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Optimization of food waste utilization in the RDF recovery energy facility

[1*]Abdul Rashid, Z., [1]Alias, A.B., [1]Ku Hamid, K.H., [2]Wan Omar, W.A. and [3]Wan Abdul, K.G.

[1]*Faculty of Chemical Engineering, Universiti Teknologi MARA, 40450, Shah Alam, Malaysia*
[2]*Perunding Bebas Risiko Ekonomi dan Alam Sekitar, Malaysia*
[3]*Department of Chemical and Environmental Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia*

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Abstract

It is well known that there is a significant increased in the quantity of Municipal Solid Waste (MSW) generated every year. Therefore, the management of MSW must be handled carefully by experts. Malaysia as one of the developing country with population nearly 30 millions also facing problems related to MSW management and this issue is quite critical. Even though various programmes were established and few model technologies were introduced by the government to manage MSW effectively, but the impact remain unsatisfaction. For example, the energy facility recovery project which use MSW gathered around Kajang as an alternative fuel still not successful to provide energy according to the design capacity of that particular facility. This failure was observed due to the impact composition of MSW collected which consists huge amount of food waste (57%), 16% plastic, 15% diaper, 9% mixed papers and the remaining 3% textile. The existing process technology at Refused Derived Fuel (RDF) facility is no designed to create a new economic benefit from abundant incoming food waste to the facility. Therefore in this paper, the analysis and suggestion of technology on existing RDF recovery energy facility will be discussed especially on how to overcome the abundant composition of food waste..

Introduction

Environmentally safe solid waste management is getting more and more relevant in all parts of the world in order to protect the natural resources like soil, ground and surface water, air, flora and fauna as well as our fellow human beings. Thus, appropriate waste management approaches and schemes require consequent collection of the refuse and as a minimum its disposal in sanitary landfills comprising leachate and gas collection. However, due to vast Malaysian MSW characteristic differences compared to developed country MSW such as the varies MSW technologies are developed and the non separation of MSW at source which is the status quo in Malaysia has resulted the Malaysia government to find the best available technology solution. Consequently, in the year 2009 an RDF plant comprises of solid waste receiving area (8 conveyors), waste recovery, shredding, drying and separation units for the RDF production was built at Semenyih, District of Hulu Langat, Selangor, Malaysia. The plant can process about 700 tonnes of raw MSW per day, and operate 16 hours a day. The general process of RDF plant combustion utilizes an engineered RDF moving grate combustion furnace at a temperature between 550°C -630°C and the produced gases are combusted in a secondary combustion chamber at a temperature approximately 1100°C. Heat energy is recovered by exchange with water to generate steam and drive a turbine for generation of 7.35 MW electricity power. Nevertheless, the RDF alternative fuel is still not successful to provide energy according to the design capacity of that particular facility. This failure was observed due to the impact composition of MSW collected which consisted huge amount of food waste (57%), as compared to the plant designed receiving of food waste composition which is 30 to 49%. Therefore in this paper, the analysis and suggestion of solution on existing RDF recovery energy facility will be discussed to overcome the abundant composition of food waste.

*Corresponding author.
Email:*zulmas06@yahoo.com.my*

Materials and Methods

The assessment of waste composition and characteristics implication at RDF plant is based on our plant visit investigation, some discussions with the top management team and the technology provider consultant, as well as on the literature review of the market report on the RDF technology applications and practices. Five years audited financial report (2005 to 2009 financial years) and plant performance progress report prepared by the company auditor submitted were also reviewed.

Expected of waste composition and characteristics

It is expected that there will be about 150-200 lorry trips per day. The municipal solid waste generation rate is also expected will be increased to 2.5% per annum. The major MSW generated within Kajang district are kitchen wastes, plastics and papers that make up of 65 to 75% of the waste collected. The calorific value of these waste is in the range of 1250 to 1500 kcal/kg. The characteristics of raw municipal solid wastes as reported in (DEIA, DOE, 2004) are as shown in Table 1.

Expected of material flow

It is expected that the material flow is shown in the RDF process flow chart (Figure 1) where the sequence and amount of recyclables, residues and product is expected to be obtained as shown in Table 2.

Table 2. Operational condition for RDF plant

Item	Operational condition
Operating lines	2 lines for the first 12 months of operation /4 lines after 15 months
Treatment capacity	231,000 tonnes of MSW per year
Expected operation period	330 days

Table 1. RDF MSW Average values

Basis	700	Tonnes per day	MSW processed			
Items	kg	%w/W	%w/W (wet basis)	Tonne	Water range %w/W	water %
Combustible Food waste	1,205.10	30 to 50	41.14	288	30-65	51
Mix paper	310.5	5 to 15	10.6	74.21	30-50	41
Plastic thin	499.7	7 to 25	17.06	119.42	5-10	8
Plastic rigid	95.2	1 to 5	3.25	22.75	5-10	8
Polystyrene	42.5	1 to 5	1.45	10.16	5-10	8
Textiles	50.5	1 to 5	1.72	12.02	20-35	25
Rubber& leather	36.6	1 to 5	1.25	8.75	10-20	15
Wood	76.9	1 to 5	2.63	18.38	40-60	50
Other combustible	30.6	2 to 10	1.04	7.31	40-60	50
Yard waste	157.8	1 to 5	5.39	37.71	40-60	50
Fines	38.5	2 to 10	1.31	9.2	30-60	45
Diapers	120.3		4.11	28.75	40-60	50
Total	2664		90.95	636.66		

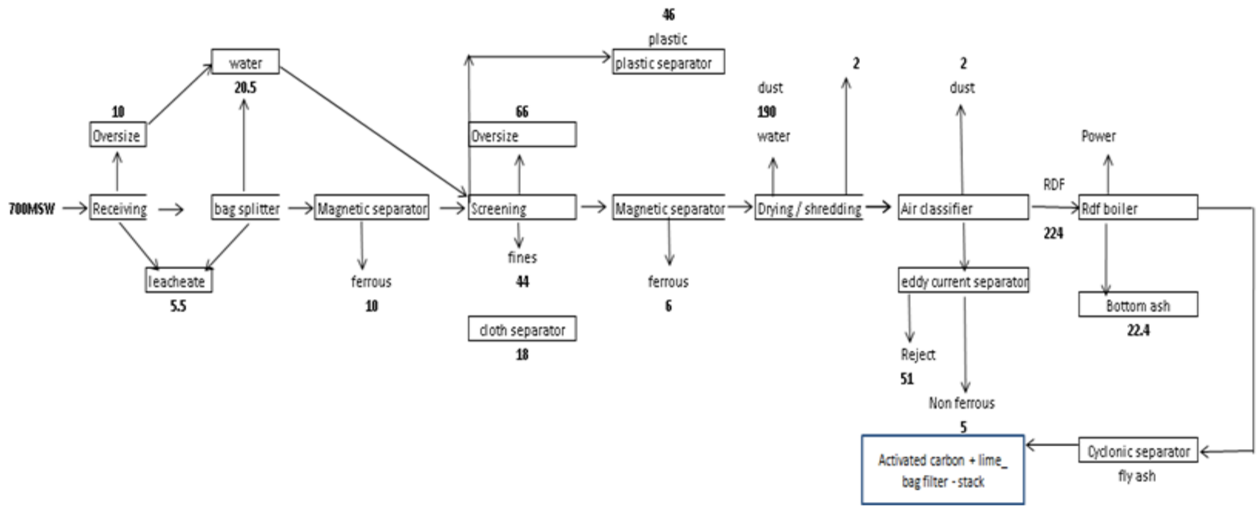

Figure 1. RDF process flow chart (476 tonnes per day + RDF processed 224 tonnes per day)

Results and Discussion

Assessment of material flow

Appendix 1 shows incoming and outgoing waste during nine weeks observation period outside of the plant. The volume of incoming waste to the plant varies from day to day from the highest 593.7 tonnes per day to nothing at all. There are several days (6.7% of total days) during our investigation period that the plant declines to accept incoming MSW. The outgoing waste volume also shows a similar pattern in terms of high and low of tonnage. The high tonnage of outgoing waste from the plant is 475.0 tonnes per day, and there are days that there is no outgoing waste from the plant. Details of the waste volume composition are presented as in Figure 2. The composition of MSW from Kajang area for 4 days consists of 55-57% food waste, 16% plastic, 15% diaper, 9% mixed papers and the remaining 3% textile. Meanwhile, the waste composition within the bunker of the plant comprises of 48% food waste, 18% plastic, 11% diaper, 14% mixed paper and 9% textile. However, according to company representative, waste characterisation has not been a regular practice at the RDF plant presently.

Assessment from RDF process plant performance

Basically, RDF facility receives waste primarily from Kajang. The RDF plants have four parallel lines of material recovery facilities (MRF), and larger throughput can be accommodated with adjustment to operational hours. Nevertheless, not all lines could be fully operational ran to receive all MSW from Kajang Municipal township (KMT) presently due to some technical and operational problems. The plants also have experienced several intermittent stoppages as results from major repair works from fire and technical failures. The receiving waste composition to Recovery Energy Company (REC) facility comprises predominantly kitchen wastes, plastics and papers that make up of 65 to 75% of the total wastes collected (DEIA, DOE, 2004). Whilst the residue materials consisting of some inert and non-recyclables and bottom ash and, fly ash are disposed at a sanitary landfill and a hazardous landfill site, respectively.

The REC/Waste to Energy (WtE) facility consists of the following physical entities (DEIA, DOE, 2004): RDF Plant, Recycling Centre, Power Generation Area, Leachate Treatment Plant, Water Treatment Plant and Composting Plant.

	1st Day (BJV 6718 Alam Flora)			2nd Day (Bunker)			3rd Day (BHU 2972 Desa Bangi)			4th Day (Bunker)			TOTAL		
Items	Kg	Range % w/W	% w/W (wet basis)	Kg	Range % w/W	% w/W (wet basis)	Kg	Range % w/W	% w/W (wet basis)	Kg	Range % w/W	% w/W (wet basis)	Kg	Range % w/W	% w/W (wet basis)
A. Combustible															
Food Waste	111.95	30 to 50	55.14	37.32	30 to 50	33.93	48.70	30 to 50	41.81	67.50	30 to 50	43.09	265.47	30 to 50	45.59
Mix Paper	9.68	5 to 15	4.77	14.94	5 to 15	13.58	15.68	5 to 15	13.46	16.38	5 to 15	10.46	56.68	5 to 15	9.73
Plastic Thin	29.62	7 to 25	14.59	13.66	7 to 25	12.42	14.98	7 to 25	12.86	26.32	7 to 25	16.80	84.58	7 to 25	14.53
Plastic Rigid	5.06	1 to 5	2.49	3.52	1 to 5	3.20	2.90	1 to 5	2.49	3.84	1 to 5	2.45	15.32	1 to 5	2.63
Polystyrene	1.76	1 to 5	0.87	1.18	1 to 5	1.07	1.30	1 to 5	1.12	1.48	1 to 5	0.94	5.72	1 to 5	0.98
Textiles	6.62	1 to 5	3.26	12.90	1 to 5	11.73	3.42	1 to 5	2.94	6.56	1 to 5	4.19	29.50	1 to 5	5.07
Rubber & Leather	3.16	1 to 5	1.56	2.18	1 to 5	1.98	0.78	1 to 5	0.67	0.38	1 to 5	0.24	6.50	1 to 5	1.12
Wood	n/a	1 to 5	0.00	2.00	1 to 5	1.82	0.46	1 to 5	0.39	0.48	1 to 5	0.31	2.94	1 to 5	0.50
Other Combustible	0.32	1 to 5	0.16	0.92	1 to 5	0.84	1.10	1 to 5	0.94	2.96	1 to 5	1.89	5.30	1 to 5	0.91
Yard Waste	2.90	2 to 10	1.43	3.10	2 to 10	2.82	3.20	2 to 10	2.75	3.28	2 to 10	2.09	12.48	2 to 10	2.14
Fines	3.73	1 to 5	1.84	0.98	1 to 5	0.89	0.42	1 to 5	0.36	0.38	1 to 5	0.24	5.51	1 to 5	0.95
Diapers	23.06	2 to 10	11.36	7.06	2 to 10	6.42	19.56	2 to 10	16.79	17.44	2 to 10	11.13	67.12	2 to 10	11.53
Total A	**197.86**		**97.45**	**99.76**		**90.69**	**112.50**		**96.58**	**147.00**		**93.83**	**557.12**		**95.69**
B. Non Combustible															
Glass	2.22	1 to 5	1.09	3.80	1 to 5	3.45	2.14	1 to 5	1.84	6.50	1 to 5	4.15	14.66	1 to 5	2.52
Ferrous	n/a	1 to 5	0.00	1.05	1 to 5	0.95	0.32	1 to 5	0.27	0.00	1 to 5	0.00	1.37	1 to 5	0.24
Aluminium	0.87	1 to 5	0.43	0.22	1 to 5	0.20	0.26	1 to 5	0.22	0.18	1 to 5	0.11	1.53	1 to 5	0.26
Non Ferrous	0.87	1 to 5	0.43	0.98	1 to 5	0.89	1.16	1 to 5	1.00	0.72	1 to 5	0.46	3.73	1 to 5	0.64
Other Inorganic	1.22	1 to 5	0.60	0.25	1 to 5	0.23	0.10	1 to 5	0.09	2.26	1 to 5	1.44	3.83	1 to 5	0.66
Total B	**5.18**		**2.55**	**6.30**		**5.73**	**3.98**		**3.42**	**9.66**		**6.17**	**25.12**		**4.31**
TOTAL	**203.04**		**100.00**	**106.06**		**96.42**	**116.48**		**100.00**	**156.66**		**100.00**	**582.24**		**100.00**

Figure 2. Waste characterization at the REC/RDF/WtE for 3 days

Within these facilities are the unit processes of: MSW bag splitting, Leachate collection system, Magnetic separation, Screening process – trammel and vibrating screens of various sizes, Plastic separation – by airlift system, Cloth separation – manual process, Hazardous and recyclables separation – manual process, Two-stages drying and shredding – for drying and sterilisation of combustible portion into bio-inerts, Air classifiers as a differential density separator, Bunker storage of RDF and feeding to power plant, Power plant and Effluent treatment – ammonia treatment, chemical treatment, anaerobic and aerobic treatment and final polishing

Based on observation at the operation, the equipment is is slightly different with proposed plant described in Detail Environmental Impact Assessment (DEIA) report. MSW from bunker is grabbed into the hopper through bag splitter. Plastic bags have been split inside the bag splitter and transferred onto a conveyor to the rotary screen. According to the plant proposal, there are magnetic separator before screening process and another magnetic separator together with cloth separator after screening process. But currently there is no cloth separator and only one unit of magnetic separator used after screening process. Meanwhile clothes are sorted by manual picking. Ferrous material is removed out by using magnetic separator before and after rotary screen. But the current operation magnetic separator is only used before the waste has been dried in the pre-dryer. The dry waste was then transferred to the main conveyor to be shredded. According to RDF representatives, air classifier is no longer used to separate solid rejects from RDF needed as proposed, due to the calorific value of solid reject is exceeded 3450 kcal/kg. This showed that the solid reject is currently used as fuel or RDF in order to generate energy. Thus, REC/RDF decided to stop using the air classifier for the existing plant.

Optimization new bio energy facility to RDF process plant facility

One of the main functional capabilities of RDF plant is to recover recyclable materials from MSW for sale in the open market, so as to generate an additional revenue for the plant. Management's estimate for the recyclables is about 2.0 per cent of the total input MSW consisting of RDF fluffy, plastic scraps, and some metallic items. The average price for the RDF fluffy in the open market is estimated at RM 1,000 per tonne which is highly demanded by the kiln cement plants in Malaysia. Other recyclable items are also reported to be easily saleable locally as there are numerous recycling plant presently operating in Malaysia. The other income opportunities for the plant include sale of compost from the proposed composting facility. Thus the plant is planned to be equipped with composting facility with capacity of 105 tonnes per day and the average selling price for compost is estimated at RM 25.00 per tonne. The quantity of food waste received by rdf plant facility is high, which is more than 40 to 60% about 200- 280 tonnes per day (from 400 to 500 tonnes dry waste per 700 tonnes) with a huge moisture content therefore, the amount of MSW fuel to be used is low. With the proposed bio- recycling system to utilized food waste for fuel ethanol production, it is predicted that the RDF plant revenue going to be increased. The bio energy waste facility consists of a two-stage fermentation process which is based on (Koike *et al*., 2009) method involving the preservation of the garbage, crushing, dilution with water, saccharification of the garbage, solid–liquid separation, continuous ethanol fermentation of the separated saccharified liquid and anaerobic treatment of the saccharification residue. SSF Koike *et al* method has improved when water from leacheate treatment plant is re-used during food waste dilution process. Meanever heat recovery from furnace combustion system is used to reduce energy costs for distillation, therefore those processes are expected to improve and enhance plant efficiency. For the assessment of mass and energy balance of the Simultanaeus Saccharification Fermentation (SSF) process is used. Food waste (288 tonnes as in Table 1) was liquefied with α-amylase, fermented by SSF, and subsequently anaerobically digested by dry methane fermentation. The concentration of ethanol produced during SSF was 45.8 g/kg—fermented mash and the distillation yield was about 98%. By following Koike *et al*. (2009) mass calculation, the gas evolution efficiency was predicted to produced 850 ml/g-VTS (volatile total solid). Thus the amount of biogas evolved during dry methane fermentation is estimated 3.2 x 10^7l and the methane content at 850 ml/g-volatile total solid VTS and 51%, respectively is 1.6 x 10^7l. The combustion energy of garbage, liquefied garbage, fermented mash and stillage was measured with a calorimeter. The total measured combustion energy of the fermented mash was only 1.89 x 10^8 kcal/288kg - 656.36 kcal/kg. The total combustion energy was then corrected to 2.8 x 10^8 kcal (917 kcal/kg) by addition of the energy of ethanol contained in the fermented mash (6,747.8 kcal/kg—ethanol (lower heating value of ethanol)×13.02t = 8.8 x 10^7kcal).This low value was considered to be due to the vaporization of ethanol during the sample preparation through drying. As shown in Figure 3, 98.8% of the combustion energy of the garbage was

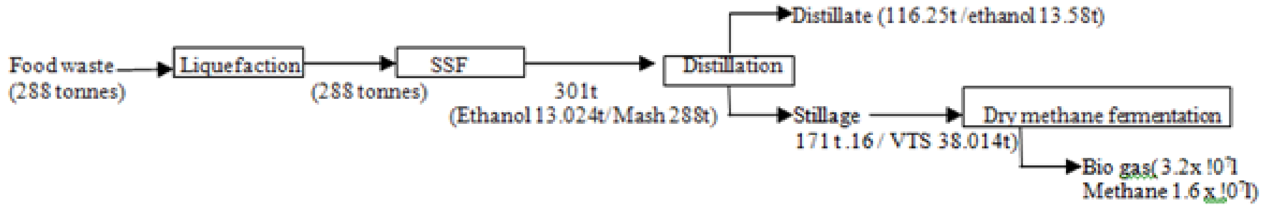

Figure 3. Material and energy balance of the liquefaction–SSF–dry methane fermentation of food waste followed modified (Keiko et al., 2009) method.

As reported in detailed EIA report (DEIA/DOE 2004), a 7.35MW steam power plant is installed based on RDF fuel as in Figure 4. The turbo generator set will be the extraction –condensing type.

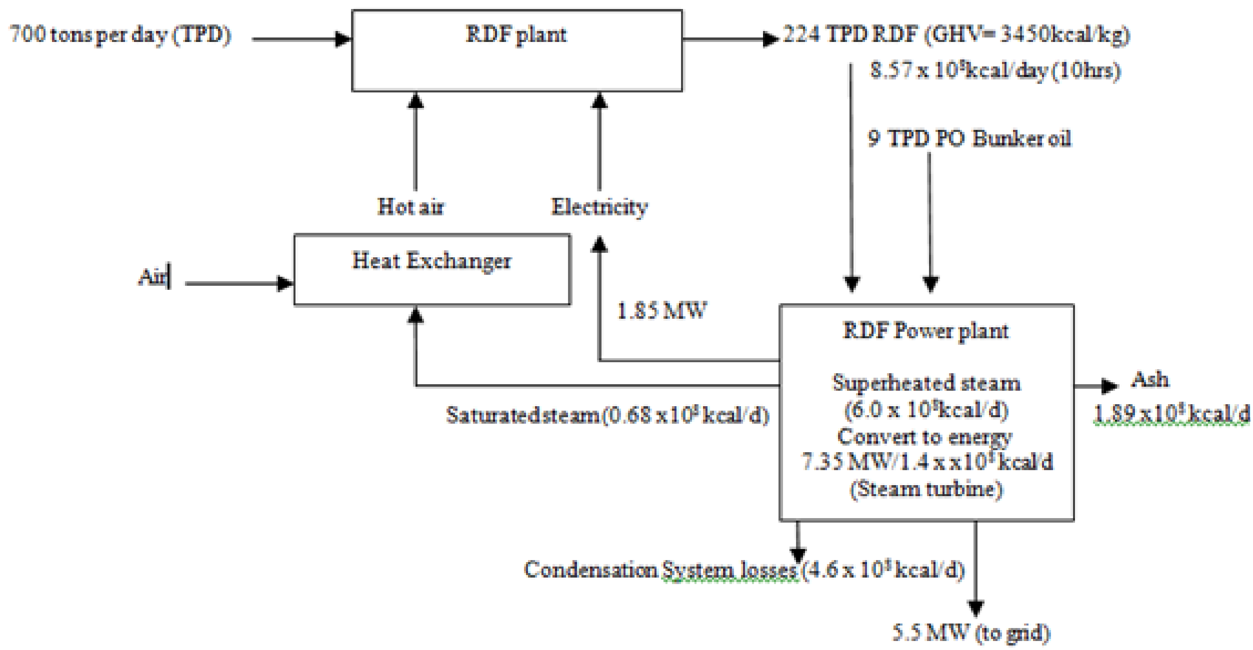

Figure 4. Material and Energy balance turbo generator set

recovered by liquefaction of the garbage followed by SSF, while 99% of the combustion energy of the fermented mash was recovered after distillation. The results indicate that 85% of the combustion energy of the garbage was recovered as ethanol and methane by a process comprised of liquefaction, SSF and dry methane fermentation (Keiko *et al*., 2009).

As reported in detailed EIA report (DEIA/DOE 2004), a 7.35MW steam power plant is installed based on RDF fuel as in Figure 4. The turbo generator set will be the extraction –condensing type. As shown in Figure 4, the plant is equipped with power plant with power output at 7,350 kW/h. About 2,000 kW/h of generated power will be used internally by the plant and the balance of 5,500 kW/hour will be sold to TNB under a sale of recovery power agreement. However based on the past five years audited performance of the financial reports of RDF plant from Financial Year (FY) 2005 to 2009, the plant still does not really portray a full operating performance as a complete RDF plant per se. Both balance sheet and income statement show a negative trend throughout the period. The main reason is that the plant is not operating with profit because of higher opex than expected and the additional revenues from recyclable and sale of recovery power have not materialised. The results of calculated Altman Z-score (Amling, 1989; Caputo, 2001a, 2001b) confirms the overall financial picture of the RDF operating company, from decreasing at an average 45 per cent per annum from -0.407 in FY2006 deterioting to -0.822 in FY2009 (KPMG 2000). Table 3 confirm that the RDF plant is having severe liquidity problem due to negative operating margin.

The baseline operating margin is RM 34.70 based on from the findings of pilot study that was conducted in the year 2000. On this basis, the RDF plant is prepared to receive MSW from Kajang for a tipping fee at RM 35.00 per tonne. Even without the sale of power revenue, the RDF plant will still make an operating margin of RM 11.00 per tonne MSW or more than 30 per cent margin. Therefore the plant is predicted to over-estimates the opex figures when comes to the actual operations as shown in Table 3 by the large deviation (value %) of operating margin from the baseline figure.

Table 3. Operating margin in RM per ton MSW

Year	Baseline 2000	2006	2007	2008	2009
Tipping fee	35	35	35	35	46
Less: opex	24	86.8	96.7	94	159.74
Add	11	-51.8	-61.7	(59.00)	-113.74
Sale of Recovery power	23.7	-	-	-	4.89
Sale of Recyclables	-	5.63	8.16	18.46	10.2
Operating margin	34.7	-46.17	-53.54	(40.54)	-98.65
Deviation from baseline	-	-233%	-254%	-217%	-384%

The current level of (operational expenditure) OPEX is well above the tipping fee received from the Kajang for the MSW delivered at the RDF plant, thus generating a negative in operating margin amounting from RM 51.80 per tonne in 2006 to RM 113.74 per tonne in 2009 financial year, or depleting by an average of 16.9 per cent year. With this scenario, the future of the RDF plant will no longer economically sustainable unless a drastic action is taken to address this problem. Therefore by implementing the SSF–dry methane fermentation of food waste followed modified Keiko *et al* method, revenue power recovery is estimated will be added about 2.8 x 10^8 kcal/day as shown in figure 3.

Conclusion

It can be concluded that a new economic model is proposed when the SSF fermentation is introduced to RDF plant power recovery, to make the RDF revenue a viable investment provided adopt the new capex and total opex requirements. Beside that in order to make the technology is economically viable, the opex per tonne should be not more than the existing landfill tipping rate per tonne so that their benefit is more than the costs.

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Appendix 1

DATE	TOTAL INCOMING	TOTAL OUTGOING	% OF UNPROCESSED WASTE (OUTGOING WASTE)
Wed 16/12/2009	420.00	320.00	76.19
Thu 17/12/2009	400.00	320.00	80.00
Fri 18/12/2009	400.00	325.92	81.48
Sat 19/12/2009	415.89	413.89	99.52
Sun 20/12/2009	120.00	n/a	n/a
Mon 21/12/2009	555.31	90.23	16.25
Tue 22/12/2009	436.68	18.69	4.28
Wed 23/12/2009	394.83	n/a	n/a
Thu 24/12/2009	348.00	31.62	9.09
Fri 25/12/2009	546.00	116.91	21.41
Sat 26/12/2009	n/a	474.71	n/a
Sun 27/12/2009	n/a	210.96	n/a
Mon 28/12/2009	4.10	388.14	n/a
Tue 29/12/2009	2.88	367.14	n/a
Wed 30/12/2009	3.61	388.96	n/a
Thu 31/12/2009	223.32	313.25	n/a
Fri 01/01/2010	350.30	234.85	67.04
Sat 01/02/2010	1.85	270.52	n/a
Sun 01/03/2010	n/a	n/a	n/a
Mon 04/01/2010	4.07	91.91	n/a
Tue 05/01/2010	3.84	327.18	n/a
Wed 06/01/2010	1.07	309.30	n/a
Thu 07/01/2010	1.65	134.43	n/a
Fri 08/01/2010	1.77	280.67	n/a
Sat 09/01/2010	3.30	275.63	n/a
Sun 10/01/2010	4.00	22.41	n/a
Mon 11/01/2010	4.07	91.91	n/a
Tue 12/01/2010	3.84	327.18	n/a
Wed 13/01/2010	400.00	n/a	n/a
Thu 14/01/2010	404.89	70.36	17.38
Fri 15/01/2010	435.87	233.42	53.55
Sat 16/01/2010	471.38	139.62	29.62
Sun 17/01/2010	103.60	n/a	n/a
Mon 18/01/2010	593.65	250.21	42.15
Tue 19/01/2010	572.99	328.66	57.36

DATE	TOTAL INCOMING	TOTAL OUTGOING	% OF UNPROCESSED WASTE (OUTGOING WASTE)
Wed 20/01/2010	477.48	222.68	46.64
Thu 21/01/2010	400.73	376.56	93.97
Fri 22/01/2010	450.06	402.77	89.49
Sat 23/01/2010	418.79	308.38	73.64
Sun 24/01/2010	104.04	23.35	22.44
Mon 25/01/2010	561.59	354.61	63.14
Tue 26/01/2010	560.31	319.91	57.10
Wed 27/01/2010	387.42	198.12	51.14
Thu 28/01/2010	422.17	359.38	85.17

Recapitulation

	Incoming	Outgoing	%
Max	593.65	474.71	99.52
Min	1.07	18.69	4.28
Total days	44	44	44
No Waste	3	5	21
% No Waste of Total days	6.8%	11.4%	47.7%