SAFE OPERATION OF ANODE BAKING FURNACES

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Abstract

The baking of anodes is a process in which combustible substances are released. Ring main fires do occur and even explosions in the fire zones, ring main or fume treatment plant have happened in carbon plants. The risks associated with different process deviations and the possible consequences of these, can be evaluated for both existing and new furnaces to be built.

European and IEC safety standards give useful guidelines for the design of process control and safety systems applicable to the baking process.

This paper will present and discuss methods for evaluating the risks and consequences, and give examples for how operational procedures and the design of safety systems can reduce the occurrence of unwanted events for open as well as closed top furnaces.

Introduction

The total energy consumption in modern baking furnaces amounts to typically 4.8 – 5.2 GJ/t baked anodes, which is a combination of the following fuel sources:

- Oil or gas: 40 – 50 %
- Pitch volatiles: 40 %
- Packing coke: 10 – 20 %

The pitch volatiles may be classified in two main groups of hydrocarbons:

- Condensable hydrocarbons (tar), which are mainly poly-cyclic aromatic hydrocarbons (PAH).
- Non-condensable substances, which are mainly hydrogen and methane.

The condensable hydrocarbons appear during distillation of the lightest fractions in the pitch. The non-condensable substances appear in complex chemical reactions, polymerization and cracking at temperatures above 400 °C. In total, the volatilized components of the pitch coking are:

- Tar: Released at temperatures of 200 – 500 °C;
- Methane: Released at temperatures of 400 – 800 °C;
- Hydrogen: Released at temperatures of 400 – 1000 °C.

Particular safety aspects of baking furnace operations are related to the following specific features:

- Only 40 - 50 % of the total energy input is controllable by immediate actions.

- Strict control of the air to fuel ratio is practically hampered by false air ingress into the furnace atmosphere.

International safety recommendations, i.e. European and IEC safety standards, prescribe essential design and operational characteristics to be fulfilled for safe operation of similar furnaces.

A risk assessment of the anode baking furnace has been completed based on hazard analysis by explosion simulation. Explosion simulations are particularly useful to evaluate hazardous consequences caused by process disturbances, and to reduce the risks by design measures. This paper describes the furnace operation conditions used in simulations, the results of simulations and aspects of the safety systems required to safeguard against explosions and fires.

Principal Risk Assessment

Flammability of Flue Gas Compositions of Baking Furnaces

The vaporization and pyrolysis of pitch generates a large number of components throughout the ordinary heat treatment range of anodes. The resulting fuel composition may vary [1,2]. For this study the following, typical average composition was chosen:

- Tar: 91.3 weight %
- Hydrogen: 6.5 weight %
- Methane: 2.2 weight %

Homogeneous, combustible gas-air mixtures are flammable within a limited range of compositions. In the flammable range a flame can propagate freely upon ignition. The flammable range is defined by the following limits:

- The Lower Explosion Limit (LEL).
- The Upper Explosion Limit (UEL).
- The Limiting Oxidant Concentration (LOC).

The relationship between combustible gas, air and inert gas and the location of the flammable range can be visualised by a ternary diagram as shown in Fig. 1 and Fig. 2. The stoichiometric air to fuel ratio \( \lambda = 1 \) is also shown.

Tars are known to include a large number of components (3000-4000). Analysis carried out by Charette et al. [3] found that the poly-cyclic aromatic hydrocarbon (PAH) components constitute approximate 70% of the total hydrocarbon loss. For this study, an average formula weight of approximately 200 g/mol with a C/H – ratio of 1.6, as for fluoranthene and pyrene \((C_{16}H_{10})\), was chosen.
as the average, representative characteristics of tar and is referred to as “Tar” in this paper.

Zabetakis [4] gives LEL of aromatic hydrocarbons as \((50\pm2)\times10^{-3}\) g/l, giving the LEL of Tar as approximately 0.6 vol%, while the value of UEL of Tar can be derived as approximately 6.0 vol%. All values are normalised to 25 °C and atmospheric pressure.

In typical combustion regions, where the temperatures of the flue gas and the brickwork are higher than the Auto Ignition Temperature (AIT) of the combustible gases, the flammable region of the gas mixture is irrelevant and available oxygen will be consumed by oxidation. Process deviations may, however, increase the risk of forming gas-air mixtures within the flammable range downstream the combustion region of the fire zones:

1. Loss of draft situations followed by re-establishment of draft.
2. Sub-stoichiometric combustion. Too high fuel supply or too low draft, or a combination of the two conditions.

Oxygen deficit situations as described above may also be the root cause of formation of ignition sources. Cracking of heavier hydrocarbons forms soot/carbon particles. Light, glowing particles transported into the preheating sections facilitates ignition in pockets of flammable gas-air mixtures, or deposit in low velocity areas of the ring main system. High flue gas temperatures may also serve as ignition sources of soot/tar deposits in the ring main.

If the furnace is operated at oxygen deficit conditions caused by too low draft or excessive fuel, the resulting sub-stoichiometric concentration will be as shown in Fig. 1.

Equation of Tar Combustion

The average values of reactants and products of combustion at normal operation measured in a closed top baking furnace are provided in Table 1.

The total of the combustion products is approximately 1300 Nm³/t, while the total flue gas rate at the outlet of the combustion region is 1600 – 1900 Nm³/t, since the furnace is operated at an oxygen surplus.

The flue gas entering the Tar combustion region contains the combustion products of the preceding fuel sources, e.g. propane, coke and the non-condensable substances from pitch pyrolysis. The principal equation of the stoichiometric Tar combustion \((\lambda=1)\) in the fire can thus be described by:

\[
C_{16}H_{10} + 18.5(O_2 + 3.76N_2) + \Sigma_{\text{Inert}} \rightarrow 16CO_2 + 5H_2O + 69.6N_2 + \Sigma_{\text{Inert}}
\]  

(1)

The average total of combustion products from energy sources other than Tar (\(\Sigma_{\text{Inert}}\)) at normal operation is approximately 193 [mol/mol Tar], as shown in Table 1.

Explosion simulations are carried out at stoichiometric air to fuel ratios. The stoichiometric air to fuel ratio of Tar combustion is 88:1 [Nm³/Nm³], as seen from Eq. 1, and is one of the essential factors considered by explosion simulation.