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Optimization of Working Temperature and Determination of Dross Recycle Soldering Machine Control Type Based on Specific Energy Consumption

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Abstract— *Solder Dross Recycle (SDR) machine role is to extract solder out of solder dross. SDR machine has two parameters which are working temperature and controller type. There are three working temperature references which are 220 °C, 250 °C, dan 298 °C. Controller type of the machine are available for two options which are ON-OFF and PID controller. The aim of this research is to determine working temperature combination and controller type. The SDR machine is tested with variations of working temperature and controller type. Data needed for choosing the best working temperature are extracted solder mass (ESM) and energy consumption (EC). EC is obtained from measurement by digital power meter, while MST is obtained by measuring final solder weight. EC is divided by MST to obtain Specific Energy Consumption (SEC). Data needed for choosing the best controller type is electrical power which is recorded every 10 minutes. Testing period is decided to be 200 minutes. The result of working temperature testing showed that the bigger the working temperature the smaller the KES so that the suitable working temperature in this experiment is 298 °C. The result of controller type testing showed that the smallest SEC was in PID controller with the working temperature of 298 °C which is 0.55 kWh/kg. The SEC value of 0.55 kWh/kg is less as much as 10.9% than the smallest SEC value of ON- OFF controller whose working temperature is 298 °C which is 0.61 kWh/kg. The chosen working temperature based on SEC is 298 °C with SEC of 0.55 kWh/kg out of 220 °C and 250 °C. The chosen controller type is PID controller with SEC of 0.55 kWh/kg with setting of Kp. Ki, and Kd respectively are 9, 250, and 7 out of ON-OFF controller with hysteresis setting of 0.5 °C.*

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1. INTRODUCTION

The Solder Dross Recycle (SDR) machine is designed to extract solder from solder dross. The SDR machine operates on two primary parameters: operating temperature and control type. The performance of the machine, as measured by Specific Energy Consumption (SEC), is optimized by tuning these parameters. Three reference operating temperatures are considered: the datasheet for SMIC type M705 solder, the operating temperature of the SDS-10MS SDR machine, and the standard set by the company's Research & Development Headquarter division in Japan. The SDR machine's control type offers two options as part of the temperature controller: ON-OFF and PID**.**

A review of various references indicates a range of optimal operating temperatures for solder extraction using the SDR machine. The datasheet for SMIC type M705 solder recommends a temperature of 220 °C. Conversely, the operational standards for the SDS-10MS SDR machine specify an optimal operating temperature of 250 °C. Furthermore, guidelines provided by the company's Japanese Research and Development Headquarters suggest a recommended operating temperature of 298 °C.

Depends on [1] and [2] have demonstrated that heating dross can yield solder recovery rates exceeding 90%. The potential to further enhance solder extraction through temperature optimization has been explored in journal [3].

The studies reviewed employed various control types, including Model Predictive Control (MPC), Fuzzy Logic Control (FLC), PID, and ON-OFF. This study, however, will focus solely on comparing PID and ON-OFF control types in terms of energy consumption. Research conducted in [4-7] suggests that PID control outperforms ON-OFF control in terms of energy consumption (EC). However, findings from [8] indicate that a hysteresis-based control with a 0.5°C threshold yields better results compared to PID control. To assess the overall efficiency of a machine, energy consumption is a crucial metric. According to [9], energy consumption in this context refers to fuel consumption, typically measured in liters for aviation turbine fuel (avtur).

The primary objective of this studies is to achieve the specific energy consumption (SEC) by determining the ideal operating temperature and selecting the most suitable control type.

This studies incorporates the specific energy consumption (SEC), enabling the evaluation of machine performance from a specific energy consumption (SEC) perspective. Unlike previous studies [1-3] which analyzed SDR machines without considering SEC, this study aims to fill this gap by quantifying the energy efficiency of the system.

The control object in this study is the SDR machine, which differs from the studies conducted in [4-8] where the control object was a RHVAC (refrigeration, heating, ventilation, and air-conditioning) system.

1.2 Specific energy consumption

Specific Energy Consumption (SEC) is a metric that quantifies the amount of energy required to produce a unit of product [10]. Generally, SEC is calculated by dividing the total energy input by the total product output. A lower SEC value indicates higher energy efficiency of a machine.

In this study, the unit of product used is Extracted Solder Mass (ESM) (kg) and the primary energy source is electricity (kWh). The Specific Energy Consumption (SEC) can be expressed as Equation (1).

$$SEC = \frac{EC}{ESM} \quad (1)$$

Which are:
SEC = Specific Energy Consumption [kWh/kg]
EC = Energy Consumption [kWh]
ESM = Extracted Solder Mass [kg]

2. METHODOLOGY

The tools used in this research are detailed as follows:

1. SDR Engine
2. Digital power meter
3. Weight scale

This research focused on the utilization of dross as the primary material.
In this condition, the SDR machine will be tested with various combinations of operating temperatures and control types. The data required for the analysis of suitable temperature selection are ESM and EC, while the data needed for the analysis of control type selection is the electrical power.

ESM and EC data were collected at the 200 minutes mark to determine the optimal operating temperature. The EC and ESM data were then processed into SEC using Equation (1).

Electrical power data is necessary to analyze the characteristics of a control system, allowing for a comparison of the performance of different control types. Electrical power was measured every 10 minutes for a duration of 200 minutes.

3. RESULT AND DISCUSSION

The results and discussion are divided into two sub-chapter: determination of operating temperature and determination of control type. The obtained data is presented in tables and visualized using graphs.

3.1 Determination of working temperature

EC and ESM data was processed into SEC by substituting it into Equation (1). For each row, the value in the EC column is divided by the value in the ESM column, and the result is stored in the SEC column. The temperature examination data is presented in Table 1.

Table 1. Working temperature examination data

No.	Control Type	T [°C]	ESM [kg]	EC [kWh]	SEC [kWh/kg]
1	ON-OFF	220	2.65	2.348	0.89
2		250	3.21	2.653	0.83
3		298	4.57	2.773	0.61
4	PID	220	2.58	1.945	0.75
5		250	3.36	2.203	0.66
6		298	4.7	2.585	0.55

For the purpose of better analysis, the data presented in Table 3 is visualized in graphically variation of working temperature and two distinct control strategies, ON-OFF and PID, are depicted in Figure 1.

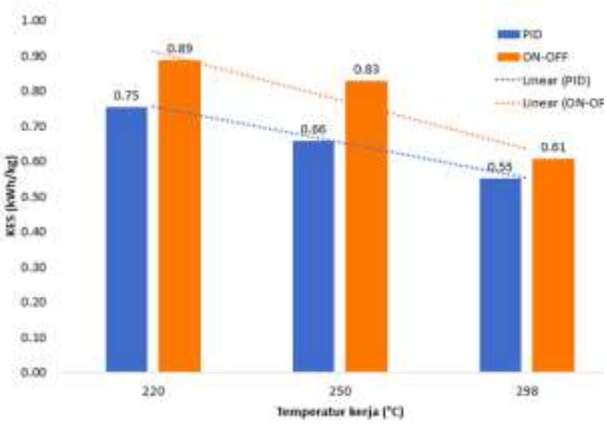

Figure 1. Graph of Working Temperature Variation against and SEC

To determine the working operating temperature, the temperature with the lowest Specific Energy Consumption (SEC) among the three tested temperatures was selected. As illustrated in Figure 1, both the ON-OFF and PID control linear lines exhibit a decreasing trend. This consistent trend indicates that as the operating temperature increases, the SEC decreases. Based on this observation, the highest tested temperature, 298 °C, was determined to be the most suitable operating temperature and will be implemented in the SDR machine.

3.2 Determination of Control Type

The electrical power data for determining the optimal control type is presented in Table 2.

Table 2. Control type examination data

No.	minute	Power [W]		Temperature [°C]	
		ON-OFF	PID	ON-OFF	PID
1	0	766.1	799	26	26
2	10	766.4	530.4	64	45
3	20	760.4	672.6	105	82
4	30	772.5	692	161	136
5	40	754.4	795.4	203	179
6	50	760.4	614.4	232	208
7	60	706	692	250	236
8	70	754.4	692	263	258
9	80	754.4	692	268	276
10	90	790.6	672.6	273	290
11	100	796.6	601.5	278	298
12	110	766.4	601.5	283	298
13	120	754.4	524	288	298
14	130	754.4	627.4	293	297

No.	minute	Power [W]		Temperature [°C]	
		ON-OFF	PID	ON-OFF	PID
15	140	791	498.1	298	298
16	150	0	659.7	298	298
17	160	799	601.5	296	298
18	170	790	569.2	298	298
19	180	788	588.6	298	298
20	190	787	549.8	297	297
21	200	793	763.1	297	296

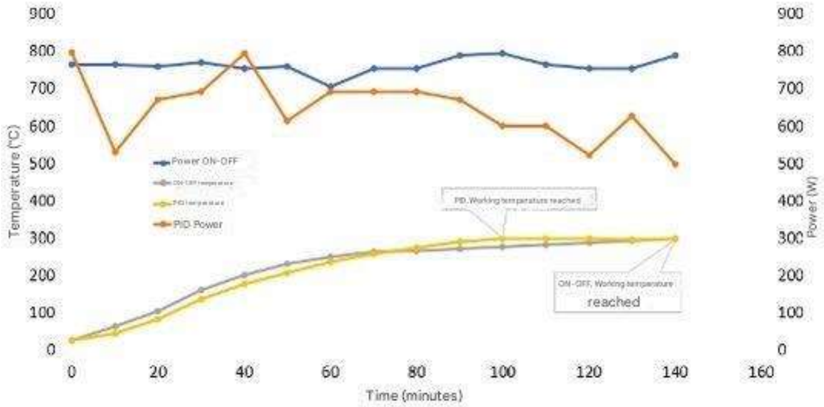

Figure 2. Transient response graph for working temperature 298°C

The data presented in Table 2 is graphically represented as both transient and steady-state response plots. The transient response is illustrated in Figure 2.

Based on the transient response depicted in figure 2, the ON-OFF control characteristic, which constantly supplies 100% power to the actuator, results in higher energy consumption compared to the PID control characteristic that reduces power to the actuator as it approaches the setpoint temperature. This implies that, overall, the PID control delivers less power to the actuator compared to the ON-OFF control, resulting in lower energy consumption, which is directly proportional to the SEC.

The steady-state response graph for the ON-OFF control at an operating temperature of 298 °C is presented in Figure 3. Based on the steady-state response in Figure 3, the ON-OFF control is observed to cut off power to the actuator at the 150th minute due to the temperature still being within the ON-OFF control hysteresis zone. From the 150th to the 200th minute, the ON-OFF control is recorded to supply power to the actuator ranging from 787 W to 799 W. Within the time range from the 150th to the 200th minute, the temperature is recorded to be below the temperature at three data points: at the 160th minute it is 296 °C, and at the 190th and 200th minutes it is 297 °C.

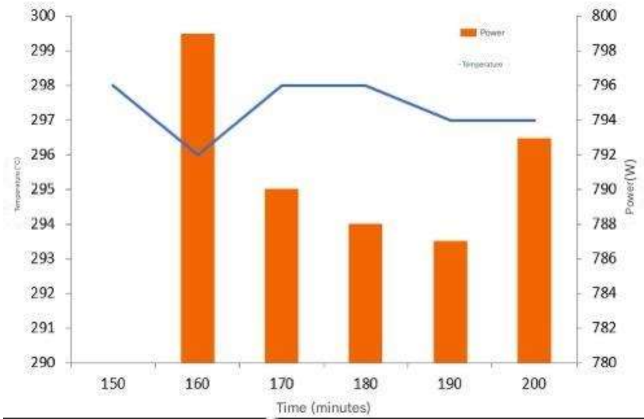

Figure 3. Steady-state control ON-OFF response graph in 298°C working temperature

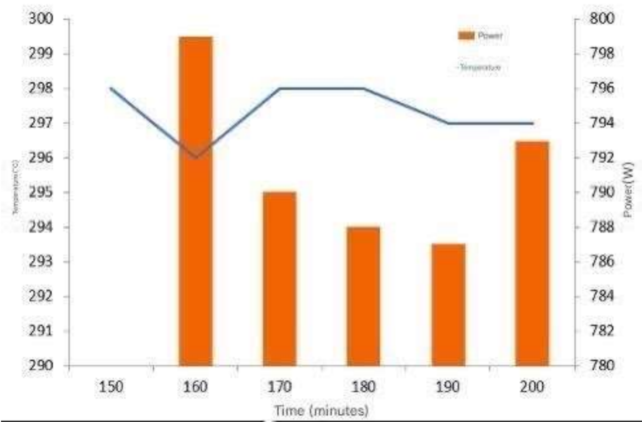

Figure 4. Steady-state control PID response graph in 298°C working temperature

Steady-state response for ON-OFF control on 298°C working temperature, illustrated in Figure 4.

Based on the steady-state response in Figure 4, within the time range from the 110th-minutes to the 160th-minutes, the PID control supplied varying power to the actuator, ranging from 498.1 W to 659.7 W. The temperature was recorded to be below the setpoint temperature at the 130th-minutes, specifically at 297 °C.

From the perspective of temperature response, PID control outperforms ON-OFF control as evidenced by the PID controller's ability to maintain temperature more consistently in the steady-state response graph. Additionally, PID control reached the setpoint temperature of 298 °C at the 11th-minute, which is faster compared to the ON-OFF control that reached the setpoint temperature at the 14th-minute.

From an electrical power perspective, PID control consistently delivers less power compared to ON-OFF control.

Based on a comprehensive analysis of both the transient and steady-state response graphs, PID control is selected as the most suitable control type for the SDR machine. This finding aligns with the results presented in journals [4], [5], [6], and [7].

4. CONCLUSION

Based on the studies results above, the following conclusions are:

1. The results of the operating temperature tests indicate that as the operating temperature increases, the Specific Energy Consumption (SEC) decreases. This is evident from the test results of the control types, which show that at an operating temperature of 298°C, the SEC value is the lowest at 0.55 kWh/kg, compared to temperatures of 220°C to 250°C, where the SEC varies from 0.89 to 0.66.
2. The best SEC value is, of course, the lowest one, which is 0.55 at an operating temperature of 298°C.

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