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Design and Performance Assessment of a Stove Fueled by Waste Cooking Oil based on FFEAS Technology: An Alternative Energy for SMEs

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***Abstract*—Waste cooking oil or used cooking oil is potentially carcinogenic waste and dangerous to human health if used for cooking repeatedly. If waste cooking oil is disposed of in the environment, it can harm soil structure by impeding water movement in soil pores. Therefore, the development of waste cooking oil stove technology designed using the French method can be a solution to utilize waste cooking oil as an alternative fuel. The results of this research are a stove design and device that can use used cooking oil. This stove uses abundant waste cooking oil with efficient and clean combustion results through the use of FFEAS Technology. This stove uses a floating wick and an excess air system which makes the combustion process easier. The performance of the stove being developed can be seen in several tests such as ignition combustion duration, required pressure, operational time, fuel consumption rate, sensible heat, and latent heat. The results of three tests that have been conducted show that the average ignition duration of the stove is 12 minutes, the optimal pressure is 4-5 bar, the fuel consumption rate is 8.34ml/minute, the average latent heat is 1,095.82 watts, and the average sensible heat is 132.48 watts.**

Keywords—Combustion, FFEAS, Stove, Waste cooking oil.

I. INTRODUCTION

Waste cooking oil is waste that can come from corn oil, vegetable oil, and ghee which is carcinogenic, acidic, and high in peroxide [1-2]. This oil is used oil for household needs and is used repeatedly up to 3-4 times. As the consumption of cooking oil in households increases, the prices of genuine cooking oil continue to rise [3]. This is causing people to opt for reusing waste cooking oil, which has become a popular choice among both households and small entrepreneurs to keep their businesses running [4]. A lot of people improperly dispose of waste cooking oil by throwing it in the trash or the environment, rather than recycling it [5-6].

Judging from its chemical composition, used cooking oil is waste [7]. Currently, the level of public knowledge regarding the dangers of disposing of used cooking oil into the environment is still low [8], due to this type of formulation is not soluble in water and can pollute the environment. Careless disposal into the environment results in soil and water pollution [9]. Used cooking oil is a place for aflatoxin fungi to grow and reproduce. This fungus produces aflatoxin poison which can cause various diseases, especially the liver [10].

On the one hand, waste cooking oil that is used repeatedly up to 3-4 times contains very high levels of free fatty acids and can cause desquamation of the small intestinal villi and the formation of free radicals. Apart from that, used cooking oil has the potential to cause hypertension, stroke, and coronary heart disease [11-12]. Even though the waste cooking oil obtained has been filtered several times, this process does not remove substances that arise after cooking oil is heated repeatedly at high temperatures [13].

The accumulation of waste cooking oil in society has reached significant proportions, as evidenced by Indonesia's annual production of approximately 4,000,000 tons [14]. This substantial quantity poses serious risks to both public health and the environment, highlighting the urgent need for strategies to repurpose waste cooking oil into products with economic value for communities [15]. If left unaddressed, the associated environmental and health hazards could result in profound and far-reaching consequences.

Waste cooking oil requires good handling to avoid environmental pollution [16-17]. There is a solution to deal with this problem, namely by using waste cooking oil as an alternative fuel amidst the current energy shortage. Based on its chemical structure, waste cooking oil has a hydrocarbon composition with a long carbon chain so it has the potential to be used as an alternative fuel. Therefore, this waste cooking oil stove innovation is here as an alternative solution for utilizing energy sources that can be renewed and are affordable for the community. This stove technology fueled by waste cooking oil can be the right solution amidst the scarcity of conventional fuel.

II. LITERATURE REVIEW

The literature review is the previous studies that critically evaluate information, concepts, or findings in academic literature and develops theoretical and methodological contributions to specific issues [18].

The first study examines using used cooking oil (UCO) as an alternative cooking fuel. It surveyed food establishments on UCO volume and disposal practices and developed a modified pressurized stove designed to use UCO. Tested with kerosene-UCO mixtures, the stove demonstrated performance comparable to pure kerosene. The findings indicate that UCO could be a cost-effective, sustainable fuel alternative for

SMEs, reducing kerosene dependency and environmental impact [19].

The second previous study examines using waste cooking oil (WCO) as an alternative fuel in a modified bio-fuel pressure stove. Motivated by the high cost and limited supply of kerosene and LPG, as well as the environmental harm from improper waste oil disposal, the research developed a prototype stove capable of using WCO and plant oils like palm and castor oil. The stove demonstrated efficient combustion, low emissions, and high flame temperature, offering a cost-effective and sustainable option for low-income users. This innovation supports energy diversification, reduces fossil fuel dependency, and benefits small vendors and households [20].

Both studies highlight the potential of used or waste cooking oil (UCO/WCO) as a sustainable, alternative cooking fuel to traditional fossil fuels like kerosene and LPG. In both cases, specialized modified stoves were developed to address the unique properties of UCO/WCO, allowing for effective combustion and energy output comparable to conventional fuels. Each study emphasizes the environmental benefits of reusing UCO/WCO, particularly in reducing pollution and waste associated with improper disposal. Additionally, these solutions present economic advantages, especially for small enterprises and low-income households, by providing a locally sourced, cost-effective fuel alternative. Together, these findings support a promising pathway for sustainable energy use in developing regions, contributing to energy diversification and improved waste management practices.

III. RESEARCH METHOD

This research method is descriptive analysis, which requires breaking down routinely collected data before providing a reasonable understanding and justification to the reader. This was done to explore the use of FFEAS (Floating Fire Excess Air System) technology in waste or used cooking oil-fueled stoves, which is an environmentally friendly and economical alternative for Small and Medium Enterprises (SMEs) in Indonesia.

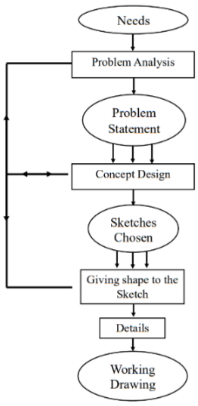


Fig. 1. Block Diagram of French Method

For this particular research in the field of mechanical engineering product design, the French Method was chosen. The French method is preferred due to it divides the design process into clear and structured stages. These stages include identifying needs, searching for concepts, selecting concepts, designing forms, and designing details. By breaking down the design process into these stages, designers can work on each stage systematically. This method makes it easier for designers to create mechanical engineering products by considering market needs and technical aspects. The French Method provides a structured and systematic framework for designing mechanical engineering products.

The French design method considers design as a comprehensive process that involves conception, discovery, visualization, calculation, preparation, refinement, and detailed specifications to determine the engineering form. This method follows a design process flow diagram represented in blocks, as shown in Fig. 1. The circles in the diagram indicate the stages already achieved, and the rectangles represent ongoing activities. Hence, the French method divides the design process into several distinct stages that are systematically sequenced and clearly defined.

A. Problem Analysis

This stage consists of identifying the desired needs by finding and defining the problem. There are 3 elements of a problem statement, namely the design problem, specification limits, and expected optimal solution criteria.

B. Concept Design

This stage consists of formulating the problem and generating a broad solution in the form of a scheme with scope for further development. The device's design is informed by data collected during field observations. In the explanation section of the product design, research is conducted to determine which design is most appropriate for this project. This is achieved by referring to similar research and field observations, which helps to establish device specifications.

C. Sketches Chosen

This section is an embodiment of the scheme into a more concrete design. This stage consists of several alternative schemes which are worked out in detail in the form of conceptual designs.

D. Working Drawing Detail

This final stage in the design system requires a good-quality design with the help of computer software to minimize errors. There are 3 main problems in the design, namely creating a good scheme, selecting the best solution in realizing the design, and evaluating design alternatives. SolidWorks application was used to create the hardware design, due to this software can create detailed working drawings and renderings [21].

E. Testing

Sensible heat is the heat required to change the air temperature. Meanwhile, latent heat is heat that affects relative humidity which influences changes in the state of water vapor in the air [21]. The amount of sensible heat from the heating/cooling coil and heat exchanger is calculated by Equation 1 [22].

$$Q_s = q_v \, . \, \rho \, . \, c_p \, . \, (t_{out} - t_{in}) \qquad (1)$$

Where :
Q_s = sensible heat
q_v = air flow rate (m^3/s)
ρ = specific gravity of air (kg/m^3) = 1.2 kg/m^3
c_p = specific heat of air (kJ/(kg.K) = 1.00 kJ/(kg.K)
t_{out} = coil outlet air temperature (^oC)
t_{in} = coil inlet air temperature (^oC)
All values apply to air density. ρair = 1.2 kg/m^3

If the air humidity changes, the amount of instantaneous sensible heat for cooling/heating the air is calculated using Equation 2.

$$Q_s = q_v \,.\, \rho \,.\, (h_{in} - h_{out}) \quad (2)$$

Where :

Q_s = sensible heat when air humidity changes

q_v = air flow rate (m^3/s)

ρ = specific gravity of air (kg/m^3) = 1.2 kg/m^3

h_{out} = enthalpy of air leaving the coil (kJ/kg)

h_{in} = enthalpy of air entering the coil (kJ/kg)

Instantaneous latent heat for the heater/cooling coil and heat exchanger (dehumidification or humidification of air in the cooling coil) is calculated using Equation 3 [30].

$$Q_l = q_v \,.\, \rho \,.\, (x_{in} - x_{out}).\, 2500 \quad (3)$$

Where

Q_l = latent heat

q_v = air flow rate (m^3/s)

ρ = specific gravity of air (kg/m^3) = 1.2 kg/m^3

x_{out} = water vapor content of the air leaving the coil (kg.water vapor/kg.dry air)

x_{in} = water vapor content of the air entering the coil (kg.water vapor/kg.dry air)

2500 = condensation/evaporation of water vapor at moderate coil exit temperatures (kJ/kg)

Calculating sensible heat and latent heat without considering condensation or evaporation factors so that the calculation of sensible heat and latent heat follows Equations 4 and 5.

$$Q_s = m \,.\, \Delta h \quad (4)$$

$$Q_l = m \,.\, \Delta x \quad (5)$$

Total heat (Q_t) from the cooling/heating coil is the amount of sensible and latent heat, it can be calculated using Equation 6 [29]:

$$Q_t = Q_s + Q_l \quad (6)$$

IV. Results and Discussion

A. *Design of a Stove (Burner) Made from Waste Cooking Oil*

Waste cooking oil stoves are designed to be eco-friendly cooking stoves that use biomass as fuel. The biomass, in this case, is cooking oil derived from processed CPO that is no longer suitable for use. In addition to being environmentally friendly, these stoves are more economical as they utilize waste cooking oil that would otherwise be discarded from kitchen burners daily. Below are the design and components of a waste cooking oil stove.

1. *Furnace*

The stove is designed by applying various theoretical considerations that correlate with the scientific field of Engineering. Fig. 2 shows the rendering design of a waste cooking oil stove. Some of the theories used include Bernoulli's principle in fluid flow, Hess's law in combustion, capillarity theory, and other relevant theories. The application of these theoretical considerations is conducted so that stove design can be conducted carefully so that the resulting technology can be applied and commercialized for the wider community. This is important considering that the world's energy needs continue to increase every day, this biofuel stove can be an alternative solution for the future that is environmentally friendly and sustainable.

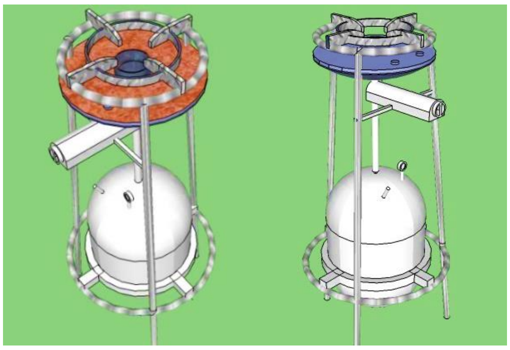
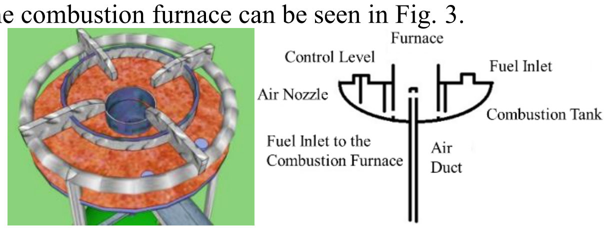


Fig. 2. Waste Cooking Oil Stove Design

The stove consists of several important components. Among them are furnaces with FFEAS (Floating Fire Excess Air System) technology which are very environmentally friendly. This technology relies on air as excess water in the combustion process as in general combustion reactions:

Vegetable Oil + O_2 ⟶ CO_2 + H_2O + Energy

Assembling the combustion furnace is conducted using the metal joining method using metal inert gas (MIG) based welding which is usually used in the manufacturing and construction industries [23]. The amount of oxygen injected into the fuel is directly proportional to the amount of fuel that will burn. For instance, if 5 moles of oxygen are injected, then 5 moles of fuel will also be burned. Combustion efficiency will increase with excess air conditions, as more excess air is injected, resulting in more complete combustion. However, it is important to pay attention to the optimum excess air ratio to avoid being excessive. Combustion efficiency will increase up to a certain limit of excess air ratio. The design of the combustion furnace can be seen in Fig. 3.



(a) (b)

Fig. 3. Combustion Furnace Design (a) 3-Dimensional (b) 2-Dimensional

Floating Fire means a burning fire that occurs on the surface of liquid fuel with the help of a burning medium. The burning medium used in this design is cosmetic cotton (cotton ball). Cotton functions as a wick like in a kerosene stove. Considering that waste cooking oil has a higher viscosity than kerosene, the wick media is designed to be on the surface of the fuel and in direct contact with the oil. The combustion furnace is designed with a manual protection system where the liquid fuel in the tank is isolated from the outside air. The goal is to prevent fire from entering the fuel tank. Several other components in the combustion furnace include a level indicator to see the volume of fuel in the tank, an air nozzle for air entry, and a fuel inlet for refilling liquid fuel [24].

2. *Air Valve*

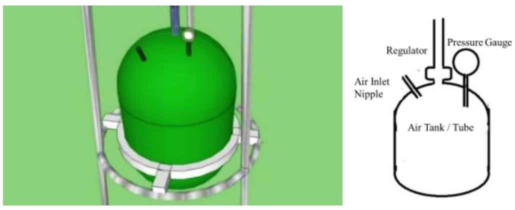
To adjust the flame produced by this stove, you can simply adjust the valve opening in the air valve system. The size of the flame can be regulated by adjusting the size of the valve opening. This mechanism allows users to control the heating process according to their specific needs. For instance, if you want to boil water quickly, you can open the air valve wider to produce a larger flame. Conversely, if you want to fry food at medium temperature, you can open the valve with a smaller opening. The air valve system of this stove is designed to adjust the flame size according to the user's requirements. Fig. 4 shows the design of the air valve that is used in the development of stove.

(a) (b)

Fig. 4. Air Valve (a) 3-Dimensional (b) 2-Dimensional

3. *Air Tank*

The tube as shown in Fig. 5 is designed to provide combustion air, and its working principle is similar to a hot air balloon filled with compressed air. It features several components, including an air valve for refilling air. Users can refill the tube with the help of a manual tire pump or compressor at a repair shop. The tube can also be disassembled for easy refill. Additionally, there is a pressure gauge to monitor the pressure in the tube, which indicates the amount of air available. A regulator is also included to stabilize the air pressure, so it remains at the desired working pressure even when the pressure in the tube decreases due to air usage. Overall, this air cylinder is practical, refillable, and ensures a steady supply of combustion air. Fig. 6 shows the three-dimensional and two-dimensional design of the water tank that has been designed.



(a) (b)

Fig. 5. Air Tank (a) 3-Dimensional (b) 2-Dimensional

B. *Stove Operation*

Fig. 6 shows a trial of using the stove, the way to turn on a waste cooking oil stove is different from the way to turn on a stove in general. There is special treatment so that operations can run optimally. Operation steps include:

1) Fill fuel (waste cooking oil) in the form of used cooking oil into the fuel tank on the stove.
2) Arrange the cotton ball as a burning medium into the combustion chamber as effectively as possible so that all parts submerged in oil are evenly covered. It is important to pay attention that the burning medium does not sink too much into the oil because this can make it difficult for the stove to ignite.
3) Pour the alcohol-based fuel evenly over the surface of the combustion medium, ensuring uniform distribution to facilitate consistent and efficient ignition.
4) Light the fire on the burning medium using a lighter, then wait a few moments until a flame forms on the surface of the oil.
5) After the fire burns evenly across the surface of the burning medium, slowly flow air from the air tube until the fire spreads evenly throughout the combustion chamber.
6) Perfect combustion is indicated by the blue flame color, adjust the size of the air valve opening to the desired amount of heat.
7) To extinguish the stove, securely cover the combustion chamber with a metal lid to eliminate the oxygen supply, thereby causing the fire to extinguish itself.

Fig. 6. Trial of Boiling Water Using a Waste Cooking Oil Stove

C. *Ignition Time Analysis*

Performance tests are conducted to evaluate the tool's operational system due to a tool can function properly when it produces the expected output [25]. One of the performance tests conducted is ignition time analysis. In terms of ignition duration, based on three test results with a fuel volume of 100 ml as shown in Table I, a stove with 100% waste cooking oil can burn for an average of 12 minutes. Mathematically, this figure shows that the specific fuel consumption for the stove being developed requires around 8.34ml of waste cooking oil per minute for combustion.

The testing of this used cooking oil stove was conducted using an experimental protocol that included precision measurements with a calibrated thermocouple and a flow meter to obtain fuel consumption data. The testing conditions were set at room temperature (25°C ± 2°C) using used palm oil that had been reused 3-4 times, representing practical conditions in household and small to medium-sized business settings. The measurement procedure involved recording the ignition time, fuel consumption rate, combustion temperature, and flame quality using industry-standard measuring equipment.

TABLE I. *TESTING STOVE IGNITION ON COMBUSTION TIME*

Test	Composition of Waste Cooking Oil	Ignition Time on Combustion
1	100%	11 Minutes 57 Seconds
2	100%	12 Minutes 12 Seconds
3	100%	12 Minutes 05 Seconds

In Table II, the results of temperature observations, latent heat calculations, and sensible heat calculations on the waste cooking oil stove being developed are shown. During three tests, the flames seen when testing all the fuel were blue and burned smoothly. The flame was greatly influenced by the pressure in the fuel tube. If the pressure in the tube was less than 4 bar, the flame would become smaller making it easier to extinguish. During testing, a pressure of 4 to 5 bar would be optimal. When the flame becomes smaller and unstable, the stove will emit smoke which is the result of fuel evaporating but failing to undergo the combustion process. Apart from that, the average latent heat produced was 1,095.82 watts and the average sensible heat produced was 135.48 watts.

TABLE II. *PIPE WALL TEMPERATURE AND HEAT DURING GAS EXITS*

Test	Waste Cooking Oil	Temperature (°C)	Latent Heat (w)	Sensible Heat (w)
1	100%	247	915.09	108.88
2	100%	254	1,211.05	155.87
3	100%	250	1,161.31	141.67

Compared to previous studies that used cooking oil stove technologies, this design demonstrates significant advantages in terms of combustion efficiency and flame control. The FFEAS technology enables cleaner and more uniform combustion than conventional methods, with lower emissions and more optimal fuel utilization. The design's safety features, including the fuel tank insulation system and precise air valve mechanism, make this stove safer and more reliable than its predecessor prototypes. The potential for scaling this stove technology is highly promising, not only for micro and small enterprises (MSEs) but also for broader commercial applications. In restaurant kitchens or catering facilities, the stove's modular design can be adapted to process larger volumes of used cooking oil. Furthermore, with design enhancements, this technology has the potential to be integrated into urban waste management programs or become part of community initiatives for large-scale recycling of used cooking oil.

V. CONCLUSIONS

The stove developed in this research is an environmentally friendly and cost-effective stove that uses waste cooking oil as fuel. This technology can be an alternative solution amidst the scarcity of conventional fuel oil. The stove is designed using the French method which applies optimal FFEAS (Floating Fire Excess Air System) engineering and combustion principles. The average ignition time required for the stove is 12 minutes and the fuel consumption rate is 8.34ml per minute. The optimal pressure required by the stove is 4-5 bar. Meanwhile, if the pressure is less than 4 bar it cannot withstand the pressure of the fuel vapor produced and will cause a very small flame. The average latent heat and sensible heat produced are 1,095.82 watts and 135.48 watts. The developed used cooking oil stove is not only a technical solution for recycling waste but also a representation of sustainable innovation in alternative energy management. This technology provides an approach to address three key challenges: used cooking oil waste management, the need for sustainable energy, and community economic empowerment. By converting used cooking oil into an efficient energy source, this stove has the potential to make a tangible contribution to reducing environmental pollution, decreasing dependence on fossil fuels, and creating a circular economy model that supports more responsible consumption and production practices.

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