ADAPTATION OF AN INDUCTIVELY COUPLED PLASMA FOR CHLORINATED ORGANIC LIQUID WASTES DESTRUCTION

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Abstract:
The CEA develops for several years different kinds of plasma process in order to treat nuclear wastes. It has appeared that some of them could be used to destroy other industrial hazardous wastes such as organo-halogenated liquids, largely used as precursor in chemical industry. This is the case for the IDOHL process specifically developed by the CEA to ensure the destruction of radioactive organic liquids thanks to inductively coupled plasma. A mockup implemented at the Marcoule Center has been used to assess the feasibility of such destruction by using water as oxidative agent. This mockup, fitted with a 4kW inductively coupled plasma torch, allows the treatment of 75g.h\(^{-1}\) of chlorinated liquid fed together with around the same feeding rate of water. Downstream the plasma reactor, the gases are cooled and the acidic species are neutralized in a scrubbing column. If the first results obtained through the treatment of chloroform (CHCl\(_3\)) showed a good efficiency of destruction, they highlight that the use of water as oxidative agent leads to limit the feeding rate because of two main issues: the high energy requirement to vaporize the water and the immiscibility of some organic liquids in water. These results led to propose the substitution of water by oxygen in order to increase sensibly the throughput of liquid supposed to be incinerated in the plasma. The experiments performed with this new running mode have been carried out with CHCl\(_3\) for feeding rates ranging from 100 to 400g.h\(^{-1}\). As forecast through a thermodynamic approach, the results display a destruction efficiency upper than 99% and assure that the production of phosgene COCl\(_2\) remain small even if the hydrogen coming from water previously has been eliminated. Indeed, less than 1g.h\(^{-1}\) of phosgene is produced when HCl and Cl\(_2\) content remain within the regulation limits in exhaust gas. This shows that the temperatures inside the plasma area are high enough to transform molecules into atoms and also that the oxygen content is sufficient during the cooling step to obtain finally oxidized stable and non-toxic molecules such as H\(_2\)O and CO\(_2\). Based on these results, the process can subsequently be installed in a radioactive zone to validate the destruction of actual contaminated wastes. It could also be optimized in order to propose new treatment routes for other industrial hazardous liquid wastes.

Keywords: Nuclear wastes, organic liquid, chlorine, plasma.
1. Introduction
Organohalogens are often cited as responsible for climate change and occupational diseases [1]. These compounds are used in many processes in the chemical, nuclear, and processing industries where the quantity of waste generated is a problem requiring a solution at an industrial scale. Conventional thermal destruction (ie incineration & pyrolysis) is often used industrially as treatment, but if not sufficiently controlled it raises the risk of emissions that can be even more toxic than the initial waste. During combustion, chlorinated hydrocarbons are also known to interfere with and considerably modify the process, if only by the presence of chlorine which prevents the oxidation of CO to CO\textsubscript{2} [2] and favors the production of harmful products such as dioxins, furans, phosgene, etc. Organohalogen compounds are also very poorly biodegradable, and their chemical stability requires destruction by energy-intensive processes.

Thermal processes can be used, including thermal plasma. Several recent studies have proposed the thermal plasma process for the destruction of halogenated organic waste [3-5]. Compared with other methods for the destruction of halocarbons, thermal plasmas have unique characteristics such as rapid decomposition with high throughput, fast startup and shutdown, and high energy delivery.

In order to reduce the waste volumes, The CEA recently patented an “Installation for the Destruction of Organo-Halogenated Liquids” (IDOHL: French patent FR 0450303) using inductively coupled argon plasma. This type of plasma has several advantages as the geometry of the torch which allows the treatment not only of gases but also of liquids without prior evaporation, the absence of electrodes, the kinetics and the extended residence time. The initial tests with this device, at a higher power level (41–45 kW) than in the present work, demonstrated the feasibility of chloroform destruction using water as the oxidant [6]. Pure liquid CHCl\textsubscript{3} was completely degraded with a calculated energy efficiency (waste mass decomposed per hour / torch power) of 19 g.kWh\textsuperscript{-1} and converted to HCl and CO\textsubscript{2}. Unfortunately, simultaneously supplying water and waste can lead to major overconsumption of the initial plasma energy because of the high energy necessary to heat and vaporize the water. This drawback can limit the waste input and thus affect the energy efficiency. In addition, not all waste compounds are fully miscible with water, and their destruction can occur under pyrolytic conditions, although the importance of destroying chloromethanes under oxidative rather than pyrolytic conditions is well known [7]. These limitations led us to choose a new procedure using oxygen instead of water. A smaller (4–4.5 kW) plasma reactor was built to demonstrate the feasibility of processing radioactive liquid organochlorine waste. Chloroform was also selected as the organochlorine model for this study. This compound is classified as toxic and is used as a solvent in the production of many chemicals and pesticides; it has high thermal stability and contributes to global warming [1]. With its Cl:H ratio of 3:1 there is a strong possibility of forming toxic gases such as Cl\textsubscript{2} and COCl\textsubscript{2} during its destruction. Research has been carried out on the destruction of CHCl\textsubscript{3} by thermal oxidation [2], photocatalysis [8] and nonthermal air plasma [9,10].

![Fig.1 Equilibriums in Argon conditions](image)

2. Theoretical approach through thermodynamic calculations
In order to predict the composition at equilibrium conditions, thermodynamic calculations based on minimizing the Gibbs free energy were performed with the commercial software package, FactSage\textsuperscript{®} (Center for Research in Computational Thermochemistry, Canada). The calculations were also intended to predict the optimum quenching temperature for decomposition.

For C-H-O-Cl system, more than 70 chloro-carbon species were taken into account. The calculated equilibrium results for thermal destruction of chloroform under pyrolytic conditions are shown in Figure 1. At 4000 K, CHCl\textsubscript{3} is entirely degraded; gaseous Cl, H, C radicals together with HCl are found in the system. Solid carbon appears below 3500 K, and HCl, Cl, C\textsubscript{1} and C\textsubscript{0} are the main thermal decomposition products of chloroform between 2500 K and 3500 K. It is preferable to avoid the formation of other haloalkanes (for example, the Global Warming Potential of CCl\textsubscript{4} is 1400 times greater than that of CO\textsubscript{2} and 10 times higher than that of CHCl\textsubscript{3}) and solid carbon must be converted to CO\textsubscript{2} for greater safety and performance. For all these reasons, it is necessary to supply an oxygenated species to the system, which during recombination can ensure the formation of small, simple molecules (CO\textsubscript{2}, H\textsubscript{2}O).
Figure 2 shows the equilibrium calculations in the presence of oxygen in equimolar quantities with the waste. At high temperatures, decomposition is ensured by appreciable concentrations of radicals such as Cl, O, H, OH and ClO, all of which are strongly oxidizing species (for example, the hydroxyl radical, OH, has the second highest known oxidation potential after fluorine).

The initial carbon is present in the form of CO, and soot is theoretically no longer formed. Between 2500 K and 3500 K the equilibrium composition is dominated by Cl, HCl, CO, CO$_2$, O$_2$ and H$_2$O. It is important to note that, based on the calculation and input composition, no new organic product with a molar fraction exceeding $10^{-3}$ is formed during the recombination process. The decomposition of chloroform becomes complete under these oxidative conditions.

The equilibrium calculations thus reveal that carbon monoxide forms mainly at high temperatures. The oxidation kinetics of CO to CO$_2$ are known not to be fast when the temperature decreases; in practice, moreover, this oxidation is complicated by the presence of chlorine. It was therefore considered advisable to work with excess oxygen relative to chloroform in order to avoid these drawbacks. The calculated results for a simulation with a large excess of oxygen (O$_2$/CHCl$_3$ molar ratio = 20:1) in Figure 3 shows that chloroform is still satisfactorily degraded at high temperature, as the radicals are present to ensure its decomposition. Compared with stoichiometric conditions (Figure 2), Figure 3 shows that excess oxygen during the atomic recombination process favors the formation of H$_2$O over HCl. This would result in increased quantities of molecular chlorine (Cl$_2$) in the cold off-gas stream. When dealing with chlorinated compounds it is preferable to favor the formation of HCl (more readily neutralizable) rather than Cl$_2$ which may also combine with CO to form toxic compounds such as phosgene, COCl$_2$. It is thus advisable to work with excess oxygen at high temperature, but to ensure rapid cooling of the gas to prevent the formation of undesirable products and enhance the formation of HCl, CO$_2$ and, to a lesser extent, H$_2$O.

In order to suitably control the off-gas release we also examined the formation of toxic intermediate compounds. We have already mentioned that COCl$_2$, a particularly toxic gas, is liable to form during the oxidative destruction of chlorinated compounds. Its formation, which has no economic advantage in this work, must be minimized. According to the literature, the formation of phosgene is relatively stable between 500 K and 2100 K during combustion of organohalogens [15-17]. This species was targeted in this study as a molecule representative of the off-gas quality to limit its toxicity.

We used thermodynamic equilibrium calculations to assess the impact of the O$_2$/CHCl$_3$ molar ratio on the destruction efficiency and off-gas quality. For a mixture with an O$_2$ deficiency the calculations predicted a large formation of phosgene in the temperature range studied with a peak near 780 K (Figure 4, curves $\lambda<1$). Simply starting with a stoichiometric mixture or with excess oxygen has a beneficial effect on reducing the quantity of phosgene formed (Figure 4, curves $\lambda=1$, $\lambda>1$). Excess oxygen appears to have a positive effect on reducing the quantities of COCl$_2$ liable to form. Figure 4 shows that from O$_2$:CHCl$_3$ = 10:1, the COCl$_2$ concentration is < 1 ppm.

The thermodynamic analysis led to the following conclusions:

- Oxygen must be added to the system in order to oxidize carbon to CO and CO$_2$, it must be in excess to accelerate the conversion to CO$_2$ and especially to minimize
the risk of producing toxic gases such as phosgene and incomplete combustion products such as CO;
• The off-gas must be cooled rapidly after the reaction to prevent undesirable recombinations.

<table>
<thead>
<tr>
<th>Table 1. Operating conditions</th>
</tr>
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<tbody>
<tr>
<td><strong>Parameters</strong></td>
</tr>
<tr>
<td>Supplied plasma power</td>
</tr>
<tr>
<td>Pressure</td>
</tr>
<tr>
<td>Total argon flow</td>
</tr>
<tr>
<td>Oxygen flow</td>
</tr>
<tr>
<td>Chloroform</td>
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<tr>
<td>O₂CHCl₃ molar ratio</td>
</tr>
<tr>
<td>Additional air flow</td>
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</table>

3. Experimental

3.1 Thermal treatment process description

The experimental device is shown schematically in Figure 5. The plasma source is an induction plasma torch (Tekna PL-50) with high-purity argon as the plasma and sheath gas. It is supplied by a high-voltage power supply coupled with a high-frequency (64 MHz) transmitter supplying a 7-turn copper induction coil to generate the plasma. The maximum power rating is 4.5 kW. The plasma is confined in a quartz tube with an inside diameter of 35 mm. The gas is ionized at high temperature (over 6000 K for argon plasma). The torch is coupled with a chemical reactor consisting of three main parts (Figure 5A):

• The first is the reaction stage itself (341 mm long, 43 mm inside diameter), comprising a refractory alumina shell to prevent temperature gradients, inside a water-cooled stainless steel jacket. When empty (without added reactants), the reactor design allows gas temperatures of about 1200 K to be reached at the output of this stage.

• The second part of the reactor is the afterburner stage consisting of a Venturi system. Turbulent mixing is obtained by injecting two airstreams to enrich the medium in oxygen in order to fully oxidize the residual carbon to CO₂ and hydrogen to H₂O, as well as to sharply reduce the temperature of the gas mixture from the first stage. A thermocouple at the output of this stage indicates temperatures of around 500 K for no load operation.

• The third stage of the reactor is a stainless steel tube 300 mm long and 43 mm in inside diameter. The reaction products are further quenched in this column, after which they are analyzed before being released to the atmosphere.

The entire process operates under slight negative pressure (≤ 30 mbar) to prevent leakage.

3.2 Feeding system

After starting the argon plasma and stabilizing the temperatures in the reactor stages, oxygen is injected in the reactor via an alumina tube (4 mm inside diameter) to establish fully oxidizing conditions. When the temperatures stabilize again, liquid chloroform (> 99% purity, Sigma-Aldrich, France) is introduced via an alumina tube (1.5 mm inside diameter); the two tubes form a coaxial cylindrical injection system (Figure 5B). As the chloroform passes through the tube already containing oxygen, the two reactants are mixed well before they enter the plasma. The injection tube can be placed in several positions in the plasma. In this study the tube was positioned between the 5th and 6th coils from the top; the CHCl₃ +
O₂ mixture was thus injected directly into the plasma. As the system is hot, combustion begins in the lower part of the injection tube. We tested various flow rates for both CHCl₃ and O₂; Table I indicates the test conditions.

3.3 Measurement tools

Analysis was performed at two locations: (i) just at the bottom of the reactor to measure the efficiency of the thermal treatment alone, (ii) after the scrubber in order to have performance of the entire process.

A gas sample is taken at the bottom of the reactor and analyzed continuously by a Fourier transform infrared spectrometer (Gasmet™ DX4000, Finland). The spectrometer output signal is updated every 20 seconds. It is capable of simultaneously analyzing more than 30 gaseous species, notably the following in our study: CHCl₃, HCl, CO₂, H₂O, CO, COCl₂. The instrument was calibrated with certified chloroform concentrations ranging from 0 to 200 ppm. The same method was used to calibrate the other species analyzed.

As Cl₂ is not analyzed by the IR spectrometer, its formation was identified by bubbling a fraction of the reactor off-gas stream through a 1 M sodium hydroxide solution, followed by a reaction with KI. The iodine generated by the reaction between KI and chlorine was titrated with an aqueous solution of sodium thiosulfate, Na₂S₂O₃.

The off-gas was then trapped in an aqueous sodium hydroxide solution to ensure a clean process. In the case of chloroform destruction, the main reason for caustic scrubbing is to absorb and thus neutralize the acidity due to the major chlorinated species (Cl₂ and HCl) generated. The scrubbing solution pH is automatically adjusted when it drops below 9.

4. Results and discussion

Throughout these tests the argon flow rate was maintained constant at 40Nl min⁻¹. The plasma operating power was obtained by multiplying the instantaneous voltage and current readings; the power remained around 4.2 kW at all times (Figure 6, curve A). However, with this type of plasma torch only 50% of the electrical energy is transferred to the gas at the output of the torch [6].

4.1 Process temperatures

Figure 6 and table II show typical operating conditions, with the temperatures variations measured at the bottom of the first stage of the reactor (curve B) and those recorded after the injection of cooling air (curve C). The air injection rapidly cooled the gas stream, as shown by a temperature difference of about 650°C between curves B and C.

In the following paragraphs we will examine the temperature variations in the first stage of the reactor (Figure 6, curve B).

In the remainder of the procedure, oxygen is injected in the system (7Nl min⁻¹, i.e. 15 mol% of the total gas flow). Figure 6 (sequence 2) shows that the temperature in the reactor suddenly drops to 880°C before rising again and stabilizing at about 930°C. As the argon flow rate is the same as in sequence 1, the plasma energy density (power divided by the total gas flow rate) diminishes when oxygen is added and may affect the temperature in the reactor. The temperature decrease can also be attributed to the energy consumption necessary for heating the oxygen molecules (between 0.5 and 0.7 kW for an O₂ flow rate of 7Nl min⁻¹) and their subsequent dissociation at about 4000K [18]. The effect of injecting oxygen into an inductively coupled argon plasma was investigated Atsuchi et al. [18]. Using a torch of comparable power (5kW), they showed that an axial oxygen injection (between 10% and 30% of the total flow rate) results in a temperature decrease in the hottest part of the plasma; numerical calculations attributed this decrease to the dissociation of oxygen molecules. Similarly, Wagatsuma and Hirokawa [20] showed that the addition of oxygen to an argon plasma...
decreases the intensity of the light emission in a glow discharge plasma.

When oxygen is added and the temperatures have stabilized again, the organochlorine waste is introduced via the injection tube together with oxygen as described above. Another temperature variation is observed when the chloroform is injected. An injection of CHCl$_3$ at a rate of 100 g·h$^{-1}$ causes the temperature to increase (Figure 6, sequence 3) and stabilize at about 970°C (a variation of about +40°C). In addition to the heating effect, which continues to raise the temperature in the reactor, this increase can also be due to the destruction of CHCl$_3$.

The waste injection rate was subsequently increased. Oxygen was first added to the system; the oxygen flow rate increased from 7 to 10 Nl·min$^{-1}$ (the O$_2$ concentration in the mixture increased from 15% to 20%). This increase resulted in a sudden temperature drop in the reactor (transition from sequence 3 to sequence 4 in Figure 6). This decrease can be interpreted as above for the transition from sequence 1 to sequence 2. Assuming all the CHCl$_3$ was destroyed in the previous sequence, the excess oxygen here will consume energy. After, there are little temperature increases that occur during a change of parameters (sequence 4 to sequence 8), which indicate degradation of the waste and therefore the good working of the process. During the shutdown procedure (sequence 9), the chloroform injection is first stopped and the temperature initially diminishes, indicating the end of the combustion reaction; the oxygen injection is then stopped, resulting in a sudden temperature increase (the opposite of sequences 2 and 4). Finally, when the plasma is stopped, the temperature decreases rapidly at first, then more slowly. This decrease is due to the gradual release of the stored energy from the refractory.

4.2 Oxygen as oxidizing agent

Decomposition is clearly illustrated in Figure 7, which compares the FTIR spectra before and after the destruction of CHCl$_3$. After injection in the plasma torch and recombination in the reactor, the spectral properties of CHCl$_3$ clearly disappear. Peaks are observed for CO$_2$, HCl and H$_2$O.

The decomposition efficiency is calculated as follow:

$$\text{Destruction of chloroform (\%)} = \frac{\text{moles of CHCl}_3 \text{ converted}}{\text{moles of initial CHCl}_3} \times 100$$

The results obtained under the different test conditions are indicated in Table III. Near 100% destruction of the initial chloroform was obtained regardless of the chloroform injection rate (100–400 g·h$^{-1}$). When sufficient oxygen is injected, complete destruction of the initial chloroform is guaranteed. The energy efficiency increases with the chloroform injection rate up to a relatively high value of 100 g·kWh$^{-1}$ (i.e. 400 g·h$^{-1}$ CHCl$_3$ entirely degraded in a 4kW plasma). For the same degraded compound, the energy efficiency is significantly improved in comparison with the previous study where the value was 19 g·kWh$^{-1}$ in which liquid H$_2$O was used as the oxidant [6]. The energy efficiency obtained here is also higher than reported by Föglen et al. [3] for thermal destruction of CHCl$_3$ by inductively coupled plasma, or by Krawczyk et al. [21] and Song et al. [5] for gliding plasma arc decomposition of chloroform.
ble CO concentrations in the reaction off-gas (below 0.001%); CO₂ was thus the main carbon species measured by FTIR. The measured CO₂ production can therefore be a suitable performance indicator for this process. The CO₂ conversion factor was calculated with the following relation:

\[
\text{Fraction converted to CO}_2 (\%) = \frac{\text{moles of CO}_2 \text{ produced}}{\text{moles of CHCl}_3 \text{ converted}} \times 100
\]

Column in Table III shows very satisfactory conversion of the initial carbon. The conversion results are generally better than 90%, indicating that the initial carbon is effectively converted to CO₂. Although increasing the oxygen flow rate (and thus the molar ratio) reduces the temperature in the reactor under certain conditions (Figure 6), the overall performance of the process was not affected by the temperature drop.

### Table 3. Experimental results

<table>
<thead>
<tr>
<th>CHCl₃ feed rate (g·h⁻¹)</th>
<th>O₂ flow rate (NL·min⁻¹)</th>
<th>CHCl₃ destruction (%)</th>
<th>Carbon conversion to CO₂ (%)</th>
<th>HCl conversion to CO₂ (%)</th>
<th>Chlor conversion to CO₂ (%)</th>
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<tr>
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<td>99.98</td>
<td>94.33</td>
<td>26.30</td>
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</tbody>
</table>

ND: Not determined

In addition to the conversion of the initial carbon to CO₂, it was very interesting to observe the fate of the initial chlorine in the CHCl₃. The fraction of initial Cl converted to HCl was calculated from FTIR measurements of HCl for each of the test configurations using the following relation:

\[
\text{Fraction converted to HCl (\%) = } \frac{\text{moles of HCl produced}}{5 \times \text{moles of CHCl}_3 \text{ converted}} \times 100
\]

Between 25% and 33% of the initial chlorine was converted to HCl (Table III, column 5). For each chloroform injection rate, the overall percentage of Cl converted to HCl tends to diminish when the oxygen flow rate increases (i.e. for increasing excess oxygen). The same behavior was reported by Huang et al. [12] for plasma decomposition of CH₂Cl₂. The 5% missing can be due to the measurement uncertainties.

4.3 Off-gas quality

Chloroform injected into the plasma is destroyed and converted mainly to CO₂, HCl, Cl₂, and H₂O. However, it is very important to check the level of degradation by-products. Since the small gas quantities released here are not economically useful, their nontoxicity must be ensured. The formation of phosgene is often feared when organochlorines are heat-treated.

We present on the Table IV, the maximum quantities of phosgene obtained for the various CHCl₃ injection rates. The maximum release rate was 1g·h⁻¹ for waste injected at a rate of 400g·h⁻¹, and the maximum concentration was 30ppm. Current French legislation requires that gaseous effluents comply with limits depending on the maximum permissible hourly flow rate: in the case of phosgene, the maximum rate is 10g·h⁻¹, but if this value is exceeded the release concentration limit is 1ppm [22]. Table IV clearly shows that in this study the maximum phosgene for-
mation rate before scrubber was well below the limit. Although chlorine was formed here during chloroform destruction, we have already indicated above that CO was fully oxidized and absent from the reactor. The elimination of carbon monoxide is unquestionably an advantage in preventing the formation of toxic chlorine compounds.

**Table 4** Phosgene released

<table>
<thead>
<tr>
<th>Initial composition</th>
<th>COCl₂ conc. (ppm)</th>
<th>Mass of COCl₂ released (g h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHCl₃ (g h⁻¹)</td>
<td>O₂ (NL min⁻¹)</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>7</td>
<td>0.30</td>
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<tr>
<td>400</td>
<td>20</td>
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</tr>
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</table>

Concerning another aspect of the off-gas quality, Cl₂ and HCl formed by decomposition of CHCl₃ are toxic gases that must not be released untreated into the atmosphere. One technique for simultaneous absorption of these gases is to absorb them in an aqueous solution by direct reaction with excess sodium hydroxide to form sodium hypochlorite and sodium chloride. These reactions can be considered complete as long as the pH remains basic, as it was the case in our experiments.

At the outlet of the scrubbing column a gas sample was analyzed; the FTIR spectrum is shown in Figure 8. The final gas stream after destruction of CHCl₃ by our process thus consists only of CO₂ and H₂O.

![Fig 8 FTIR spectra of exhaust gases](image)

4.4 Comparison with theoretical approach

The experimental FTIR values for CO₂ (to take the initial carbon into account) and HCl (for the initial hydrogen and chlorine) were compared with theoretical values predicted by the FactSage® commercial software package. Equilibrium calculations were performed at the first stage temperatures corresponding to each operating mode in the destruction of CHCl₃ shown in Figure 6, curve B (sequences 3–7). The results of this comparison are shown in Figure 9. For all the conditions tested, the experimental results are very near the thermodynamic predictions. The major species predicted by equilibrium calculations are the same as those obtained experimentally, as are the CO₂ and HCl conversion factors. The process of destruction by inductively coupled plasma described here can thus be modeled by equilibrium calculations, as long as sufficient power is available to convert the initial waste into small, simple and stable molecules (CO₂, HCl, Cl₂, H₂O).

![Fig 9 Theoretical and experimental comparison](image)

6. Conclusion

The effective destruction of chloroform – a model of liquid organochlorine – is proven using argon inductively plasma with oxygen as oxidant to obtain complete and safe destruction. The results demonstrate that the destruction of CHCl₃ is highly effective (near-100% decomposition regardless of the test conditions) with relatively high energy efficiency (the decomposed waste mass per kWh can reach 100 g) and a satisfactory destruction rate (up to 400 g h⁻¹). These results reflect a significant improvement in energy efficiency over the original process using water as the oxidizing species. In the presence of oxygen, CHCl₃ was converted mainly to CO₂, Cl₂ and HCl. A fraction of the initial hydrogen was also converted to H₂O. Moreover, the production of toxic compounds such as COCl₂ was limited (≤ 1 g h⁻¹). The carbon balance showed that soot rarely formed in the reactor, even when severe conditions were imposed on the process (high initial waste concentration, high oxidizing gas flow rate). These experimental results are very near the values predicted by thermodynamic simulations. The plasma reactor described
here is effective in reaching the equilibrium conditions predicted by energy minimization calculations. The acidic chlorinated products (HCl and Cl₂) were easily and suitably trapped by an aqueous soda scrubbing column before release of the final off-gas into the atmosphere.

Based on these results, the system presented in this work can be considered as a clean technology for the destruction of liquid organohalogens with the advantage of direct liquid waste injection into the plasma without any prior evaporation or treatment. These results are of considerable importance for industrial applications. The final objective of this study is to use this reactor for small-scale treatment of radioactive halogenated organic liquid waste. The waste is contaminated by 14C and 3H. The encouraging results and destruction efficiency observed on a pure compound containing 89 wt% chlorine allowed us to validate this small-scale unit. The process can subsequently be installed in a radioactive zone to test the destruction of actual radioactive waste. The transfer operations are currently in progress. It could be also optimized in order to propose new treatment routes for other industrial hazardous liquid wastes.

6. References