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Research article

Prototype System for Production of Refuse Derived Fuel (RDF-5) from Municipal Solid Waste Using Natural Rubber as Binder

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Abstract: The development of RDF-5 fuel from community waste using natural rubber as a binder was investigated. The results showed that the calorific and heat values were increased proportionately to the amount of rubber added. The ratio with the highest calorific value was 50:50, followed by 75:25, 90:10, and 95:5. The calorific value was 40.67 MJ/kg (9720 kcal/kg), 40.24 MJ/kg (9,617 kcal/kg), 39.28 (9,389 kcal/kg) and 39.18 MJ/kg (9,365 kcal/kg), respectively. Compared with 100:0, have a calorific value of 38.84 MJ/kg (9,284 kcal/kg). The experimental addition of natural rubber as a binder makes the combustion process more complete, resulting in faster fuel ignition time or easier igniting, less ash content, and being environmentally friendly. The research team chose to develop the ratio of 95:5 because the economic analysis showed a fast payback period of only 5.72 years. So, the ratio of 95:5 is the optimal condition that can scale up to the industrial level. The production cost of RDF-5 is 1,935 baht/ton for 50 baht/kg of natural rubber. The amount of emission caused by the combustion process of RDF-5 (95:5) passed the standard. Therefore, the evaluation of this research found that RDF-5 fuels from community waste using natural rubber as a binder. It is one of the attractive alternatives to renewable fuel generation and solid waste management solutions and helps improve the environmental quality of communities.

Keywords: RDF-5 fuel, municipal solid waste, natural rubber binder, prototype system

1. Introduction

Satun is a small province with world-famous tourist attractions such as Koh Lipe, and on April 17, 2018, it was certified as Thailand's first world geopark (Satun Global Geopark). Satun has thus become a world-class new tourist attraction in terms of geology. It found that in 2018 there were 1.5 million visitors, of which 1.04 million were tourists, an increase of 8.43% from the previous year [1], resulting in the problem of overflowing waste. It found that the amount of waste generated in 2018 was 110,476 tons, the average municipal solid waste generation rate was 1.15 kg/person/day [2]. While the amount of waste continuously increases, the daily waste generation rate is higher than the disposal rate. This results in a large amount of old waste left over, but the waste management on the floor is only a landfill method, and there is a limited amount of landfill space causing the responsible person to be unable to solve the problem of waste overflowing the city. In the experiment, the feasibility of RDF-5 production from the Integrated Waste Management Center, Kamphaeng Subdistrict, La-Ngu District, Satun Province. There are about 100,000 tons of residual and new waste, which the landfill plan designed to use as a landfill for 15 years. The average amount of waste entering the center is 50 tons per day, selected only 2 tons of organic waste, recyclable waste 8 tons, and landfill 40 tons. There are also 300 tons of waste from Koh Lipe per month, transported twice a month. Information reported by the Integrated Waste Management Center, Kamphaeng Subdistrict, La-Ngu District, Satun found the problem of overflowing waste in the area of La-ngu district and the finding urgent measures to deal with the problem, which, if left affected to the environment deteriorate in a short time, and this will affect the economy, income and the health of people in the community.

RDF-5 is a compression-densified fuel (density greater than 600 kg/m^3) and comes in various shapes, such as pellets, spheres, cuvettes, briquettes, or similar shapes [3]. The advantages of compression are increased bulk density, low moisture content, high calorific value, and ease of transportation [4, 5]. RDF can generally be manufactured using three leading technologies; piston press, screw press, pelletizing process, etc. [6]. Searching for research papers, no studies using natural rubber as a binder have been found for RDF-5. So not comparing RDF-5 production with past research reports, similar research papers have prepared RDF-5 from sawdust powder, cardboard, polyethylene bags, and dry cooked rice using glycerol as a binder [7]. It found that using glycerol as a binder increased overall thermal efficiency. Natural rubber has good cohesiveness. Therefore, natural rubber is expected to be a great binder in RDF-5 production. Additionally, using natural rubber as a binder can enhance the used quantity of natural rubber, which is economic promotion.

The research team is aware of such problems. Therefore, guidelines have been established to manage the waste overflow problem by producing RDF-5 solid fuel from municipal and combustible waste. It is the most likely choice because it has a heating value three times higher than biomass fuels. This research applies the concept of using natural rubber as a binder in the production of RDF-5 solid fuels. It has an explosive property, a higher heat value, and the standards required by the industry.

2. Materials and methods

2.1 Preparation of RDF-5

Our study aimed to study the feasibility of utilizing solid waste at the Integrated Waste Management Center, Kamphaeng Subdistrict, La-Ngu District, Satun Province, which could be utilized to produce RDF-5. In the experiment, municipal solid waste chose to use solid waste through the separation process before landfill which most solid waste of combustible components, such as non-recyclable plastics (not including PVC), paper cardboard, labels, and other corrugated materials, etc. After that, solid waste and natural rubber were ground pieces into flakes about 1-2 cm x 1-2 cm in size (Figure 1). Mixed the crushed municipal waste with natural rubber and varied the amount of dry rubber in the range of 5-50% of the weight (Table 1).

Figure 1. Materials used in the experiment; (A) Municipal solid waste, (B) Ground solid waste, and (C) Ground natural rubber

Table 1. The raw material ratio for the preparation of RDF-5

Ratio	Municipal solid waste (g)	Natural rubber (g)
100:0	50.0	0
95:5	47.5	2.5
75:25	37.5	12.5
50:50	25.0	25.0

Figure 2. A prototype system for the production of refuse-derived fuel (RDF-5) at a production capacity of 800 kg/day

2.2 Study on the physical and chemical properties of RDF-5 fuel

RDF-5 is produced in a prototype system shown in Figure 2. Raw materials from step 2.1 were sent to the extrusion system with a single-screw extruder with a temperature of 170 °C and cut the sample into pieces of the required length to produce RDF-5 fuel. The rubber acts as a binder to the fuel ratio and cools rapidly to room temperature as the RDF-5 fuel leaves the extrusion. The produced RDF-5 waste fuels were analyzed for the performance of RDF-5 waste fuels and pollution according to ASTM standard methods as follows calorific value (suitable in the range of 13 - 18 MJ/kg), ASTM D 5865 volatile matter, ASTM D 3172 ash content (ash), ASTM D 3174, density, ignition time, and moisture content (moisture), which calorific value is a direct analysis. The sample of fuel waste is ground to a size of about 1 mm and analyzed by the Bomb Calorific Method. The heat value called Dry Solid Calorific Value (DSCV) is the heat value obtained from complete combustion. Finally, analyze emissions arising from the RDF-5 combustion process such as carbon dioxide (CO_2), oxide of nitrogen as NO_2, sulfur dioxide, total suspended particulate, etc.

3. Results and Discussion

3.1 Effect on physical and chemical properties of RDF-5 fuel

The addition of natural rubber results in a significant increase in heat. The heating value will increase in proportion (%) of the added natural rubber (Table 2). The heating value of the fuel is directly proportional to the amount of natural rubber. The highest heat was a ratio of 50:50, followed by 75:25 and 95:5 with a heat value of 40.67 MJ/kg (9,720 kcal/kg), 40.24 MJ/kg (9,617 kcal/kg) and 39.28 (9,389 kcal/kg) respectively, and when compared with solid waste alone (100:0), the calorific value was 38.84 MJ/kg (9,284 kcal/kg). The addition of rubber to RDF-5 fuel significantly promoted synergism, as shown in Figure 3. From Figure 4, it was found that every ratio of RDF-5 fuel had a higher heating value than the solid fuel production standard of 15 MJ/kg (ASTM standard). The thermal benefits of RDF-5 fuel production can be obtained. Therefore, results from research can bring each fuel ratio to produce RDF-5 fuel. It was found that all fuel ratios passed the production standard criteria. Solid fuels are fuels in each ratio that contain moisture content of fuel not more than 10% (Figure 5(A)). The ash content of each fuel ratio is in the range of 0.21-11.32%, with the ratio with the highest ash content being 100:0, followed by 95:5, 90:10, 75:25, and 50:50, respectively(Figure 5(B)).

Table 2. Resulting in the calorific value of RDF-5 fuel

Ratio	Municipal solid waste (g)	Natural rubber (g) (dry weight)	Results	
			Calorific value (kcal/kg)	Calorific value (MJ/kg)
100:0	50.0	0	9,284	38.84
95:5	47.5	2.5	9,365	39.18
90:10	45.0	5.0	9,389	39.28
75:25	37.5	12.5	9,617	40.24
50:50	25.0	25.0	9,720	40.67
Rubber (0:100) [8]	-	-	10,127	42.40
Municipal solid waste (100:0) [9]	-	-	8,927	37.50

Figure 6 showed that the density of each fuel was inversely proportional to the amount of natural rubber added, resulting in a decrease in the density value when the ratio of rubber added more rubber which is the opposite of the calorific value, possibly because natural rubber has high elasticity properties. It can quickly return to its original or similar size shape after deformation due to external force [10], resulting in the density of RDF-5 decreasing when natural rubber is added to the increasing ratio. Although adding rubber to the amount will help with the increased heating value and ash content decreased because it causes complete combustion. The addition of natural rubber must be in the appropriate amounts to promote synergism, and production costs must be considered when operating on an industrial scale. From the experiments, it was found that every ratio used in the experiment exceeded the ASTM standard of density at 600 kg/m^3. It could use as RDF-5 fuel (Figure 6). Ignition time is the amount of time the fuel temperature is heated. It can see from Figure 7 that adding natural rubber to RDF-5 fuel makes Rdf-5 fuel easier to ignite. Compared to 100:0, which is RDF-5 made from municipal waste alone, it takes 20.41 minutes when adding natural rubber, the ratio is 95:5, 90:100, 75:25, 50: 50, causing the ignition time to be reduced to 12.67, 12.40, 11.04 and 10.19 minutes, respectively. Adding a higher ratio of rubber nature resulted in a faster or easier ignition time of RDF-5 fuel significantly.

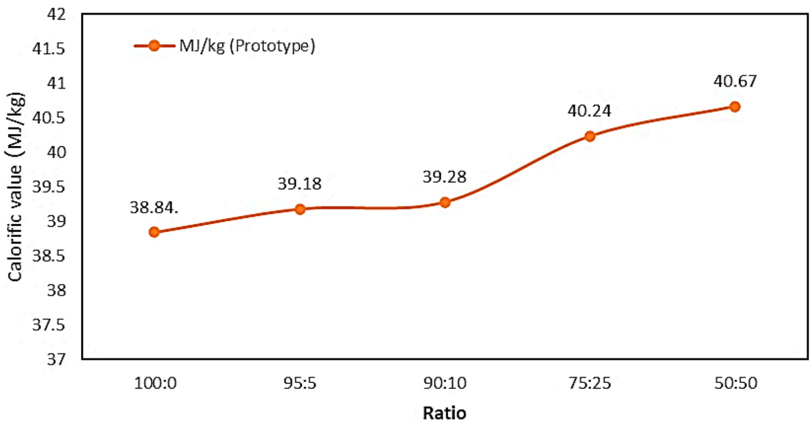

Figure 3. Effect of mixture ratio on the calorific value of RDF-5 fuel

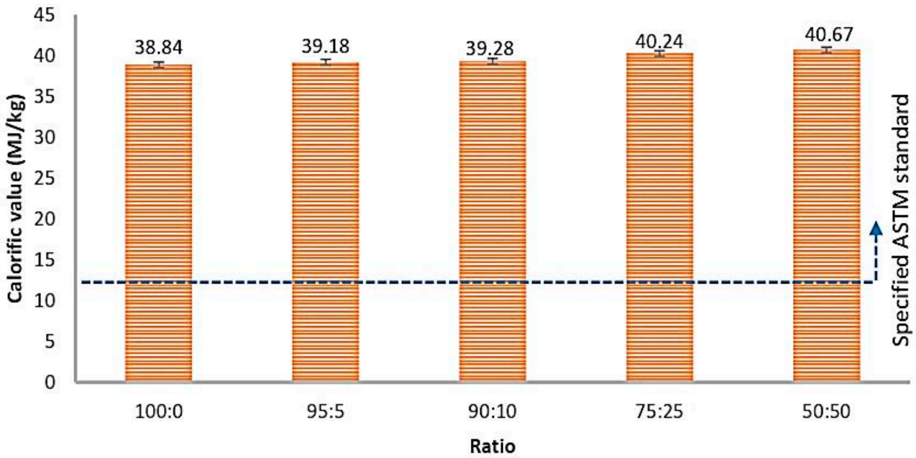

Figure 4. The calorific value of RDF-5 compared to ASTM standard calorific value

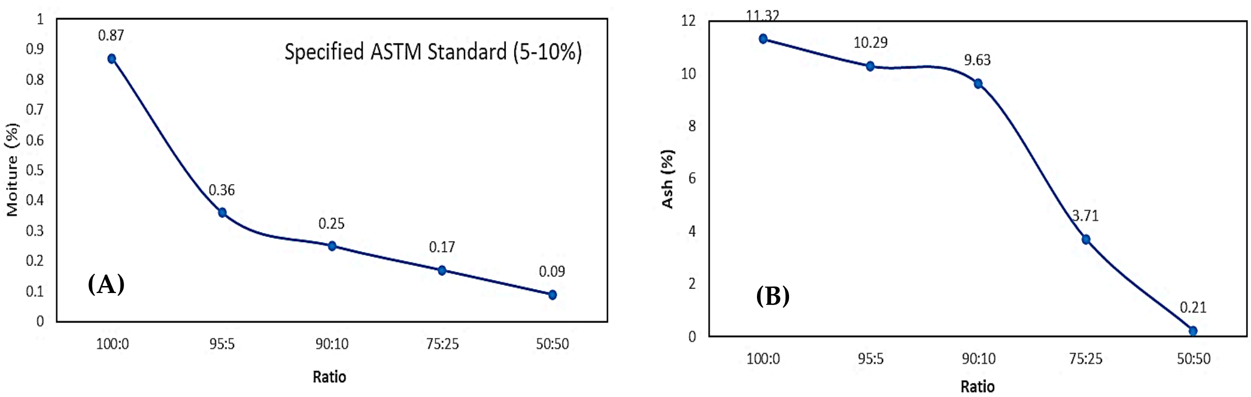

Figure 5. Effect of mixture ratio on (A) moisture and (B) ash of RDF-5 fuel

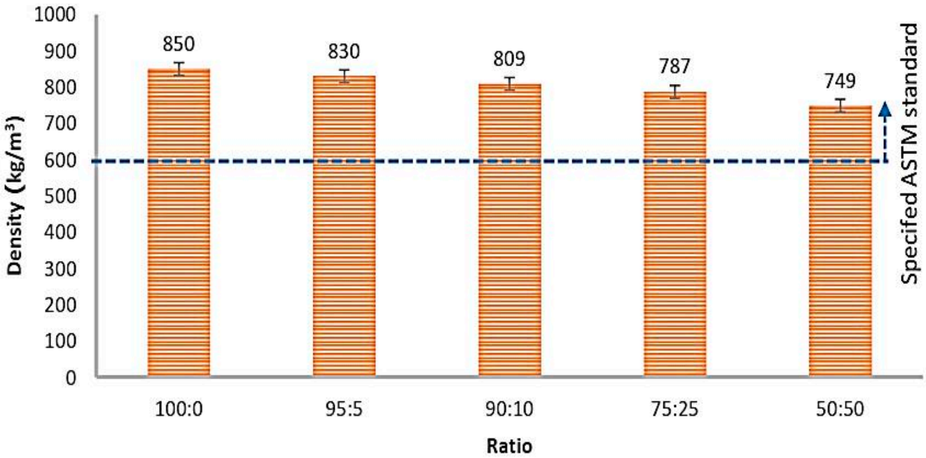

Figure 6. Effect of mixture ratio on the density of RDF-5 fuel

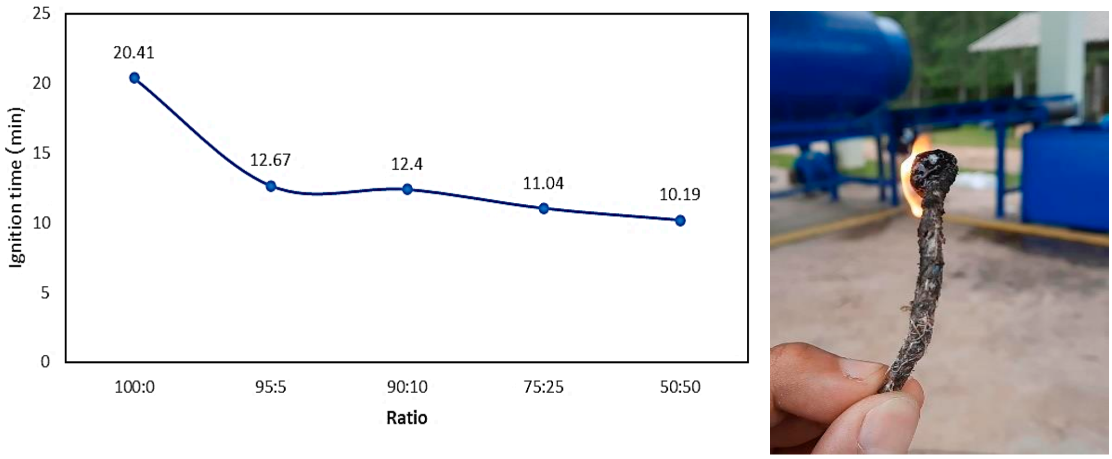

Figure 7. Effect of mixture ratio on ignition time of RDF-5 fuel

The experimental results in Table 3 show that all ratios can use as RDF-5 fuel. Making the combustion process more complete resulted in a faster or easier ignition time of the fuel and less ash content environmentally friendly, but adding the addition of natural rubber into the amount is too high and may affect the cost of production. As a result, the research team developed a 95:5 ratio as a commercially viable ratio because is a possibility of both production costs, combustion, and environmental performance. Prototype RDF-5 fuel production with rubber binder at 95:5 ratio, which could convert 800 kg./day of waste to produce 400 kg/day of fuel waste (RDF-5), dispose of 80 kg./day of organic waste, and lose water from the hot extrusion process by single screw extruder with temperature control of 170 ^{o}C, resulting in weight loss of 320 kg/day, with wastewater generated from the production process of 3.36 m^3/day. The material balance in the prototype system is shown in Figure 8.

Table 3. Summarize the fuel properties of RDF-5 from municipal waste with a rubber binder

properties	Ratio (%by weight)					Solid waste after the MBT process: crude oil sludge [5]
	100:0	95:5	90:10	75:25	50:50	95:5
Calorific value (MJ/kg)	38.84	39.18	39.28	40.24	40.67	38.13
Moiture (%)	0.87	0.36	0.25	0.17	0.09	1.00
Density (kg/m^3)	850	830	809	787	749	475
Ash (%)	11.32	10.29	9.63	3.71	0.21	6.26
Ignition (min)	20.41	12.67	12.40	11.04	10.19	-

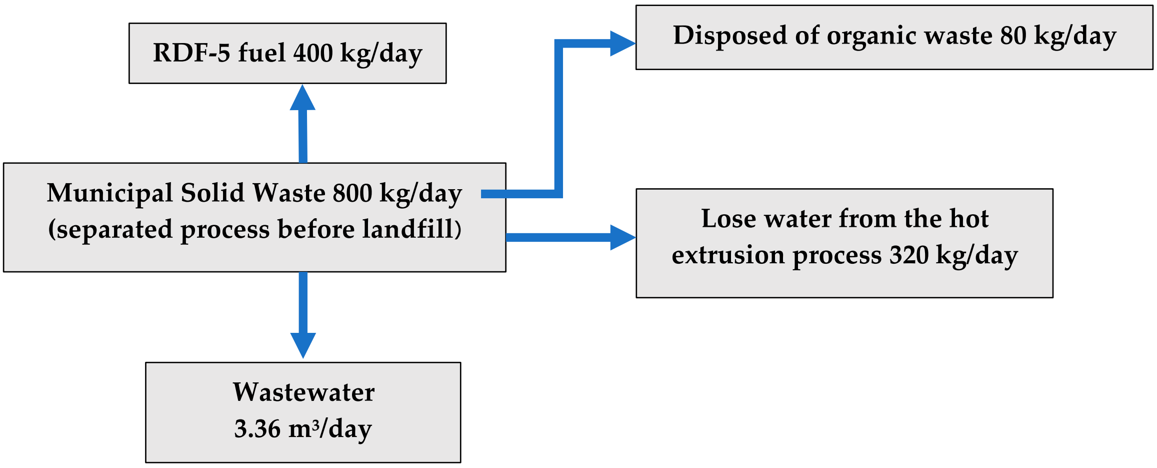

Figure 8. Material balance of prototype RDF-5 fuel production with rubber binder at 95:5 ratio

3.2 Emission effects from the RDF-5 combustion process

Emission analysis from the RDF-5 combustion process (95:5 is the optimal ratio) found that SO_2 was 1.05 ppm, CO_2 was 3.25 ppm, NO_x was 90.68 ppm, and particulate matter was 112.45 mg/m^3, all of which passed the standards of the Pollution Control Department and passed the emission standards of biomass power plants and is less than the emission from diesel combustion as shown in Table 4. In the combustion process of RDF-5, the amount of emission depends on the appropriate proportion of para rubber or the amount of para rubber used to mix. Especially carbon dioxide (CO_2) and sulfur dioxide (Sulfur Dioxide) should be little or none because the natural rubber used in the experiment does not use acids containing sulfur compounds in the production process. Additionally, the use of RDF-5 seems to reduce emission problems when comparing the amount of carbon generated with other fuels. Punin et al. [5] reported that RDF-5 has a beneficial effect on air emissions and residual ash compared to municipal waste incineration, which had SO_2 emission of about 0.16 ppm by the production of RDF-5 from solid waste after the MBT process: crude oil sludge of 95:5 ratio.

Table 4. Emission effects from the RDF-5 combustion process.

Emission	RDF-5 (95:5)	Diesel of diesel combustion [11]	Standard [12]	Standard of biomass power plants [13]
SO_2 (ppm)	1.05	-	< 30	No exceed 60
CO_2 (ppm)	3.25	4.28	-	-
NO_x (ppm)	90.68	104.25	< 250	No exceed 200
Particulate matter (mg/m^3)	112.45	-	< 400	No exceed 120

3.3 Production cost of RDF-5 fuel

Calculation of the RDF-5 production cost (95:5) compared with the price of natural rubber in the price range of 30 – 100 baht/kg found that the production cost of RDF-5 (95:5) from new waste (with waste cost) is 2,358 baht/ton (Rubber price 50 bath/kg for example), but without adding rubber, the charge is 2,133 baht/ton (Figure 9) and the production cost of RDF- 5 (95:5) from residual waste (no waste cost) at 1,935 baht/ton, without adding rubber, the charge is 1,685 baht/ton, as shown in Figure 10. The production cost of RDF-5 varies directly with the quantity of natural rubber used and rubber prices according to the economic conditions.

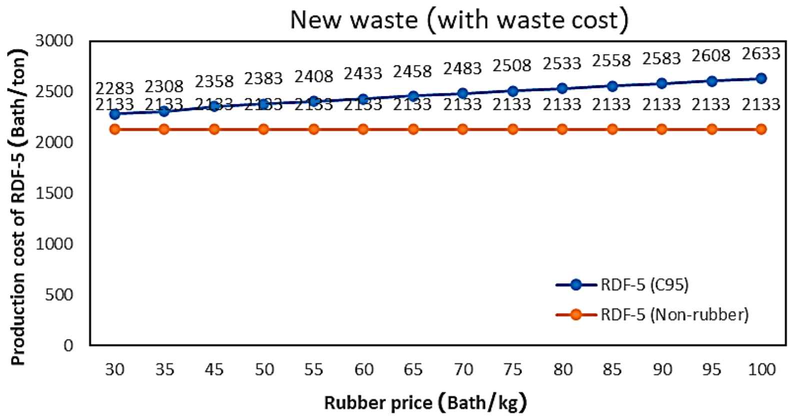

Figure 9. The production cost of RDF-5 at a 95:5 ratio from new waste (with waste cost)

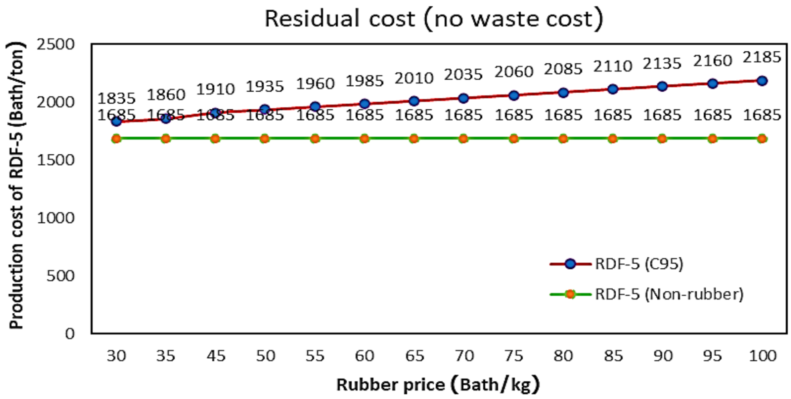

Figure 10. The production cost of RDF-5 at a 95:5 ratio from residual waste (no waste cost)

Table 5. Summary of the economic suitability analysis of RDF-5 fuel (95:5)

Issues of consideration	Units	RDF-5 (95:5)	Decision Criteria
1. Payback period (PBP)	years	5.72	PB ≤ 10 years
2. Net present value (NPV)	Bath	117,334.77	NPV ≥ 0
3. Internal rate of return (IRR)	%	12	> 10%

The results of the analysis of the economic suitability of RDF-5 fuel from municipal waste with natural rubber as a binder at the ratio of 95: 5 are shown in Table 5. The various assumptions used in economic calculations were time working (261 days/years), Total multiple solid wastes (50 tons/days), solid wastes used to produce RDF-5 (40 tons/days), amount of RDF-5 produced per day (20 tons/days). Comparative analysis results of the economic suitability of RDF-5 fuel found that the payback period is only 5.72 years with a positive net present value (NPV) and has an internal rate of return of 12%, which is 10% greater than the weighted average cost of capital required, as shown in Table 5. So, RDF-5 (95:5) is an alternative energy fuel in producing electricity or heat interesting, and it is economically worthwhile to invest.

4. Conclusions

Municipal solid wastes from the Integrated Waste Management Center, Kamphaeng Subdistrict, La-Ngu District, Satun Province, could be utilized to produce RDF-5 which an optimal ratio was 95:5 by using a natural rubber binder. The physicochemical properties of the optimal weight ratios (95:5 ratio) of RDF-5 found that the RDF-5 fuel passed the ASTM standards all property. The addition of natural rubber to RDF-5 fuel could significantly increase synergism. Emission analysis from the RDF-5 combustion process found that SO_2 was 1.05 ppm, CO_2 was 3.25 ppm, NO_x was 90.68 ppm, and particulate matter was 112.45 mg/m^3, all of which passed the standards of the Pollution Control Department and passed the emission standards of biomass power plants and is less than the emission from diesel combustion. The economic suitability of RDF-5 fuel found that the payback period is only 5.72 years. Production of refuse-derived fuel (RDF-5) from municipal solid waste using natural rubber as a binder was the new product in the future due to fuel being environment-friendly and having high calorific value.

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Conflicts of Interest: The authors declare no conflict of interest.

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