INDUSTRIAL TRIALS OF THE GLIDARC PLASMA REACTOR

T. Janowski, H.D. Stryczewska, A. Ranaivosoloarimanana*, and A.Czernichowski*

Lublin Technical University, 20-618 Lublin, Poland
*Orléans University, 45067 Orléans cedex 2, France

The trials are carried out on the pilot plant installed in the paint shop of metallurgical factory. Paper presents the characteristics of the object, the plasma reactor with supplying system and some partial results of their investigation, as the pilot is still during its assembly.

1. Introduction

Plasma methods to treat gas pollutants from industrial processes have recently been more often applied. They are cheaper than the chemical ones commonly used, they do not result in by-products such as gypsum and let us recover thermal energy from many processes. The more severe requirements of international and country regulations cause that interest in the treatment of toxic gases emitted to the atmosphere rapidly develops. These methods to treat gas emissions from industrial processes are relatively new and there has been only a minor experience in industrial applications, so far.

For industrial applications the plasma should be produced in large volume as to ensure to treat considerably large gas flow at atmospheric pressures. The classic arc, produced in a plasma torch or in a welder, cannot be used for toxic gas incineration, because the cleaned gas is not able to penetrate the high temperature area of the arc.

Low temperature plasma reactors used to treat the gases are different but all of them consist of two basic elements: a plasma chamber where the gas treatment takes place and an electric supply system providing the proper operation of the chamber. The electric supply system should ensure a stable maintenance of the plasma in the chamber at high energetic efficiency. Because of very non-linear arc resistance and other electrical requirements the supply system must consider the reactor character and match it properly. To treat a gas emission from a paint shop the plasma reactor with a gliding arc has been used. Its type is GLIDARC worked out in the University in Orléans since 1988. For the ignition the supply system uses the third harmonic of the magnetic flux of a single phase transformer [1], [2]. We can present briefly the operation of the plasma reactor and its supply system working for the needs of a pilot plant in the paint shop in metallurgical factory URSUS Co. in Lublin, Poland.

2. Characteristics of the object

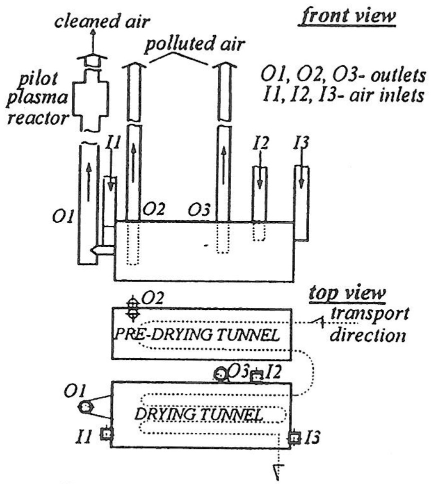

Fig. 1. Diagram of the drying system with outlets and inlets arrangement and the pilot plasma reactor installed on one of the outlets.

During the process of painting and drying of engineering castings, the paint shop in the metallurgical factory emits to the atmosphere, by three outlets, toxic gaseous pollutants from varnishes and paints mixed with hot air (Fig. 1) .

As the chemical analysis shows, the polluted gas of 2000 m^3/h flow contains xylene, butanol, turpentine and kerosene and its temperature on the outlet is 150°C. The plasma reactors installed on the extractors should limit the toxic gas emission by not less than 75%. Moreover, the cleaned gas is going to be recirculated and used in the drying process, which should give significant energy savings.

The diagram of the electrically heated drying system, the plasma reactor, and outlets and inlets arrangement is given on Fig. 1, and the scheme of the drying system operation after its modernization in Fig. 2.

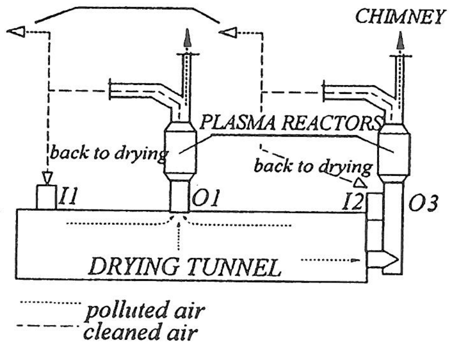

Fig. 2. Scheme of the drying system after modernization (with recirculation of cleaned air, which one portion is vented and another is recycled to the drying).

3. Plasma Reactor

GlidArc plasma reactor, as an electrical energy receiver, differs considerably from the other plasma reactors and its cooperation with supplying system requires suitable analysis. The inter-electrode resistance depends on the gas ionization degree and during a single cycle of reactor operation its value changes significantly. The electrode couple arc current should not exceed 10 A, the ignition voltage at minimal electrode distance (2-5 mm) has to reach at least 10 kV, but during the reactor operation this voltage does not exceed 2 kV. So, the arc voltage is only 10-20 % of arc ignition voltage. In the point of ignition the discharge has the arc nature, but while moving across the electrodes under effect of the fast flow of the treated gas it becomes rather glow and its temperature is quite low. The effect of such a discharge on gas is surely non-thermal but it permits to treat sufficiently a lot of dangerous gaseous pollutants. The principle of the GlidArc plasma reactor construction and operation is presented in Fig. 3.

The advantage of the GlidArc plasma reactor is its simple construction and good processing effectiveness on many kinds of gases, see [3].

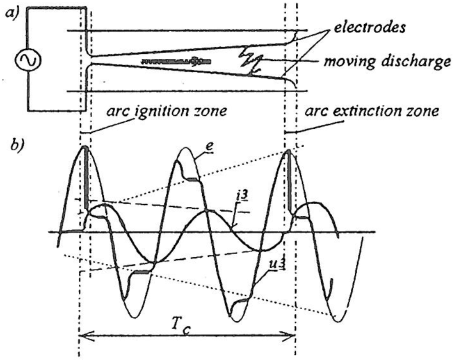

Fig. 3. The principle of construction and operation of the plasma reactor:

a- construction of the discharge chamber,

b- plots of instantaneous values of arc voltage and current in one cycle of plasma reactor operation.

The pilot reactor for the URSUS plant will be very similar to those already used to clean-up highly soot and NO_x charged flue-gases from an open burning of the spent munitions. At the gas flow-rate up to 200 m^3/h and the electric power of less than 10 kW almost complete disappearance of soot (and pyrolytic hazardous products adsorbed on it), and substantial lowering of the NOx and CO concentrations were achieved there [4].

Before going to Lublin plant, a preliminary study on a similar pilot reactor has been performed in Orléans. The reactor is composed of a 80 mm in. dia. Pyrex tube (350 mm long) in which 3 knife-shaped main steel electrodes are put around the tube axis. The main electrode gap is starting at 5 mm (ignition) to become about 70 mm at the electrode top (discharge disappearance). An additional small ignition electrode is put between main electrodes. Only three reactors are assembled together, one after the other, and powered by the Lublin's supplying system described further. The electric power injected to the reactor was carefully measured via digital watt-meter. The input gas flows were also measured (via gas chromatography analysis coupled to a precise mass-flow metering) so the Specific Energy Input (SEI) is precisely determined for each experiment.

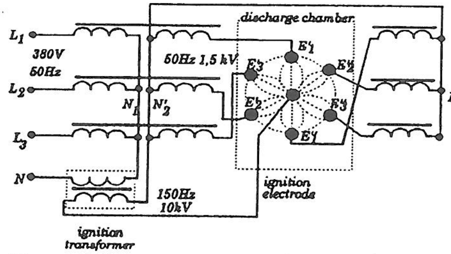

Fig. 4. The connection scheme of the sixth electrode plasma reactor energized from the integrated supplying system with ignition transformer which uses the third magnetic flux harmonic.

4. Supplying System

The main element of every plasma reactor supplying system is a transformer which makes the cooperation of the reactor with mains possible. It usually has special construction with increased internal reactance or DC current magnetization and it can be equipped with chokes, resistors, transducers, and resonance and SCR circuits.

Increased number of supplying system elements improves the supplying system performances but makes it more complicated and expensive and often less reliable and efficient. GlidArc plasma reactor for industrial trials is energized from the supplying system which integrates the function of a magnetic frequency tripler and a transformer with increased leakage reactance. For arc ignition the third magnetic flux harmonic is used and the arc operation after ignition is maintained by the fundamental one.

The connection scheme of the integrated supplying system is presented in Fig. 4 and the data of the system are given in Tab. 1.

Table 1. Data of the 50 Hz transformer of the pilot

winding		
Wire number of primary winding	-	226
Wire number of secondary winding	-	2250
Cross section of the primary wire	mm^2	7.07
Cross section of secondary wire	mm^2	0.8
core		
Cross section	m^2	$20\ 10^{-4}$
Length of magnetic circuit	*m*	0.51
Height of column	*m*	0.154
Thickness of transformer sheet	*mm*	0.30

The main advantages of integrated system are: the inherent cooperation of the ignition (150 Hz) and operation (50 Hz) circuits, symmetric load of the mains and the possibility to create multi-electrode systems. System permits to utilize the power from the mains much more efficiently than other systems, which is presented on Fig. 5.

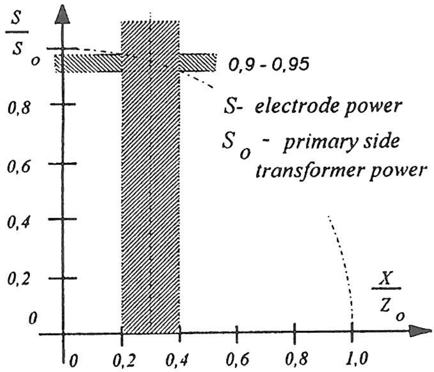

Fig. 5 The power utilization in the integrated system in function of the relative leakage reactance of the transformer, where: X - leakage reactance, $Z_0 = \sqrt{R_a^2 + X^2}$, R_a - static arc resistance.

At suitably chosen leakage reactance of the operating transformer (not greater than 30 % of the static arc resistance) the discharge chamber operation is stable and the utilization of transformer power is high.

5. Trials results

5.1. Electrical tests

The results of experiments are given in Fig. 6, where instantaneous values of arc voltage and current during two cycles of the plasma reactor operation are presented.

All the power consumed by our pilot is measured by an electronic wattmeter. We messure the energy loss inside the supply with a calorimetric method. Thus, we deduct the efficiency of the power supply to be equal to 76 %.

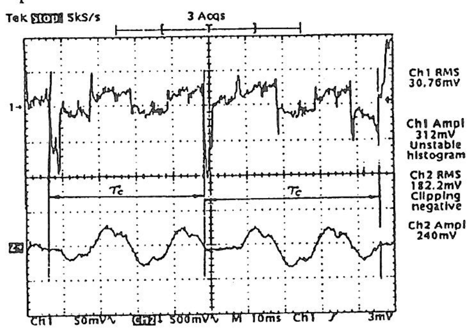

Fig. 6. Oscillograms of the arc current and voltage for the GlidArc plasma reactor energized from integrated supplying system.

5.2. Chemical tests

Some experiments were performed for two model gases : propane and butane. These gases can be easily admixed to air but contain only 3 or 4 carbon atoms and therefore are quite hard to be incinerated, especially for low gas concentrations. Two different initial gas compositions and two polluted air flow-rates at almost constant dissipated power were experienced. No chemical corrosion, no erosion and no short-circuits of GlidArc electrodes or their supports were observed during all experiments. The test results are presented in Tab. 2.

Tab. 2. Diluted propane or butane incineration in GlidArc reactor.

	PROPANE		BUTANE	
Init.vol.conc.%	1.26	0.48	0.85	0.345
Destruction %	54	22	47	19
Flow-rate scm/h	74	88	75	87
Power kW	4.3	3.8	4.2	4.1
T_{input} °C	25	22	28	28
T_{output} °C	410	188	400	210
SEI kWh/scm	0.057	0.044	0.056	0.047
SER kWh/kg	4.3	21	5.4	28

6. Conclusions

Plasma reactor with gliding arc (GlidArc) energized from transformer in which the third magnetic flux harmonic is used for ignition and the fundamental one for power transferring (integrated supplying system) operates stable during plasma treatment of gases.

Quite high cleaning efficiency of the surrogate flue-gas was achieved. This operation was performed at a relatively low energy cost ranging from 4 to 28 kWh per kg of mineralized light hydrocarbons. Almost all this electrical energy and an additional chemical energy from the hydrocarbon combustion can be easily reused in the paint shop. The flue-gas partial recycling in the drying tunnel makes it possible to accept only partial gas cleaning at pollutant concentrations sufficiently far away from the flammability level.

7. References

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[4]. A. Czernichowski, P. Labbe, F. Laval, H. Lesueur, Plasma Assisted Cleaning of Flue Gas from a Sooting Combustion. Case of Organic Nitrates, ACS Symposium Series, in press.