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Subsurface injection of gaseous effluents of stationary internal combustion engines

Salam J. Bash AlMaliky
AlMustansiriya University, Iraq

* E-mail of the corresponding author: salambash2000@yahoo.com bashs@ohio.edu

Abstract

The exposure to poisonous gaseous effluents of stationary internal combustion engines has become one of the major causes of various adverse public health effects. This paper was aimed to study the injection of these gaseous effluents into subsurface soil and the use of soil as natural gas filter. The exhaust hose of 2KV gasoline power generator was made to inject its effluent into each of four subsurface depths; 20cm, 40cm, 60 cm and 80cm, for two types of natural soil; sandy and clay soils, in order to test their gas filtration performance. Results of four weeks of operation have demonstrated that almost 100% of CO and NO_2 gases were kept underground at depths higher than 60cm for both types of soil. The clay soil has showed around 55% higher performance as compared to that of sandy soil for the dissipation of NO_2 and around 36% for CO at the same measurement locations. Injection of gaseous effluents has failed at 80 cm depth due to the inability of soil at that depth to disperse gases without affecting the machine`s backpressure.

Keywords: back pressure, gaseous effluents, gas filtration, soil, subsurface injection.

1. Introduction

Mother earth has been always an inspiring source and fate for unlimited life resources such as plants and fuels, since the very creation of the universe. The Nobel Quran “Al–Ma’idah, 27-31” (1999) and Holly Bible “Genesis 4:1-8” (2011), have mentioned that Qabil (Cain), son of Adam, was the first human being who discovered the use of underground soil in order to hide the corpse of his brother Habil (Abel), that might be considered as a potential sources of pollution. Many researchers have turned their sights towards the use of underground soil in order to relief the environment from pollution loads of various kinds of pollutants such as domestic and industrial solid wastes, radioactive residues and hazardous wastes. for decades, the low- and intermediate-level radioactive waste disposal at shallow depths (land burial), has been experienced in many countries, such as Canada, France, India, UK, USA, and the former USSR in order to prevent their populations from the potential hazards of these wastes via the application of strict design, administrative and regulative measures that guarantee the recipient environment`s safety (Richter, 1978). Environmental deterioration issues were loudly raised for decades also, against the underground burial of such wastes such as those linked to Love canal disaster at New York city, and the radioactive materials storage at North Carolina and Idaho, USA (AlMaliky, 2012). From another side, the underground disposal approach for domestic wastes was found as not easy to be implemented at less developed nations where public were not so supportive and understanding (Aldu, Osman and Lu, 2012).

Stationary Internal Combustion Engines ICE were recognized as of the major air pollution sources at heavily crowded residential areas, due to their emission of large amounts of criteria pollutants; particulate matter PM, hydrocarbons HC, nitrogen oxides NOx, and carbon monoxide CO, that had led to numerous health and economic negative impacts (Lee, 2010). Many researchers had studied the possibilities of using natural resources for the control of these gaseous emissions in order to meet the permissible exposure limits that were stipulated by many relevant agencies such as those in Table 1. Myrtle tree had proved significant control performance against the gaseous emissions of small power generators, where about 82% and 73% of the emitted CO and NO_2 gases were absorbed by its leaves respectively (AlMaliky, 2010) and comparative to these results were reported by Kapoor, Bamniay and Kapoor (2012).

The goal of this paper was to test the ability of two types of subsurface soils to serve as a filtration media for the contaminated air streams such as those originated from internal combustion engines.

2. Experimental setup

Gasoline 2KV power generator was used as the gas pollutants’ source for this study that was lasted for four weeks in two hours daily operation, during which the exhaust hose of the generator was attached to an extra one to be buried at each of four different subsurface depths during each of the operation sets. A pressure vessel was used as an intermediate passage for the gaseous stream between the generator and the subsurface injection location, as shown in figure 1. At each depth, the hose was ended by a 20cmx20cmx30cm tunnel in order to allow for gases to diffuse without affecting the back pressure of the generator and to avoid blockage by incidentally falling soil. Two types of natural soil; sandy and clay soils, were used in order to test their filtration performance. The concentrations of CO, and NO_2 were measured via TG-501 gas analyzer 10 cm above ground at horizontal distances of 30cm, 60cm and 100cm from the end of the subsurface tunnel, after two hours of operation. These results were to be compensated with the values in the absence of the pollution source; the generator, in order to determine the actual effectiveness of subsurface burial as a pollution control measure. Moreover, Soil porosity was measured at each burial depth to investigate its role in governing the pollution control process. The saturation method was followed in order to determine the soil porosity at various depths for the two soils under study (Vojko Matko, 2003). This method was based on the determination of total volume of soil sample and the water volume required to pour into that sample until it reaches saturation status. The porosity was calculated according to the formula:

$$Porosity = \frac{Water\ volume}{Totalvolume} \qquad (1)$$

The average surface gas concentration results were statically handled by two way ANOVA via Minitab16 software in order to investigate the significance of each of the two factors; subsurface injection depth and the surface measurement horizontal distance, on the surface gas concentration (response) in addition to any possible differences.

2.1 Machine backpressure

A pressure gauge with a zero to 100 kPa scale was utilized to measure exhaust backpressure. A small hole was drilled into the exhaust pipe just ahead of the converter and a fitting for the pressure gauge was attached. This hole was to be plugged afterwards with a self-tapping screw or a small spot weld. In-line pressure vacuum relief valve Model 2300 .A, was attached to the pressure vessel in order to set it to activate at the required generator`s backpressure.

3. Results and Discussions

The pressure relief valve was set to activate at 1.3 psi that was measured as the backpressure limit, in order to avoid negative effects on the power generator during the study period.

3.1 statistical analysis

The results of two way ANOVA test have demonstrated high significance of subsurface injection depth and measurement horizontal distance away from the pollution source as factors impacting the surface gas concentrations at measurement location at 95% confidence interval, as tabulated in Table 2 for the sandy soil and table 3 for clay soil that showed so low probabilities (P) as compared with 0.05 significance level, for all variables (factors) in both soil types and this might be interpreted as that the responses (surface gas concentrations) were not occurred by chance . Detailed statistical analysis were graphically demonstrated by figures 2 and 3 for sandy soil and figures 4 and 5 for clay soil.

3.2 subsurface pollution control

Deeper Injection of gaseous pollutants has proved more effectiveness in the protection of surface environment, as illustrated by figure 6 - figure 9 that showed lower surface CO and NO_2 concentration as the subsurface injection level was raised from 20 cm to 40 cm and then to 60 cm, at which zero surface concentrations were achieved at detection points 100 cm away from the pollution source (generator). The injection setup has failed at the depth of 80 cm, at which, the pressure vacuum relief valve has activated as a result of the failure of subsurface soil in dispersing the gaseous stream in an efficient manner without affecting the generator`s back pressure, and this might be attributed to the increased compactness of soil under that depth that was reflected by the significant reduced soil porosity as compared to its values at lower depths that were tabulated in Table 4 , hence that depth has not been accounted for the purpose of this study. Clay soil has demonstrated better dispersion performance than the sandy soil for both gases at the same subsurface injection depths. In average the surface NO_2 concentrations were around 55% less with the clay soil as compared to the sandy soil (figures 7 and

9), and that percentage was around 36% for CO gas (figures 6 and 8). These results might be attributed to the water content of clay soil that act as absorption media and hence increase the ability of soil. That indication was more obvious by the result of having about 85% reduction in surface CO gas concentration at 30 cm horizontal distance measurement point with the injection depth of 60 cm as compared to that with 20 cm injection depth. Another indication from these figures was that, according to the records of 60 cm horizontal distance measurement point, about 70% of CO gas was dispersed into the clay soil at subsurface injection depth of 40 cm, while about 43% of that gas was dispersed into the sandy soil at the same depth, and these percentages were about 62% and 51% respectively for the dispersion of NO_2.

4. Conclusion

Much of natural resources are yet to be investigated in order to remediate the environment against deteriorations due to various pollution types. Subsurface injection of gaseous emissions of stationary internal combustion engines at each of four different depths was studied for two types of soils in Baghdad city in order to examine their performance as gas filtration media that would be reflected on the surface records of three gas analyzers that were located at different horizontal locations in order to measure CO and NO_2 gas concentrations away from the pollution source. Two way ANOVA tests have suggested strong dependence of surface gas concentrations on the horizontal (surface) and vertical (subsurface) distances from the pollution source. Clay soil has proved higher filtration performance for the both gases as compared to the sandy soil. The tests had demonstrated that the majority of the two gases was filtrated from the gas stream at the depth of 60 cm for both soils under study, while the experimental setup had failed at the 80 cm depth due to the inability of both soils to disperse the gas stream effectively without affecting the pressure gas relief valve that was set to activate prior to the reach of the machine (pollution source) backpressure.

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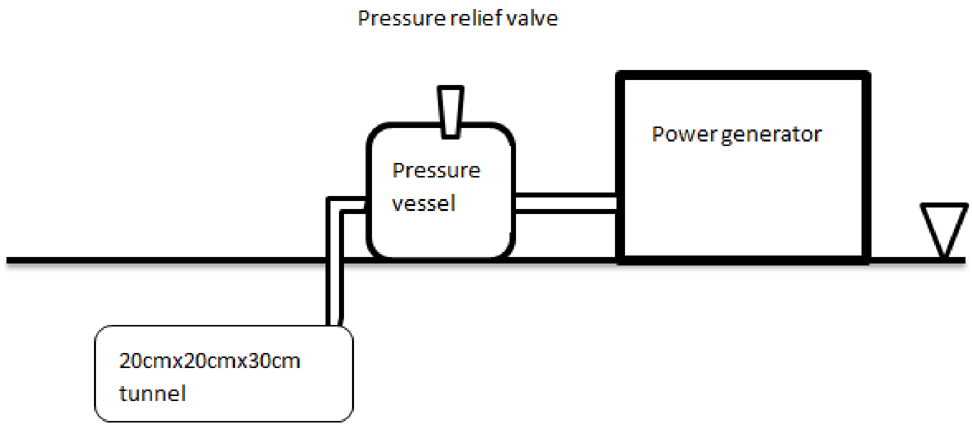

Figure 1 Experimental setup for subsurface gas injection tests

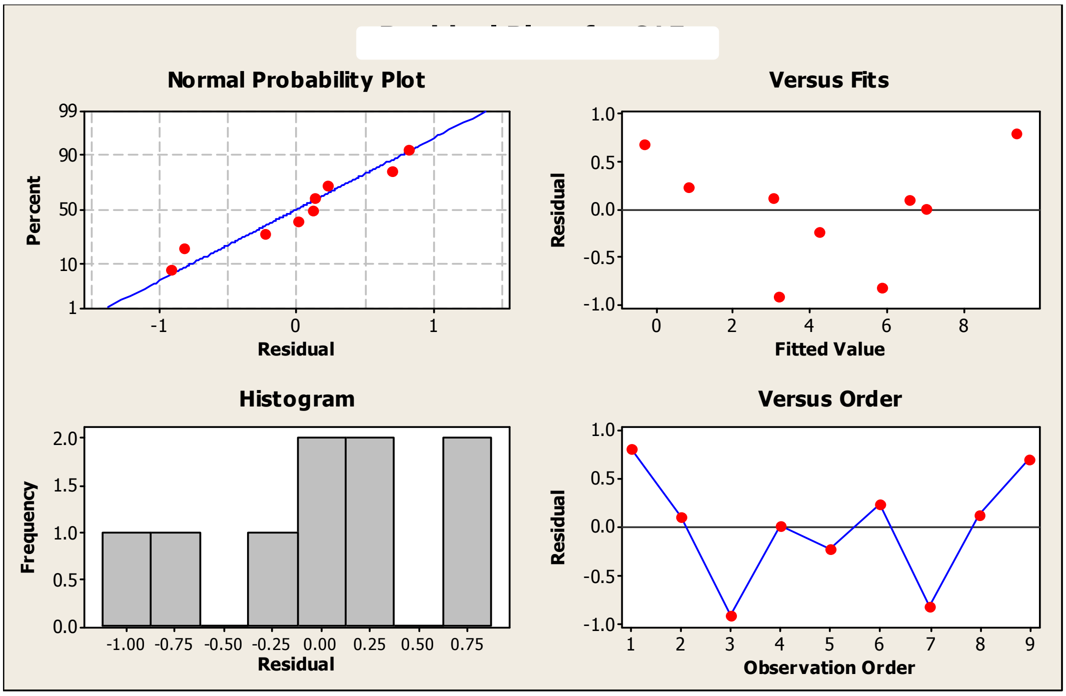

Figure 2. Residual plots for surface CO gas concentration due to subsurface gas injection into sandy soil

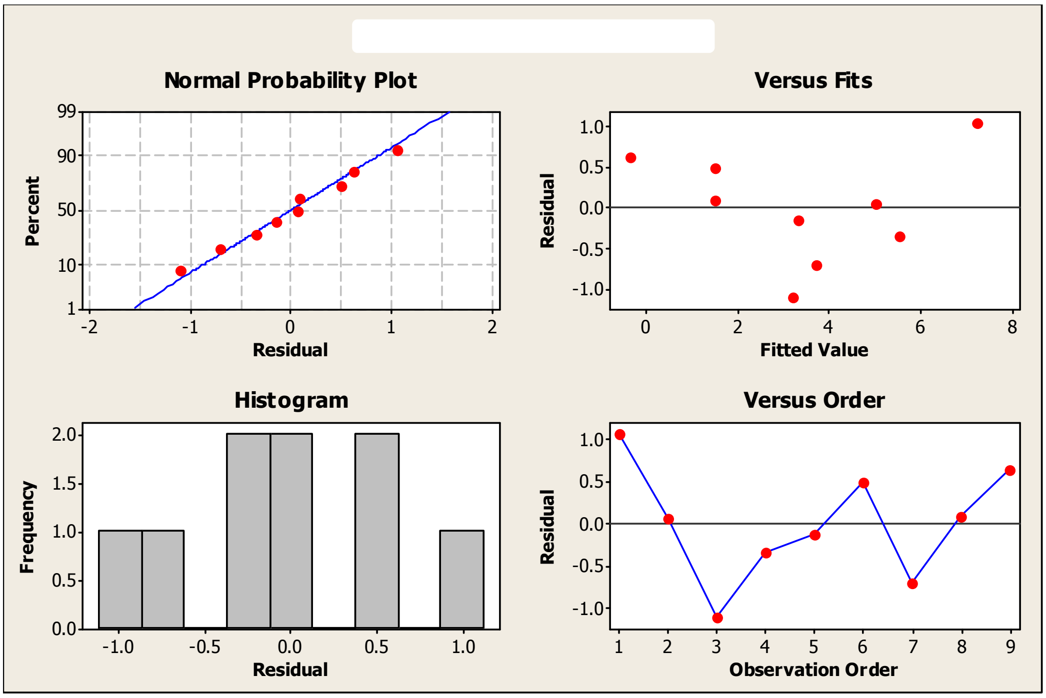

Figure 3. Residual plots for surface NO_2 gas concentration due to subsurface gas injection into sandy

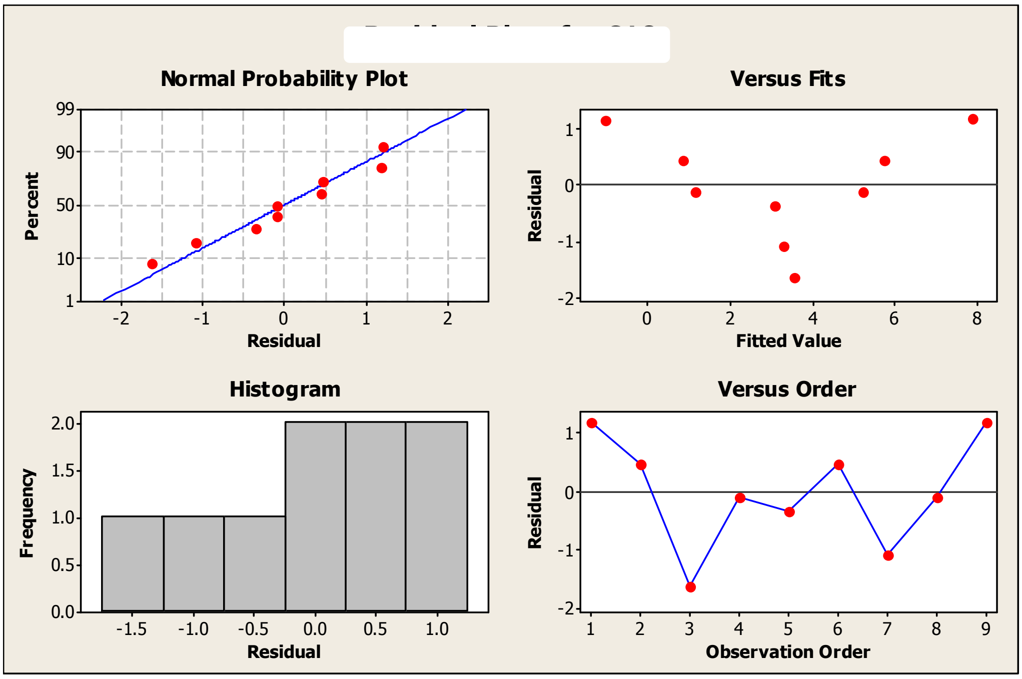

Figure 4. Residual plots for surface CO gas concentration due to subsurface gas injection into clay soil

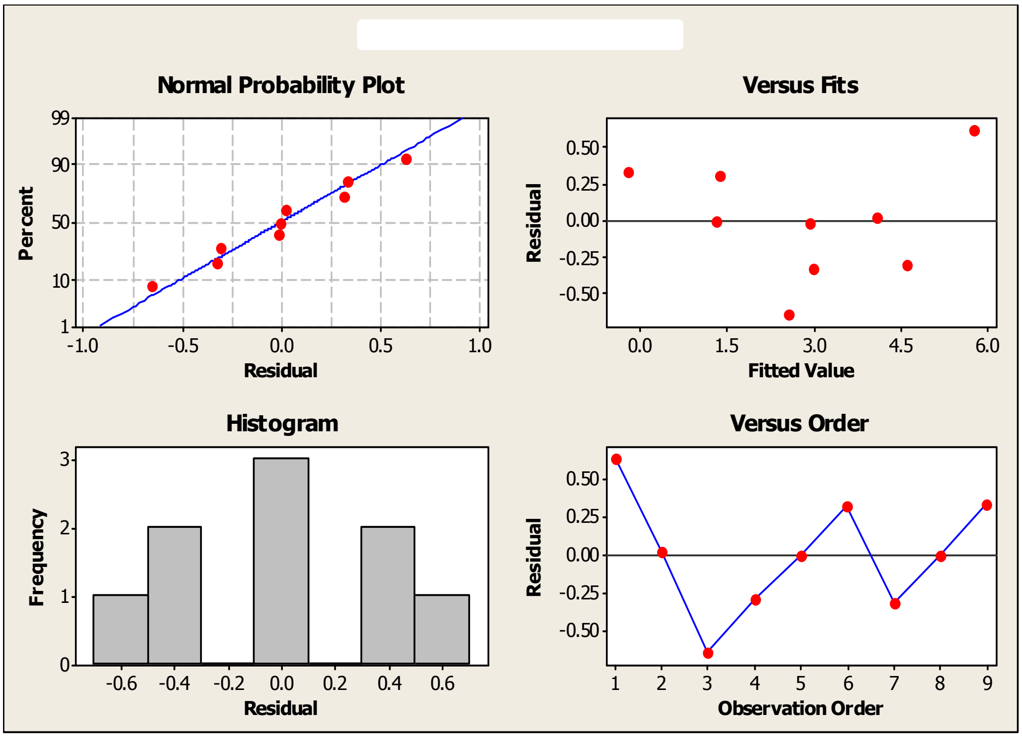

Figure 5. Residual plots for surface NO_2 gas concentration due to subsurface gas injection into clay soil

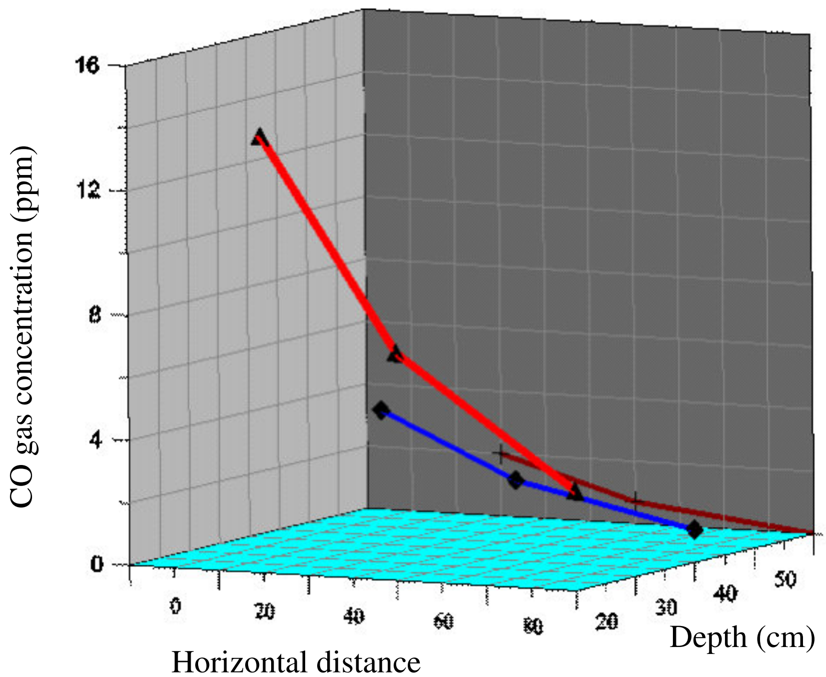

Figure 6. CO surface concentration due to various subsurface injection settings of gaseous pollutants at sandy soil

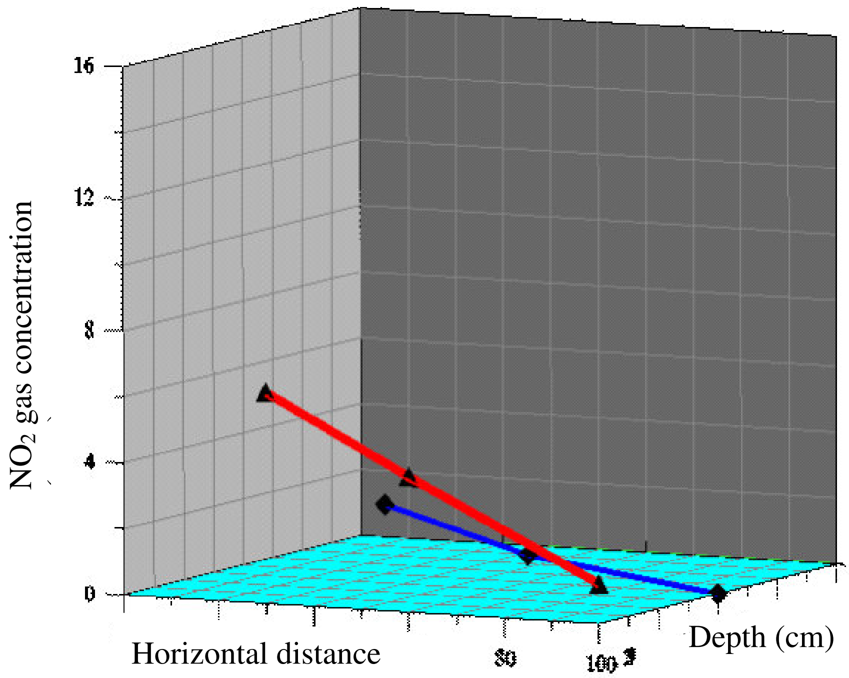

Figure 7. NO_2 surface concentration due to various subsurface injection settings of gaseous pollutants at sandy soil

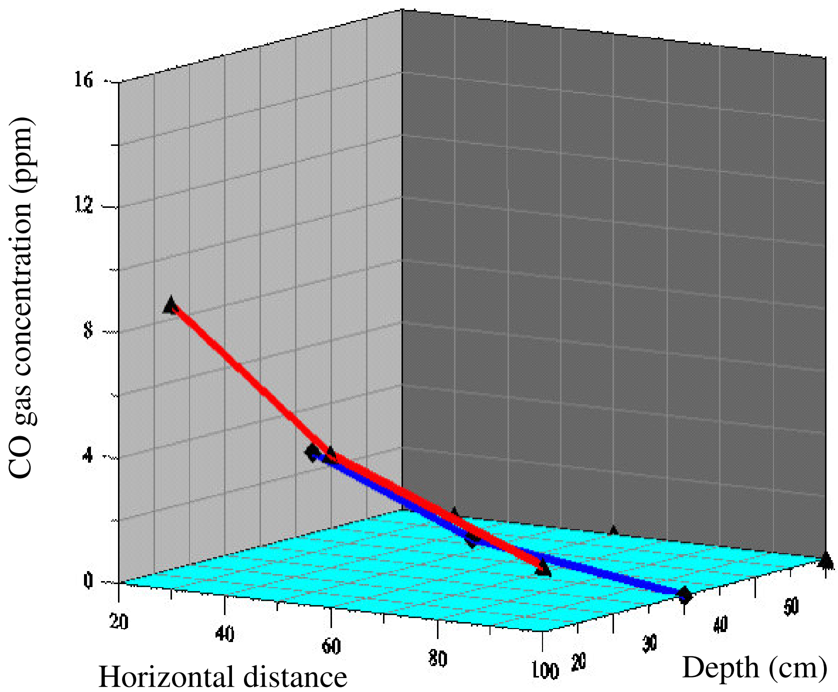

Figure 8. CO surface concentration due to various subsurface injection settings of gaseous pollutants at clay soil

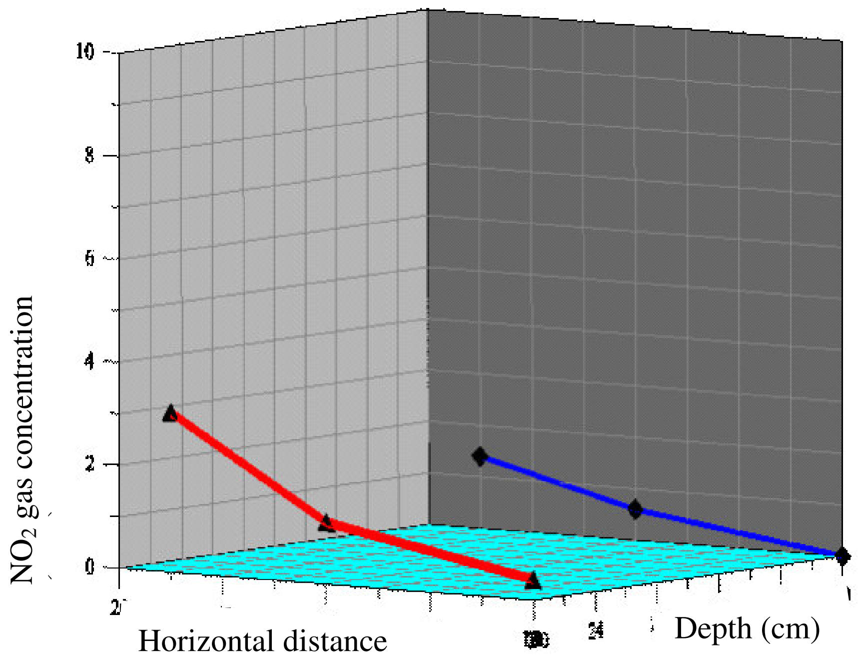

Figure 9. NO_2 surface concentration due to various subsurface injection settings of gaseous pollutants at clay soil

Table 1. Exposure Limits for Gaseous Pollutants [ppmv/8 hr] (United States Occupational Health Regulations, 2007)

Substance	OSHA PEL	OSHA 88*	MSHA TLV	ACGIH TLV
CO	50	35	50	25
CO_2	5000	5000	5000	5000
NO	25	25	25	25
NO_2	(C) 5	1^d	5	3

* - not legal limits (PELs adopted in 1988 were later remanded by court)
d - 15-minute short term exposure limit (STEL)
(C) - Ceiling value

Table 2. Statistical results of the two way ANOVA for the sandy soil.

Factors	CO		NO_2	
	F-test	Probability	F-test	Probability
Subsurface injection depth	13.68	0.016	10.32	0.026
Horizontal distance	40.47	0.002	13.48	0.017

Table 3. Statistical results of the two way ANOVA for the clay soil.

Factors	CO		NO_2	
	F-test	Probability	F-test	Probability
Subsurface injection depth	8.89	0.034	18.93	0.009
Horizontal distance	7.86	0.041	25.33	0.005

Table 4. Subsurface soil porosities of the soils under study

Depth (cm)	Porosity	
	Clay soil	Sandy soil
20	0.60	0.44
40	0.54	0.40
60	0.48	0.38
80	0.31	0.24

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