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COMPUTER AIDED DERATING ASSESSMENT OF OIL-DESIGNED WALL-FIRED UTILITY BOILERS USING COAL-WATER SLURRY FUEL

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COMPUTER AIDED DERATING ASSESSMENT OF OIL-DESIGNED WALL-FIRED UTILITY BOILERS USING COAL-WATER SLURRY FUEL

by

S.R. Griffin*, W.A. Shaw* and H. Whaley**

ABSTRACT

In order to assess the potential derating of oil-designed utility boilers when using coal-water mixtures fuels, CANMET has issued two contracts to Babcock & Wilcox Canada. The first contract, described in this report, was to make a computer aided assessment of the derating of two typical Eastern Canadian front-wall fired boilers representing the extremes of operating practice for this type of boiler. The derating was to be assessed for two boiler sizes 60 and 200 MW(e), coal-water mixtures of high ash and low ash composition and also for pulverized coal firing.

A similar contract describing the potential derating of tangentially-fired boilers typical of Eastern Canada has been completed and will be reported in the near future.

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ÉVALUATION À L'AIDE DE L'ORDINATEUR DU TAUX DE RÉDUCTION DE CHAUFFE DES CHAUDIÈRES À BRÛLEUR AVANT CONÇUES POUR UTILISER DU PÉTROLE ET ALIMENTÉES EN BOUES CHARBON-EAU

par

S.R. Griffin*, W.A. Shaw* et H. Whaley**

RÉSUMÉ

CANMET a accordé deux contrats à Babcock & Wilcox Canada en vue d'établir les taux de réduction de chauffe possibles des chaudières conçues pour l'utilisation du pétrole et alimentées en mélanges charbon-eau. Le présent rapport traite du premier contrat accordé visant à établir, à l'aide d'un ordinateur, les taux de réduction de chauffe de deux chaudières typiques.à brûleur avant de l'Est du Canada qui sont des cas extrêmes dans cette catégorie au niveau du fonctionnement. L'évaluation visait l'établissement des taux de réduction de chauffe de deux chaudières de 60 et de 200 MW(e) alimentées en mélanges charbon-eau à haute et à faible teneur en cendres et en charbon pulvérisé.

Un autre contrat portant sur l'évaluation des taux de réduction de chauffe possibles des chaudières à bruleur tangentiel utilisées habituellement dans l'Est du Canada a été réalisé et fera l'objet d'un rapport ultérieur.

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INTRODUCTION

Largely as a result of skyrocketing prices in the 70's, government policies aimed at reducing the use of oil in electric power generation have been formulated and put in-place in most industrialized western countries. Canada, being no exception, announced the creation of the Utility Off-Oil Fund and the establishment of other special Atlantic initiatives as part of the National Energy Program (NEP) in 1980.

These policy thrusts were two pronged in approach. The immediate priority in Canada's Atlantic region was to replace existing oil fired capacity with lower-cost alternatives. To this end, government funds were allocated "...to finance on a grant basis up to 75 per cent of the cost of environmentally acceptable conversions of oil-fired electricity plants to coal." (1).

The second priority identified for regional electricity development was to provide government support for those investments that are considered essential longer-term steps in the efficient expansion of the non-oil generating systems. This longer-term focus included financial support for hydroelectric development in Labrador, funding and technical support for exploratory tunneling and assessment of indigenous coal reserves, and government funding in support of coal research and development and the eventual commercialization of new coal-use technology.

More recently and to address both the immediate and secondary statements of priority, Energy, Mines and Resources Canada (EMR), has singled out the development of coal-water slurry fuel technology as one area of high potential. As a result, under the special Atlantic initiatives, Coal Utilization Program, funding is being provided to build a commercial coal-water slurry fuel preparation plant, to develop burners to burn the fuel and to demonstrate the combustion of this fuel in utility boilers.

In technical support of these programs, CANMET and Babcock & Wilcox Canada (BWC) initiated an investigation into the potential reduction in maximum steam generation capability when coal-water slurry fuel is fired in a boiler originally designed for fuel oil. It has been recognized that significant boiler derating could have a major impact on coal-water slurry economics and the initiatives currently underway.

This paper presents the results of a computer aided derating study of coal-water slurry firing. Study "ground rules" and assumptions with respect to unit selection, basic equipment scope, fuel quality and performance parameters are reviewed. In addition, some consideration has been given to the limiting impact of auxiliary equipment typically incorporated in oil fired boilers. The potential for equipment modifications is also discussed.

The results developed and presented are generic in nature. General trends and the derating interrelationships between various boiler performance parameters can be extracted from this review, however, a careful assessment of site specific limitations and their impact on unit derating would probably be required prior to drawing any conclusions regarding the economic or technical attractiveness of converting any existing oil-designed generator to coal-water slurry firing.

STRATEGY AND METHODS

To ensure the broadest range of applicability and to produce a cornerstone reference for future site specific derating studies, a generic approach was selected. The study plan incorporated such basic steps as the selection and design of the reference oil-capable boilers, a derating assessment for pulverized coal firing and, finally, a derating assessment for firing coal-water slurry (where the slurry is produced from the same coal used in the pulverized coal derating review). The main factors contributing to derating were evaluated and ranked in priority, without introducing site specific variables.

REFERENCE UNIT SELECTION

Since the program was to be carried out under the special Atlantic initiatives, the reference units were selected to reflect the size and style of oil-capable, wall-fired utility boiler typically found in Eastern Canada. A detailed review of Maritime generating stations was conducted to ensure that the boiler performance parameters used in the design of the reference units was representative of those used in the design of existing East Coast equipment.

Two very different boiler styles, each in two sizes, were selected as the reference units for this study: small and large Babcock & Wilcox El Paso design and small and large Babcock & Wilcox Carolina design. These units were designed to current B&W standards for oil firing. Care was taken to maintain the generic nature of the design and avoid the incorporation of any site specific prejudice. Figures 1 and 2 present the El Paso and Carolina style reference units, respectively. Full load steam conditions for these units are given in Table 1.

FUELS SPECIFICATION

The heavy oil, parent pulverized coal and resulting coal-water slurry fuels specified for this study are detailed in Tables 2 and 3. Both high ash (as received) pulverized coal (PC) and slurry alternative and low ash (beneficiated) PC and slurry alternative were examined.

MODELLING

As noted above, four oil-designed units representing typical B&W El Paso and Carolina style boilers were selected for study.

In analyzing the performance of these units for the different fuels, two computer models were used. The first, a multiple zone furnace model performs combustion calculations and, for a required boiler output, determines unit efficiency and required fuel and air inputs. These data are used in combination with furnace emissivity, to calculate furnace absorptions and the flue gas temperature at the furnace exit plane.

The convection pass model uses outputs from the furnace model to calculate heat transfer performance, select and economically group superheater tube materials and calculate gas and steam-side pressure drops for the particular convection section geometry.

In the initial reference unit design, these programs were used in setting the geometry and arrangement of each steam generator for full load oil operation. In the subsequent derating calculations, steam generator geometry remained fixed and, using the design and performance parameter limits for the pulverized coal or slurry, these programs were used to calculate the output available from each generator.

The calculated output was then compared with the oil fired full load output to quantify the basic unit derating (BUD), resulting from that particular fuel conversion.

SCOPE AND ASSUMPTIONS

The scope of this study was limited to the consideration of the boiler proper, fans, regenerative air preheaters and sootblowers. It is to be recognized that coal slurry technology is still in the developmental stage hence proven performance of burners and fuel train is not available.

To complete this study, a number of limiting assumptions had to be made. These deal primarily with the boilers, the fuels, and coal-water slurry-firing boiler performance parameters.

BOILERS

- The superheater/reheater control range for the oil firing reference designs was assumed to be from 100 to 60%.
- BUD calculations were made assuming no changes to boiler pressure parts.
- Appropriate burner, fuel train and boiler control design is assumed to be available for retrofit to produce the minimum acceptable performance specified herein.
- The necessary changes to handle the ash resulting from coal or coal-water slurry firing were not considered.
- No consideration was given to the impact of coal-water slurry conversion on boiler structural steel.
- Reheat steam temperature control for the large El Paso style unit is achieved with burner level input modulation, whereas the Carolina unit uses gas recirculation.

FUELS

- It was assumed that beneficiation to a "low ash" coal would have no effect on the ash elemental analysis.
- It was assumed that slurrying would have no effect on the ash elemental analysis, the ash fusion temperature, or the slagging and fouling potential of the parent coal (2).

PERFORMANCE

- Since there is little full scale operating data available, many of the slurry-firing performance parameter limits had to be assumed. For the purpose of this study, pulverized coal limits were applied to the following slurry-fired parameters:

- heat input per burner
- burner zone heat release rate
- plan area heat release rate
- furnace exit gas temperature
- furnace volumetric liberation rate
- flue gas velocity
- allowable tube spacing vs. gas temperature
- excess air quantities
- surface cleanliness factors

- For the beneficiated coal and coal-water slurry cases, it was assumed that the reduced ash content would correspondingly reduce the requirements for erosion barriers in the convection sections.
- No consideration was given to the effects of the slurry atomizing medium on performance of the units.
- Based on B & W coal-water slurry experience, it was assumed that a minimum secondary air temperature of 260°C (500°F) would be required for stable combustion.
- The unit performance for coal and coal-water slurry firing was determined at the maximum attainable boiler loads. No part-load performance was considered.

TECHNOLOGY

Prior to a detailed discussion of the results, a brief review of the El Paso and Carolina designs and some of the more important design and performance parameters is in order.

EL PASO DESIGN

The El Paso style boiler was developed for oil and gas firing applications. Since there is little ash in the combustion products, tube metal erosion in the convection pass is not a limiting design consideration. Consequently, gas velocities in the convection banks of an El Paso style unit are comparatively higher than those in a coal-designed boiler. This will result in a tight, compact convection section arrangement in that the high velocities promote high heat transfer efficiencies and minimize the overall heating surface requirements; and the high allowable velocities also permit the designer to select fairly narrow transverse tube spacing, which maximizes the heat transfer surface to volume ratio in the convection pass (Fig. 1).

The El Paso design is characterized by a horizontal arrangement of all heating surfaces which can be drained by gravity. The efficient and compact convection section design allows the placement of all superheater, reheater and economizer surfaces above and within the same plan area as the furnace.

Overall, for oil and gas firing, the El Paso style unit is very cost effective. However, field modifications to the convection section for pulverized coal or coal-water slurry firing could be complicated by the initial compact arrangement of superheat/reheat tube banks and their tube support design.

CAROLINA DESIGN

As a result of the different combustion kinetics of coal and the presence of ash, boilers designed for coal firing are larger than those for oil. The features that typically characterize the coal-designed unit (in contrast to oil-designed) include a relatively large furnace, a more steeply sloped hopper with a wider hopper throat, more liberal burner spacings, soot-blowing capability in both the furnace and convection passes, and wider convection surface spacing. For this study, it was assumed that these features would also characterize a coal-water slurry designed unit. Allowable gas velocities and gas temperatures in the convection banks are lower for coal firing than for oil or gas firing.

At the design stage, these limits are set by the ash slagging and fouling potential and by the abrasive potential of the fly ash. The lower allowance velocities and temperatures lead to a requirement for more heat transfer surface in the convection section of coal fired units.

The Carolina style boiler was developed to accommodate the larger amounts of convection surface. In this type of unit, large quantities of wide spaced heat transfer surface are hung, pendant-style, in the high gas temperature regions in the upper furnace and crossover area (Fig. 2).

In general, an oil firing Carolina boiler would only be seen when the unit-style selection had been made on the basis of oil firing with future provision for coal or when the unit was originally designed for coal firing and then converted to oil at some point in its operating history.

DESIGN PARAMETERS

Heat Input per Burner

The heat input per burner is limited by either the furnace depth or the burner's proximity to adjacent burners or water cooled surface. Care must be taken to avoid elevated spot absorption rates, flame impingement or, in the case of coal firing, excessive slagging.

Burner Zone Heat Release Rate

The burner zone heat release rate (BZHRR) is defined as the total burner heat release divided by the water cooled surface area in the burner zone. The burner zone area is defined as the flat projected water cooled surface in the vertical walls surrounding the combustion zone, plus the flat projected area of the horizontal furnace plane below the burners. Limits are imposed upon this parameter in order to control NO_x generation in the furnace. In coal fired units, the application of these limits also helps to minimize lower furnace slagging.

Plan Area Heat Release Rate

The plan area heat release rate (PAHRR) is defined as the input divided by the furnace plan area at the burner level. Allowable limits for coal firing are usually between one-half and two-thirds of the permitted PAHRR's for oil or gas firing. The exact limits applied to coal fired units depend upon the slagging classifications of the coal.

Furnace Volumetric Liberation Rate

The furnace volumetric liberation rate (FVLR) is defined as the input per unit furnace volume and is related to particle residence time in the furnace. Limits are applied only for coal firing and specifically to minimize unburned combustible losses and the resultant reduction in boiler efficiency.

Furnace Exit Gas Temperature (FEGT)

FEGT is often empirically related to such parameters as the heat available to the furnace and the furnace surface available for heat transfer.

Ideally, the furnace box must be large enough that the combustion products entering the convection banks have been cooled to a level consistent with the fouling characteristics of the fuel being burned.

For coal firing, this usually means that the FEGT is limited to some temperature below the initial deformation temperature (IDT) of the ash. FEGT's for oil or gas firing - where fouling is not an issue - are typically much higher.

Convection Pass Gas Velocities

For coal firing, tube metal loss due to erosion is related to the total ash quantity passing through the unit. It is also an exponential function of the flue gas velocity. Since, for a given coal, the total ash is fixed, the method used to ensure minimal erosion is to limit gas velocities to acceptable levels. Limits are usually applied in the convection passes where velocities are the highest.

For oil or gas-designed and fired units, where erosion problems are not expected, allowance convection pass gas velocities are much higher.

Tube Side Spacing vs Flue Gas Temperature

Convection section transverse tube spacing and flue gas temperature are two parameters that are examined and evaluated jointly in the design of a coal fired unit.

Limits are imposed on the pairing of these parameters so as to prevent the build-up and eventual bridging of ash deposits between adjacent bundles. These bridges, were they to occur, could plug sections of the convection pass and cause an off-design heat absorption pattern to be set up.

Although the limits applied to spacing vs. temperature depend on the fouling characteristics of the coal being fired, the general trend is that the higher the gas temperature, the wider the required side spacing.

RESULTS AND DISCUSSION

Table 4 details the BUD (Basic Unit Derating) calculated for each of the 16 boiler-type/ fuel combinations. The range of BUD varies from 37 to 59%. Also shown in Table 4 is the design parameter which has been identified as the load limiting factor (LLF) leading to the BUD. Although it varies for the different unit sizes and types, for each particular unit, this limiting factor is independent of the fuel alternative.

Additionally, to rank the derating impact of other design parameter limits, a series of derating sensitivity calculations was performed. These involved calculating the deratings that would result from a particular performance parameter design limit, while neglecting the effects of all other limits - particularly those resulting in a more severe unit derating. For high and low ash coal-water slurries, the results are presented graphically in Fig. 3 to 6.

SMALL EL PASO

Table 4 shows that converting the small El Paso unit from oil firing to coal or coal-water slurry firing would produce a BUD of approximately 60% for all the studied fuel options. This result stems from a consideration of the limits imposed on FEGT when firing an ash-laden fuel.

In practice, two constraints would combine to produce this derating. The first is only concerned with design limits - where the maximum permissible FEGT's for the coal or coal-water slurry firing are lower than those for oil. The second is a consequence of the presence of ash in the fuel and the resultant impact on furnace heat absorption.

Firing pulverized coal or coal-water slurry would result in slag deposits on the furnace walls. Due to the relatively low thermal conductivity of this slag, the furnace wall tubes may be partially insulated and this would tend to reduce the heat absorption capability of the furnace. Unless the coal or coal-water slurry firing rate is cut-back, the reduced furnace heat absorption will result in an increased FEGT which will give rise to a number of downstream problems.

To avoid this FEGT excursion and meet coal firing design limits, while allowing for furnace slagging, the coal or coal-water slurry firing rate in this oil-designed El Paso unit must be reduced to a level such that the maximum attainable boiler load is cut to 42% for pulverized coal firing and 41% for slurry firing, (i.e., derated by almost 60%).

The slightly lower attainable load for coal water slurry firing is a result of the reduced boiler efficiency due to the need to evaporate the moisture added during slurrying.

Beneficiation to a "low ash" coal or slurry was seen to have no impact on the FEGT-based BUD.

Figure 3 shows the ranking and relative derating impact of other performance parameters for the high and low ash coal-water slurry cases. Consideration of side spacing vs. gas temperature in the convection banks resulted in a deration comparable to the BUD. This was due to the relatively tight side spacing of convection surface at the furnace exit.

The next most critical parameter was convection pass gas velocity. Coal fired design limits applied to this parameter produced a deration of 45% for high ash coal-water slurry and 36% for the low ash slurry. The nine percentage point difference was a consequence of the assumption that erosion shields would not be required in the beneficiated case due to reduced ash loading. The absence of erosion shields results in the full use of the convection pass free flow area and, therefore, lower gas velocities.

The next most critical parameter was FVLR. Since it primarily deals with residence time and unburned combustible loss, this parameter is not normally considered nor limited on a unit designed solely for oil or gas firing. Neglecting the impact of all other parameter limits, the coal firing limits on liberation rate could only be met - in this oil-designed furnace - if the coal water slurry firing rate is decreased to a level such that the maximum attainable boiler load is reduced to 61% of the full load capability on oil.

No load derating effect was seen when coal fired design limits were applied to the heat input per burner, the BZHRR and the PAHRR. This is an outgrowth of the fact that, often, on small boilers with relatively low heat inputs, the physical space and clearance necessary to install the burners is well in excess of the clearances that would be specified by only considering heat release rates in the burner zone.

In this case burner clearance requirements were such that oil firing limits on the heat input per burner, the BZHRR and the PAHRR were never closely approached and, when the more severe coal firing limits were applied, there was still ample margin to meet full load requirements.

LARGE EL PASO

As seen in Table 4, the BUD for the large El Paso reference unit varies from 37 to 47%. In this case, convection pass gas velocity - particularly gas velocity entering the first primary superheater bank - was identified as the load limiting factor.

For both pulverized coal and coal-water slurry, a derating variation was noted between the high and low ash cases. As with the small El Paso unit, this was a consequence of the assumption that erosion shields would not be required in the beneficiated case.

As well, for both the high and low ash cases, the coal-water slurry deratings were slightly higher than those for pulverized coal. This was due to the slurry's higher moisture level, resulting in a greater quantity of combustion gas for the same fuel (Btu) input. The increased combustion gas flow directly translates to higher operating gas velocities which, in turn, result in slightly higher derating levels when subject to the coal firing design limits.

Figure 4 details the impact of other performance parameters for both the high and low ash coal-water slurry cases. As with the small El Paso unit, coal fired limits applied to FEGT and tube side spacing vs gas temperature result in comparable unit deratings - followed by FVLR.

Unlike the small El Paso, however, coal fired limits imposed on the heat input per burner and the PAHRR now come into play, resulting in marginal unit derating. For this size of oil-designed unit the mandatory burner installation clearances do not necessarily result in highly conservative oil fired heat release rates at the burners and when the more stringent coal fired limits are applied, the noted deratings result.

SMALL CAROLINA

For the small Carolina reference unit, the BUD was calculated to be 40% for coal-water slurry firing and 42% for pulverized coal. The load limiting factor was tube side spacing vs. gas temperature.

In contrast to the pattern established by the El Paso units, the pulverized coal fired BUD for this boiler is greater than for the coal-water slurry firing. In this case the derating advantage to slurry firing is attributable to the moisture added during slurry preparation. This increased moisture results in higher moisture content in the flue gas and increased flue gas flow due to less efficient combustion. This ultimately resulted in a lower flue gas temperature (for coal-water slurry firing) entering the tightly spaced reheat surface of the Carolina style units due to more efficient heat transfer to upstream surface.

In comparison with the small El Paso, Fig. 5 shows that the application of Carolina-style design standards results in a relatively liberal furnace configuration - the FEGT and FVLR based deratings are much lower for the small Carolina than for the El Paso. As well, the deratings required to meet convection pass gas velocity limits are lower. As before, with the small relatively low input furnace, no derating results from the application of coal fired limits to heat release and heat input parameters in the burner area.

LARGE CAROLINA

The BUD for the large Carolina-style reference unit were established at 58% for pulverized coal firing and 56% for coal-water slurry. As with the small Carolina unit, the load limiting factor was tube side spacing vs gas temperature and, therefore, the coal-water slurry derating was lower than that for pulverized coal firing.

The next most critical performance parameter limit was that applied to convection pass gas velocity, followed by FEGT (Fig. 6). Again, the Carolina-styled unit tends toward a more liberal furnace design with a less severe FEGT-based derating than the comparable sized El Paso. Of special interest in these results are the unit deratings resulting from the limits applied to the heat input per burner and the BZHRR. A review of Fig. 1 and 2 shows that, in contrast to the square-shaped El Paso, the plan area of the Carolina is rectangular. As such the Carolina furnace is not as deep as that on the El Paso and, for coal firing, a lower allowable heat input per burner must be specified in order to preclude rear wall flame impingement. Therefore, and in comparison with the El Paso results, heat input per burner limits applied to the large Carolina produce a more severe boiler derating.

The burner pattern (the number of rows of burners and the number of burners per row) is another area where furnace geometry can impact unit derating potential. As can be seen in Fig. 1 and 2, the burner pattern selected for the large El Paso and Carolina reference units was different. Largely due to the use of one less burner row, the burner zone area on the Carolina was smaller than that on the El Paso and, for the same heat available, the original oil-design BZHRR was higher. As a result, the application of coal firing limits to the Carolina burner zone led to a unit derating of 13% for both the high and low ash coal-water slurries whereas no comparable derating was seen on the El Paso.

The PAHR deratings on the El Paso and Carolina units were comparable.

AUXILIARY EQUIPMENT

Converting an oil-designed unit to fire coal-water slurry will affect the selection and operation of equipment such as fans, regenerative air heaters and sootblowers. The degree to which this will occur is somewhat a function of unit size.

SMALL OIL FIRED BOILERS

Small oil fired boilers normally have one forced draft (FD) fan, one steam coil air heater (SCAH) and one regenerative air preheater. Characteristically, these units operate with a pressurized furnace. Due to the presence of ash fines, however, pressurized operation would not normally be recommended for pulverized coal or coal-water slurry firing and, therefore, an induced draft (ID) fan should be retrofitted for balanced draft operation.

Assuming the addition of an ID fan, a review of the coal-water slurry fired FD fan duties showed that, at BUD loads, the fan would be operating well within (and below) its operating capabilities. Since this could result in some instability problems and would definitely limit the available turndown, a detailed investigation of fan operating characteristics would be necessary to ensure satisfactory operation.

An examination of the oil-designed regenerative air preheater showed that, although the heater has more surface than necessary, minimum acceptable performance limits could be met when firing coal-water slurry at BUD loads. This, however, would require continuous operation of the steam coil air heater for cold end corrosion protection.

Converting an oil-designed unit to coal-water slurry firing will require the installation of additional sootblowers due to the increased potential for furnace slagging and fouling of the convection surface. For the small Carolina or El Paso units, the number of blowers installed for oil firing would roughly have to be doubled to accommodate coal-water slurry.

LARGE OIL FIRED BOILERS

Units in this size range are usually balance draft fired with two FD fans, two ID fans, two regenerative air preheaters and two steam coil air heaters (SCAH). As well, the Carolina-style units usually include two gas recirculation fans for reheat steam temperature control at reduced loads.

An examination of the oil-selected forced and induced draft fans showed that, as with the smaller boilers, the fan duties would be well below fan capabilities when the units were operating at BUD loads. Again, fan instability problems might result. On the other hand, the additional option of using only one force draft fan, rather than two, provides extra turndown capability.

A review of gas recirculation fans for the large Carolina showed that, based on a reduced reheat steam exit temperature, the gas recirculation fans selected for oil firing would be adequate for coal-water slurry firing.

The oil-selected regenerative air preheaters for both large reference units were analyzed with respect to coal-water slurry firing at BUD loads. This analysis showed that these units provide only marginal performance and that the secondary air temperatures may not be high enough to support stable combustion when firing coal-water slurry. Some steam coil preheat of secondary air may be necessary.

As with the smaller units, conversion to coal-water slurry firing would necessitate a doubling of sootblower capacity.

MODIFICATIONS TO REDUCE DERATING

To reduce the derating impact of coal-water slurry firing in an oil-designed boiler, a number of options involving field modifications to the unit are available. From a practical point of view, probably the most effective unit modifications would be those that would serve to reduce Furnace Exit Gas Temperature (FEGT), reduce flue gas velocities in the convection pass or increase convection section tube side spacing while not seriously degrading the unit's load generation capability on oil.

As noted earlier, one of the singularly most important parameters when firing pulverized coal or coal-water slurry is FEGT. As long as this temperature is kept below the Initial Deformation Temperature (IDT) of the ash, convection bank deposition will remain manageable. One obvious method of controlling and reducing FEGT is to limit the heat input to the unit, i.e., to derate the boiler. In some cases, however, this reduced load operation is not economically feasible.

Another method available for FEGT reduction is to place more heating surface in the furnace. This can be accomplished by using water cooled wing walls located in the upper furnace. This modification would require a detailed engineering study to ensure that boiler circulation is maintained and cyclone steam separators are not overloaded.

Finally, for units using gas recirculation for reheat steam temperature control, another method available to reduce FEGT is gas tempering. With this technique, recirculated gas extracted at the economizer exit is introduced to the furnace just below the furnace exit plane. This cooler flue gas reduces the gas temperature entering the convective heat transfer surface without affecting furnace heat absorption.

Where the load-limiting performance criterion is flue gas velocity or tube side spacing vs gas temperature, the tube spacing can be altered by removing alternate tube rows or replacing entire banks of tubes. However, as noted previously, convection pass re-arrangement on an El Paso-style unit will be complicated by the initial compact convection section design. This would be especially true in situations where the removed surface would have to be added elsewhere in the boiler to meet the steam temperature requirements.

SUMMARY AND CONCLUSIONS

Neglecting any and all site specific considerations, the boiler performance-related deratings resulting from coal-water slurry firing in oil-designed, wall-fired units, typical of those found in Eastern Canada, could be expected to range from 0 to 60%, depending on the unit modifications. The major and most critical derating parameters are Furnace Exit Gas Temperature (FEGT), convection pass gas velocity, and convection pass tube side spacing vs gas temperature.

As previously stressed, these results and conclusions are generic and as such, a complete and detailed engineering study, incorporating all site specific variables, would be necessary before the practical and economic impact of coal-water slurry conversions at a specific site could be assessed.

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Table 1 - Steam conditions

	Small	Large	Units
Secondary superheater outlet			
- Flow	0.3175 (700)	0.5511 (1 215)	10^6 tonnes/h (10^6 lbs/h)
- Pressure	9 053 (1 313)	13 508 (1 959)	KPa (Psig)
- Temperature	516 (960)	541 (1 005)	°C (°F)
Reheat Outlet			
- Flow	-	0.4694 (1 035)	10^6 tonnes/h (10^6 lbs/h)
- Pressure	-	2 592 (376)	KPa (Psig)
- Temperature	-	541 (1 005)	°C (°F)
Feedwater			
- Flow	0.3175 (700)	0.5788 (1 276)	10^6 tonnes/h (10^6 lbs/h)
- Pressure	9 963 (1 445)	14 582 (2 115)	KPa (Psig)
- Temperature	226 (440)	414 (446)	°C (°F)
Drum Operating Pressure	9 846 (1 428)	14 369 (2 084)	KPa (Psig)

Table 2 - Heavy fuel oil

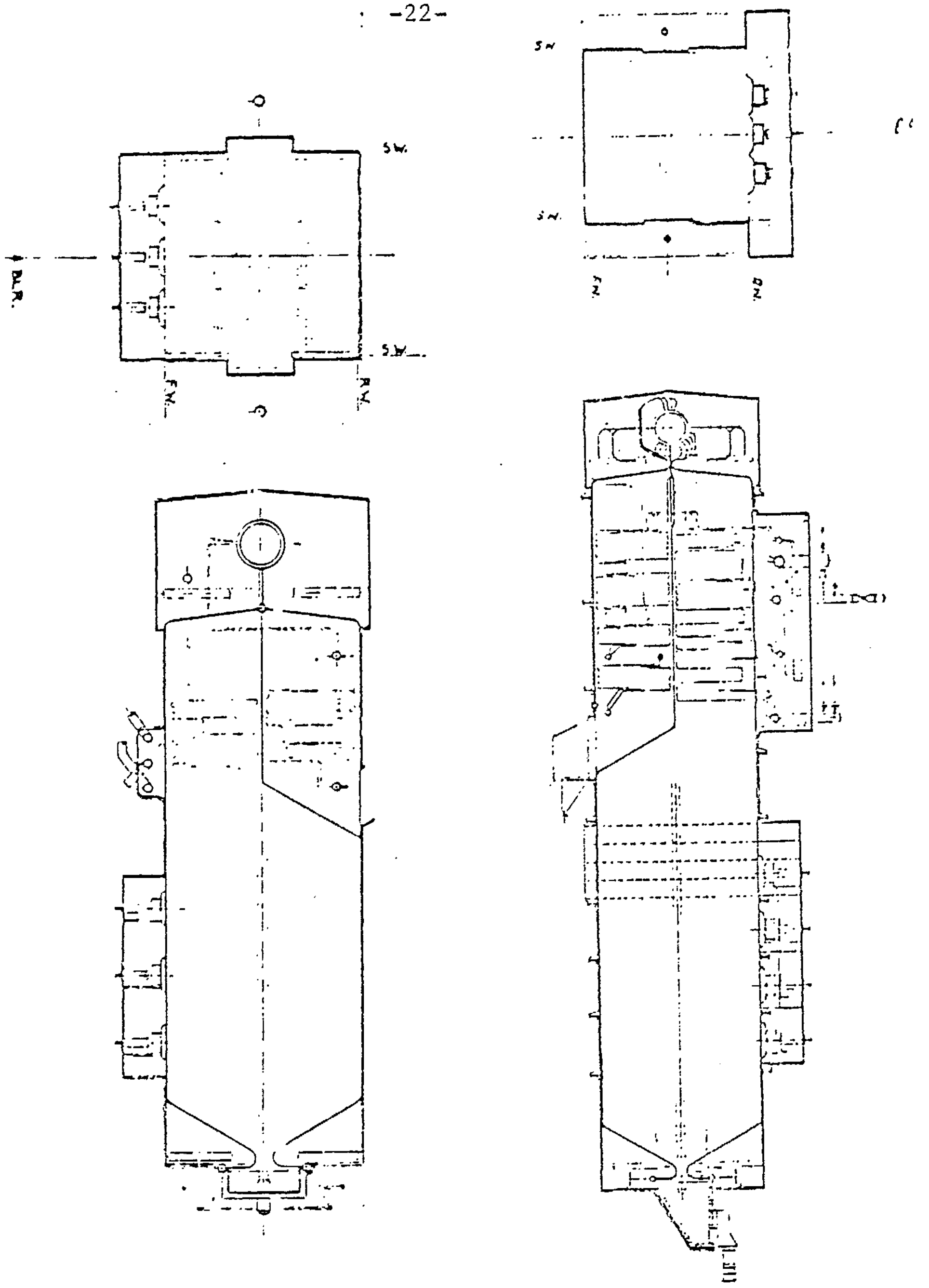
Ultimate Analysis (as fired)	
Carbon	87.87%
Hydrogen	10.33%
Sulphur	1.16%
Oxygen	0.50%
Nitrogen	0.14%
Calorific Value	
HHV = 42.80 MJ/kg (18 400 Btu/lb)	

Table 3 - Coal and coal-water slurry fuels

	Pulverized coal		Coal-water slurry	
	High Ash (%)	Low Ash (%)	High Ash (%)	Low Ash (%)
Ultimate Analysis				
(as fired)				
Carbon	66.20	70.30	51.49	54.86
Hydrogen	4.42	4.69	3.44	3.66
Sulphur	3.31	3.51	2.58	2.74
Nitrogen	1.26	1.34	0.98	1.04
Oxygen	6.74	7.16	5.23	5.60
Ash	8.07	3.00	6.28	2.10
Moisture	10.00	10.00	30.00	30.00
	100.00	100.00	100.00	100.00
HHV	27.91 MJ/kg (12 000 Btu/lb)	29.77 MJ/kg (12 800 Btu/lb)	21.69 MJ/kg (9 323 Btu/lb)	23.09 MJ/kg (9 928 Btu/lb)
Ash Analysis				
SiO_2	32.54	32.54	32.54	32.54
Fe_2O_3	39.42	39.42	39.42	39.42
P_2O_3	0.08	0.08	0.08	0.08
MgO	0.82	0.82	0.82	0.82
Na_2O	0.59	0.59	0.59	0.59
Al_2O_3	20.44	20.44	20.44	20.44
TiO_2	0.80	0.80	0.80	0.80
CaO	1.64	1.64	1.64	1.64
SO_3	0.95	0.95	0.95	0.95
K_2O	1.14	1.14	1.14	1.14
Ash Fusibility				
(Initial Deformation)				
Oxidation	1366°C (2490°F)			
Reduction	1093°C (2000°F)			

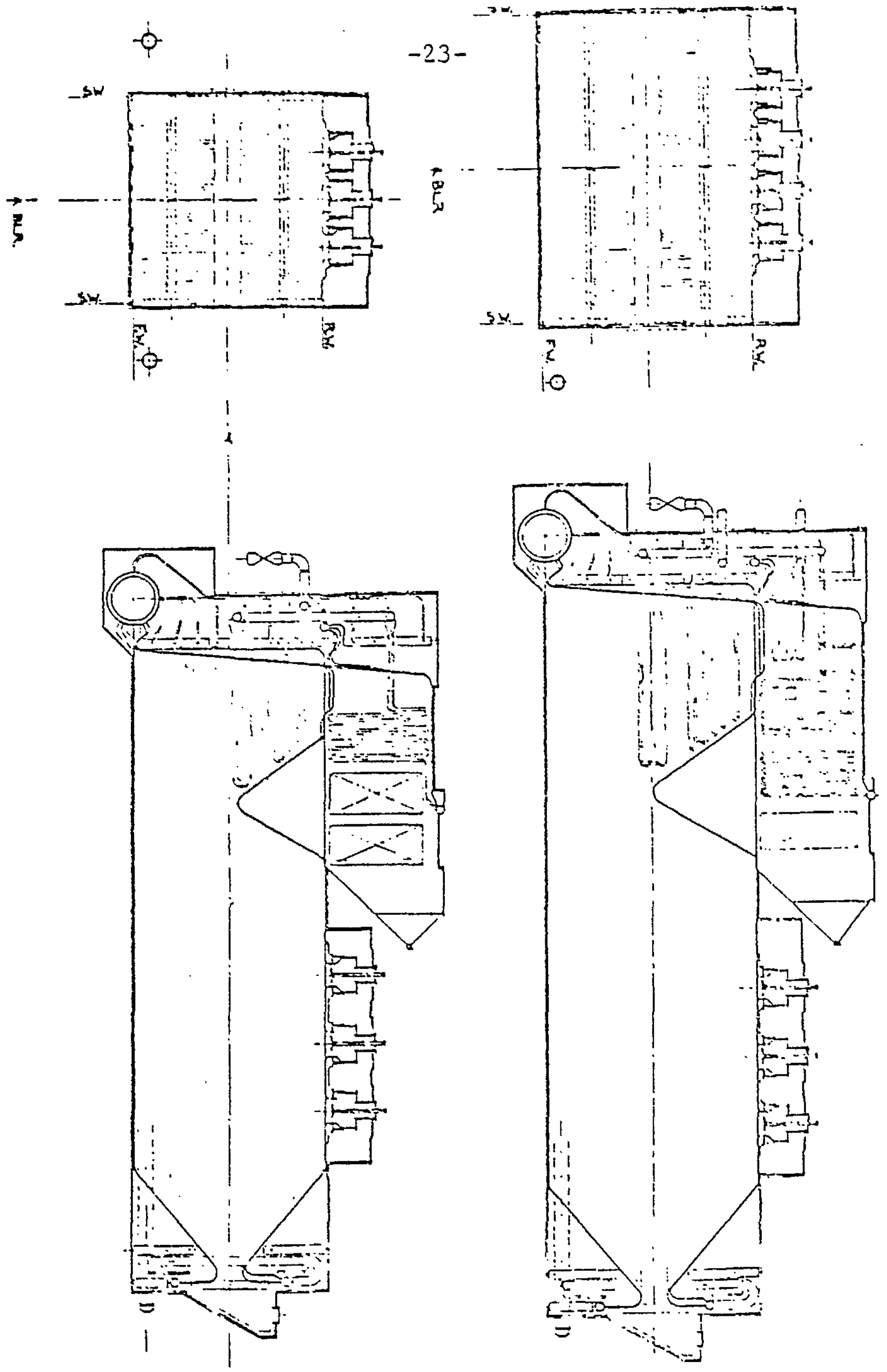
Table 4 - Basic unit derating

	Fuel options				
	High Ash Pulverized Coal (%)	Low Ash Pulverized Coal (%)	Low Ash Coal-Water Slurry (%)	Low Ash Coal Water Slurry (%)	(LLF) Load Limiting Factor
Small El Paso	58	58	59	59	Furnace exit gas temperature
Large El Paso	43	37	47	39	Convection pass gas velocity
Small Carolina	42	42	40	40	Tube side spacing vs gas temperature
Large El Paso	58	58	56	56	Tube side spacing vs gas temperature



	SMALL EL PASO	LARGE EL PASO
Furnace Width	7.3 m (24 ft.)	9.3 m (30.5 ft.)
Furnace Depth	7.0 m (23 ft.)	8.5 m (28 ft.)
Furnace Height	23.0 m (75.5 ft.)	40.8 m (133.8 ft.)
No. of Burners	9	12
Hopper Slope	30°	30°
Hopper Throat	0.6 m (2 ft.)	0.6 m (2 ft.)

Fig. 1 - El Paso reference units



	SMALL CAROLINA	LARGE CAROLINA
Furnace Width	7.3 m (24 ft.)	11.0 m (36 ft.)
Furnace Depth	6.7 m (22 ft.)	7.3 m (24 ft.)
Furnace Height	24.0 m (78.8 ft.)	27.4 m (89.8 ft.)
No. of Burners	9	12
Hopper Slope	50°	50°
Hopper Throat	0.9 m (3 ft.)	0.9 m (3 ft.)

Fig. 2 - Carolina reference units

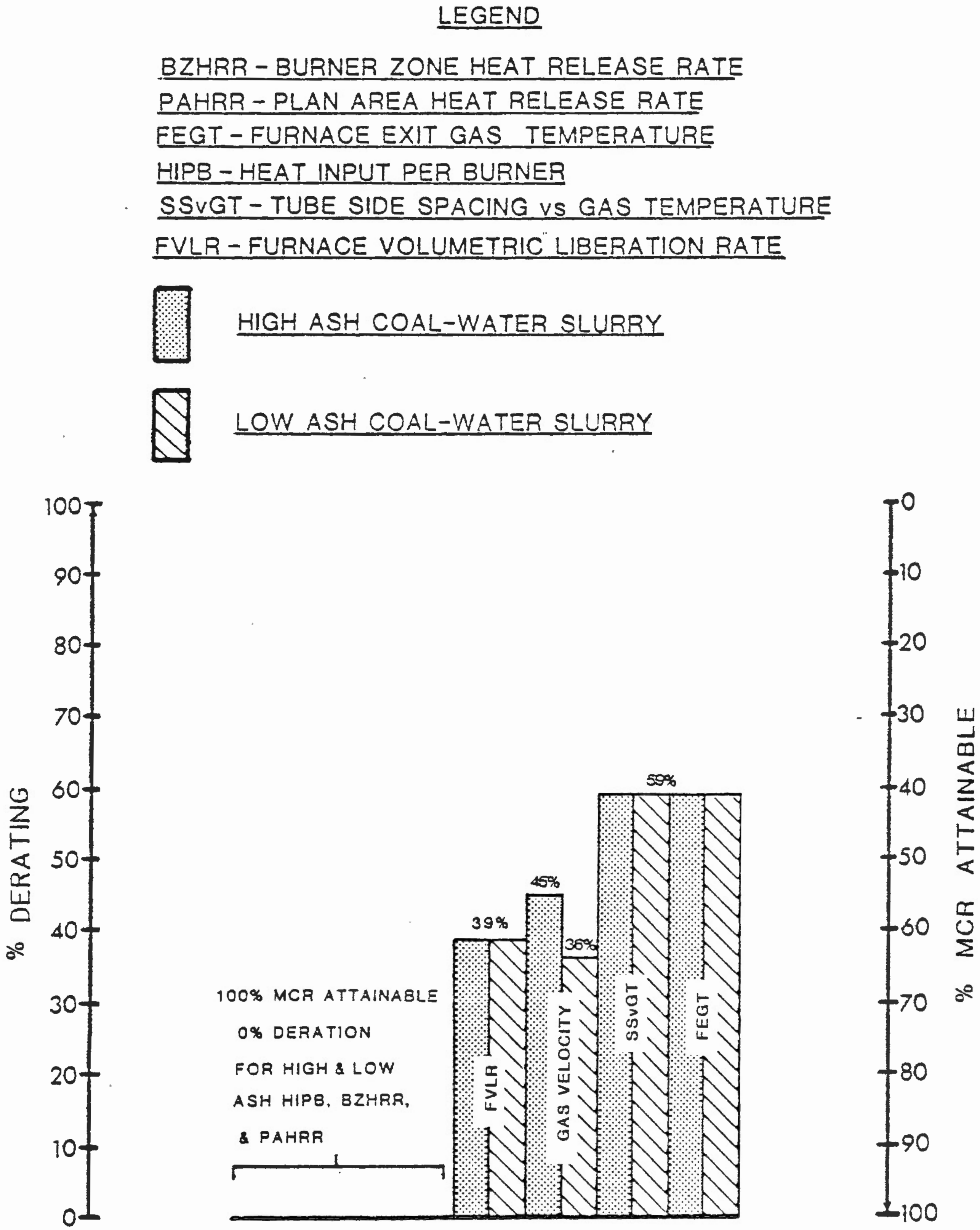


Fig. 3 - Small El Paso unit

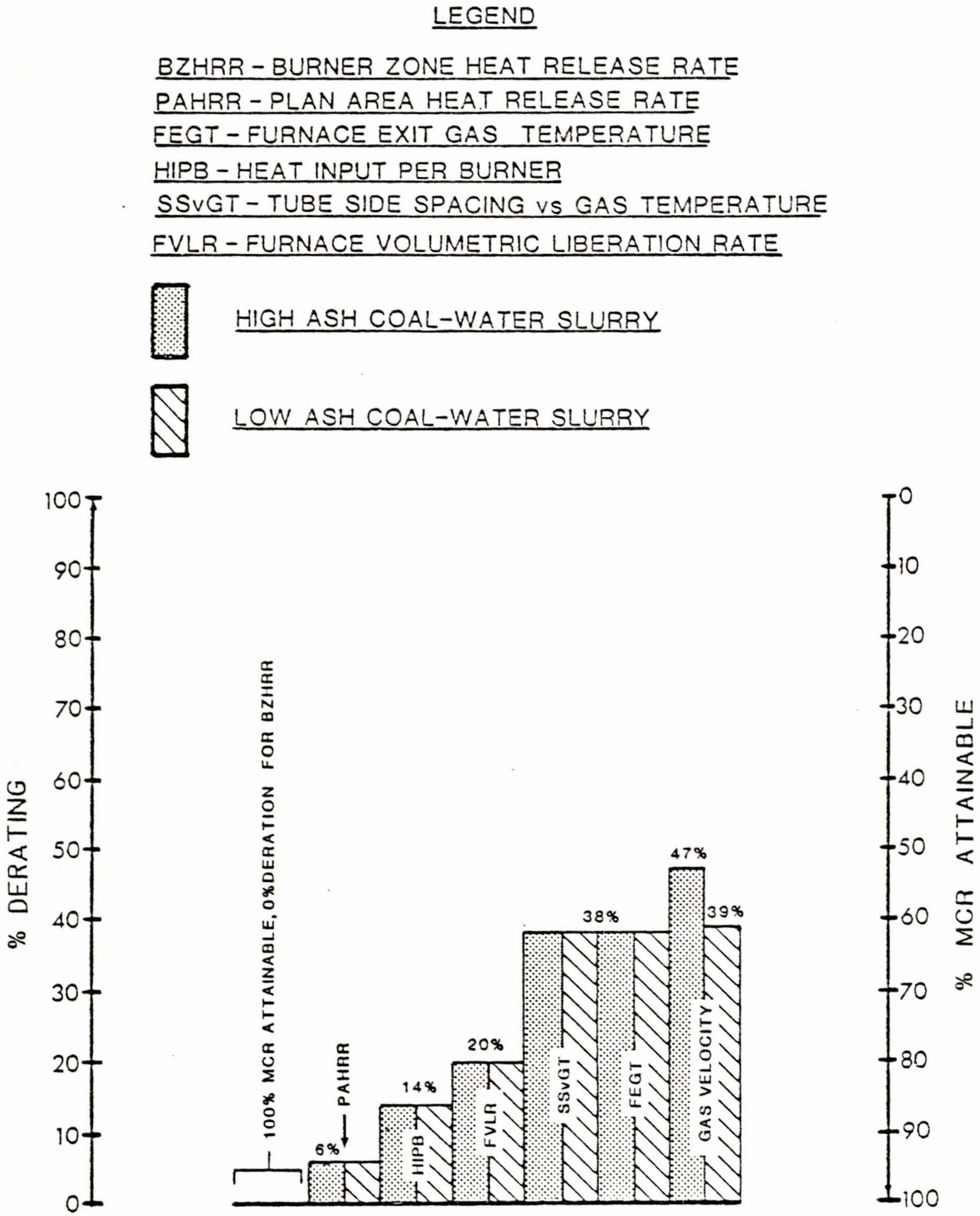


Fig. 4 - Large El Paso unit

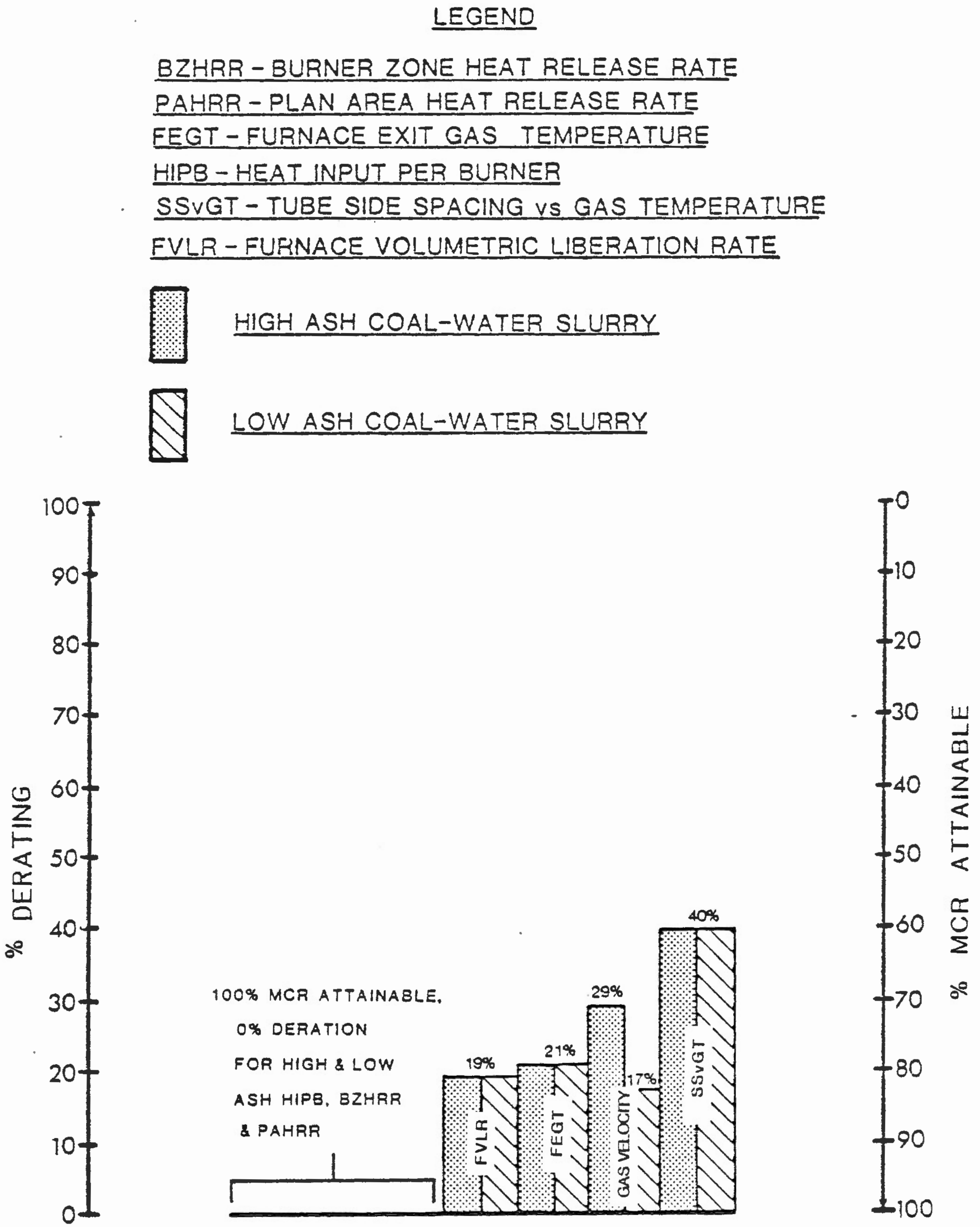


Fig. 5 - Small Carolina unit

LEGEND

BZHRR - BURNER ZONE HEAT RELEASE RATE
PAHRR - PLAN AREA HEAT RELEASE RATE
FEGT - FURNACE EXIT GAS TEMPERATURE
HIPB - HEAT INPUT PER BURNER
SSvGT - TUBE SIDE SPACING vs GAS TEMPERATURE
FVLR - FURNACE VOLUMETRIC LIBERATION RATE

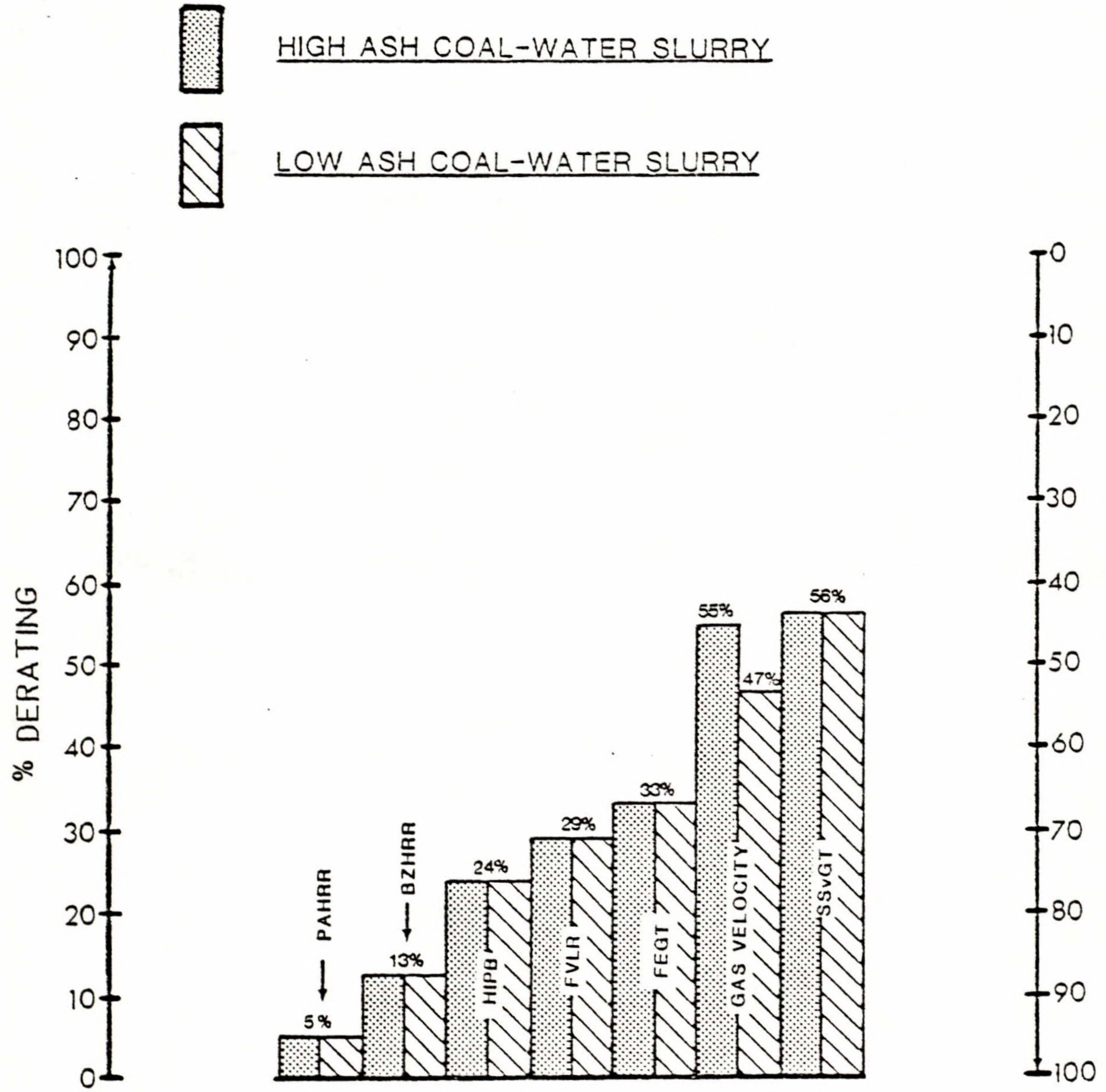


Fig. 6 - Large Carolina unit