UNIVERSITY OF MAURITIUS RESEARCH JOURNAL – Volume 15 – 2009
University of Mauritius, Réduit, Mauritius

Research Week 2007

Prospects for Recycling of Waste PET Bottles in Mauritius

Vikram Seebaluck *
Faculty of Engineering,
University of Mauritius
Email: v.seebaluck@uom.ac.mu

Weedad Bibi Koussa
Mauritius
Email: weedad.johar@postgrad.manchester.ac.uk

Paper Accepted on 17 August 2009

Abstract

This paper analyses the status and prospects of waste PET (PolyEthylene Terephthalate) bottles recycling in Mauritius. Over the past decade the packaging industry has witnessed a momentous swing away from glass bottles and cans into fully recyclable PET plastic bottles, being viewed as a more consumer friendly product. However, the main snag of PET containers is its subsequent proper disposal after use where the non-biodegradable nature of the material poses a problem. Recycling is a potential way out. Hence, in this study, the different alternatives for collection and recycling of plastic bottles from an environmental protection perspective were investigated. The environmental impacts of waste PET recycling were compared with landfilling, the current disposal method. A PET recycling plant was subsequently designed to investigate into the possibility of recycling the plastic bottles in Mauritius itself instead of exporting the PET flakes to emerging international markets.

An industrial survey conducted among the different stakeholders of the plastic industry revealed around 2500 tonnes of PET bottles being put into the market by the beverage industries in the year 2005. With a proper collection system of either kerbside collection or bottle bill legislation, being determined as the preferred disposal options for the public, more than 2000 tonnes of waste PET bottles has been found to be potentially recyclable. The total capital investment of a grass root waste PET recycling plant was found to be 168 million MUR coupled with a payback period of around 5.4 years showing feasible options for implementing such a plant in Mauritius. The capital investment can be lowered through the revamping of an existing sorting plant where the payback period was found to be

4.1 years. Besides being economically feasible, it was found that the environmental impacts of the recycling process was significantly lower that the current disposal technique.

Keywords: PET bottles, waste, recycling, environmental protection, economic feasibility.

**For correspondences and reprints*

1. INTRODUCTION

Mauritius is a small island developing state with a population of around 1.2 x 10^6 million inhabitants (CSO, 2004). During the past decade, the island has experienced a constant improvement in economic development through industrialization and urbanization. The gross domestic product (GDP) has skyrocketed from Rs 74,336 million in 1997 to Rs 186,973 million in 2005 (CSO, 2004) which gave an indication of the progression in the standard of living of Mauritian people. However one of the aftermaths of this improvement in the lifestyle of the population is an increase in volume of waste produced daily. 381,204 tonnes of solid waste was generated in the island in the year 2004, which was higher by 2.3% of the annual amount produced in 2003 (CSO, 2004). It has been found that the amount of waste generated annually increased constantly over the past decade. On the other side, it has been forecasted that the current waste disposal method will be unable to cope with this enormous quantity of waste being produced in the near future, unless alternative disposal means are being identified.

Among the different kinds of waste being generated, waste plastics which represent around 3% of the total waste produced in Mauritius, is one of the major components that presents a significant threat to the environment due to its non-biodegradable nature. In developed countries, waste plastics can contribute up to 20% of the waste stream and is mainly linked to the high standard of living. In a broader-spectrum, it has been found that over the years the plastic industry has built up a language and a terminology of its own. Mauritius has not been spared by this plastic era, where the amount of plastics imported has increased by 63 times during the last 5 years (MOE, 2001). Polyethylene terephthalate (PET) plastic bottles which have replaced glass bottles and cans are the major components of waste plastics. A survey carried out by the Ministry of Environment in 2004 showed that around 94 million PET bottles were put in the market annually, 75% of which represented the beverage and water bottles. The remaining was used in the packaging of detergents, alcohols, oils, vinegar, juice and other food stuffs.

PET is a linear thermoplastic produced from purified ethylene glycol and mono-terephthalic acid by the polycondensation process. It was first used to make fibres due to its high strength, low water absorption and crease resistance. Today, it is a globally treated commodity polymer. Since PET provides an excellent barrier against oxygen and carbon dioxide, it has become a material of choice for bottling beverages. It is also widely used for microwave food trays and food packaging films. PET offers good design flexibility and is safer and sturdier than most other alternatives, particularly glass. Since it is extremely light it requires less fuel during transport, and hence helps in saving energy. PET is well known for its transparency and it has a high heat resistance and chemical stability. This polymer has minimal sensory impact and it is fully recyclable. However, the main disadvantage of PET bottles is that they are not biodegradable and thus cause a real eyesore in the society. Unfortunately, when incinerated, they liberate carbon dioxide, the most important and major greenhouse gas, together with some other emissions.

PET can be recycled either by mechanical or chemical means. Mechanical recycling is simple which mainly involves melting of the PET flakes in an extruder

to form the final products. This technique does not require additional input of resources but the purity of the product can be an issue. However, this problem can be overcome by adopting sorting practices. As for chemical recycling, it is a depolymerization process that breaks down plastic molecules into their constituent monomers. Although this process produces high purity products, it needs additional use of chemicals and heat energy, which can offset the benefits of recycling. For instance, the different chemicals used in chemical recycling have their own environmental impacts associated with their manufacture. This project focused on mechanical recycling of PET bottles for the production of yarn.

2. METHODOLOGICAL FRAMEWORK

The different steps adopted for undertaking this study has been summarized in the schematic diagram shown in Figure 1.

A literature review was performed on polyethylene terephthalate to get a thorough knowledge of the material under study. The amount of PET bottles used was then quantified, being a critical step to enable the proper design of the recycling plant. This information was obtained from an industry survey carried out among almost all the stakeholders involved in the PET plastic bottle industry. Since public involvement plays an important role in the collection of PET, a public survey was carried out to determine the most appropriate and preferred handling method. Based on these results as well as from experiences and lessons learnt from other countries, new schemes were subsequently proposed to improve the existing collection practices. Finally, a waste PET bottle recycling plant was designed based on the most appropriate collection scheme that has the highest potential of generating such waste bottles with a view to investigate into its economic viability.

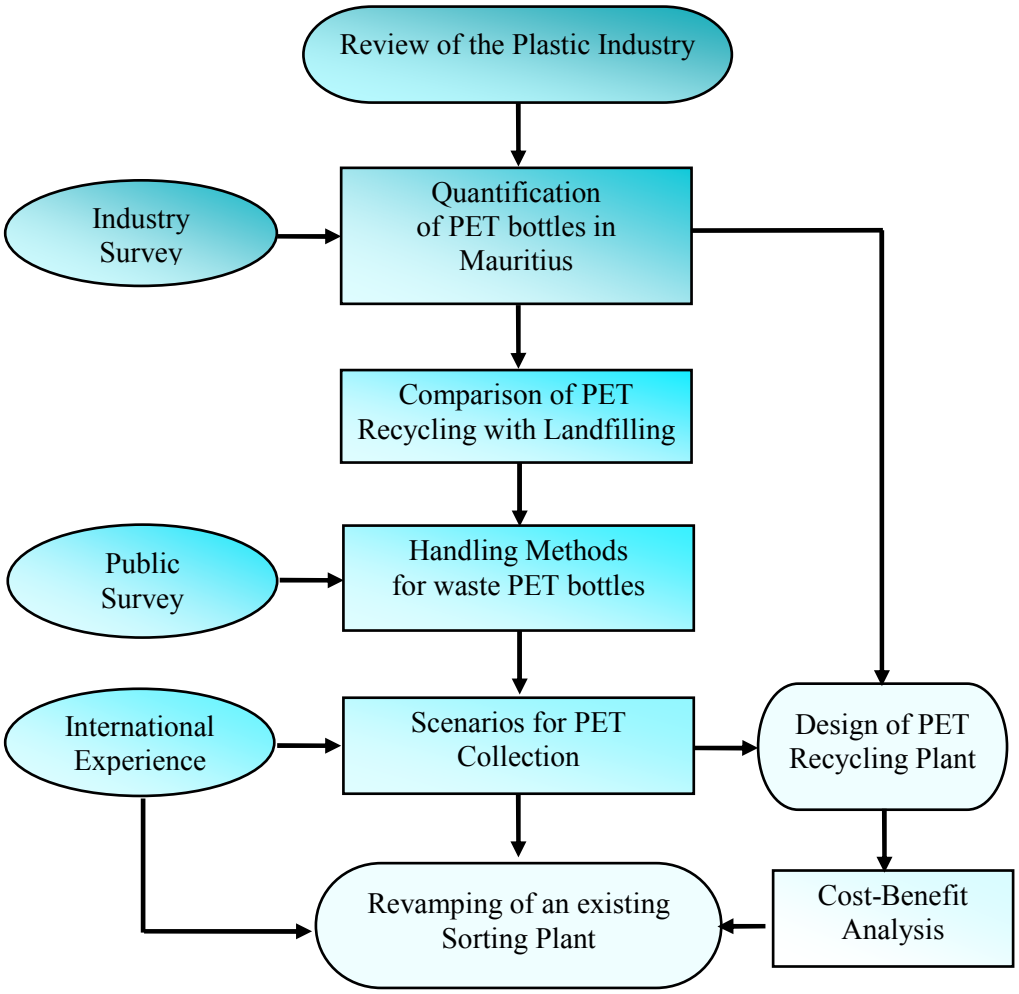

Figure 1: Schematic diagram of the methodological framework for performing this study

3. QUANTIFICATION AND HANDLING WASTE PET PLASTIC BOTTLES

3.1 Quantification of PET plastic bottles

An industry survey was conducted among all the major PET plastic users to determine the amount of waste PET bottles being generated. The total amount of PET produced by the soft drink industries in 2005 was 2511.3 tonnes. As for the detergent and oil industries, they produced only 7.28 tonnes since they use other types of plastics as well for the packaging of their products. For instance HDPE (High Density Polyethylene) was used for the 5 litre detergent bottles and LDPE (Low Density Polyethylene) for oil pouches. The typical sizes of the PET containers being used by the soft drink industries were also determined during the industry survey which is shown in Figure 2. It was found that the 0.5L and 2L soft drinks bottles sizes represented around two third of the total amount of bottles used by the soft drink producers. More than half of the total amount of water bottles produced was of 1.5L size.

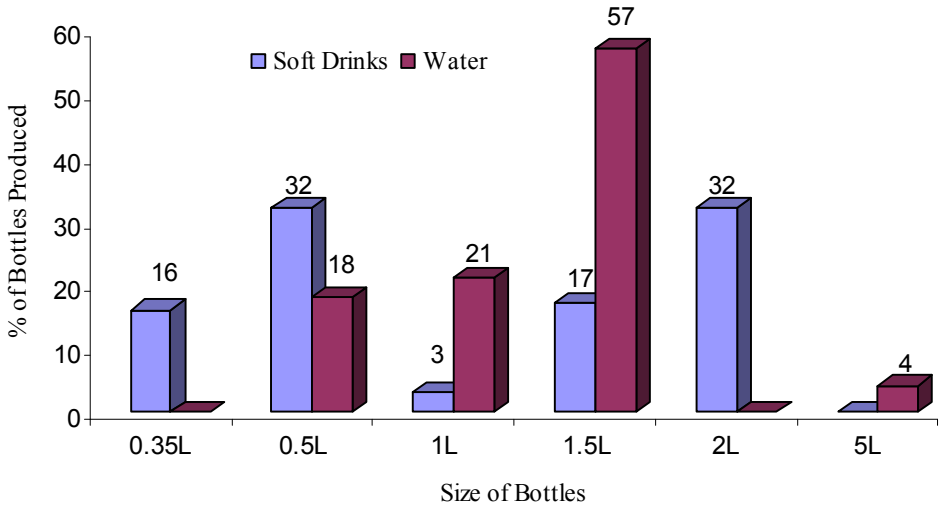

Figure 2: Amount of PET bottles produced in 2005

3.2 Comparison of PET recycling with landfilling

In Mauritius most post consumer PET bottles find their way at Mare Chicose, which has almost reached its saturation point. Since these bottles are voluminous and non-biodegradable, they occupy a large space in the landfill, which could otherwise be used to accommodate other non-valuable wastes. Moreover, they contribute to other negative impacts of landfilling such as breeding ground for insects and health hazards. One alternative means of disposal would be to recycle these PET containers into useful products, which would provide a source of revenue and at the same time create job opportunities. Other benefits of recycling PET are as follows:

a) It decreases the dependence on the natural oil reserves.
b) It saves energy and reduces greenhouse gas emissions.
c) It minimises the environmental impacts associated with raw material extraction, refining, manufacture and transportation.
d) It increases the lifespan of the landfill.

3.3 Public involvement in the recycling programme

A public survey was conducted to know whether the population was aware of the negative impacts of waste PET plastics when dumped into the environment. Concurrently, the preferred method for the proper disposal and collection of the used plastic containers was determined among the public. It was also determined whether there would be a market for recycled products from waste PET bottles.

It was found that most Mauritian was aware of the impacts of PET on the environment. However, only 61% of the population was aware of the presence of specific bins placed around the island for disposal of used PET plastic bottles. As for the most preferred handling method of post-consumer bottles, 79% of the persons surveyed prefer source separation rather than drop off points since they

found it more practical. As far as bottle bill legislation is concerned, 79% of the population is interested in this system mainly because of the cash received in return. Prize competitions can encourage the collection of PET since money or gifts are given to the winner. However it was found that only 58% of the population is interested in this activity where again the main reason being the gifts received in return. It will be useless to spend large amounts of money on the recycling process if there is no market for recycled products. Response to this question proved that 93% of the population would be willing to buy such products with a view to help for the protection of the environment. But, they also expect the products to be cheaper than those made from virgin materials.

4. PROPOSED SCENARIOS FOR COLLECTION OF PET

The collection and disposal of solid waste is a difficult task, particularly in Mauritius. Therefore, in this age of mushrooming technology and scientific innovation, modern methods of collection should be adopted to alleviate the problem of land pollution, caused partly by waste PET plastic bottles. In this section, different collection scenarios are proposed and evaluated according mainly to their implementation costs as well as public acceptance.

4.1 Scenario 1: Actual system

This scenario consists of the usual collection of mixed household waste by the public and private haulers, which are then brought to the five transfer stations in the country namely La Brasserie, La Laura, Poudre d'Or, Roche Bois and St Martin, where they undergo compaction before being disposed at Mare Chicose, the only landfill. However, to improve this system, a Material Recovery Facility (MRF) could be introduced to sort, process and store the different recyclable materials, one of which is PET. Each recyclable could then be sent to their respective recycling plant. The MRF would handle the commingled waste more efficiently and in a cost-effective manner. Moreover, since the five transfer stations already exists in the island they can be converted into MRFs and thus reduce the capital costs involved in implementing such facilities. Another advantage of the MRF would be the creation of jobs for a number of people.

4.2 Scenario 2: Kerbside collection system

From the survey carried out it was found that 79% of the population prefers source separation. To implement such system in Mauritius, it is necessary to supply each household with a new bin to cater for PET plastic bottles only. However, to make the collection more economically viable and improve waste recycling, other recyclables can be collected at the same time, which would also result in lower CO_2 emissions arising from their transport. Thus, a minimum of two more bins of different colours will have to be supplied to the households. This collecting method is well established in many developed countries such as Belgium and Germany. Regarding space requirements for the bins, the two-wheeled type, suitable for lifting and emptying at the collection vehicles using hydraulic powered mechanism could be considered since they are more compact. However at the beginning of the implementation phase it would be difficult to supply all the bins at the same time. The main disadvantage of this system is its high initial cost. However, plastic bags of different colours can be given to the population as an alternative.

Collection of the separated wastes can be done using existing equipments such as refuse collection trucks, pickup trucks, and dump trucks, which can then be expanded by using more specialized vehicles such as the compartmentalized vehicles shown in Figure 3.

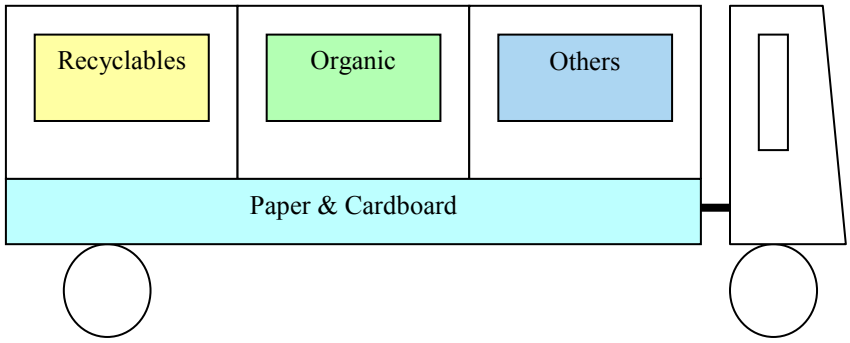

Figure 3: Compartmentalized vehicle for waste collection

4.3 Scenario 3: Drop off points

This system is already in place in Mauritius since 2001 where around 60 bins have been placed in supermarkets, on the beaches and in some centres. However, this collection technique can be made more successful by providing larger quantities of bins all over the island so that they are accessible to almost everyone, as is being done in Italy, where more than 40 % of the population has accessed to some 24,500 PET bins and in Switzerland, where there are more than 12,000 drop off points (Petcore Organisation, 2006). During the initial phase of the project, the bins could be placed in strategic places where PET is extensively being used such as schools and universities, shopping areas, food courts, stadiums, and other public places. An awareness campaign through posters, media and other relevant means would highly favour public participation.

4.4 Scenario 4: Bottle bill legislation

This legislation establishes a redemption value on carbonated beverage and water containers and thus provides an economic incentive for the consumers to return their bottles. This approach has a high recovery rate of 90% and is well established in Scandinavian countries, the Netherlands, Germany, Switzerland and Austria (Petcore Organisation, 2006). The survey conducted on the public showed that 79% of Mauritians agree with this initiative, which facilitates recycling by aggregating large quantities of PET bottles at the retailers and wholesalers that are then collected by recyclers. This system seems the best alternative for collection of PET since it has a low capital investment.

Figure 4: Bottle-shaped recycling bin
(Source: Napcor)

4.5 Scenario 5: Return vending machines

Some return vending machines can be placed in children parks and fairs only to make the young population conscious about the environment. Sweets or chocolates can be received upon placing the PET bottles in the machines and they could contain schematic diagrams of the PET cycle, which can be done using cartoons so as to attract the attention of the children. Thus, the vending machine can also serve as a means of awareness among the young population thereby inculcating a new culture towards recycling and the efficient use of natural resources.

4.6 The Proposed scenario for PET collection in Mauritius

Each scenario has its own benefits and constraints. Since people are usually reluctant to change their habits, scenario 1 (actual system) seems to be more appropriate in this context. However, significant capital investment will be required to convert the five existing transfer stations into MRFs, where different sorting technologies will be needed. Moreover, it will take quite a long time before they could operate. As for scenario 2 most of the Mauritians are willing to undertake source separation, which is one of the most appropriate means to collect PET. However, bins should be supplied to the households, which would again require an initial high capital. An alternative would be to supply plastic bags to kick off the project. As far as scenario 3 is concerned, supplying more bins on the island would require additional investment, space and time but their presence would be very important. If recycling and buy back centres are considered, a large land area is required to accommodate all the recyclables. Furthermore, significant funding will be needed for the recycling process, which also has some environmental impacts on both human and on the ecosystem, such as noise, water pollution and aesthetic problems. Scenario 4 appears to be the best method to collect PET since it does not require any land space and capital investment and it is approved by 79% of the population.

However to maximize the recovery and value of PET plastic containers it is equally important to establish an effective and ongoing consumer education program, regardless of collection system design. Studies made by the American Plastics Council indicate that participation in local recycling programs can be increased by 10% to 20% following educational and promotional campaigns. However, it has also been shown that participation will decline unless the educational and promotional efforts are maintained.

5. DESIGN OF PET RECYCLING PLANT

Figure 5 shows a schematic diagram of the different unit operations required for PET recycling. The different steps are explained in the following sub-sections.

5.1 Collection

PET can be collected by different methods as discussed in Section 4. The main options are:

a) Kerbside collection, which consists of separating the bottles from other household waste into special bags for pick up by the private haulers.
b) Drop off system, which consists of collecting the PET bottles and disposing them into special bins.
c) The bottle bill system, where a redemption value is paid upon purchase of any beverages and this amount is given back to the consumer when the bottles are returned.

The bottle bill legislation system is considered in this study.

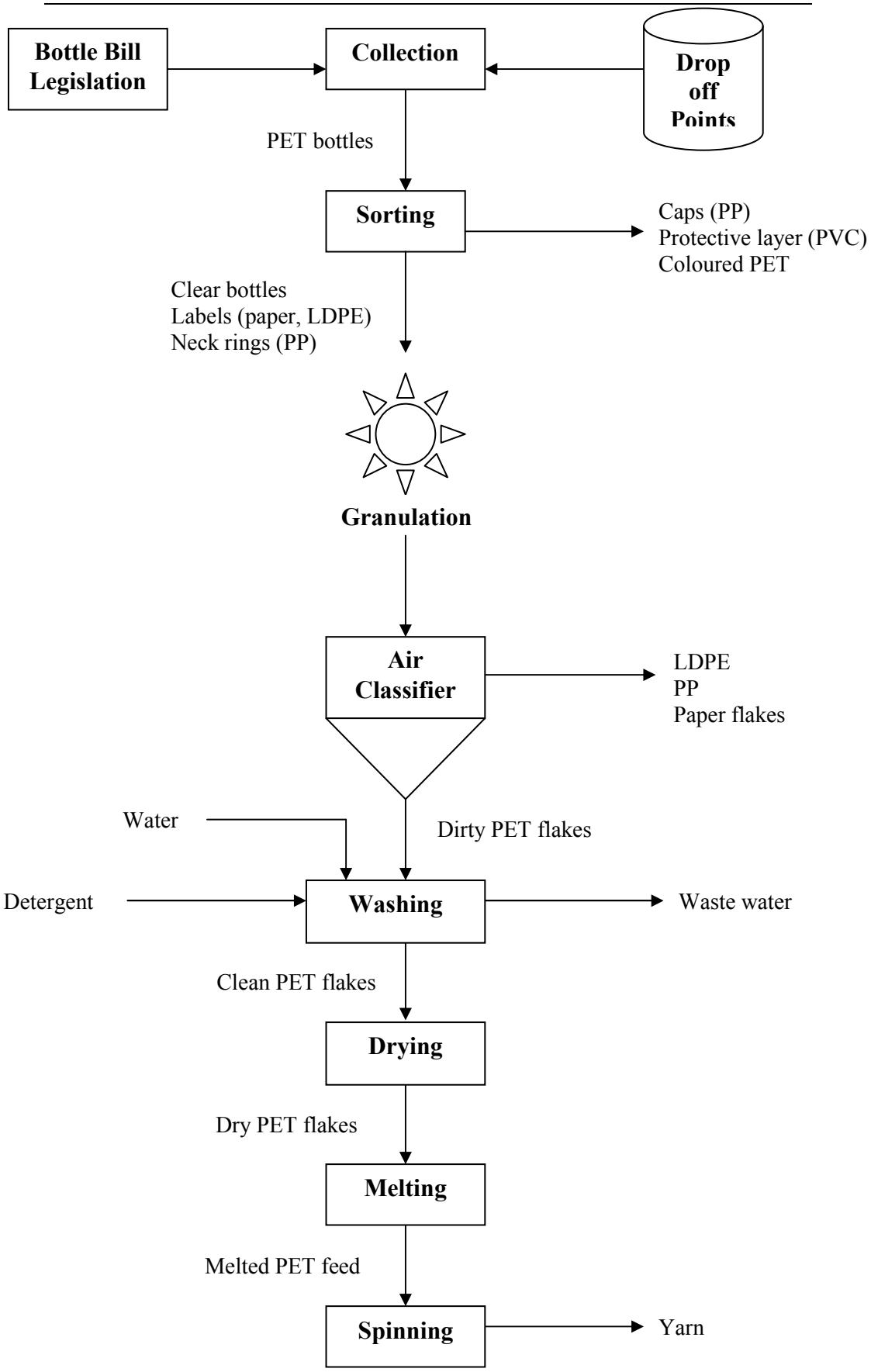

Figure 5: Schematic diagram of a waste PET bottles recycling plant

5.2 Sorting
After collection of PET plastic bottles, they are sorted and prepared for sale. PET becomes more valuable after each step in the recycling process and is in a better form to be marketed. It can be sorted manually or automatically based on the plastic type or number, colour, processing method and product type. This process is very important for PET since a small amount of contaminants such as PVC will result in very poor quality flakes, which will be difficult to be marketed.

5.3 Granulation
In this process the sorted PET bottles are cut into small flakes by a granulator. There are many types and sizes of granulators available on the market, each with specific design configurations. The choice of the equipment will depend on many factors such as the feed size and type, motor size, the size reduction ration and the throughput.

5.4 Washing
During the washing process, water and detergent are used to remove glue and dirt from the chips. Washing is done in two steps after which the flakes are rinsed.

5.5 PET Separation
After the flakes are washed and rinsed, they are sent to a settling tank where PET sinks to the bottom and lighter material such as PE floats. This tank works on the principle of difference in densities. The separation tank is supplied with a mixing tank, paddle rollers and PET screw feeder. Sometimes the separation process is done by an air classifier just after granulation.

5.6 Drying
The two types of dryers usually used in the PET recycling plant are the mechanical dryer and the thermal dryer with an injection blower. The mechanical dryer is used to dry the flakes by removing all the water molecules whereas the thermal dryer is used to reduce the moisture content of the flakes.

5.7 Melting
The dried PET flakes are then sent to an extruder, which is one of the most important elements in polymer processing. It consists of a heated barrel with a rotating screw inside. As the flakes move to the extrusion die they are converted into a melt under the action of heat and friction of the viscous flow and the mechanical action between the screw and the walls of the barrel.

5.8 Spinning Process
This process is used to manufacture all polyester fibres since it is the easiest spinning method. The equipments generally used for spinning consists of the extruder, which is connected to a manifold, which in turn is linked to different pack boxes. Each pack box contains a perforated steel plate with holes having a diameter of 200-500 mm. As the melt passes through the spinneret it splits into individual filaments generally at a rate of 5-30 m/min. Since fibres cool quickly after leaving the spinneret, they do not have enough time to assume the most stable thermodynamic state. Therefore drawing or stretching the fibres can improve their properties by increasing orientation, crystallinity and strength. As the filaments are

drawn away at rate of 250-5000 m/min quench air is blown over them so that they cool and become steady. The yarns must also be relaxed to achieve a low shrinkage to allow acceptable yarn packages to be produced. The final product, that is yarn, is sold to the textile industries for processing into cloth or carpets.

6. PRELIMINARY COSTING

A preliminary cost estimate was performed for a grass-root recycling plant having a capacity of 258 kg/hr and was found to have a payback period of 5.4 years. However, in Mauritius there already exists a facility which granulates PET for export. Therefore by expanding the actual facility into a complete recycling plant for the manufacture of textile yarn both the capital investment and the payback time can be reduced as given in Table 1. Hence recycling of waste PET bottles can be claimed to be economically viable in the island.

CASH FLOW	Grass Root Plant	Existing Recycling Plant
Fixed Capital Investment	141,971,970	110,494,721
Working Capital	25,053,877	19,499,068
Cost of collection bins	1,000,000	1,000,000
Total Capital Investment	168,025,847	130,993,789
Total Production Cost	124,935,333	97,235,354
Revenue	44,259,016	44,259,016
Gross Profit	-248,702,165	-183,970,128
Payback Period	5.4	4.1

Table 1: Cash flow for the grass root and existing recycling plant

7. CONCLUSION

Among the different types of plastics used in the packaging industry, PET is the most preferred one due to its high strength and good clarity. However, it is ubiquitous and causes a real eyesore in society if not properly disposed after its use. Unfortunately in Mauritius waste disposal is subjected to some constraints and some waste PET plastic bottles can be found freely dumped in the environment. As for those which did find their way to the landfill, they take up a large space which is becoming scarce nowadays. Therefore waste management has to be improved as early as possible to protect the environment.

Waste PET bottles could be collected through a number of options among which Kerbside collection system could be very appropriate for Mauritius, where the different components of the waste stream would be separated at home itself. This method is very efficient with a low level of contamination and it is actually in place

in many developed countries. However, extra bins would need to be supplied to each household, which would require some initial investment. The bottle bill legislation, which favours least capital investments, could also be applied in the island with the provision of some bins near the supermarkets. Indeed, the different schemes proposed in this study could be considered to make the collection of waste more economically viable. If compartmentalized trucks are used, transport cost would be minimized since the different categories of the waste could be collected at the same time and sent to their respective recycling facilities. Hence, it will favour recycling of other waste materials thereby enhancing the efficient and sustainable use of other natural resources.

8. RECOMMENDATIONS

It is highly recommended to make the Mauritian population aware about the solid waste disposal problem in the island with a view to boost up their participation in the recycling programme. Awareness is one of the vital components to help foster market development among the public and private sectors. The recycling programme should involve all the stakeholders of the PET plastic industry. The implementation of the recycling program will be successful only with the participation of the general public.

Some collection and pre-processing facilities could be implemented around the island, where their main purpose would be to provide opportunities for private individuals as well as some businesses to drop off their recyclable materials at a convenient distance from their residence and place of work. These facilities could be designed to treat the incoming waste for sales to the recyclers as is being done in most countries around the world where plastic recycling is practiced.

9. FUTURE WORKS

The quantity of waste PET plastic bottles can be found to be limited in the longer run. In this context, the cost benefit analysis of importing additional waste PET bottles from the region or surrounding islands could be performed based on the availability of the material.

The main components of the waste water coming from the recycling plant are sodium hydroxide solution, food residues and other waste particles. Therefore, this effluent should be characterized to check for any non-conformity with the effluent discharge regulation and thus propose appropriate treatment methods for the waste water. From the preliminary findings, it was found that the total water consumption was 1.2-1.4 m^3/h, which resulted in 3088.8 m^3 of water used per year having a total cost of Rs 30,900. However, the exact amount of water needed by the entire plant should be determined and at the same time investigate whether it is possible to recycle the water for reuse in the factory.

The spinning process is usually an energy-intensive process. It is necessary to determine the energy consumption of the facility and find alternative methods to minimize the energy requirements.

ACKNOWLEDGEMENTS

The authors are grateful to Mr. Ismet Koussa from Quality Beverages Limited, Mr. Claude Pougnet from Phoenix Camp Minerals and Mr. Akhil Ramjaun, from Polypet Recyclers Limited for all the useful information provided for the realization of this project.

REFERENCES

AMCOR, 2000. *More Recycled PET from Amcor*. Available from: http://www.beveragedaily.com/misc/misc.asp

AMERICAN PLASTIC COUNCIL. *The History of Plastic*. APC, USA. Available from: http://www.plasticresource.com

ANON, 2005. *National Waste Management Profile*. Available from: http://www.iswa.org/uploadfiles/final_waste [1st October 2005]

ANON, 2005. *Report from the Ministry of Environment*. Mauritius

BUHLER, A.G. *Transforming PET Bottle Back Into Bottles*. Sovereign Publications, Germany. Available from: http//www.buhlergroup.com [15 March 2006]

CARL BRO, 2005. *Environmental Solid Waste Management Project*. Feasibility Report. Government of Mauritius.

CENTRAL STATISTICS OFFICE, 2004. *Digest of Demographic Statistics 2004*. Ministry of Economic Development, Financial Services, Corporate Affairs, Mauritius.

CENTRAL STATISTICS OFFICE, 2004. *Digest of Environmental Statistics 2004*. Ministry of Economic Development, Financial Services, Corporate Affairs, Mauritius.

CENTRAL STATISTICS OFFICE, 2004. *National Accounts of Mauritius Year 2004*. Ministry of Economic Development, Financial Services, Corporate Affairs, Mauritius.

COULSON, J.M., RICHARDSON, J.F., SINNOTT, R.K., 1989. *An Introduction to chemical Engineering Design*. Macmillan, New York.

FITCHNER, 2000. *Environmental Solid Waste Management Program*. Feasibility Report. Government of Mauritius.

HOUGHTON, H.W., 1981. *Developments in Soft Drinks Technology*. Applied Science Publisher, USA.

MINISTRY OF ENVIRONMENT, 2005. *Mauritius Staking Out the Future*. Ministry of Environment, Mauritius.

MINISTRY OF ENVIRONMENT, 2001. *Environment 2001 Year of Achievement*. Ministry of Environment, Mauritius.

PEPSICO INTERNATIONAL. *The Manual for PET Bottles Requirements*. QBL, Mauritius.

PETCORE ORGANISATION. *Polyethylene Terephthalate*. Available from: http://www.petcore.org

POLYPET INDUSTRIES LIMITED, 2005. *Monthly report.* Ministry of Environment, Mauritius.

SOUTH AFRICAN POLYESTER RECYCLERS, 2005. *PET-Refreshed*. SAPR, South Africa.

MINISTRY OF ENVIRONMENT, 2002. *Meeting the Challenges of Sustainable Development.* Ministry of Environment, Mauritius.

TCHOBANOGLOUS, G.H., THIELSEN, H.,VIGIL, S., 1993. *Integrated Solid Waste Management.* McGrawhill, New York.