The application of thermal plasma for the treatment of soil polluted by bitumen.

M. Aikas[1], A. Tamošiūnas[1], D. Gimžauskaitė[1], R. Uscila[1], J. Eimontas[2]

Plasma Processing Laboratory, Lithuanian Energy Institute, Kaunas, LT-44403, Lithuania
Laboratory of Combustion Processes, Lithuanian Energy Institute, Kaunas, LT-44403, Lithuania
Keywords: bitumen, soil treatment, thermal plasma, hazardous waste management
Presenting author email: Mindaugas.Aikas@lei.lt

Introduction

Petroleum hydrocarbons are the most frequently found organic pollutant in the environment. Additionally, oil spills or leakage appearing during its extraction, transportation, or other anthropogenic activities causes aquatic and terrestrial environment contamination and negatively impacts living beings. Thus, the treatment of these pollutants from contaminated sites (e.g. soil) is highly required. Hence, fast and effective soil treatment methods are being searched to prevent adverse environmental outcomes. Consequently, this experimental research aimed to investigate the thermal plasma ability to treat soil contaminated by bitumen. It was found that bituminous soil surface morphology changed after treatment with thermal water vapor plasma or thermal air plasma.

Experimental setup and methodology

The treatment of bituminous soil was performed using thermal water vapor plasma and thermal air plasma. Soil and produced gas analysis were done before and after the treatment with different thermal plasmas utilizing the energy dispersive X-ray spectroscopy, scanning electron microscopy, the gas analyzer, elemental analyzer, fuel calorimeter and a thermogravimeter. The sticky bituminous soil clump was placed on the grate in the plasma-chemical reactor. The treatment of the bituminous soil with a different type of plasma was carried out under atmospheric pressure for ~20 min. The working parameters of the plasma system were the same using both water vapor plasma and air plasma. Accordingly, the power of the plasma torch was 51.2 kW, current 160A and voltage 320V. Water vapor flow rate was equal to 3.8 g/s, while the airflow rate was equal to 4.9 g/s.

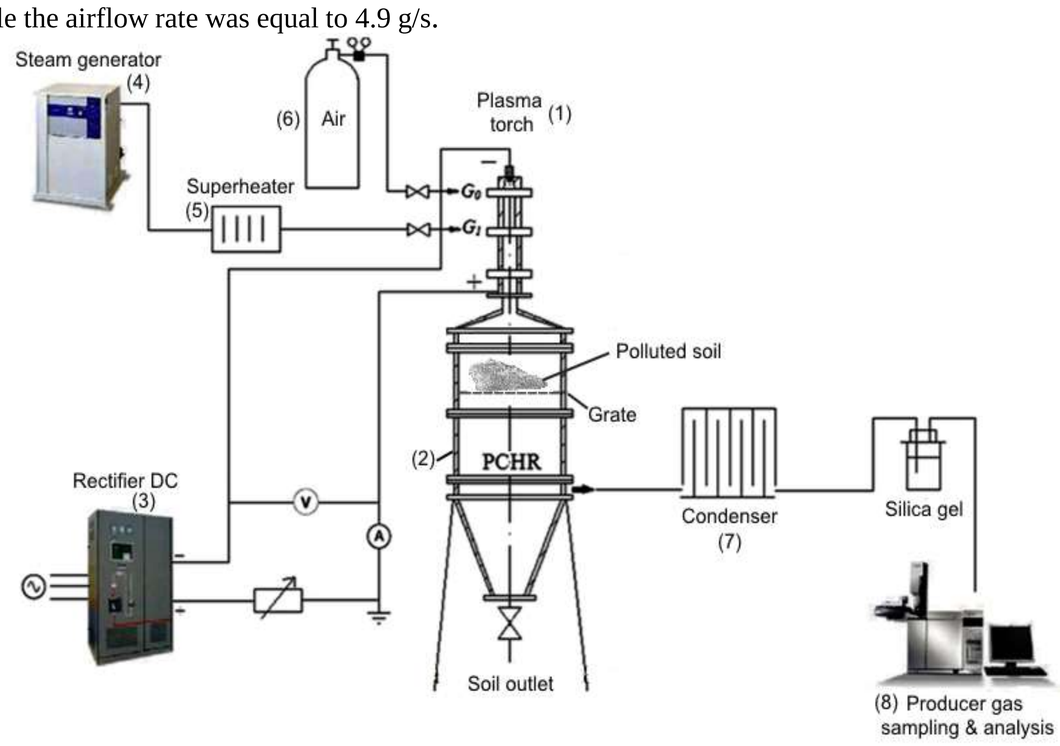


Fig. 1 A schematic view of the plasma-chemical reactor system utilized for the treatment of the soil polluted by bitumen. The system is composed of the atmospheric pressure DC arc plasma torch (1), a plasma-chemical reactor (2), a power supply system (3), a steam generator (4), a superheater (5), an air supply system (6), a condenser (7), and a gas analyzer (8). The reactor used in this research was 1 m long with the 0.4 m inner diameter.

Table 1. The ultimate and proximate analysis of the bitumen polluted soil

Ultimate analysis, wt.%	Soil polluted with bitumen
Carbon (C)	18.39
Hydrogen (H)	2.28
Nitrogen (N)	0.1
Sulfur (S)	0.47
Oxygen (O)[a]	1.3
Proximate analysis, wt.%	
Moisture	0.18
Ash	77.28
Lower heating value, MJ/kg	12

Proximate analysis revealed that ash and moisture content in the soil was equal to 77.28 wt.% and 0.18 wt.%, respectively. The lower heating value of the bituminous soil was identified to be equal to 12 MJ/kg.

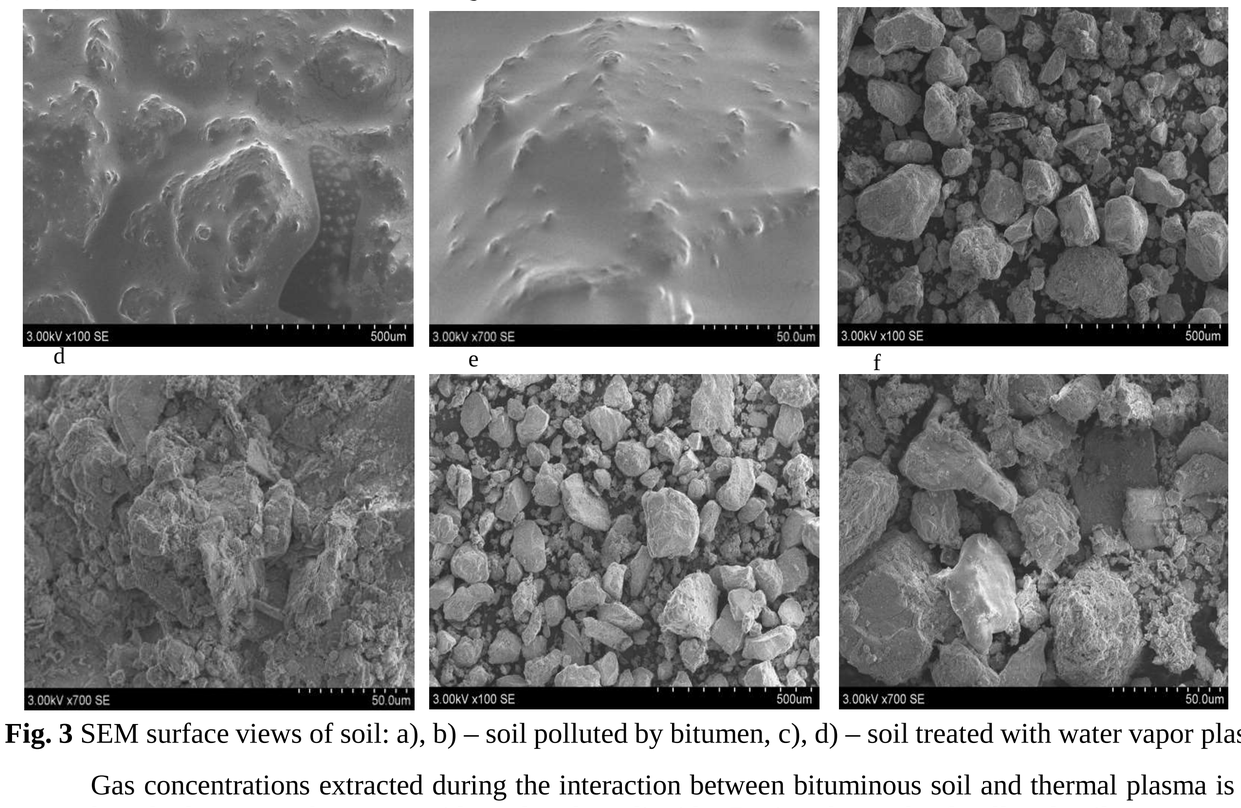
Table 2. The experimental parameters of the bitumen polluted soil treatment with thermal plasma

Parameter	Treatment of bitumen polluted soil with water vapor plasma	Treatment of bitumen polluted soil with air plasma
Arc current, A	160	160
Arc voltage, V	320	320
Power, kW	51.2	51.2
Gasifying agent flow rate, g/s	3.8	4.9

Results and discussion

a b c

Fig. 2 Bituminous soil before treatment (a) and after treatment with water vapor plasma (b) or air plasma (c)



d e f

Fig. 3 SEM surface views of soil: a), b) – soil polluted by bitumen, c), d) – soil treated with water vapor plasma, e), f) – soil treated with air plasma

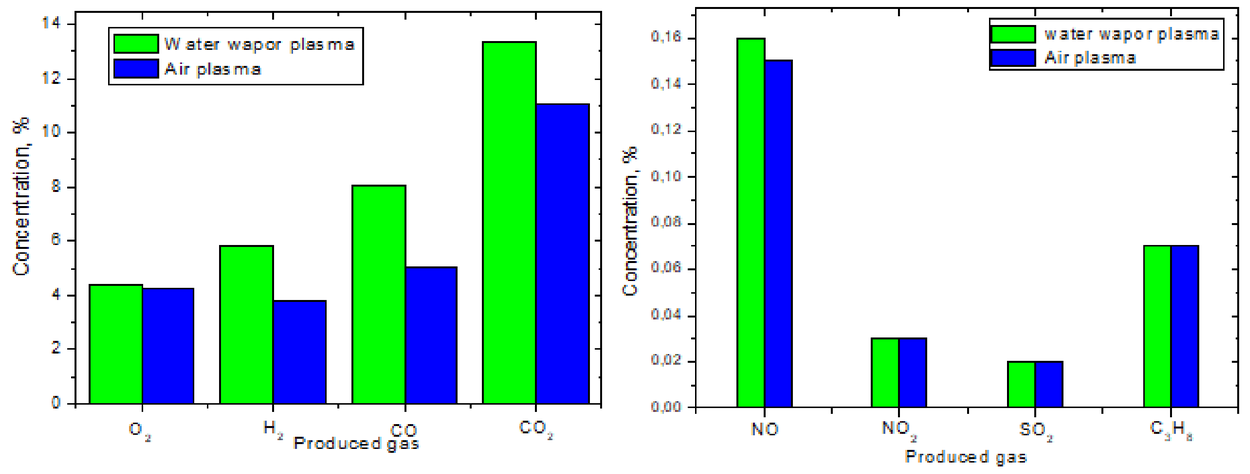


Fig. 4 Gas concentrations extracted during the bituminous soil treatment process

Table 3. Main elements composing bituminous soil and plasma-treated soil

Element	Soil polluted by bitumen, at %[a]	Polluted soil treated with water vapor plasma, at %	Polluted soil treated with air plasma, at %
Carbon	79.29	12.62	9.58
Oxygen	15.97	57.32	59.53
Silicon	2.03	19.50	19.42
Sulfur	1.12	0.50	0.51

Gas concentrations extracted during the interaction between bituminous soil and thermal plasma is shown in Fig. 4. The hydrocarbons constituting bitumen were mainly transformed into gaseous compounds such as hydrogen, carbon monoxide and carbon dioxide. During the peak of polluted soil treatment with water vapor plasma, the concentrations of the H_2, CO and CO_2 achieved 5.81%, 8.08% and 13.37%, respectively. In the case of using air plasma, the concentrations of the H_2, CO and CO_2 were equal to 3.80%, 5.03% and 11.04%, respectively. The polluted soil treatment with water vapor plasma caused the formation of higher produced gas content. Moreover, decrease in oxygen concentration from 21 % to 4.22–4.40% was recorded during the bituminous soil treatment process with air plasma and water vapor plasma, respectively. Additionally, the traces of NO (up to 0.16%), NO_2 (up to 0.03%), SO_2 (up to 0.02 %), and C_3H_8 (up to 0.07%) were recorded in both experimental cases (Fig. 4). The formation of NO, NO_2, SO_2, and C_3H_8 was mostly attributed to the composition of bitumen (Table 1) and the usage of the air as a plasma-forming gas or as a cathode shielding gas.

Conclusions

In this experimental study, the treatment of bituminous soil was performed using thermal water vapor plasma and thermal air plasma. Analysis of the soil surface morphology showed changes after interactions with thermal plasmas. Polluted soil distinguished itself with a relatively smooth surface and had spherical bubbles – a feature of bitumen. After exposure to the thermal plasma environment, the metallic brightness and spherical particle vanished from the soil. Instead, the soil had a granular structure, and its surface became relatively rougher. The results obtained with the energy dispersive X-ray spectroscopy showed that the carbon concentration in the soil after the treatment with water vapor plasma or air plasma decreased to 12.62% and 9.58%, respectively, from the initial 79.29% concentration of the polluted soil. Also, the sulfur concentration decreased from 1.12% to ~0.50% in both cases. Moreover, during the treatment process, the produced gases mainly consisted of H_2, CO and CO_2.The comparison of bituminous soil treatment with water vapor plasma and air plasma revealed that both thermal plasmas could remediate soil polluted by bitumen

Acknowledgements

This work was supported by the Public Agency “Soil remediation technologies”, project No. 17-34/15-1775.18.