LIFE CYCLE INVENTORY ANALYSIS IN ADSORBENT PREPARATION FOR WASTE MANAGEMENT: A CASE STUDY

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ABSTRACT
Life Cycle Inventory Analysis (LCIA) is a part of the Life Cycle Assessment (LCA) and is a thorough procedure accounting for the environmental loads during the product's life cycle. LCA is an approach to analyze the environmental implications of product and service systems. An indigenous adsorbent is prepared in the laboratory from sawdust using chemical-thermal treatment mechanism. A close analysis of the several activities involved in the process revealed that, the raw material, i.e., sawdust is being converted into an adsorbent, i.e., product. In other words, conversion of a material from one form into another is taking place. Simultaneously, a useful product is being obtained that is used in another activity. LCIA based on material balance approach is applied for the primary data generated in the laboratory for the preparation of the adsorbent using sawdust. Few suggestions are floated for minimizing the waste generated in the process. It is found that the LCIA can be successfully applied in the adsorption studies to assess the material flow changes and identify the options for minimizing the waste emissions and for reducing the load on natural resources.

1. INTRODUCTION

Life Cycle Inventory Analysis (LCIA) is a part of the Life Cycle Assessment (LCA), a thorough procedure accounting for the environmental loads during the product's life cycle. LCIA is conducted by both mass- and energy- balance approaches to assess the release of loads to environment. Life Cycle Assessment (LCA) is an approach to analyze the environmental implications of product and service systems [Chubbs & Steiner, 1998]. LCA is a methodology, which has its roots in the late 1960s and early 1970s when a number of studies were conducted to predict the impacts of the utilization of the world's raw material and energy resources [Marano & Rogers, 1999]. An LCA framework can be used to assess potential improvement activities to identify when a change results, in effect, in the shifting of environmental burdens among media (for air, water, land) or to another stage of the life cycle [Aelion et al., 1995; Curran, 1995]. Methodologies have been developed incorporating process performance, economics, and life cycle inventory data to synthesize process systems that meet life cycle impact-improvement targets at lowest possible cost [Marano & Rogers, 1999].

2. LCIA IN WASTE MANAGEMENT

Removing pollutants from waste is the most important aspect in Waste Management. Very few applications are available in literature on LCIA [McDougall & White, 1998] alone but a wide range of applications based on complete LCA are reported in literature addressing issues in Waste Management such as, Highway waste Management [Contadini et al., 2001], Wastewater treatment [Suh & Rousseaux, 2001], Solid waste Management [Finnveden, 1998], Resources Management [Turkulainen et al., 2000], Effective management of building materials [Paulsen, 2001] etc. Incidentally, no studies are reported in the usage of LCIA for preparation of an adsorbent.

Adsorption is one of the proven techniques for treatment of both liquid and gaseous pollutants [Peavy et al., 1985]. Commercial Activated Carbon (CAC) prepared from charcoal is widely used for adsorption of pollutants [Peavy et al., 1985; Metcalf & Eddy Inc., 1979]. However, a number of non-conventional adsorbents are being attempted by several investigators in order to develop an alternative to the CAC satisfying techno-economic requirements [Namasivayam, 1995; Tare & Chaudhari, 1995; Rai et al., 1998]. The investigators attempted a number of methodologies (Physical treatment (P); Thermal treatment (T); Chemical treatment (C); and combinations of all the these options) to develop adsorbent from a parent raw material [Babu & Ramakrishna, 2001]. The adsorbent with thermal treatment is found to have more effective surface area than developed from chemical treatment [Satyasai et al., 1997]. An indigenous adsorbent is prepared in the laboratory from sawdust using a combination of Chemical & Thermal (CT) treatment methodologies of which thermal treatment is predominant.

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3. WHY LCI ANALYSIS ON ADSORBENT PREPARATION?

A close analysis of the several activities involved in the process revealed that, the raw material, i.e., sawdust is being converted into an adsorbent, i.e., product. It means conversion of a material from one form into another is taking place. Simultaneously, a useful product is being obtained that is used in another activity.

The productivity or efficiency obtained in the process depends on the conversion efficiency of raw sawdust into a suitable adsorbent designated for pollution abatement objective and waste releases into the atmosphere. LCA addresses these aspects under LCI analysis. Babu and Ramakrishna (2003) observed the following from their recent studies:

1. The research in the adsorption studies is focused on developing a low cost adsorbent.
2. A large number of adsorbents are being prepared from materials based on cheaply available Agricultural Wastes.
3. A high number of adsorbents are prepared with a simple Physical (P) treatment and Nominal (N) pretreatment.
4. The effectiveness of the adsorbent as measured by them using Freundlich Isotherm showed that CT & Chemical treatment (C) categories are better than P & N categories.
5. Cost of the adsorbents prepared from CT & C categories will be slightly higher than that of P & N categories.

The cost of the adsorbent is not the only criterion in the Waste Management. Its effectiveness is also an important aspect and is to be seriously considered. A detailed LCIA on the adsorbent preparation covering both material and energy changes will give the exact cost aspects involved in this activity. The present study focuses on application of LCI in the preparation of adsorbent from sawdust for adsorption studies. In this study, the primary (laboratory) data generated in the preparation of adsorbent is used and only material changes are accounted for developing material balance calculations.

4. LIFE CYCLE INVENTORY (LCI) ANALYSIS

LCI is the second step of the LCA. It deals with the identification & quantification of energy & materials used, and waste released to- & resources depleted from- the environment. The LCIA can serve to identify and quantify the particular aspects of a chemical process or a product, which generate significant environmental loads [Aelion et al., 1995]. The main components involved in the LCIA are:

- Environmental Load
- Environmental Impact
- Mass Eco-vector
- Energy Eco-vector
- Waste Eco-vector

The basic definitions of the above components are available in literature [Aelion et al., 1995]. Consider a single-product process (Refer Fig.1) with two inputs IP_1 and IP_2 that are converted to useful product P_1 and a waste release of W_1 into the atmosphere. All input and waste streams in a system or subsystem must be allocated the respective non-waste output streams. When an output stream becomes an input stream to the next process step, it carries the environmental loads onto the next output streams.

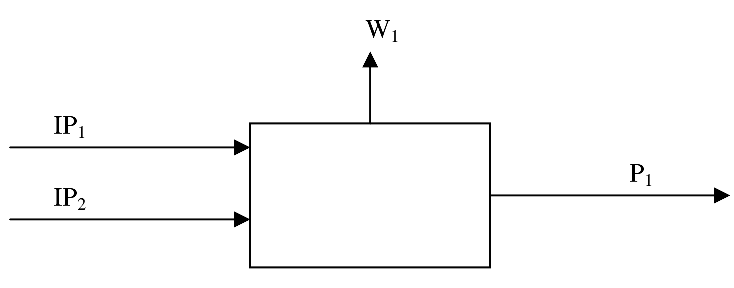

Fig. 1: Typical single-product process

4.1. Estimating Total Production Load (TPL)

In a manufacturing process, many periods of operation such as startup, shutdown, and maintenance may exist. It can be expected that environmental loads are associated with these periods of operation. In addition, manufacturing processes do not always operate as intended. In certain processes, occasional discarding of out-of-date material is also necessary. Accidents and accidental releases during the process can also contribute to pollution. The TPL is the summation of the environmental loads released during all such cases.

5. METHODOLOGY

The LCIA is applied to identify and quantify the materials involved in the investigations carried out in the laboratory for preparing adsorbent from sawdust. It can be inferred from the basic definition of LCI that there are two approaches available for LCIA viz., mass balance approach and energy balance approach. Of the two available approaches of LCI, only the material balance approach is considered in the present study.

5.1 Laboratory Investigations

The following methodology is adopted for preparation of adsorbent from sawdust:

1. Initial sieving of the raw sawdust to remove any impurities in it.
2. Washing with single distilled water (SDW) and acid (10% solution of 0.02N H_2SO_4) separately, to remove inorganic and greasy particles.
3. Drying the sample in oven at 105-110^{0}C for 24 hours for removal of moisture.
4. Thermal treatment of the sample in a muffle furnace at a temperature maintained at 400^{0}C for one hour.
5. Washing with SDW and acid (10% solution of 0.02N HCl) separately, to remove inorganic and ash particles.
6. Drying the sample in oven at 105-110^{0}C for 24 hours. The dried sample is stored for its use as adsorbent.

6. RESULTS AND DISCUSSION

For applying LCIA, few items involved in the conversion of sawdust into an adsorbent are selected based on their significance with respect to Environmental aspects. The details are given in Table-1. It can be noticed from Table-1 that a wide range of Environmental aspects such as consumption of natural resources, renewable raw material; generation of solid, liquid and gaseous emissions are addressed even in a simple process such as conversion of sawdust into an adsorbent. The above-identified aspects justify the application of LCI, whose basic principle is based on the identification & quantification of energy & materials used, and waste released to- & resources depleted from- the environment [Aelion et al., 1995].

Table-1: Justification of items selected for LCI analysis

Item description	Justification
Sawdust	Renewable raw material
Single distilled water	Natural resource
Acid	Non-renewable material
Sawdust rejects	Solid waste
Loss of moisture on drying	Air emissions
Wastage of single distilled water	Liquid discharge/Natural resource
Wastage of acid	Liquid discharge

The activities involved in the steps described under laboratory investigations are divided into two phases, viz., activities involved under items 1-4 as Phase-I and rest as Phase-II. The liquid input, i.e., both SDW and acid are taken as one unit. Seven items are considered for generating mass eco-vector for the LCIA.

The material balance calculations are performed using the primary data generated in the laboratory assuming that the mass density of both the acid solutions, H_2SO_4 and HCl used in the study are taken equal to that of water as very low concentrations of acid are used. The calculations are performed using a simple and systematic approach, which is explained in brief as follows. The sawdust is collected in the available metal trays of different size (designated as sample sets) and subjected to different stages of converting it into an adsorbent by the methodology suggested above. The detailed information at each and every step of the experiment is collected using a Datasheet comprising the Items listed in Table-2. A total of twelve sample sets are subjected to these tests. The sample information for one of the sample sets is given in Table-2.

The summation of the quantities for all the twelve sets is given in the last column of Table-2. This information is used in developing the Material balance diagram given as Fig.2. The item listed against S.No. 6 in Table-2 is the final product (shown in bold letters).

The eco-vector is computed for the raw material consumption and waste releases with respect to the primary raw material assuming steady state production. The Total Production Load (TPL) under steady-state condition is calculated using the respective raw materials for each item. The stages regarding discarding out-of-date materials and risks are negligible in this particular case. The TPL is calculated for the production data only. The TPL per unit of the product is given in Table-3. The TPL is calculated based on the mass of final product and the material balance data for the items. For example, TPL per unit of product for Distilled water is equal to (21090+4719)/324.5 = 79.535 units. The TPL per unit of product is calculated similarly for the other items. Assuming the material eco-vectors are same for the product i.e., adsorbent prepared from sawdust, the eco-vector for the product is also calculated and given in the last column of Table-3. It can be thus understood from Table-3 that 11.535 kg of raw material is required and 79.535 kg of SDW is consumed for preparation of one kg of adsorbent.

Table-2: Sample calculations for Material balance

S.No	Item Description	Data for a Sample set	Total of 12 sample sets
1	Weight of sieved samples, g	200	2461.2
2	Weight of sample after Distilled water and H_2SO_4 wash, g	612	7231.4
3	Weight of sample after oven drying, g	160	1794.4
4	Weight of sample after furnace burning, g	38	488.2
5	Weight of sample after HCl wash, g	77	1024.2
6	Weight of sample after oven drying, g	22	**324.5**
7	Distilled water used in Phase-I, mL	1520	21090
8	H_2SO_4 used in Phase-I, mL	80	1110
9	Distilled water used in Phase-II, mL	289	4719
10	HCl used in Phase-II, mL	15	249
11	Weight of raw sawdust, g	332	3255

Table-3: Total Production Load under steady-state production

Item description	Raw materials, kg		Waste releases, kg		Total Production Load (TPL), kg	TPL per unit of product, kg/kg
	Phase-I	*Phase-II*	*Phase-I*	*Phase-II*		
Sawdust	3,255	488.2	--	--	3,743.2	11.535
Single distilled water	21,090	4,719	--	--	25,809	79.535
Acid	1,110	249	--	--	1,359	4.188
Sawdust rejects	--	--	793.5	--	793.5	2.445
Loss of moisture on drying	--	--	6,743.2	699.7	7,442.9	22.937
Wastage of single distilled water	--	--	16,588.8	4,210.4	20,769.2	64.000
Wastage of acid			871.4	221.6	1,093	3.368

The waste-and non-waste emissions in the process are carefully studied. The following suggestions are floated to minimize the waste load from the process of preparation of adsorbent from sawdust:

- The rejects from sawdust are of the order of 2.4453 kg per kg of the finished product. The rejects can be used as supplementary fuel.
- The SDW wastage is accounting for 64 kg per kg of finished product. This is presently discharged into drain. This can be diverted for gardening purpose that can save the load on natural resource (water) consumption. The SDW wastage is accounting to a total of 80% of total SDW consumed under both the phases and 95% of total liquid wastes.
- The loss of moisture and acid retained in the sawdust by oven drying and furnace heating (approximately 23 kg of finished product) is leading to air pollution. This cannot be controlled since the amount of moisture and acid absorbed during the respective washes depends upon specific material that is being used.

7. SUMMARY AND CONCLUSIONS

LCIA is carried out for the primary data generated in the laboratory for the preparation of adsorbent using sawdust. Few suggestions are floated to minimizing the waste generated in the process. It is found that the LCIA can be successfully applied in the adsorption studies to assess the material flow changes and identify the options for minimizing the waste emissions and for reducing the load on natural resources.

REFERENCES

Aelion, V., Castells, F., Veroutis, A., "Life Cycle Inventory Analysis of chemical processes", Environmental Progress, 14 (3), pp. 193-200 (1995).

Babu, B.V., Ramakrishna, V., "Novel adsorbents for solid-liquid separations", Proceedings of Seminar and Intensive Course (SIC-2001) on *Novel Separation Techniques and their applications to Indian Chemical Industries*, March 21-23, BITS, Pilani, pp. 1-7, (2001), the presentation of which is available via Internet at http://bvbabu.50megs.com/custom4.html/#semat

Babu, B.V., Ramakrishna, V., "An approach for ranking of adsorbents based on Method of Preparation and Isotherm Fitting", CHEMCON-2003, Communicated (2003).

Chubbs, S.T., Steiner, B.A., "Life Cycle Assessment in the Steel industry", Environmental Progress, 17 (2), pp. 92-95 (1998).

Contadini, F., Moore, R.M., Sperling, D., Sundaresan, M., "Life Cycle Emissions of Alternative Fuels for Transportation: Dealing with Uncertainties", SAE 2000 World Conference, March 6-9, 2000, Detroit, Michigan, Publication No. UCD-ITS-RP-00-09 (2000).

Curran, M.A., "Using LCA-Based approaches to evaluate pollution prevention", Environmental Progress, 14 (4), pp. 247-253 (1995).

Finnveden, G., "Life Cycle Assessment of Integrated Solid Waste Management Systems". In Sundberg, J., Nybrandt, T. and Sivertun, Å. (Eds): System engineering models for waste management, AFR-Report 229, 261-275, AFN, Swedish EPA, Stockholm, Sweden (1998).

Houthoofd, J.M., "Pollution prevention applications in Construction and Water Resource Management", Environmental Progress, 14 (4), pp. 254-260 (1995).

Marano, J.J., Rogers, S., "Process system optimization for Life Cycle improvement", Environmental Progress, 18 (4), pp. 267-272 (1999).

McDougall, F.R., White, P.R., "The Use of Life Cycle Inventory to Optimise Integrated Solid Waste Management Systems: A Review of Case Studies", Systems Engineering Models for Waste Management. International Workshop, Gothenburg, Sweden 25 - 26 February (1998).

Metcalf & Eddy Inc., (Revised by George Tchobanoglous) *Wastewater Engineering: Treatment, Disposal, Reuse*, Tata McGrawHill Publications, New Delhi (1979).

Namasivayam, C., "Adsorbents for the treatment of wastewaters", in Encyclopedia of Environmental pollution and control, Edited by R.K. Trivedi, Enviromedia, Karad, Vol. 1, pp. 30-49 (1995).

Olbina, R., "Development of a computer supported information system for measuring pollution prevention progress", Environmental Progress, 14 (4), pp. 280-288 (1995).

Paulsen, J., *Life Cycle Assessment of Building Products-The significance of the usage phase*, Ph.D. Thesis, Royal Institute of Technology, Stockholm (2001).

Peavy, H., Rowe, L., Tchobanoglous, G., *Environmental Engineering*, McGraw Hill International Publications, Civil Engineering Series, Singapore (1985).

Rai, A.K., Upadhyay, S.N., Kumar, S., Upadhyay, Y.D., "Heavy metal pollution and its control through a cheaper method: A Review", Journal of Indian Association for Environmental Management, 25 (1998), pp. 22-51 (1998).

Satyasai, P.M., Ahmed, J., Krishnaih, K., "Production of activated carbon from coconut shell char in a fluidized bed reactor", Industrial Engineering & Chemistry Research, 36 (9), pp. 3625-3630 (1997).

Suh Young-Jin, Rousseaux P., "Considerations in Life Cycle Inventory Analysis of Municipal Wastewater systems", Presented at COST 624 WG Meeting, 26-27 April (2001).

Tare, V.S., Chaudhari, S., "Heavy metal pollution: Origin, Impact and Remedies", in Encyclopedia of Environmental pollution and control, Edited by R.K. Trivedi, Enviromedia, Karad, Vol. I, pp. 386-411 (1995).

Turkulainen, T., Katajajuuri, J., Malkki, H., "Applying LCA to Integrated Resources and Waste Management-Substitution of Primary Energy Sources", Industrial Environmental Economics (IEE) Reports, No. 03/00, Publication of Chemical Technology, IEE, Finland (2000).

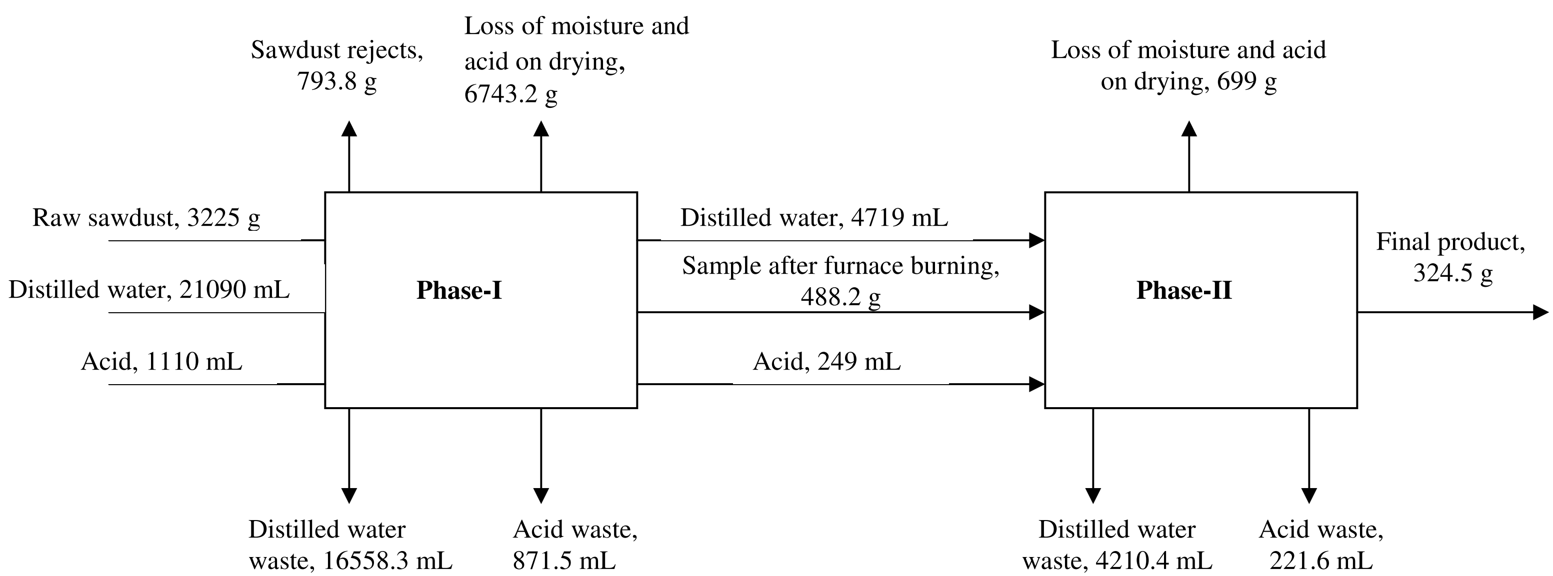

Fig. 2: Material balance for the adsorbent prepared from sawdust