Packing Material in Carbon Baking Furnaces

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Abstract

Most carbon baking furnaces, open and closed top, use carbon-based packing material to support carbon blocks in the furnace pits. Care should be taken to select best suited material and maintain packing material in baking furnaces correctly. Degradation of carbon material sources gives new challenges to deal with, like increased packing material consumption and workers' health issues. Solutions are available, but should be selected according to plant situation. Ideas for improvement may be applied to solve old and new issues. This paper discusses the purpose, selection, maintenance, problems and solutions as well as ideas for improvements of packing material usage in carbon baking furnaces.

Keywords: Carbon baking furnaces; Packing material, Degradation of packing material.

1. Introduction

Depending on plant, baking furnace packing material can receive from no attention at all to a lot of attention. There are different packing materials available and they should be selected according to purposes to be met in baking furnaces. Once introduced in a baking furnace, packing material should be maintained, because most of it is recycled over and over, so a problem left at one time is a problem that may grow with time.

Some known packing material sources, like calcined petroleum coke, degrade with time. This leads to problems unknown a few years ago, that grow unnoticed for a while, until they become impossible to miss. One of them is a health issue for workers in baking furnace.

A good understanding of packing material, its use, its maintenance and problems that may be encountered is required to avoid carbon blocks defects, excess packing material consumption and operation problems.

2. Purpose

Packing material in baking furnaces has many purposes:

- Sustains carbon blocks mechanically during baking when binder softens while temperature rises;
- Allows optimal heat transfer from flue walls to carbon blocks;
- Allows volatile gas transfer from carbon blocks to flues;
- Blocks infiltration of air though packing material;
- Oxidises preferentially, to protect carbon blocks themselves from oxidation.

Packing material in baking furnaces should not:

- Shrink with temperature;
- Contaminate carbon blocks;
- Contaminate environment;
- Be harmful to people.

2.1 Support of Carbon Blocks During Baking

Packing material should flow freely around carbon blocks to be able to fill voids between carbon blocks and on carbon blocks themselves to sustain them. This implies that angle of repose of packing material should be quite low. Generally, angle of repose becomes larger with a reduction of particle size. Large particles have low angle of repose (Figure 1). Small particles and dust, have a high angle of repose. Particle shape also has an effect. Round particles flow more freely than irregular-shaped particles.

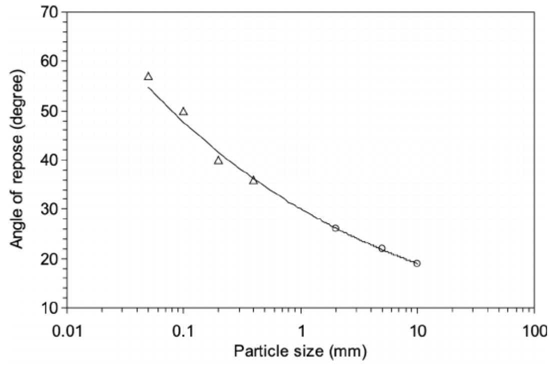

Figure 1. Angle of repose of granular material, example.

Problems involving insufficient support are: carbon blocks slumping, carbon blocks curving (carbon blocks which are close to the flue walls) and paste decompaction in specific block positions like middle of corners of carbon blocks and part of stud holes (Figure 2). Large decompacted paste chunks may sometimes detach from carbon blocks and cause other problems, like blocking packing material witdraw pipe or block advances on roller conveyors, by getting stuck between rollers.

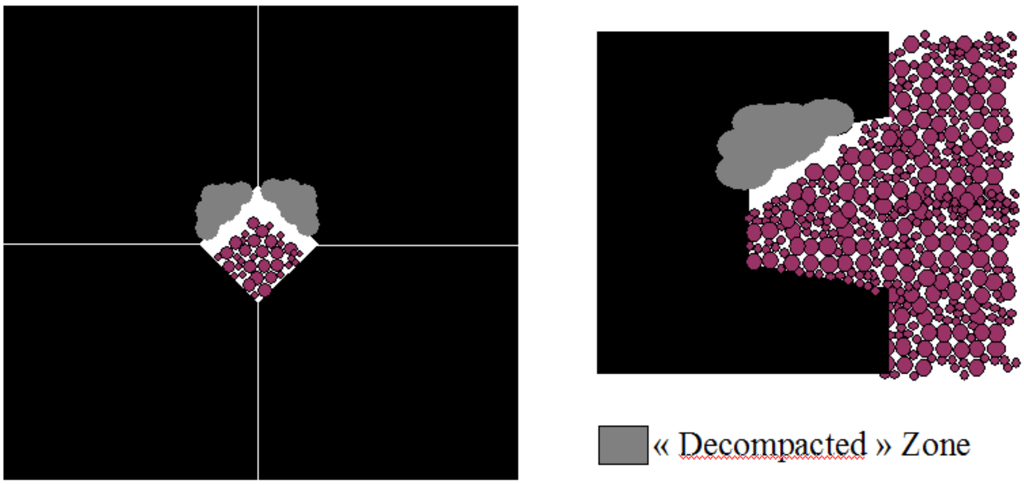

Figure 2. Blocks corners and stud holes decompaction caused by defective packing support.

2.2 Heat Transfer to Carbon Blocks

Heat transfer depends on many factors:

- Density of particles; higher is better, because higher density particles have better thermal conductivity;
- Particles size; bigger is better. So fine particles are to be avoided. (Figure 3, from Reference [1])

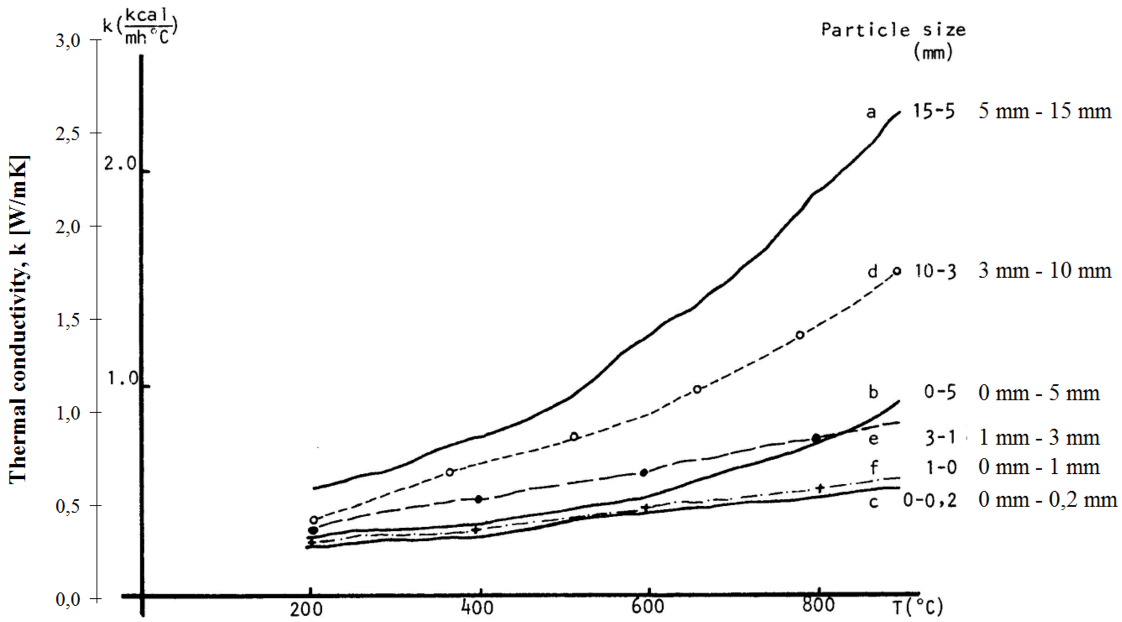

Figure 3. Particles thermal conductivity (k) according to size and temperature from reference [1]. Additional scale and right comments added for clarity

High heat transfer may also cause problems. If carbon blocks to flue walls distance is relatively small and thermal conductivity of the packing material is high, then volatile gas may be released from the carbon blocks before flue gas temperature reaches auto-ignition temperature of volatile gas. This causes tar condensation in ducts, blockage of dampers, stuck in tar, and tar fumes emission to the atmosphere. This also causes an increase of fuel consumption, because heat input from volatile gas combustion is absent.

2.3 Allowing Volatile Gas Transfer

Volatile gas coming from carbon blocks should be able to travel from carbon blocks to flues to be captured and ideally burned. To achieve this, particles size should be large. This allows for large interstitial space between particles, voids through which volatile gas may travel (Figure 4, from reference [2]).

Fine particles block volatile gas transportation and cause packing material to stick to flue walls, because part of volatile gas transform to solid coke while travelling through packing material.

As gas transit length is different between an open top furnace and a closed top furnace (Figure 5), granulometry specified by baking furnace supplier is different. Coarser particles are used in closed top furnace, because of longer volatile gas pathway in packing material. This is why closed furnaces suppliers recommend more porous packing material.

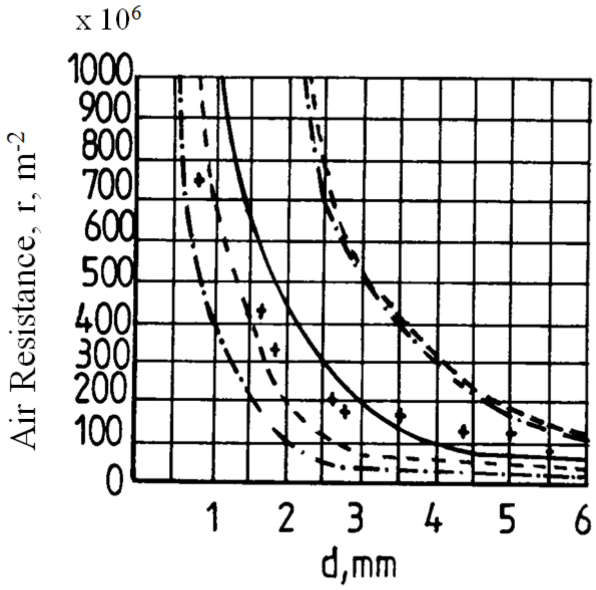

Figure 4. Particles network resistance to air penetration (r) according to size, each curve is a different source or equation. See reference [2] for details. The lower, the better.

2.4 Blocking Air Infiltration

Air should not be allowed to infiltrate through packing material, because air infiltration lowers flue gas temperature. Air infiltration may also cause packing material oxidation.

Packing material size affects considerably air permeability. Size from 1.0 to 1.5 mm and below insures the highest air resistance (Figure 4). This contradicts the large particles size required for volatile gas transport. So, there is a compromise to be done to meet both targets. Or targets should be met in another way.

2.5 Sacrificial Oxidation

In case of air oxidation, packing material has to oxidize first- to protect carbon blocks from oxidation. This is why packing material is usually carbon based.

2.6 Avoiding Packing Material Shrinkage

One may think about using baking furnaces to calcine anode or cathode granular raw material, or packing material itself. This is not recommended since green raw material shrinks significantly when it is calcined. This lowers support of carbon blocks during baking and may cause block defects.

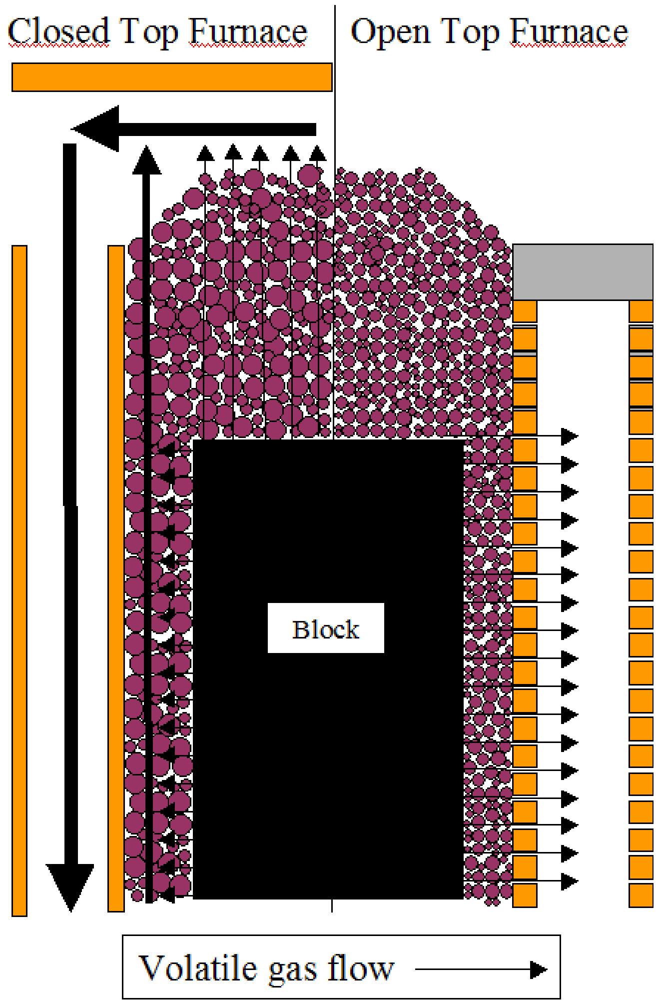

Figure 5. Volatile gas flow in different types of baking furnaces

2.7 Avoiding Contamination of Carbon Blocks

The quantity might change, but some packing material always sticks to carbon blocks. This may contaminate end product, aluminium, or recycled material, like cathode machining waste. This is the reason why packing material is usually carbon based.

Contaminants also concentrate in fine size particles. Recycling of dust collector product from baking furnaces packing material handling cranes into carbon blocks manufacturing may be problematic. Recycling may be possible if contamination is spread across all production. Otherwise, disposing of dust collector product may be the best option.

2.8 Avoiding Environmental Contamination

Flying dust inside baking furnace building is the most common environmental contamination. Rough handling of packing material causes it to break down. Falling particles cause a lot of material breakage [3]. Particle fall happens during loading of pits with packing material and when packing material falls into packing material handling crane silo.

High speed of particles, when withdrawn by packing material handling crane, is problematic because it is necessary to change particle direction from upward, coming from section, to downward, when filling crane silo. To achieve direction change, the two most common ways are the utilisation of a hit plate and 180-degree pipe turn (Figure 6). Hitting a solid plate is quite rough on particle size. The second option 180-degree pipe turn is a slightly better, but still high-speed packing material collide with the material already in crane silo. Breakage level is proportional to the square of particle speed [3], hence slower particles are damaged less.

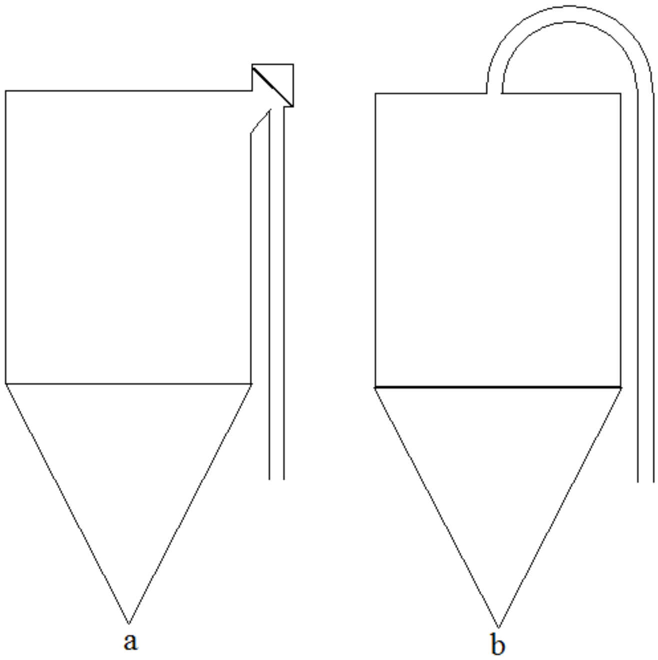

Figure 6. Typical ways to divert packing material direction a) hit plate b) 180° pipe turn

Oxidation of particles also reduces particle size. Complete oxidation of particles leaves only ash particles. This is the reason why very fine packing coke is usually heavily contaminated with ash.

Dust removal from packing material is usually limited to dedusting of packing material crane silo. So, dust which didn't fly into crane silo is not collected, thus it is not recycled back into packing material. When loading pits with packing material, dust will be emitted. Removing dust from packing material has many advantages. It improves heat transfer and volatile gas transfer to flues and lowers dust emission. It also improves air permeability between carbon blocks and flue walls, which is desired. But, it also increases the air permeability between the carbon blocks and pit top, which is not desired.

2.9 Protecting Human Health

A relatively new problem is noticeable emission of SO_2 and CO in baking furnace buildings. This is caused by oxidation of packing material during cooling phase of baking [4]. In open top furnaces, degassing slots are built into flue walls to allow volatile gas capture by keeping flues under vacuum. When cooling, degassing slots allows cooling air to percolate through packing material. This problem has worsened in last years for two reasons.

The first one is acceleration of baking cycle. Hence cooling time decreases and this is usually compensated by increasing cooling air flow in flues. This causes an increase of static pressure in flues and, consequently, it increases air infiltration into packing material through degassing slots [4]. As a result packing material oxidises, causing emission of SO_2 and CO from baking furnace to atmosphere.

The second one is increasing vanadium and nickel levels in calcined petroleum coke, over the years [5]. Both contaminants are known air oxidation catalysts for anodes. The effect is the same for packing material. Even without an increase of air infiltration through degassing slots, air oxidation happens faster, and worse, at lower temperature.

In both cases, cooling is slowed down because of the heat generated during packing material oxidation [4]. So, increasing cooling air flow to cool faster, gives exactly the opposite effect.

This results in a rotten egg smell in the building atmosphere where the baking furnace is located, from SO_2, and headache, from breathing CO gas. In some plants, baking furnace crane cabins are now equipped with CO detector to warn crane operators when CO level is too high.

This phenomenon can be detected by a steady decrease of packing coke level in cooling zone and lots of “red eyes” (red hot burning packing material) distributed in cooling zone.

Repacking with packing coke is a first step to stop air infiltration in pits. It lowers pit permeability, so, less air infiltrates through coke.

3. Packing Material Selection

Here are used and potential packing materials:

- Calcined petroleum sponge coke;
- Calcined metallurgical coke;
- Calcined petroleum fluid coke;
- Calcined petroleum shot coke;
- Calcined anthracite.

The list is not exhaustive, but it contains what is used or can be used as packing material in baking furnaces. Table 1 summarizes type of packing material used for different technologies, and advantages as well as inconveniencies of each one.

3.1 Calcined Petroleum Sponge Coke

Calcined petroleum sponge coke is the most widespread packing material. It is used in open and closed top baking furnaces. It is usually available from paste plant and its granulometry can, most of time, be adjusted to suit baking furnace needs. It is easy to withdraw with vacuum system, because it is fairly light material. Being light, it crushes and easily grinds, hence it produces dust quite easily. When fines are removed, it is a good packing material, because it is fairly permeable to volatile gas and it transfers heat well.

3.2 Metallurgical Coke

Metallurgical coke is used in closed top baking furnaces. It is usually quite economical, but it has a very high ash level, which is a good for a closed top furnace. When metallurgical coke oxidizes under the cover, it forms a protective slag that limits further oxidation. It is also easy to withdraw with vacuum system because it is, like calcined petroleum sponge coke, fairly light. It is also easy to crush and grind, so it produces dust easily. When fines are removed, it is also a good packing material, because it is fairly permeable to volatile gas and it transfers heat well.

Table 1. Packing Materials, Advantages and Inconveniencies.

	Calcined petroleum sponge coke	Calcined metallurgical coke	Calcined petroleum fluid coke	Calcined petroleum shot coke	Calcined anthracite
Used in furnaces	Open / closed	Closed	Open	Not used at all	Closed
Readily available from paste plant	Yes	No	No	No	No
Easy to vacuum, medium to low particle density	Yes	Yes	No, high particle density [6]	No, high particle density [7,8]	No, high particle density
Dusty, porous, grind easily	Yes	Yes	No, high particle density [6]	No, high particle density [7-8]	No, high particle density
Good heat transfer, high particle density	No, medium to low particle density, when fine	No, medium to low particle density, when fine	Yes	Yes	Yes
Good volatile gas transfer, coarse material	When coarse	When coarse	No [6]	Yes [7,8]	Yes
Difficult volatile gas transfer	When fine, crusting on flue walls	When fine, crusting on flue walls	Yes, crusting on flue walls [6]	No	No
Form protective coating of molten ash, high ash level (closed top furnaces)	No	Yes	No	No	Yes
Low repose angle, fill easily voids	When coarse	When coarse	Round particles	Round particles	When coarse

3.3 Calcined Petroleum Fluid Coke

Calcined petroleum fluid coke is a fairly fine material, sometimes used in open top baking furnaces. Particles are very dense and it does not crush or grind easily, so it does not produce a lot of dust. Being dense, it can be difficult to withdraw with a vacuum system. Being fine, volatile gas has difficulty to pass through it and this sometimes results in coke crusting on flue walls [6]. Heat transfer is relatively high [6], because particles are dense, but is handicapped by its fineness.

3.4 Calcined Petroleum Shot Coke

Calcined petroleum shot coke is not currently used (as far the author knows) as packing material, because it is mostly used in titanium oxide industry. It would be a good candidate for use in open top baking furnaces. Particles are very dense, so it would not crush or grind easily [7, 8]. It is also fairly coarse, so volatile gas would easily pass through it. Heat transfer is high, because particles are dense and mostly coarse particles. It would be difficult to withdraw with vacuum suction system.

The author saw an interesting idea to manufacture the equivalent of calcined petroleum shot coke, by recycling packing material dust. In the seventies, a cathode plant was equipped with a carbon dust disk pelletizer, using lignin as binder. The idea was to recycle dust collector product from vacuum suction system crane as carbon round pellets to be used as packing material. The author was unable to find out why the disk pelletizer plant was not used after start up of cathode plant.

3.5 Calcined anthracite

Calcined anthracite is very dense, and after screening, it becomes quite coarse material. It is usually used in closed top baking furnaces, when baking anthracite or semi-anthracite cathode blocks. It has a high ash content, which means it forms a protective slag that limits further oxidation when under the cover. Particles are very dense so it does not crush or grind easily. It is also fairly coarse, so volatile gas easily passes through it. Heat transfer is high, because particles are dense and mostly coarse. It is difficult to withdraw them by withdraw them suction system.

4. Packing Material Problems and Solutions

4.1 Fines Accumulation in Packing Material

The first and most obvious problem of packing material, whatever its source is, is crushing and grinding of coarse particles into dust. Handling is the main source of comminution [3]. Packing material suction systems are designed to handle large quantity of material fast. There is also quite low headroom on cranes inside baking furnace buildings. So, changing material direction from upward -coming from section to downward when falling into silo is not easy. As described earlier hit plates and 180-degree turns are the most common ways of changing packing material direction.

Ideally, packing material should decelerate and fall freely into silos. It is not an easy system to design, knowing available space on cranes.

Whatever suction system, even the best designed, will end up handling fines that have to be removed one way or another. There is usually no continuous packing material cleaning system on coke handling cranes, aside from packing material silo dedusting. So occasional screening is the most used method of packing coke cleaning. Regular sampling of used packing material should be done to measure fines level to decide if the cleaning is required or not.

One possible option is to install a cyclone at reception on top of a silo. Cyclonic action would slow down particles and, by adjusting central tube height, it would be possible to withdraw fine particles to dust collector (Figure 7).

The second cause of packing material size reduction is air oxidation. It causes two problems. First is the production of fines. Second is SO_2 and CO production in baking furnace building during cooling phase.

There are a few ways to lower air oxidation. The first one is to protect packing material from air infiltration. This may be achieved, on open top furnaces, during preheating by using a plastic sheet on sections. This usually works on first two sections in preheating. Temperature becomes too high for plastic sheets on third section in preheating. High temperature tarps may be used on the third section, but this kind of tarp is usually quite heavy to transport.

Another way, for open top furnaces, is to install an aluminium foil in packing material. When filling with packing material, the crane operator stops at the fourth or the fifth row of bricks from the top of flues. An aluminium foil is put on packing material and filling of packing material is completed on top of aluminium foil (Figure 8). Aluminium foil resists to fairly high temperature. It ends up oxidised into alumina, because of its position in a high temperature zone, but, nevertheless the foil is still present at cooling stage. Resulting alumina is withdrawn with packing material, so there is usually no need to remove anything.

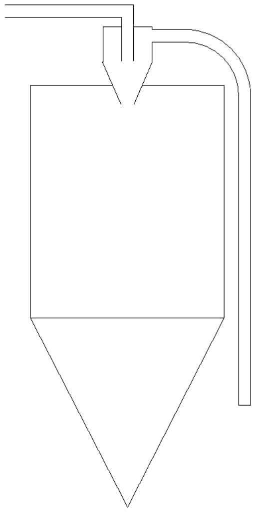

Figure 7. Possible arrangement of cyclone for reception and dedusting of packing material.

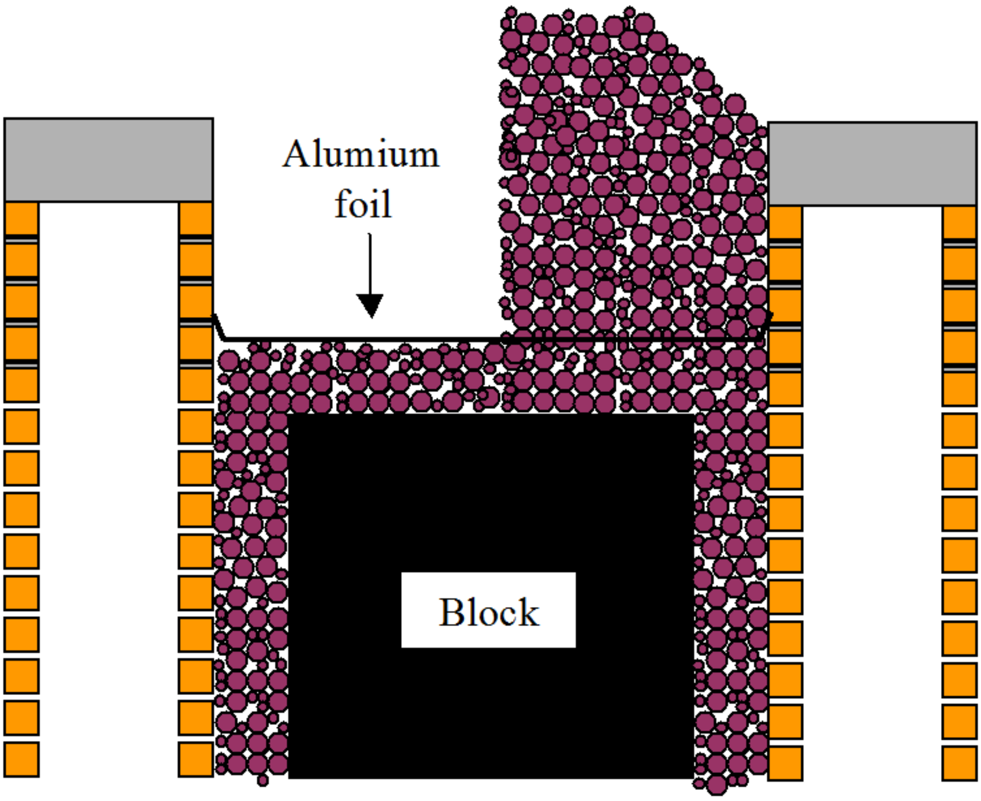

Figure 8. Use of aluminium foil to block air infiltration

Topping with aluminium foil may also be used as a last resort method to extinguish large "red eyes" which cannot be cooled down by topping with packing material. Air infiltration through packing material then consumes packing material faster than topping can replace it. The author used it with success for this specific purpose.

For closed top baking furnaces, aside from slag cover resulting from oxidation of high ash packing material, putting a non-oxidizing material on top of packing material was tried with success. First attempts were made with crushed bricks or bricks layered by hand when manpower is not expensive. It works in both cases, but removal of bricks or crushed bricks is not easy and it creates an additional work. Another solution was tried with success is; putting a rather thin layer of non-oxidizing powder on top of packing material. See reference [9] for a complete explanation and results of these experiments.

One unusual way to lower packing material oxidation is to block it by using an oxidation blocker. One material tested for carbon anode is boron [10]. Boric acid decomposes into boric oxide, which melts at 450 C, a fairly low temperature. This is why boric oxide is used for fire proofing and in welding fluxes. Liquid boron would cover packing material surface and block the access of air into this material. But, there are many issues to manage.

First, boron would end up in aluminium after anode baking. Casting houses usually ask for low or no boron at all in aluminium. Boron may disappear through reaction with vanadium in aluminium, if there is less boron than vanadium in aluminium. Actually, casting houses remove vanadium from aluminium; by adding boron to improve aluminium electrical conductivity.

A second problem would be that packing material may also stick to carbon blocks or flue walls if boron level in packing material is too high (see section 4.4 about low melting point ash)

A third problem is that boron will react with fluoride and will be emitted to atmosphere through scrubber chimneys. It has to be checked if there is any problem associated with the presence of boron or a limit for boron fluoride emission to atmosphere.

But, this would solve the problem of raising levels of oxidation catalysts (vanadium and nickel) in calcined petroleum sponge coke.

Removing fines also gives packing material a lower angle of repose, which helps to get an optimal mechanical support during baking. It also helps volatile gas transfer through packing material, by making it more permeable. Furthermore, it facilitates heat transfer through coarser packing material. So, there is no detrimental effect of fines removal from packing coke, except for air infiltration on top of sections in open top baking furnaces.

4.2 Improving Heat Transfer, During Heating and Cooling

To improve heat transfer during preheating and heating under fire, the first step is to reduce air infiltration using plastic sheets, tarps, aluminium foil, etc. on pit top and reducing air infiltration through peep holes and other openings in flues, for open top baking furnaces.

The second step is to obtain a coarse packing material, by removing fines and adding new coarse material, to compensate for material attrition and oxidation.

The third step is to get dense packing material, but this may not be possible.

A known method for fast cooling is water injection in flues of open top baking furnaces [11]. But be aware that water injection may cause thermal shock in bricks and vertical cracking of flue walls at water injection points, as a consequence, flues life shortens.

To avoid reheating caused by packing material oxidation; in open top baking furnaces, the contact of cooling air with carbon-based packing material has to be avoided. Sealing degassing slots is not an option. Static pressure of cooling air in flues should be reduced. Two options are available. The first one is to open as much as possible available openings at flue top. The second one is to add suction cooling fan to remove cooling air from flues (Figure 9). Using suction fans to remove cooling air from flues is already a common practice in closed top baking furnaces. But it requires only one fan by section. For open top baking furnaces, one fan by flue would be required. Suction lowers static pressure to subatmospheric levels, thus lowering the average static pressure in sections under cooling, slowing down or eliminating cooling air infiltration in packing material through degassing slots. But this requires an additional equipment to install on flues during fire advance sections.

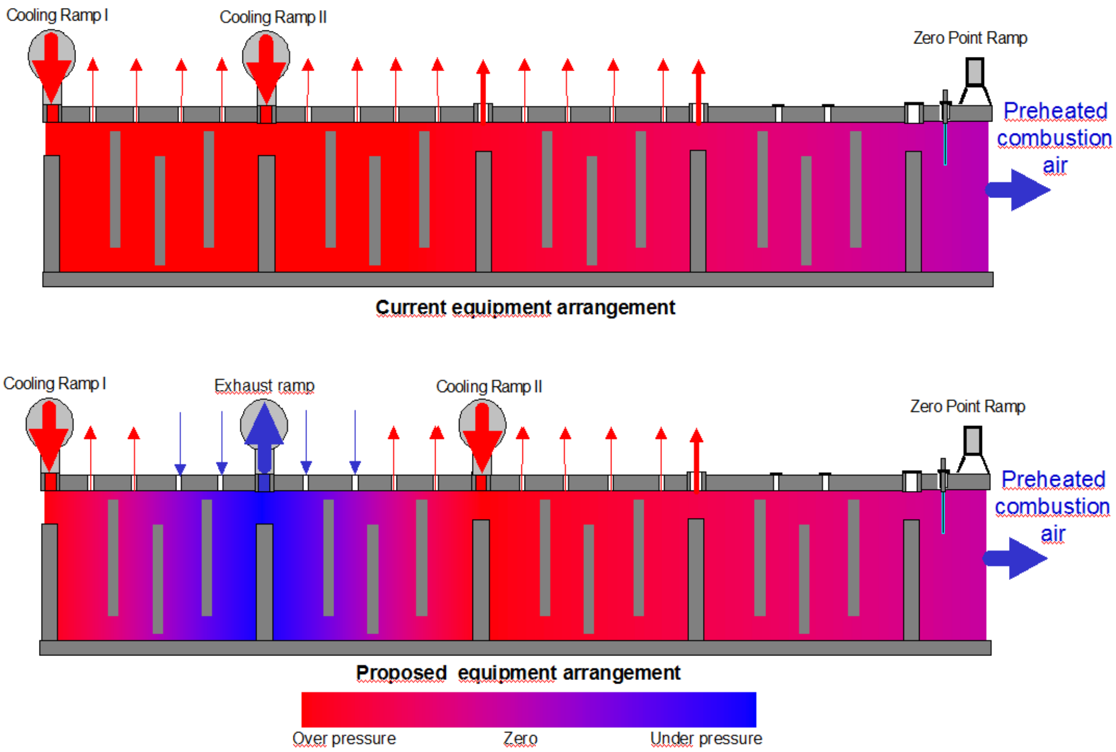

Figure 9. Way to lower static pressure in cooling sections.

4.3 Deformation of Carbon Blocks

Deformation of carbon blocks and stud holes in sections is caused by insufficient support by packing material. One problem may be insufficient space for packing material to flow in. This happens when carbon blocks are packed too close to flues or they lean toward flues. Block stacking procedures in sections are to be followed as much as possible. Flue wall replacement, if they are too bent, should also be considered. If carbon blocks were enlarged with time, sections may not be large enough for the new block size. Baking furnace design itself may have to be reconsidered.

Packing material may not flow well enough to fill the voids during packing. The angle of repose may be lowered by removing fines or adding coarser material. The care must be taken when mixing coarse material with finer material in order to avoid that packing material becomes highly permeable to air. This would cause “red eyes”, due to packing material oxidation.

4.4 Sticking of Packing Material to Carbon Blocks or Flues

Most obvious reason for packing material sticking to carbon blocks is to have high binder content. Numerous articles detail optimal binder adjustment strategies, none will be provided here.

A less common cause of packing material sticking to carbon blocks is low melting point ash. With oxidation, ash level in packing material rises. Also, the presence of a high sodium level, coming from insufficient butt cleaning, may result in low melting point ash. This is more likely to occur in closed top baking furnaces, because ash chunks form by packing material oxidation under the cover. Low melting point ash may also fill expansion joints and block sliding of flue walls in expansion joints, causing flue walls bending.

Packing material sticks to flues because of volatile gas carbonization in this material [6]. Removing fines may be a first step to reduce this problem. Keeping degassing slots clean may also help, because blocked degassing slots have the same effect as fine material. Consequently, volatile gas is left in a very hot environment, where it may transform to coke. This occurs in absence of air to burn the carbonised volatile since oxygen exists only inside flues walls.

5. Conclusion

Keep packing material coarse. It only has advantages. The only problem, in open top furnace, is that coarse packing material allows air infiltration from top of pits.

To counter this problem, use ways to block air infiltration: plastic sheet, tarp, aluminium foil. Or invent an open top furnace pit cover, similar to closed top furnace cover. Or use fine packing material on top of pit only.

Limit air oxidation of packing material. Lower air oxidation catalysts level when it is possible to do it. Or use ways to counter catalysts. Lower air static pressure in cooling sections, to limit reheat from packing material oxidation, that slows down cooling process, and useless waste of packing material.

Packing material is not only a consumable in baking process. It is an important actor in baking process itself. It should not be neglected.

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