECIFICATION

If the boiler alone is not to dictate the inside diameter of the concrete pressure vessel, it must fit into the space left after the cylindrical core, shielding and fuelling equipment have been fitted into the smallest diameter that will accommodate them. This results in the boilers having to fit in the annular space between the core shielding and the spherical inside wall of the pressure vessel. To this end, an almost continuous annular shape of tube bank was selected with two small gaps provided for access purposes. To permit the longest possible length of heating surface between tube bends and a minimum number of boiler elements, the boiler tubing is arranged in the form of multiloop sections having an involute shape in plan. See Figs. 4 & 5.

The smallest element of the tube bank is referred to as a platten. This consists of three continuous interleaved tube lengths, each tube being fed separately from the economiser water box. The three tubes are joined together at the top of the tube banks before connecting to a superheater outlet header. There are a total of 992 plattens making up the boiler tube bank.

Each platten consists of the already mentioned three tubes. Each tube is 240 ft. long and increase from 1" diameter at the economiser section, to 1 1/4" diameter at the evaporator section and the 1½" at the superheater section. The three tubes are doubled back and forth in multiloops to form the platten. Except for the vertical return bends, all the pipework is finned. All the tubes of the platten are secured together with straps and clips.

Sixteen plattens are secured together with spacers and clips to form a packet, there being a total of 62 packets in the boiler tube bank. Each boiler packet is hung from a boiler packet support frame. This frame bridges the gap formed between the reactor outer shield tank and the boiler tank with the boiler packet filling the gap formed between these two 'tanks'. Each platten has a number of supports suspended from the support frame. The centre ones are straps which provide accurate vertical and horizontal location of the tubes within the packet. The two end supports are channel sections which also provide a baffling system to ensure a flow of heated gas over the unfinned return bends.

The complete boiler is divided into four sections, each section being fed from one of four feed mains and each section passing steam out into one of four steam mains. Each of these boiler sections is then sub-divided into eight further sections, these sub-sections each being associated with a penetration through the pressure vessel at the feed inlet and another penetration at the steam outlet. This gives a total of 32 feed penetrations and 32 steam penetrations through the pressure vessel.

Each of the feed penetrations feeds two packets with feed water. All the packets associated with one boiler section are not grouped together but interspaced with packets from the other three boiler sections so that should it be necessary to take boiler sections out of service it can be done without creating hot or cold spots within the boiler bank.

The compact design of the boiler meant that if was essential both during construction of the plattens and packets and their fitting in the boiler annulus great care was exercised to maintain design clearances and tolerances thus ensuring even distribution of cooling gas over the tubes.

Again because of the compact design, it is not possible to gain access to the boiler to effect repairs in the event of a tube leak. With this in mind, during the in works manufacture of the plattens a percentage of the welds were X-rayed. On completion, each platten was acid cleaned internally and passivated, hydraulically tested, dried and vacuum tested for leaks. However, it was anticipated that some leaks would still occur so about 10% extra plattens were incorporated in the boiler design so that blanking off of a leaking platten would not result in a loss in generation.

To give an appreciation of size, each boiler packet is approximately 29 feet high, is 15 feet 10 inches long across the tips of the edge channels and is 2 feet 4 inches wide and weighs 52 tons, giving an overall weight for the boiler in excess of 3,000 tons.

The design conditions for the boiler are as follows:

Steam pressure at superheater outlet	-	700lb/in
Steam temperature at superheater outlet	-	396°C
Feed water temperature	-	135°C
Steam output	-	$5.9x10^6$ lb/h
Gas inlet temperature to boiler	-	405°C
Gas outlet temperature from boiler	-	246°C
Gas flow rate	-	$88.51x10^6$ lb/h
Gas inlet pressure	-	375 lb/in
Net efficiency	-	31.4%
Net electrical output	-	590MW
Specific heat output	-	$9.7KW/ft.^3$

Due to corrosion problems on mild steel components within the reactor pressure vessel on early magnox stations, the gas outlet temperature had to be reduced to 360°C. This also applied to Wylfa and resulted in the above design criteria being adjusted accordingly.

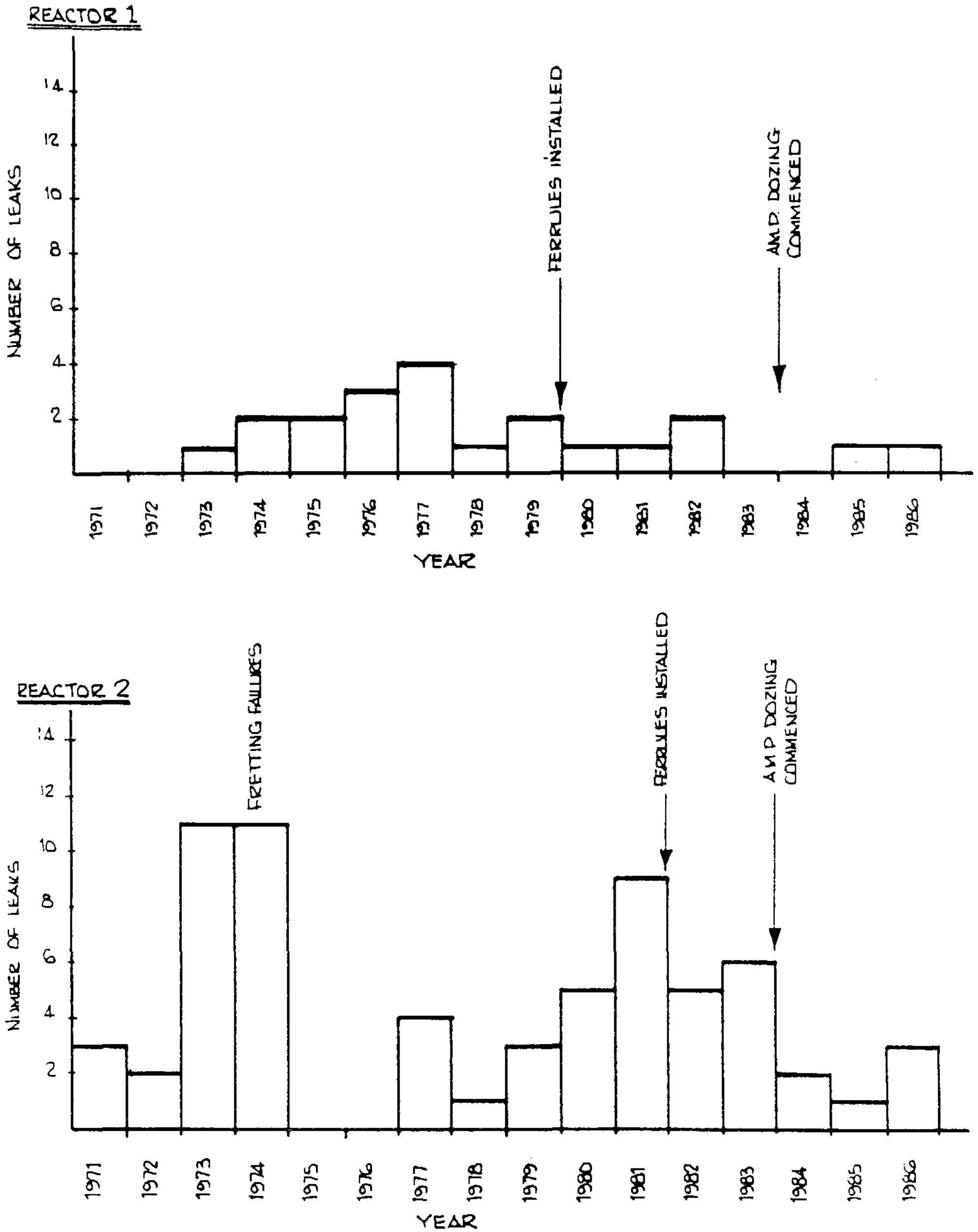
BOILER OPERATING HISTORY

Reactor 1 commenced operation in January 1971 and Reactor 2 in June 1971. Initial reactor operation was relatively trouble free with the steam turbines giving the major problems. However, in late 1972 boiler tube leaks began to have an impact on the operation of reactor 2 which persisted into 1973. It had been expected that the initial incidence of boiler leaks would be high as the flow rate, temperature and pressure transients due to normal operational manoeuvres exposed weaknesses not detected during construction and commissioning. It had also been expected that the incidence of leaks would then reduce and remain relatively steady for many years operation.

It soon became apparent that this was not the case with reactor 2 especially when compared to the incidence of leaks of reactor 1 (see Table 1). In an attempt to 'clean up' the boiler and bring the leak problem to a head, the decision was made to carry out an acid clean. As expected, this produced a flurry of leaks but after these had been plugged the incidence carried on at the same rate as before the acid clean.

By mid 1974 the situation had become intolerable with leaks occurring every few days resulting in considerable loss of generation while the leaks were plugged. (The following section 'Method of Boiler Tube Repair' describes low leaks are plugged and the resulting generation loss). Following much deliberation and consultation with CEGB departments the decision was made to retrieve one of the leaking tubes to determine its mode of failure. This involved cutting a hole through the boiler support tank, through the inner boiler casing to expose the boiler return bends (see Fig. 6) and then locating and removing a failed section of tube.

TABLE 1. WYLFA POWER STATION: INCIDENCE OF BOILER TUBE LEAKS



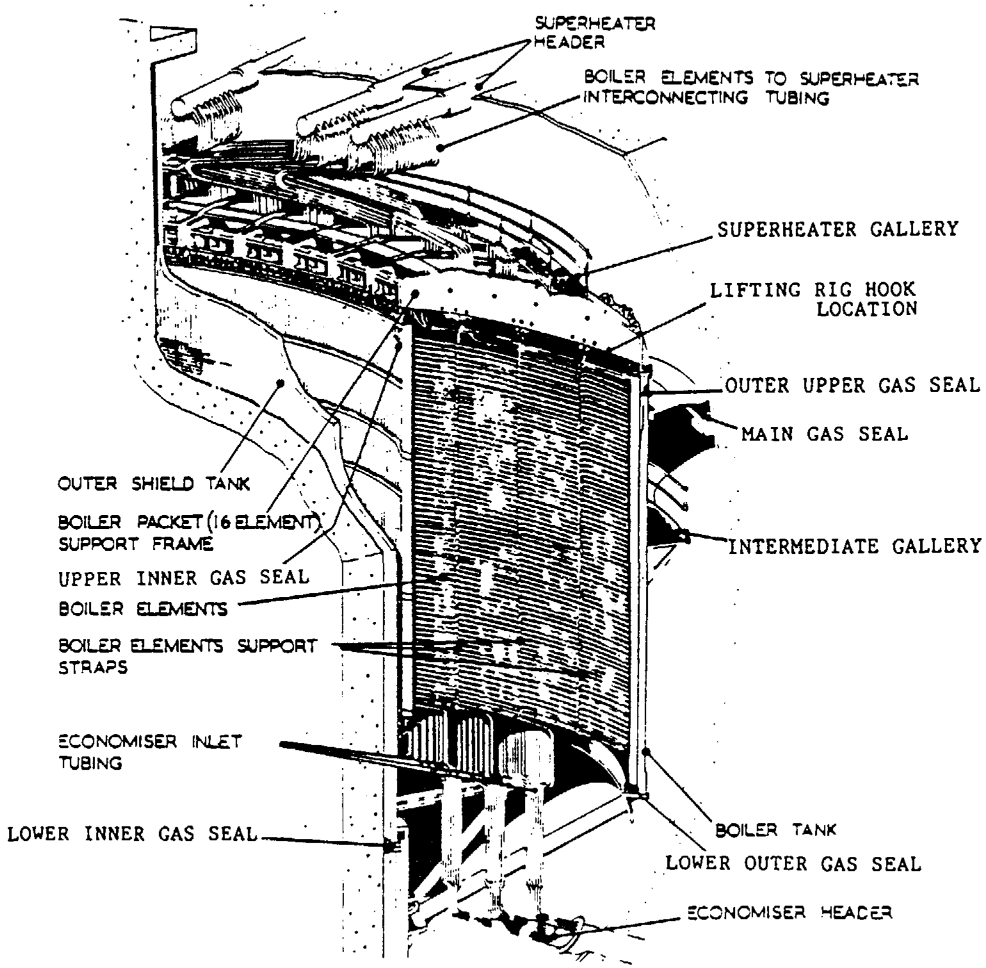


FIG.6. Section of boiler.

Firstly the height of the leak in the boiler had to be determined and this was done by manometric means. Stress calculations were carried out and showed that it was acceptable to cut a large enough hole in the support tank to enable a failed tube to be removed. The operation was carried out and a failed tube located. Inspection of this showed that failure was due to fretting between the unfined section of the tube and its securing clip at the platten end channel. An extensive operation followed whereby all of this type of clip were inspected by means of fibre optics. This indicated that fretting damage had occurred only on end of packet plattens in the economiser region of the boiler. Further investigations revealed that the whole of the boiler sections had become displaced resulting in comparatively large gaps between packets, i.e. up to about 1 inch.

The reason for tube failure had now been identified but it was still necessary to determine the cause of the vibration. To do this the boilers were extensively fitted with instrumentation and a series of cold runs at various gas circulator conditions carried out. The results from these runs were analysed and indicated that the fretting was due to resonant vibration of the tubes, mainly in the vertical plane. See Figs. 7 and 8.

Resonant vibration is a coincidence of a peak frequency in the excitation and a natural frequency of vibration of the tube.

The source of the excitation i.e. the energy input, was vortex shedding of the gas as it passed vertically down over the tubes. The frequency at which vortex shedding occurs depends on the gas velocity over the tube and the proximaty of other tubes. The natural frequency of vibration of the tube depends on how tightly it is being secured by the clips attaching it to the boiler frame.

From this it can be seen that resonant vibration depends on interpacket gaps, gas flow dictated by circulator inlet guide vane setting and the tightness of the tubes within the clips.

The cold runs showed that the excitation frequency within a boiler packet is of the order of 33HZ in the horizontal plane and 66HZ in the vertical plane. With a 1 inch interpacket these figures are 45HZ and 90HZ respectively. The natural frequency of the tube varies depending on the state of the tube clips but most are in the range 30HZ to 50HZ for their first critical and 60HZ to 120HZ for their second critical. This shows that the excitation frequency and natural frequency ranges overlap and are coincident at certain gas velocities giving rise to resonant vibration. Fig. 9 shows a typical vibration graph from the cold run tests.

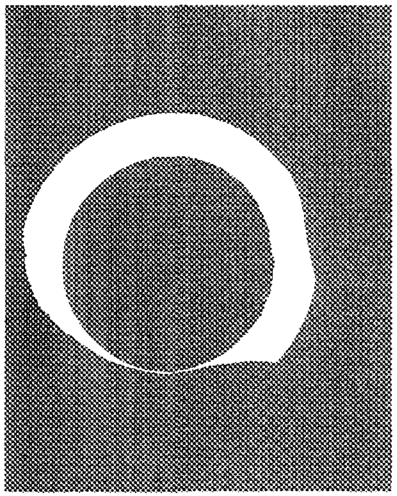


FIG.7. Fretted tube.

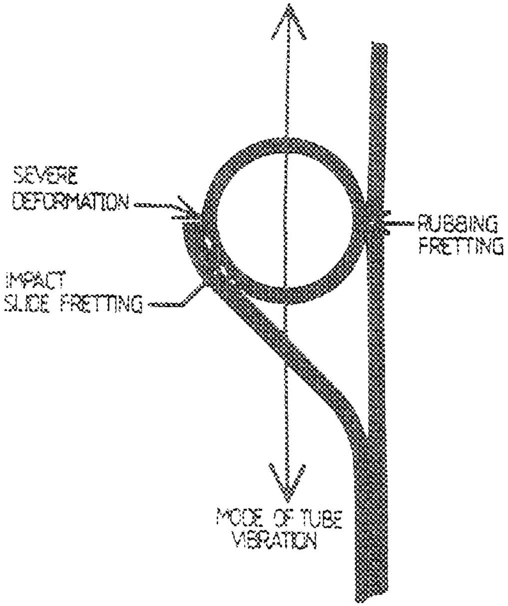


FIG.8. Most probable mode of tube vibration. Clip-to-cube arrangement and location of fretting damage.

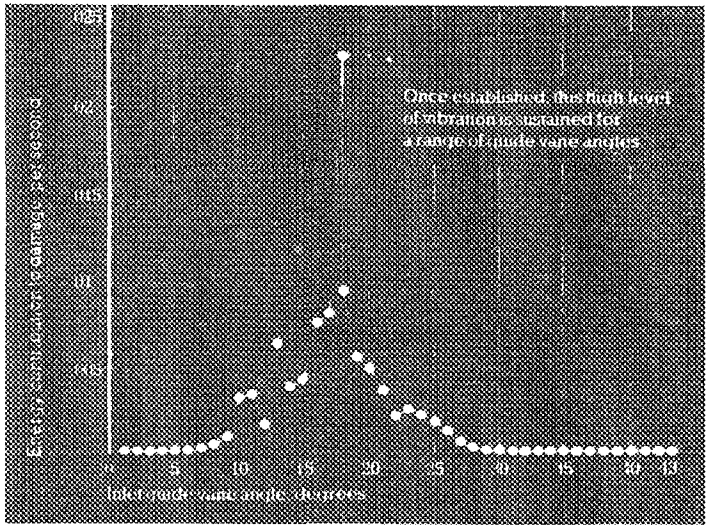
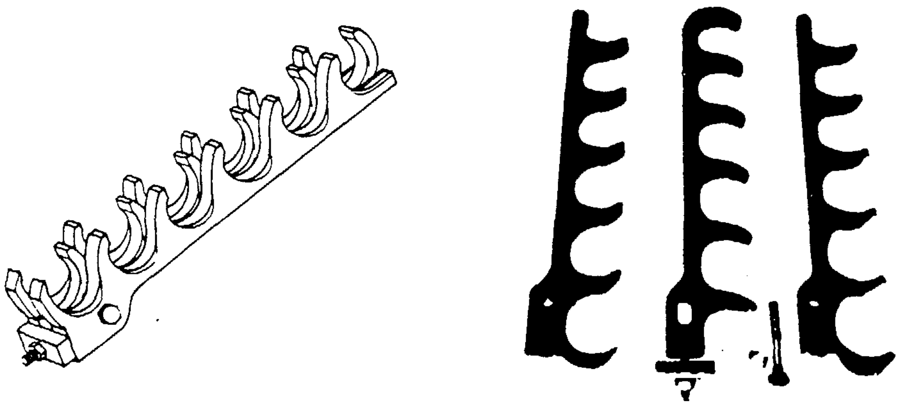


FIG.9. Gas-mass-flow dependent resonance peak, showing the vibration energy of one of the tubes against guide vane angle with four circulators operating. The critical guide vane angle is different for each tube.

Investigations were carried out to determine if there was an acceptable range of operating conditions available which would prevent the fretting continuing. The conclusions were that as interpacket gaps varied and tube clip tightness varied there was no operating condition which would avoid all of the economiser tubes suffering fretting damage.

Various solutions to the problem were considered and the final outcome was a two part course of action. Firstly, the tubes in the economiser section of the boiler would have to be restrained to 'stiffen' them up. Secondly the boiler packets would have to be repositioned to reduce and equalise the interpacket gaps.

To restrain the tubes a scissor type clamp was designed which was capable of clamping the bottom 18 tubes of the economiser together, see Fig. 10. Because of the limited space between the packets it had to be fitted in three separate sections and brought together and tightened in position. Two of these clamps were fitted at the outer end of each of the end of packet plattens, a total of 248 clamps.



(a) Assembled Clamp (b) Dismantled Clamp

FIG.10. 'Short' boiler tube clamp.

To move the boiler packets back into position slipper jacks were used. These are basically a pair of opposed wedges which are driven together to gain a lift motion. The jacks had a low-fiction teflon coating on the face of the wedges and on the top so that a sideways sliding motion could be obtained on the top surface.

Once back in position restraint plates were fitted just below the boiler frame to lock it to the boiler tank. At the bottom of the boiler a continuous garter structure was fitted which let the packets 'breathe' as much as necessary for operating but prevented any gross movement. Protective shear pin devices were incorporated into the restraints to prevent any damage being caused in the event of excessive forces being produced during operation.

All the above work was carried out in a hostile environment. Conditions were cramped, access restricted and all work carried out in protective clothing and repirators.

Although the reactor was shut down in mid 1974, the actual repair work took only 7 months and was completed in December 1975 and the reactor returned to power in January 1976. Following an internal inspection after 70 days running, which proved all was well, the reactor was given commercial clearance in late summer 1976.

Reactor 1 was inspected to determine if the same fault existed but it was found not to be the case. Even so as a precautionary measure, restraints were fitted to the outer end of the packets.

While the work was being carried out on Reactor 2 a series of leaks developed in reactor 1. These leaks were seen to be occurring in tubes adjacent to the boiler accessways. Examination of a tube sample, removed in a similar way to that as described for reactor 2, revealed insignificant fretting but erosion/corrosion was found on the inside of the tube at the bend. This was attributed to flow instability in adjacent plattens and consequent imbalance in heat transfer. This is highlighted in the accessway regions where there are higher gas flows. To overcome this problem it was necessary to control flow more accurately.

Following extensive experiments on tests rigs, modified orifice plates were installed in the feed lines to the economiser waterboxes. In addition to these, ferrules were fitted in the platten inlet tubes at the economiser tube plates of all plattens in the accessway area of the boiler.

An additional aid was to increase the dosing of the feed water with ammonia. This had the effect of raising further the feed water pH thus improving the integrity of the protective oxide layer on the boiler tube walls.

The erosion/corrosion type of failure was also encountered on reactor 2 on its return to service so the orifice plate/ferrule/ammonia dosing exercise was carried out its boilers also.

These changes reduced, but did not eliminate, leaks due to erosion/corrosion. Operating experience has shown that sizing of the ferrules is critical and some difficulty has been encountered in omptimising sizes both in service and on test rigs.

Extensive rig testing was carried out on alternative methods of dosing the feed water and consequently in 1983 Amino Methyl Propanol (AMP) was introduced to the feed water. (See following section on 'Feed Water Treatment'). This has had a dramatic effect on the incidence of tube leaks (see Table 1).

Tube leaks are still occurring but at a much reduced, and acceptable, rate. Some leaks follow no pattern and some are 'end of line' failures due to damage suffered before corrective measures were introduced.

BOILER FEED WATER TREATMENT

The Wylfa low pressure once through boiler system, when designed in the mid 1960's, was new and untried. This lack of operating experience together with the inaccessibility of the boilers for repair caused great concern among Chemists over possible waterside tube corrosion. At that period serious problems were being experienced on conventional high pressure natural recirculation boilers due to a virulent form of internal tube corrosion referred to as "On Load Corrosion". In the period approximately 1965 and onwards it was discovered that the underlying cause of On Load Corrosion was extreme concentration of acid or alkali in the water phase at the boiling zone and that the method of overcoming the attack was by exercising great care over feed water purity, restricting dosing chemicals in the boiler water to a minimum and "blowing down" to prevent accumulation of aggresive chemicals in the boiler water.

In a subcritical once through boiler there is no opportunity to exercise chemical control by blowdown and the use of solid treatment in the conventional way is not possible.

It was therefore considered that reliance had to be put on high feed water purity and volatile alkali treatment to avoid the development of acidic conditions at the boiling zone which could give rise to "On Load Corrosion" attack. Experimental work on a full size model of a Wylfa boiler section showed some evidence of the possibility of this type of attack during operation of the full scale plant and the need therefore to exercise great care over water purity.

Experience at that time of steam volatile alkalis was largely restricted to ammonia and during early plant operation this was added to the feed water to maintain a pH of 9.0 to 9.2. Full flow condensate polishing plant was installed to remove corrosive water impurities from the condensate. Shortly after commissioning however it was found that chloride ion was passing preferentially in small concentration through the Polishing Plant creating potentially dangerous acidic conditions in the boiling zone where the protection afforded by ammonia in the aqueous phase is poor. To combat this difficulty a decision was made to dose continuously a small quantity of sodium phosphate into the feed water such that a reserve of alkali was present in the aqueous phase at the boiling zone in a form which would not dangerously concentrate and attack the protective magnetite oxide film. The concentration in the feedwater of the phosphate salt added was 10μg/litre and this has continued to be added to date.

In practice the concentrations of solid impurities within the boiler do not continually build up since any plant disturbance of steady steaming conditions brings solids forward from the boiler to the condensate system where they are removed by the Polishing Plant.

To improve plant efficiency a change was made in 1982/83 to the steam conditions through the turbines when the live to bled steam reheaters were converted to water separators. These are situated after the H.P. cylinder. As a result an increase in station output of 34MW's has been achieved.

The chemical effect of the change however was to provide a preferential path for impurities back to the boilers without passing through the condensate polishing process. A closed loop was formed in which impurities concentrated in the separator condensate are pumped directly back into the deaerator.

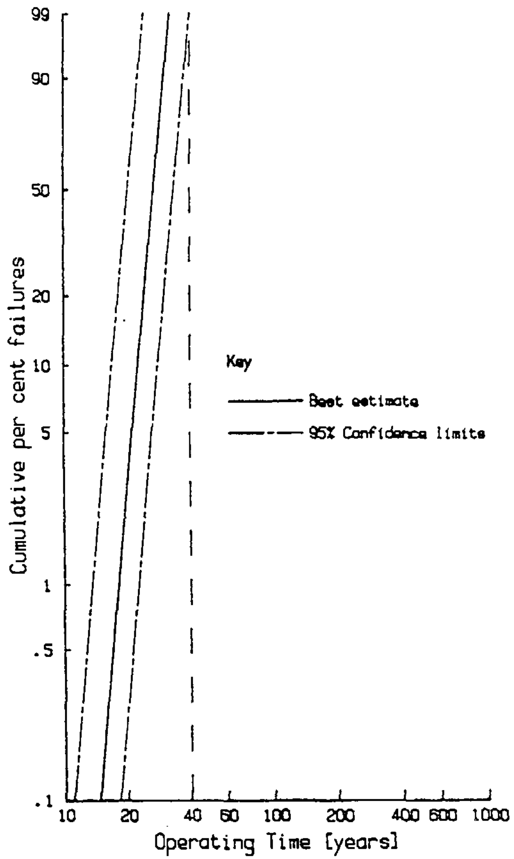
As mentioned in the previous section another form of tube attack on the water side, erosion corrosion, (fully discussed by G. S. Harrison), was found to be taking place when a reason was sought for failures to tubes adjacent to boiler accessways. The orifice plates and ferrules which were subsequently fitted greatly improved the problem of flow inbalance and reduced the rate of attack in the access way zones, but a chemical solution was still necessary to prevent more general attack causing possibly large numbers of tube failures later in the station life.

Experimental work on a full size boiler platten showed that the areas of tube most at risk were those containing two phase fluid with steam content of approximately 70%. The major requirement to alleviate the problem was for an increase in pH of the aqueous phase to reduce iron solubility. Ammonia, due to its adverse water steam partition coefficient and relatively low basicity is not adequate for this purpose and although the feed water pH was increased to 9.6 (25°C) there was an urgent need for a more effective alkalising agent.

As a result of research work within the C.E.G.B. on alternative alkalis a recommendation was made to adopt the amine 2-amino - 2-methyl propan-1-ol as the alkalising agent. This material has more favourable chemical characteristics than ammonia in the at risk areas and it is believed that the required working life of the boilers will be obtained without excessive failures. (Figs. 11 and 12 reproduced by permission of G. S. Harrison et al from "A review of the two phase erosion-corrosion problem at Wylfa Power Station). This amine also has advantage of low flammability, low toxicity and relatively low cost compared to the alternatives examined, morpholine and piperidine. The cost is however a factor of eight higher than ammonia at £450,000 in 1985.

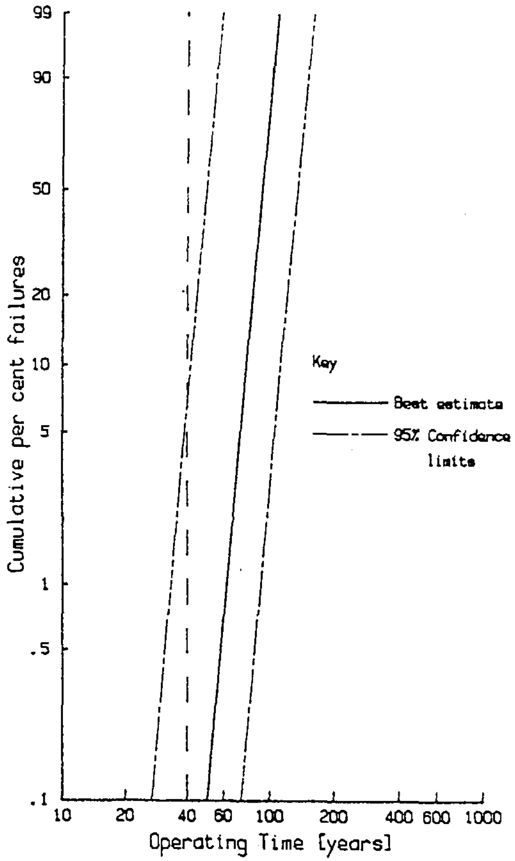
The amine was brought into use in the Autumn of 1983 and is currently added to the feedwater at a concentration of 10 ppm producing a pH(25°C) of 9.75. The current assessment of the beneficial effects are favourable but as yet, from a practical standpoint of tube failure, it is too early to be overconfident. The histogram, Table 1, of tube failure shows the failure rate due to vibration and the reduced failure rate when ferrules were installed as well as the effect of introducing AMP.

The use of an organic material such as AMP results in a number of side effects briefly mentioned at this point. Due to the physical conditions at which it operates the AMP molecule and other amines tend to breakdown producing in particular low molecular weight acids which are not readily removed by the condensate polishing plant. The acids also preferentially enter the water phase in the steam separators and are recycled to the boiler without appearing substantially in the main condensate. Fortunately the preference of AMP for the aqueous phase and the presence of the phosphate dosed into the boiler feed prevent any serious effect of pH reduction in the sensitive areas both for erosion corrosion and on load corrosion.



Failure predictions for 1ppm ammonia.

FIG.11.



Failure predictions for 10ppm AMP.

FIG.12.

The use of AMP has also affected the efficiency of the polishing plant. Resin kinetics for the removal of anionic impurities are being quickly and badly affected from the installation of new resin changes, causing considerable cost for resin renewal. The problem is as yet unresolved but investigation to date is indicating polishing plant design, the Wylfa installation is an early example, and the physical breakdown of the cation resin.

Research is proceeding to identify substances other and better than AMP for boiler protection and a number of materials e.g. 3 Hydroxy Quinuclidine are promising.

METHODS OF BOILER TUBE REPAIR

As previously mentioned access to repair boiler leaks is not possible therefore the boilers were designed with a surplus of plattens so that the few expected leaks could be plugged off permanently without a loss of generating capacity. To this end a remote plug insertion and welding kit was supplied by the boiler manufacturers. To understand the method of repair it is best to consider one platten in isolation.

A platten, as described in an earlier section consists of three continuous interleaved tube lengths each being fed separately from an economiser penetration tubeplate which is outside the reactor pressure vessel. The 3 tubes of the platten connect into one superheater tube by means of a double bifurcation. The superheater tube is attached to the superheater penetration header inside the pressure vessel. Each economiser penetration feeds 96 feed inlet tubes and each superheater penetration accommodates 32 superheater tubes. When a leak occurs in a tube it is obviously necessary to isolate the whole platten from the boiler to prevent moisture from the leak entering the pressure vessel gas side. It is relatively easy to plug the tubes at the economiser penetration as these are outside the vessel and easy access available inside the economiser waterbox. The superheater is a much more difficult problem as the tube to be plugged is about 30 feet down a 10 inch bore header.

The device provided by the manufacturer consist of a carriage which travels down the header with a television camera attached for steering and location purposes. The carriage mounted machine has a facility for inserting a plug in the tube to be sealed and then welding it in place by a multirun, wire feed, shielded arc, electronic welding process. It has compressed air supplies for actuation and cooling and the welding head is electrically driven.

To use this machine the reactor must be taken off load, depressurised to atmospheric pressure to accommodate the welding process, and the temperature reduced to 50°C or less to safeguard the machine electrical system. Due to the limitations placed on the machine by the header size and the accuracy of the header manufacture, the reliability of the welding process was poor with a failure rate of up to 1 in 5 being experienced. The consequences of a failed weld are having to establish a reactor entry to enable the superheater tube to be cut just below the header and a plug welded into the tube.

The time involved in carrying out a successful machine weld is approximately 10 days from reactor shutdown to returning to power. Should it be necessary to carry out a repair inside the vessel then the time taken can be 22 days. Thus it can be seen that boiler tube leaks result in a considerable loss of generation if repairs are carried out in the prescribed manner.

With the large number of tube leaks being experienced in 1973 it was decided that a quicker method of sealing the leaks should be sought and consequently various alternatives were investigated. By far the most promising idea was that of plugging off the superheater tube with a plug held in position by a jack acting across the header bore.

This idea was developed and the result was a car type scissor jack with an integral plug which was inserted by a remote handling tool. (See Fig. 13).

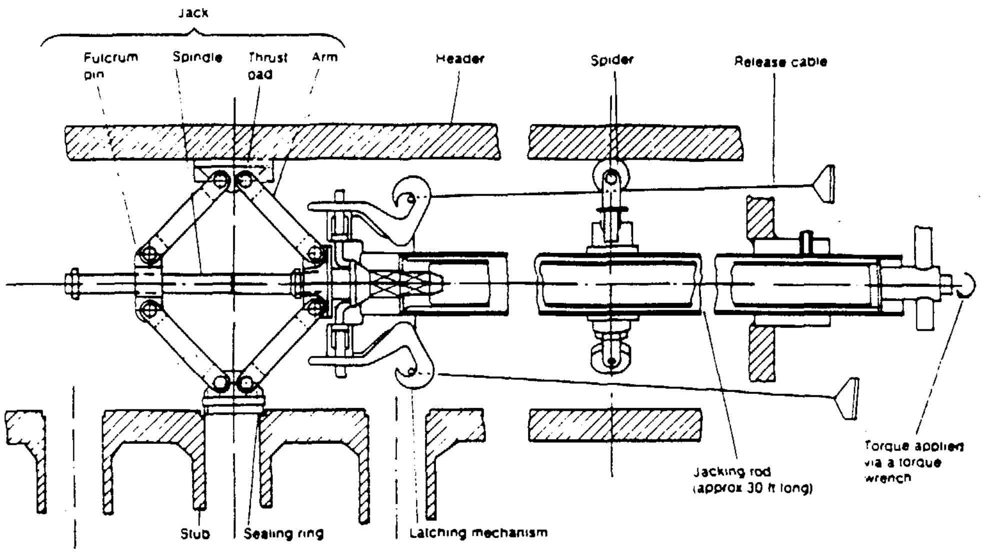


FIG.13. Original design of jack and insertion tool.

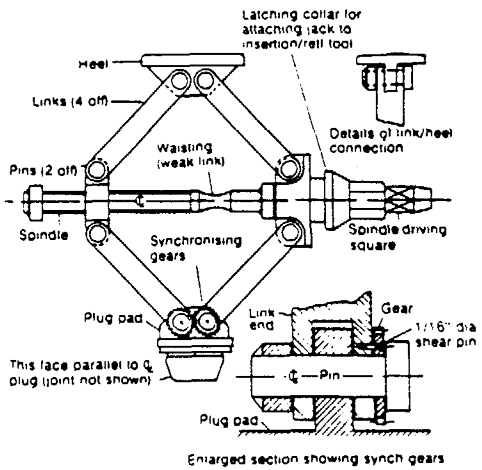
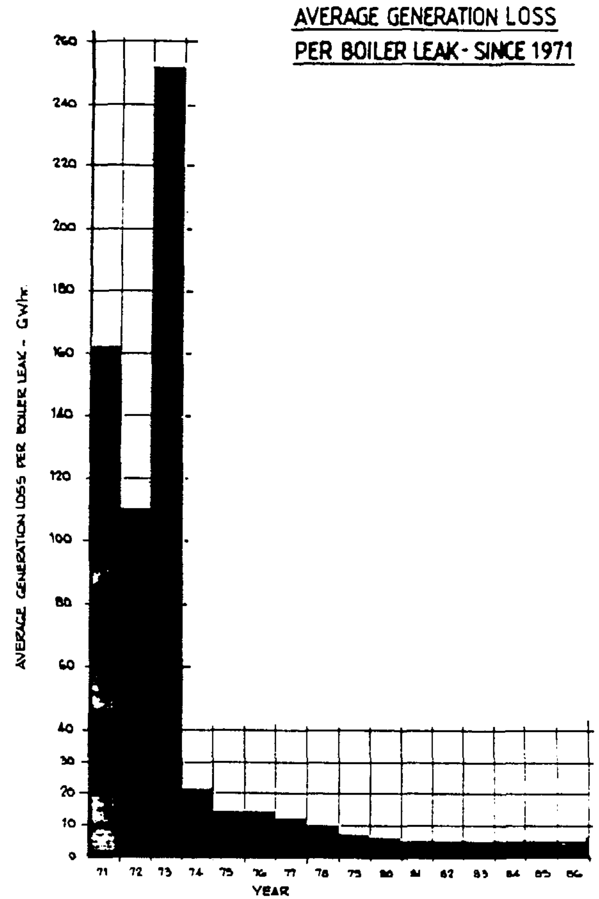


FIG.14. Later design of jack.

Stress calculations and rig tests were carried out to determine the maximum force which could be exerted by the jack on the header. These proved that sufficient force could be applied to the jack to enable a seal to be established between the plug and header when a spirally would carbon filled sealing ring was used. A 'weak link' was built into the jack by means of a necked section on the spindle to prevent an overload of the header.

Although some difficulties were experienced with the early design the method proved a great success. Through operating experience, the jack and tool have been developed until it is now a relatively straight/forward operation to fit one. The main improvements have been a redesigned plug giving a better lead into the tube to be sealed and synchronising gears to prevent the plug being diverted by escaping gas during fitting. (See Fig. 14).



WYLFA POWER STATION

The main advantage of using the jack system is that the reactor can remain on load during fitting. Only the offending boiler and its associate need be taken out of service and by increasing load on the remaining boiler pair 80% full load can be maintained. From identifying a leaking boiler to return to full power can now take as little as 24 hours.

DESIGN AND PERFORMANCE OF THE HELICALLY COILED BOILERS OF TWO AGR POWER STATIONS IN THE UNITED KINGDOM

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Abstract

The Hartlepool and Heysham-I AGR stations have been commissioned and operating since 1983. The main features, of the design of the helical once-through boilers raising the steam for power generation, are outlined. The modifications to the feed inlet flow ferrules, necessary to improve the boiler performance and optimize the power output, have been described. Comparisons between the thermal and hydrodynamic performance of the boilers before and following these alterations are given. The improvements in the computer code predictions of the plant performance have also been presented.

1. INTRODUCTION

The Hartlepool and Heysham-I 1300 M.W. AGR power stations are fitted with helically coiled boilers manufactured by Babcock Energy Ltd. Each boiler comprises a reheating section and a once-through high pressure heating surface in the same pod casing. The design and performance of both the heating surfaces and external boiler plant were subject to operating temperature limits imposed by material properties limitations and gas side corrosion and water/steam side stress corrosion constraints. Safety considerations, during early operation, had set up an upper limit of 78.5% M.C.R. for the plant operation. Plant measurements, operating experience and results, from performance analyses for various operating conditions, since 1983, indicated that operating the plant above 75-80% M.C.R. would invoke these considerations and temperature limitations. Description of the boiler design and plant arrangement and assessment of early plant performance [1] were presented at the last Specialists' Meeting on Heat Exchanging Components in Duesseldorf in the Federal Republic of Germany (16-19 April 1984). However an outline of the main features will be given here for completeness.

In view of this, Babcock and other organisations concerned in the U.K. continued the assessment and analysis of the thermal and hydrodynamic performance of the boiler at selected load conditions to ensure the safe operation of the plant within the design constraints and investigate ways of increasing its performance. As a result of these studies it became apparent that it would be necessary to alter the feed flow distribution in the high pressure section of the boiler to achieve appreciable increase in the power generated within these constraints. This only involved changing the hydrodynamic resistances of the ferrules fitted to the feed inlet headers of the boilers either by selectively reaming out some of the currently installed ferrules or alternatively replacing them by high impedance ferrules.

Extensive performance analyses which include detailed mathematical modelling of the heating surfaces, description of the hardware changes and plant measurements have been carried out. Detailed comparisons between the performance of the boiler plant, prior to and following the modifications of the feed flow ferrules will be discussed and presented in the following sections. The measurements from the comprehensively instrumented boiler plant will also be compared with the predictions of the specially developed computer codes that employ 2-D models of the heating surfaces and interbanks.

2. DESIGN FEATURES AND LIMITATIONS

The helical design concept was selected for the manufacture of the heating surfaces of the once-through boiler plant for the Hartlepool and Heysham-I nuclear power stations for its simplicity and optimum usage of the available space in the reactor concrete pressure vessel. The surface arrangement adopted (Fig. 1) is simple where the tube helix angle, pitch and length are the same for all the 19 high pressure section and 13 reheater heating surface helices. This has resulted in a considerable simplification of the tube manufacture and coiling and the assembly of the boiler surface.

Right from the start, in addition to space envelope limitations and gas side pressure drop considerations, the design of the heating surfaces has been subject to operating temperature constraints imposed by the physical, mechanical and corrosion resistance properties of the materials available at the design stage some 20 years ago in the mid-sixties. Beside these design constraints on the internal boiler components, additional limitations were specified for the operation of the boiler plant external to the pressure vessel to safeguard the integrity of the high pressure pipe-work and turbine during the economic life of the station. Design optimisation studies, given the above constraints and limitations had resulted in the selection of three materials for the manufacture of the heating surface components; carbon, 9% chromium and 316 stainless steels. The ferritic materials have been employed in the economiser and the evaporator sections and the austenitic material in the superheating and the reheating sections of the boiler.

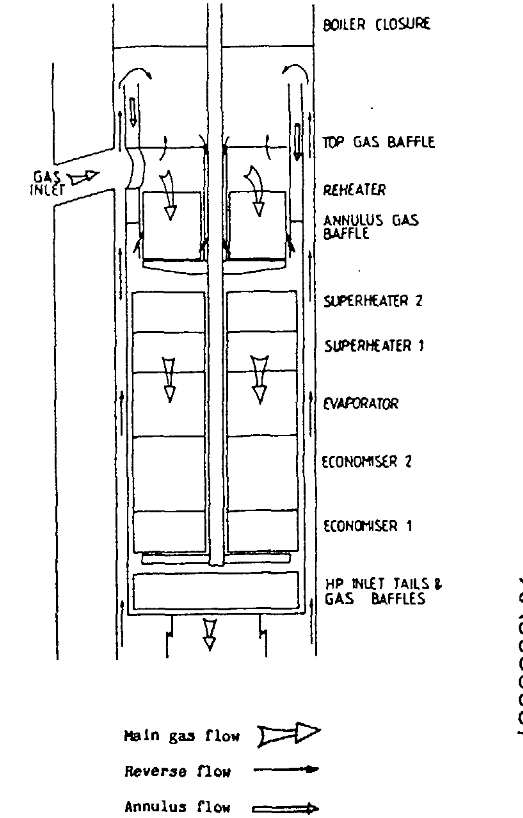

Fig. 1 Pod boiler heating surface arrangement