Cold Plasma Systems for Large Volume, Industrial Air Emissions Odor Abatement

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***Abstract*— There are about 250 Cold Plasma systems operating in industry worldwide, installed over the last 15 years or so, treating the odorous vented air emissions that is typical from facilities like municipal waste handling, food production, drying and cooling of pet foods and other organic material processing. The volume of air flow's being treated is in line with typical industrial needs, ranging from 10,000 to over 100,000 cubic meters of air per hour (m3/h). This paper will describe the most common implementations of Cold Plasma, which is also known as non-thermal plasma (NTP) technology and how it is used for abatement and control of these odors. (*Abstract*)**

Keywords—Odor control; cold plasma; non-thermal plasma; large volume air emissions

I. Introduction

Cold Plasma technology is a good option for oxidizing odorous compounds typically found in air vented from large scale processes treating organic source materials. Cold Plasma technology is capable of treating large air volumes and it also has attractive capital and operational advantages. Cold Plasma is also a "Clean Tech" solution in that needs no chemicals or fossil fuels in operation; it only needs electricity.

II. Applications

Typical vented, odorous air treated applications include:

- Municipal Solid Waste handling
- Sewage sludge handling
- Tobacco processing
- Aquaculture feed & animal feed production
- Human food production
- Biodiesel production
- Slaughterhouses, meat packing
- Rendering (animal meat waste)
- Vegetable Oil & Proteins
- Tire manufacturing
- Pharmaceuticals production
- Other biological processing

These facilities typically vent odorous air volumes ranging from 5,000 m3/h to greater than 100,000 m3/h, with the more common installations typically venting between 5,000 to 50,000 m3/hr. Cold Plasma technology is typically modular, so one needs only to add multiple units in parallel to treat any air flow volume.

III. Technology Description

Cold Plasma systems in industry are adaptations of two principle designs. One type is known as the Dielectric Barrier Discharge (DBD), sometimes also called Silent discharge. This design has a dielectric (insulator) between two conductors (electrodes) and an air gap. When an alternating voltage is applied to the electrodes a capacitive current is established that has electrons crossing the air gap between the electrodes. These free electrons in the air gap form what is known as a cold plasma field because the electricity forms micro arcs that fill the air gap in the entire electrode area. A number of different electrode configurations exist with DBD systems and they can be energized with a wide range of frequency and voltages.

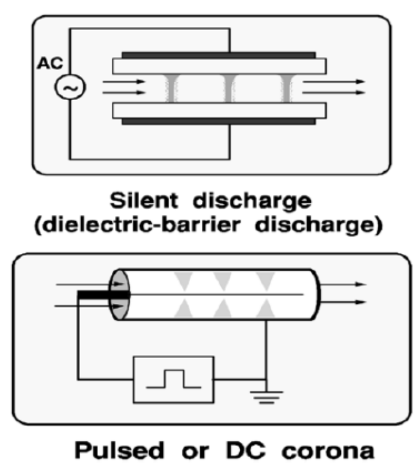

Fig. 1. Schematic diagrams of representative dielectric-barrier discharge (upper) and pulsed corona (lower) reactors. The DBD reactor can also be constructed in cylindrical form. Both reactors create similar electric-discharge streamers in the process gas.

The second major type is the Pulsed Corona Reactor (PCR). These systems have typically have a thin conductor running down the centre of a cylindrical or hexagonal tube with only air between the electrodes (in other words – no dielectric barrier in this design). As such, the plasma field is formed by

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having applying short duration pulses to the electrodes; necessary to keep the electrons crossing the air gap from forming an intense electrical arc in any particular location. One consequence of this design is that much larger electrodes are needed to treat the same volume of air, as the plasma field cannot be as intense as in a DBD design. Another requirement in this design is that it needs a sophisticated voltage controlled, pulsed power supply, which is much more costly that the power supply needed for DBD systems.

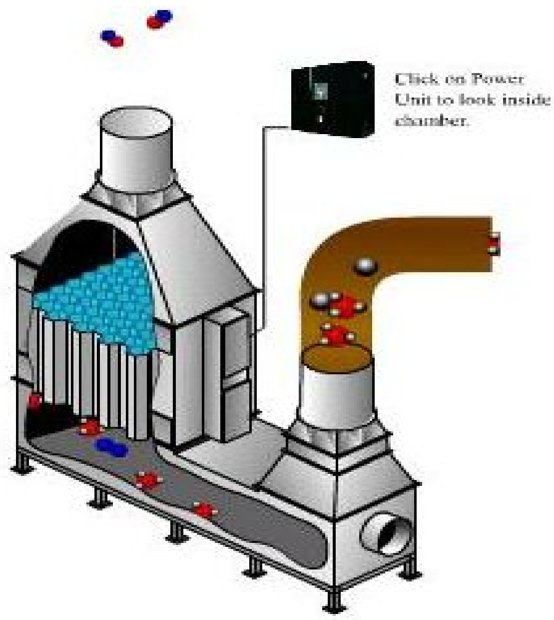

Fig 2: Typical corona, flow through system

However, both types create Cold Plasma, or NTP fields, both use about the same electrical energy when operating in the similar applications and both can be scaled to accommodate a wide range of air volumes.

IV. GAS PHASE CHEMICAL REACTIONS

All Cold Plasma fields primarily consist of highly energetic electrons which collide with the air and water vapour molecules in the air and this activity creates a wide range of highly reactive oxidative and reductive species (ROS), e.g., atomic oxygen (O3P), hydroxyls, xOH, N, H, NH, O_3, O_2, and plasma (free) electrons in free air. The reactive species also exist at many different levels of ionization further contributing to their chemical reactivity. When the highly reactive ROS come into contact with odorous compounds, the compounds are quickly oxidized or partially oxidized to non-odorous forms upon contact, with most reactions completed in less than 1 second. Typical odor reduction efficiencies can exceed 94% in some applications on some very large volumes of air. It is important to note that Cold Plasma system are not ozone systems as the ROS created in an NTP are much more reactive and effective in odor reduction than simple ozone.

It is also worth noting that “odor” is actually made up of many Volatile Organic Compounds (VOC’s), some of which are biological source and many more from other, non-biological chemical processes. There is a great deal of research in the use of NTP to treat most types of VOC’s emitted in industry, from biological and other sources showing good success in many cases using intense NTP fields generated with arrays of DBD systems.

Configuration Options with Cold Plasma

Cold Plasma systems can be configured in a few ways, with the optimal method depending on the type of Cold Plasma used, air volume and odor to be treated.

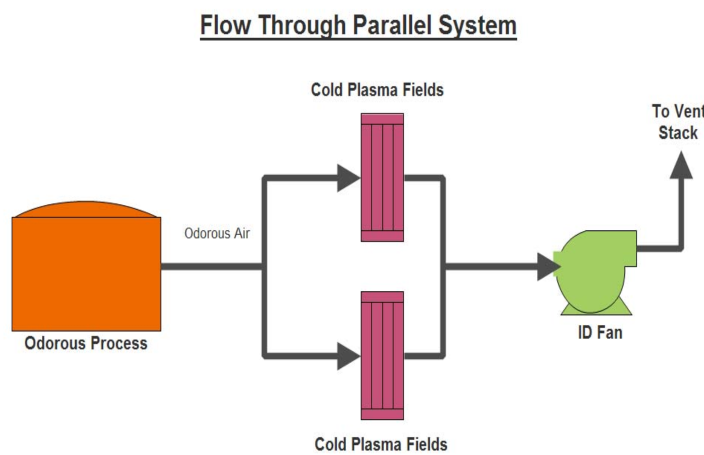

Fig 3: Flow through odor treatment with Cold Plasma systems

As can be seen from the above schematic, all the air to be treated flows through the Cold Plasma fields.

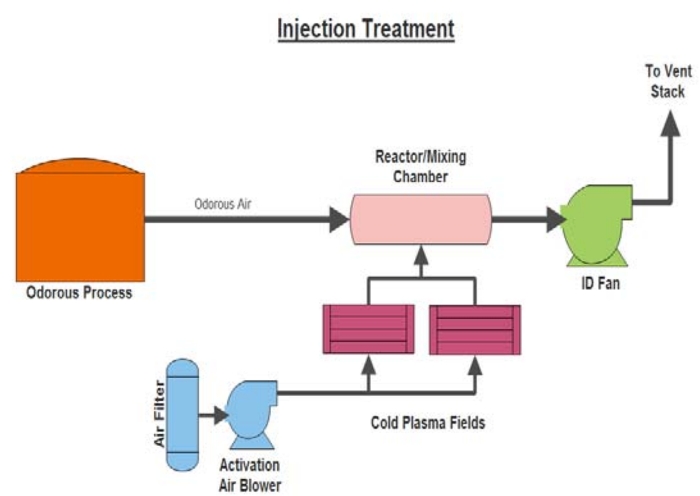

Fig 4: Injection odor treatment with Cold Plasma systems

Fig. 5: Flow through, PCR based Cold Plasma system

Each of the two modules in the above system has an airflow rating of <20,000 m3/h and a power rating of 10 – 25kW, with an absolute maximum of 30kW.

Fig. 6: Injection, DBD based Cold Plasma system. Power rating: 36kW. Main air flow is 150,000 m3/hr, injection air is 25,000 m3/hr

The injection air flows from top down, through the Cold Plasma electrodes under the blue cover into the main airstream passing underneath the wooden enclosure.

Sizing a Cold Plasma system

Typical example: Building vent air from an MSW tipping floor.

- Building air space volume: 10,000 cubic meters
- Building air changes per hour: 5
- Vent air volume: 5 air changes x 10,000 cubic meters = 50,000 m3/hr.
- Atmospheric air conditions, sometimes damp, sometimes dry

There are four major factors involved in design selection and sizing a Cold Plasma system:

1. The energy per unit volume needed to treat the VOC's in the air.
2. The total volume of air to be treated:
3. The dirt/dust load and humidity of the air to be treated.

The design will typically proceed as follows:

1. Energy per Unit Volume: A Cold Plasma equipment supplier will know from past experience what energy is usually needed to treat common odors. In this example, 0.7 watts / cubic meter / hr is a typical requirement for this type of odor, so that means the plasma field will need 0.7 * 50,000 = 35kW. It is common to add a margin to the equipment capacity, so I'd expect a 40 to 45kW system to be sized here. As the energy is used to produce the Reactive Oxygen Species (ROS), it only matters that the ROS get mixed with the air to be treated, thus both Injection or Flow Through designs will work – if Cold Plasma works. Note, Cold Plasma does not work so well (yet) on automotive paint emission odor.

2. Total Volume of Air to be Treated: A typical Cold Plasma system will be modular and those modules can create an NTP field only up to the design power limit of each module. Let's say the limit for one vendor is 10kW per module. The requirement is for 40kW, so the vendor in question will need at least 4 modules to meet the power requirement. All Cold

Plasma modules (both PCR and DBD's) have design air flow ranges as well.

- PCR Flow Through Design: Considering the flow through option, given that a module of this type can handle < 20,000 m3/h and has 30kW of power available, you would need 3 units for a capacity of 60,000 m3/hr. This would also allow 90kW of power, more than what the application needs.
- DBD Injection Design: Typically can handle about 2000 m3/h with 12kW per unit. As we need to get 40kW of ROS into the process that would mean 4 DBD systems would be needed. However as they allow 4*2000=8,000 m3/h air flow, this would be injected into the main airflow.

3. Dirt & Moisture Considerations: If the process air has entrained solids, aerosol oils, high humidity or other contaminants typical of many biological handling processes, it may not be a good idea to pass this air untreated through a Cold Plasma field as the contaminants will deposit on all surfaces.
   - PCR Flow Through Design: will be affected by all contaminants and this can result in a high maintenance burden due to frequent cleaning. Changing humidity will also affect the air conductivity which affects the corona voltage attainable.
   - DBD Injection Design: In this design, only the air passing through the NTP field needs to be filtered (to MERV 8) and non-condensing. When the NTP activated ROS air is injected into the moist, aerosol laden, particulate containing air, it will react with everything in the air to reduce the odorous compounds.

In general, flow through PCR designs are more costly because the PCR Cold Plasma field is a fraction as intense as a DBD Cold Plasma field. That means that PCR system require much more electrode area is needed to get the same power into the volume of air and that translates into much larger plasma cabinets and overall installations. DBD injection systems of equal capacity can be quite compact and are more easily fitted into existing facilities. Less electrode area means smaller cabinets and a more compact installation.

Compatable with Existing Technologies

One promising area for this technology is that it can be a secondary treatment to odor control systems that are already in place. The DBD Injection systems can be used to treat very large air flow volumes with a full range of power designs. A design is possible to simply inject the ROS into existing ducting to minimize installation costs. This means it can be easily added to the outlet of existing legacy systems such as bio-filters, chemical scrubbers or whatever are in use and not quite meeting the odor reduction needs.

European Union Research

In Europe, the The DG JRC (Joint Research Centre) is responsible for the Institute of Prospective Technological Studies under the auspices of the European Commission. One role this organization has undertaken is the publication of "Reference Documents on the Best Available Techniques" for Integrated Pollution Prevention and Control in various industries. In January 2006 the IPPC published a document concerning the Food, Drink and Milk Industries(1). This document, which according to the Directive must be consulted when permitting industries in Europe, addresses the use of non-thermal plasma. The document states that the equipment is proven to reduce emissions by 75-96% depending upon the design, process conditions, and odour characteristics. Results from application in two fish meal plants are provided. Inlet concentrations on average were in the 16,000 OU/m3 range and outlet concentrations were between 1600 and 3200 OU/m3 producing reduction efficiencies of 80%±4% and 90%±1%.

Similar evaluations have not been done in the US or Canada, which may be one factor contributing to the adoption of this technology more so outside North America.

Conclusion

This paper has described Cold Plasma technology (or non thermal plasma (NTP as it is also known). We have described some of the applications where Cold Plasma is applicable and some of the alternate designs and methods of Cold Plasma system implementation in large scale processing and industrial applications. It is a good, cost effective alternative to other methods of odor control and can also be used as a secondary odor reduction to existing odor control systems where additional odor abatement is desired.

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