SCALING-UP CIRCOFLUED BOILERS FOR UTILITY APPLICATIONS

by

Dietmar J. Kestner
Robert A. l.isauskas
Riley Stoker Corporation
5 Neponset Street
Worcester, Massachusetts 01606

Presented at
EPRI Conference
on
Application of Fluidized Bed Combustion
for Power Generation
Cambridge, Massachusetts
September 23-25, 1992

RST-111

RILEY
Riley Stoker Corporation
PO. Box 15040, Worcester, MA- 01615-0040
A Member of the Deutsche Babcock Group

SCALING-UP CIRCOFLUID BOILERS FOR UTILITY APPLICATIONS

by

Dietmar I Kestner
Robert A. Lisauskas
Riley Stoker Corporation
5 Neponset Street
Worcester, Massachusetts 01606

Presented at
EPRI Conference
on
Application of Fluidized Bed Combustion
for Power Generation
Cambridge, Massachusetts
September 23-25, 1992

RST-111

SCALING-UP CIRCOFLUII ,
BOILERS FOR UTILITY APPLICATIONS

Dietmar J. Kestner
Robert A. Lisauskas
Riley Stoker Corporation
5 Neponset Street
Worcester, Massachusetts 01606

ABSTRACT

*The **Circofluul fluidized bed boiler is a hybrid** of bubbling and circulating fluidized bed combustion technology. Its unique design offers a number of advantages in scaling-up atmospheric fluidized bed combustion (AFBC) systems for utility power generation. This paper addresses key scale-up issues and describes a Circofluid utility reheat boiler design. The evolution of commercial Circofluid boiler designs and their operating history are also reviewed.*

INTRODUCTION

Atmospheric fluidized bed combustion (AFBC) has come of age. In the past decade AFBC boilers have grown from small industrial installations to 150-200 MW operating units (1). This scale-up in size has also been accompanied by numerous design refinements. As a result of this commercial experience, AFBC systems have become a viable option for utility power generation. AFBC systems are capable of meeting near term utility needs for both new capacity and for repowering older plants. The following paper discusses the scale-up of the Riley/Deutsche Babcock Circofluid’ AFBC system for utility scale power generation.

UTILITY BOILER REQUIREMENTS

The emission characteristics of AFBC have made fluidized bed boilers an attractive option for industrial boiler applications. Low combustion temperature and the ability to stage the combustion process make fluidized systems inherently low-NO_x emitters. The ability to capture sulfur in-situ by the introduction of sorbents directly to the fluidized bed has avoided the need for wet scrubbers. Perhaps the major advantage of AFBC systems is their fuel flexibility. Fluidized bed boilers are capable of burning all ranks of coal including low quality and high-sulfur coals. Coal-fired AFBC's can also be used to co-fire a variety of combustible waste materials.

While these features are also important and relevant to today's utility power generation market, there are a number of design and operating factors that differentiate utility and industrial boiler requirements. Some of the scale-up issues affecting utility AFBC design decisions are as follows:

- Plant size
- Reheat steam cycles
- Load following requirements
- Maintenance and reliability

The Circofluid system is well suited to these utility boiler requirements.

CIRCOFLUID SYSTEM

Process Description

The essential features of Circofluid steam generators are illustrated schematically in Figure 1 for both reheat and non-reheat boiler configurations. The basic design principles of this technology were developed as enhancements to both bubbling and classic circulating fluidized bed combustion (CFBC) technologies. Circofluid boilers consist of two boiler passes connected by cyclone separators. The first boiler pass, which contains the combustion chamber, is formed by cooled membrane walls. These walls form part of the evaporation system and may be designed for either natural circulation or once-through forced flow. The lower section of the first pass includes the fluidizing air plenum, dense bed combustion zone and freeboard. The transition from the dense bed to freeboard is marked by a distinct drop in suspended particle density.

A thin coating of insulating refractory on the combustor walls produces near adiabatic conditions for high combustion efficiency at all loads. The resulting rise in freeboard temperature is also conducive to the thermal destruction of trace gas species such as nitrous oxide (N_2O). Low particle densities leaving the freeboard permit conventional heating surfaces to be placed above the freeboard before the cyclones. Convective heating surfaces such as superheater and reheaters, therefore, can be located in the upper portion of the first pass. Flue gas entering the cyclone separators is cooled to between 570 and 930°F (300 to 500°C;). This is considerably lower than the 1500 to 1600°F typical of most CFBC systems. Solids captured by the cyclone are circulated back to the lower dense bed through an air.-fluidized siphon system. The remaining heating surfaces, eg, the air heater and economizer, are arranged in the second boiler pass.

Fuel is fed to the dense bed directly or premixed with the circulating solids. The maximum feed size for bituminous coal is approximately ^{1}/a to ^{1}/z" (6 to 12 mm). Nitrogen oxide (NO_x) control is achieved through staged combustion. Preheated combustion air is supplied as primary air through a distributor plate to the fluidized dense bed and as secondary air to the freeboard. Limestone for sulfur dioxide (SO_2) control may be added with the fuel on the conveyor feed belt or fed directly to the dense bed through a separate pneumatic feed system.

One of the characteristic features of Circofluid boilers is the dense bed and the control of combustion temperature. In Circofluid systems the heat transfer and combustion processes are controlled separately. The dense bed, in which the coarse particles are burned, is operated at velocities of 13 to 15 fps. More than one half of the fuel heat release occurs in this zone with no in-bed cooling surfaces. Dense bed temperature is controlled to a constant value of less than 1600°F over the entire load range. Cooling is provided by the flow of recirculated cyclone solids or ash. The flow of circulated ash is controlled by air flow to the siphons. Heat absorbed by the recirculated ash is transported through the freeboard and transferred to the convective heating surfaces upstream of the cyclone. As a result of this design arrangement, approximately 80% of the total heat duty of the boiler occurs in the first boiler pass. An external heat exchanger is not required.

rience

Riley and Deutsche Babcock (DB) have been designing commercial fluidized bed steam generators since 1978. Currently, there are over 30 Riley or DB operating plants and facilities worldwide. The first commercial Circofluid unit went into operation in 1988 at the ROmerbrOcke cogeneration plant in Saarbrilcken, Germany (2). Riley installed the first Circofluid boiler in the U. S. in 1990 at the Archbald Power Cogeneration Facility located near Scranton, PA (3). Overall, 24 Circofluid units have now been sold. Eight units are in operation with 16 soon to come on-line. A listing and description of these units is given in Table 1. The units now in operation have achieved NO_X emissions of 0.15 lb per million Btu or less without post combustion control. Sulfur retentions or $S0_2$ removal efficiencies of 90% or more at Ca/S molar ratios of 2 to 3 have also been demonstrated (2, 3). Overall combustion efficiencies have exceeded 99%

SCALE-UP ISSUES

Plant Size

One of the major considerations in scaling Circofluid and other fluidized bed combustion systems to utility scale systems of 100 MW or more is the impact on the fluidization and combustion. Dense bed mixing is important for both fuel, sorbent and ash distribution. The penetration depth of secondary air into the upper combustor or freeboard is another important design consideration. Both of these factors are directly related to the cross-sectional area of the combustor.

Because of its higher fluidizing velocity and staged air system, Circofluid boilers have smaller cross-sectional areas than bubbling bed systems of similar capacity. Higher fluidizing velocities promote the mixing of fuel, ash and sorbent in the dense bed and reduce the number of required fuel feed points. Figure 2 illustrates the resulting scale-up of Circofluid boilers from 25 to 150 MW. Circofluid boiler designs have also been developed for capacities up to 300 MW.

There are other factors, in addition to' cross-sectional area, that influence scale-up. As shown in Figure 2, the boiler portion of the Circofluid system does not differ from a conventional pulverized coal boiler. Therefore, pressure part components and auxiliaries such as fans, air heater and baghouse are not limiting factors in scale-up. This is true of even process components. Since the solids recycle temperature is. lower than other CFBC systems, the cyclones and recycle system are much smaller for Circofluid boilers.

Table 2 summarizes the progression in size of Circofluid boilers. Several commercial plant designs are compared with a reference 150 MW design fired with Illinois No. 6 coal. The largest commercial Circofluid installation has been built for the German utility Rheinisch-Westfglisches Elektrizitatswerk (RWE). This 80 MW lignite-fired power station located near Cologne, Germany is currently undergoing start-up. Since the fuel is a low rank lignite with moisture content of up to 60%, the dimensions of the RWE unit correspond to a bituminous coal-fired unit of more than 140 MW in size.

Reheat Steam , cles

Reheat steam cycles do not require process design changes to Circofluid boilers. The upper combustor solids particle density in Circofluid systems is only 10 to 20% that of classic CFBC systems. As a result, reheat surface can be placed in the upper portion of the first boiler pass along with other high pressure heat transfer surface. A typical Circofluid reheat boiler design is shown in Figure 3. The heat transfer characteristics are well known for this reheater configuration and are identical to high pressure superheater and economizer surfaces.

The Circofluid boiler arrangement is very similar to a pulverized coal tower boiler design. This similarity is illustrated by the comparison given in Figure 4. The complexity of adding an external heat exchanger (EHE) in the solids recycle loop to accommodate reheat surface has been avoided.

Load Following

In the years ahead U. S. electric utilities are likely to experience a growing need for cycling as well as baseload capacity. A substantial need for peaking capacity already exists in some parts of the U. S. Circofluid systems have the same load response and part load characteristics as pulverized coal-fired boilers.

Some of the factors that have limited the load response of industrial fluidized boilers is their large refractory content and large inventory of recycle solids. Circofluid boilers use substantially less refractory than other CFBC systems. Only a thin coating of refractory is required over the dense bed and freeboard waterwalls to control erosion and heat absorption. The low cyclone inlet temperature also significantly reduces the amount of cyclone lining required. Figure 5 compares the Circofluid cold cyclone refractory design with other CFBC hot cyclone refractory designs. Lower hot face temperatures and smaller temperature difference across the refractory eliminate the cyclone as a limiting factor during cold start-up of Circofluid boilers.

Because of its low refractory content and low recirculating solids inventory, the load response characteristics of Circofluid boilers are similar to conventional pulverized coal-fired boilers. The maximum heat up rate is generally limited by drum thickness and the design of pressure part components. Load changes of 5 to 6% per minute have been achieved on several European units. These operating units have also demonstrated that minimum load can be achieved within 2.5 hours following a cold start and full load after approximately 3 hours.

Maintenance and Reliability

Maintenance and reliability are of prime concern to utility boiler operators. Outages due to refractory failure have been a major problem for many operating industrial fluidized bed boiler systems. Here again, the low refractory content of Circofluid boilers offers an advantage by reducing the risk of forced outage due to refractory failure. Refractory structural failures due to thermal shock are much less likely in a low weight refractory system. Thin silicon carbide and alumina tiles are used in the furnace and cyclones. Tiles rather than a monolithic refractory coating were first employed by Riley on its anthracite culm fired unit at Archbald, PA (3). The dense bed and freeboard waterwalls were lined with 1½" (40 mm) tiles. This tile system has proven to be hard, durable and easily maintained. Erosion can also be a problem in fluidized bed boiler systems and can lead to reduced unit availability. This is true even for CFBC systems without lower furnace "in bed" tube surfaces. As shown in Figure 6, erosion is a strong function of gas velocity as well as solids particle density, the abrasive nature of the ash, and the arrangement of heating surfaces. Process parameters place the Circofluid system in the pulverized coal-fired boiler operating range and far below that of traditional CFBC boilers. The potential for general, as well as localized, erosion in Circofluid boilers is much lower. We believe this is an important feature for meeting utility availability and reliability criteria.

SUMMARY

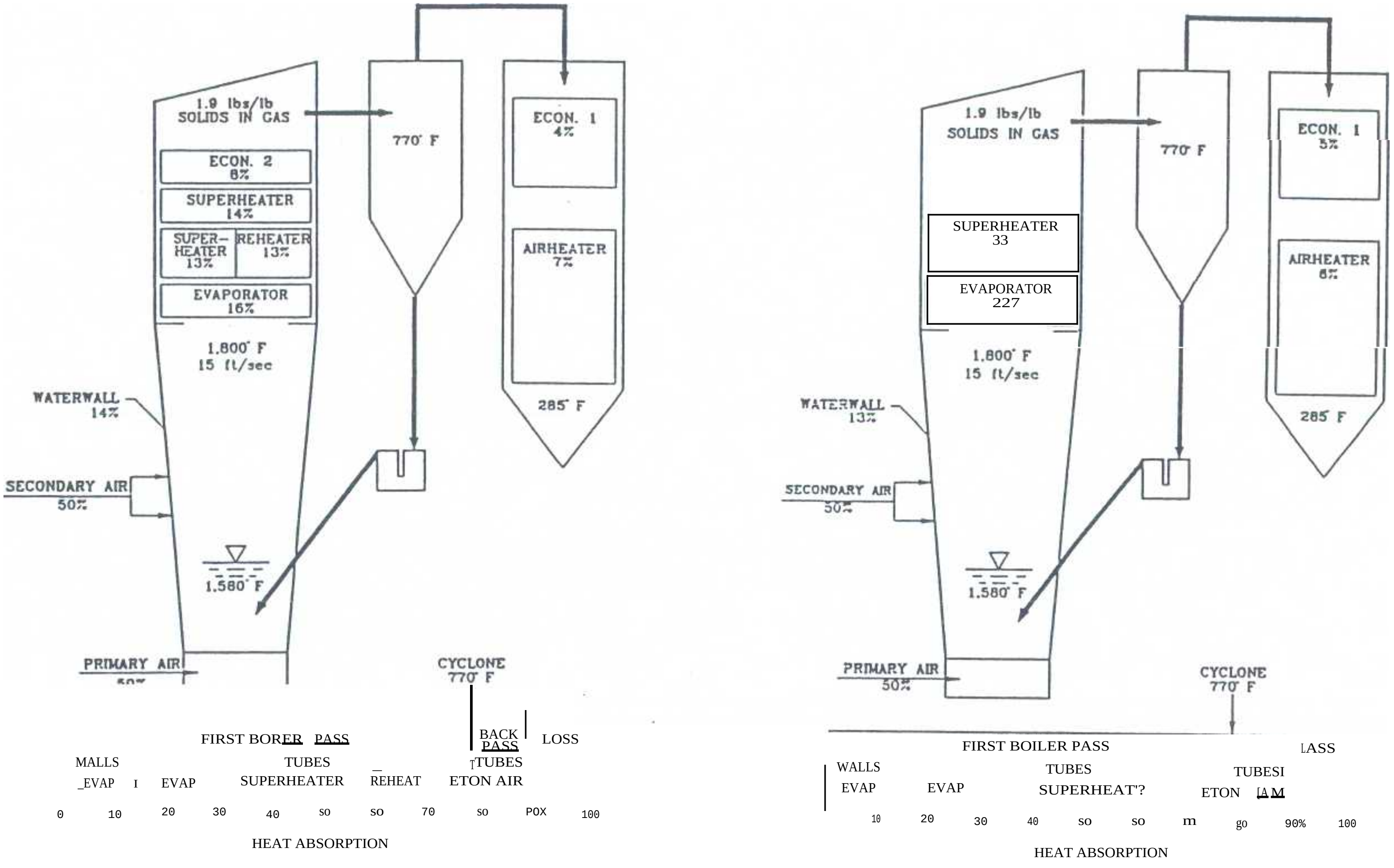
Circofluid boilers are well suited for large power station operation. A new utility-sized unit operating at a utility site is now coming on-line in Europe. Riley has developed standard Circofluid boiler designs for a full range of applications including utility boiler systems. Units of 150 MW and larger in size have been designed for reheat steam cycles. These designs build upon our recent commercial experience and can be applied to both high rank, high sulfur coals as well as lower grade fuels of variable quality. The operating characteristics of Circofluid boilers are comparable to pulverized coal-fired boilers. Commercial operating plants have demonstrated their performance under stringent environmental and operating requirements. Circofluid boilers have proven to be reliable and capable of following utility operating cycles.

REFERENCES

1. J. Makansi. "Boilers, Combustion Systems, and their Auxiliaries." Power, vol. 136, No. 6, June 1992, p. 51.

2. K D. Tigges and D. Kestner. "Experience with the Commissioned Operation of the SaarbrOcken Circofluid Boiler." In Proceedings of the 1989 International Conference on Fluidized Bed Combustion. Vol 1, 1989, pp. 625-631.

3. D. J. Kestner. "Operating History of a 20 MW Culm-Fired Circofluid Boiler." Presented at the International Power Generation Conference, 91-JPGG-Pwr-41, San Diego CA, October 1991.



a. Reheat Design

b. Non-Reheat Design.

Figure 1. Circofluid Process Diagrams for Reheat and Non-Reheat Boiler Designs Fired with Bituminous Coal.

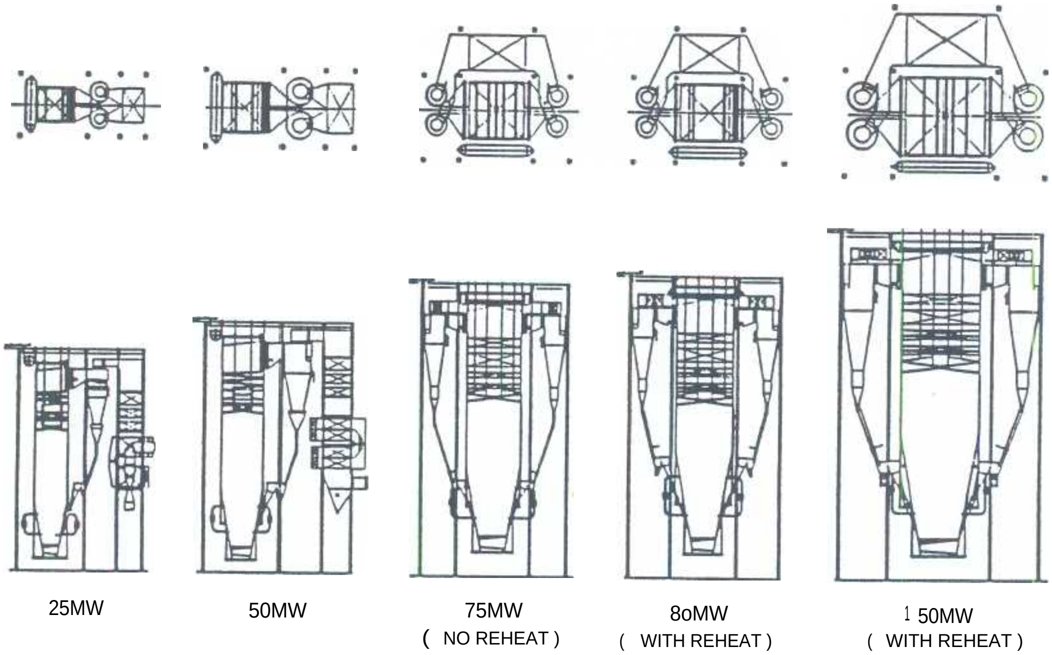


Figure 2. Scale-up of Circofluid Boilers From 25 to 150 MW.

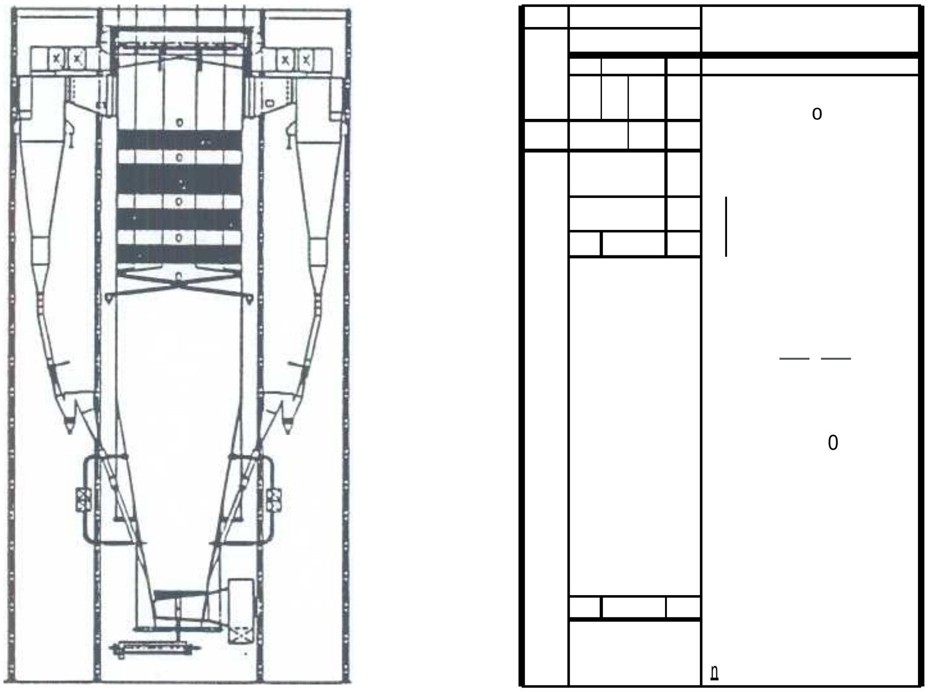


Figure 3. Typical Circofluid Reheat Boiler.

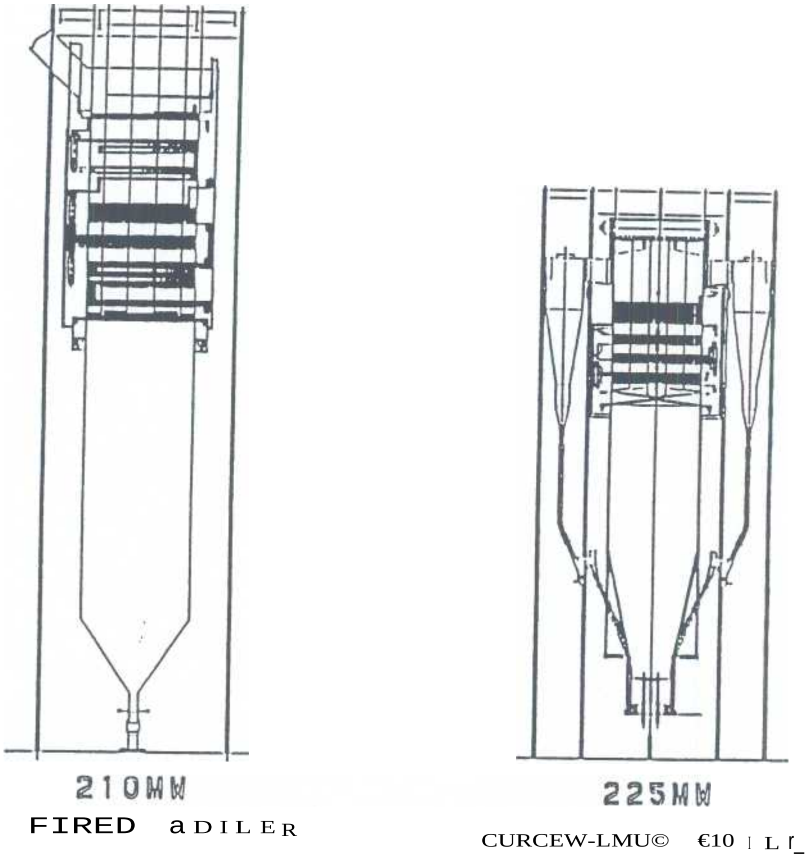
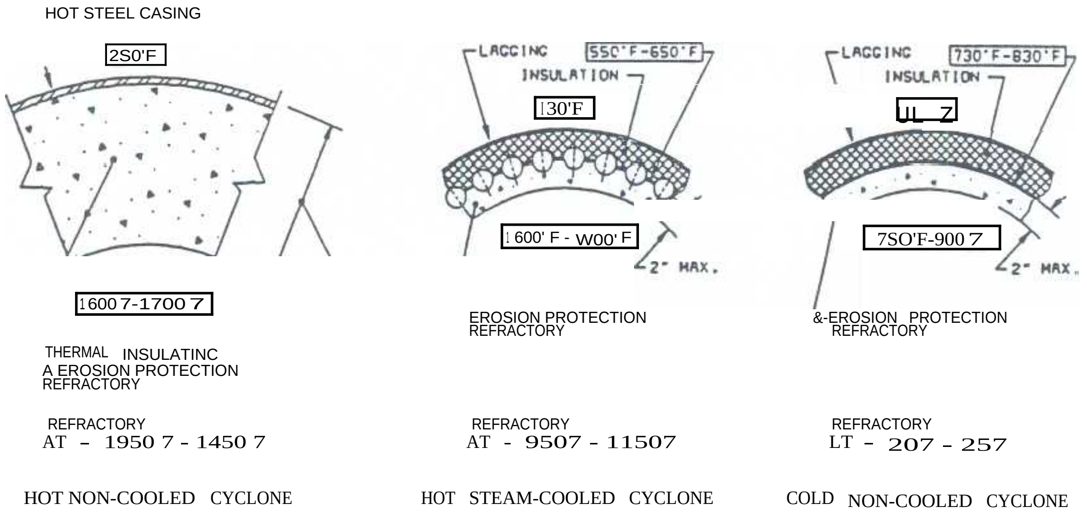


Figure 4. A Comparison of Circofluid and Pulverized Coal-Fired Boiler Designs.



HOT NON-COOLED CYCLONE HOT STEAM-COOLED CYCLONE COLD NON-COOLED CYCLONE

Figure 5. Cyclone Refractory Comparison.

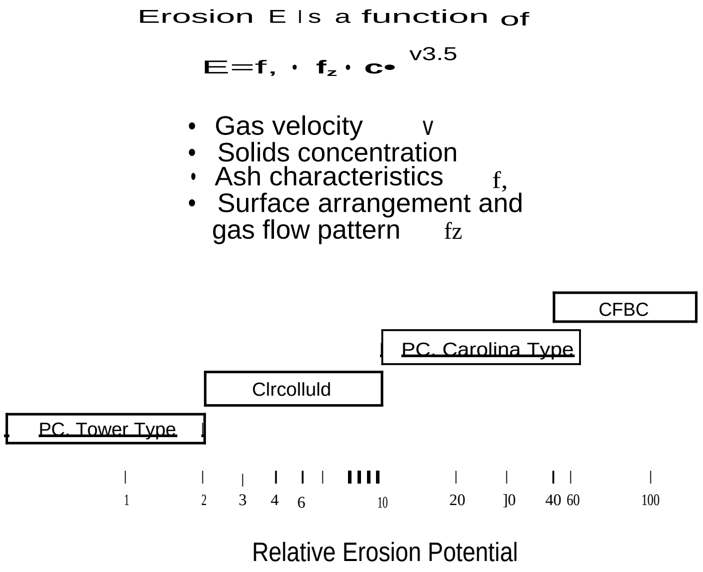


Figure 6. Erosion Potential of Circofluid Versus Other Coal-Fired Boilers.

Table 1

Circofluid Installation List.

Client and Location of Plant	Number	Steam Capacity kpph	Steam Pressure psig	Stcnm 'Temp 'F	Fuel	Year of Commission.
Deutsche Babcock AG Fricdrichsfcld/Germany	1	7 MBIUAtr	--	-	C/US	1985
Energieversorgung Offenbach AG Offenbach/Germany	2	244	1,155	995	C	1988
Stadtwerke SaarbrUckcn AG 14KW R6mcrbrocke SaarbrUckcn/Germany	1	330	1,640	995	C/S	1983
Kawasaki Heavy Industries Akashl/Japan	1	3 MB11J/hr	--	--	C/US	1988
Deutsche Solvay-Wcrkc Rheinberg/Germany	1	1'13	1,700	977	C	1989
Archbald Power Corporation Pennsylvania/USA	1	200	1,335	995	S	1990
GEW Min AG - HKW Mcrheim Cologne/Germany	1	114	1,230	977	L	1991
CEZ - HKW Trmice V Trnticc/CSFR	2	353	1,960	1,004	L	1993
Rhelnisch-Wcstf5liscltcs Eiektrizitdtswcrk AG Goldenbcrg-Werk/Gennany	1	640	1,155	941	L	1992
Hal Cheng lleat & Power Llaoning/China	3	165	780	842	C	1993
Bayer AG Krefeld-Uerdingen/Germany	1	300	1,870	1,004	C/L	1992
Zhang Zhou Fujian/China	3	165	570	842	A	1993
Suedzucker AG Zcitz/Germany	1	220	1,350	999	L	1993
SEP Novaky A Novaky/CSFR	1	276	1,380	1,004	L	1994
Luoyang Henan/China	2	287	780	842	C	1994
Jin-Zhou Llnoning/China	3	165	780	842	C	1994
TATA Chemicals Ltd. Mithopur/fndia	1	441	1,620	1,058	C/L	1994

A = Anthracite
C = Bituminous Coal
L = Lignite
S = Special Fuels

Table 2

Circofluid Boiler Scale-Up Parameters.

UNIT	ARCHBALD	BAYER	SAARBRUCKEN	RWE	150 MW+
Design Fuel	Culm	Anthracite	Bituminous	Lignite	Bituminous
HHV, Btu/lb	4,200 60:	14,000	8,600	4,200	11,250
Ash, %		6	36	8	12
Moisture, %	5;,	8	6	50	12
Sulfur, %	0.3	0.8	1.2	0.5	3.5
Steam Flow, lb/hr		300,000	330,000	640,000	1,005,000
		25,000	56,000	220,000	120,000
	300,000	340,000	450,000	1,140,000	1,320,000
Furnace Bottom Plan, ft x ft	7 x '26	9 X 20	12 X 20	17 X 44	18 X 47
Freeboard Plan, ft x ft	14 x 26'	20 X 20	21x20	32x44	30x47
Number of Feed Points	4	4	8/4*	8	8
Number of Cyclones	2	2	4	4	4
Cyclone Diameter, ft	10	11	8	12.5	13

* Fuel feed on one side only
Reference Plant Design