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ENERGY EFFICIENCY

Technical design of aluminium scrap processing machines by utilizing direct exhaust air using conveyor drying system

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Abstract. The purpose of this study is to technically design an aluminium scrap processing machine by utilizing the direct exhaust hot air using a conveyor drying system. The automotive parts manufacturing industries use aluminium, a material that requires large amounts of energy for processing. As a result waste heat energy and scrap aluminium are produced – both could be used for savings and efficiencies. One option is utilizing exhaust hot air for the drying process of scrap material for reprocessing. The technical design of the machine follows four steps: analysing the production flow; calculating the potential energy of utilizing the exhaust hot air; designing the exhaust air utilization system for the washing and drying system; analysing the energy savings and the additional techno-economic value added from the system to reprocess the scrap aluminium chips and powder. Our analysis suggests the core melting process still uses 50% of raw material from ingot, but the other 50% from scrap (20% dry scrap briquettes and 30% dry scrap solids). The added value of the design is the material cost savings from the difference between the selling price of unprocessed scrap material and the price of the raw material purchased.

Keywords: energy efficiency, energy conservation, waste heat, flue gas utilization, material cost savings, automotive parts industry.

1. INTRODUCTION

The industrial sector in Indonesia consumed around 34% of the final energy consumption in 2019 [1]. Due to the depletion of fossil energy reserves and the challenge of reducing carbon emissions, the industrial sectors in Indonesia are asked to play a more substantial role in achieving energy efficiency (EE) [2]. The industrial sector must support government programs to realize national energy security [3]. Currently, the Indonesian government focuses on an energy-saving program for industries that consume energy above 6,000 TOE per year [4]. They must apply energy management and report the energy consumption to the government every year. In general, EE in the industry is still not intensively carried out with the more simple programs. There are many opportunities to improve EE in industries [5,6].

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In industry, a lot of energy is wasted for various reasons, consciously and unconsciously. The energy waste occurs in production, utilities, offices, warehouses, etc., both in electrical and thermal energy [7]. During the thermal process, energy is exhausted in hot water and air [8]. Usually, the hot air escapes through a channel to the open air outside. The exhaust hot air temperature varies, depending on the process and the energy used. The wasted hot air can be converted into electricity with the Organic Rankine Cycle (ORC) [9] or used directly by radiation for space heating [10] and bio-material drying [11,12].

The automotive parts manufacturing industry uses aluminium as main raw material [13]. This industry requires large amounts of energy [14]. However, it also produces waste heat energy as well as scrap aluminium. For savings and efficiency, wasted energy and aluminium scrap need to be used. One option is using waste heat for the drying process of scrap material [15]. This activity can assist government programs to energy security through the EE program in the industrial sector in a sustainable manner [16]. Besides, the government program also aligns with the company's vision of the EE program.

Many researchers have studied the direct use of flue hot air for drying in different metal industries, such as aluminium. Brough and Jouhara [17] reviewed the aluminium process flow from ore to metal alloy products. They compared the latest technology for a more efficient aluminium recycling process than the primary process. Yang et al. [18] proposed physical and chemical methods to recover waste heat for processing aluminium dross. Pocola et al. [19] evaluated the heat recovery system in an aluminium foundry based on a thermal power balance. The proposed heat recovery from waste heat was able to supply more than 25% of the total thermal power of the burners. Arink and Hassan [15] designed a furnace using flue gas to preheat the aluminium. Flue gas with a flow rate of 4 kg/s at 677 ^{o}C can heat 76 tonnes of aluminium at 2 ^{o}C/min. Selvaraj et al. [20] discussed an innovative methodology that uses the exhaust heat for aluminium preheating. By arranging aluminium powder between the scrap and the host casting, the heat recovery can achieve 5.7%. Wagiman et al. [21] reviewed the usage of direct hot extrusion of the aluminium chip in the recycling of aluminium, focusing on the end product, properties and processing route. Li et al. [22] developed a novel method to recycle and reuse iron scraps from machining. The iron scraps were compressed into scrap cakes using an auto hydraulic metal block machine. The iron scrap cakes possessed higher green density and strength. The result showed that the material yield rate of iron scrap cakes reached more than 90%, while the dispersed iron scraps have an average value of 82%. The technique to select the process combination and routes on the product type and properties, degree of contamination of chip and size, was proven as a viable method for aluminium recycling [15,17–22].

Based on the previous studies, waste heat has been used in processing chips and powder aluminium scrap. However, more studies examined technologies and application methods of the exhaust heat for recycling aluminium scrap. The exhaust heat from the oven is recoverable during processes such as washing and drying. The program can reduce production costs by minimising the energy cost component. For that, this study proposes the technical design of the aluminium scrap processing machine that utilizes direct hot air using a conveyor drying system.

2. METHODOLOGY

First, for stability and availability of heat energy, it is necessary to analyse the utilization of exhaust air from other processes. Besides, the thermal energy storage from the exhaust air to another thermal energy also needs to be considered; for example, using hot water storage. The stored heat energy can be used as a backup or used for the other processes. This method needs to be analysed further both technically and economically.

Likewise, in the machining process, wet scrap chips occur. The two forms of scrap were compressed into wet scrap briquettes and dried in the briquette drying oven. Then, they continued to the cooling process to become the dry scrap briquette. The heat energy for the briquette drying oven came from the direct use of the exhaust waste heat from the hot hanger cleaner/burner process.

Second, we calculated the potential energy of the hot air from the oven that can be used for other processes, Q_{ex} as

$$Q_{ex} = m_a c_{p,a} \Delta T, \tag{1}$$

where $\dot{m}$ [kg/s] is the mass flow rate of air, $c_{p,a}$ [J/kg^{o}C] denotes the specific heat of air, and ΔT is the temperature difference between the high temperature of hot air $T_{e,x}$ [^{o}C] and the ambient air temperature T_e [^{o}C]. A thermocouple was placed in the air duct to measure the oven's exhaust hot air temperature. The control panel recorded the measured data.

Third, we designed the exhaust air system for the process of washing and drying the aluminium scraps. There were several important points to consider, such as optimising the exhaust air uses to reduce the heat energy input, reducing moving parts to make it easier and cheaper in maintenance, etc.

Fourth, we analysed the energy savings and the additional techno-economic value-added. The analysis considered the costs and benefits analysis such as energy-

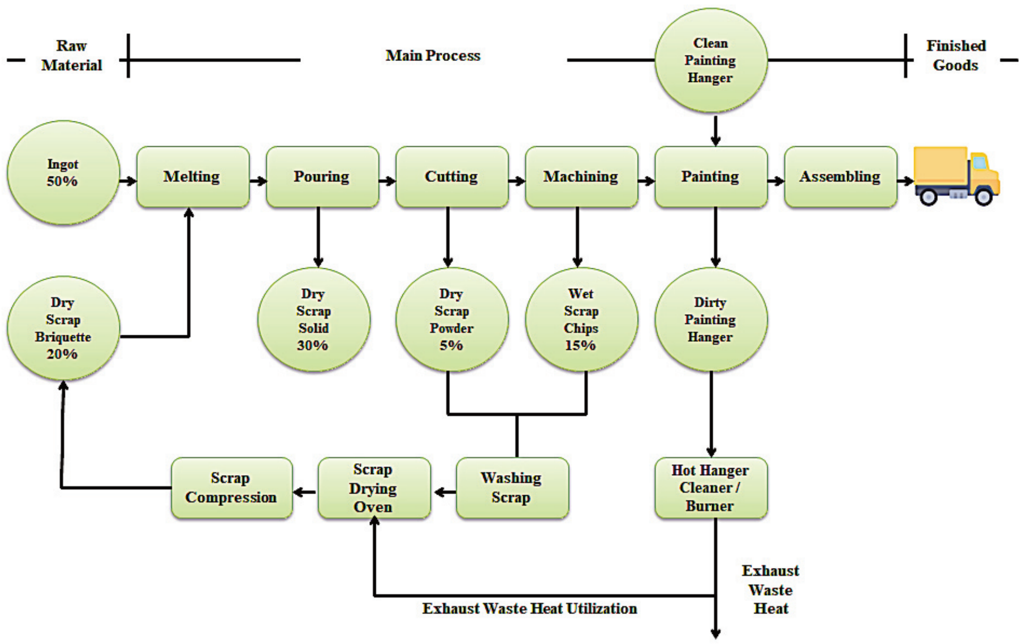

Fig. 1. Process flow of production and oven exhaust air utilization for aluminium scrap drying.

saving, ratio of return on investment (ROI), cost reduction, etc. [23,24].

As an investment for energy savings in the production process C_{inv} (given in Indonesian Rupiahs [IDR]) ROI was calculated as

$$ROI = \left(\frac{C_{sav}}{C_{inv}}\right) x100\%, \quad (2)$$

where C_{sav} is the ingot material cost saving due to the reprocessed of wet scrap aluminium (powder/chips) $A_{scr,w}$ into dry scrap briquette $A_{scr,d}$ by utilizing exhaust hot air. The C_{sav} can be calculated as

$$C_{sav} = \left(P_{vir} - P_{scr,d} - C_{p,w-d}\right) x A_{scr,d}, \quad (3)$$

where $C_{p,w-d}$ is the operational cost for processing wet aluminium scrap per kg that can be calculated as

$$C_{p,w-d} = \frac{A_{scr,w}}{E_{p,w-d}}, \quad (4)$$

where $E_{p,w-d}$ is the daily energy cost of exhaust hot air utilization.

3. RESULTS AND DISCUSSION

Figure 2 shows the exhaust hot air temperature profile and potential energy utilization in time. The blasting process used sand as a medium of heat delivery at a constant temperature of 117 °C. The process took 60 minutes. The loading-unloading process took 10 minutes. Those processes continued without reducing the temperature. The blasting door was opened, the hanger pulled, and the products were lifted using a hoist. Then, the next hanger was inserted into the chamber. The process is repeated 17 times a day. The total time was 20.5 hours. The average wind speed was 0.3 m/s. The exhaust pipe length was 1 meter. The surface airflow was 1,017.4 m^3/h. The calculated air flow rate was 1,220.8 kg/h. The measured maximum air temperature was 194 °C. The ambient air temperature was 30 °C as a reference. The calculated maximum thermal energy reached 15.72 kW_{th}.

Figure 3 shows the flow design concept for exhaust hot air utilization. As shown, the wet scrap chips (WSC) must be cleaned in the washing process, after which they were heated simultaneously with dry scrap powder (DSP) in the conveyor oven. The conveyor oven process received heat from the exhaust waste heat in the hot hanger cleaner process. Then, the process continued to conveyor oven, press and fresh air cooling to get the dry scrap briquette (DSB) product.

Figure 4 shows the modified process flow after using the exhaust air based on the initial process flow in Fig. 1. As shown, the melting process still uses 50% of raw material from ingot, but the other 50% from scrap – 20% DSB and 30% dry scrap solids (DSS). DSBs go through the processes of melting, pouring, cutting, machining, painting, assembling and becoming

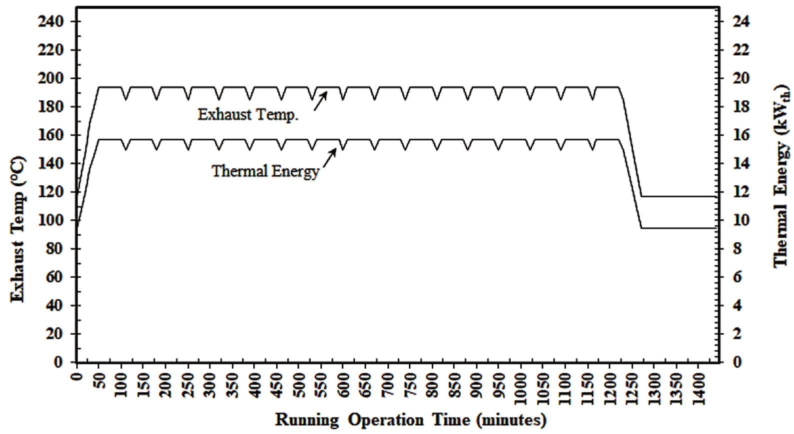

Fig. 2. Exhaust hot air temperature profile and potential energy utilization vs time.

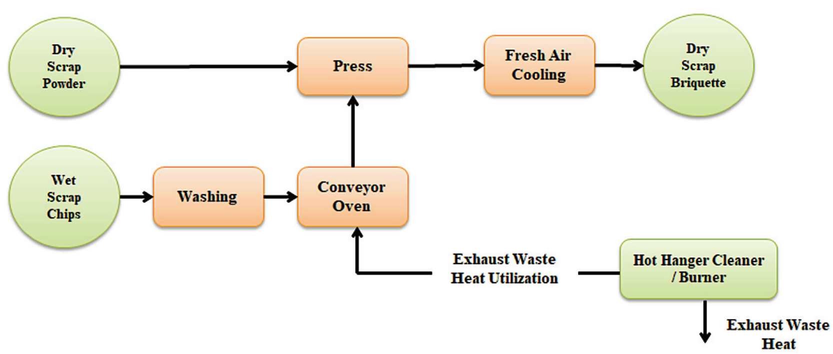

Fig. 3. The flow design concept for exhaust hot air use.

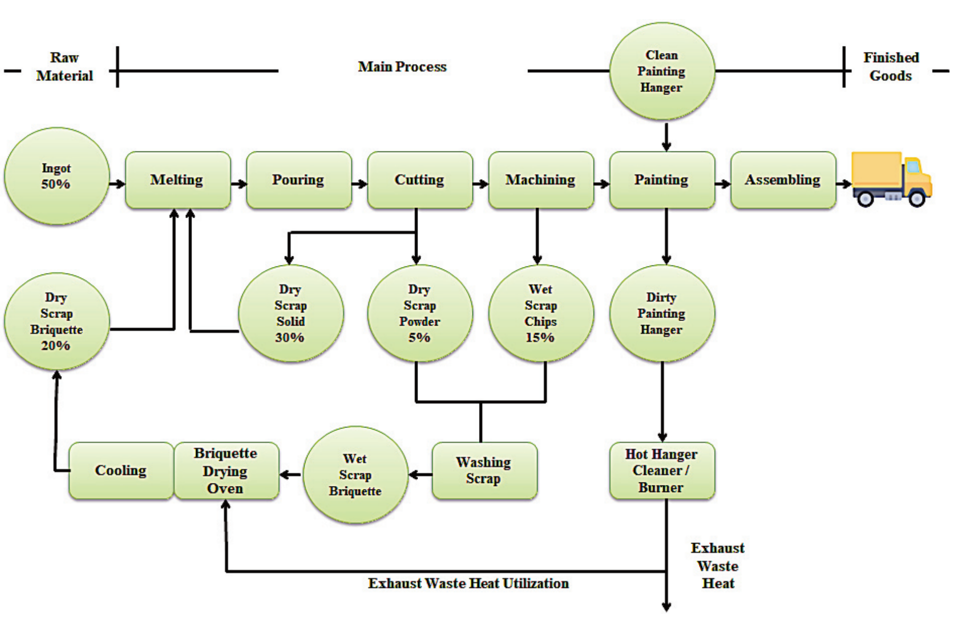

Fig. 4. Modified process flow of production and oven exhaust air use for scrap drying (hot hanger cleaner/burner process as a source of exhaust air use).

finished goods. In the cutting process, dry scrap powder occurred. Likewise, in the machining process, wet scrap chips were produced. The two forms of scrap were compressed into wet scrap briquette and dried in the briquette drying oven. Next, the material continued to the cooling process to become DSB. The heat energy for the briquette drying oven process came from the direct utilization of the exhaust waste heat from the hot hanger cleaner/burner process.

Figure 5 shows the setup design for exhaust air uses. The scrap from machining is mixed with coolant and then cleaned by the washing machine. The conveyors move products from one process to another. The washing machine treats material with hot water and an air blower. The further drying process is optimized with an automated exhaust hot air oven process for 10 minutes with the oven room temperature maintained at 110 °C. The oven's heat source comes from the use of exhaust air in the hot hanger cleaner process. The estimated heat source of furnace heat ducting is around 194 °C. Next, the dry scrap moves to the compaction machine. It produces one DSB with dimensions of 80 × 80 cm per minute. Finally, the DSB reaches into a storage tank with the capacity of 25 pcs of DSB. The total time of the DSB process is 20.5 hours/day.

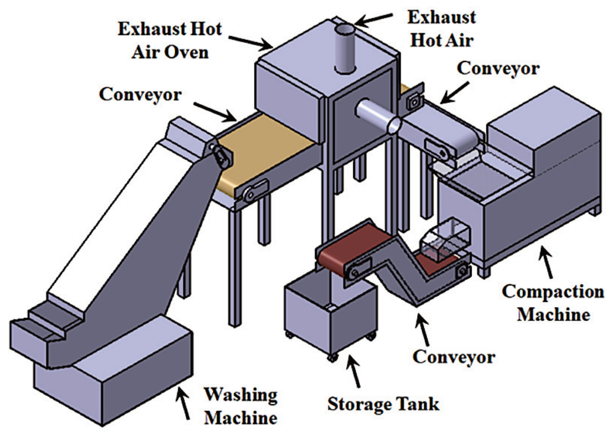

Fig. 5. Set up design for exhaust hot air utilization.

Using the information from Table 1 and the calculated results in Table 2, $E_{p,w-d}$ is 1,422,583 IDR, then $C_{p,w-d}$ from Eq. (4) as the daily energy cost of exhaust hot air

Table 1. Data for aluminium production

Items		Unit	Value	Remarks/References
Total aluminium processed	A_{tot}	Kg	1,000	*Production report*
Virgin ingot consumption	A_{vir}	Kg	500	*Production report*
Dry scrap aluminium briquette	$A_{scr,d}$	Kg	500	*Estimated*
Wet scrap aluminium	$A_{scr,w}$	Kg	500	*Estimated*
Price of virgin ingot	P_{vir}	IDR/kg	30,000	[25]
Price of wet scrap aluminium	$P_{scr,w}$	IDR/kg	13,000	*Traditional market price*
Price of dry scrap aluminium briquette	$P_{scr,d}$	IDR/kg	30,000	*Traditional market price*

Table 2. Energy consumption cost for scrap aluminium processing

Items	Conversion factor	Rating Power (kW)	Operating cost (IDR), $E_{p,w-d}$		
			Daily (20.5 h)	Monthly (22 d)	Yearly (12 m)
Pre-heat oven heater	0.25	4.5	34,630	761,870	9,142,444
Exhaust hot air potential	0.6	33.9	625,967	13,771,283	165,255,397
Fan motor	1.0	1.5	46,125	1,014,750	12,177,000
Washing machine	1.0	6.0	184,500	4,059,000	48,708,000
Conveyor system	1.0	1.5	46,125	1,014,750	12,177,000
Washing pump	1.0	1.5	46,125	1,014,750	12,177,000
Additional heater	1.0	14.3	439,110	9,660,420	115,925,040
Total		63.2	1,422,583	31,296,823	45,051,087

utilization is 2,845 IDR/kg. If 500 kg of aluminium is reprocessed daily according to the modified production process presented in Fig. 4, the potential annual savings from purchasing materials C_{sav} is 2,394,000,000 IDR. Deducing from Eq. (2), assuming the investment cost C_{inv} will not exceed 1,000,000,000 IDR, the design could give a ROI of 300%.

Based on the results explained, three aspects need to be discussed. First, related to the potential utilization of exhaust hot air [15,17–21]; in order to ensure the stability and availability of heat energy, it is necessary to analyse the utilization of exhaust hot air from other processes. Besides, the storage of heat energy from the exhaust hot air to the other thermal energy also needs to be considered. For example, hot water can be used. The stored heat energy can be used as a backup or used for other processes. This method needs to be analysed further technically and economically.

Second, regarding the design of conveyor drying system [26]; to achieve the sustainability of the conveyor oven, the operating system should be easier and more efficient, minimizing human handling. For that, the system design must be simple with minimal investment costs. However, the system performance must be optimal, with the standard expected productivity and quality [27].

Third, addressing the need for energy efficiency [28–30]; in addition to utilizing the waste heat from the exhaust air in aluminium waste treatment processes, industrial system design needs to consider the use of renewable energy sources. For this system, a hybrid photovoltaic and thermal collector can supply heat and electricity simultaneously [31,32]. This system can also be integrated as a complement to the concept of ICT (information and communication technology) based energy security in a smart energy system [33,34].

The practical application of this research is to directly modify the main production processes of the industry by adding a step for aluminium scrap chip and powder recycling [35]. This research, with the necessary modifications and adjustments, can also be applied to other metals and generally to other industrial processes [36]. This research contributes in terms of energy efficiency and also cost savings, especially for aluminium processing industries [37]. Future research on the topic should continue evaluation analysis and standard modification of the process using simulations to obtain more accurate results [38].

4. CONCLUSIONS

The technical design of the aluminium scrap processing machine that recovers the direct exhaust air using a conveyor drying system has been discussed. The exhaust air from the hot hanger process can be utilised, especially in the drying process of scrap aluminium chips and powder. Therefore, scrap aluminium can be recycled into raw material. The melting process still uses 50% of raw material from ingot; however, the other 50% is recovered from scrap, comprising 20% of dry scrap briquettes (DSB) and 30% of dry scrap solids (DSS). In addition to energy savings, the added value of using exhaust air is material cost savings from the difference between the selling price of unprocessed scrap material and the price of the raw material purchased.

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Alumiiniumijäätmete töötlusseadmete tehniline disain protsessis tekkiva väljatõmbeõhu taaskasutamisel konveierkuivatuse meetodil

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Käesolevas töös kajastatakse alumiiniumijäätmete töötlemise tehnilist disaini. Välja on toodud ka protsessis tekkiva väljatõmbeõhu taaskasutamine ja sedasi saavutatav energiasääst, kui kasutada konveierkuivatussüsteemi. Kõrgetemperatuurilisest alumiiniumijäätmete töötlemise protsessist väljuvat õhku kasutatakse eelkõige alumiiniumijääkide ja -pulbri kuivatamisel. Vanametalli jääke ja alumiiniumipulbrit saab heitõhu taaskasutamise lisatoel töödelda tooraineks energiaefektiivsemalt. Alumiiniumi sulatusprotsessis kasutatakse 50% toormaterjali valuplokist, seejärel ülejäänud 50% vanametallist, mis muudetakse 20–30% kuivaine sisaldusega purubriketiks. Lisaks energiasäästule annab väljatõmbeõhu taaskasutamine lisaväärtust materjalikulude kokkuhoiul.