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HIGH PERFORMANCE SEALING FOR ANODE BAKING FURNACES

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Abstract

Anode baking requires important volumes of air and fumes for combustion and thermal exchange. Efficient refractory port sealing is an important condition required to reach rated flows inside flue walls. Conventional sealing techniques have many problems which can lead to process inefficiency and degraded operating conditions. A new technology has been developed and then tested at the Mozal smelter to enhance this sealing function: it is based on the use of advanced materials that combine flexibility, resistance to the extreme conditions in the furnace and offers a new potential of process improvement in anode baking furnaces.

A flexible membrane is held between two rigid plates and encloses the inner refractory port when inflated. As a consequence, cold air incursion into the fume exhaust ramp is reduced. The results obtained, including a limited condensation of exhausted fumes and an increased furnace thermal efficiency, are presented in this paper.

Introduction

In order to direct only the exhaust gases into the external Fume Treatment Center and prevent cold air from the upstream end of the adjacent fire group from flowing backwards into the exhaust, a seal is placed inside the flue wall against the fume path opening (Figure 1).

The design commonly used in open type furnaces, known as « folding shut-off gate », is a flat, flexible, high temperature cloth that is placed across the internal rectangular opening, also called « Port », in the headwall (Figure 2).

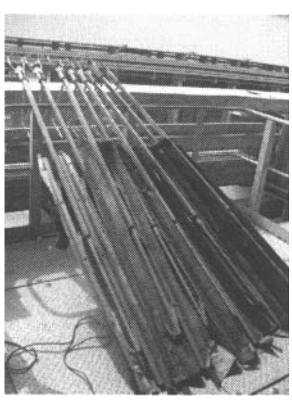

Figure 1: Standard "folding shut-off gate"

The problem with this technology is that the sealing contact of the cloth with the refractory is not perfect and sealing capacity may vary with the gate position, flue wall deformation or gate cloth wear. These defects may cause incomplete combustion due to a lack of draught inside the flue walls and can generate condensation of hydrocarbon volatiles in the ring main due to cooling effect of added ambient air at the exhaust manifold.

Another main issue of cold air leaking at the exhaust is the formation of corrosive agents, mainly sulphurous and hydrofluoric acids, when moist air meets hot fumes, leading to rapid deterioration of exhaust pipes and ducts.

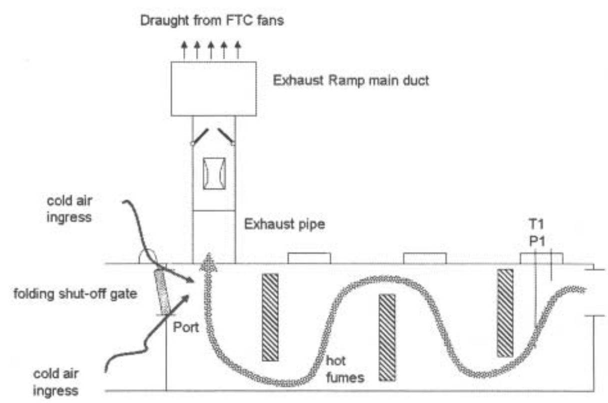

Figure 2: Air leakage at port shut off gate

A sealing technology based on an inflatable membrane

The new solution proposed by Fives Solios is an alternative to folding shut-off gates dedicated to improve sealing of flue walls. It is registered as a patented invention.

The Port Sealing Ramp (PSR) is equipped with an air blown inflatable sealing membranes. The inflatable membrane is surrounding a metallic structure that can be easily inserted and removed from the peephole (Figure 3).

The membrane is inflated and deflated by mean of an air fan. Switching from inflation to deflation modes is simply done by operating a hand valve. The advantage of an inflatable membrane is that the port is closely sealed even if it is deformed or it contains deposits.

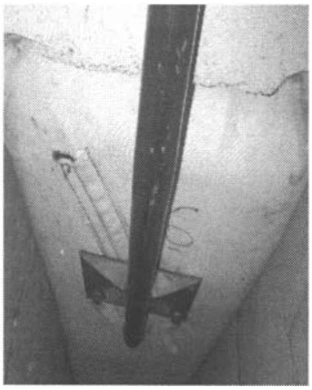

Figure 3: Inflatable gate in position in the port

The inflatable membrane material is designed to be flexible enough to fit the port inner surface as well as to sustain temperature, abrasive and corrosive conditions. The elasticity of the material selected allows a total expansion of the membrane at low pressure, generating a negligible stress on the refractory port. The membrane is protected from abrasion and impacts by a cover that can be easily replaced.

Integrated solution designed considering ergonomics and safety principles

The PSR is an independent structure that holds the inflatable shut-off gates and the air pressure distribution circuit (Figure 4). The Ramp is equipped with walkway platforms allowing the operator to install the shut-off gates safely even when pits of the preheating zone of an adjacent section are not loaded with anodes.

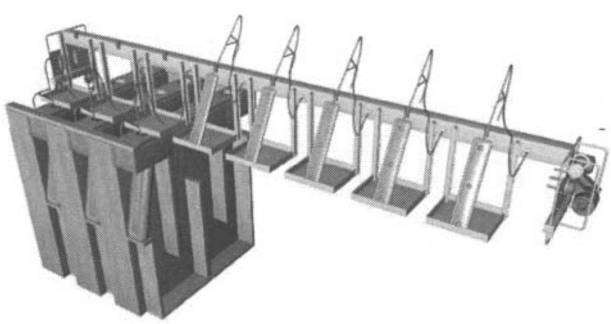

Figure 4: PSR with inflated membrane in position in the port

The inflatable shut-off gate, designed with consideration of ergonomic principles, has a total weight lower than 10kg. The membrane is retracted inside 2 plates when deflated, allowing the inflatable shut-off gate to be installed and removed easily through the peepholes. The PSR is designed to be positioned along the exhaust ramp during the FTA loading operation in the sealed section (Figure 5).

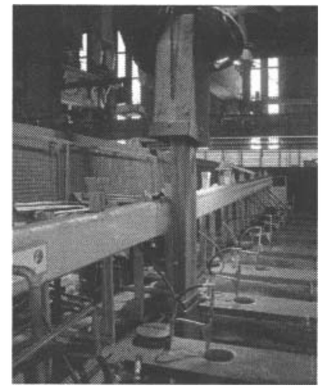

Figure 5: PSR in position for FTA loading

Technical textiles to sustain furnace environment

The membrane material must be able to face simultaneously:

- thermal constraints due to the temperature level in the port,
- corrosive and aggressive ambient conditions due to some fume components,
- severe and various mechanical constraints due to inflation / deflation, abrasion along bricks of the peephole when set in / out, or shocks when handled and rested on the PSR

But it also requires to remain:

- flexible enough to retract properly between plates, to allow an easy insertion through the peephole, and to fit properly against the refractory walls.
- air proof in order to stay properly inflated during the fire cycle without significant air consumption,
- light for ergonomic reasons,
- easy to manufacture (by gluing or thermoforming rather than expensive sewing),
- a cost effective material.

The technical specification was very challenging and in order to select appropriate materials to sustain furnace conditions, several life duration tests were conducted in real operation at MOZAL smelter ABF n°1 from August 2009 to June 2010.

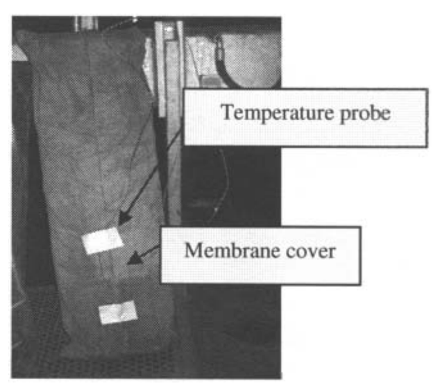

Figure 6: Temperature measure on the inflatable gate cover

The first consideration was to identify the maximum temperature reached inside the port at the end of the cycle. Temperature probes positioned on the membrane cover recorded a maximum of 152°C for an exhausted fume temperature of 309°C at the end of the preheating process (Figures 6 and 7).

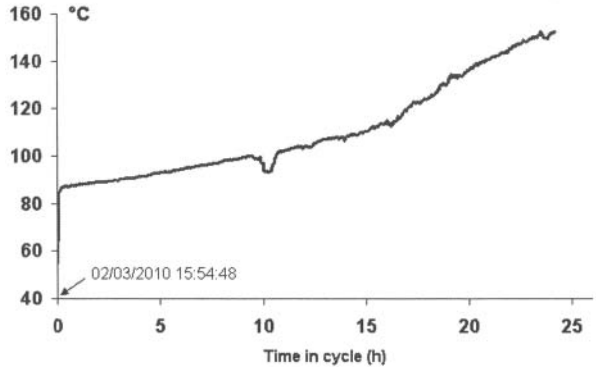

Figure 7: Cover surface temperature recorded during a baking cycle

Another issue is related to the exhausted fumes composition and particularly the presence of gaseous fluorides, sodium and sulfur oxides that are very corrosive agents. Gaseous fluorides and sodium are mainly coming from the anode butts that are part of the recipe of green anodes, Sulfur oxides are mainly originating from coke and fuel combustion.

Analyses have been performed to determine the main factors of corrosion of the gate materials after using it several weeks in the refractory ports. Scanning Electron Microscope (SEM) observation and Spectrometry were used. The analyses revealed that a chemical degradation mainly from sulphurous and fluoride compounds occurred on the cover, causing modifications of the properties of the material (Figure 8). Such chemical degradation is catalysed under the thermal effect.

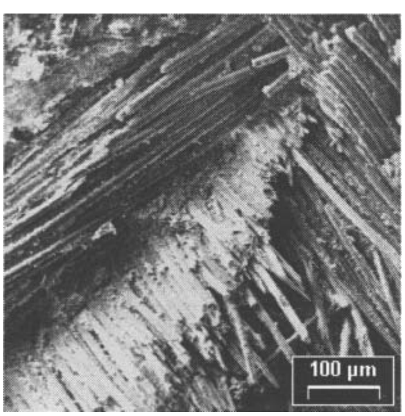

Figure 8: SEM picture of degraded material matrix

No satisfactory potential material was found to meet every requirement and it was finally decided to split the list of requirements by using a cover around the inflatable membrane. The role of this cover is to protect the membrane from abrasion and chemical corrosion, thus relaxing some constraints in the selection of the membrane textile. The membrane material shall mainly remains flexible, heat-proof and airtight.

Following temperature measurements and chemical analysis, several combinations of materials for membrane and cover have been selected and tested at the MOZAL smelter (Figure 9).

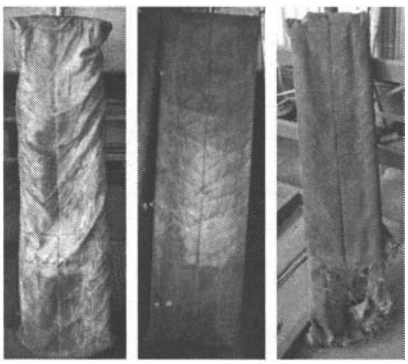

Figure 9: Tested covers

In total four materials for cover and three materials for membrane were selected among thermoplastic polymers. The best material "M3" for the membrane is still operating normally after 140 days. The longest cover lifetime duration recorded with material "C4" is 115 days. It is important to note that lifetime duration of both the membrane and the cover are dependent on many factors like flue wall conditions, handling operation, baking parameters. The lifetime duration of the membrane and cover materials recorded in real operation are summarized in Table I and Table II.

With the combination of material C4 and M3, the lifetime duration of the inflatable shut-off gate is 3 months on average.

Table I: Results of cover life duration tests

Material ref.	C1	C2	C3	C4
DAYS (min/max)	39	30 / 60	30 / 80	75 / 115
Origin of damage				
chemical attack	√	√		
Mechanical wear	√		√	√
temperature	√	√		

Table II: Results of membrane life duration tests

Material ref.	M1	M2	M3
DAYS (min/max)	2 / 37	11 / 40	79 / >140
Origin of damage			
mechanical wear		√	√
temperature	√		

Draught capacity rise due to membrane sealing

The trials performed in operation at MOZAL aluminium smelter showed an increase of draught inside the flue wall up to 30% compared with a folding shut-off gate in the same conditions, proving the excellence of an inflated membrane at eliminating the ingress of cold air into the fumes exhaust line (Table III).

Table III: Records of draught increase with inflatable gates

Date	Time	Section	fw	P1 (Pa) FG	P1 (Pa) IG	Δ (Pa)	Δ (%)
10/08/2009	15:35	43	6	-78	-91	-13	+ 16.7%
10/08/2009	15:37	43	8	-73	-93	-20	+ 27.4%
10/08/2009	15:38	43	9	-85	-95	-10	+ 11.8%
11/08/2009	10:15	44	8	-117	-133	-16	+ 13.7%
11/08/2009	14:10	44	2	-100	-111	-11	+ 11.0%
11/08/2009	13:57	44	9	-60	-74	-14	+ 23.3%
12/08/2009	13:45	45	9	-75	-90	-15	+ 20.0%
12/08/2009	13:45	45	7	-145	-160	-15	+ 10.3%

P1 Static negative pressure recorded in the first preheating section
FG Folding Gate
IG Inflatable Gate

In most of flue walls tested, whatever original pressure level, draught improvement was recorded showing that most of standard shut off gates are not positioned correctly along the port or are damaged (Figure 10).

Because air leakage at the port is very difficult to identify, sealing problems with standard shut-off gate remain hidden but have a large impact on baking process performance. For example, a 30% reduction in draught due to cold air leakage at the port represents a 15% drop in the volume of fumes and air flowing through the flue walls, impacting thermal efficiency and in some cases combustion quality.

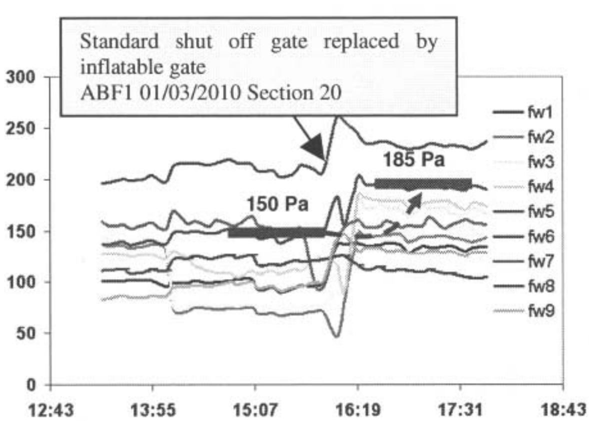

Figure 10: Draught increase with inflatable gate (fw1 to fw9)

Improvement of combustion quality in ageing furnaces

It is assumed that combustion occurs as a balanced stoichiometric reaction. For example, the complete combustion of 1 Nm^3 of Natural Gas requires 2 Nm^3 of oxygen that represents approximately 10 Nm^3 of air. If the volume of available air drops below the volume required for stoichiometry, incomplete combustion starts leading to unburnt hydrocarbons and typically Carbon Monoxyde (CO) formation (Figure 11).

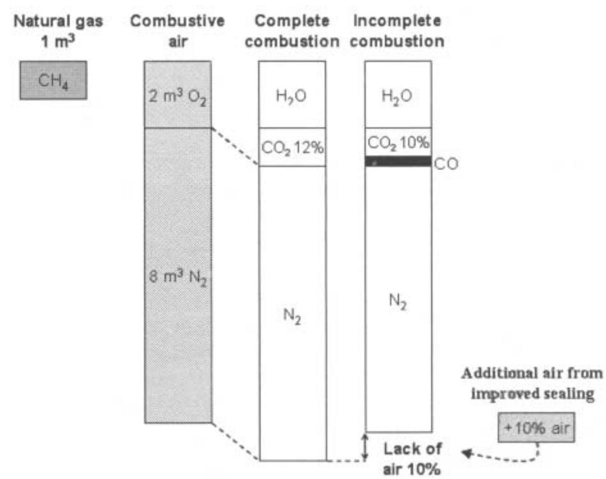

Figure 11: Stoichiometry of natural gas combustion

During trials in the ageing furnaces with deformed and even obstructed flue walls at MOZAL, additional air volume from membrane sealing allowed to switch from incomplete to total hydrocarbons combustion, especially in sections located at the end of the ring main where draught capacity was very poor, less than half of the requested level.

This phenomenon is illustrated by the significant drop of Carbon Monoxide (CO) content in the exhausted fumes when using the PSR instead of standard shut off gates (Figure 12)

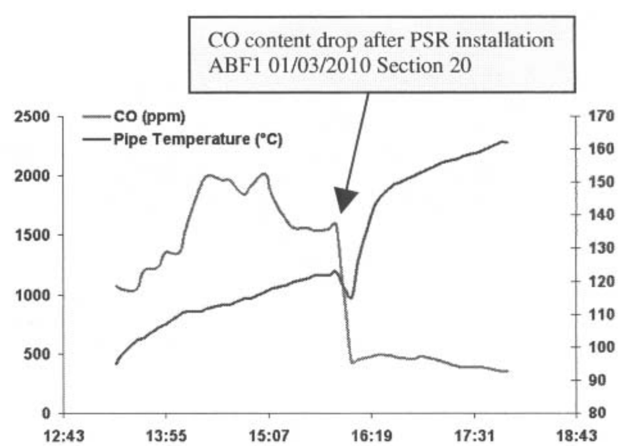

Figure 12: Combustion improvement with inflatable gate

The direct consequence of combustion quality improvement is the reduction of unburnt hydrocarbons inside ducts as well as a thermal efficiency increase. This was confirmed at MOZAL by a 15% increase on average of the preheating gas temperatures recorded at the end the baking cycle, only 2 cycles after PSR was installed in the fire group (Table IV).

Table IV – Preheating gas temperatures (°C) recorded at the end of the baking period in the first preheating section peephole 1 and in the Exhaust pipe. ABF1 Fire 1 from 01/03/2010 to 03/03/2010

		without PSR	With PSR – 2 cycles later	Δ (%)
1st preheating section	fw1	560	625	+10%
	fw2	640	740	+14%
	fw3	725	740	+2%
	fw4	725	675	-7%
	fw5	510	710	+28%
	fw6	625	725	+14%
	fw7	670	730	+8%
	fw8	560	740	+24%
	fw9	280	480	+42%
	Avg (fw)	**588**	**685**	**+15%**
ER pipe		**250**	**300**	**+17%**

Therefore, improvement of flue wall sealing by means of membranes may contribute to breaking the vicious circle "lack of air" → "hydrocarbons deposit → "pressure drop in exhaust pipe and ring" → "air volume reduction" that causes process instability, baking level inconsistency and fire risks particularly in ageing furnaces.

Further advantages of the proposed solution

In new operating furnaces, the Port Sealing Ramp promotes process stability by avoiding any air ingress from the wall port and thus maintaining permanently draught at its full capacity. As explosion risk is mainly related to loss of draft or very low flue gas rate in anode baking furnaces [1], PSR also contributes to improve safety during baking process.

Contrary to the standard folding shut off gate, when an inflatable gate is damaged, the loss of draught in the flue wall is apparent and so high that membrane replacement is necessary to maintain process operations inside the flue wall. In this way, hidden infiltrations degrading process performances all along baking cycles are avoided.

Another advantage resulting from the improvement of flue wall port airtighntess is to avoid corrosive attacks of exhaust ramp and ring main metallic structures that occur when moisture from infiltrated cold air meets hot combustion gases, forming highly corrosive agents.

PSR, a long-term cost effective solution

PSR solution requires higher maintenance costs than standard shut-off gates, mostly because of membrane design and material. But the gap represents a minor part of the total costs required to bake anodes.

Furthermore, as port sealing improvement tends to raise combustion quality, particularly in ageing flue walls, the following production costs will be cut when using PSR equipment in the same operating conditions:

- maintenance expenses dedicated to exhaust pipes, ring main and FTC duct cleaning,
- energy required to bake anodes.

Finally, by ensuring stable under-pressure in the flue walls, the PSR solution also promotes baking uniformity that impacts positively on potline operation and consequently metal production costs.

Evaluation of the benefit is not available yet, but the balance between the new PSR equipment extra costs and baking furnace operational cost savings thanks to port sealing improvement is expected to be largely positive.

From prototype to first industrial version

Increasing performance of sealing in anode baking furnace thanks to PSR has been demonstrated during the trials at Mozal smelter. But using a prototype in real operation also reveals downsides of the equipment.

A noticed disadvantage of the current version is that it requires a crane to be lifted during the fire move operation, impacting negatively the FTA availability. By reducing the PSR structure weight, the first industrial version of the ramp will be lighter and movable directly by furnace operators.

Another operational issue identified is the difficulty to move the PSR along the exhaust ramp, limiting the FTA access to pits during anode loading operation. The PSR structure of the first industrial version will be lowered and resized to comply with the FTA filling pipe movement. This problem is largely minimised when front section is loaded before the fire move as per normal practise.

Conclusion

Sealing of fire groups in open type anode baking furnaces has been underestimated, mainly due to technological barrier.

With the recent progress in technical textiles, a high performance seal for flue wall port was designed and patented. A test campaign was held at the MOZAL smelter on a prototype Port Sealing Ramp (PSR). The first trials have demonstrated the capability of the new equipment to enhance process efficiency and to promote safety. It also confirmed that flue wall port sealing, all too often neglected, is a major operation in anode baking furnaces.

References

[1] Inge Holden, Olav Saeter, Frank Aune, Tormode Naterstad, "Safe Operation of Anode Baking Furnaces", Light Metals 2008, 906, 908