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論文題目	Waste management options associated with greenhouse gas emissions reduction and dioxins control （温室効果ガス排出とダイオキシン制御を考慮した廃棄物管理に関する研究）		

（論文内容の要旨）

The main objective of this thesis was to investigate waste management options considering sensitivity and uncertainty analysis of parameters which effect GHG emissions and behaviour of dioxins. The specific objectives were as follows: 1) To measure waste generation rate, and composition in Surabaya, Indonesia, 2) To estimate PCDD/Fs emission factor to residue in open burning.and to discuss control measures, 3) To quantify GHG emissions from waste management employed with applicable options and to discuss management options.

1) Waste generation rate and composition in Surabaya, Indonesia

Waste survey was carried out at the source of generation in Surabaya, Indonesia. The average waste generation rate was slightly different among income groups, amounting 0.30 kg/capita/day for high income group, and 0.33 kg/capita/day for middle income group and 0.25 kg/capita/day for low income group. Food waste was the predominant fraction, ranging from 54-67%, which the largest fraction measured from the high income group, followed by the middle income group. Plastic was the second largest fraction, followed by paper, ranging from 12-20% and 8.9-9.6%, respectively.

2) Open burning of waste and dioxins emission

Two open dumping sites with different management practices were investigated; particularly soil layering on top of the open dumping site in Surabaya, and the other without soil layering in Palembang. PCDD/Fs in soils of the open dumping site in Palembang ranged from 61-310 pg-TEQ/g, and 6.3-32 pg-TEQ/g for DL-PCBs. In contrast, very low PCDD/Fs and DL-PCBs were measured at the open dumping site in Surabaya, ranging from 0.075-0.098 pg-TEQ/g, and 0.00032-0.095 pg-TEQ/g, respectively. PCDD/Fs emissions factors to the residue from open burning of waste were analysed and simulated by mass balance model. The ratios of waste burned at an open dumping site were adjusted based on classification of disposal sites considering methane correction factors, ranging from 0-72% of waste burned. Through sensitivity analysis, the maximum PCDD/Fs emissions factors to the residue could be 5600 pg-TEQ/g. PCDD/Fs can be controlled by improving design of the solid waste disposal sites. For example, transforming the unmanaged-deep disposal site to the semi-aerobic landfill could reduce emission factor of PCDD/Fs to the residue from 5600 pg-TEQ/g to 390 pg-TEQ/g. 3) Waste management options and greenhouse gas emissions

A simplified life-cycle assessment was conducted to estimate greenhouse gas (GHG) emissions and energy production from each component of biogenic waste treated in an open dumping site, composting, anaerobic digestion, and incineration employed with additional options. We found that open dumping site was the largest GHG emissions source for treating the components of the biogenic waste. For example, net GHG emissions from treatment of food waste by open dumping could range from 0.30-3.67 Gg CO_2 eq/Gg. In contrast, net GHG emissions from anaerobic digestion (biogasification) was the lowest, ranging from □ 0.72-0.10 Gg CO_2 eq/Gg, followed by incineration, and compositing, ranging from 0.10-0.26 Gg CO_2 eq/Gg, and 0.15-1.05 Gg CO_2 eq/Gg, respectively. Our results also revealed that the moisture content

of food waste and the biomass-derived carbon and methane concentration of the landfill gas of biogenic waste subjected to open dumping are the most sensitive parameters across all the treatment methods because they have a significant effect on the amount of GHG emissions. Waste management employed with applicable options could potentially reduce more GHG emissions. Such applicable options at the open dumping site included soil layering, gas collection system, energy recovery, and semi-aerobic system. Transforming the open dumping site into semi aerobic system was the most effective option, which could reduce GHG emissions up to 57% (1.16 Gg CO_2 eq/Gg) from the treatment of only food waste. The other applicable options such as soil layering, gas collection system, and energy recovery could reduce GHG emissions by 10% (0.20 Gg CO_2 eq/Gg), 28% (0.57 Gg CO_2 eq/Gg), and 31% (0.63 Gg CO_2 eq/Gg), respectively.

4) Conclusions and recommendations

Waste management with applicable options could greatly prevent the formation of dioxins, and reduce GHG emissions from considerable amount of waste treated. It is desirable to use semi-aerobic landfill and/ or to adopt biogasification system rather than open dumping. Biogasification system was the most effective waste management option associated with GHG emissions reduction, indicated by the lowest net GHG emissions, ranging from □ 0.72-0.10 Gg CO_2 eq/Gg. Semi aerobic landfill site could be the most attractive applicable option because of reducing GHG emissions up to 57%, and emission factors of PCDD/Fs to the residue over 90%. When biogas either produced from semi aerobic landfill or biogasification is used to generate electricity by gas engine, PCDD/Fs could also release to the air. We estimated net electricity consumption from semi-aerobic landfill, amounting 4400 GJ/Gg, and 2100 GJ/Gg from biogasification, with gas engine efficiency of 37%. By subtracting net energy consumption (2300 GJ/Gg), and considering mix energy generation in Indonesia in 2009 (using 49.5% coal, and 19.2% oil), and emission factor of PCDD/Fs to air from coal-fired power plant (10 µg-TEQ/TJ), and that from heavy fuell power plant (2.5 µg-TEQ/TJ), additional PCDD/F emissions released from the semi aerobic landfill could be 12.17 ug-TEQ.

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（論文審査の結果の要旨）

本論文は、インドネシアの廃棄物組成や投棄埋立地におけるダイオキシン類の調査分析を行い、廃棄物管理オプションに関する温室効果ガスとダイオキシン類に関するシステム分析を行っており、得られた主たる研究成果の以下のとおりである。

１．インドネシアの Surabaya における都市ごみ組成分析から、食品ごみが 54-67%と多くを占め、プラスチック類は 12-20%、紙類は 8.9-9.6%であった。食品ごみ組成が多いことを前提とした廃棄物管理方策が必要である。

２．インドネシアの２つの廃棄物投棄サイト土壌のダイオキシン類を調査したところ、Palembang の廃棄物投棄サイト土壌のダイオキシン類濃度は、塩素化ダイオキシン類で 61-310 pg-TEQ/g、ダイオキシン様ＰＣＢで 6.3-32 pg-TEQ/g であった。一方、 Surabaya の場合は低く、塩素化ダイオキシン類で 0.075-0.098 pg-TEQ/g、ダイオキシン様ＰＣＢで 0.00032-0.095 pg-TEQ/g であった。マスバランスモデルにより、廃棄物の野外焼却に伴う残渣へのダイオキシン類排出係数を検討したところ、残渣への排出係数は最大で 5600 pg-TEQ/g になることが分かった。廃棄物処分方法による改善効果は大きく、管理のない廃棄物投棄から準好気性埋立への転換により、排出係数は 5600 pg-TEQ/g から 390 pg-TEQ/g へ低減できることが分かった。

３．生物由来廃棄物のさまざまな処理シナリオ（投棄埋立、コンポスト化、嫌気性消化、焼却）に対して、温室効果ガスやエネルギー生産を指標として、ライフサイクル分析を行った。埋立投棄によるネットの温室効果ガス排出は 0.30-3.67 Gg CO_2 eq/Gg と最も多く、嫌気性消化で □ 0.72-0.10 Gg CO_2 eq/Gg、焼却で 0.10-0.26 Gg CO_2 eq/Gg、コンポスト化で 0.15-1.05 Gg CO_2 eq/Gg であった。温室効果ガス排出に影響の大きなパラメータとしては、廃棄物の含水率、生物由来炭素、埋立ガスのメタン濃度であった。投棄埋立から準好気性埋立への改善で 57%の温室効果ガス排出の抑制となる。

以上、本論文は、食品廃棄物の多い地域の廃棄物管理について、現状の廃棄物投棄を避けて管理型埋立に転換することの重要性を示し、温室効果ガスとダイオキシン類発生の視点から嫌気性消化プロセスを活用したシステムの効果を定量的に評価し、効果に寄与する要因について明らかとしており、学術上、実際上寄与するところが少なくない。よって、本論文は博士（工学）の学位論文として価値あるものと認める。また、平成 25 年 2 月 22 日、論文内容とそれに関連した事項について試問を行って、申請者が博士後期課程学位取得基準を満たしていることを確認し、合格と認めた。