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## Fluidized bed combustion of pesticide-manufacture liquid wastes

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**Abstract:** Industrial liquid wastes can be in the form of solutions, suspensions, sludges, scums or waste oil and have organic properties. The objective of this work was to demonstrate the technical feasibility of a fluidized bed as a clean technology for burning liquid waste from a pesticide production plant. The combustion of liquid waste mixtures, obtained from realistic samples, was investigated in a pilot scale fluidized bed with quartz sand particles of 0.63–1.25 mm in diameter and 2610 kg/m<sup>3</sup> in density at 800–950 °C. To ensure complete combustion of liquid waste and additional fuel, the combustion chamber was supplied with excess air and the  $U/U_{mf}$  (at ambient temperature) was in between 1.1 and 2.3. In the fluidized bed chamber, liquid waste, additional liquid fuel and air can be brought into intense contact sufficient to permit combustion in bed without backfire problems. The experimental results show that the fluidized bed furnace offers excellent thermal uniformity and temperature control. The results of the combustion tests showed that degradation of liquid wastes can be successfully realized in a fluidized bed with no harmful gaseous emissions by ensuring that the temperatures of both the bed and the freeboard are not lower than 900 °C.

**Keywords:** fluidized bed incinerator; liquid waste; pesticide production plant; design; operating experience.

### INTRODUCTION

Pesticide manufacture, formulation, and packaging facilities produce significant amounts of hazardous materials, including raw materials and intermediate/final products. The handling, storage, and transportation of these materials should be managed properly to avoid or minimize their environmental and health im-

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pacts.<sup>1</sup> Unused dilute pesticide formulations and equipment rinse water contain high levels of pesticides that can lead to contamination of soil and eventually of water resources if not properly managed.<sup>2</sup>

The accumulation and bad management of various pesticides and other hazardous chemicals constitute a threat for health and the environment, locally, regionally and globally. Estimates indicate that large amounts of obsolete pesticides are accumulated globally, especially in developing countries. A considerable amount of the accumulated obsolete pesticides are persistent organic pollutants that possess toxic properties, resist degradation, bio-accumulate and are transported, through air, water and migratory species, across international boundaries and deposited far from their place of origin, where they accumulate in terrestrial and aquatic ecosystems. Organochlorine pesticide residues have been detected in air, water, soil, sediments, fish and birds even more than one decade after being banned and it is reasonable to believe that contaminated sites and mixed waste still represent locally and regionally important on-going primary source inputs of hazardous compounds to the global environment.

Several international environmental conventions aim to protect human health and the environment through measures that will destroy and irreversible transform hazardous chemicals and reduce and/or eliminate emissions and discharges of pesticides and persistent organic pollutants. The hazardous waste has mainly been transported to developed countries for high-temperature incineration in dedicated facilities, a practice that does not stimulate development of local solutions and capacity building. In addition, this approach involves higher costs and increased risks of accidents and spills. These international conventions acknowledge that there is an urgent need for environmentally sound disposal of hazardous chemicals and that developing countries and countries with economies in transition need to strengthen their national capabilities for chemical management, *i.e.*, of special relevance is the stimulation and development of local treatment of hazardous wastes.<sup>3,4</sup>

The pesticide manufacturing industry started already in the 1970s to explore possible treatment options for obsolete pesticides and pesticide wastes and combustion was soon considered as the prominent method. In order to treat these wastes, destruction in high temperature incinerators was established by Environmental Protection Agency (EPA), after extensive expert and public reviews, to be the best-demonstrated available technology for most organic hazardous wastes. This is because incineration safely and effectively destroys the hazardous constituents in the waste.<sup>5</sup>

To achieve complete thermal destruction, a sufficiently high temperature, oxygen supply, residence time and mixing conditions are required. The combustion temperature and residence time needed for mixed hazardous wastes cannot be readily calculated and are often determined empirically. Some common sol-

vents, such as alcohols and toluene, can be easily combusted at lower temperatures, while other more complex organic halogens require more stringent conditions, such as incineration criteria of 2 s residence time at 1200 °C and 3 % excess oxygen in the stack gas,<sup>6</sup> or incineration of waste criteria of 1100 °C for at least 2 s if more than 1 % of halogenated organic substances are to be incinerated.<sup>4,7</sup>

The main advantages of the incineration of industrial hazardous wastes are the following: 1) the marked reduction of the organic part of the wastes by oxidation reactions with the oxygen in the air supplied, 2) the complete elimination of the hazardous properties in the wastes and 3) recovery of the heat released by the incineration of the waste.

Many different types of incinerators have been tested. Among them, suitable equipment for the thermal treatment of industrial hazardous wastes is the fluidized bed type of incinerator. A fluidized bed incinerator provides all the advantageous characteristics of gas–solid fluidization technologies. First, the particle sizes in industrial liquid wastes (suspension, sludge, *etc.*) are usually small and uniform; therefore, they have relatively large contact areas with the oxygen in the air for carbon oxidation to be realized. Second, the waste particles are suspended by means of the fluidizing air; therefore, further contact between the waste particles and the fluidizing air is obtained. Third, the fluidization promotes the mixing of the waste and the bed of sand particles; consequently, a uniform combustion temperature is achieved in the fluidized bed.

Other significant advantages of fluidized bed combustors over conventional combustors include their compact furnace, simple design, and effective burning of a wide variety of wastes and fuels. Fluidized bed combustors can be designed to combust almost any solid, semi-solid or liquid fuel without the use of supplement fuel, as long as the heating value is sufficient to heat the fuel, drive off the moisture and preheat the combustion air.<sup>8</sup>

The objective of this work was to demonstrate the technical feasibility of a fluidized bed as a clean technology for the burning of a liquid waste from pesticide manufacturing process. Sunflower oil was used as an additional fuel for the combustion of high moisture liquid wastes. The combustion efficiency and the flue gas composition were investigated using a pilot scale unit.

This paper provides an overview of the thermal decomposition of a pesticide manufacturing liquid waste in a fluidized bed incinerator.

#### EXPERIMENTAL

The technological scheme of the pilot scale unit for liquid waste combustion is given in Fig. 1.

The main part of the pilot unit is the fluidization column of 124 mm in diameter in the lower part and 150 mm in diameter in the upper part, with overall column height of 1800 mm. The atmospheric pressure fluidized bed incinerator was made of stainless steel. The air dis-

tributor plate was placed at the column bottom (1a). The column was filled with quartz sand, size fraction 0.63–1.25 mm and density 2610 kg/m<sup>3</sup> (1b). The static height of sand bed was 200 mm. This unit was designed to operate at temperatures up to 950 °C with a fluidizing air velocity of 0.5–2 m/s at ambient temperature. Liquid waste was fed onto the bed surface from a sealed reservoir (9) and the flow rate was controlled by a peristaltic pump (10). The supplement liquid fuel (sunflower oil) was fed onto the bed surface from a reservoir (6) using a pump (7) and twin fluid nozzle-gas/liquid ejector (8), located 80 mm from the column bottom. The residence time in the fluidized bed incinerator varied between 0.6 and 0.8 s.

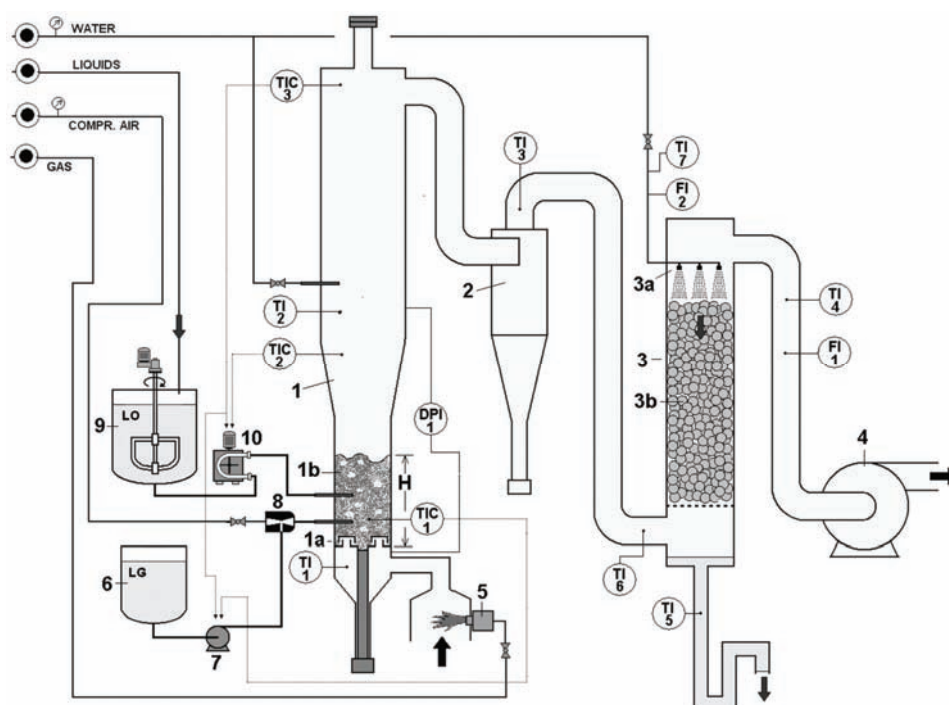


Fig. 1. Technological scheme of the pilot scale unit for liquid waste combustion in a fluidized sand bed (1-fluidized column, 1a-air distributor, 1b-sand, 2-cyclone, 3-scrubber, 3a-water nozzles, 3b-packing, 4-blower, 5-gas burner, 6-additional liquid fuel reservoir (LG), 7-pump for additional liquid fuel, 8-twin fluid nozzle-gas/liquid ejector, 9-liquid waste reservoir (LO), 10-pump for liquid waste, H-bed height, TIC1–TIC3-temperature indication and control, TI1–TI7-temperature indication, FI1-air flowrate indicator, FI2-water flowrate indicator, DPI1-indication of the differential pressure difference in the fluidized column).

Three tubes with manholes, covered with hardened quartz glass, placed above the dynamic sand bed height (2 manholes) and at the top of the fluidized bed chamber (1 manhole), enabled visual observations during the combustion experiments.

The other constitutional parts of the pilot unit were a cyclone (2) of 100 mm in diameter and scrubber (3) of 124 mm in diameter and 800 mm in height. Aluminum Rashig rings (3b) with dimensions 20×20 mm were employed in the scrubber. An air blower (4) was placed at

the end of the process line, in such way the pilot unit operated under vacuum with respect to the atmospheric pressure.

In order to limit heat losses, all constitutional parts of the pilot unit as well as the pipe lines were thermally isolated with mineral wool of thickness 50 to 100 mm.

The bed temperature, freeboard temperature and other characteristic temperatures were measured by means of sheathed Ni/Cr–Ni thermocouples. Combustion gas samples were obtained from a sampling port located at the scrubber exit. Only the VOCs and  $\text{NO}_x$  concentrations were measured, while measurements of the CO concentrations were neglected due to the sufficiently high process temperatures and high oxygen concentration. The concentration of the total hydrocarbons at the outlet of the system was measured by an on-line gas chromatograph (Perkin–Elmer 3920B) equipped with a flame ionization detector (FID). The concentration of nitrogen oxides ( $\text{NO}_x$ ) was analyzed by a  $\text{NO}$ – $\text{NO}_2$ – $\text{NO}_x$  analyzer (Thermo Electron Model 44). The air and gas flow rates were measured by calibrated rotameters.

*Process control.* After startup of the pilot unit, the gas burner (5) was turned on. The fuel used for heating the fluidizing air was a commercial propane–butane mixture (50–50 %), supplied in pressurized bottles with a nominal heat capacity of 45.8 MJ/kg.<sup>9,10</sup> When the temperature in the middle of the bed (TIC1) reached the value of 600 °C, the additional liquid fuel pump was turned on and the feeding process begun by the twin fluid nozzle (8). The additional fuel was sunflower oil with a nominal heat capacity of 39.6 MJ/kg.<sup>11</sup> The temperature controllers TIC1 and TIC3 controlled the feeding pump for additional liquid fuel in such manner that the pump operated in the on/off mode, *i.e.*, the pump was turned on if the temperature in the middle of the bed (TIC1) was below 880 °C and if the temperature at the top of the fluidization column (TIC3) was below 950 °C. The temperature controllers TIC2 and TIC3 controlled the feeding pump for liquid waste (10) in such manner that the pump operated in the on/off mode, *i.e.*, the pump was turned on if the temperature above the fluidized bed (TIC2) was 800 °C at least and the pump was turned off if the temperature at the top of the fluidization column (TIC3) exceeded 950 °C. After the stationary state was attained, the pilot unit operation was fully automatic.

The flue gases were exhausted at the top of the fluidized bed chamber, and were passed to a cyclone, to capture any elutriated particles of the bed material. The effluent gases from the cyclone were passed through the scrubber to cool out and to eliminate the finest particles and odors. In all runs, the cooling water flowrate in the scrubber was 2.8 L/min. The cooling water flowrate was chosen in order to keep the outlet cooled air temperature (T14) below 65 °C and the wastewater temperature (T15) below 75 °C. In all runs, the air flow rate in the stationary state (calculated for 20 °C) was between 35 and 40 m<sup>3</sup>/h.

The employed bed material was quartz sand. The main characteristics of the bed are presented in Table I.

TABLE I. Characteristics of the bed material

Quartz sand, granulation $d_p$	0.63–1.25 mm
Mean particle diameter, $d_{p\text{-avg}}$ 0.94	mm
Sand density, $\rho_s$ 2610.00	kg/m <sup>3</sup>
Sand bulk density, $\rho_{s\text{-bulk}}$ 1488.00	kg/m <sup>3</sup>
Sand bed height (static), $H_s$ 0.20	m
Superficial air velocity at minimum fluidization (at 20 °C), $U_{mf}$ 0.64	m/s
Superficial terminal air velocity (at 20 °C), $U_t$ 7.93	m/s
Mass of the sand, $M_s$ 3.59	kg

Six realistic samples, *i.e.*, different rinsates from a pesticide production plant, the specifications of which are given in Table II, as well as three different mixtures, *i.e.*, mixture 1 (samples 1, 2 and 5 in volume proportions 1:1:1), mixture 2 (samples 3, 4 and 6 in volume proportions 1:1:1), mixture 3 (samples 1, 2 and 6 in volume proportions 1:1:1), were used in combustion experiments.

TABLE II. Rinsates after different products from the pesticide production plant

Sample	Product type	Active matter	Washing fluid
1	Herbicide	Atrazine	Water
2	Herbicide	Paraquat	Water
3	Herbicide	2,4-D	Water
4	Fungicide	Carbendazim	Water
5	Herbicide	Acetochlore	Water
6	Fungicide	Tebuconazol (carrier: sunflower oil, colored with Basonyl Red)	Water

## RESULTS AND DISCUSSION

Wastewater from pesticide formulation and packaging operations typically has low levels of organics and the pH is generally neutral. The level of toxicity and biodegradability depends on the presence of chemicals such as pesticide residues, organic solvents and other auxiliary substances that may be toxic to aquatic organisms.

The main aim of these experimental investigations was to determine the operating regimes that enable satisfactory combustion of the propane–butane mixture (50–50 %), additional oil and liquid waste, the oxidation of combustibles in the fluidized bed incinerator to be as high as possible and, at the same time, to avoid fouling of the incinerator walls, and sintering and agglomeration of the bed material.

All available data supplied by the pesticide production company indicated to variability in the quality and quantities of wastewaters and other liquid wastes to be treated. Therefore, the identification of a profound solution that would not be sensitive to these factors was important.

Supplementary fuel consumption, air flow and specific solution consumption for the three chosen representative test runs are given in Table III.

TABLE III. Flow rates of liquid waste, supplementary fuels (propane–butane mixture 50–50 %, sunflower oil) and air

Run	Propane–butane $Q_{\text{gas}} / \text{kg h}^{-1}$	Sunflower oil $Q_{\text{LG}} / \text{L h}^{-1}$	Liquid waste $Q_{\text{LO}} / \text{L h}^{-1}$	$G_{\text{air}} / \text{kg h}^{-1}$	Liquid waste mixture
1 0.728		0.971	2.442	70.0	1: Samples 1,2,5 (1:1:1)
2 0.728		0.611	2.532	74.6	2: Samples 3,4,6 (1:1:1)
3 0.760		0.291	2.536	75.0	3: Samples 1,2,6 (1:1:1)



The samples 1 to 6, according to the specification given in Table II, were investigated. In addition, mixtures of these samples were also investigated, *i.e.*, mixture 1 (samples 1, 2 and 5 in volume proportions 1:1:1), mixture 2 (samples 3, 4 and 6 in volume proportions 1:1:1) and mixture 3 (samples 1, 2 and 6 in volume proportions 1:1:1). The duration of each run was up to 3 h. All information about the liquid waste composition is the property of the factory for pesticide manufacture and, therefore, these data are not presented.

During system heat up, with air in excess, the combustion was least efficient at the lowest temperatures, with relatively high total hydrocarbons concentrations. As the bed heated up, the total concentration of hydrocarbons dropped rapidly to below the limit of detection (below 1 ppm). In an idealized combustion process, all chemical and thermal steps have to occur in the bubbling bed only. According to the fluidized bed geometry and operational conditions, it is possible that a fluidized bed exhibits a slugging behavior. It was visually observed that the fluidized bed showed uniform bubbling behavior after attaining steady-state conditions. Micro-explosions were noted during the experiments over a wide temperature range (up to 800 °C); they were associated with acoustic effects, detectable by the ear, and oscillations of the temperature. The light released during the explosions was clearly visible from the top of the column as flashes. It was not possible to distinguish clearly if the micro-explosions occurred within the bed or in the freeboard. Therefore, there is possibility that the most of the burn off occurred above the bed.

When hazardous wastes with high moisture contents are added into the incinerator, the moisture evaporates instantaneously due to the amount of heat stored in the bed sand without any change of the combustion temperature. Once the moisture evaporation of the wastes is complete, then combustion follows. The sand bed will absorb the heat released during the combustion. This type of heat recirculation in the fluidized bed maintains a uniform total heat content.<sup>13</sup>

A typical diagram of the temperature variations as a function of time during combustion tests in the pilot scale unit is given in Fig. 2.

The test mixture 2 (samples 3, 4 and 6 in the volume proportions 1:1:1) contained component 6, containing a high percent of mineral oil with a high combustion capacity. It can be seen from Fig. 3 that the consumption of auxiliary liquid fuel required to maintain the desired temperature values in the bed was lower in comparison with the combustion of mixture 1. After steady operation was attained, the feeding of the propane-butane mixture 50–50 % was stopped, which was followed with a sudden TII temperature drop. It can be seen from Fig. 3 that the heating value of mixture 2 was sufficient to maintain combustion at the desired temperatures in the fluidized bed chamber. There was no significant temperatures drop due to released heat from combustion of mixture 2 after 170 min. In the runs

with the liquid waste with a high energy potential (*i.e.*, sample 6), the additional liquid fuel consumption was very low.

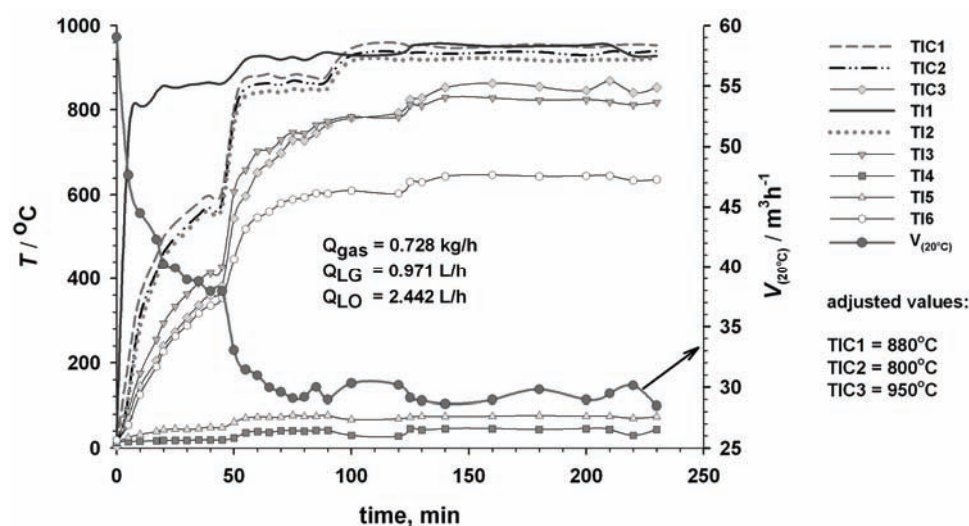


Fig. 2. Typical temperature profiles and exit air volumetric flowrate ( $V_{(20^{\circ}\text{C})}$ ) in the pilot fluidized bed incinerator under turbulent bed conditions (Run 1).

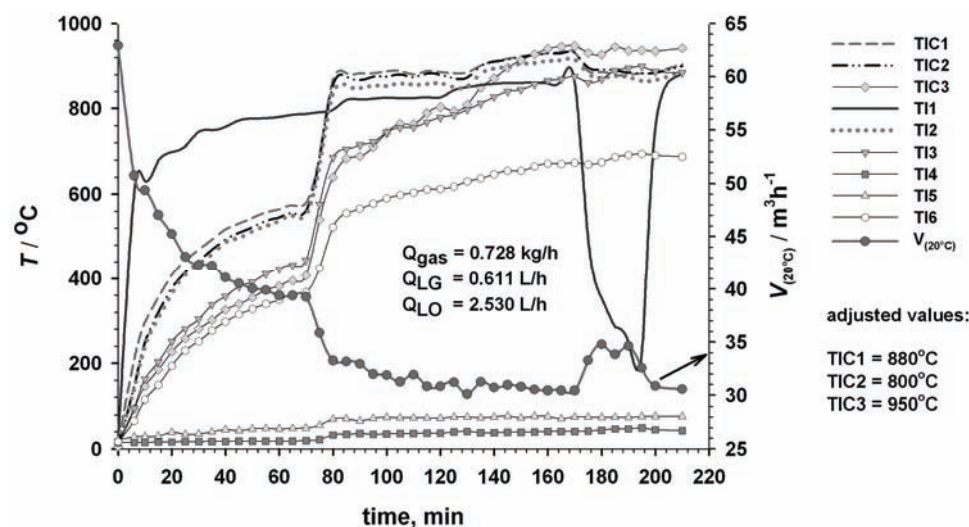


Fig. 3. Temperature profiles and exit air volumetric flowrate ( $V_{(20^{\circ}\text{C})}$ ) in the pilot fluidized bed incinerator under turbulent bed conditions (Run 2).

The hot fluidizing air flows into the fluid bed zone of the incinerator and fluidizes the inert bed of sand. The turbulence of the fluid bed zone serves to disperse the liquid waste and additional liquid fuel. The large surface area of the



fluidized sand particles results in the efficient heat transfer from the fluidizing air to the sand and from the sand to the feeds.

Primary combustion occurs in the bed zone. The freeboard height (above the fluidized sand bed) is an important factor, since volatiles released from the bed will continue burning in the freeboard region. The proper choice of the freeboard height provides the necessary residence time. The residence time in the pilot scale unit was about 0.6 to 0.8 s, which is well below the recommended value for a combustion system, *i.e.*, 2 s at 1100 °C.<sup>2,7</sup>

When the temperature at the top of the column (TIC3) was above 900 °C, the overall hydrocarbons concentration (expressed as xylylene concentration) at the system outlet was below the detection limits of the gas chromatograph, as illustrated in Fig. 4, while the NO<sub>x</sub> concentrations were low (< 25 ppm). NO<sub>x</sub> can be formed by two paths, from the combustion of nitrogen containing compounds from the liquid waste and as a consequence of elevated temperatures. Under the proper temperature profile along the fluidized bed incinerator (TIC3 > 900 °C), despite the short residence time, the detected levels of hydrocarbons and NO<sub>x</sub> in effluent gasses indicated that the combustion efficiency was very high.

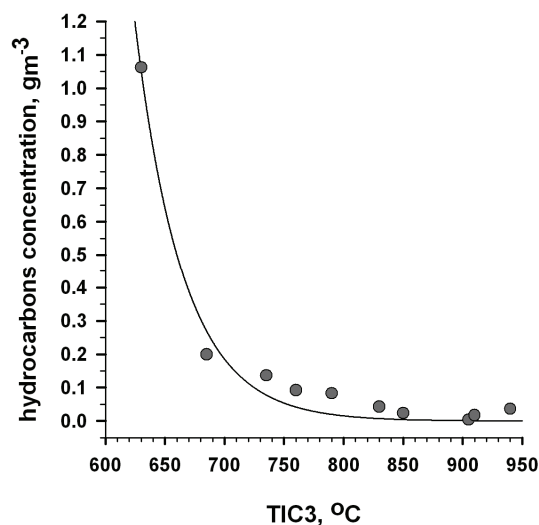


Fig. 4. Gas chromatography analysis of the outlet gases from the fluidized bed incinerator (Run 3).

It should be emphasized that in the runs in which the freeboard temperature was below 900 °C, only partial combustion of the supplementary fuel and organic compounds in the waste solution occurred. This resulted, to some extent, in fouling of the walls above the bed of the fluidized bed incinerator and the appearance of soot in the exit gases and in the exit scrubber water. The lower freeboard temperatures resulted in higher emissions in the flue gasses.

In fluidized bed incinerators, incomplete combustion, *i.e.*, generation of CO, can be caused by “bad-burning” (the combustion conditions are deteriorated, *i.e.*, the combustion is frozen because of a temperature drop despite an abundant air supply) or “over-burning” (combustion becomes excessive relative to the air supply, *i.e.*, the liquid mixture is not homogeneous and clusters of high fuel concentration gas appear in the freeboard).<sup>12</sup> Hence, it is necessary to ensure stable combustion by preventing over-combustion or bad combustion. However, even if operations are performed under stable conditions, changes in emissions concentrations in the output gases could occur due to changes in the quality of the liquid waste and other factors.

In several runs, the “over-burning” phenomenon occurred, *i.e.*, an open flame above the sand bed was visually observed. This was confirmed by fluctuating and higher concentration of organics.

As the gas velocity increases, the bed of solid particles goes through the states of minimum fluidization, bubbling, turbulent to fast fluidization, and eventually become a transport reactor when the gas velocity exceeds the terminal velocity of the sand particles. The regime under which the system is operated is an important factor. The minimum fluidizing velocity ( $U_{mF}$ ) for the sand particles ranged between 0.42 and 0.44 m/s under dense bed conditions (TIC2, TIC3 = 900–950 °C). The  $U/U_{mF}$  ratio ranged between 6.4 and 6.8 under steady state conditions, the regime was turbulent, which was consistent with the visual observation through the viewing manholes on the combustion chamber. In this manner, the finest sand particles were carried over during the experiment, which was confirmed by the continuous pressure drop in the sand bed with time. This effect was much more pronounced in the preliminary experiments conducted in the fluidized bed chamber with a shorter freeboard zone.

Defluidization of the bed is particularly critical in the combustion of industrial wastes. A high risk of agglomeration might occur in the area where mixing is not perfect or when local over-heat zones exist in the bed. Bed sintering symptoms were not noticed during the combustion tests. Although the experiments were conducted at much lower temperatures (up to 950 °C) than the critical temperature for the transformation of quartz to cristobalite (around 1400 °C),<sup>14</sup> results are inconclusive with respect to the cumulative effect in long term operation. Additional investigations regarding defluidization caused by sintering are required in order to obtain reliable data for an industrial plant project.

The first priority for any waste management strategy should be practices that prevent or at least minimize generation of waste and promote recycling of materials. If reuse and recycling are not feasible options, then treatment technologies must be employed.

This study was specifically focused on the experimental development of a treatment for rinsates that cannot be recycled or reused for production of “ready to use” products. In addition, an important fact that had to be considered was the

higher energy input as a consequence of the high water content in the liquid waste. Recovering the calorific value of the used solvents and other organic compounds present in liquid wastes refers to the proposed “waste to energy” concept rather than just co-incineration. Since the energy released during the process might be utilized to generate hot water and steam, the disadvantage of high-energy consumption of the chosen treatment technology is mainly compensated.

The organics content (expressed as xylene of 5.33 vol. %) and the liquid waste flowrate of about 60 kg/h (150 m<sup>3</sup>/year) were adopted for preliminary calculations of an industrial unit. According to these calculations, the size of sand particles in the fluidized bed has no effect on the heat balance, but has effect on the column diameter and residence time (Fig. 5). With finer sand particle granulation, the residence time is longer, which is preferable, but at the same time, the column diameter is larger. The sand particles size and column diameter have to be chosen in order to meet the recommended values for the combustion system, *i.e.*, minimum 2 s at 1100 °C.<sup>7</sup> According to the preliminary design of the industrial plant for the chosen operating conditions, the plant would operate for about 100 days only during the winter period, with the basic concept of utilizing the heat released during the combustion for heating within the factory.

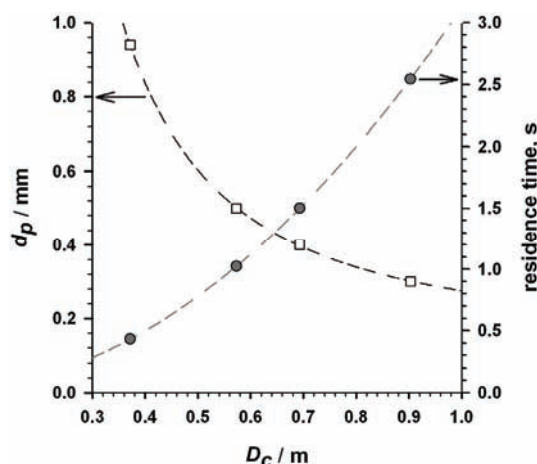


Fig. 5. The effect of the size of the sand particles ( $d_p$ ) in the fluidized bed on the column diameter ( $D_c$ ) and residence time.

The main objectives were achieved: the liquid waste was safely decomposed; fouling problems and emission levels could be eliminated under proper operating conditions. Doubtless, the industrial unit will be more efficient, since the freeboard residence time will be longer and temperatures will be higher.

#### CONCLUSIONS

The results of experimental investigations the disintegration of liquid waste (generated in a pesticide production plant) in a fluidized bed incinerator are given in this paper.

The obtained results indicate that this technology can be used for this purpose since it enables good control of temperature, which was found to be the most critical parameter. The main conclusions derived after these investigations are as follows:

1. The pilot scale unit operation was stable; bed sintering symptoms were not noticed.

2. In all runs, with sufficient excess air, where the temperature at the top of the column (TIC3) was above 900 °C, the overall hydrocarbons concentration at the system outlet was below the detection limits of the gas chromatograph, while the NO<sub>x</sub> concentrations were negligible. It should be noted that the residence time in the pilot scale unit was nearly 0.8 s, which is below the recommended value for combustion systems (2 s at 1100 °C). As different molecules might be present in the wastewater, including those containing chlorine, in order to prevent toxic emissions, high enough temperatures, residence times and turbulence in the combustion chamber should be ensured in order to prevent emissions of dioxins and furans. In addition, the temperature profile should be carefully controlled to prevent re-formation during cooling or starting-up.

3. The consumption of the propane-butane mixture was 0.72 kg/h, the consumption the additional liquid fuel (L G, sunflower oil) varied between 0.3 and 0.97 L/h, depending on the energy potential of liquid waste, and the liquid waste (LO) combustion capacity was in range of 2.2 to 2.5 L/h.

4. In the runs with the liquid waste with a high energy potential (sample 6, the consumption of the additional liquid fuel was negligible.

5. The obtained test results were used for a preliminary design of an industrial plant for incinerating 150 m<sup>3</sup>/year of these liquid wastes.

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#### ИЗВОД

#### САГОРЕВАЊЕ ТЕЧНОГ ОТПАДА ФАБРИКЕ ПЕСТИЦИДА У ФЛУИДИЗОВАНОМ СЛОЈУ

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Индустријски течни отпад може бити у облику раствора, суспензија, муља, пене, отпадног уља и генерално садржи различите органске компоненте. Предмет овог рада је демонстрација третмана течног отпада са високим садржајем загађујућих материја фабрике за производњу пестицида методом термичке деструкције у флуидизованом слоју песка као технички практичне и оптималне технологије. Испитивања сагоревања реалних течних отпад-

них смеша фабрике пестицида су извршена у полуиндустријском-демонстрационом постројењу, тј. у флуидизационој колони са слојем кварцног песка гранулације 0,63–1,25 mm и густине 2610 kg/m<sup>3</sup> на 800–950 °C. У циљу обезбеђења потпуног сагоревања течног отпада, у флуидизационој колони је увођен ваздух у вишку и однос  $U/U_{mf}$  (на температури околине) је износио између 1,1 и 2,3. У флуидизационој колони се течни отпад, додатно течни гориво и ваздух могу довести у стање интензивног контакта што омогућава стабилно и хомогено сагоревање у слоју. Резултати експерименталних испитивања показују да се у флуидизованом слоју песка остварује веома добра термичка униформност и контрола температура. Резултати испитивања сагоревања су показали да се течни отпад са високим садржајем загађујућих материја може успешно термички третирати у флуидизованом слоју песка без емисије штетних продуката сагоревања, под условом да су у слоју и изнад слоја обезбеђене температуре изнад 900 °C.

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#### REFERENCES

1. *Environmental, Health and Safety Guidelines for Pesticide Manufacturing, Formulation, and Packaging*, [http://www.ifc.org/ifcext/sustainability.nsf/AttachmentsByTitle/gui\\_EHSGuidelines2007\\_Pesticides/\\$file/Final+-+Pesticides.pdf](http://www.ifc.org/ifcext/sustainability.nsf/AttachmentsByTitle/gui_EHSGuidelines2007_Pesticides/$file/Final+-+Pesticides.pdf) (06 April, 2009)
2. A. S. Felsot, K. D. Racke, D. J. Hamilton, *Rev. Environ. Contam. Toxicol.* **177** (2003) 123
3. *Stockholm Convention on Persistent Organic Pollutants*, [http://chm.pops.int/Portals/0/Repository/convention\\_text/unep-pops-cop-convttext-full.English.pdf](http://chm.pops.int/Portals/0/Repository/convention_text/unep-pops-cop-convttext-full.English.pdf) (06 April, 2009)
4. K. H. Karstensen, *The Potential of using Cement Kilns for Environmentally Sound Destruction of Obsolete Pesticides in Developing Countries*, [http://www.coprocem.com/documents/19potential\\_cement\\_kilns\\_in\\_developing\\_countries.pdf/view](http://www.coprocem.com/documents/19potential_cement_kilns_in_developing_countries.pdf/view) (06 April, 2009)
5. *Hazardous Waste Incineration: Advanced Technology to Protect the Environment*, <http://www.vessa.eu/images/hazardous%20waste%20incineration.pdf> (06 April, 2009)
6. *Federal Register Environmental Documents*, <http://www.epa.gov/fedrgstr/1999.htm> (06 April, 2009)
7. *Official Journal of the European Communities: Directive 2000/76/EC of the European Parliament and of the Council on the incineration of waste*, [http://www.wbcsd.org/web/projects/cement/tf2/2000-76\\_en.pdf](http://www.wbcsd.org/web/projects/cement/tf2/2000-76_en.pdf) (06 April, 2009)
8. S. Patumsawad, K. R. Cliffe, *Energ. Convers. Manage.* **43** (2002) 2329
9. R. Natarajana, N. S. Karthikeyana, A. Agarwaala, K. Sathiyanan, *Renew. Energ.* **33** (2008) 2423
10. J. B. Kandpal, R. C. Maheshwari, T. C. Kandpal, *Energ. Convers. Manage.* **36** (1995) 1067
11. *Vegburner Report: Vegetable Oil as a Fuel*, <http://vegburner.co.uk/report.html> (06 April, 2009)
12. Y. Miyamoto, Y. Kurosaki, H. Fujiyama, E. Nanbu, *Control Eng. Pract.* **6** (1998) 1159
13. J. C. H. Chu, *Korean J. Chem. Eng.* **16** (1999) 795
14. R. Yan, D. T. Liang, L. Tsen, *Energ. Convers. Manage.* **46** (2005) 1165.