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Production of Alternative Fuel from Optimized Mixture of MSW Residuals, Non-Hazardous Industrial Wastes and Agricultural Residues.

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Abstract
This study aims to produce an alternative fuel from optimized mixture of municipal solid waste residuals, non-hazardous industrial wastes and agricultural residues with a production plant design and detailed economic feasibility study. Waste types examined in this study are rice straw, cotton stalks, plastics, wood, used tires, olive pomace oil, paper, and dried digested sludge. Optimum mix selection criteria are; calorific value with a weighting factor 30%, density 15%, moisture content 15%, oxygen content 10%, and gas emissions 30%. Eight mixes are investigated and the optimum mix was 23% rice straw, 19.52% wood, 24.58% plastics, 18.43% cotton stalks, and 14.47% used tires. The optimum mix has a calorific value of 5272 cal/g, density of 311 kg/m^3, and moisture content of 1.94%. The proposed selling price of the alternative fuel produced is 1200 LE per ton covering all capital costs and operational & maintenance costs.

Keywords: Solid Waste, Solid Fuel, Alternative Fuel, Cement Manufacturing, Plant Design, and Economic Feasibility.

1. Introduction
The increase of human life quality as well as rapid industrial development have created a huge volume of solid waste (SW), which has become one of the most serious current environmental problems. Many methods have successfully been used to reuse different types of SW. Most of the SW can be transformed into useful products, and thus the proportion of SW that is being recycled, reused and recovered is increasing. Egypt's municipal solid waste (MSW) generation is 21 million tons per year in 2012 (NSWMP, 2013) and suffering from waste disposal problems and fuel shortages. In a way to partially solve both waste and energy problems simultaneously, some types of waste can be utilized as alternative fuel (AF) in energy intensive industries.

Cement production is considered an energy and carbon-intensive industry, accounting for 5% of global man-made carbon dioxide (CO_2) emissions (WBCSD, 2009), and consumes nearly 120 kg of coal per ton of cement. About 25 million ton of coal in the European Union is required annually by the cembureau members to cover the demand of cement in Europe. In 2005, the world cement industry consumed about 9 exajoules (EJ) of fuels and electricity for production (IEA, 2007). According to the data of the European Cement Association (cembureau, 2014), Global cement production in 2014 is estimated at 4.3 billion tones. Cement production is consuming thermal energy about 3.3 GJ/ton of clinker produced which is considered about 30 – 40 % of production costs (Giddings et al., 2000). Electrical energy consumption is around 90 – 120 kWh/ton of cement (European Commission [EC] 2001). The use AF in cement kilns is now common and increasing (Moses, and Chinyama, 2011). The usage of AF in cement manufacturing not only helps to reduce the emission but also has significant ecological benefits of conserving non-renewable resources (Trezza, and Scian, 2000).

Methodology
The methodology adopted in this study is presented in Fig. (1).

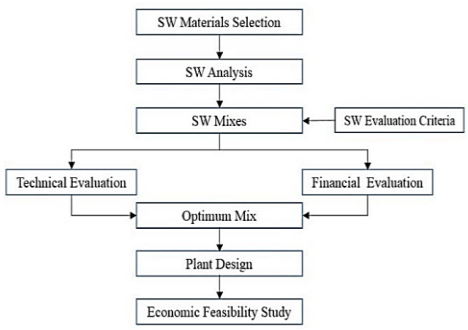

Fig. (1): Study Methodology

2. Solid Waste Materials Selection
Many types of SW materials can be used as an AF such as are petroleum coke, paper waste, dried pulp sludge, sewage sludge, used tires, plastic residues, wood waste, rice straw, cotton stalk, oil contaminated soils, green waste and other biomass, food waste, drill cuttings, tars, chemical wastes, used

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oil, and olive pomace oil. The selection criteria for the types to be used as AF in the current study are: availability in the Egyptian market, sustainability, high energy content, and low cost.

Based on these criteria, the following eight types are considered in this study:

- Rice straw, and cotton stalks (agriculture waste).
- Plastics, and paper (municipal solid waste).
- Olive pomace oil, wood, used tires, and dried digested sludge (industrial waste).

3. Solid Waste Analysis

The analysis results of each parameter are presented in Table (1). The analysis is carried out in science and technology center of excellence and new and renewable energy authority

Table (1): Solid Waste Materials Analysis Results

Parameter	Rice Straw	Wood	Sludge	Olive Pomace	Plastics	Paper	Cotton Stalk	Used Tires
CV (ca/g)	3,717	4,801	2,601	5,282	5,565	3,067	4,661	8,657
MC (%)	0.09	0.06	4.48	0.39	0.08	6.12	9.86	0.48
Density (Kg/m3)	60	450	600	910	72	63	113	1179
Carbon (%)	50.65	50.05	67	54.99	45.3	45	51	81.16
Nitrogen (%)	0.15	0.3	2.2	2.22	0.18	0.3	1	0.47
Sulpher (%)	0.08	0.05	0.8	0.08	0.08	0.3	0.01	1.64
Hydrogen (%)	6.2	6.04	5	8.21	6.17	6.1	4.9	7.22
Oxygen (%)	43	43.61	25	34.38	45.5	42.4	43.87	2.07

4. Solid Waste Evaluation Criteria

The criteria of SW mixes evaluation parameters are to maximize CV, and oxygen and to minimize MC, density, and gas emissions (carbon, nitrogen, and sulphur). Each parameter is given an optimum target value (based on analysis results) and proposed weighting factor from 100% as presented in Table (2). Five trials are conducted with different weighting factors to investigate the sensitivity of optimum mix selection to weighting factor.

Table (2): Criteria of Waste Mixes Evaluation

Parameter	Criteria	Target Value	Weighting Factor (%)				
			Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
CV (cal/g)	Max.	8657	30	20	20	40	40
MC (%)	Min.	0.06	15	20	10	10	20
Density (kg/m^3)	Min.	60	15	20	10	10	20
Oxygen (%)	Max.	45.5	10	10	15	10	5
CO_x (g CO_x/g fuel)	Min.	149.7	10	10	15	10	5
NO_x (g NO_x/g fuel)	Min.	0.35	10	10	15	10	5
SO_x (g SO_x/g fuel)	Min.	0.09	10	10	15	10	5
Total			100%				

5. Candidate Solid Waste Mixes

Considering each waste material is used alone (without mixing with any other material), the technical score of each SW material is calculated according to the presented criteria in Table 2. The SW materials are ranked from 1 to 8 to determine its priority in the mixing procedure as presented in Table (3).

Table (3): Score and Rank of Each Waste Material (No Mix).

Trial No.	No Mix	Rice Straw	Wood	Sludge	Olive Pomac Oil	Plastics	Paper	Cotton Stalk	Tires
1	Score	63%	53%	27%	34%	67%	45%	50%	39%
	Rank	2	3	8	7	1	5	4	6
2	Score	67%	53%	24%	30%	69%	46%	48%	30%
	Rank	2	3	8	7	1	5	4	6
3	Score	62%	52%	31%	34%	65%	47%	55%	32%
	Rank	2	4	8	6	1	5	3	7
4	Score	59%	53%	29%	39%	65%	44%	53%	49%
	Rank	2	3	8	7	1	6	4	5
5	Score	63%	55%	22%	35%	69%	43%	45%	47%
	Rank	2	3	8	7	1	6	5	4

The analysis shows that the weighting factor has insignificant impact on the ranking of SW materials, and therefore Trial No. 1 is selected as a basis for further analysis. Taking into consideration the SW materials ranking and score (Table 3), and the number of SW materials to be mixed, Table (4) presents the possible eight SW mixes for Trial 1.

Table (4): Candidate SW Mixes

Rank	2	3	8	7	1	5	4	6
Mix No.	Rice Straw	Wood	Sludge	Olive Pomac Oil	Plastics	Paper	Cotton Stalk	Tires
1	0%	0%	0%	0%	100%	0%	0%	0%
2	48.34%	0%	0%	0%	51.66%	0%	0%	0%
3	34.28%	29.09%	0%	0%	36.63%	0%	0%	0%
4	26.89%	22.82%	0%	0%	28.73%	0%	21.55%	0%
5	23.00%	19.52%	0%	0%	24.58%	0%	18.43%	14.47%
6	19.75%	16.76%	0%	0%	21.10%	14.15%	15.82%	12.42%
7	17.81%	15.12%	0%	9.80%	19.03%	12.77%	14.27%	11.21%
8	16.55%	14.05%	7.05%	9.11%	17.69%	11.87%	13.27%	10.42%

6. Technical Evaluation

Considering the evaluation criteria presented above, Table (5) presents the technical score and ranking of each possible mix of trial 1.

Table (5): Technical Evaluation and Ranking of Possible Mixes

Mix No.	CV (cal/g)	MC (%)	Density	Oxygen (%)	COx (g/g	NOx(g/g fuel)	SOx (g/g fuel)	Technical Score	Rank
1	5565	0.08	72	45.5	166.1	0.39	0.16	78%	1
2	4671	0.09	66	44.29	174.4	0.35	0.16	75%	2
3	4709	0.08	178	44.09	177.1	0.44	0.14	72%	3
4	4699	2.19	164	44.05	179.2	0.81	0.11	67%	5
5	5272	1.94	311	37.97	153.3	0.69	0.1	69%	4
6	4959	2.53	276	38.6	154.9	0.68	0.17	63%	6
7	4991	2.32	338	38.18	159.5	1.08	0.17	60%	7
8	4822	2.47	356	37.25	154.7	1.46	0.37	54%	8

7. Financial Evaluation

Table (6) shows the price per ton of each waste material based on the Egyptian market.

Table (6): price of solid waste material

Material	Paper	Plastics	Wood	Sludge	Olive Pomace Oil	Rice Straw	Cotton Stalk	Used Tyres
Price (EGP/ton)	750	2750	60	110	1500	300	250	900

The price per ton of each mix in Trial 1 is calculated as presented in Table (7) to determine the financial evaluation score and ranking using the lowest mix cost as a target value (Mix No 8 has a minimum cost).

Table (7): Financial Evaluation

Mix No.	1	2	3	4	5	6	7	8
Price (EGP/ton)	2750	1566	1212	1005	989	956	1009	946
Financial Score	34%	60%	78%	94%	96%	99%	94%	100%
Rank	8	7	6	4	3	2	5	1

8. Selection of Optimum Mix

The technical and financial scores are merged to obtain the overall score and then the optimum mix. Different merging ratios are selected to investigate the sensitivity of optimum mix to merging ratios. The results are presented in Table (8) and show that Mix No. 5 is the optimum at merging (T/F) ratios from (80/20) to (40/60). Therefore, Mix No. 5 is selected as the optimum mix.

Table (8): Overall Scores at Different Mixing Ratios of Trial 1

Technical	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%	0%
Financial	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Mix No.	Overall Score (%)										
1	77.6	73.2	68.9	64.6	60.3	56	51.6	47.3	43	38.7	34.4
2	75.3	73.8	72.3	70.8	69.3	67.8	66.4	64.9	63.4	61.9	60.4
3	71.9	72.5	73.1	73.7	74.3	74.9	75.6	76.2	76.8	77.4	78
4	66.8	69.5	72.2	75	77.7	80.4	83.2	85.9	88.6	91.4	94.1
5	68.7	71.3	74	76.7	79.4	82.1	84.8	87.5	90.2	92.9	95.6
6	63	66.6	70.2	73.8	77.4	81	84.6	88.2	91.8	95.4	98.9
7	59.6	63	66.4	69.8	73.2	76.7	80.1	83.5	86.9	90.3	93.7
8	54.2	58.7	63.3	67.9	72.5	77.1	81.7	86.2	90.8	95.4	100

9. Alternative Fuel Production Plant Design

The plant design is carried out for Mix No. 5 which consists of the following SW materials: rice straw (23%), wood (19.52%), plastics (24.58%), cotton stalks (18.43), and used tires (14.47%). The production capacity is taken as 50 ton/d. The block flow diagram for the AF production is shown in Fig. (2).

10. Process Description

Taking a basis of 1 ton / hour flow, the camion will arrive on the entry balance at the entry of the factory to record the entering weight. Then it will unload the raw material in the specified place in the receiving area. The camion will go out of a specified exit in order to record the exit balance. The loader present in the receiving area will be used to transport the raw materials to the shredder and to the loading area. Agriculture wastes will be entered into a 35 Kwh shredder in order to reach the specified size for the process. The proposed mixture will be prepared in the loading area and feed to the belt conveyor by a loader for the entry into the mixing tank. A mixing tank is installed in order to homogenize the mixture before entering into the pelletizer .The homogenized raw material will be taken out on a belt conveyor to be transported to the pelletizer which will produced the final pellets, The pellets produced is usually associated by high temperature, the produced pellets will go into a cooler then into the packaging area to be prepared for selling.

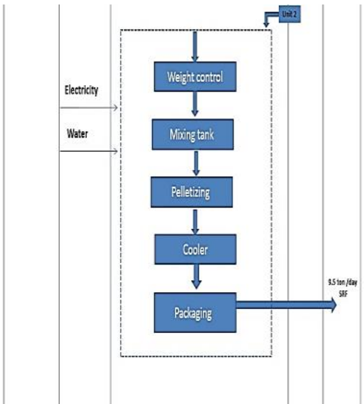

Fig. (2): Block Flow Diagram of AF Production

The process flow diagram (PFD) of the AF plant shown in Fig. (3) .

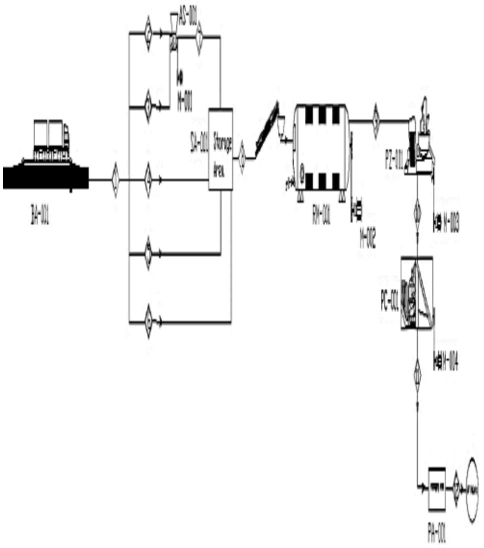

Fig. (3): Process Flow Diagram of the AF Plant

From the above-mentioned production stages, machines dimensions, Fig. (4) presents a general layout of AF plant (50 ton/d) with surface dimensions of 60X60 m^2.

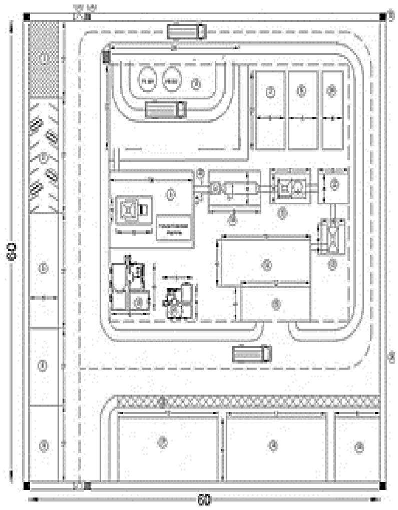

Fig. (4): Designed AF Production Plant Layout

The mass balance of SW material quantities passing through different processing operations is shown in Table (9) and the mass balance flow sheet is presented in Fig. (5).

Table (9): Mass Balance of AF Plant

Property /Stream	BA-001 to RA-001	RA-001 to SA-001	RA-001 to AS-001	AS-001 to RM-001	RA-001 to RM-001	RM-001 to PZ-001	PZ-001 to PC-001	PC-001 to PA-001
Rice Straw (ton)	5	0.4	4.6	4.6	0	0	0	0
Cotton Stalks (ton)	5	1.31	3.686	3.686	0	0	0	0
Wood (ton)	5	1.1	0	0	3.904	0	0	0
Plastics (ton)	5	0.08	0	0	4.916	0	0	0
Used Tires (ton)	5	2.11	0	0	2.894	0	0	0
Pellets (ton)	0	0	0	0	0	20	20	20
Total In (ton)	20	5	8.286	8.286	11.71	20	20	0
Total out (ton)	0	0	0	0	0	0	0	20

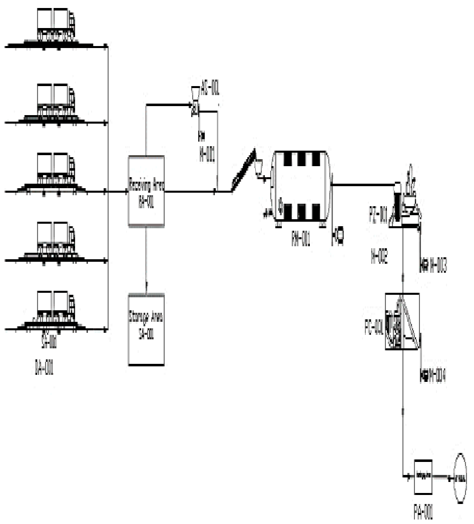

Fig. (5): Mass Balance Flow Sheet

The energy balance of AF production is shown in Table (10) and the energy balance flow sheet is presented in Fig. (6).

Table (10): Energy Balance of AF Plant

Property / Stream	BA-001 to RA-001	RA-001 to SA-001	RA-001 to AS-001	AS-001 to RM-001	RA-001 to RM-001	RM-001 to PZ-001	PZ-001 to PC-001	PC-001 to PA-001
Rice Straw (MJ)	77760	6221	71539	71539	0	0	0	0
Cotton Stalks MJ	97508	25625	71883	71883	0	0	0	0
Wood (MJ)	100437	22016	0	0	78421	0	0	0
Plastics (MJ)	116420	1956	0	0	114464	0	0	0
Used Tires (MJ)	181104	76281	0	0	104823	0	0	0
Pellets (MJ)	0	0	0	0	0	441111	441111	441111
Total In (MJ)	573229	132099	143422	143422	297708	441111	441111	0
Total out (MJ)	0	0	0	0	0	0	0	441111

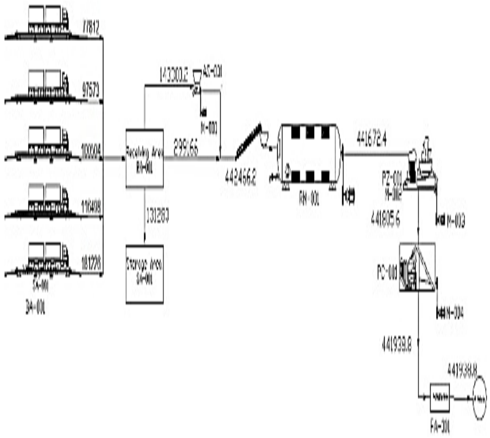

Fig. (6): Energy Balance Flow Sheet

The receiving area in the AF production plant is designed as shown in Fig. (7)

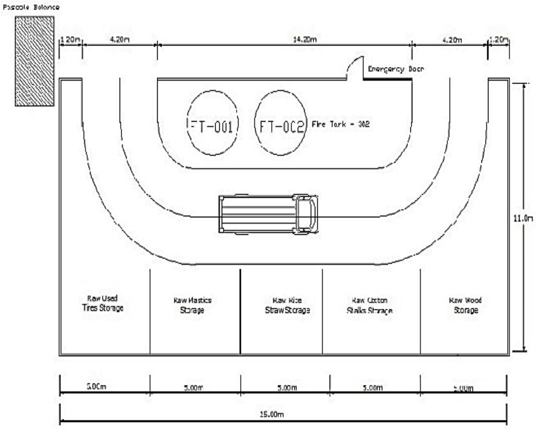

Fig. (7): Receiving Area in the AF Plant

11.Economic Feasibility Study for Alternative Fuel Production

The economic feasibility study is based on the capital costs, operation maintenance costs, and cash flow analysis for a plant with a production capacity of 50 t/day with working hours 20h/day, and working days are 300 day in one year for 11 year (1 year for construction and 10 years of operation).

$$Annual\ Production = 50\frac{t}{d}\ X\ 300\frac{d}{y}15{,}000\ t/y$$

Capital Costs

Capital costs are the costs incurred in the purchase of land, buildings, construction, site work, and machines to be used in the production of AF. Table (11) presents the CC of AF plant (50 ton/d).

Operating and Maintenance Costs

Operation and maintenance costs are the expenses which are related to the raw materials, power consumption, salaries, operation of machines as presented in Table (12)

Table (11): Capital Costs of AF Plant

Component	Description	Cost (EGP)
Land Cost	3600 m2 at 1100 EGP/m2	3,960,000
Machine Cost[1]	Shredder	80,000
	Rotating	50,000
	Pelletizer	100,000
	Cooler	40,000
	Sub Total	270,000
Service Buildings	1800 m2 at 1500 EGP/m2	2,700,000
Site Works	Infrastructure Works	2,000,000
Total		8,930,000

Table (12): Operation Maintenance Costs of AF Plant

Component	Description	Cost (EGP/y)
Raw SW Material	Rice Straw 23% at 300 EGP/ton	14,843,700
	Wood 19.52% at 350 EGP/ton	
	Plastics 24.58% at 2750 EGP/ton	
	Cotton Stalk 18.43% at 250 EGP/ton	
	Used Tires 14.47% at 900 EGP/ton	
	Sub Total Cost of AF = 989 EGP/ton	
Power Consumption[1]	Power of all machines is 155.25 kw/h and the price of kilowatt in Egypt is 0.4 LE	372,700
Salaries	About 40 employees	1,212,000
Maintenance	Assumed to be 10% of the machines cost	27,000
Total		16,455,200

Sales

Selling price is calculated according to the capital costs and operation costs as the following:

Selling price $= [(\frac{8{,}930{,}000}{10} + 16{,}455{,}200)/15000] = 1157EGP$, therefore, the proposed selling price of AF is 1200 EGP per ton (about 3% : 5% profit).

$$Sales = 15{,}000\frac{t}{y}X\ 1{,}200\frac{EGP}{t} = 18{,}000{,}000\ EGP/y$$

Economic Analysis Measures

Economic analysis is conducted based on net present value (NPV), internal rate of return (IRR), benefit to cost ratio (B/C), and payback period taking into consideration the inflation and discount rates. The following equations are used;

Cost Calculation

$$C_t = \sum_{t=1}^{t=11} C_o\,(1+r)^t$$

Benefit calculation

$$B_t = \sum_{t=1}^{t=11} B_o\,(1+r)^t$$

Net Present Value

$$NPV = \sum_{t=1}^{t=11} \frac{B_t - C_t}{(1+i)^t}$$

Benefit to Cost Ratio

$$B/C = \frac{\sum_{t=1}^{t=11} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{t=11} \frac{C_t}{(1+i)^t}}$$

Internal rate of return

Cash flow over a 11 years was presented in Table (13).

Table (13) Cash Flow

Year	CC (EGP)	OMC (EGP)	osts (CC+OM	Benefit (EGP
1	8930000	0	8930000	-
2	0	16455200	16455200	18,000,000
3	0	16455200	16455200	18,000,000
4	0	16455200	16455200	18,000,000
5	0	16455200	16455200	18,000,000
6	0	16455200	16455200	18,000,000
7	0	16455200	16455200	18,000,000
8	0	16455200	16455200	18,000,000
9	0	16455200	16455200	18,000,000
10	0	16455200	16455200	18,000,000
11	0	16455200	16455200	18,000,000
Sum	8,930,000	164,552,000	173,482,000	180,000,000

The Economic parameters according to the latest web site report of the (Central Bank of Egypt) are:

The discount rate = 10.25 % (June 2013)

The inflation rate = 12.30% (May 2016)

- Table (14) presents the cash flow and the calculation of NPV according to equation 3 taking into consideration the inflation rate and discount rate.

Table (14) Cash Flow and NPV calculations

Year	Inflation Rate 12.30%	Total Costs (CC+OMC) EGP	Benefit (B) (EGP)	[B - (CC+OMC)] EGP	NPV
1	1.123	10,028,390	0	-10,028,390	-9,096,045.35
2	1.261	20,752,130	22,700,322	1,948,192	1,602,782.44
3	1.416	23,304,642	25,492,462	2,187,820	1,632,584.75
4	1.59	26,171,113	28,628,034	2,456,922	1,662,941.20
5	1.786	29,390,160	32,149,283	2,759,123	1,693,862.10
6	2.006	33,005,149	36,103,644	3,098,495	1,725,357.95
7	2.252	37,064,783	40,544,393	3,479,610	1,757,439.44
8	2.53	41,623,751	45,531,353	3,907,602	1,790,117.45
9	2.841	46,743,472	51,131,709	4,388,237	1,823,403.08
10	3.19	52,492,920	57,420,910	4,927,990	1,857,307.63
11	3.582	58,949,549	64,483,681	5,534,133	1,891,842.60
Sum		379,526,058	404185790.9		8,341,593

NPV=8,341,593 EGP

Table (15) presents the calculation of (B/C) according to equation 4.

Table (15) Calculation of B/C

Year	Discount Rate (i)	[B/(1+i)^t] EGP	[(CC+OMC)/(1+i)^t] EGP
1	0.1025	0	9,096,045
2	0.1025	18,675,611	17,072,829
3	0.1025	19,022,867	17,390,283
4	0.1025	19,376,581	17,713,639
5	0.1025	19,736,871	18,043,009
6	0.1025	20,103,860	18,378,502
7	0.1025	20,477,673	18,720,234
8	0.1025	20,858,437	19,068,320
9	0.1025	21,246,281	19,422,878
10	0.1025	21,641,337	19,784,029
11	0.1025	22,043,738	20,151,896
Sum		203,183,257	194,841,664

B/C= 1.0428

Calculation of Internal Rate of Return

According to equation 5, IRR =14%.

Calculation of Pay Back Period

It is noticed that payback period = 5.95 year according to the revenue of the first three years of the project.

Conclusions

This study aims at the determination of the optimum mix of non-hazardous SW materials to be utilized as AF. Waste types examined in this study are rice straw, cotton stalks, plastics, wood, used tires, olive pomace oil, paper, and dried digested sludge

Optimum mix selection is based on CV with weighting factor 30%, density 15%, MC 15%, oxygen content 10%, and gas emissions 30% taking into consideration SW materials cost.

Eight mixes are investigated and the optimum mix is found to be rice straw 23%, wood 19.52%, plastics 24.58%, cotton stalks 18.43%, and used tires 14.47%. The optimum mix has a CV of 5272 cal/g, density of 311 kg/m^3, MC of 1.94%, CO_x of 153.28 (g/g fuel), NO_x of 0.69 (g/g fuel), and SO_x of 0.10 (g/g fuel).

The AF plant is 3600 m^2 covering all service buildings and all of production machines. The production rate is 50 ton/d.

Capital costs and operation maintenance costs of the AF plant are 8,930,000 and 16,455,200 EGP respectively.

IRR of AF plant is 14%, NPV is 8,341,593 EGP, B/C ratio is 1.0428, and the payback period is 5.95 years.

The cost per ton of AF produced from the optimum raw waste materials mix is 989 LE without any processing costs and the proposed selling price is 1200 LE per ton of AF covering all the processing costs.

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