GlidArc-assisted cleaning of flue gas from conventional or chemical weapons destruction

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Abstract: Very simple process based on GlidArc plasma reactor considerably reduces the nuisances of waste explosives combustion processes in which soot, VOC, PAH, NO_x, CO, and other toxics are present in the flue gas. Similar GlidArc-based Oxidizer is already commercially used to completely decontaminate the gas issued from a controlled detonation of old chemical weapons in Japan and in Belgium.

Keywords: GlidArc, nitrobenzene, TNT, oxidation, chemical weapon, flue gas cleanup

1. Introduction

Huge inventory of explosives is accumulating as a consequence of military downsizing. Traditional "open burning" is rather simple and the destruction cost is minimum, but huge quantities of dangerous combustion products are released into the air. Therefore, a ban on open burning forces the military to improve the combustion, to clean-up the flue-gas or to search for other disposal methods. The simplest way to eliminate an explosive material seems to be also its detonation in open atmosphere, under the water, or under the ground - but a relatively large part of toxic materials become dispersed into the soil and the flue-gas problems remain the same. Since 1993 we are involved in a GlidArc-assisted cleaning of flue gas from combustion of conventional munitions [1].

Additionally, thousands tons of obsolete (but still extremely dangerous) chemical weapons are stored throughout the World and become very unstable with age. Nowadays, ECP has been associated in even more ambitious program of Kobe Steel Ltd. (Japan) and Ceramatec Inc. (Utah) related to the chemical weapons destruction in a Japanese port Kanda as well as in Belgium storage site of Poelkapelle (close to famous WW-I chemical battlefield Ypres). Next destructions sites are under construction…

2. Technology

2.1. Classical explosives

Two experimental installations were used: a laboratory set-up for a preliminary check of a plasma assisted cleaning of the Flue Gas (FG) issued from an open burning of nitrobenzene (NB), and a pilot-scale installation devoted to clean the FG from a controlled open combustion of the trinitrotoluene $CH_3{\cdot}C_6H_2{\cdot}(NO_2)_3$ (TNT).

2.1.1. Tests with nitrobenzene

This liquid is non-explosive but quite close to the TNT as concerns its chemical composition and combustion properties. A vertical device similar to a petroleum lamp was used to its controlled combustion. The lamp was put into a large tube supplied by a controlled flow of a cold or hot air. The black fumes entered directly a two-stage GlidArc incinerator. This plasma incinerator was simply a 1/3 part of the six-stage GlidArc incinerator that we had to attach to the pilot-scale installation of the TNT combustion on a military camp in France.

GlidArc is a very simple and energy-efficient non-thermal plasma generator that has been already successfully applied for various processes (www.glidarc-tech.com) since 1988. Its principle is shown on **Fig. 1**.

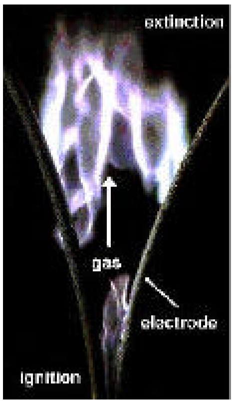

Fig. 1. Principle and time-integrated photo of the GlidArc-I discharge

At least two electrodes diverging with respect to each other are placed in a relatively fast gas or vapor flow (>10m/s) and in the flow direction. A gliding discharge is produced between the electrodes and across the flow. It starts at the point where the distance between the electrodes is the shortest and immediately spreads by gliding along the electrodes in the direction of flow until it disappears after running a certain path. This path is defined by the geometry of the electrodes, by the composition and other conditions of flow, and by the characteristics of the power supply. Then, the discharge immediately reforms at the initial spot. The fast displacement of the discharge roots on non-cooled electrodes prevents their chemical corrosion or thermal erosion by an arc-roots establishment. The electrical energy is directly and totally transferred to the fast and turbulent gas flow. The average voltage ranges from 0.5 to 15kV for average currents from 0.1 to 3A (per discharge). The instantaneous voltage, current and dissipated electric power show almost random feature of the history of each breakdown.

Transient electrical phenomena observed under near-to-atmospheric pressure are similar to the "corona discharge" type but at a much higher dissipated power. A large ionized gas volume, obtained at low energy density, gives a non-equilibrium and reactive medium well adapted to run plasma-chemical reactions allowing efficient gas, vapors or even solid particulates processing. Physical model of the GlidArc shows that in such plasma the exact notion of "temperature" cannot be used [2].

The nitrobenzene lamp mass difference (before and after an experiment), air flow-rate, inlet air temperature, temperatures at the entry and exit of GlidArc incinerator, and time were measured for each run. The covered ranges of these parameters (for a constant electric power) were following:

Nitrobenzene combustion rate (CR)	0.9 - 4.4g/min
Air flow-rate (AFR)	32 – 110L(n)/min
Temperature at the plasma reactor inlet (tI)	70 - 280°C
Temperature at the plasma reactor exit (tE)	85 - 282°C

Only the total Volatile Organic Compounds (VOC) content in both treated and untreated FG were determined after the soot filtering, using a simplified gas chromatograph (GC) with an empty column (1/8", 10m, 40°C) and a FID signal. A ratio of the FID signal from the non-treated FG over the signal from the treated FG (when plasma reactor was operating) gave us a Relative Cleaning Factor (RCF) for each run. Some results of the tests are presented below:

CR (g/min)	1.3	1.2	1.1	0.9	4.4	3.7
AFR [L(n)/min]	41	110	63	47	63	74
tI (°C)	190	170	118	145	280	70
tE (°C)	222	220	228	240	282	85
RCF	17	5	6	4	4	3

These results indicate that one should work at the highest possible FG inlet temperature and the highest possible VOC initial concentration in the FG. In such a way the plasma reactor will work as a simple continuous igniter of practically self-combustion of the organic pollutants. Even if the soot after-combustion was not measured during these experiments - a visual observation of the plasma incinerator action on the emitted FG clearly indicated a spectacular diminution of the smoke darkness.

2.1.2. TNT Pilot Experiment

The set-up for the TNT controlled combustion and the off gas processing (**Fig. 2**) includes:
- elevated grate carrying the TNT,
- adjustable orifice and its diffuser located under the grate,
- hood covering all the grate and having an exit of gas, liquid and/or solid particle effluent in its top,
- thermally insulated pipe connecting the hood top to the GlidArc device, the last one being connected to a variable-speed ventilator,

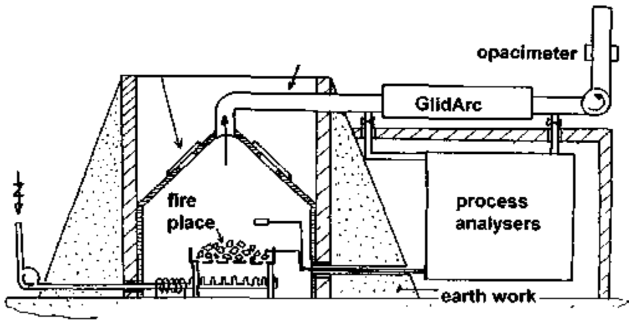

Fig. 2. Pilot plant for TNT burning and Flue Gas cleanup

- measurement part: TV cameras and sensors connected to the installation and checking its parameters, like thermometers, gas analyzers (spectrometer, NO_x, CO_2, CO, O_2 sensors, chemical analysis by absorption, GC, UV Photoionization Organic Vapor Meter, and opacimeter),
- water spray circuit that can be operated by remote control in case of emergency; for the same reason the hatches fitting the hood can be ejected in case of explosion,
- room protected from possible explosions where operations of remote control are conducted.

Each section (of 6) of the GlidArc reactor (see **Fig. 3**) was composed of a 80mm quartz tube (250mm long) in which 3 knife-shaped steel electrodes are put around the tube axis. The electrode gap is starting at 3mm (ignition) to become about 70mm at the electrode top (discharge disappearance). Six similar sections were assembled together, one after the other, so that the total length of this plasma incinerator was close to 2m.

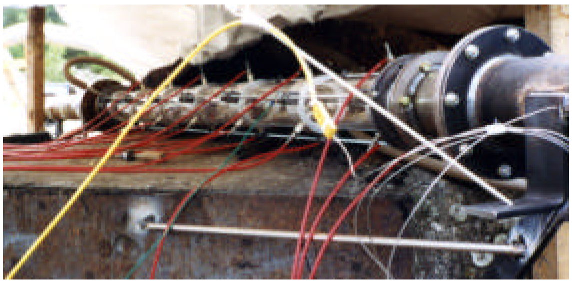

Fig. 3. GlidArc reactor for flue gas cleanup

The whole reactor was connected to the high voltage, 50Hz, 3-phase, power supply with current control. The electric power injected to the reactor (1 to 9kW) was carefully measured *via* both digital wattmeter and classical kWh-counter. The input gas flow rates (up to 200m^3/h) were also measured (via gas-velocity sensor) so the Specific Energy Input (SEI) could be precisely determined for each experiment.

Several experiments were performed for different TNT mass (a couple of kilograms), FG initial composition and temperature (up to 300°C), gas flow-rate, and dissipated GlidArc power. No chemical corrosion, no erosion and no short-circuits of GlidArc electrodes or their supports were observed during experiments when processing a very smoky FG. A typical result related to the TNT combustion with plasma assisted FG cleaning is as follows:

FG flow rate: 50m^3/h
Power dissipated in GlidArc: 3.2kW

FG composition	before	after
CO (ppm)	760	515
NO_x (ppm)	1180	406
NO_2 (ppm)	206	158
CO_2 (%)	3.4	14.8
O_2 (%)	17.6	13.0
Soot	abundant	very little

A high cleaning efficiency of the Flue-Gas (FG) from the sooting combustion of organic nitrates was achieved: almost complete disappearance of the soot (and the Products of Incomplete Combustion PIC adsorbed on it) as well as an important lowering of the NO_x and CO concentrations. This operation was performed at a relatively low energy cost of about 0.06kWh per cubic meter of the treated FG.

Very simple plasma-chemical process based on GlidArc reactor can considerably reduce the nuisances of combustion processes in which soot, VOC, PIC, Polycyclic Aromatic Hydrocarbon PAH, NO_x, CO, and other toxics are present in a FG. Using such electrical method allows a full control of energy expense. This non-thermal and reactive plasma can substitute high-energy consuming and troublesome thermal or catalytic FG cleaning units. Conditions of the GlidArc use are very flexible since it may be operated without any practical limit of pressure, temperature, flow-rate, and initial composition of the FG. The process requires no particular FG pre-treatment and may be adapted to any size. It may be started, adjusted and stopped rapidly and easily. The pressure drop is low, and the reactor is very compact.

A patent [3] was granted based on these results tests … and then abandoned soon. It is still much cheaper to "dispose" waste conventional explosives recycling them for local wars or burning/exploding them far away from public control on remote military grounds.

2.2. Chemical weapons

A controlled detonation system DAVINCH™ developed by Kobe Steel destroys various weapons containing a chemical agent and explosives without previous dismantling, but by a single detonation in a soft-vacuum chamber. At close to 3000K and 10GPa explosion conditions most of chemical agent is destroyed [4]. Remaining pollutants are then completely neutralized in a second step Cold-Plasma Oxidizer based on ECP's GlidArc discharge, see **Fig. 4** and **5**.

A test with Sarin (a newer nerve agent) surrogate [4] shows its still dangerous 1.38ng/m^3 residual content in the chamber off-gas - so 99.999998% destruction efficiency. While crossing then the GlidArc Oxidizer its concentration lowers to 0.04ng/m^3 (for allowed Short Term Exposure Limit set at 0.1ng/m^3). Residual CO concentration of 200ppm in the chamber off-gas lowers to zero at the exit of the GlidArc Oxidizer at its bottom temperature of 550°C.

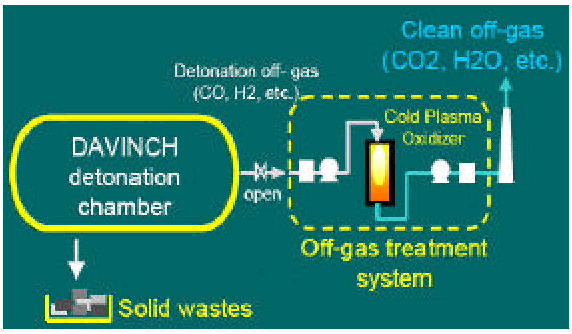

Fig. 4. Principle of the technology [4]

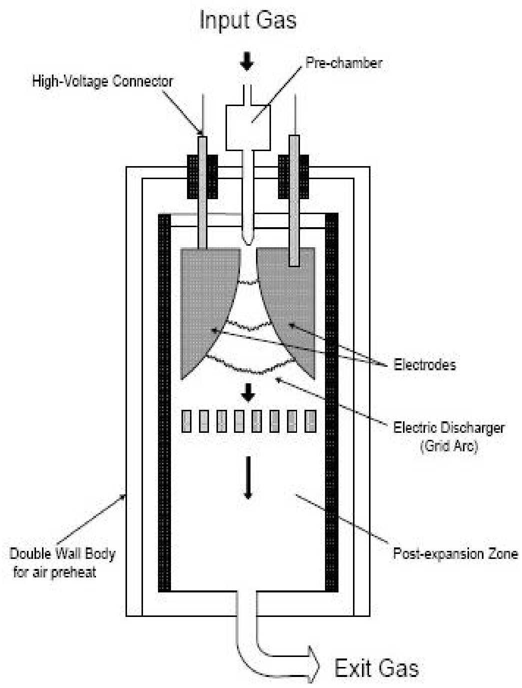

Fig. 5. GlidArc Oxidizer scheme

Since 2004 more than 1300 chemical "yellow" and "red" bombs were successfully destroyed in Kanda plant. A second commercial plant in Poelkapelle works properly since April 2008. A routine operation TNT-equivalent charge is there at least 20kg per explosion - corresponding to about 100 chemical shells per month. **Fig. 6** shows such industrial-size GlidArc Oxidizer being a part of that plant.

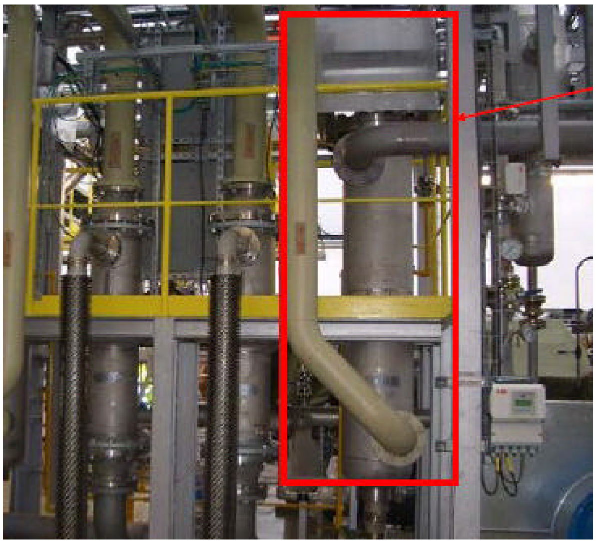

Fig. 6. Industrial-size GlidArc Oxidizer

New project of Flexible Mobile DAVINCH system is under development; it includes an independent GlidArc Oxidizer module for the chamber off-gas deep cleaning.

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