Spontaneous Ignition/Low Temperature Oxidation of Municipal Solid Waste

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Spontaneous ignition of waste stockpiles represents a serious economic and safety problem. The said type of processes are deemed very important for determining a tendency of municipal solid waste (MSW) towards self-ignition, as well as for identifying appropriate technical measures (ventilation, forced cooling) that need to be implemented in order to prevent fires and pollutant emissions from MSW management facilities, especially waste transfer stations, waste storages, etc. The paper describes waste oxidation and spontaneous combustion processes, which are closely related to similar processes occurring in many other organic materials. Regardless of the considered process nature, results indicate that consumption of oxygen and heat transfer rate in the waste stockpile are significant and thus favorable for fire outbreak or explosion incidents. The "constant oxidation rate" values obtained, considered to be the process indicators, were significantly larger than the corresponding values obtained for different coal varieties.

Keywords: low temperature oxidation, spontaneous ignition, municipal solid waste

As it is well-known, coal and many other organic materials have a tendency towards self-heating [2, 4, 6, 8, 11]. As a result of ineffective heat dissipation or heat transfer in the stockpiled material, a hot spot may develop in the material which may eventually lead to the spontaneous pile ignition. Extensive analyses and studies were conducted in order to fully explain these self-ignition processes. Spontaneous ignition, or as specified in some studies, the low temperature oxidation, represents one of the most important problems associated with proper MSW management. A tendency of MSW towards self-ignition has been well documented in various fossil fuel research investigations. Practical verification of the phenomena considered is provided by daily fires occurring at unregulated waste dumps, self-ignition of wood waste at storage facilities etc. The issues of human and construction safety related to the problem considered require additional research, at least to the extent of the attention given to the fossil fuel research. Various research investigations conducted up to date have demonstrated that with respect to the self-ignition tendency i.e. tendency towards low temperature oxidation, solid waste represents a very complex and sensitive material [1, 5, 7, 10]. In the aforementioned statement, low temperatures are considered to be those ranging from the room temperature to approximately 100°C. The term "low temperature oxidation" is related to specific physical and chemical processes occurring in the specified low temperature range. The meaning of the term "temperature" should be taken with some limitations, since low temperature oxidation results in heat generation and formation of a sufficiently developed temperature field in a layer of the material analyzed.

Results of various research investigations found in the literature are very important and may be used when designing ventilation systems in enclosed waste storage areas of the waste treatment plants, particularly in situations where waste must be stored for several days [9]. A properly designed ventilation system protects the human health and prevents health threats caused by the lack of oxygen or suffocation caused by the release of carbon monoxide or other harmful gases.

Experimental part

Sampling and analysis

For the purpose of the research investigation conducted, 551 kg of waste samples were collected from a landfill site in Belgrade. The samples were collected during the winter period, as described in [12]. Approximately 150 to 200 kg of waste was collected per day (app. 1.5 to 2 m^3) in 3-4 separate samplings, with 400 to 700 l of waste collected from waste collection vehicle during each sampling. The waste collected originated from the urban zones of the city of Belgrade.

Parts of the collected waste sample were dried at atmospheric conditions and ground to the particle size of 5 mm. Proximate and ultimate analyses of the waste samples are shown in table 1.

For the purpose of determining a tendency of a material towards self-oxidation and self-ignition, several methods have been identified and proposed in the literature [3]. Experiments based on the proposed methods provide good results for carbon-rich coal varieties, but poor results for lignite and similar "young", low-carbon-content fossil materials. Veselkovski V.S. [3] proposed a parameter named "constant oxidation rate" to be measured. The said parameter was deemed indicative of thermal and chemical activities of a material under self-ignition conditions. However, certain observations and limitations of the method proposed have been identified and must be acknowledged [3]: mass of the material examined relative to the volume of the reactor must be analyzed for the relevant thermal and chemical elements, taking into account similarities of the phenomena apparent under actual and laboratory conditions; at temperatures above 60°C, increase in the amount of oxygen adsorbed on the material surface results in decreased oxidation rate.

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Table 1
LABORATORY ANALYSIS OF SAMPLED WASTE

Proximate analysis				Ash analysis	
wt., %	As is (as received)	Dry basis	Ash and moisture free		wt., %
Moisture	2.62			SiO_2	47.88
Ash	46.85	48.11		Fe_2O_3	10.66
Sulfur, total	1.84	1.89		Al_2O_3	2.63
Sulfur in ash	1.14	1.54		CaO	13.27
Sulfur, combustible	0.70	0.72	1.38	MgO	3.20
Char	53.62	55.06	13.40	SO_3	15.17
C-fix	6.77	6.95	13.40	Fe_2O_5	0.98
Volatiles	43.76	44.93	86.60	TiO_2	0.36
Combustibles	50.53	51.88	100.0	Na_2O	3.95
Heating value, kJ/kg				K_2O	2.01
higher	12179	12505	24103		
lower	11304	11664	22483	Reaction	acid
Ultimate analysis (wt., %)				Temperature of ash in oxidized atmosphere (°C)	
Carbon	58.30	29.45	30.25	Sintering temperature	1010
Hydrogen	7.88	3.98	4.09	Melting temperature	1060
Sulfur, combustible	1.38	0.70	0.72	Hemisphere forming temperature	1120
Nitrogen + oxygen	32.44	16.40	16.83	Flow temperature	1190

During the research investigation conducted, measurements were simultaneously performed on the samples stored in a water-saturated environment as well as on the samples stored in an environment with relative humidity of less than 100%.

The said approach was primarily used due to the still-accepted postulate that increase in the relative humidity causes an increase in the rate of low temperature oxidation, increasing a tendency of the material towards auto-ignition (as determined during related coal research and research on the properties of some mineral materials).

When dealing with MSW, the above statements should be treated with extreme caution, primarily due to high moisture content of MSW (which sometimes reaches even 85%). The said was also confirmed by the results of the research investigation presented herein.

Experimental apparatus used in the research investigation performed is shown in figure 1.

A 840 mL glass vessel (vessels E1-E12) (6) was filled with 6 mm diameter glass pellets (having a weight of 300 g and a volume of 100 mL), followed by the placement of analyzed waste sample (3). A glass tube (2), indented to be used for pouring water into the vessel or discharging water from the vessel, was inserted all the way to the bottom of the vessel. 10 mL of distilled water was poured into the vessel and the vessel was then placed into the drying chamber (7). Before being closed, the vessel (6)

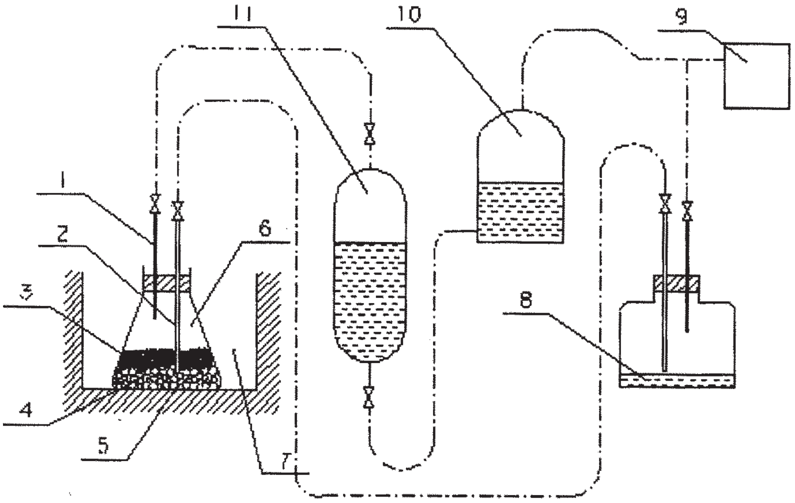

Fig. 1 Experimental instalation used for MSW low temperature oxidation research
1. Gas sample tube, 2. Water pouring and extracting tube, 3. Biomass sample, 4. Glass pellets, 5. Distilled water, 6. Vessel, 7. Drying chamber, 8. Liquid separator, 9. Vacuum pump, 10. Liquid accumulation vessel, 11. Gas sampling chamber

was left open until the required temperature in the drying chamber was reached. Once the required temperature had been reached, the vessel was hermetically closed and left to rest for approximately 24 h. Once during each of the following testing days, a gas sample was taken from the vessel (6) and directed into a gas sampling chamber (11) by the means of a vacuum pump (9) and a liquid accumulation vessel (a saturated aqueous salt solution was used in order to avoid absorption of gases resulting from low temperature oxidation) (10). The vessel (6) was then air ventilated for five minutes by the means of a pipe (1), additional pipe (2), liquid separator (8) and a pump (9). Simultaneously with the said ventilation process, distilled water (5) was discharged from the main vessel (6). 10 mL of distilled water was then poured back into the vessel (6) and the vessel (6) was then placed in the drying chamber (7) and hermetically sealed after 15 min (the time required for thermodynamic balance to be achieved). This process was repeated daily for 11 consecutive days. The value of the "constant oxidation rate", obtained in the investigation conducted, represents the amount of oxygen consumed by 1 g of the waste sample during 1 hour.

Experiments were conducted at 20°C (nominal ambient air temperature), 35 and 50°C.

Results and discussions

The "constant oxidation rate" (SK) can be calculated using the following expression:

$$SK = -\frac{V_o}{m_u \cdot \Delta\tau} \cdot \ln\frac{(1 - C_o) \cdot C_a}{C_o \cdot (1 - C_a)}, \frac{ml}{g \cdot h}, \qquad (1)$$

where gas volume in the vessel, for the adopted (standard) conditions, is calculated using the following equation:

$$V_o = \frac{(p_b - p'_{H_2O})}{p_N} \cdot \frac{(273.16 + t_{oN})}{(273.16 + t_{oK})} \cdot V_v, \text{ ml}, \qquad (2)$$

where:

m_u, g,– mass of the analyzed sample,

$\Delta\tau$, h,– time interval between two consecutive measurements of the gas phase composition (≈ 24h),

C_o, kmol/kmol,– air oxygen content (0,2096 kmol/kmol),

C_a, kmol/kmol,– oxygen content of the gas in the vessel,

p_b, mbar,– barometric pressure,

p'_{H2O},mbar,– water vapor saturation pressure at t_{oK},

p_N, mbar,– standard pressure (adopted value of 1013 mbar),

t_N, °C,– standard temperature (adopted value of 25°C),

t_{oK},°C,– ambient temperature (drying chamber temperature).

Volume of the gas phase in the vessel can be calculated using the following expression:

$$V_v = V_s - V_p - V_u - V_w, \text{ ml}, \qquad (3)$$

where:

V_s, mL,– volume of the vessel,

V_p, mL,– volume of the glass pellets,

V_u, mL,– volume of the waste sample,

V_w, mL,– volume of distilled water.

Calculated value of "constant oxidation rate" is expressed in mL of oxygen consumed by 1 g of analyzed sample during 1 h. The calculated values of "constant oxidation rate" are shown in figures 2-4. Changes in gas composition compared to the SK value are shown in figures 5 – 7.

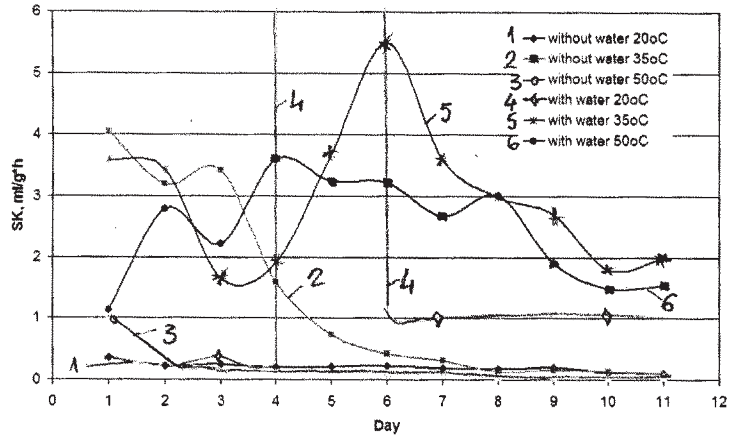

Fig. 2. Results of low temperature oxidation experiments – sample I (30 g)

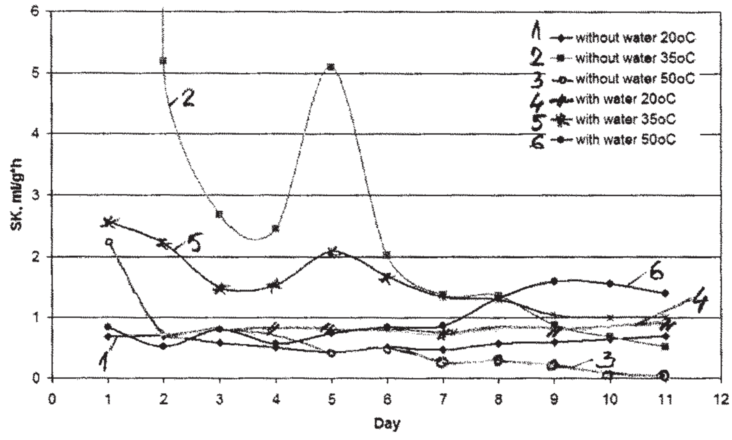

Fig. 3. Results of low temperature oxidation experiments – sample II (30 g)

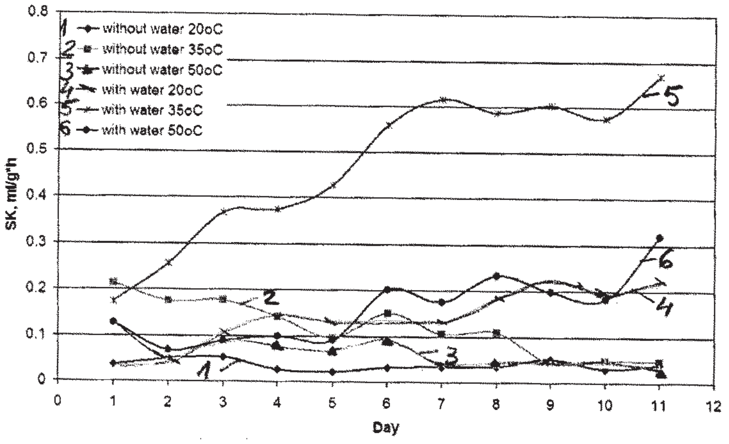

Fig. 4. Results of low temperature oxidation experiments – sample III (30 g)

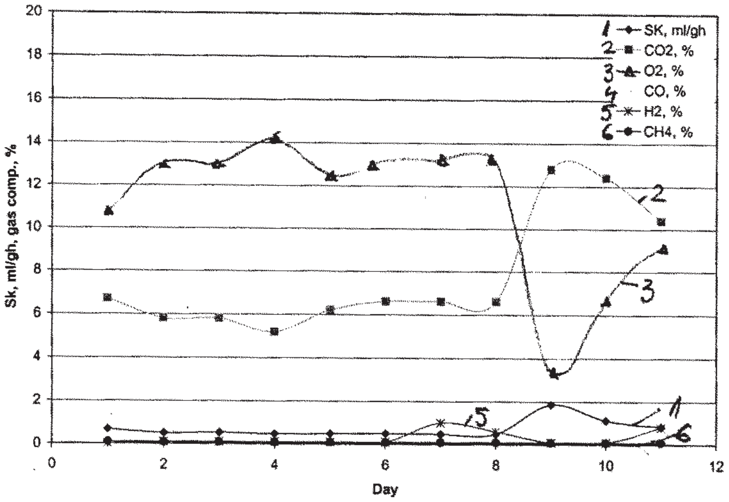

Fig. 5. Transformation of SK and gas composition during experiment performed (experiment conducted with no water in the vessel and at 20°C)

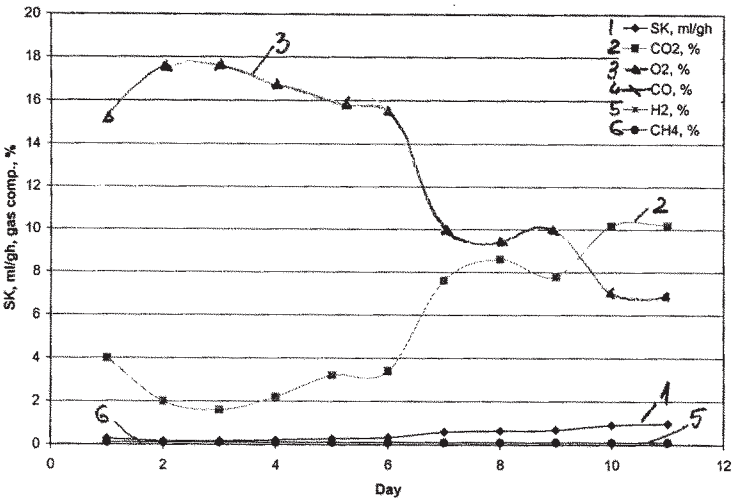

Fig. 6. Transformation of SK and gas composition during experiment performed (experiment conducted with no water in the vessel and at 35°C)

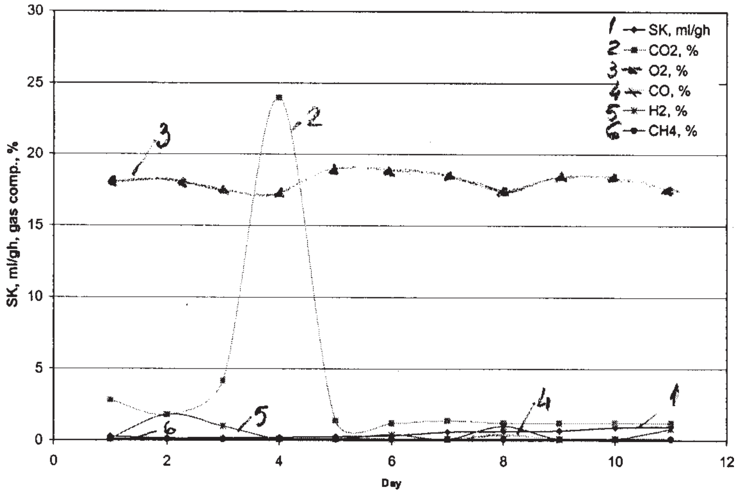

Fig. 7. Transformation of SK and gas composition during experiment performed (experiment conducted with no water in the vessel and at 50°C)

Research investigation performed with MSW samples has shown that the presence of water in the vessel does not affect the SK, since experiments conducted with the water-free vessel resulted in the SK value of ∞. The said means that all available oxygen in the air was consumed during a 24 h period. On the other hand, in case of different coal varieties, presence of water in the vessel was deemed to have had a considerable effect on the SK, causing the SK value to be even up to 60% higher than the corresponding value obtained for the case of the water-free vessel. Maximum SK value of lignite coals equals app. 0.6 mL/(g×h) and was obtained between the first and the third day of testing (during the 11-day testing period). The maximum SK value of the examined MSW samples equals (SK)max=∞. The specified maximum value was obtained between the first and the eleventh day of testing, depending on the particular sample examined.

If the results are applied with an engineering point of view, calculation shows that 1000 tons of stored MSW (the quantity of MSW collected during one day in a city with a population of one million residents) can consume even up to 20.000 m^3 of air during a 24 h period. The specified value clearly indicates a necessity for an efficient ventilation system to be designed in waste storage facilities and green barriers (generating oxygen) adequately distributed in the surroundings of waste dumps and landfills. The above specified numerical indicator is valid only under the assumption that the equilibrium in the vessel is reached in the 24 h period. If the equilibrium is reached faster, oxygen consumption is even higher.

Conclusions

Regardless of the very nature of the process examined, research results obtained indicate that specific transformations that occur in the MSW stockpiles, together with consumption of ambient oxygen and heat radiation that also take place, create conditions favorable for potential fire outbreak or explosion incidents.

Analysis of the research results and particularity of the extreme values obtained, indicates that low temperature oxidation occurs independently of the municipal solid waste characteristics. The content of CO_2 and O_2, as well as the ratio between the two, measured during the same day in different waste samples or measured in the same sample but over a period of several days, has shown that the composition of the waste, degrading during oxidation, is not constant.

In order to prevent fire outbreaks and explosion incidents in MSW stockpiles, results of the research conducted may be used to estimate and determine a maximum storage period for municipal solid waste, maximum size of the waste stockpile and other factors deemed relevant in the phenomena considered.

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