Journal of Multidisciplinary Engineering
Published by DigitoPub | Digitodontics International Academy
DigitoPub
Open Access & Peer-reviewed
Indexed in: Crossref, ICI, Google Scholar

Quantification and Preliminary Thermal Treatment of Haemodialysis Tubing Waste in Western Libya

Mufida M. Adabousi[1] | Adel Banana[2]* | Abdulbasit A. Mohammad[2]

[1]Higher Institute of Marine Sciences Techniques Sabratha, Sabratha, Libya.
[2]Department of Environmental Engineering, Faculty of Engineering, Sabratha University, Sabratha, Libya.

ABSTRACT

Purpose: To quantify used haemodialysis blood tubing waste generated by six dialysis facilities in western Libya and provide preliminary evidence on its potential for controlled thermal recovery.

Materials and Methods: Patient and session data were used to estimate weekly, monthly, and annual tubing-set consumption. Waste mass was estimated using 0.460 kg per set. A single 460 g used-tubing sample underwent thermal treatment, and the condensed liquid was analyzed by gas chromatography with flame ionisation detection (GC/FID).

Results: The six facilities served approximately 798 patients and were estimated to consume 2,277 sets per week, 9,867 per month, and 118,404 per year, corresponding to 54.47 t of tubing waste annually. The thermal-treatment run produced 250 g of condensed liquid from 460 g of tubing (54.35% yield). After exclusion of the solvent peak, C12 and C13 represented 89.83% and 10.17% of the combined detected peak area, respectively.

Conclusions: The findings demonstrate a substantial and quantifiable dialysis-tubing waste stream in western Libya and provide preliminary evidence that thermal treatment warrants further investigation. Because the experiment comprised a single run using an uncharacterised polymer, the yield and chromatographic profile are provisional and cannot establish product quality or suitability for use. *(J Multidiscip Eng 2026;1:87-93)*

Keywords: Haemodialysis waste, medical plastic waste, waste quantification, thermal treatment, pyrolysis liquid.

ARTICLE INFO

*Corresponding author:
Adel Banana
Email: adel.banana@sabu.edu.ly

Received: 10-08-2026
Accepted: 03-10-2026
Published: 11-10-2026

DOI:
https://doi.org/10.26629/jme.2026.11

Copyright: © 2026 by the authors.
Articles published in the *J Multidiscip Eng* are licensed under a Creative Commons Attribution-Noncommercial 4.0 International License.
https://creativecommons.org/licenses/by-nc/4.0/

Audioabstract:

How to cite this article | Adabousi MM, Banana A, Mohammad AA. Quantification and preliminary thermal treatment of haemodialysis tubing waste in western Libya. J Multidiscip Eng. 2026;1:87-93.

1. INTRODUCTION

Health-care activities generate wastes with different levels of potential risk. The World Health Organization estimates that most health-care waste is non-hazardous, whereas the remainder may be infectious, chemical, or radioactive and therefore requires dedicated management. Inadequate management can expose health-care workers, patients, communities, and the environment to infection, injury, and pollution, while uncontrolled burning of health-care waste may release hazardous air pollutants.s[1,2] Source segregation is therefore a fundamental component of safe health-care waste management because it reduces unnecessary contamination of otherwise recoverable materials and limits the volume of waste requiring specialized treatment.[2] Haemodialysis is a resource- and consumable-intensive clinical service. Each treatment session generates a considerable amount of single-use material, including blood tubing sets, dialysers, needles, gloves, and solution containers.[3] Piccoli et al. estimated that plastic waste associated with a haemodialysis session may range from approximately 1.5 to 8 kg, depending on equipment and waste-management practices, highlighting the

environmental burden associated with dialysis care.[4] Although these materials are essential for infection control and patient safety, their single-use nature creates a continuous and relatively predictable stream of post-use plastic waste.

Plastic waste can be managed through several recovery pathways, including mechanical recycling and chemical or feedstock recycling. Among chemical recovery technologies, pyrolysis involves the thermal decomposition of polymeric materials into gaseous, liquid, and solid fractions and has attracted considerable interest as a potential route for recovering value from difficult-to-recycle plastics.[5] However, pyrolysis products from plastic waste can contain complex mixtures of hydrocarbons and other compounds, and reliable characterization generally requires analytical techniques such as gas chromatography–mass spectrometry (GC-MS) or comprehensive two-dimensional gas chromatography.[6,7] When the feedstock originates from health-care activities, additional requirements related to infection control, prior sterilization, handling, and environmental safety must also be considered.

Recent studies demonstrate that organized collection and segregation can make recovery of dialysis-related plastic waste technically feasible. Quantification of recyclable plastics from home peritoneal dialysis programs has demonstrated the importance of measuring waste generation before developing recovery strategies,[8] while a pilot program involving the recycling of polyvinyl chloride from automated peritoneal dialysis waste further demonstrated the potential for recovering value from dialysis-associated plastic waste.[9] Practical environmental guidance for dialysis facilities also recommends segregation of recyclable materials at the point of generation and improved monitoring of waste-management practices.[10]

In the Libyan context, sustainable waste-management practices are also influenced by environmental awareness, sustainable behavior, and participation in environmental initiatives. Recent evidence from Libya has highlighted the relevance of environmental literacy, sustainable behaviors, community participation, and awareness of the Sustainable Development Goals in promoting sustainable environmental practices.[11,12] In addition, recent field-based research conducted in Libyan healthcare facilities has demonstrated the value of collecting primary data directly from healthcare settings to examine locally relevant health practices and associated socioeconomic factors.[13]

Despite the growing interest in sustainable management and recovery of health-care plastics, quantitative information on specific dialysis waste streams remains limited in Libya. In particular, there is a lack of documented estimates of used haemodialysis blood tubing generation across multiple dialysis facilities in western Libya and limited preliminary evidence regarding the potential thermal conversion of this material. Establishing the magnitude of this waste stream and generating initial evidence on its thermal-treatment behavior can provide a basis for subsequent laboratory-scale studies, environmental assessment, and evaluation of potential non-medical recovery pathways.

Therefore, this study aimed to: (1) quantify the consumption and corresponding waste generation of used haemodialysis blood tubing sets across six dialysis facilities in western Libya; (2) estimate the associated annual plastic waste mass; (3) conduct a preliminary thermal-treatment experiment to determine the condensed-liquid yield and obtain an initial chromatographic profile of the liquid product; and (4) propose a controlled management and recovery pathway together with the analytical and experimental requirements needed for future investigation.

2. MATERIALS AND METHODS

2.1 Study setting and data sources

Six public health institutions providing haemodialysis in the western region of Libya were included: Zawiya Dialysis Centre, Sorman Hospital, Al-Jmail Hospital, Ajaylat Hospital, Sabratha Hospital and Regdalin Hospital. Patient numbers were obtained from unit staff (Table 1). Zawiya provided a detailed weekly session schedule; for the other five facilities only patient numbers were available, and sessions were estimated from these. Sorman's figure (170) is the upper value reported for a unit with 84 beds, and the figures for Ajaylat and Sabratha are approximate.

2.2 Quantification of tubing consumption and waste mass

Each session was assumed to consume one tubing set, since sets are single-use. Sets consumed therefore equal sessions performed. For Zawiya, weekly sessions were summed from the operating schedule (women's sessions on three days at 120 per day; men's sessions on three days at 140 per day; and intensive-care cases at an average of 9 per day over seven days). For the other facilities, weekly

sessions were calculated as S_w = P × 3, where P is the number of patients and three sessions per patient per week was assumed. Consumption was then extended as follows:

$$Lw = Sw \times 1; \quad Lm = Lw \times 52/12; \quad Ly = Lw \times 52 \quad M = L \times 0.460\ \text{kg}$$

where L_w, L_m, and L_y are weekly, mean monthly, and annual numbers of sets, respectively, and M is waste mass. The value of 0.460 kg per set was taken from the mass of the experimental sample and assumed to represent one session's tubing set.

2.3 Thermal treatment experiment

One sample of used dialysis tubing (460 g) was subjected to thermal treatment, and the vapours were condensed and collected in a graduated vessel. The mass of condensate was measured and the yield calculated as Y = (m_liquid / m_sample) × 100. The balance (m_sample − m_liquid) is reported as residue/loss, which includes solid char, non-condensable gas, and handling losses because these were not individually measured. The tubing brand and polymer type, pre-treatment and sterilisation method, washing/drying procedure, reactor type, atmosphere, final temperature, heating rate, residence time, condenser temperature, and safety controls were not specified in the supplied manuscript and must be completed before submission to satisfy the journal's reproducibility requirement.

2.4 GC/FID analysis

An aliquot of the liquid was by gas chromatography with flame ionisation detection (GC/FID). Peaks were recorded with retention times and integrated areas, and were assigned to the C12 and C13 carbon-number ranges. Percentages were calculated both on total peak area and on the combined C12 + C13 area after excluding the solvent peak. Peak-area percentages from FID are not mass fractions and were used only as a relative indicator. The supplied manuscript does not specify the instrument model, column, temperature programme, injection volume, split ratio, carrier gas, solvent identity and dilution, or the basis for carbon-number assignment; these details should be added before submission.

2.5 Proposed management pathway

Drawing on WHO and EDTNA/ERCA guidance 2,10, a sequential pathway was defined: segregation of tubing at the dialysis station in dedicated containers; sealed internal transport; daily logging of sets and weight; short controlled storage; documented sterilisation (steam, dry heat, validated chemical or dedicated medical-waste system); drying; size reduction after sterilisation; thermal treatment in a closed or semi-closed system with vapour condensation and emission control; and laboratory testing before any use of the product.

3. RESULTS AND DISCUSSION

3.1 Patient numbers and tubing consumption

The six facilities served approximately 798 patients. Estimated consumption totalled 2,277 sets per week, 9,867 sets per month and 118,404 sets per year (Table 1, Fig. 1a). Zawiya accounted for 37.02% of the total, followed by Sorman (22.40%) and Sabratha (15.15%).

Table 1: Estimated consumption of dialysis tubing sets by facility.

Facility	Patients	Sets/week	Sets/month	Sets/year	Share (%)
Zawiya	320	843	3,653	43,836	37.02
Sorman	≤170	510	2,210	26,520	22.40
Al-Jmail	53	159	689	8,268	6.98
Ajaylat	~100	300	1,300	15,600	13.18
Sabratha	~115	345	1,495	17,940	15.15
Regdalin	40	120	520	6,240	5.27
Total	~798	2,277	9,867	118,404	100

3.2 Estimated waste mass

At 0.460 kg per set, the estimated annual mass of used tubing was 54.47 t (54,465.84 kg), ranging from 2.87 t at Regdalin to 20.16 t at Zawiya (Table 2). Because mass scales linearly with the assumed set weight, each ±0.1 kg deviation in mean set mass changes the regional total by approximately ±11.8 t yr−1.

Table 2: Annual Tubing Mass and Projected Thermal-Treatment Fractions.

Facility	Tubing mass (t/yr)	Liquid product (t/yr)	Residue/loss (t/yr)
Zawiya	20.16	10.96	9.21
Sorman	12.20	6.63	5.57
Al-Jmail	3.80	2.07	1.74
Ajaylat	7.18	3.90	3.28
Sabratha	8.25	4.49	3.77
Regdalin	2.87	1.56	1.31
Total	54.47	29.60	24.86

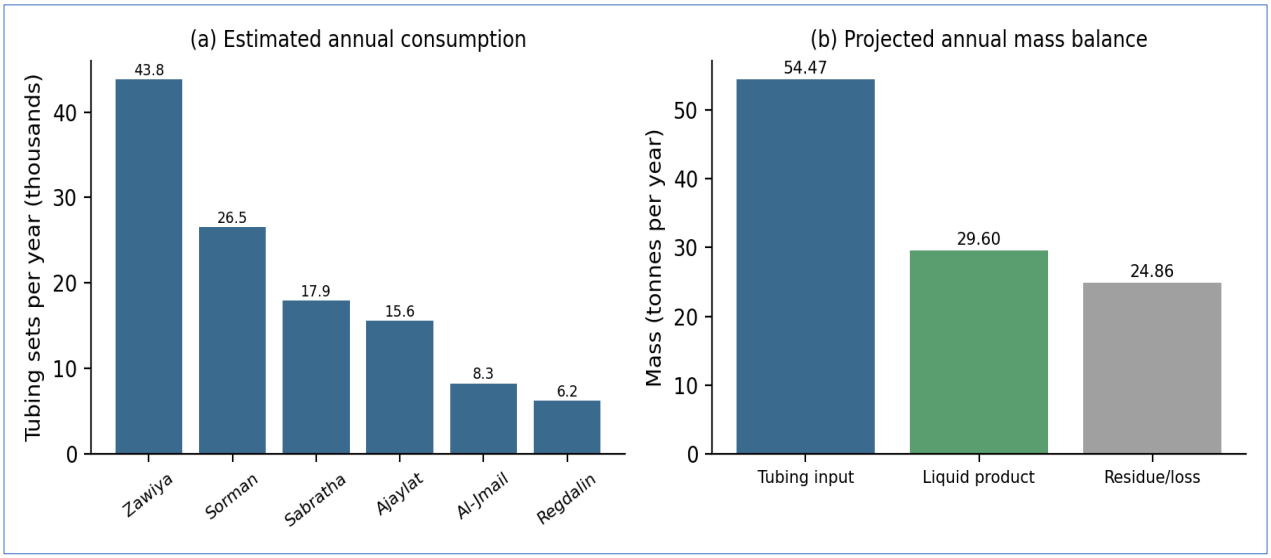


Fig. 1. (a) Estimated annual consumption of tubing sets by facility. **(b)** Projected annual mass balance for the six facilities combined, based on 0.460 kg per set and a single-run yield of 54.35%.

3.3 Thermal-treatment yield

Treatment of 460 g of tubing produced 250 g of condensed liquid, giving a liquid yield of 54.35%; the remaining 210 g (45.65%) was residue, gas, and loss (Table 3). This is a single observation (n = 1), so no measure of variability is available.

Table 3: Mass balance of the thermal-treatment experiment.

Item	Value
Tubing sample before treatment	460 g
Condensed liquid	250 g
Residue / gas / loss (by difference)	210 g
Liquid yield	54.35%
Residue / loss	45.65%

3.4 GC/FID results

The chromatogram was dominated by the solvent peak (98.905% of total area). Two analyte peaks were detected, at retention times 5.4845 min (C12; 0.9836% of total area) and 6.2388 min (C13; 0.1114%). After excluding the solvent, C12 represented 89.83% and C13 10.17% of the combined area (Table 4).

3.5 Scale of the waste stream

The inventory shows that dialysis tubing is a regular, countable waste stream: more than 118,000 sets per year in six facilities, corresponding to about 54 t of plastic. The figure is consistent with the observation that dialysis is plastic-intensive [4], and lies at the lower end of the per-session plastic range reported there, as expected because it covers tubing only and not dialysers, containers, or packaging. The concentration of about 37% of the volume in a single centre (Zawiya) is operationally useful: a pilot collection and treatment scheme in one unit would address a substantial share of the regional stream and would generate the measured weights and session counts that this study had to assume.

Table 4: GC/FID peak summary of the liquid product.

Peak	RT (min)	Area	% of total area	% excl. solvent
Solvent	0.6100	2,722,169	98.905	—
C12	5.4845	27,071	0.9836	89.83
C13	6.2388	3,066	0.1114	10.17
C12 + C13	—	30,136	1.0950	100

3.6 Interpretation of the yield and chromatographic data

A liquid yield of 54.35% shows that a large fraction of the tubing mass can be volatilised and condensed, but it cannot yet be treated as a process parameter. First, the result comes from one run. Second, the polymer was not identified. Blood tubing is frequently made of plasticised PVC, whose thermal decomposition releases hydrogen chloride and yields liquids that may contain plasticiser-derived compounds, water, and chlorinated species, rather than the paraffinic/olefinic mixtures typical of polyolefin pyrolysis.[5,6] The condensate could therefore differ substantially from a clean hydrocarbon fuel, and the observed yield may partly reflect non-hydrocarbon components. Third, the residue fraction was obtained by difference and does not distinguish char, gas, and losses, which limits mass-balance closure.

The GC/FID trace confirms hydrocarbon-range compounds at C12 and C13, but it is weak evidence about product quality. The solvent contributed almost 99% of the area, so the analyte signal is small; FID area percentages are not mass fractions; only two peaks were reported; and FID does not provide structural information comparable to mass spectrometry. Comprehensive characterisation by GC-MS or GC×GC 6,7, together with measurement of density (ASTM D4052),[14] kinematic viscosity (D445),[15] flash point (D93),[16] heat of combustion (D240),[17] water, sulfur, chlorine, and ash, is required before the liquid can be considered for any use.

3.7 Safety, environmental considerations, limitations, and next steps

Used tubing is potentially infectious, so sterilisation must precede shredding and heating, with documented validation for each batch. Thermal treatment must be performed in a closed system with condensation, emission control, and fire-safety measures, never as open burning, because uncontrolled burning of health-care waste produces hazardous pollutants[1,2] and PVC-containing feed can generate corrosive and toxic chlorinated emissions. The liquid product may be flammable and should be stored and labelled accordingly. Intended uses should be restricted to non-medical, non-food, and non-contact industrial applications, and no reuse of tubing in clinical practice is envisaged. Any transport or pilot operation would require approval from the competent health and environmental authorities.

The main limitations are that consumption for five of six facilities was estimated from patient numbers and an assumed three sessions per patient per week; some patient figures are approximate or upper bounds; the assumption of one set of 0.460 kg per session rests on a single sample; only one thermal-treatment run was performed with no replicates, unspecified polymer identity, and no separate quantification of gas and char; GC/FID analysis was qualitative/semi-quantitative and dominated by solvent; and no economic, life-cycle, or emissions assessment was undertaken.

Future work should include daily registration of sessions, sets, and actual weights at each centre; weighing sets from several manufacturers; identification of the polymer (e.g., FTIR) and chlorine content; at least triplicate thermal-treatment runs per feed type with mean and standard deviation and separate collection of gas and char; GC-MS characterisation and the ASTM tests listed above; comparison with catalytic pyrolysis and mechanical recycling of segregated tubing; and a techno-economic and emissions assessment against current disposal costs. A phased implementation involving documentation and segregation, sterilisation and preparation, trial treatment, analysis and evaluation, and conditional scale-up would allow safety and quality data to determine whether expansion is justified.

4. CONCLUSION

Used haemodialysis tubing in six western Libyan facilities amounts to an estimated 118,404 sets and about 54.5 t of plastic waste per year, concentrated in a few large units. A preliminary thermal-treatment experiment produced a condensed liquid at 54.35% of feed mass containing

hydrocarbon-range compounds (C12 and C13), suggesting that thermal recovery merits further study. However, the evidence is preliminary: the yield derives from a single run of an uncharacterised polymer, and product quality and safety are unverified. The proposed pathway of source segregation, validated sterilisation, controlled closed-system treatment, and full product testing, limited to non-medical industrial uses, offers a framework for the replicated, quality-controlled studies required before any practical application.

ACKNOWLEDGEMENT

The authors would like to acknowledge the dialysis facilities and their staff for providing the patient and session information used in this study, and the laboratory personnel involved in the thermal-treatment and GC/FID analyses. Specific names and institutional contributions should be completed by the authors before submission.

AUTHOR CONTRIBUTIONS

All authors contributed equally for: Conceptualization, methodology, writing – original draft, investigation, data curation, validation, manuscript preparation, critical review, writing – review & editing, and final approval of the manuscript.

CONFLICT OF INTEREST

The authors declare no conflicts of interest concerning the research, authorship, and publication of this article.

FUNDING

This research received no external funding.

REFERENCES

1. World Health Organization. Health-care waste (Internet). Geneva: World Health Organization; 2024 (cited 2026 Jul 3). Available from: https://www.who.int/news-room/fact-sheets/detail/health-care-waste.
2. Chartier Y, Emmanuel J, Pieper U, Prüss A, Rushbrook P, Stringer R, Townend W, Wilburn S, Zghondi R, editors. Safe management of wastes from health-care activities. 2nd ed. Geneva: World Health Organization; 2014.
3. Al-Salem SM, Lettieri P, Baeyens J. Recycling and recovery routes of plastic solid waste (PSW): a review. Waste Manag. 2009;29(10):2625-2643. doi:10.1016/j.wasman.2009.06.004.
4. Piccoli GB, Nazha M, Ferraresi M, Vigotti FN, Pereno A, Barbero S, et al. Eco-dialysis: the financial and ecological costs of dialysis waste products: is a "cradle-to-cradle" model feasible for planet-friendly haemodialysis waste management? Nephrol Dial Transplant.2015;30(6):1018-1027. doi:10.1093/ndt/gfv031.
5. Ragaert K, Delva L, Van Geem K. Mechanical and chemical recycling of solid plastic waste. Waste Manag. 2017;69:24-58. doi:10.1016/j.wasman.2017.07.044.
6. Dao Thi H, Djokic MR, Van Geem KM. Detailed group-type characterization of plastic-waste pyrolysis oils by comprehensive two-dimensional gas chromatography including linear, branched, and di-olefins. Separations. 2021;8(7):103. doi:10.3390/separations8070103.
7. Toraman HE, Dijkmans T, Djokic MR, Van Geem KM, Marin GB. Detailed compositional characterization of plastic waste pyrolysis oil by comprehensive two-dimensional gas-chromatography coupled to multiple detectors. J Chromatogr A. 2014;1359:237-246. doi:10.1016/j.chroma.2014.07.017.
8. Rao N, Rajan T, Stigant C. Quantification of recyclable peritoneal dialysis plastics in a home dialysis program—an opportunity for resource stewardship. Kidney Int Rep. 2023;8(2):365-367. doi:10.1016/j.ekir.2022.11.018.
9. Berman-Parks N, Berman-Parks I, Gómez-Ruíz IA, Ardavin-Ituarte JM, Piccoli GB. Combining patient care and environmental protection: a pilot program recycling polyvinyl chloride from automated peritoneal dialysis waste. Kidney Int Rep. 2024;9(6):1908-1911. doi:10.1016/j.ekir.2024.03.008.
10. Stragier A, Boccato C, Miriunis C, Milo E, Pellicia F, Pancirová J, et al. Environmental guidelines for dialysis: a practical guide to reduce the environmental burden of dialysis. EDTNA/ERCA and Fresenius Medical Care; 2011.
11. Elhrari W, Abdalgader A, Elaziby N, Ageel N, Elbuzedi M, Klash A, Elhodiry R, Sultan O. Transforming waste into value: cellulose extraction from native Libyan plant species for sustainable resource management. Euro-Mediterranean Journal for Environmental Integration. 2025 Dec;10(6):5507-15.
12. Alakhdar A, Kasheem A, Alsaeh F, Baroud N, Omran S, Alashkham W. Environmental literacy, sustainable behaviors, community participation and

SDG awareness in Libya. Asskruie J Pengabdian Kepada Masyarakat. 2026;3(2):56-72.
13. Lemamsha H, Akrim T, El Hemiedy R, Mohamed M, Randhawa G. Micronutrient supplementation and socioeconomic determinants among pregnant women in Tobruk, Libya: a cross-sectional analysis. Sharwes Scientific Journal. 2025 Aug 19;6(2):447-33.
14. ASTM International. ASTM D4052-22: Standard test method for density, relative density, and API gravity of liquids by digital density meter. West Conshohocken (PA): ASTM International; 2022.
15. ASTM International. ASTM D445-24: Standard test method for kinematic viscosity of transparent and opaque liquids. West Conshohocken (PA): ASTM International; 2024.
16. ASTM International. ASTM D93-20: Standard test methods for flash point by Pensky-Martens closed cup tester. West Conshohocken (PA): ASTM International; 2020.
17. ASTM International. ASTM D240-19: Standard test method for heat of combustion of liquid hydrocarbon fuels by bomb calorimeter. West Conshohocken (PA): ASTM International; 2019.