

EVALUATION OF THE OXYCLEAN TECHNOLOGY FOR INCINERATING INFECTIOUS WASTE IN LUXEMBOURG

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Executive summary

The present report concerns a preliminary evaluation of a patented technology called OXYCLEAN® in its adequacy to perform incineration of waste (mainly infectious material) in Luxembourg. The main objective is to limit the primary risk that could be linked to an inefficiency of the technology or its non-compliance to environmental legislation.

In the OXYCLEAN technology, a classical vertical 5-m³ (considering 1072 kg/ton) incinerator operating at 400-500°C has been supplemented by an innovative system allowing the ionization of air flowing into the combustion chamber. Ionization is made by permanent magnets which generate reactive oxygen species (ROS) having decontamination properties which act in addition to the combustion itself. The combustion chamber is followed by an efficient treatment of fumes. Combustion operated without the need for external fuel; the waste being the combustible.

The patents supporting the OXYCLEAN technology are granted in Brazil. They are based on solid theoretical foundations. Further evidence that could rise from a more experimental approach would strengthen the position on the market. This could be an interesting objective of a second phase of evaluation with pilots in Luxembourg. Geographical coverage of the patents can be extended to Europe without problem.

Two systems running in Brazil have been analyzed as far as emissions are concerned (data provided by two independent engineering offices (Eurofins and Chaminé)) and visited by HM Cauchie in October 2019. It appears that the technology is efficient in burning infectious waste and is compliant with the major emission limits in place in Europe. In particular, the emissions of dioxins and furans are below the limit of 0.1 mg/Nm³.

One strength of the technology is its easiness of implementation. This consists of relatively small size units that can be installed with a small land hold. An installation of pilots in Luxembourg is feasible and would allow the testing of the solution with local waste.

The combustion technology is also flexible in terms of combustible that can fuel the system. This allows to treat other types of waste including some industrial waste. The technology is a good candidate to fulfill the principles of self-sufficiency and proximity of waste collection and destruction in Luxembourg in the future.

As a conclusion, the OXYCLEAN technology is evaluated by LIST as free of primary risks. A phase of testing in Luxembourg can therefore be considered as timely.

1. Introduction

Waste incineration became widespread in the 1970s in order to face the increasing production of municipal solid waste. Even if today's policies aims at reducing the production of wastes and to promote recycling and reuse in the context of the implementation of circular economy¹, solid waste remains a major issue in most countries. In Luxembourg, SIDOR processes 160,000 tonnes of waste per year in the country's only incineration plant, located in Leudelange.

As far as hospital and pharmaceutical wastes are concerned, destruction by incineration remains the most adequate solution but it is often done separately from the destruction of municipal waste. Currently, in Luxembourg, the destruction of these wastes is done abroad. However, the volume of infectious wastes from hospitals and research centres are significant enough to consider an incineration on Luxembourg's territory, complying in this way to the "principles of self-sufficiency and proximity" of waste collection and destruction according to the EU directive 2008/98/EC on waste (Article 16).

The OXYCLEAN technology is proposed as a solution for the destruction of infectious waste in Luxembourg. LIST has been mandated to make a preliminary expertise about the ability of the technology to treat infectious wastes and about the environmental performances of the technology, based on:

- The granted patents concerning this technology;
- The results of measuring campaigns concerning fumes and effluents of OXYCLEAN systems running in Brazil;
- A visit of installations in Brazil.

2. Description of the technology

The OXYCLEAN technology is allowing the combustion of waste with a high content of organic carbon and a high humidity at relatively low temperature (400 – 500°C). It is intended for the destruction of biological or industrial waste.

The equipment (Figures 1 and 2) is composed of a combustion chamber (dimensions: 1,835mm x 1,832mm x 1,832mm) made in steel sheets (5/16" – 0.8mm). Two lateral doors (0.750mm x 0.590mm) are screwed on two opposite lateral sides (Figure 1 right). They allow the cleaning of the ashes after combustion. A system of airlocks (volume = from 0,500m³ to 0,750 m³ according to the model) allowing the introduction of waste to be treated is located above the combustion chamber. A system of two sliding doors allows the introduction of the waste by the top and, when the airlock is filled and the upper door is closed, to open the lower door to introduce the waste in the combustion chamber. The airlock doors are electromechanical and are operated remotely by an operator.

¹ Plan National de gestion des déchets et des ressources – Ministère du Développement durable et des infrastructures, Administration de l'Environnement - 2018
https://environnement.public.lu/dam-assets/documents/offall_a_ressourcen/pngd/plan/PNGD.pdf



Figure 1 – Oxyclean incinerators with (A): loading ramp; (B) airlock; (C) incineration chamber; (D) nozzle, (E) lateral doors. Left: incinerator in Contagem; Middle and right: incinerator in Santa Luzia.



Figure 2 – Schematic of the OXYCLEAN system with the combustion chamber on the left and the fume treatment (Venturi scrubber) on the right.

Combustion is initiated by igniting flammable substances with low moisture content such as cardboard with an ethanol-impregnated pad, and portable industrial torch. It takes 4 hours to bring the combustion chamber to the required temperature (200°C) for starting the treatment of waste. The equipment requires no fuel to run, except the waste, which makes it an environmental correct economical system.

The equipment is fed in a semi-continuous way, batches of waste to treat being introduced after one hour and half or two hours (according to the waste being treated). The wastes progress by gravity. A vibrator facilitates the downward movement of waste.

The equipment is allowed to cool down after 10 days of the treatment (4 ton/day on average), in order to remove the accumulated ashes.

At the base of the combustion chamber, nozzles open laterally and allow the combustion chamber to be supplied from below (Figure 3). The main innovation of the OXYCLEAN technology is in the design of these nozzles. They are cylindrical and extend 150 mm into the combustion chamber. Two static magnets made of neodymium (magnetic flux density = 8,000 G or 0.8 T) are placed on both sides of the nozzle at a distance of 300 mm from each other, outside the combustion chamber. Diatomic oxygen that makes up the air is ionised by the magnetic field and yields reactive oxygen species (ROS) such as oxygen free radicals. ROS are considerably more oxidative than diatomic oxygen. As they enter the combustion chamber, they will participate to the oxidation of organic matter and will notably degrade infectious materials.



Figure 2 – External (left) and internal (right) views of the nozzle tubes with (A) permanent magnet positions, (B) drilled plate for the manual air flow adjustment, (C) nozzles tubes inside the combustion chamber.

These characteristics are described in two patents². Besides the main innovation based on the use of static magnets for ionising oxygen, the main characteristics highlighted by the inventors (Anderson Guimaraes de Souza and Hiroshi Aoki) are the following.

² Patent BR1020120138363, entitled “Combuster of solid organic substance”, granted on 28/04/2015, see annex I; Patent BR102013013620, entitled “Perfectionings (sic) introduced in equipment of combustion of solid organic substance”, granted on 19/04/2016, see annex II.

1° - The combustion of the solid organic material to be treated is made from bottom to top, allowing time to dry in the wastes introduced in the combustion chamber.;

2° - The operation of the system provides a sufficient time and temperature for the carbonization of the solid organic material before it is reached by the oxygen in the air, which is sucked up by the upward flow of the hot gases generated;

3° - The nozzles can be operated (currently manually but this can be automated) in order to regulate the quantity of air sucked in so that the operating temperature is always between 400 and 500°C (control by sensors);

4° - The system ensures, by the quantity of controlled air entering the installation enclosure, that there is no or minimum formation of dioxins, NO_x, sulphides, sulphites, sulphates, phosphates and phosphates;

5° - The combustion humidity and the water from the scrubber are collected and condensed in order to treat, by splashing, the gases generated by the combustion chamber;

6° - A layer of ash is maintained in the lower part of the combustion chamber, which acts as follows catalysts for the combustion of gases generated by carbonization and to adsorb or react with NO_x, sulphides, sulphites, sulphates, phosphates and other compounds.

The fumes are treated by a combination of a classical Venturi scrubber (Figure 4) which allows efficient trapping of particulate (fly ashes) and gaseous (especially sulphur dioxide) compounds (Pak & Chang, 2006; Moharana et al., 2017), and an activated carbon filter, which complete the removal of pollutants by adsorption (e.g. of dioxins and furans or mercury; Quina et al., 2008; Lu et al., 2012). Washing water from the Venturi scrubber is partly reinjected in the scrubber in order to thicken the residual water, which turns to be tar.

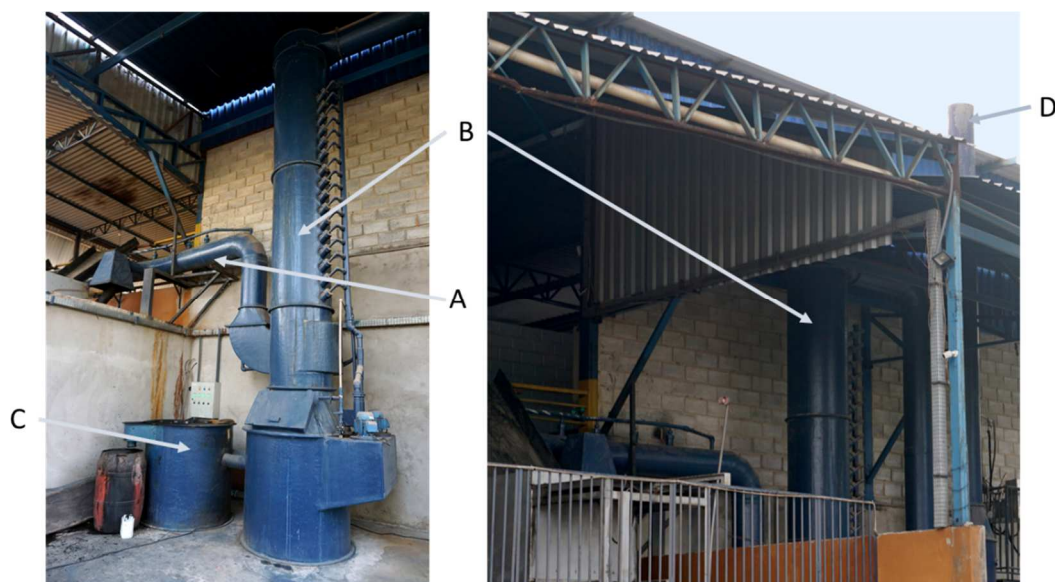


Figure 4 – System of fume treatment with (A) inlet fume pipe, (B) Venturi scrubber, (C) tar thickener, (D) chimney.

3. Evaluation of the innovation brought by the patents

Free radicals and other compounds produced by the ionisation of diatomic oxygen are known to exert a disinfection action against pathogenic bacteria (Zhang et al., 2013, Duday, Cauchie, et al. 2013, Dasan et al, 2018) or viruses (Terrier et al., 2009; Park and Ha, 2018). Reported experiments have been made using cold atmospheric plasma fed with oxygen at ambient temperature (25°C). This supports the hypotheses on which the patents are based, i.e. that the generation of reactive oxygen species (ROS) can provide decontamination *per se*.

In the patented set-up, the oxygen is passing between static magnets, whose magnetic flux density are supposed to be high enough to ionise oxygen efficiently. Although magnetic phenomena are associated with charged radicals and electrons in motions, there is only a few published studies. Gugkova et al. (2005) has nevertheless demonstrated the formation of ROS in electromagnetic fields. However the experimental conditions were different from the OXYCLEAN application.

As a conclusion, ROS are certainly produced and can be active in waste treatment in the combustion chamber. It will be interesting to further investigate which are the precise composition of the ROS and their lifetime in order to fine-tune the treatment. The current lack of these additional scientific results does not however prevent the system from being performant in destroying infectious material through the sole temperature effect.

Indeed, above 120°C, all infectious agents are destroyed, including thermo-tolerant spores, after thermal treatment longer 70 min (Tortora et al., 2003; Berk, 2018). As far as they are concerned, thermo-tolerant antibiotics (which are generally present in hospital waste) are all degraded above 250-300°C (even the antibiotic with high thermal tolerance such as amoxicillin, penicillin V, penicillin G, ciprofloxacin or sulfamethoxazole (Svahn and Björklund, 2015).

The effective production of ROS would be an additional, but not mandatory treatment.

Waste with a thermal stability over 500°C, must be isolated from the waste before treatment.

4. Conformity of the technology with the requirements of the European Directive 2010/75/EU

The OXYCLEAN treatment must be considered as “waste incineration plant” in the sense of the directive 2010/75/EU on industrial emissions (integrated pollution prevention and control) (translated into Luxembourg’s national legislation as the Loi du 9 mai relative aux émissions industrielles). As such, the OXYCLEAN treatment must, among others, fulfil requirements of Art. 46 of this directive (“Control of emissions”) on “*emissions into air from waste incineration plants and waste co-incineration plants shall not exceed the emission limit values set out in parts 3 and 4 of Annex VI or determined in accordance with Part 4 of that Annex*” and on “*Discharges to the aquatic environment of waste water resulting from the cleaning of waste gases shall be limited as far as practicable and the concentrations of polluting substances shall not exceed the emission limit values set out in Part 5 of Annex VI*”.

LIST obtained results from two waste incineration plants located in the suburbs of Belo Horizonte. These two plants have also been visited by Henry-Michel Cauchie from LIST on October 21st and 22nd, 2019. The fumes and the wastewater of the plant located at Santa-Luzia has been analysed by the engineering office Chaminé (<http://www.chaminesolucoes.com.br/>) while the wastewater of the plant located at Contagem has been analysed by Eurofins (<https://www.eurofins.com.br/>).

Not all the variables required by the directive 2010/75/EU are required in Brazil. Moreover, the measurements are the results of point sampling while the limits concern average concentrations over one day. However, these results give a first useful overview of the environmental performances of the OXYCLEAN treatment. The tables 1 and 2 present the most relevant results obtained on the two Brazilian sites.

The results obtained at Santa-Luzia and Contagem indicate a conformity of the air and wastewater effluents according to the EU directive, except concerning the total dust concentration at Santa-Luzia. In particular, it must be noted that the concentrations of dioxins and furans are largely below the emission limits.

Concerning ashes, “waste incineration plants shall be operated in such a way as to achieve a level of incineration such that the total organic carbon content of slag and bottom ashes is less than 3 % or their loss on ignition is less than 5 % of the dry weight of the material” (Directive 2010/75/EU, Article 50, §1). LIST have made a loss-on-ignition analysis of the ashes obtained from Contagem plant. The results indicates a loss on ignition lower than 5% of the dry material.

Globally, the results obtained on these two plants indicate that the OXYCLEAN incineration technology will certainly comply with the European standards.

Table 1 – Air emissions from the waste incineration plant of Santa-Luzia. Variables indicated in the directive 2010/75/EU (annex VI, part 3, §1.1) that were not analysed: Gaseous and vaporous organic substances, expressed as total organic carbon (TOC) and heavy metals in gases. Units and abbreviations: mg/Nm³ = milligrams per normo cubic meter; SD = standard deviation.

Variables	Emission limits mg/Nm ³	Measured values	
		Average mg/Nm ³	SD mg/Nm ³
Total dust	10	25.7	2.2
Hydrogen chloride (HCl)	10	3.9	0.2
Hydrogen fluoride (HF)	1	0.5	0.1
Sulphur dioxide (SO ₂)	50	14.3	1.1
Nitrogen monoxide (NO) and nitrogen dioxide (NO ₂) ¹	400	23.1	1.9
Dioxins and furans	0.1	0.041	0.002

¹ expressed as NO₂ for existing waste incineration plants with a nominal capacity of 6 tonnes per hour or less

Table 2 – Emissions in wastewater from the waste incineration plants of Santa-Luzia and Contagem. Variables indicated in the directive 2010/75/EU (Annex VI, part 5) that were not analysed: total suspended solids, thallium, copper, nickel, zinc, dioxins and furans.

Variables	Emission limits mg/l	Measured values	
		Santa-Luzia mg/l	Contagem mg/l
Mercury and its compounds, expressed as mercury (Hg)	0.03	0.0001	<0.0002
Cadmium and its compounds, expressed as cadmium (Cd)	0.05	0.001	0.011
Arsenic and its compounds, expressed as arsenic (As)	0.15	0.001	<0.005
Lead and its compounds, expressed as lead (Pb)	0.2	0.001	0.144
Chromium and its compounds, expressed as chromium (Cr)	0.5	0.005	1.099

5. Considerations about incineration temperature

There has been great concerns about the dioxin, furans and PCBs contamination due to incineration in the past decades. Dioxins may form when incinerating many different type of waste (paper, wood, PE, PS, PET, PVC...). There are two types of reactions associated with the formation of dioxins. The main production of dioxins occurs at 450-800°C following a homogeneous reaction in gaseous phase. There can be formation of dioxins following a heterogeneous reaction between 200-400°C³. However, at these temperatures, dioxins are formed on solid surfaces such as fly ash and soot by some catalysis (metals) (Shibamoto et al, 2007) that can be trapped by performant fly ash and fume scrubbers. According to the results presented in section 3, if heterogeneous reactions occur, the fume treatment caught the dioxins that would have formed during the OXYCLEAN treatment.

Dioxin formation is however a very complex process where temperature is not the only important parameter. As it has been shown that dioxin concentration was reduced as the temperature was rise above 800°C in some lab-scale reactors (among others Hatanaka et al., 2001; Li et al., 2015), it is generally advised to have short periods of combustion temperature over 850°C. This is notably indicated in the EU directive 2010/75/EU, where a 2-second combustion at 850°C is advised (Article 50).

The OXYCLEAN system is not currently providing such very short combustion at high temperature but still have very low dioxin emissions. Referring to the Article 51 of the above mentioned Directive, the OXYCLEAN system can therefore benefit from an “authorisation to change operating conditions” as mentioned in Article 51 of this Directive.

6. Conclusions

The purpose of this study was to remove any uncertainty regarding the primary risks of the technology. Based on the patent description and the results of the chemical analyses, no significant risk appears preventing to go to the testing step in Luxembourg.

³ Homogeneous reactions are chemical reactions in which the reactants and products are in the same phase, while heterogeneous reactions have reactants in two or more phases. Reactions that take place on the surface of a catalyst of a different phase are also heterogeneous.

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