World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:13, No:12, 2019

Investigating the Thermal Characteristics of Reclaimed Solid Waste from a Landfill Site Using Thermogravimetry

S. M. Al-Salem, G.A. Leeke, H. J. Karam, R. Al-Enzi, A. T. Al-Dhafeeri, J. Wang

***Abstract*—**Thermogravimetry has been popularized as a thermal characterization technique since the 1950s. It aims at investigating the weight loss against both reaction time and temperature, whilst being able to characterize the evolved gases from the volatile components of the organic material being tested using an appropriate hyphenated analytical technique. In an effort to characterize and identify the reclaimed waste from an unsanitary landfill site, this approach was initiated. Solid waste (SW) reclaimed from an active landfill site in the State of Kuwait was collected and prepared for characterization in accordance with international protocols. The SW was segregated and its major components were identified after washing and air drying. Shredding and cryomilling was conducted on the plastic solid waste (PSW) component to yield a material that is representative for further testing and characterization. The material was subjected to five heating rates (β) with minimal repeatable weight for high accuracy thermogravimetric analysis (TGA) following the recommendation of the International Confederation for Thermal Analysis and Calorimetry (ICTAC). The TGA yielded thermograms that showed an off-set from typical behavior of commercial grade resin which was attributed to contact of material with soil and thermal/photo-degradation.

***Keywords*—**Polymer, TGA, Pollution, Landfill, Waste, Plastic.

I. Introduction

THERMOGRAVIMETRY is a popular method for studying the degradation, thermal stability, reaction kinetics and weight loss; of materials. It relies on subjecting an organic material to a given heating rate (β) under a controlled atmosphere. It can also provide a detailed analysis of the reaction kinetics under certain reaction conditions such as pyrolysis [1], [2]. It can also result in the prediction of kinetic parameters after implementing various analytical methods [3]-[5]. The ICTAC has established recommendations and guidelines to govern such practices, which were previously published in Vyazovkin et al. [6], [7]. Recent research has focused on implementing these guidelines in studying the thermal degradation and stability, in addition to degradation kinetics; of various materials [8], [9]. In this work, reclaimed SW from a landfill site that operates within the urban borders of the State of Kuwait was investigated using TGA. The thermograms of the material investigated were analyzed against common commercial resin grades. The work shows the impact of landfilling on the thermal stability of materials which can lead to determining its integrity for future upgrading and treatment in thermal recycling units.

S. M. Al-Salem is the Environmental Pollution & Climate Program Manager and the Waste Management Research Unit (WMRU) Supervisor at the Kuwait Institute for Scientific Research, P.O. Box: 24885, Safat 13109, Kuwait.

G. A. Leeke is a Full Professor of Chemical Engineering at the School of Chemical Engineering, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK.

H. J. Karam is a Research Associate at the Environmental Pollution & Climate Program of the Kuwait Institute for Scientific Research, P.O. Box: 24885, Safat 13109, Kuwait.

R. Al-Enzi is an Associate Professor at the Chemical Engineering Department, College of Technological Studies, Public Authority for Applied Education & Training, Safat 13092, Kuwait.

A. T. Al-Dhafeeri is a Principle Senior Research Technical at the Wastewater Technologies Program of the Kuwait Institute for Scientific Research, P.O. Box: 24885, Safat 13109, Kuwait.

J. Wang is a Senior Lecturer at the European Bioenergy Research Institute, Aston University, Birmingham, B4 7ET, UK.

II. Experimental

A. Site Description

The site chosen was an active landfill operating around the urban development of Kuwait City (lat. 29° 19' 33.24" N; long. 47° 36' 41.04" E). The landfill site operates under unsanitary landfilling practices without lining or segregation. The landfill processes commingled SW collected from the city boarders. Weighing is conducted by weight bridge which enters the landfill premises. The granulometric distribution of the landfill sites and level of pollutants within its soil is reported elsewhere [10].

B. Waste Reclamation and Assessment

The waste was reclaimed from the landfill pits following internationally recognized protocols governing such practices [11]. Samples were reclaimed using a spade tractor vehicle and the activities were conducted during the rainy season in Kuwait on the 13th November 2018. The SW was extracted from a singular ditch (pit) in each disposal site (1 meter in depth) where the waste was buried for six months [12]. This was done to have a consistent sample among the studied materials disposed in each landfill in the same period. Readers are referred to this research group early work for more description [12], [13]. The majority of the reclaimed material was of PSW, hence it was considered to be the material of choice for further analysis (see Figs. 1, 2).

Fig. 1 Spade Tractor at the Site Reclaiming the Material

Fig. 2 The SW Reclamation Process at Disposal Site

C. Samples Preparation and Conditioning

The reclaimed material was air blown and washed using a high pressure washer (2 bar) with a water stream to remove all suspended particles of dust. After which, waste samples were washed with tap water; and left to dry in open air for three days. The samples were stored in laboratory conditions (22-23 ^{o}C/50% relative humidity) in sealed plastic containers before conditioning. Weighing scales were used to quantify the amount of the waste reclaimed from each site. The PSW samples, which contained both rigid and film waste, were then shredded using a three V cutting knifes Vema Company shredding machine operated at 580 rpm speed, with a mesh size of 5-15 mm. The waste samples were yielded as flakes with an approximate size of 4 mm (manually measured) after three shredding cycles [12]. A Retsch Cryomill equipped with a 50 l liquid nitrogen tank (stainless steel grinding ball size = 25 mm) was used with a grinding and pre-set program as follows: Number of cycles (9), pre-cooling time and frequency (30 s and 5 Hz), cycle time (3 mins. and 25 Hz) and pre-set time (1 min and 5 Hz). Readers are referred to Al-Salem et al. [12] for more details.

D. TGA

A Mettler-Toledo TGA coupled with StarE data acquisition software was used to conduct the TGA experimental runs using a 1 ± 0.1 mg sample weight. The instrument was set to record the data every second under five heating rates (β) (i.e., 5, 10, 15, 20, and 25 ^{o}C·min^{-1}). A constant flow of pure (99.99%) dry nitrogen with a flow rate of 50 Ml.min^{-1} was maintained throughout the experiments. The experiments were conducted following the ICTAC recommendations [6], [7].

III. Results & Discussion

The experimental results from the TG and DTG graphs of the tested samples are shown in Fig. 3. The result that one major step (mass loss curve) is apparent in the beginning of the thermogram due to the volatilization in the temperature range from 230 ^{o}C to 350 ^{o}C. After which, a second step occurred in the range between 370 ^{o}C to 450 ^{o}C. Residual mass loss was detected in the temperature range 460 ^{o}C to 535 ^{o}C. Smoothening of the experimental data could reveal a more consistent graphical deception of the dataset [14]. The dataset is also a clear representation of a blend of two major polymeric blends or a high content additive polyolefinic material. Table I shows the thermal profile obtained for the samples tested in this work with respect to each heating rate.

TABLE I
Thermal Profile of the Tested Specimens

β (^{o}C min^{-1})	Onset Temperature (T_{os}, ^{o}C)	Inflection Point (T_{if}, ^{o}C)	Final Temperature (T_f, ^{o}C)
5	403.92	403.92	403.92
10	415.00	415.00	415.00
15	421.75	421.75	421.75
20	426.66	426.66	426.66
25	430.41	430.41	430.41

The thermal properties depicted in the aforementioned table also point towards samples having typical polyethylene (PE) characteristics. Rizzarelli et al. [15] showed that PE starts to decompose in TGA at a temperature around 450 ^{o}C. On the other hand, Gou et al. [16] analyzed PE using TGA and showed that the onset temperature was measured at around 400 ^{o}C. Their results are in-line with the past findings of Tuffi et al. [17]. By association and in comparison to past findings in literature, we can associate our samples tested in this work with PO polymers namely PE. The residual mass in our case is also indicative of high additive content of commercial grade plastics as previously depicted in past studies [1], [4].

IV. Conclusions

In the current work, the reclamation of municipal solid waste (MSW) from an active landfill site was conducted in an effort to determine the characteristics of its thermal profile. The determination of landfilling was also studied on the tested specimens. The following concluding remarks summarize the main findings of this research effort:

- The majority of the reclaimed waste materials was of PSW and inorganic substances. This indicates that the organic fraction deteriorates in landfill ditches over the short time span of six months, which lead the research team in this work to characterize the PSW fraction obtained.

- The thermal properties were investigated using standard thermogravimetric methods approved by the ICTAC.
- The thermal profile indicated that the materials investigated were conforming with polyolefin polymers reported in past works, and a slights shift in onset temperature was detected and attributed to the degradation of the plastics in harsh and arid environment landfill conditions.

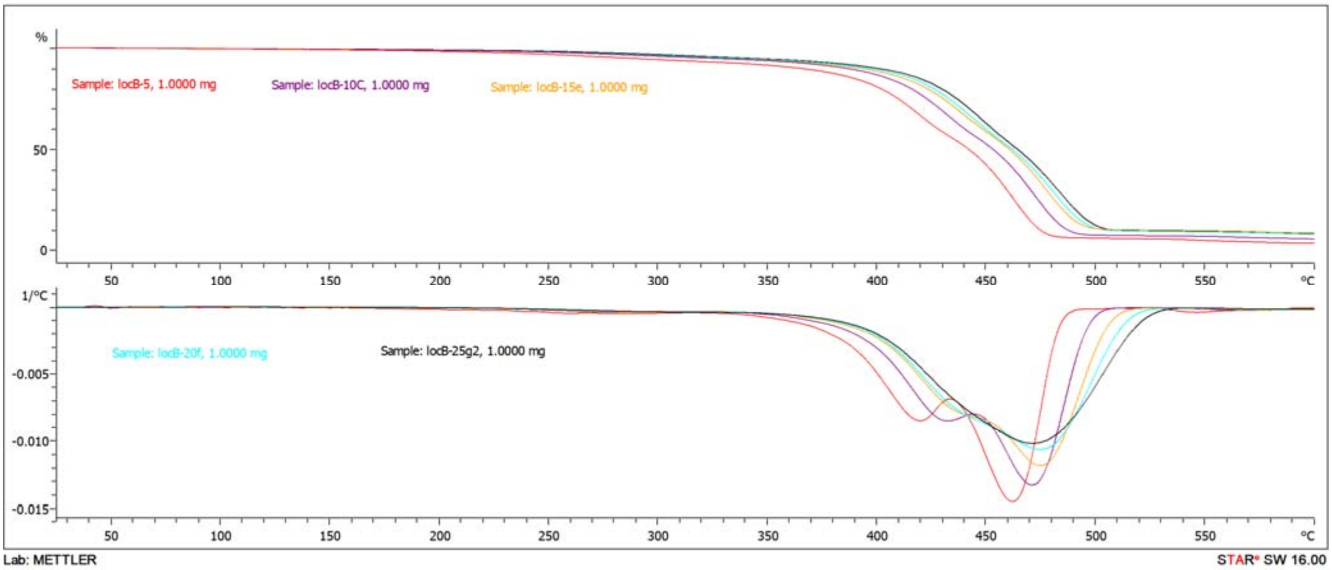

Fig. 3 TGA Result of the PSW Sample

The continuation of this work by investigating the heat flow analysis using differential scanning calorimetry and melt point determination, will confirm the findings obtained so far.

ACKNOWLEDGMENT

The authors would like to thank the Kuwait Institute for Scientific Research (KISR) and The British Council/UK-Gulf Institutional Links for funding and supporting this research project through Grant # 2793-5936-4. Kuwait Municipality (KM) staff are gratefully acknowledged for their contribution.

REFERENCES

[1] S.M. Al-Salem, A.Y. Al-Nasser, M.H. Behbehani, H.H. Sultan, H.J. Karam, M.H. Al-Wadi, A.T. Al-Dhafeeri, Z. Rasheed, M. Al-Foudaree, "Thermal Response and Degressive Reaction Study of Oxo-Biodegradable Plastic Products Exposed to Various Degradation Media" *Int. J. Polym. Sci* 2019, 9612813. DOI: 10.1155/2019/9612813.

[2] S.A. Salaudeen, S.M. Al-Salem, M. Heidari, B. Acharya, A. Dutta, "Eggshell as a Carbon Dioxide Sorbent: Kinetics of the Calcination and Carbonation Reactions" (Accepted) *Energy Fuels* DOI: 10.1021/acs.energyfuels.9b00072.

[3] S.M. Al-Salem, M.H. Behbehani, H.J. Karam, S.F. Al-Rowaih, F.M. Asiri "On the Kinetics of Degradation Reaction Determined Post Accelerated Weathering of Polyolefin Plastic Waste Blends" *Int. J. Environ. Res. Public Health* 2019, 16(3), 395; https://doi.org/10.3390/ijerph16030395.

[4] S.M. Al-Salem, A. Bumajdad, A.R. Khan, B.K. Sharma, S.R. Chandrasekaran, F.A. Al-Turki, F.H. Jassem, A.T. Al-Dhafeeri "Non-isothermal degradation kinetics of virgin linear low density polyethylene (LLDPE) and biodegradable polymer blends" *J. Polym. Polym. Res.* 2018, 25: 111. DOI: 10.1007/s10965-018-1513-7.

[5] S.M. Al-Salem, B.K. Sharma, A.R. Khan, J.C. Arnold, S.M. Alston, S.R. Chandrasekaran, A.T. Al-Dhafeeri "Thermal Degradation Kinetics of Virgin Polypropylene (PP) and PP with Starch Blends Exposed to Natural Weathering" *Ind. Eng. Chem. Res.* 2017, 56(18), 5210–5220. DOI: 10.1021/acs.iecr.7b00754.

[6] S. Vyazovkin, A.K. Burnhamb, J.M. Criadoc, L.A. Pérez-Maquedac, C. Popescud, N. Sbirrazzuolie, "ICTAC Kinetics Committee recommendations for performing kinetic computations on thermal analysis data" *Thermochim. Acta* 2011, 520, 1–19. https://doi.org/10.1016/j.tca.2011.03.034

[7] S. Vyazovkin, K. Chrissafis, M.L. Di Lorenzo, N. Koga, M. Pijolat, B. Roduit, N. Sbirrazzuoli, J.J. Suñol, "ICTAC Kinetics Committee recommendations for collecting experimental thermal analysis data for kinetic computations". *Thermochim. Acta* 2014, 590, 1–23. DOI: 10.1016/j.tca.2014.05.036

[8] F. Biryan, K. Demirelli "Thermal degradation kinetic, electrical and dielectric behavior of brush copolymer with a polystyrene backbone and polyacrylate-amide side chains/ nanographene-filled composites" *J. Moluc. Struc.* 2019, 1186, 187-203. https://doi.org/10.1016/j.molstruc.2019.03.026

[9] S.M. Al-Salem "Kinetic Studies Related to Polymer Degradation and Stability" Chapter 9 In: Plastics to Energy: Fuel, Chemicals, and Sustainability Implications, Elsevier, 1st Edition, 2019, 233-268. https://doi.org/10.1016/B978-0-12-813140-4.00009-1

[10] S.M. Al-Salem, A. Al-Nasser, A.T. Al-Dhafeeri "Multi-Variable Regression Analysis for the Solid Waste Generation in The State of Kuwait" *Process Safe. Environ. Protect*. 2018, 119; 172-180. https://doi.org/10.1016/j.psep.2018.07.017

[11] S. Mor, K. Ravindra, A. De Visscher, R.P. Dahiya, A. Chandra "Municipal solid waste characterization and its assessment for potential methane generation: A case study" *Sci. Tot. Environ.* 2006, 371: 1-10. https://doi.org/10.1016/j.scitotenv.2006.04.014

[12] S.M. Al-Salem, G.A. Leeke, R. Al-Enezi, H.H. Sultan, H.J. Karam, M.H. Al-Wadi, A.T. Al-Dhafeeri, A.A. Boota, J. Wang "Potential for Thermal and Solar Power Pyrolysis In Treating Reclaimed Real Life Solid Waste From A Landfill Disposal Site" (Accepted) In Proceedings of the 17th International Waste Management and Landfill Symposium, 30 Sept. - 4 Oct., Cagliari, Italy.

[13] S. Al-Salem, G. Leeke, J. Wang, R. Al-Enezi, H. Sultan, H. Karam, M. Al-Wadi, A. Al-Dhafeeri, A. Boota "Solar Powered Fast Pyrolysis for Producing Bio-Oils from Municipal Solid Waste in the State of Kuwait" KISR, Progress Report, Project EM103, February 2019.

[14] S.M. Al-Salem, A. R. Khan "On the degradation kinetics of

poly(ethylene terephthalate) (PET)/poly(methyl methacrylate) (PMMA) blends in dynamic thermogravimetry" *Polym. Degrad. Stab*. 2014, 104: 28-32.

[15] P. Rizzarelli, M. Rapisarda, S. Perna, E. Francesco Mirabella et al. "Determination of polyethylene in biodegradable polymer blends and in compostable carrier bags by Py-GC/MS and TGA" *J. Anal. App. Pyrolysis* 2016 117: 72-81.

[16] X. Gou, X. Zhao, S. Singh, D. Qiao "Tri-pyrolysis: A thermo-kinetic characterisation of polyethylene, cornstalk, and anthracite coal using TGA-FTIR analysis" Fuel 2019, 252: 393-402.

[17] R. Tuffi, S. D'Abramo, L.M. Cafiero, E. Trinca and S. Vecchio Ciprioti, "Thermal behavior and pyrolytic degradation kinetics of polymeric mixtures from waste packaging plastics" *eXPRESS Polym. Lett.* 2018, 12: 82–99.