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≪ Research Paper ≫

Treatment Cost Comparison and Development of Sustainability Indices for Microwave Soil Remediation of TPHs(Total Petroleum Hydrocarbons)

Dong Uk Kim · Ja-Kong Koo*
Department of Renewable Energy Engineering, Jungwon University

ABSTRACT

The three processes of 1) high- & low-temperature microwave heatings, 2) the soil washing, and 3) the thermal desorption processes in soil remediation are analysed on the treatment cost data for 2003-2012 years. The cost of microwave heating method with at temperature 500-700°C, for 30 minutes, and at 4-6 kW is approximately 10 $/ton (13,000 ₩) due to the deep through heating of micro-wave, the soil washing with chemicals is about 80 $/ton (85,000 ₩) due to the chemicals & duration, and the thermal desorption process is around 40 $/ton (41,000 ₩) from the less efficiency. Furthermore the sustainability has been assessed, and suggestions are made. 1) Green; the minimal environmental footprint, 2) Growth; the least cost, 3) Shared; the social & environmental justice, 4) Smart; the microwave characteristics of deep through irradiation & heating, and 5) Mutuality; the flexibility of the technology. More additives including water, the government support, and public relation are suggested realizing the microwave in this condition is not harmful to human beings.

Key words : Microwave heatings, Soil washing, Thermal desorption, SSaM-GG (Smart, Shared, and Mutual - Green Growth), Sustainability middle indices

1. Introduction

The industrialization inevitably causes the soil contamination. Soil and groundwater contaminations are proceeding very slowly, difficult to recognize the damage ranges, the remediation cost is high, and usually takes much longer duration. Purification business is characterized by the diversity and complexity of the contamination, and a variety of expertises are being utilized to the comprehensive Engineering System (Back, 2012).

In Korea from January 1996 the Soil Preservation Act were able to force the restoration of the clean state. Also in Japan, the revised Water Pollution Prevention Act proclaimed at later part in 1996, it was stated that the duty to cleanse is for polluters (Kim, 2010; Gwak, 2006).

To purify the 1 ton contaminated soil, a civil engineering technology is usually adopted with 50 to 500 U.S. dollars to handle, and if you are using special techniques it costs more than $ 1,000s.

The chemicals and labor force costs or a number of technologies are developed, attempted, and analysed. Among several soil remediation methods, the most efficient and economical method is turned out as the microwave-assisted method (Kim, 2010).

In this paper, three categories of technology are compared and conducted an economic assessment: (1) microwave-assisted soil remediation centered on TPHs, (2) soil washing, and (3) conventional thermal desorption. Furthermore the sustainability has been assessed, and suggestions are made with middle indices as in Fig. 5. And the quantifiable characteristics of the economic aspect, this is keenly analysed in this paper.

2. Methods and Microwave Heating

The principles and field practices are reviewed shortly for the easy understanding.

High-frequency microwave radiation as classified according to the electromagnetic frequency: (1) 30-300 kHz, long wave, (2) 300-3000 kHz, medium wave, (3) 3,000 MHz

*Corresponding author : Koo@jwu.ac.kr
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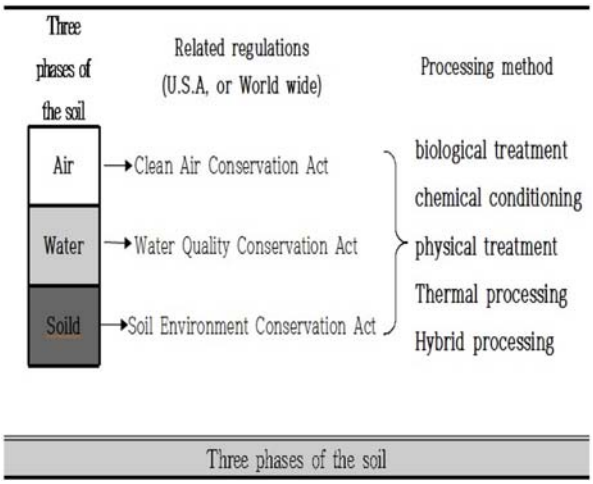

Fig. 1. Three-phase of the soil and treatment method category (source: Back. J.G, 2012).

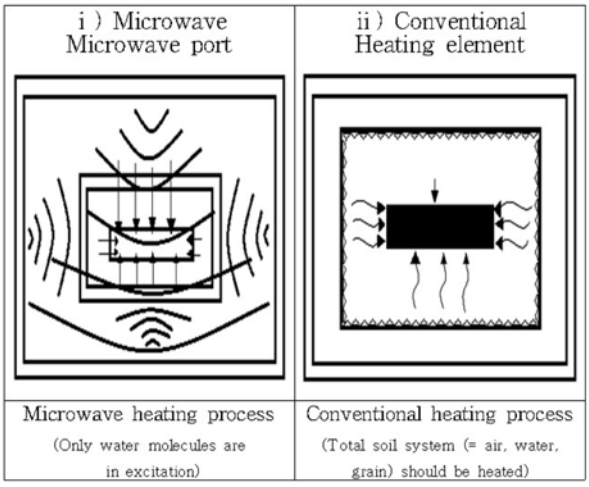

Fig. 2. The difference between i) microwave and ii) conventional heating.

(3GHz)-30 GHz, centimeterwave, (4) 30-300 GHz, submilimeterwave, and (5) 300 GHz or more as the meterwave.

This is one of the 300 MHz-30 GHz microwave electromagnetic waves up to the shorter-wavelength light, which has a wave-like properties, and have a nature of straight speed, reflex, and absorption. Therefore, the communication industry is widely used, but to avoid the duplication of frequencies for the household or industrial microwave heating where 12.2 cm (2.54 GHz) or 33.3 cm (900 MHz) are being used (Back, 2012).

As shown in Fig. 2, the General Electric resistance heating method heats by conduction, convection, & radiation, but the microwave heating the substance itself is heated by the heat generated from the activation of water molecule. So the energy loss is almost gone, and heating in a very short time. Also the uniformity of heating, and the thermal efficiency is high (Back, 2012).

In addition, the advantages of microwave are; (1) heat-drying efficiency of five times faster than conventional methods, (2) energy usage of 30%-50% of the existing method due to selective heating is possible, (3) it is convenient to control, and simple by the manipulation criteria. There are several processing types for automatic control; on the touch panel, or manually. The time and temperature can be adjusted freely to the quality level of production, and (4) environmental-friendly, and reduces the column volume. Microwave heating reduces the noises or the exhaust gases (soot), fuel waste of traditional method, and the other waste does not occur at all (Kim, 2010).

3. Case Studies, Results and Discussion

Contaminated soils used in this study were from the automobile dismantling site contaminated with high concentrations of lubricating or engine oils with C18-50 or more. Samples were collected at the junk yard in city B for the water content and oil concentrations analyses.

Samples were dried at 105~110ºC for 4 hours, and analyzed. For oil component analysis using the gas chromatography of the Agilent 7890 GC with FID detector as in Table 1. Moisture of the samples used in this study was shown to be 9.5%, and TPHs appeared to 12,088 mg/kg (Ha and You, 2012).

Previous research showed the result of microwave soil remediation. TPHs incoming concentrations is 12,088 mg/kg, which used 4-6 kW for 500ºC-700ºC heating. As shown

Table 1. Characteristic of soils used in this study

Moisture concents (%)	Solid content (%)	TPH concentration (mg/kg)	
9.5	90.5	Rubricating oil, & Fuel oil 12,088	Diesel, & Gasoline 35,318

(source: Ha S.A., You M.Y., 2012)

in Table 2. TPHs removal was more than 85% for 30 minute, and the treatment costs was about 12 $/ton (13,000 ₩). This research was run in the laboratory that is a unit price of a laboratory scale (Ha and You, 2012; Yeom, 2008).

Other Research (Park et al., 2003), used the soil washing method. Soil washing machines from 8 October 2002 November 2002 was operated approximately for 14-32 days, at an average of approximately 12 ton/hr, 5.5 hours for a daily average being received around 65.7 tons of throughput.

Analysis of the types of soil washing, washing of contaminated soil with the oversize fraction of 3/8 inch or more, the coarse fraction of the 8 inch-3/100 mesh, and the fine fraction less than 100 mesh. The wash water where two fractions of the coarse and the fine in the mixture was continuously monitoring. The average concentration of the soil TPHs before washing showed the 4,500 mg/kg, and after washing was an average 460 mg/kg, thus the efficiency was approximately 90.47%. Soil washing device design, machine production costs, and the treatment cost was about 80 $/ton (85,000 ₩). This research was performed on the field (Park et al., 2003).

Another Research (Yeom, 2008) resulted in total cost of electricity, and column at 300°C was about 38 $/ton (41,000 ₩), 500°C 89 $/ton (96,000 ₩), and 700°C 176 $/ton (190,000 ₩). This research was run in the laboratory and result of the microwave preconditioning to reduce the water content of thermal desorption method (Yeom, 2008).

As from the results above, the microwave using the processing power of 6kW for 700°C device temperature, and for 30 minutes turns out to be the most economical. As shown in Table 3.

Though the result are from 2003 to 2012 years, the rough significant digits are adopted for the reasonable cost comparison.

Table 2. The analytical conditions of TPHs by Gas Chromatography

Conditions	Value
Oven temp. (°C)	50
Initial temp (°C)	450
Detector temp. (°C)	320
Rate (°C/min)	10
Flow rate (ml/min)	1~2
Injection volume	2 μl
Split ratio	20 : 1

(source: Ha S.A., You M.Y., 2012)

4. Development of the Sustainability Indices, & Suggestion

SSaM-GG (Shared, Smart, and Mutual- Green Growth) for the microwave heating remediation is evaluated.

By the 2012 after the long (more than 10 years) study, the 5-axis green (so called "Green Star") was developed as in Fig. 3 in addition to TBLs (Triple Bottom Lines) that is 1)

Fig. 3. SSaM-GG Green Star, original (source: Koo et al., 2014).

Table 3. Comparison of microwave heating, soil washing, and thermal desorption (2003-2012)

3 Processes (@Ref.)	Microwave power	Temperature	Total cost ($/ton)
Microwave heating element (Ha et al., 2012), (Kim., 2010)	4 kW	300°C	17.60
		500°C	11.10
		700°C	10.20
	6 kW	500°C	13.00
		700°C	12.10
Soil washing (Park et al., 2003)	–	–	78.80
Thermal desorption (Yeom., 2008)	4 kW	300°C	38.00
	4 kW	500°C	88.00

environmental preservation, 2) economic growth, and 3) social development, to axes are added with 4) Science, technology, & art, 5) Mutuality due to the Trade-Offs among 1), 2), & 3). The SSaM-GG or GG-SSaM for the global use, and the Chinese word ("永續 發展") for the persistent development or sustainable development has been suggested (Koo et al., 2014; Koo, 2012; Koo, 2008; Koo et al., 2012).

The SSaM-GG are researched for the evaluation on microwaves remedation:

1. Shared; The social justice can be promoted by the environment-friendly equity for the reductions of the exhaust gases (soot), fuel & other wastes volumes, noises or opening levels, and the schedule also. The government support and the public relation or investor relation are required.
2. Smart (Science, Tech. & Art); Simultaneous heatings with the outside or hollow tube are possible. Takes a short time because the wave's penetration. In addition, it is possible seal and vacuum heating facility, too. Adoption of more additives including water at various field conditions is suggested.

And,

3. Mutual (=Voluntary); Production automation and control is simply fabricated, thus it's convenient, and is quicker. Several automatic control programs on the touch panel or on computer, or by manual control are possible thus adjusted freely to the quality of the producted soil. Education for citizen that the microwave in this condition is not harmful to human being is necessary.
4. Green: Due to the low temperature sterilization, the soil nutritions can be preserved whenever possible. Therefore, compared to the conventional thermal-desorption method, the shorter-time sterilization can be

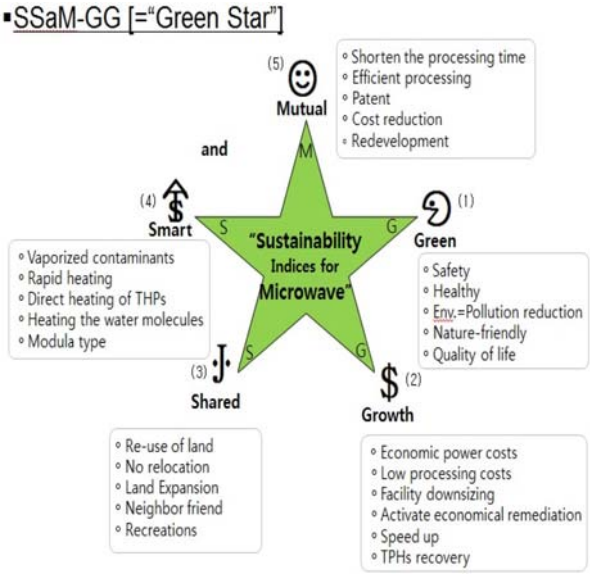

Fig. 4. SSaM-GG Green Star for Microwave Soil Remediation.

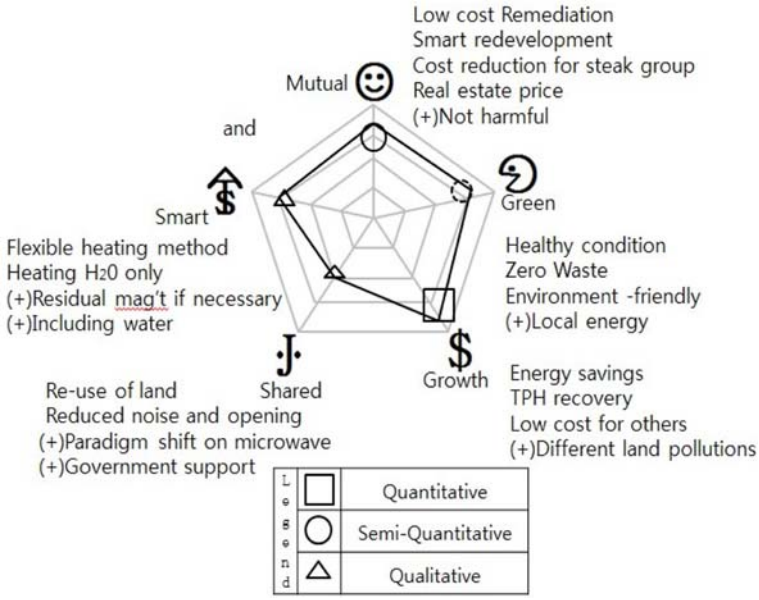

Fig. 5. Suggestion (+) and assesment for microwave industry.

done. Safe food nutritions are not lost or destroyed. Safety, Health, Environment, Nature friendliness, and the Quality of life can be enhanced. The use of local energy seems to be necessary if possible.

5. Growth (Economic): Energy saving is more than 30 to 50% by the unnecessary energy consumption for the heating system chamber thus result in the cost savings. Thus the related shadow prices can be used in other necessary demand. Also the diverse combination of technology is suggested at different land pollutions.

In this way, by taking advantage of better energy efficiency, the construction of the Korea with energy independence, energy stability & security can be possible, and the country may be more livable as in Fig. 4 evaluation.

5. Conclusions

1) the high- & low-temperature microwave heating, 2) the soil washing, and 3) the thermal desorption processes in soil remediation are analysed on the treatment cost data for 2003-2012 years. The cost of microwave heating method with at 500-700ºC, for 30 minutes, and at 4-6 kW is approximately 12 $/ton (13,000 ₩), soil washing about 79 $/ton (85,000 ₩), and thermal desorption around 38 $/ton (41,000 ₩). By the deep through heating of micro-wave, the chemicals & duration, and better efficiency of the thermal desorption are the major reasons. Furthermore the sustainability has been assessed as in Fig. 5 and suggestions are also made with realizing that microwave irradiation is not harmful to human beings.

References

Back, J.G., 2012, Studies on the Oxidation and Desorption Reaction in Used Oil Contaminated Soil Remediation Microwave, Daegu Univ, 96 p.

Gwak, M.Y., 2006, Soil Remediation Industrial Revitalization, *J. Soil Groundw. Environ*., Autumn Proceding, 1-5.

Ha, S.A. and You, M.Y., 2012. A study on treatment of a contaminated soil by oil using continuous system of high temperature heating element and microwave, *J. Soil Groundw. Environ*., **17**(1), 8-12.

Park, I.S., Jo, J.S., Kwon, O.S., Kim, Y.O., and Kim, S.H., 2003, Petroleum Contaminated Soil Remediation through Application of Soil Washing Process, Autumn Proceding, 148-151.

Kim, D.K., 2010, The Study on Oil Contaminated Soil Dispose Using Purification System for Continuous Microwave and High Temperature Heating Element, Silla Univ, 80 p.

Koo, J.-K., 2012, Korea's Green Independency Hurray, Hurray!, 2008, Korea Solid Wastes Engineering Society, 25-year History, 212-214.

Koo, J.-K., 2008, Low-carbon Green Growth of GS Construction Co., Korea Organic Resource Recycling Association, Autumn Conference 33-44.

Koo, J.-K., Park S.R., and Lee S.K., 2012, Five indices of SSaM-GG (=Smart, Shared, and Mutual - Green Growth) for sustainable development, Korea Organic Resource Recycling Association, **20**(4), 127-133.

Koo, J.-K. and An, H.W., 2014, Proposition of green star for the practice of Rio+20, and application of four rivers project, 2014, Korea Organic Resource Recycling Association, **22**(1), 35-39.

Yeom, H.K., 2008, Microwave and Low Temperature Thermal Desorption Process Research Association for Oil Pollution Restored, Silla Univ, 124 p.