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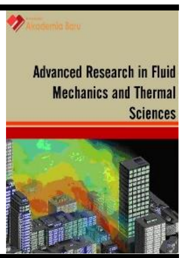

Thermal Energy Storage System from Household Wastes Combustion: System Design and Parameter Study

Janter Pangaduan Simanjuntak[1,*], Samsudin Anis[2], Mochamad Syamsiro[3], Baharuddin[1], Eka Daryanto[1], Bisrul Hapis Tambunan[1]

[1] Mechanical Engineering Department, Universitas Negeri Medan, Medan 20221, North Sumatera, Indonesia
[2] Mechanical Engineering Department, Universitas Negeri Semarang, Kampus Sekaran, Gunungpati, Semarang 50229, Indonesia
[3] Mechanical Engineering Department, Universitas Janabadra, Yogyakarta 55231, Indonesia

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ABSTRACT

The main problem related to thermal energy is that the thermal energy must be used directly and immediately as generated. For example, the thermal energy of solid waste combustion can be directly utilized for power generation. However, studied of thermal energy storage technology is still placed on the second opinion on waste to heat energy. The heat can be stored using a simple or mobilized system which can store thermal energy and can be brought to somewhere it is needed, for example on domestic heating or drying usage. This article studied and evaluated a micro thermal energy storage system from household waste combustion into a warm water that is great for washing clothes, dishes, shower, and other purposes of household needs. System considered was a simple manner and water is used as the heat energy storage medium. In this study, the equations for initial parameter calculation were presented theoretically based on thermodynamic principle. This paper is hopefully beneficial to the researchers and engineers for preliminary design and development of a heat storage systems technology.

1. Introduction

Until now, the largest user of electrical energy in the world is the household sector, where 20 to 50% of electrical energy is used for lighting [1], the rest is utilized to power electronic and heating devices. Although the availability of electrical energy is adequate, however the inaccuracy utilization resulted in a large loss of electrical energy and usually the losses electrical energy cannot be returned to the grid. Unlike the energy from the sun and wind power which are not always available, it depends to the weather, the thermal energy from solid fuel and waste combustion is abundant, always available, and can be stored and utilized at any time to produce electrical energy that must be generated and available all the time to meet the consumer's demand. However,

* *Corresponding author.*
E-mail address: janterps@unimed.ac.id

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electrical energy can also be stored and returned to the network by using an appropriate mechanism but at a high cost.

Sources of thermal energy can be either biomass or household wastes. Household wastes are in the form of paper, plastic, and rubber waste which can be converted into energy which known as waste to energy conversion. Directly, thermal energy sources can be from the sun and the geothermal. However, the main problem related to thermal energy is that the thermal energy must be utilized directly or even be stored in the heat form. Several technologies have been developed to store thermal energy. By using molten salt as the heat transfer medium, a solar tower power system can be used to store the thermal energy of the sun [2]. Low grade waste heat energy from geothermal plant can be captured and used for drying. A heat pipe heat exchanger equipment can successfully heated-up the air up to 70 ^{0}C with a specified velocity [3]. Another case that the thermal energy from wastes combustion is abundant every day. During combustion, the heat generated must be immediately used for cooking or heating purposes. A study by Mustafa *et al.*, [4] has tried to convert the heat directly to electricity by using solid material called thermoelectric. Thermal efficiency about 4% to 5% can be obtained from a liquid-fuel combustion-based stove. This is a relative low value that indicates that a lot of thermal energy is still lost. Therefore, to increase the thermal efficiency, the heat must be captured, stored and utilized when is needed.

Thermal energy can be obtained by directly burning wastes in a furnace rather than throwing it into a garbage can. This is still better where the waste can be a serious problem that has a direct impact on human life. In Indonesia itself, the waste problems include household wastes becomes a serious issue because its production reached a thousand of tons per day. Therefore, starting in year 2019, the government has been built 12 Pembangkit Listrik Tenaga Sampah (PLTsa) which capable to generate 234 MW of electricity. The construction of these plant is inseparable from the issuance of Presidential Regulation No. 35 year 2018 concerning about acceleration of PLTSa development program to respond the problems caused by the wastes and is hoped adding the capacity of new renewable energy plants.

In Indonesia, some researchers have also tried to develop systems that capable to convert wastes into energy. By using a microwave device, pyrolysis process can be used to produce some valuable fuels from food waste of household wastes which can be used for power generation, transportation, and another useful material [5]. Fuels in the form of solid, liquid, and gas can also be obtained from another waste of tire by using pyrolysis process with rotary kiln reactor type [6]. A valuable oil from plastic drinking water waste could also is gained using a simple thermal device with distillation process [7].

Until now, waste to energy research focused on industrial scale and very little is applied on small scale such as domestic scales. Some research is currently on the use of a domestic stove to produce thermal energy from wastes [8]. Unlike electricity, which can flowing through the grid, the thermal energy can only be used directly or carried or mobilized [9], meaning a portable system that can store thermal energy and can be carried to another places that need it, for example for heating purpose.

The problem caused by the household garbage can be solved by involving the family itself. By applying waste to energy technology, a family can have a waste processing unit into heat energy, which can be used for household purposes such as the need of warm water for showering. This method can reduce electricity consumption for water heating purposes. Energy from wastes combustion can be stored by using a thermal energy storage sub-system, so it can be used whenever be needed [10]. Thermal energy can be stored in the form of sensible heat or latent heat [11,12]. Some of the technologies applicable are using heat recovery device with heat storage medium such as water, phase change materials, or solid.

To address the issues mentioned above, the objective of this paper is to develop a sensible heat thermal storage system (S-TES). Water was employed as the fluid medium due to its appropriate heat capacity. Besides, it undergoes a small volume change during charging process, low cost and chemically stable in transportation of mobilized thermal energy system. It has been widely applied in solar energy storage, energy conservation in buildings, as well as in the waste heat recovery. In this paper, an S-TES system with water filled into the water tank to accomplish storing/releasing heat in a few hours was designed for household waste combustion to produce heat for water heating.

2. State of the Art of the Proposed Technology

2.1 Sensible Heat Thermal Energy

Energy can be stored in the form of hot or cold. It depends on the nature of the fluid medium used. Cold energy storage systems, which are usually intended to increase the efficiency of electrical utilization. This system works by exploiting the latent heat properties of materials known as PCM. A lot of researcher studied PCM based on theoretical, analytical, and experimental as reviewed by Che Sidik *et al.,* [13]. Sometimes the fluid medium is mixed with other materials to increase the heat capacity. Kee *et al.,* [14] succeed in increasing the heat capacity of the water by mixing it with Ethylene Glycol (EG) as the fluid medium of a large capacity cooling system. The increase in the heat capacity of the fluid medium is even more enhanced when it is mixed with nanoparticles which have high heat capacity as investigated by Kean *et al.,* [15]. However, for hot energy storage, sensible heat properties of the fluid medium are suitable. Using water as the fluid medium is attractive compare to PCM due to its simple treatment and easy to use.

Source of heat energy that classified as waste is abundant. In addition to exhaust gas from industrial and automotive engines, it can also be obtained from combustion of solid fuels. Usually, waste caused problems if it is not managed properly, however it can produce thermal energy if it is burned properly. The thermal energy can be directly used or stored. There are three types of heat energy, namely thermochemical, sensible, and latent heat [16]. A device that generally used for storing high temperature water is a water flask that can maintain water temperatures as long as possible. Depend on the desired period, researchers studied in storing thermal energy within the range of days or weeks period.

For storing sensible heat energy, a small capacity can be used in private homes for the purposes of warm water in the bathroom. The thermal energy contained in the water can then be recovered at any time. Sensible thermal energy storage systems are very suitable for use in homestay because the operation is not too difficult, and the price is quite low. Besides, it can utilize household waste as fuel. It has implications for saving electric previously used for water heater in the bathroom. Thermal energy storage system works in a cycle, namely charging, storage, and the period of use or discharging.

2.2 Simple Thermal Energy Storage Technology for Residential Application

The main requirements of thermal storage system design are high energy density of the storage material or storage capacity, good heat transfer between the heat to be stored and the medium, mechanical and chemical stability of the medium, compatibility between the medium and the stored tank, complete reversibility of a number of cycles, low thermal losses during the storage period, and easy control. Moreover, the most important design criteria are the operation strategy, the maximum load needed, the nominal temperature and enthalpy drop, and the integration into the whole application system.

As an advanced energy technology, S-TES has attracted increasing interest for thermal applications such as space heating, hot water, cooling, and air-conditioning. S-TES systems have the potential for increasing the effective use of thermal energy equipment and for facilitating large-scale fuel switching. Of most significance, S-TES is useful for addressing the mismatch between the supply and demand of domestic energy. The basic principle of the S-TES is supplied heat into a storage system for removal and use later. The suggested method of domestic version is to circulate water from and to heat recovery into hot water tank during charging to store sensible heat and utilize later known as discharging [17].

Simple design diagram of the system proposed as shown in **Error! Reference source not found.**. The heat recovery device received high temperature of combustion gas together with the cold water. As the process undergo transfer of heat, the water temperature increases gradually and is collected in the water tank. Independent technical criteria for storage systems are difficult to establish, since they are usually case specific and are closely related to and generally affected by the economics of the resultant systems. Nevertheless, certain technical criteria are desirable, although appropriate trade-offs must be made with such other criteria as storage capacity, lifetime, size, cost, resources use, efficiency, commercial viability, safety, installation, and environmental standards.

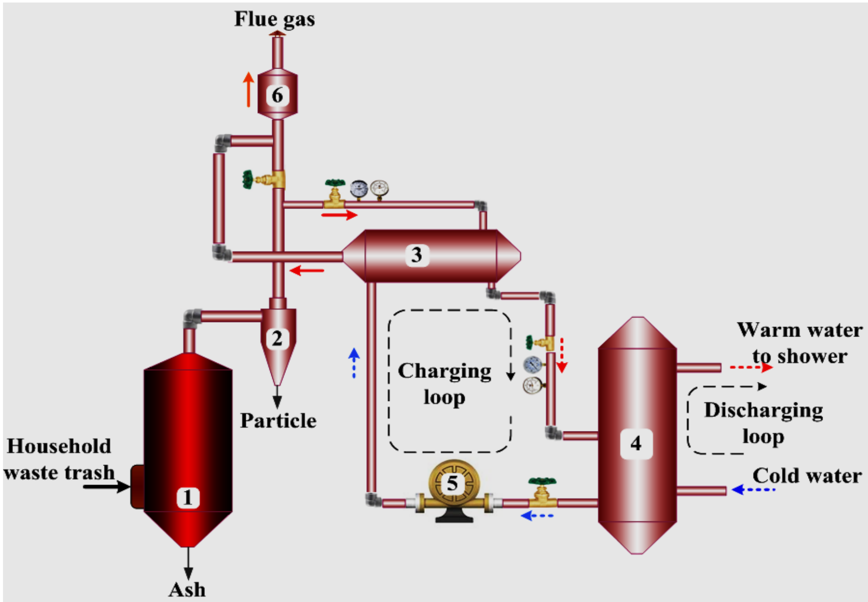

Fig. 1. The considered outdoor water heater system diagram based on sensible thermal energy storage: Incinerator (1), Cyclone (2), Heat recovery (3), Hot storage water tank (4), Water circulating pump (5), Flue gas cleaner (6)

2.3 Wastes Combustion-Based Stove

Waste is defined as a left-over, a redundant product or material of no or marginal value for the owner and which the owner wants to discard, and the wastes data used in this study taken from the literature by Christensen [18]. A mixture of trash, rubbish, refuse and garbage are the primary of the waste fuel around the world [19]. Direct combustion using fixed-bed or fluid-bed incinerators are categorized as conventional combustion types. For small capacity incinerators often called as stoves. The use of fixed-bed furnace is much easier compared to fluid-bed causes it much preferred in small and large scale combustion technology [20]. The proposed stove in this study is a domestic type with forced draft standard furnace and is placed outside of the house to reduce the negative impact on the occupants of the house. Besides having high performance, it is also low effect on the environmental air that can interfere with the user's health. Thus, combustion must be perfect according to the theoretical combustion rules by regulating combustion air requirements. For this reason, two areas of combustion are made, namely primary and secondary areas. Drying, pyrolysis, gasification, and charcoal combustion processes occur in the primary area, while in the secondary area, the flame able gasses product of gasification is burnt.

For this purpose, the stove is equipped with a primary and secondary air supply port to ensure complete combustion. A small blower is used to force the air required for combustion. A combustible gas product that has not yet been burned in the combustion zone will have a chance to burn with a secondary air supply. This has been confirmed by some researchers where combustion efficiency increased by using a secondary air supply [21,22]. As an addition, the detailed references regarding the use of stove of waste to energy have not been found in the articles. Therefore, before developing of the stove, a thermodynamic analysis is performed based on the starting point data needed, including the energy content of the waste fuel and its calorific value. The size of the stove greatly influences the complete combustion process as investigated by Aashih *et al.*, [23]. It is planned that the stove grate can be pulled in and out (removable) to facilitate reloading/refilling waste fuel and cleaning by the user. The size of the stove will be determined based on thermal energy requirements for heating and studied according to energy analysis and exergy incinerator analysis [24,25]. The heat energy generated from the waste fuel combustion in the domestic stove can be calculated by using the following equation

$$\dot{Q}_{St} = \dot{m}_{wf} LHV_{wf} \eta_{st} \quad (1)$$

$$LHV_{wf} = 348\ C\% + 939\ H\% + 105\ S\% + 63\ N\% - 108\ O\% + 245\ H_2O\% \quad (2)$$

where $\dot{Q}_{St}$ is the nominal heat load of the stove or the total input heat rate to the water in the heat recovery, $\dot{m}_{wf}$ and LHV_{wf} are the mass flow rate and the low heating value of waste fuel respectively, and η_{st} is the thermal efficiency of the stove [26]. The LHV_{wf} value is calculated from information on the material fractions in the waste, basic information of moisture, ash and combustible solids in each fraction and data on the ash and water free heating value of each fraction. The LHV_{wf} value required to control the air combustion in the stove. A Force draft stove type can reach efficiency up to 49% with biomass as fuel [27]. All Exergy analysis is used for analyzing energy systems to improve their thermal performance. Furthermore, the chemical exergy of waste fuel is important due to a highly irreversible chemical reaction, which is strongly associated with chemical elements from the equilibrium of a reference environment [28]. The input chemical exergy of waste fuel can be calculated as

$$\dot{E}_{ex} = \beta LHV_{wf} \quad (3)$$

where β is the chemical-exergy coefficient, H_{ad}, N_{ad}, O_{ad} and C_{ad} are the main component of waste fuel compositions based on dry basis and can be calculated as

$$\beta = \frac{1.044+0.016\times\frac{H_{ad}}{C_{ad}}-0.3493\times\frac{O_{ad}}{C_{ad}}\times\left(1+0.0531\times\frac{O_{ad}}{C_{ad}}\right)+0.0493\times\frac{N_{ad}}{C_{ad}}}{1-0.4124\times\frac{O_{ad}}{C_{ad}}} \tag{4}$$

2.4 Water as the Working Fluid

In this study, the water is used as the heat transfer fluid and the storage medium. Triger or driving force of heat transfer is the temperature difference between the fluid. The higher the temperature difference, the more heat is transferred. The energy needed to raise the temperature of a material from its normal temperature to its boiling temperature is called sensible heat. So, if this temperature can be maintained for a certain period, then the material still stores heat that can be reused when needed. Materials needed to store sensible heat must have a high density and specific heat capacity at low volumes. Water is a very suitable for storing sensible heat because it has a large storage capacity per weight or each volume compared to other potential materials [29]. Besides that, the water has a short charging period compared to other materials, such as phase change material [30]. However, the charging period can be increased again by making some modifications to the heat exchanger used. One disadvantage of using water is having to use a large storage tank. This is not a problem because with large capacity potential to store a lot of thermal energy and stored in relatively long time. Users do not have to do charging every day. If the availability of waste fuel is enough, the charging process can be carried out. This system has a double benefit to the users; they can manage their own wastes and gain a significant energy, which can be used for family needs.

2.5 Heat Recovery Device

The amount of thermal energy which can be absorbed by the water is greatly influenced by the availability of heat energy from the combustion of waste fuel in the stove, the type and the size of the heat exchanger used, and the water flow rate entering the heat exchanger. Heat exchangers are commonly used in practice, and an engineer often finds himself in a position to select a heat exchanger that will achieve a specified temperature change in a fluid stream of known mass flow rate, or to predict the outlet temperatures of the hot and cold fluid streams in a specified heat exchanger. As the hot gas entering the heat exchanger, temperature of the water gradually increases. In this design, the heat exchanger is planned based on indirect contact counter-flow heat exchanger types. The basic diagram flow of the heat exchanger proposed as shown in Figure 2.

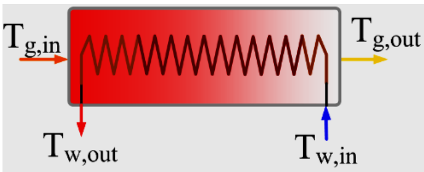

Fig. 2. Schematic of the considered heat recovery device

The capacity of heat exchanger is first analyzed using the principle of energy and energy analysis then continue to selection of the appropriate heat exchanger needed. In this design, the water temperature entering heat exchanger is assumed at 27 ^{0}C and exit at 85 ^{0}C with a flow rate of 0.20 kg/h. Whereas high temperature combustion gas enter the heat exchanger is predicted at around 250 ^{0}C and exit at 55 ^{0}C. High temperature water outlet and hot gas flow rates are the variances to achieve the capacity and the temperature of hot water into the storage tank. To find out the capacity of water storage needed can be found through the thermodynamics analysis. The idealizations are stated in practice, and they are greatly simplifying the analysis of a heat exchanger with little sacrifice from accuracy. Under some assumptions and took the inlet-outlet temperature are constant during charging/discharging period and the water is thoroughly mixed, the rate of heat transfers from the hot gas be equal to the rate of heat transfer to the cold water. That is,

$$\dot{Q}_g = \dot{m}_g c_g (T_{g,in} - T_{g,out}) \tag{5}$$

$$\dot{Q}_w = \dot{m}_w c_w (T_{w,out} - T_{w,in}) \tag{6}$$

where $\dot{m}_g$ and c_g are the mass flows and the specific heat capacity of the hot gas respectively, while $T_{g,in}$ and $T_{g,out}$ represent the temperature of the hot gas inlet and outlet to/from the heat recovery. Another $\dot{m}_w$ and c_w are the mass flow rate and the specific heat capacity of the water respectively, while $T_{w,in}$ and $T_{w,out}$ represent the temperature of the water inlet and outlet to/from the heat recovery.

Error! Reference source not found. illustrates the process diagram of the sensible heat storage system studied. The performance of the system is observed by using the thermodynamic of energy and exergy balances principles.

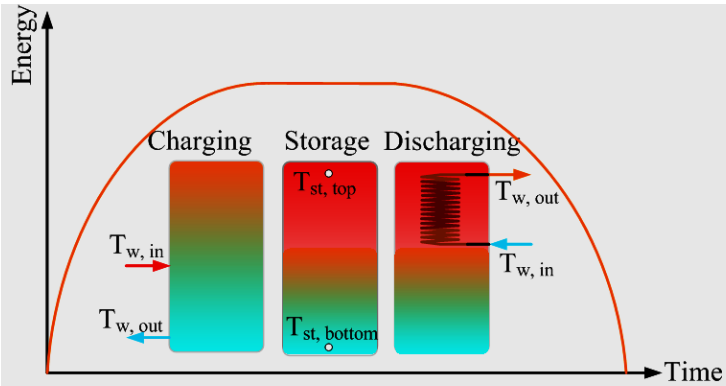

Fig. 3. Charging, storage, and discharging diagram process of a sensible heat storage unit

During charging, energy and exergy transfer are calculated based on high thermal fluid stream temperature at the inlet and outlet state as follows

$$Q_{en,ch} = m_w c_w (T_{w,in} - T_{w,out}) \tag{7}$$

$$E_{ex,ch} = m_w c_w \left[(T_{w,in} - T_{w,out}) - T_{sur} \times \ln \left(\frac{T_{w,in}}{T_{w,out}}\right) \right] \tag{8}$$

Due to the energy transfer, the variation of the energy content of the storage tank can be computed based on initial and final temperature of the water in the storage tank as

$$\Delta E_{en,ch} = m_{w,st} c_w (T_{st,final} - T_{st,initial}) \tag{9}$$

While the exergy variation of the system is calculated based on the difference between exergy content at the final state and the initial state as

$$\Delta E_{ex,ch} = m_{w,st}c_w \left[\left(T_{st,final} - T_{st,initial} \right) - T_{sur} \times \ln \left(\frac{T_{st,final}}{T_{st,initial}} \right) \right] \tag{10}$$

Assumed that the system is adiabatic, it means that no heat losses from the system. Thus, it's only the difference between the exergy input and the exergy variation of the system gives the exergy destruction caused by the internal irreversibility's as follows

$$I_{ch} = E_{ex,ch} - \Delta E_{ex,ch} \tag{11}$$

Charging energy and exergy efficiency of the system are determined as follows

$$\eta_{en,ch} = \frac{\Delta E_{en,ch}}{Q_{en,ch}} \qquad \psi_{ch} = \frac{\Delta E_{ex,ch}}{E_{ex,ch}} \tag{12}$$

The variation of the water temperature with time in the storage height tank is calculated as

$$T = \overline{T} + \left(\frac{1}{\dot{m}\, c_w} \right) \left[1 - \exp\left(-\frac{\dot{m}}{m_{wt}} \right) \right] \tag{13}$$

where $\dot{m}$ is the water stream flow rate for charging process, m_{wt} is the mass of the water in the tank, and t is the charging time period. The overbars indicate the average temperature of the storage medium that is defined by Rosen and Hooper [31] as follows

$$\overline{T} = \frac{T_{top} + T_{bottom}}{2} \tag{14}$$

2.6 Storage Tank

The purpose of heat storage is to store the thermal energy as long as possible. As a critical part of the water heating system, the heat storage tank affects the entire system's efficiency owing to the instantaneous operating characteristics. The proposed water tank storage model schematically involves an immersed coil type heat exchanger for heat recovery within the tank. It has a cylindrical form with 100 cm height and 35 cm in diameter. The inlet and exit ports are located on the same side wall at a distance of 30 cm from the tank bottom as illustrated in Figure 3. The inlet charging water flow needed is 0.20 kg/h. These data were adopted from a computer simulation study of storage tanks by Yaici *et al.*, [32]. Infarct, that the density variation of the water as a function of temperature caused a condition which is recognized as the thermal stratification. Therefore, there are the mixing areas of warm and cold water inside the tank as pointed by the dash ellipse. This phenomenon has a significant effect on the system efficiency as clarified by Christofari *et al.*, [33]. Therefore, the mixing zones should be as minimum as possible even during the charging and discharging periods.

To overcome this condition, the water should be stratified inside the storage tank, and the volumes of water with warm and cold temperatures should be kept in separate regions of the tank. To achieve the desirable stratification, it is performed by placing the inlet and outlet ports of the tank in such a way that the highest and lowest temperatures are at the top and bottom sections of the tank, respectively. This phenomenon is called a thermocline, and this technique has become well-accepted by the thermal storage community [12,34]. Another idea was by Altuntop *et al.*, [35] suggest that using an obstacle in the tank provided high thermal stratification. They found that for high thermal stratification was achieved at temperature difference of fluid stream outlet during discharging and the fluid stream outlet during charging as high as possible. In this study, the stratification criteria were taken based on water temperature differences at the top ($T_{st,top}$) and the bottom ($T_{st,bot}$) zones of the storage tank. During charging and discharging, the temperature of the water can be monitored using several thermometers. Storage tanks performance can be analysed based on thermodynamic as follows

The exergy variation during storage

$$\Delta E_{ex,st} = m_w c_w \left[\left(T_{st,final} - T_{st,initial} \right) - T_{sur} \times \ln \left(\frac{T_{st,final}}{T_{st,initial}} \right) \right] \tag{15}$$

Exergy loss to the surroundings is calculated as

$$E_{ex,st,L} = \left[1 - \frac{T_0}{T_s} \right] Q_L \qquad \text{Where, } Q_L = Q_{en,ch} - Q_{en,dis} \tag{16}$$

The internal irreversibility's during the storage period is obtained from the exergy balance equation as follows

$$I_{st} = \Delta E_{ex,st} - E_{ex,st,L} \tag{17}$$

Storage energy and exergy efficiency are calculated as follows

$$\eta_{st} = \frac{\Delta E_{ch} + Q_L}{\Delta E_{ch}} \qquad \Psi_{st} = \frac{\Delta E_{ex,sh} + \Delta E_{ex,st}}{\Delta E_{ex,sh}} \tag{18}$$

2.7 Discharging Process

Error! Reference source not found. shows schematically the discharging process which utilizes a coil type heat exchanger placed at the top in the tank. This is performed to increase the rate of discharging because the water has the highest temperature at the top [36]. Cold water enters the coil type heat exchanger and recover the heat to increase its temperature. The energy transfer during discharging process can be predicted based on fluid stream temperature at the inlet and the outlet of the coil type heat exchanger as

$$Q_{en,dis} = m_w c_w (T_{w,in} - T_{w,out}) \tag{19}$$

where $T_{w,in}$ dan $T_{w,out}$ are the respective of water temperatures inlet and outlet of the discharging coil type heat exchanger unit. While m_w and c_w are and the mass and specific heat capacity of water stream respectively. The exergy transfer during the discharging process can be calculated as

$$E_{ex,dis} = m_w c_w \left[\left(T_{w,in} - T_{w,out} \right) - T_{sur} \times \ln \frac{T_{w,in}}{T_{w,out}}) \right] \tag{20}$$

where T_{sur} is the ambient temperature of surrounding. The variation of the energy and exergy Content of the storage medium during discharging are calculated as follows

$$\Delta E_{en,dis} = m_w c_w \left(T_{st,final} - T_{st,initial} \right) \tag{21}$$

$$\Delta E_{ex,dis} = m_w c_w \left[\left(T_{st,final} - T_{st,initial} \right) - T_{sur} \times \ln \left(\frac{T_{st,final}}{T_{st,initial}} \right) \right] \quad (22)$$

It's different with the energy. The exergy can be destroyed or called as exergy destruction which can be evaluated as

$$I_{dis} = E_{ex,dis} - \Delta E_{ex,dis} \quad (23)$$

Discharging exergy, overall exergy, and the overall efficiency are calculated as follows

$$\psi_{dis} = \frac{E_{ex,dis}}{\Delta E_{ex,dis}} \quad (24)$$

$$\psi_{overal} = \frac{E_{ex,dis}}{E_{ex,ch}} \quad (25)$$

$$\eta_{ov} = \frac{Q_{en,dis}}{Q_{en,ch}} \quad (26)$$

The variation of the water temperature with time in the storage height tank during discharging as

$$T = \overline{T} + \left(\frac{Q_{en,dis}}{\dot{m}\, c_w} \right) \left[1 - \exp\left(-\frac{\dot{m}}{m_{st}} t \right) \right] \quad (27)$$

where $\dot{m}$ is the water stream flow rate, m_{st} is the mass of the water in the storage tank, an t is the time period during discharging. While the $\overline{T}$ indicate the average temperature of the storage tank medium during discharging that is calculated the same as Eq. (14).

3. Future Work

The energy and exergy based on the thermodynamic equations have been comprehensively presented in detail in this preliminary study which useful to evaluate the performance of a sensible heat thermal storage unit more realistic. Water was selected as the fluid medium due to the availability, harmfulness, corrosiveness, and large storage capacity. Overall, the system considered is quite simple, can be used on the domestic usage using household wastes as the heat source. A simple small stove can be used with a minimum impact because this system is placed out site of the house. Various energy and exergy efficiency definitions have also been presented and these may prove useful in the development of valid and acceptable standards for the performance evaluation and comparison of practical systems. This assessment needs to be proven by conducting an experimental study laboratory based.

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References

[1] Huggins, Robert A. "Hydrogen storage." In *Energy Storage*, pp. 95-117. Springer, Boston, MA, 2010. https://doi.org/10.1007/978-1-4419-1024-0_8

[2] Shatnawi, Hashem, Chin Wai Lim, Firas Basim Ismail, and Abdulrahman Aldossary. "Numerical Study of Heat Transfer Enhancement in A Solar Tower Power Receiver, Through the Introduction of Internal Fins." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 74, no. 1 (2020): 98-118. https://doi.org/10.37934/arfmts.74.1.98118

[3] Hakim, Imansyah Ibnu, Nandy Putra, Kukuh Tri Margono, and Yohanes Gunawan. "Utilization the Heat Pipe Heat Exchanger Techniques at Low Enthalpy Geothermal Energy to Coffee Drying Process." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 74, no. 2 (2020): 43-53. https://doi.org/10.37934/arfmts.74.2.4353

[4] Mustafa Sabah Mahdi, Jasim Abdulateef, Ammar Mohammed Abdulateef. "Thermoelectric Combined Heat and Power Generation System Integrated with Liquid-Fuel Stove." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 51, no. 1 (2018): 19-30.

[5] Samsudin Anis, Teknik Mesin Unnes, Yanuar Adi Kurniawan, Wirawan Sumbodo, Rais Alhakim, and Suprayoga Edi Lestari. "Thermal characteristics of microwave reactor for pyrolysis of food waste." *Journal of Physical Science* 29, no. 2 (2018): 1-13. https://doi.org/10.21315/jps2018.29.s2.1

[6] Syamsiro, M., M. S. Dwicahyo, Y. Sulistiawati, M. Ridwan, and N. Citrasari. "Development of a rotary kiln reactor for pyrolytic oil production from waste tire in Indonesia." In *IOP Conference Series: Earth and Environmental Science*, vol. 245, no. 1, p. 012044. IOP Publishing, 2019. https://doi.org/10.1088/1755-1315/245/1/012044

[7] Tambunan, B. H., Siman, and Simanjuntak, J.P. "Pyrolysis of Plastic Waste into The Fuel Oil." In *ACEIVE, 2018., 2nd Annual Conference of Engineering and Implementation on Vocational Education*. EAI, 2018.

[8] Zhao, Nan, Bowen Li, Deying Chen, Riaz Ahmad, Yingdan Zhu, Gang Li, Zhengping Yu et al. "Direct combustion of waste oil in domestic stove by an internal heat re-circulation atomization technology: Emission and performance analysis." *Waste Management* 104 (2020): 20-32. https://doi.org/10.1016/j.wasman.2020.01.007

[9] Wang, Yan, Kaixiang Yu, and Xiang Ling. "Experimental study on thermal performance of a mobilized thermal energy storage system: A case study of hydrated salt latent heat storage." *Energy and Buildings* 210 (2020): 109744. https://doi.org/10.1016/j.enbuild.2019.109744

[10] Ali, Hafiz Muhammad. "Applications of combined/hybrid use of heat pipe and phase change materials in energy storage and cooling systems: A recent review." *Journal of Energy Storage* 26 (2019): 100986. https://doi.org/10.1016/j.est.2019.100986

[11] Karami, Ramin, and Babak Kamkari. "Experimental investigation of the effect of perforated fins on thermal performance enhancement of vertical shell and tube latent heat energy storage systems." *Energy Conversion and Management* 210 (2020): 112679. https://doi.org/10.1016/j.enconman.2020.112679

[12] Li, Pei-Wen, and Cho Lik Chan. *Thermal energy storage analyses and designs*. Academic Press, 2017. https://doi.org/10.1016/B978-0-12-805344-7.00003-1

[13] Che Sidik, N. A., T.H. Kean, H.K. Chow, A. Rajaandra, S. Rahman, and J. Kaur. "Performance Enhancement of Cold Thermal Energy Storage System using Nanofluid Phase Change Materials: A Review." *Journal of Advanced Research in Materials Science* 43, no. 1 (2018): 1-21.

[14] Kee, C.H., N.A. Che Sidik, S.N. Akmal Yusof, M. Beriache, and A.T. Mohamad. "Performance Enhancement of Cold Thermal Energy Storage System using Nanofluid Phase Change Materials." *Journal of Advanced Research in Applied Mechanics* 62, no. 1 (2019): 16-32.

[15] Kean, T.H., and N.A. Che Sidik. "Thermal Performance Analysis of Nanoparticles Enhanced Phase Change Material (NEPCM) in Cold Thermal Energy Storage (CTES)." *CFD Letters* 11, no. 4 (2019): 79-91.

[16] Dehghan, Babak. "Performance assessment of ground source heat pump system integrated with micro gas turbine: Waste heat recovery." *Energy Conversion and Management* 152 (2017): 328-341. https://doi.org/10.1016/j.enconman.2017.09.058

[17] Dincer, Ibrahim. "On thermal energy storage systems and applications in buildings." *Energy and buildings* 34, no. 4 (2002): 377-388. https://doi.org/10.1016/S0378-7788(01)00126-8

[18] Christensen, Thomas, ed. *Solid waste technology and management*. John Wiley & Sons, 2011. https://doi.org/10.1002/9780470666883

[19] Klinghoffer, Naomi B., and Marco J. Castaldi, eds. *Waste to energy conversion technology*. Elsevier, 2013. https://doi.org/10.1533/9780857096364

[20] Reddy, P. Jayarama. *Energy recovery from municipal solid waste by thermal conversion technologies*. CRC Press, 2016. https://doi.org/10.1201/b21307

[21] Simanjuntak, J. P., B. H. Tambunan, H. Efendi, R. Silaban, S. Riadi, and D. Pasaribu. "A Preliminary Study of Peat Gasification Characteristics in an Improved Biomass Stove." *ACEIVE 2018* (2019): 375. https://doi.org/10.4108/eai.3-11-2018.2285651

[22] Simanjuntak, J.P. and Tambunan, B.H. "Kajian eksperimental kemampuan bahan bakar biomassa menggunakan tungku penggas." In Seminar Nasional Aptekindo, 2018.

[23] Gandigude, Aashish, and Madhva Nagarhalli. "Simulation of rocket cook-stove geometrical aspect for its performance improvement." *Materials Today: Proceedings* 5, no. 2 (2018): 3903-3908. https://doi.org/10.1016/j.matpr.2017.11.645

[24] Zhu, Yilin, Weiyi Li, Jun Li, Haojie Li, Yongzhen Wang, and Shuai Li. "Thermodynamic analysis and economic assessment of biomass-fired organic Rankine cycle combined heat and power system integrated with CO2 capture." *Energy Conversion and Management* 204 (2020): 112310. https://doi.org/10.1016/j.enconman.2019.112310

[25] Mehetre, Sonam A., N. L. Panwar, Deepak Sharma, and Himanshu Kumar. "Improved biomass cookstoves for sustainable development: A review." *Renewable and Sustainable Energy Reviews* 73 (2017): 672-687. https://doi.org/10.1016/j.rser.2017.01.150

[26] Suresh, R., V. K. Singh, J. K. Malik, A. Datta, and R. C. Pal. "Evaluation of the performance of improved biomass cooking stoves with different solid biomass fuel types." *Biomass and Bioenergy* 95 (2016): 27-34. https://doi.org/10.1016/j.biombioe.2016.08.002

[27] Raman, P., J. Murali, D. Sakthivadivel, and V. S. Vigneswaran. "Performance evaluation of three types of forced draft cook stoves using fuel wood and coconut shell." *Biomass and bioenergy* 49 (2013): 333-340. https://doi.org/10.1016/j.biombioe.2012.12.028

[28] Panwar, N. L. "Energetic and exergetic performance evaluation of improved biomass cookstoves." *International Journal of Exergy* 14, no. 4 (2014): 430-440. https://doi.org/10.1504/IJEX.2014.062910

[29] Cabeza, Luisa F. "Advances in thermal energy storage systems: Methods and applications." In *Advances in Thermal Energy Storage Systems*, pp. 37-54. Woodhead publishing, 2015. https://doi.org/10.1016/B978-0-12-819885-8.00002-4

[30] Tay, N. H. S., M. Belusko, and F. Bruno. "Experimental investigation of tubes in a phase change thermal energy storage system." *Applied Energy* 90, no. 1 (2012): 288-297. https://doi.org/10.1016/j.apenergy.2011.05.026

[31] Rosen, M. A., and F. C. Hooper. "Evaluating the Energy and Exergy Contents of Stratified Thermal Energy Storages for Selected Storage-Fluid Temperature Distributions." In *Proc. Biennial Congress of International Solar Energy Society*, pp. 1961-1966. 1991.

[32] Yaïci, Wahiba, Mohamed Ghorab, Evgueniy Entchev, and Skip Hayden. "Three-dimensional unsteady CFD simulations of a thermal storage tank performance for optimum design." *Applied Thermal Engineering* 60, no. 1-2 (2013): 152-163. https://doi.org/10.1016/j.applthermaleng.2013.07.001

[33] Cristofari, Christian, Gilles Notton, Philippe Poggi, and Alain Louche. "Influence of the flow rate and the tank stratification degree on the performances of a solar flat-plate collector." *International Journal of Thermal Sciences* 42, no. 5 (2003): 455-469. https://doi.org/10.1016/S1290-0729(02)00046-7

[34] Dincer, Ibrahim, and Mehmet Akif Ezan. *Heat Storage: A Unique Solution for Energy Systems*. Springer, 2018. https://doi.org/10.1007/978-3-319-91893-8

[35] Altuntop, Necdet, Mevlut Arslan, Veysel Ozceyhan, and Mehmet Kanoglu. "Effect of obstacles on thermal stratification in hot water storage tanks." *Applied thermal engineering* 25, no. 14-15 (2005): 2285-2298. https://doi.org/10.1016/j.applthermaleng.2004.12.013

[36] Li, Gang. "Sensible heat thermal storage energy and exergy performance evaluations." *Renewable and Sustainable Energy Reviews* 53 (2016): 897-923. https://doi.org/10.1016/j.rser.2015.09.006