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Improving industrial water use: case study for an Indian distillery

N.K. Saha, M. Balakrishnan*, V.S. Batra

TERI School of Advanced Studies, Darbari Seth Block, India Habitat Center, Lodhi Road, New Delhi 110003, India

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Abstract

Alcohol distilleries are highly water intensive units generating large volumes of high strength wastewater that poses a serious environmental concern. This study aimed at identifying options for improved water use in this sector through a case study in a local distillery. It emerged that optimization of cooling tower operation, innovative ways to reuse wastewater streams like spent lees and spentwash and employing semi-continuous/continuous fermentation could reduce water use in distilleries.

Keywords: Distillery; Water use; Conservation; Wastewater; Recycling; Reuse

1. Introduction

Alcohol distilleries are one of the most polluting industries generating an average of 8–15 L effluent ("spentwash") per liter of alcohol produced. India has around 295 distilleries with a total installed capacity of 3198 million liters per annum and a current yearly production of 1587 million liters alcohol (Ali, 2002). The manufacturing process (Fig. 1) involves fermentation of diluted sugarcane molasses with yeast. The fermentation lasts about 80h and the resulting product contains 6–8% alcohol. The yeast cells are separated by settling and the cell free broth is steam distilled and rectified to obtain 94–95% alcohol.

Fresh water is consumed at various stages of the alcohol manufacturing process namely yeast preparation, molasses dilution, bottle washing, adjusting the alcohol to the required strength for potable purpose and occasionally, dilution of the treated effluent, prior to discharge. The effluent generated is acidic in nature, has a high BOD and COD value and

* Corresponding author. Tel.: +91 11 2468 2100/2468 2111; fax: +91 11 2468 2144/2468 2145.
E-mail address: malinib@teri.res.in (M. Balakrishnan).

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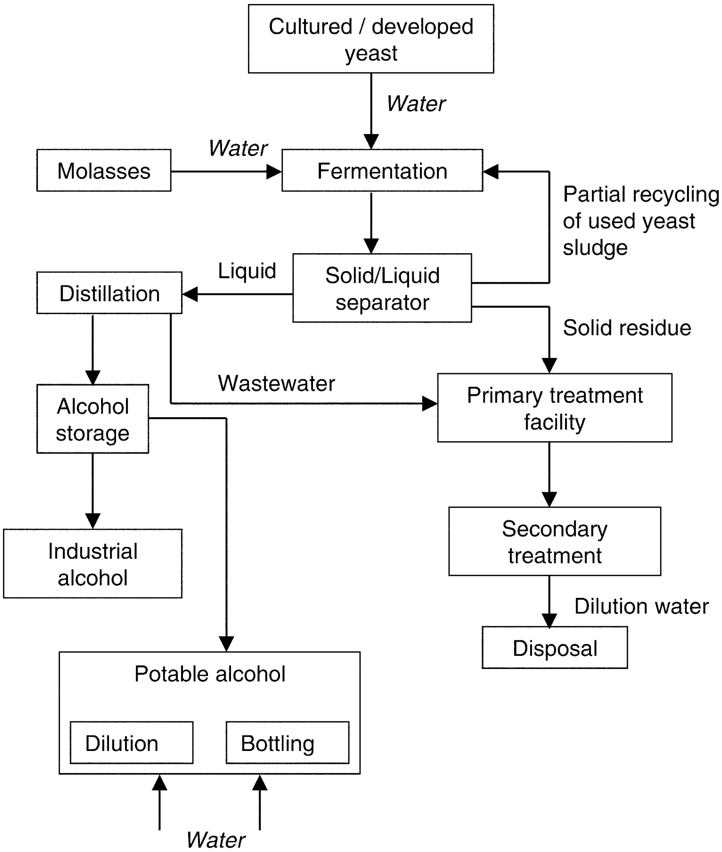

Fig. 1. Schematic of alcohol manufacturing process.

poses an aesthetic problem due to its color and odor (Table 1). Consequently, extensive treatment is required before the treated wastewater can meet the stipulated environmental norms (Table 2). Further, a maximum of 15 m^3 of effluent can be generated per kilolitre of alcohol produced as per the Water (Prevention and Control of Pollution) Cess Rule, 1978 specified by the Government of India.

In this context, improved water use in distilleries can contribute to:

- better operational efficiency;
- improved economic competitiveness through reduced water demand combined with savings in water and wastewater treatment costs;
- low environmental impact due to decrease in surface and subsurface withdrawals as well as less groundwater contaminant intrusion; also, such measures will mitigate the effects of water stress (Sinha, 2002).

This work aims to identify possible strategies that can improve water use in Indian distilleries. This was achieved through a preliminary questionnaire survey of select local distilleries in Northern India, followed by a detailed study in one unit.

Table 1
Typical characteristics of distillery spentwash (Goyal et al., 1996)

Parameter	Range
pH	3.8–4.4
Total solids (mg/L)	60000–90000
Total suspended solids (mg/L)	2000–14000
Total dissolved solids (mg/L)	58000–76000
Total volatile solids (mg/L)	45000–65000
Chemical oxygen demand (mg/L)	70000–98000
Biological oxygen demand (for 5 days at 20 °C) (mg/L)	45000–60000
Total nitrogen as N (mg/L)	1000–1200
Potash as K_2O (mg/L)	5000–12000
Phosphate as PO_4 (mg/L)	500–1500
Sodium as Na (mg/L)	150–200
Chlorides as Cl (mg/L)	5000–8000
Sulfates as SO_4 (mg/L)	2000–5000
Acidity as $CaCO_3$ (mg/L)	8000–16000
Temperature (after heat exchanger) (°C)	70–80

Table 2
Comparison of treated spentwash and effluent quality standards prescribed by Central Pollution Control Board (CPCB)

Parameter	Spentwash characteristics after primary treatment (Ali, 2002)	CPCB discharge standards (CPCB, 1998)	
		Into surface water, Indian Standards: 2490 (1974)	On land for irrigation, Indian Standards: 3307 (1974)
Temperature (°C)	~37 °C	Shall not exceed 40 °C	Shall not exceed 40 °C
pH	7.0–8.5	5.5–9.0	5.5–9.0
$BOD_5^{20\,°C}$ (mg/L)	4000–5000	30	100[a]
COD (mg/L)	25000–30000	250	–
Suspended solids (%)	1.0–1.5	100[b]	200[b]
Total dissolved solids (inorganic) (mg/L)	–	2100	2100
Oil and grease (mg/L)	–	10	10
Sulfide (S^{-2}) (mg/L)	700–800	2	–
Sulfates (SO_4^{-2}) (mg/L)	2500–4500	1000	1000
Chlorides as Cl^- (mg/L)	2000–3000	1000	600
Total residual chlorine (mg/L)	–	1.0	–
Sodium (Na^+) (mg/L)	300–500		600
Potassium (K^+) (mg/L)	1500–2500	–	–

[a] When land is used for secondary treatment, BOD up to 500 mg/L is permissible.
[b] Absolute values in mg/L.

2. Approaches towards water conservation in industries

Monitoring of water use in industries is gaining importance due to increasing competition and stringent environment norms. Water is no longer perceived as a free commodity; further, innovative technologies, along with modification of existing technologies are commercially available to reduce process water consumption. In general, reduction in industrial wastewater can be achieved through one or a combination of the following measures:

- process modification or change in raw materials to reduce water consumption;
- direct reuse of wastewater;
- in-plant reuse of reclaimed wastewater;
- use of treated wastewater for non-industrial purposes.

The final choice of the measures adopted are dictated by the availability of substitute raw material and technology, nature of pollutants, purity requirement of water for reuse, competing water demands and overall treatment cost. Table 3 summarizes some key initiatives implemented for improved water use in different industrial sectors.

3. Methods

A questionnaire survey on water use in distilleries was conducted through the All India Distillers Association. The survey was limited to distilleries in Northern India, located near Delhi. Based on the results of the survey, a distillery unit located in the state of Uttar Pradesh was chosen for further study. The detailed water balance was examined and water/wastewater samples were collected from different points in the plant. The water characteristics were determined in the laboratory following standard methods (APHA, 1989). Data on volumes of water consumed and effluent generated was obtained from the distillery records.

4. Results and discussions

4.1. Summary of questionnaire survey

The questionnaire was administered to a total of seven distilleries, of which four distilleries provided responses. The survey results are collated in Table 4.

The following salient points emerged from this exercise.

1. Ground water is the main water source. Water is pumped out of deep wells and distributed to the various points of water utilization.
2. Significant volume of water is consumed for molasses dilution, bottle washing and inoculum (yeast) preparation.
3. Water consumption for potable alcohol preparation is dependent upon the total potable alcohol production as well as the product mix in terms of country liquor and Indian made foreign liquor (IMFL).
4. The primary effluent treatment step involves anaerobic treatment with biogas generation. This is sometimes followed by aerobic treatment; alternatively, the primary treated effluent is used for biocomposting, or stored in lagoons for several months before final discharge in the rainy season. Ferti-irrigation is also practiced in some areas, after diluting with water.

Table 3
Water conservation possibilities and technological availability for different industries

Industry	Interventions	Technology adopted	Remarks
Distillery	Spentwash recycling	Modification in existing process	Successful trials with 40% spentwash recycling for molasses dilution and fermentation at Fermpro, Malaysia (Yeoh et al., 2001) 25% spentwash recycle for fermentation being used at SSK Distillery, Akluj, India (Waste Minimization Circle) Semi-continuous process reduced water consumption up to 70% in Sarina distillery, Australia (EnviroNet Australia)
Sugar	Recycling of process water from the barometric column Recycling of boiler condenser water Recycling wash water used in chimney cleaning	Developed system for cooling and collecting water	93% water savings, payback just above 24 months in San Francisco Ameca Plant Jalisco, Mexico (EMCENTRE, 1999; UNEP-WBCSD, 1998)
Dairy	Reduced water for washing Recirculation of water with cleaning solution in cleaning area	Improved hose with shut-off nozzle High pressure washing	Reduced water use by 30,000 m^3/year in a dairy in Tartu, Estonia (UNEP-WBCSD, 1998)
Pulp and paper	Change in feedstock Regeneration of water from the wastewater stream Recycle of paper machine white water, decker and screen white water, condenser cooling water	Screening Clarification Evaporation Close monitoring of operation conditions	Trials in a mill at Jämsänkoski, Finland displayed (UNEP-WBCSD, 1998) 75% reduction in freshwater consumption by changing feedstock Zero effluent pulp and paper mill
Board	Regeneration of process water from secondary treated effluent	Combined ultrafiltration and reverse osmosis	Successful pilot scale study in Turkey (Yalcin et al., 1999) showed high quality of treated water

Table 3 (*Continued*)

Industry	Interventions	Technology adopted	Remarks
Tannery	Reuse of main soak for dirt soak Drum soaking instead of pit soaking Reuse of limed water Deliming of water for subsequent usesoaking	Chemical treatment Little modification in existing facilities	Recommended by Central Pollution Control Board, India expected to result in significant reduction in water consumption (CPCB, 1999)
Textiles	Regeneration, use of dyeing and fulling wastewater	Combined ultrafiltration and reverse osmosis	Tested on pilot scale in Italy (Ciardelli et al., 2000) with estimated treatment cost 1 €/m^3
Semiconductor	Use of rejected water from deionizing unit as cooling water make-up	Chemical treatment	Practical experience in SGS-Thomson Microelectronics, Malta (UNEP-WBCSD, 1998)
	Recycling of process water	Microfiltration Ion-exchange resin treatment	Case study in Chungli, Taiwan (You et al., 2001)
Metal industries	Treatment of heavy metal polluted acidic water	Biological treatment with alkali producing algae (*Spirulina sp.*) followed by anaerobic polishing	Research experience in South Africa (Van Hille et al., 1999) shows Significant reduction in metal ion concentration when tested in a bench scale reactor Tannery or saline water can be used as nutrient for algae
Petroleum refining	Use of tertiary treated municipal wastewater as process water	Ultrafiltration and reverse osmosis	Significant savings in freshwater consumption through combined ultrafiltration and reverse osmosis of secondary treated municipal sewage in Chennai Petroleum Company Limited, Chennai, India Treatment cost is estimated to be Rs. 28/kL and is economically feasible (Viswanathan and Sethi, 2002)

Table 4
Survey results

Parameter	Distillery			
	1	2	3	4
Plant capacity (kL/day)	45	25	180	25
Molasses consumed (kg)	180000	110000	8000,000	1100000
Water source	Ground	Ground	Ground	Ground
Water use (kL/day)				
Molasses dilution	430	250	1300	160
Inoculum preparation	3.5	16	30	30
Washing	81	20	50	40[a]
Potable alcohol preparation	22	45	50	5[b]
Spentwash dilution	30	75	–	1050
Recycling/reuse	Recirculation of condenser and fermenter cooling water; fermenter washing using spentlees; wash water from bottling plant for gardening	None	Cooling water	For diluting treated effluent
Effluent treatment	Biomethanation	Biomethanation & aerobic treatment	Biomethanation, anaerobic lagooning and aerobic treatment	Biomethanation and aerobic treatment
End use of treated effluent	Biocomposting	Ferti-irrigation and discharge into drain	Discharged in rainy season	Limited ferti-irrigation

[a] For one chain (8 h/day).
[b] For 200,000 B.L. country liquor/month.

Table 5
Background of test unit

Location	Uttar Pradesh, India	
Total production capacity (kL/day)	45	
Potable alcohol (kL/day)	25	
Rectified spirit (kL/day)	20	
Molasses consumption (quintal)	1800	
Molasses concentration for fermentation (Brix)	38–40	
Total water consumption (kL/day)	1133.5	
Number of fermenters	9	
Fermenter type	Batch	
Effluent treatment		
Reactor and capacity (kL/day)	SMAG[a]	UASBR[b]
Operational	350	150
Installed	650	375
End use of treated effluent	Bio-composting with sugarcane press-mud	

[a] Submerged media attached growth.
[b] Up flow anaerobic sludge blanket reactor.

5. Concentration and incineration of the effluent is another option that is being examined. This recovers the water from the effluent and the concentrated mass can be burnt in the boiler for steam generation. The ash produced is rich in inorganics and can find application as fertilizer. Even though local firms are supplying the technology, it is still under testing.
6. There is considerable interest in water conservation among local distilleries because of strict environmental norms. In this context, cooling water recycling is a commonly practiced measure.

Of the units that responded, distillery 1 was proactively exploring water conservation and reuse. Thus, this unit was chosen for the detailed study.

4.2. Case study

The background of the chosen unit is summarized in Table 5. Fig. 2 shows the water balance and Table 6 provides the distribution of water use. Analysis of the various water/wastewater samples is listed in Table 7.

Table 6
Distribution of fresh water consumption in test unit

Activity	Consumption (kL/day)
Inoculum preparation	3.5
Molasses dilution	430
Fermenter washing	18
Boiler	187
Cooling water make-up	388
Bottle washing	30
Potable alcohol preparation	15
Effluent treatment	30

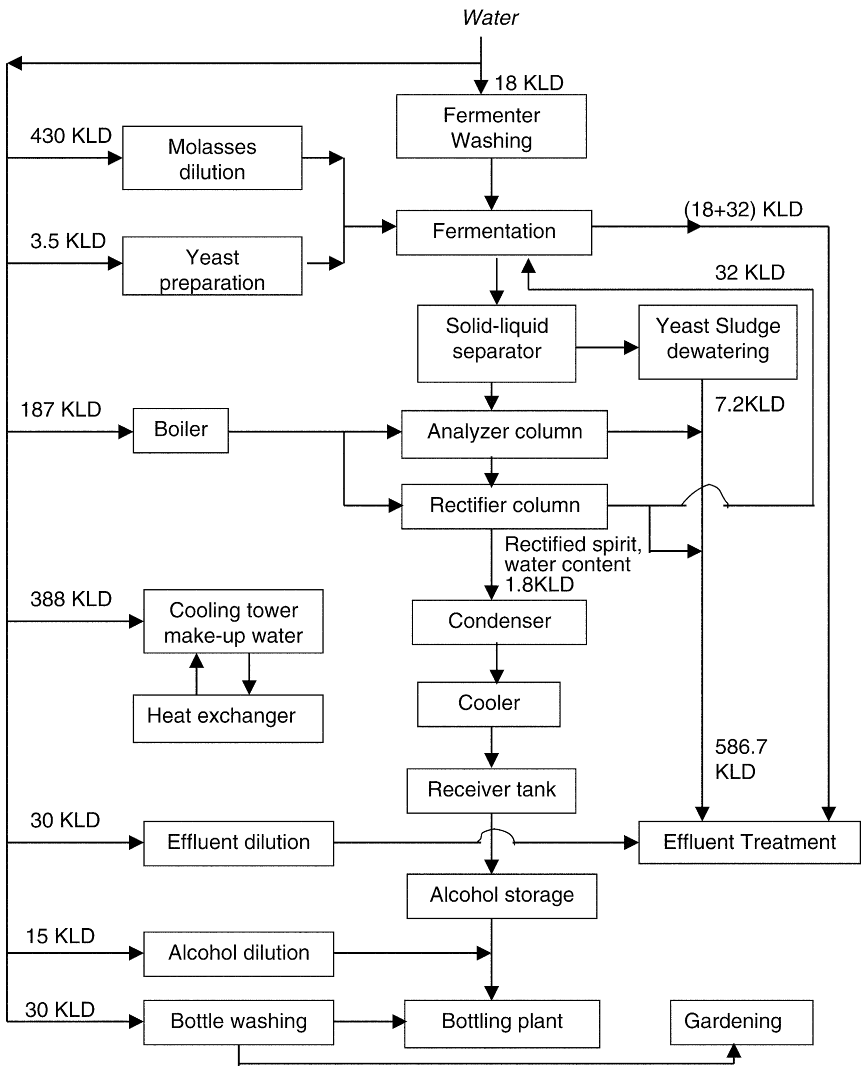

Fig. 2. Water balance diagram.

The unit uses 1133.5 kL water/day and generates around 668 kL/day of effluent. The effluent volume has been calculated on the basis of contributions from water used for molasses dilution, yeast preparation, steam generation, fermenter washing and effluent treatment. It has been assumed that other processes do not contribute to effluent generation.

Molasses dilution, cooling requirement and steam generation in the boiler are the most water intensive processes. Thirty-four percent of total daily water input to the distillery is in the form of cooling tower make-up volume that is a consequence of evaporative loss, drift loss and blowdown. Optimization of the cooling tower operation and maintenance

Table 7
Characteristics of water/wastewater in different distillery processes

	pH	Temperature (°C)	Total solids (g/L)	Total suspended solids (g/L)	Dissolved solids (g/L)	Chloride (mg/L)	COD (mg/L)
Fresh water	8.10	–	8.3	0.5	7.8	34.8	504
Demineralized water	5.70	–	8.9	0.3	8.6	17.4	1080
Bottle washing wastewater	7.94	–	17	0.5	16.5	78.4	72
Cooling water	7.65	–	7.9	0.7	7.2	87.2	2088
Spent lees	2.90	80–85	7.6	1.8	5.8	69.7	8640
Spentwash	3.90	85–90	63.8	13.8	50	8720	388800

can contribute significantly to makeup water requirement (NCDENR).[1] Possible measures include energy balance to justify the evaporative loss of water, use of drift eliminator to control drift loss and marginal increase in concentration ratio to minimize the blowdown. For instance, an increase in concentration ratio from 1.5 to 2% can result in 33% savings in makeup water (NCDENR). Further, treated wastewater can also be explored as an alternative source of makeup water.

At present, the unit uses the wash water from the bottling plant for gardening. Further, for effluent dilution, fresh water is used. The characteristics of the water generated after bottle washing are comparable to fresh water (Table 7) since the bottles, which are pre-washed, are simply rinsed without using any detergent. Thus, this wash water can replace the freshwater used for effluent dilution thereby saving about another 3% of total water input to the plant. Simultaneously, water requirement for gardening can be reduced by choosing appropriate plant species such as *Bryophyllum, Agave, Casuarina equisetifolia, Aloe vera etc.* that require less water for their growth.

Appropriate wastewater streams can be partially substituted for fresh water in fermenter washing. For instance, this distillery unit has successfully attempted partial reuse of spent lees for fermenter washing. This is in spite of the fact that the spent lees is typically at 80–85 °C and has a pH and COD significantly different from that of fresh water. This intervention contributes to a 2.7% saving in overall freshwater requirement.

Modifying the fermentation process can result in the control of both water consumption and effluent generation. In Malaysia 40% reduction in freshwater consumption has been achieved by reusing the spentwash in molasses dilution and fermentation steps (Yeoh et al., 2001). In another study, M/s S S K Distillery, Akluj, Maharashtra, India reported recycling 25% of the spentwash from the distillation column directly to the fermenter to reduce water utilization (Waste Minimization Circle).[2] The same unit also employed a modified fermentation process ("dual biofermcen process") resulting in a 40% reduction in spent wash generation (Waste Minimization Circle). In another study, CSR's Sarina distillery

[1] NCDENR, NCDENR (North Carolina Department of Environment and Natural Resources), Division of Pollution Prevention and Environmental Assistance. Water Efficiency–Water Management Options Cooling and Heating. http://www.p2pays.org/ref/04/03101.pdf.

[2] Waste Minimization Circle, National Productivity Council of India. Waste minimization case study in WMC distillery unit – conversion of BAT process http://wmc.nic.in/case-studies3.asp.

in Queensland, Australia tested a semi-continuous fermentation process (Biostil) that reportedly cut down water consumption by 70% (EnviroNet Australia).[3] Though continuous fermentation has been successfully employed in Indian distilleries in the southern state of Maharashtra, extreme variations in the ambient temperature in the state of Uttar Pradesh may limit its efficiency.

5. Conclusion

There is significant scope to improve water utilization in Indian distilleries through conservation and reuse. Though good housekeeping measures such as proper metering of water flow in individual units and maintenance of piping contribute to water savings, specific interventions should also be targeted. Our study identified optimization of cooling tower operation, innovative ways to reuse segregated wastewater streams and replacing batch with semi-continuous/continuous fermentation to be appropriate interventions to reduce water use in distilleries.

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References

Ali, S. Move towards a zero liquid discharge distillery. In: Proceedings of the Second FICCI-TERI Global Conference: Green–2002 Agenda for Industry. 7–8 February 2002, New Delhi, India.

APHA. Standard methods for the examination of water and wastewater. 17th ed. Washington, DC: American Public Health Association; 1989.

Ciardelli G, Corsi L, Marcucci M. Membrane separation for wastewater reuse in the textile industry. Resources Conserv Recycl 2000;31:189–97.

CPCB (Central Pollution Control Board). Pollution Control Acts, Rules, Notifications issued thereunder, vol. I. New Delhi: Central Pollution Control Board, Ministry of Environment and Forests; 1998. p. 311–2, 501.

CPCB (Central Pollution Control Board). Parivesh Newsletter, 1999;6:19–20.

EMCENTRE (Environmental Management Centre); 1999. http://www.emcentre.com/unepweb/tec_case/food_15/house/casename.shtml.

Goyal SK, Seth R, Handa BK. Diphasic fixed-film biomethanation of distillery spentwash. Bioresource Technol 1996;56:239–44.

Sinha AK. Sustainability of the India's water resources: challenges and perspectives. Sustainable Development International 2002;4:129–33. http://www.sustdev.org/explore/water_res_man/articles/edition4.shtml.

UNEP-WBCSD, 1998. Industry, fresh water, and sustainable development. United Nations Environmental Programme and World Business Council for Sustainable Development.

Van Hille RP, Boshoff GA, Rose PD, Duncan JR. A continuous process for the biological treatment of heavy metal contaminated acid mine water. Resources Conserv Recycl 1999;27:157–67.

[3] EnviroNet Australia. Recycling Waste Products from Molasses Fermentation, CSR Distilleries. http://www.p2pays.org/ref/04/03358.htm.

Viswanathan S, Sethi N. Down to Earth 2002;11.

Yalcin F, Koyuncu I, Oztürk I, Topacik D. Pilot scale UF and RO studies on water reuse in corrugated board industry. Water Sci Technol 1999;40(4–5):303–10.

Yeoh BG, Chen SS, Aziz AA, Nee TY, Chong TC, van de Graaff R, van de Graaff H. Cleaner production in the distillery industry—the Malaysia experience. In: Proceedings of the Third Asia Pacific Roundtable Conference for Cleaner Production. February 28–March 2, 2001, Manila, Philippines. http://www.aprcp.org/articles/papers/yeoh.htm.

You S-H, Tseng D-H, Guo G-L. A case study on the wastewater reclamation and reuse in the semiconductor industry. Resources Conserv Recycl 2001;32:73–81.