THE SELECTION AND DESIGN OF REFRACTORY IGNITION ARCHES FOR SINGLE RETORT STOKERS

BENEFITS:

- Prompt Ignition
- Increased Combustion Rates
- Higher Overall Efficiency
- Less Manual Attention
- Less Smoke

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THE SELECTION AND DESIGN OF REFRACTORY IGNITION ARCHES FOR SINGLE RETORT STOKERS

FOREWORD

The primary objective of this brochure is to acquaint users of bituminous coal, plant engineers, combustion engineers, consultants, refractory manufacturers, and others with the benefits to be derived from the use of refractory ignition arches with single retort underfeed stokers. The information contained herein should be sufficient to allow the combustion engineer to select, design, and install arches where firebox conditions warrant the use of such devices. As combustion is more an art than a science, the instructions contained herein will be more general than specific.

THE PRINCIPLE OF UNDERFEED FIRING

In an underfeed stoker fuel bed, the air and coal, in general, travel parallel to each other. Combustion occurs when the coal has reached the proper ignition temperature in the presence of oxygen. Ignition occurs by the transfer of the heat down through the mass from the hot upper side with the simultaneous passage of air upward through the coal mass. Thus

Figure 1—Boiler Room—showing bituminous single retort underfeed stokers.

Figure 2—Partially ignited fuel bed indicating sluggish combustion.
the size-consist of the fuel bed with its inherent rate of heat transfer and permeability, and the firebox temperature are important factors in the performance of underfeed stokers.

The coking and non-coking condition of fuel beds may be explained in terms of rate of ignition and rate of burning. Ignition and the rate of ignition are defined as follows: the fuel bed is considered to be ignited when it is heated to a temperature at which it would burn if air were provided, and the rate of ignition is the rate at which the fuel bed is heated to this temperature. Coking and non-coking phenomena are then defined substantially as follows: when the rate of ignition exceeds the rate of burning, excessive coking occurs, but when the rate of burning equals the rate of ignition, excessive coking is absent.

THE PROBLEM

Efficient combustion of coal depends upon the three "Ts": (1) favorable firebox or furnace temperature, (2) adequate time to complete combustion, and (3) sufficient turbulence to provide intimate contact between the air and the combustible gases from the fuel bed. It is assumed that proper fuel-air ratios are maintained to secure optimum combustion performance. When many coals are used in the single retort stoker, there is need for frequent manual attention of the bed in order to attain the rated capacity. Figure 1 shows a boiler room where two typical single retort stokers are firing fire-tube boilers. Inadequate ignition leads to a green, partially ignited fuel bed, a sluggish fire, and manual working. An example of this is shown in Figure 2. Invariably, disturbing the bed causes objectionable smoke emissions from the stack. The necessity for excessive manual attention and the resulting smoke nuisance have caused some units to be condemned and lost to competitive fuels.

One of the major factors contributing to "green beds" in single retort stokers is the fine size-consist of coals. The modern water-wall boiler, with its rapid absorption of heat, causes low firebox temperatures and slow ignition, thus contributing to the black, unreactive fuel bed over the center of the retort. Retarded ignition reduces the burning rate and lowers the output of the steam generator. Therefore, for good combustion, it is essential that means be provided for counteracting these adverse effects.
THE REFRACTORY IGNITION ARCH
AS A SOLUTION

Refractory arches are no strangers to combustion techniques. They have been contributing to the successful performance of fuel burners for many years. Combustion engineers generally agree that coal burns better under arches, whether hand or stoker fired. The locomotive arch has contributed much to the general performance of the railway steam generator. It is standard equipment and has rendered valuable service for over forty years.

The traveling grate stoker would not have attained its present degree of popularity without the now familiar front and rear arches. Multiple retort stokers also employ rear arches to advantage, and the refractory baffle has even invaded the domestic stoker field where many are installed each year. However, up to this time the single retort industrial stoker has not fully utilized the advantages of the refractory ignition arch.

Description of Arch

The refractory ignition arch developed for use with the bituminous single retort underfeed stoker is essentially a false partial furnace ceiling located over part of the fuel bed. In some ways the new firebox resulting from the arch is similar to the old Dutch oven combustion chamber. The arch may be flat or concave. It may run from the front wall of the furnace to the rear wall, or under some conditions it may be desirable to install it crosswise between the furnace sidewalls. Several different types of arches may be employed depending upon the design of the firebox, stoker, and boiler. These design variations will be discussed under the heading of Arch Design.
Function of Arch

The primary function of the arch is to increase the temperature of the furnace space directly over the fuel bed and particularly at the place where the green coal enters the furnace through the retort. This is accomplished by the reflection of heat by the arch back to the bed. Hence, prompt ignition of the coal occurs because of higher temperatures resulting from more intense combustion. In addition to accelerated and more efficient burning of the fuel, the arch causes increased turbulence and longer flame travel. Catalysis on the arch surface is another factor which results in improved combustion of the volatile gases.

Benefits Derived from Arch

The use of the ignition arch as an accessory to the single retort stoker has improved the over-all performance as follows:

1. Increased combustion rates can be expected. The degree of improvement will depend upon the going rates without the arch, and the size and characteristics of the coal. Users of the arch report significant increases in steam generator output.

2. Fuel beds under arches tend to remain stabilized and uniform, while beds without arches have a tendency to worsen unless given considerable manual attention.

3. To gain the maximum benefit from an arch with most coals, the fire should be maintained uniformly thin. This results in prompt ignition and rapid combustion.

4. Higher over-all efficiency is another benefit of the arch in most cases.

5. The unreactive fuel bed over the retort section is eliminated.

6. The arch reduces the need for manual attention.

7. The periodic smoke discharge which results from disturbing the bed is substantially reduced.

8. Smoke is further reduced by the contact of the volatile gases with the hot refractory.

9. The fly-ash carry-over to the tubes is usually less with the arch.

Arches Are Not a Cure-All

While a marked improvement has been noted with the application of this accessory to single retort stokers, it cannot be expected to correct and cover up poor engineering, faulty plant operation, inferior equipment, or poor maintenance.

Figure 6—Castable refractory arch showing supporting tubes cooled by tap water.
DESIGN AND CONSTRUCTION OF ARCHES

The effectiveness of the arch depends upon (1) the temperature of the arch, (2) the amount of heat stored by the arch, and (3) the amount of reflected heat which reaches the bed. The temperature of the arch will depend upon the kind of fuel used and the height of the arch above the bed. The heat stored by the arch depends upon the shape and the nature of the refractory. The length of the flame also affects the arch temperature.

The radiation effect of the arch upon green coal depends upon the distance, and its intensity varies inversely as the square of the distance from the radiating body. For example, an arch three feet away from the fuel bed will radiate only one-ninth as much heat as one located one foot from the bed. Heat is reflected from an arch in much the same manner as light from a mirror; that is, it follows the law that the angle of incidence equals the angle of reflection. Hence, a curved or concave arch will concentrate more heat at a particular point.

Critical Dimensions

Two important dimensions must be taken into account: the width of arch and the height of the underside of the arch above the grates. In general, the height at which the arch should be placed above the grates is the depth of bed plus 15 to 20” depending upon the firing rate (lbs. coal/sq. ft./hr.). The width of arch can be established as about 50% of the furnace width. The arch width may be varied, however, depending upon the radiation required by the coal. The amount of radiation already present depends upon the type of the firebox. For example, an all-refractory-lined combustion chamber will not require as wide an arch as will a water-wall installation.

Types of Arches

The types of arches that may be used fall into two distinct classes, the flat arch and the sprung or concave arch.

Flat Arches—Flat or straight arches may be constructed from a castable refractory or a prefired tile, Fig. 3. Tube tile shapes may vary in design, one type being shown in Fig. 4. Each kind of refractory has certain features which should be considered. Castable refractory may be poured to fit any form but requires a drying period of 24 to 48 hours before firing. Castable material also requires wooden forms and therefore carpenter labor.

Prefired shapes must be designed to fit conditions and may require a separate pattern charge. The latter is usually a minor cost because of the simple design. Most tube tile allow the slip on hole to remain and expose the supporting pipes or tubes. However, Fig. 5
shows one design wherein the tubes may be covered with a refractory cement. In general, tube tile with exposed supporting pipes should be supported by tubes which are connected to the internal circulation of treated boiler water to avoid "liming" of the inside of the tubes. All flat arches must be hung by water-cooled supporting pipes or tubes.

**Cooling the Supporting Pipes**—The problem of cooling the supporting members of the flat arch can be solved in a number of ways:

1. The boiler feedwater may be circulated by a small pump through the arch tubes to a common sump, Figs. 3 and 4.

(2) Tap water, if available at a low cost, may be run through the pipes to cool them, Fig. 6. The mineral content of raw water should be low or it may eventually cause a build-up of lime inside the pipes. If the cooling water is wasted, 1 to 2% of the heat available to the boiler may be lost with covered pipes, and when the supporting pipes are exposed the loss may exceed 10%. However, by using feed or makeup water for cooling the supports, these losses are avoided, Fig. 7.

3. A good practical solution is to connect the arch tubes directly with the main circulation system at the front and back of boiler as shown in Fig. 11. This arrangement is especially convenient for use with sectional cast iron boilers. When the supporting members are exposed, the use of boiler tubing is preferable to standard pipe because better heat transfer is attained and there is less chance of burning the metal. Tubes included in the boiler system should be sloped in accordance with manufacturers' recommendations to allow proper escape of steam and adequate circulation of the boiler water. Usually a slope of $1\frac{1}{2}$ inch per foot will suffice, although location of staybolts, etc. may require a greater inclination.
Sprung Arches—Spring arches are a very old and basic form of masonry and refractory construction and have been satisfactorily employed in furnace construction for many years, Fig. 12. This type of refractory ignition arch offers the following advantages: low cost, ease of installation, and elimination of water-cooled supporting members. The only requirement for their use is the necessity for sturdy supporting side walls to withstand the thrust of the arch weight.

Basic Principles of the Sprung Arch—Sprung arches consist of combinations of refractory brick shapes supported at the ends by skewbacks. Figure 13 shows a cross section of the simple sprung arch with its basic dimensions. The arch itself is composed of wedge brick or a combination of wedge and straight bricks depending upon the rise of the arch. The latter is commonly expressed in inches per foot of span. The arch is held in place by its weight acting on component bricks to produce a wedged mass. The side supports are skewbacks and the sloping surface thereof is termed the face. The pressure of the arch against the skewback is resolved into horizontal and vertical forces by means of the contact face angle.

Experience has shown that a simple arch should have a rise of not less than 1 1/2 inches nor more than 3 inches per foot of span. Perhaps the most common rise employed in furnace arch construction is 1 19/32" per foot and the resulting face angle is 60° so that the span and inside radius are equal. An arch which is too flat will be subject to excessive horizontal stresses; one which is too steep will tend to buckle. Both cold and hot stresses may be calculated from established formulas and tables as shown in Harbison and Walker Company handbook entitled Modern Refractories. The skewbacks must be buttressed by either adequate masonry walls or steel tierods and buckstays to withstand the anticipated thrusts.

REFRACTORIES

Numerous refractories are being marketed by many companies. Clay is the oldest and most common. Refractories are composed largely of alumina, silica, and magnesia. They are either natural or manufactured. Kaolin, chromite, bauxite, magnesite are a few of the natural type, while silicon carbide and aluminum oxide are examples of the manufactured type.

Refractories may be of plastic, castable, or pre-fired materials. Fire brick is a good example of the prefired types. Each has its advantages and field of application. Plicast 31 marketed by the Plibrico Company, Chicago, Illinois, or equivalent, has proved to be a good castable refractory. It has a P.C.E. cone of 31 (3055°F.) with a service limit of 2900°F.

A first quality firebrick such as J. H. France Refractory Company's (Snow Shoe, Pa.) Lehigh mix has a P.C.E. cone of 32 to 32½ (3130°F.). For extremely severe conditions involving slagging the J. H. France Company's Corindon brick or equivalent is recommended. It has a P.C.E. cone of 38 (3350°F.) and is also slag resistant.
STEPs IN ARCH DESIGN

Select Class of Arch—Study the firebox or furnace dimensions to see which class of arch is most suitable. Where possible use the sprung arch to keep cost at a minimum and eliminate the necessity for water-cooled supporting pipes.

Select Type of Arch—The designer may elect to install front to back center type or a side to side (crosswise) arch. The crosswise type will provide longer flame travel and hence makes more efficient use of limited furnace volume resulting from low set boilers which lack adequate combustion space, Figs. 14 and 15.

Determine Width of Arch—For most conditions a 50% firebox width or length arch (depending on type) will provide ample reflecting surface. This figure may vary from a low of 35% on an all refractory firebox to a high of 60% on a combustion chamber with completely water-cooled walls.

Determine Height of Arch—For effective radiation the distance between the top of the fuel bed and the underside of the arch should be about 15 to 20". Fig. 16 shows the comparative fuel-bed contours of stationary grate and moving grate types of single retort stoker. As the amount of radiation required for proper ignition depends on the temperature, the height may be varied to suit conditions. In general, the following factors will influence the height of the arch:

1. Nominal burning rate (lbs. sq. ft./hr.) of overall grate area. Thus the higher the rate (Btu/sq. ft./hr.), the higher the arch can be set. Table I shows typical relation between stoker width and allowable burning rates.
(2) Refractory walls mean higher combustion chamber temperature thus the higher the arch.

(3) The kind of coal should also be considered. More radiation is required for coals of finer size-consist which are more difficult to burn. Coals which slag severely will cause a gradual buildup on the under side of the arch, and 3 to 4 inches may be added to the height to allow for this.

(4) Where sprung arches are used, the setting height can be considered the average of the maximum and minimum arch height dimensions.

(5) The height and width must be considered together, for the same radiation effect can be secured with a wide high arch as with a low narrow arch. Avoid extremely wide arches because sufficient gas escape area must be maintained to avoid excessive draft losses.

**Determine Thickness of Arch**—Sprung arches may be made of standard brick (9 L x 4 1/2 W x 2 1/2) with a thickness of 4 1/2”. Arch brick also come in 9” thickness but in most cases the 4 1/2” arch is adequate, less expensive, and lighter. It is desirable to keep the arch weight at a minimum.

Flat arches made from castable material can be 4 1/2 to 6” thick and 5” is a fair standard. The thickness of a flat arch constructed of prefired shapes will depend upon the design of tube tile and the diameter of supporting pipes. Satisfactory shapes from 3 1/2 to 5 1/2 have been used with 5” being a good average thickness.

**Design of Supporting Members**—Normal two-inch standard pipe will be adequate for arches having 6 foot spans, designed with 4 supporting members embedded in the castable material. For thicker arches and spans of 7 to 8 feet, two-inch extra heavy pipe is preferred. The strength of the pipes can be checked by any structural engineer for special conditions or if there is any doubt. When the supporting members are to be partly exposed to the flames, boiler tubes are preferred. Boiler tubes are easier than ordinary pipe to connect to the boiler sheets by turning or welding. The boiler manufacturer should be consulted for the optimum size of tubes to be used to provide adequate water circulation and mechanical strength.

**GENERAL INSTALLATION DIRECTIONS**

(1) When using castable material, the pipes or tubes should be coated with a 1/32” film of paraffin to allow space for expansion when the pipes become heated. Wooden forms should be greased to prevent the wood from absorbing water from the mix.

(2) The castable material should be thoroughly dried before firing in accordance with manufacturer’s directions. A drying period of 48 hours is recommended to prevent the entrained water from flashing to steam and shattering the refractory material.

(3) Forms may be removed or burnt out. Fire should be applied gradually.

(4) Sprung arches will generally give longer life if the bricks are laid dry and buttered on the underside with an 1/8” of high grade refractory cement similar to the composition of the brick. In time, the underside of the arch will become coated with slagged ash; but until this happens, the 1/8” sealing will prevent gas from passing through the arch.
LIFE EXPECTANCY

Laboratory and field installations indicate that the supporting tubes should last many years. The life may depend upon operating conditions such as the nature of boiler water, type of water used for cooling, and so forth; but it should be comparable to the life of the boiler tubes.

The life of the refractory part of the arch will depend upon firebox conditions. Some castable refractory arches have been in service more than four years and still appear to be sound. Under average conditions, the refractory part of the arch should give a life equivalent to that of the refractory furnace walls. With very severe conditions, slugging may cause a gradual buildup on the arch; and unless this can be and is removed, it may necessitate replacement of the arch annually. The amount of coal fired under the arch, the kind of coal, fusibility and nature of the ash, firing rate, and type of load are factors upon which life of arch will depend. In the case of sprung arches the cost is such a small item that the frequent replacement can be made without adverse effects on cost of operation.

If superduty firebricks are used, the cost may be tripled. A simple wooden support can be made of plywood on the site to support the arch brick until all are in place. The wooden arch support need be only big enough to support one row of bricks at a time. Ordinarily two men can install such an arch in half a day and skilled bricklayers are not required.

If a flat arch were used for the same furnace and made of castable material, refractory costs would be between $50 and $60. Supporting boiler tubes may cost approximately $150 if installed at the factory and perhaps $300 if factory men do the same job in the field. On the other hand, if regular pipes are used and are cooled by feedwater with water circulated by a ½-HP pump, then the cost excluding the refractory may be about $160.

MAINTENANCE

The only periodic maintenance required aside from lubricating the circulating pumps, if such are included, is the scraping of the soft slag from the refractory once or twice a year. In cases where the slagging is severe, frequent removal of the slag will extend the life of the arch and avoid the buildup of excessive weight. On rarer occasions, where a crack develops in the arch or a small piece breaks loose from around the supporting pipes, a simple repair job with plastic refractory cement can extend the life of the arch for months or possibly years.
USE OF OVERFIRE AIR

A combination of refractory ignition arches and overfire air makes a very effective team in reducing and eliminating smoke. In the majority of cases where overfire air is needed, low pressure air directed on each side of the arch is sufficient to eliminate the smoke. In more stubborn cases, high pressure jets in line with practices recommended by Bituminous Coal Research, Inc. can be applied. However, as the arch divides the gas stream, the length of penetration is shortened. Consequently less air pressure is required for the same job.

TYPICAL PROBLEM

A bituminous single retort stoker has a refractory firebox 6'-0" wide by 6'-0" long. It is burning a medium volatile 1 x 0 slack coal with a large percentage of fines (50% - ¾ x 0). Maximum burning rate obtainable is only about 11 lbs. coal per sq. ft. per hour, and the result is a firebed characterized by the black center above the retort and low firebox temperatures. Frequent manual attention is required and this periodic disturbance causes excessive smoke.

Solution—The depth of bed over the center of retort was measured and found to be 7" to 8" thick during normal operation with a clean fire and before excessive amounts of unburned coal accumulated. Thus a 53% arch 38" wide was located at a height of 22 inches above the top of the grate bar level. The details of this arch are shown in Fig. 3.

A sprung arch in an identical situation was installed as shown in Fig. 12. This arch was 50% of firebox width 36" wide and had a height of 28½" at the center and 19" on the sides. Thus the average height was 23¾" as compared with 22" for the flat arch. Both arches gave satisfactory performance, but the cost of the sprung arch was about 1/6 of that of the flat arch and, moreover, eliminated the water circulation problem.

OTHER INSTALLATIONS

Other successful installations are shown in Figs. 4, 6, 7, 8, 9, 10, 11, 14, and 15. Fig. 4 shows water-cooled pipes supporting prefired tube tiles. This arch
was designed to burn very fine size-consist coals in an all refractory furnace, fired by a stoker with a 5' x 5' grate incorporating moving fire bars. The cooling water was circulated by a small pump from the feed-water sump.

Fig. 6 shows a flat arch constructed of castable material. The pipes are cooled with raw tap water which was also used for other cooling purposes and then wasted.

Fig. 7 shows a design using a castable refractory and located at a height of 36" above the grate. This stoker was burning coal above its nominal rating with a deep bed (18" thick) on stationary grate bars. The pipes were cooled by boiler makeup water. The piping details include shut-off valves, check valve, relief valve, and temperature indicating signal.

Fig. 8 shows a castable refractory arch which is supported by boiler tubes welded to the plates at the factory. The stoker employed stationary grate bars.

Figs. 9 and 10 show an arch constructed of pre-fired tube tiles supported by boiler tubes installed on the customer's site by turning into the boiler plates. The boiler is fired by a stoker having 6' x 6' firebox and moving bars.

Fig. 11 shows the design of castable refractory arch supported by pipes cooled by natural circulation of the boiler water through external connections. The boiler was a 100 HP sectional cast-iron type. The stoker was rated 350 lbs. coal per hour and employed dead plate type grates with a small central retort. Radiation was accomplished here by the combination of a higher set arch with a greater arch width. The supporting grid between the pipes was added by the plant mechanic. While this reinforcement apparently did not detract from the soundness of the structural support, it is questionable whether it improved the design.

Fig. 14 shows a side-to-side sprung arch with a 2" rise per foot. The combination of the arch and bridgwall causes the flame to travel to the front of the boiler before it reverses its direction. This 50 HP sectional cast iron stoker is fired by a 200 lb. per hour stoker with fixed grate bars. The cost of the first quality bricks for this installation was about $6.

Fig. 15 is another example of a side-to-side sprung arch which provides for increased flame travel. The arch covers 74% of the firebox length as compared to 50% in the case of Fig. 14. Overfire air was introduced at the front of the furnace by means of a low pressure blower to eliminate smoke from a high volatile coal. Normally furnaces need not be throttled to such an extent, but in this particular case satisfactory performance was obtained for an intermittent heating load. The boiler was fired by a clinkering type stoker with a central retort and dead plates.

A study of the sample installations will reveal that there is considerable latitude in the application of arch design to a combustion problem. It will also be noted that the arch dimensions may vary somewhat without materially affecting performance.

The use of sprung arches to date seems to afford certain advantages which usually make them preferable to the more costly water-cooled supported flat arch. Either type of arch, however, has proved economically worth while in improving efficiency of combustion on single retort underfeed stokers.
Figure 16—Single retort stoker bed contours for fixed and moving grate bars.