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A Comparative Case Study of Ceramic Heater and Induction Heater in Polymer Industry

Dr. Yogesh Prajapati[1], Shweta Prajapati[2], Bakul Makwana[3], Apurva Christian[4], Dr. Jatinkumar J. Patel[5]

[1]*Assistant Professor, Electrical Engineering Department, Birla Vishvakarma Mahavidyalaya Engineering College, Vallabh Vidyanagar, yrprajapati@bvmengineering.ac.in*
[2]*Lecturer, Electrical Engineering Department, BBIT, Vallabh Vidyanagar, Syp.ee7@gmail.com*
[3]*Assistant Professor, Electrical Engineering Department, Birla Vishvakarma Mahavidyalaya Engineering College, Vallabh Vidyanagar, Bakul308@gmail.com*
[4]*Assistant Professor, Electrical Engineering Department, Government Engineering. College, Godhra, apurvchristian@gmail.com*
[5]*Professor, Electrical Engineering Department, HCET, Gokul University, jjpatelgcet@gmail.com*

In the polymer industry, optimising heating systems for plastic extrusion is crucial for efficiency and energy use. This study compares ceramic and induction heaters in an industrial extruder, focusing on electrical power and thermal performance. Electrical metrics such as voltage, current, power factor, and energy consumption (kWh) were measured, while thermal imaging assessed heat distribution and retention. Results show that induction heaters are more energy-efficient, reducing unit consumption by 47% and process time by 32% compared to ceramic heaters. Additionally, induction heaters offer better thermal control, reducing heat loss and cooling time. This study suggests that induction heating provides notable advantages over ceramic heaters in energy efficiency, process optimisation, and thermal management.

1. Introduction

An extruder is a critical component in plastic manufacturing, responsible for transforming raw materials into continuous forms such as pipes, tubing, sheets, and films. The process starts by introducing plastic pellets, granules, or powder into the extruder's hopper [1] . A rotating screw then transports the material through the barrel, where it is subjected to heat and pressure until it melts. The molten plastic is then pushed through a die at the end of the barrel, which shapes it into the desired profile. Afterward, the shaped plastic is cooled and solidified, typically using water or air, before being cut or spooled to meet specific dimensions. This makes extruders indispensable for producing a wide variety of plastic products [2].

1.1 Basic Working Principle of Plastic Extruder Machine:

The core function of a plastic extruder is to heat, melt, and shape thermoplastic materials. The process begins with feeding granular or pelletized raw materials into the extruder, where they are heated and thoroughly mixed. The molten material is then extruded through a die, forming it into a continuous profile. Maintaining precise control over temperature and pressure is critical to ensuring consistent quality and uniformity in the final product. This method effectively converts raw materials into the desired forms [3].

1.2 Core Components of Plastic Extruder Machine and Their Functions

Figure 1.1 illustrates the core components of a plastic extruder machine, each playing a vital role in the extrusion process:

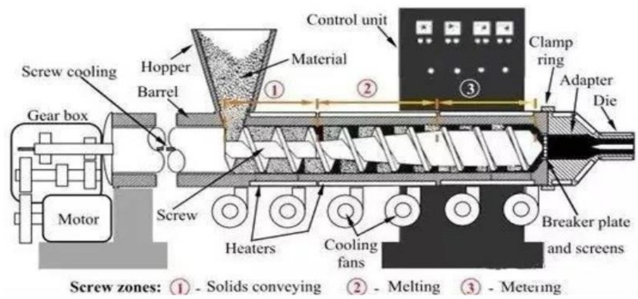

Fig. 1.1 Core Components of Plastic Extruder Machine

- Hopper: Serves as the entry point for raw materials, maintaining a consistent feed [4].
- Screw: The core component, responsible for transporting, melting, and mixing the materials [5].
- Barrel: Encloses the screw and contains heating and cooling elements, crucial for controlling extrusion quality [6].
- Heater and Cooler: Manage the barrel's temperature to melt and cool the material effectively [7].
- Die: Molds the molten plastic, determining the complexity of the final product's shape [8].
- Drive System: Consisting of a motor and gearbox, it regulates screw speed, impacting the overall efficiency of the extruder. These components work together to ensure efficient plastic extrusion [9].

2. The Extrusion Process Flow

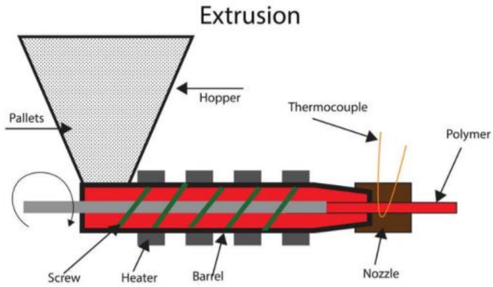

Fig. 1.2 Extrusion Process

The extrusion process begins with the introduction of materials into the hopper, which directs them into the barrel [10]. As the material advances through the barrel, the rotating screw generates heat, causing it to melt. Throughout the process, temperature and consistency are carefully controlled [11]. When the molten plastic reaches the die, it is shaped before undergoing cooling and solidification. Figure 1.2 depicts the step-by-step progression of the extrusion process [12].

2.1 Screw Design and Its Importance

The dimensions of the screw, including its diameter, length, and pitch, are essential to the extrusion process. These parameters influence heat generation, mixing efficiency, and pressure development within the barrel, and must be adapted according to the specific material being processed [13].

2.2 Thermal Management

Effective control of heating and cooling within the barrel is vital for optimal extrusion. Heaters are used to achieve the necessary material temperature, while cooling systems are critical to prevent thermal degradation, ensuring consistent extrusion quality [14].

2.3 Die Configuration and Product Formation

The design of the die is crucial as it determines the extruded product's dimensions, shape, and surface texture. Complex profiles necessitate sophisticated die designs to achieve the desired characteristics [15].

2.4 Extruder Applications

Extruders are employed across various industries, including construction, automotive, and consumer goods. They are used to manufacture a range of products such as pipes, insulation materials, automotive parts, trims, plastic bags, and toys, demonstrating their versatility and ability to handle different materials and design requirements [16].

3 About the Heating process in the plant

3.1 The ceramic heating

The ceramic heater ring operates by elevating the temperature of plastic pellets inside the extruder barrel, causing them to soften and melt [17]. As the molten plastic moves through the extrusion die, it is molded into the desired shape [18]. Figure 1.3 illustrates the ceramic heater's design. Its effective heat transfer capabilities are crucial for maintaining accurate temperature regulation, which is essential for consistent material properties and high-quality end products throughout the extrusion process [19][20].

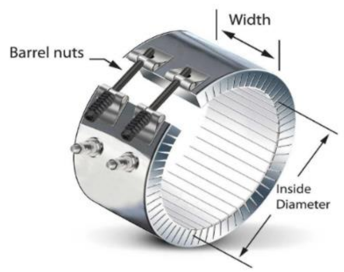

Fig. 1.3 Ceramic Heater

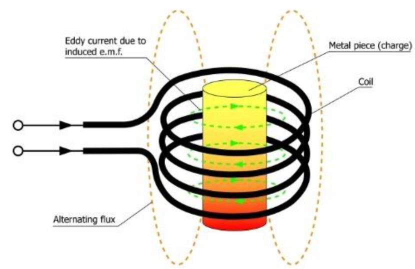

Fig. 1.4 Heat produced by Induction heating.

3.2 The Induction heating

The induction heating system efficiently generates heat directly within the extruder barrel, leading to reduced startup times and lower energy usage [21]. Unlike conventional heater bands, induction heating utilizes alternating current passed through coils surrounding the barrel [22]. This process induces eddy currents, producing heat internally within the barrel [23]. Figure 4 provides a depiction of the induction heating mechanism and its components [24]. As shown in Figure 1.5, heat is generated in areas where eddy currents flow due to their interaction with the metal's electrical resistance.

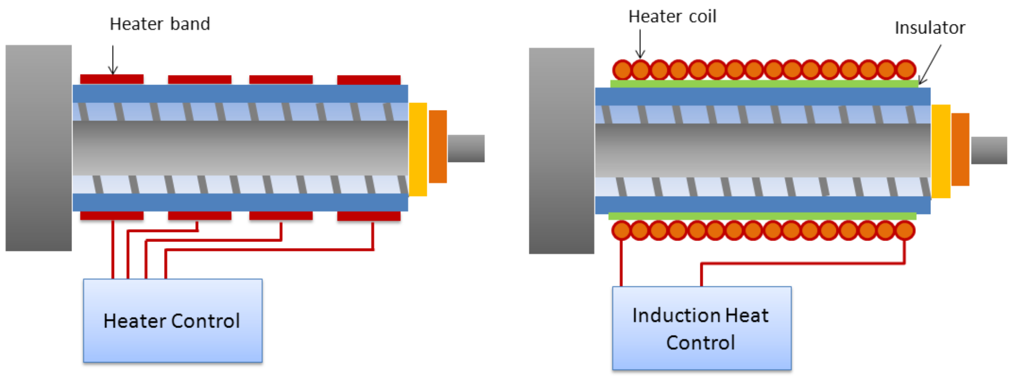

Fig. 1.5. Cross-section of extruder barrel shown the comparison of classical heating and induction heating.

4 Comparative Analysis of Ceramic Heater and Induction Heater

A comparative evaluation was performed between ceramic and induction heaters, focusing on two primary aspects: Electrical Power Analysis and Thermal Performance Analysis [25-28].

Electrical parameters including voltage, current, power factor, real power, reactive power, total power, voltage harmonics, current harmonics, and energy consumption (kWh) were measured using a Power Analyzer Model ALM 36. For the thermal analysis, thermal images were captured with a thermal imager to assess temperature variation and heat distribution.

4.1 Electrical Power Analysis

An assessment of the heater's energy consumption was performed for an output of 122 kg. This total includes 100 kg of finished product and 22 kg of waste derived from the initial 122 kg of raw material. The die employed in the process has a diameter of 150 HOL.

4.1.1 Induction Heater based Extruder – 2.

The extruder's heater and the PQA meter that was fitted for recording purposes are shown in figures 2.1 and figure2.2 below.

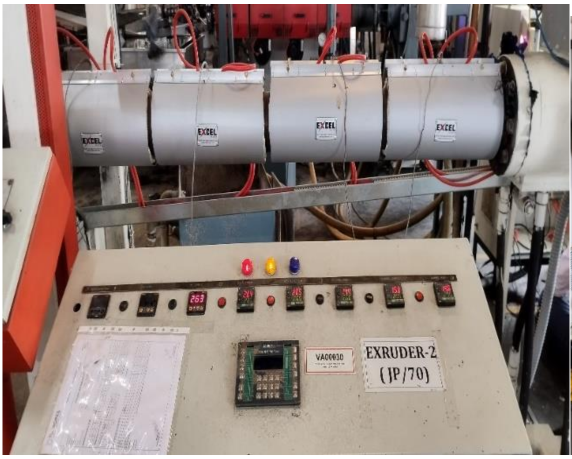

Fig. 2.1 Existing Induction Heater

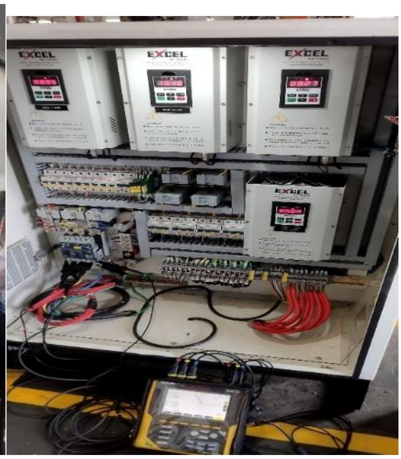

Fig. 2.2 PQA Meter Installation

The unit consumption cycle recorded throughout the testing period is shown in the following table 1.

Table 1 Induction heater cycle

Sr. No	Process	Activity	Start Time	Stop Time	Time (Min.)	Temperature (^{0}C)	Unit Consumption (Kwh)
I	Heating Cycle	Heating Start & Stop	8:18 am	8:30 am	12	Zone 1- 35/270	3.546
II	Die setting cycle	Manually setting of Die	8.30 am	9.50 am	20	Zone 2- 47/275	9.993 – 3.546 = 6.447
III	Thread setting cycle	Thread setting	9.50 am	10.34 am	45	Zone 3- 60/280	14.288 – 10.026 = 4.262
IV	Production Cycle	Production Start & Stop (0-122 kg)	10.34 am	11.20.a m	46	Zone 4- 106/285	21.768 - 14.288 = 7.84
	Total	122 kg			122		21.735

The energy consumption pattern and current consumption pattern is presents for Sr. No. 1 to 4 are presented bellow from figure 2.3 to figure 2.8.

I. Heating Cycle:

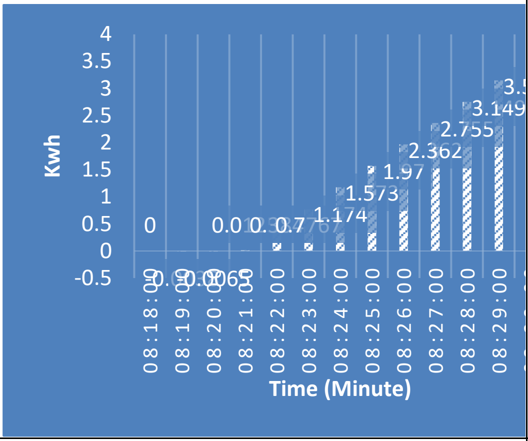

Fig. 2.3 Unit Consumption (Kwh) during the

Heating Cycle (Unit = 3.546 kwh, T=12 min)

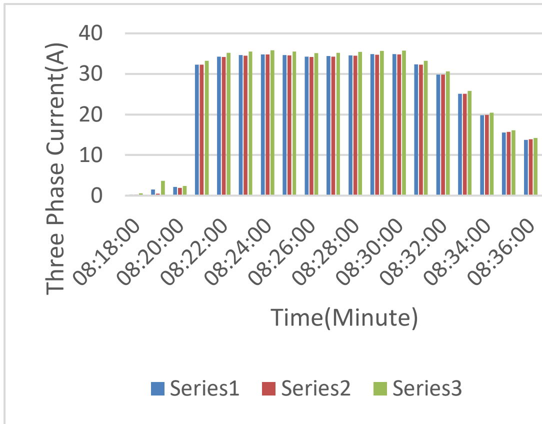

Fig. 2.4 Three Phase Current During the Heating Cycle (A)

II. Die setting cycle:

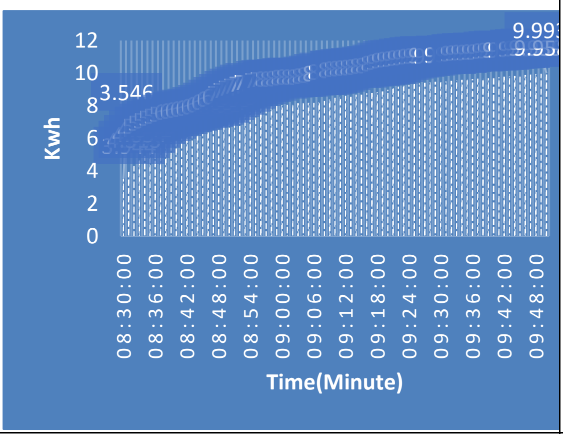

Fig. 2.5 Unit Consumption (Kwh) during the Heating Cycle (Units = 9.993 – 3.546 = 6.447 kwh, T=20 min)

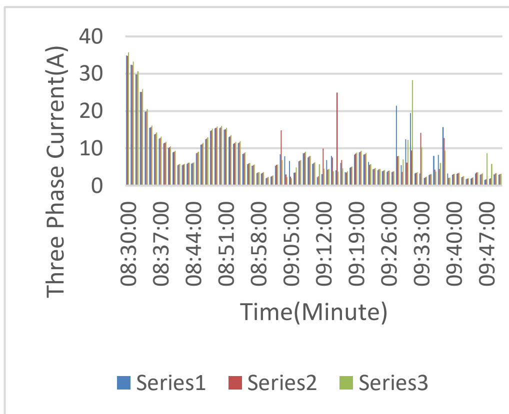

Fig. 2.6 Three Phase Current During the Heating Cycle (A)

III. Thread setting cycle:

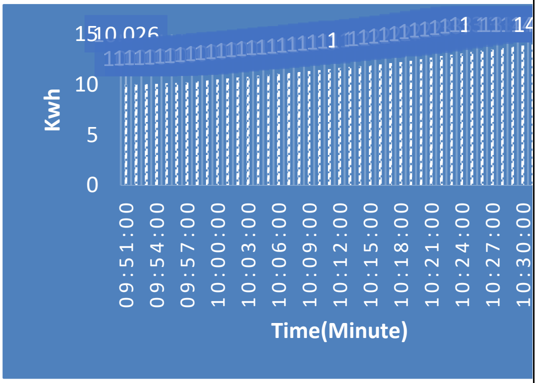

Fig. 2.7 Unit Consumption (Kwh) during the Heating Cycle

Units = 14.288 – 10.026 = 4.262 Kwh, (T= 45 min)

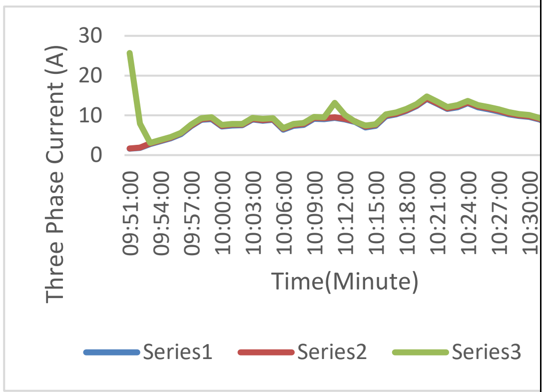

Fig. 2.8 Three Phase Current During the Heating Cycle (A)

IV. Production Cycle

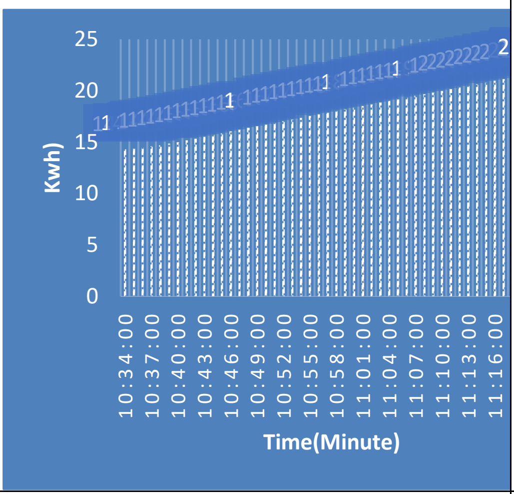

Fig. 2.9 Unit Consumption (Kwh) during the production Cycle

(Production = 122 kg, Units = 21.768- 14.288

= 7.84 kwh, T= 46 min.)

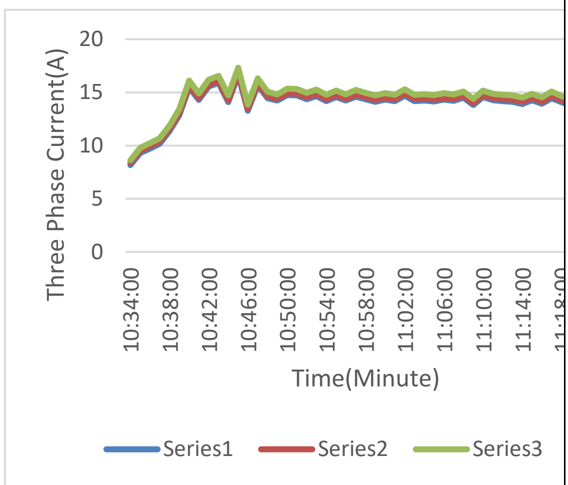

Fig. 2.10 Three Phase Current During the Heating

Cycle (A)

4.1.2 Ceramic Heater based Extruder – 2.

The extruder's heater and the PQA meter that was fitted for recording purposes are shown in figures 2.11 and figure2.12 below.

Fig. 2.11 Ceramic Heater

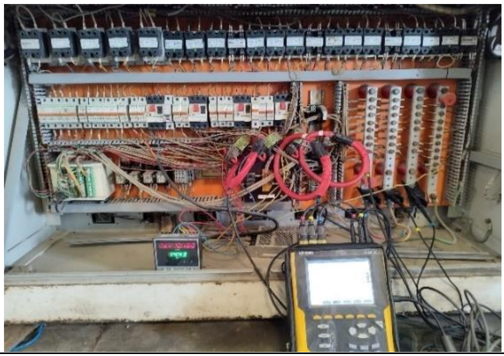

Fig. 2.12 PQA Meter Installation

The unit consumption cycle recorded throughout the testing period is shown in the following table 2.

Table 2 Ceramic heater cycle

Sr. No	Process	Activity	Start Time	Stop Time	Time (Min.)	Temperature (^{0}C)	Unit Consumption (Kwh)
I	Heating Cycle	Heating Start & Stop	11.37 am	11.57 pm	20	Zone 1-51/245	7.053
II	Die setting cycle	Manually setting of Die	11.57 am	13.06 pm	69	Zone 2-52/250	17.398-7.053 = 10.345
III	Thread setting cycle	Thread setting	13.06 pm	14.00 pm	54	Zone 3-58/255	25.788-17.698 = 8.09
IV	Production Cycle	Production Start & Stop (0-122 kg)	14.00 pm	15.00 pm	60	Zone 4-110/260	39.995-25788 =14.207
	Total	122 kg			203		39.695

The energy consumption pattern and current consumption pattern is presents for Sr. No. 1 to 4 are presented bellow from fig. 2.13 to fig. 2.20.

I. Heating Cycle

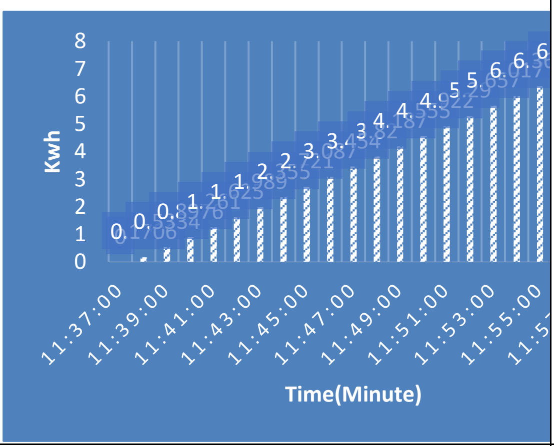

Fig. 2.13 Unit Consumption (Kwh) during the Heating Cycle

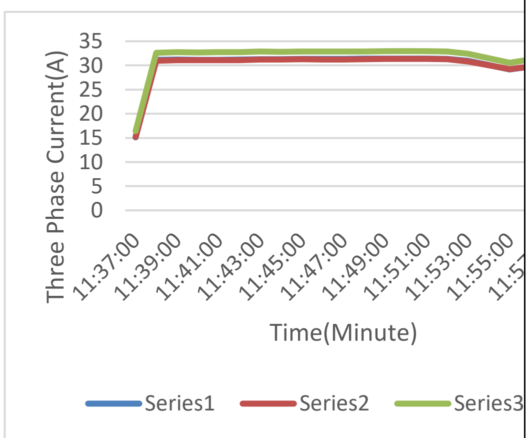

Fig. 2.14 Three Phase Current During the Heating Cycle (A)

(Unit = 7.053 kwh, T=20 min)	

II. Die setting cycle:

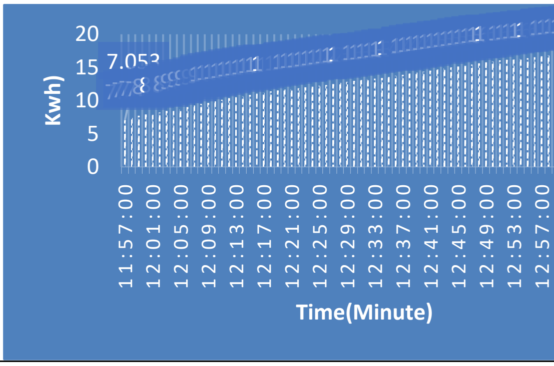	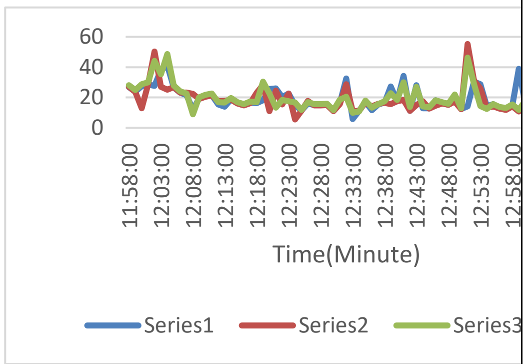
Fig. 2.15 Unit Consumption (Kwh) during the Heating Cycle (Unit = 17.398-7.053 = 10.345 kwh, T=69 min)	Fig. 2.16 Three Phase Current During the Heating Cycle (A)

Thread setting cycle

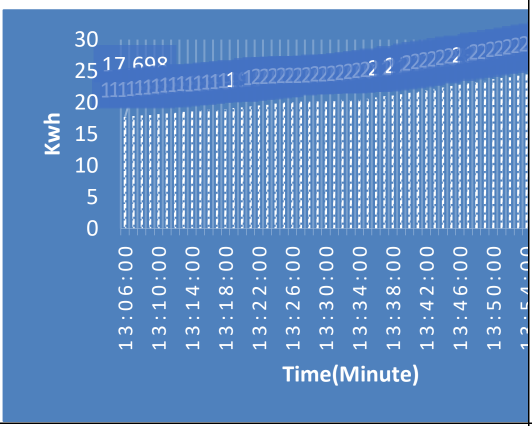	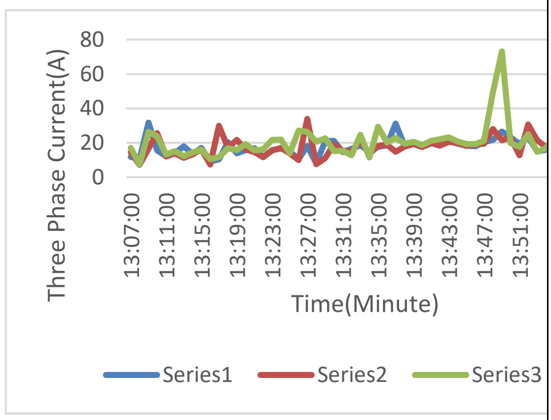
Fig. 2.17 Unit Consumption (Kwh) during the Heating Cycle (Unit = 25.788-17.698 = 8.09 kwh, T=54 min)	Fig. 2.18 Three Phase Current During the Heating Cycle (A)

III. Production Cycle

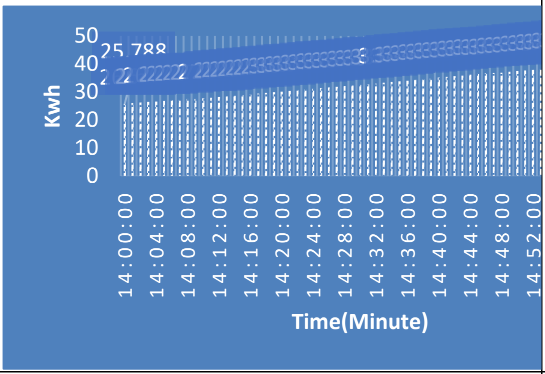

Fig. 2.19 Unit Consumption (Kwh) during the Heating Cycle

(Unit = 39.995-25788 =14.207 kwh, T=60 min)

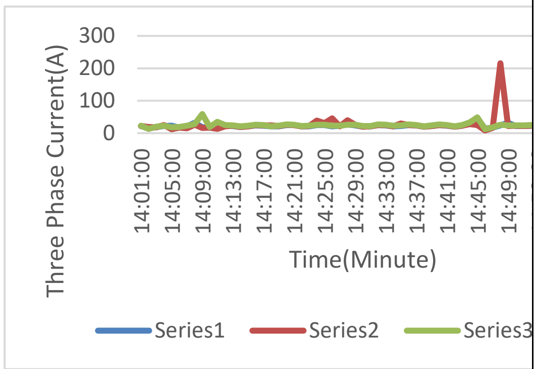

Fig. 2.20 Three Phase Current During the Heating Cycle (A)

Thermal Analysis

Once the heater reaches the desired temperature, a thermal imager is used to capture an image of the hot area during its operation. The following figures from Fig. 2.21 to Fig. 2.24 depict the thermal images of the heater cover surface and the heater surface.

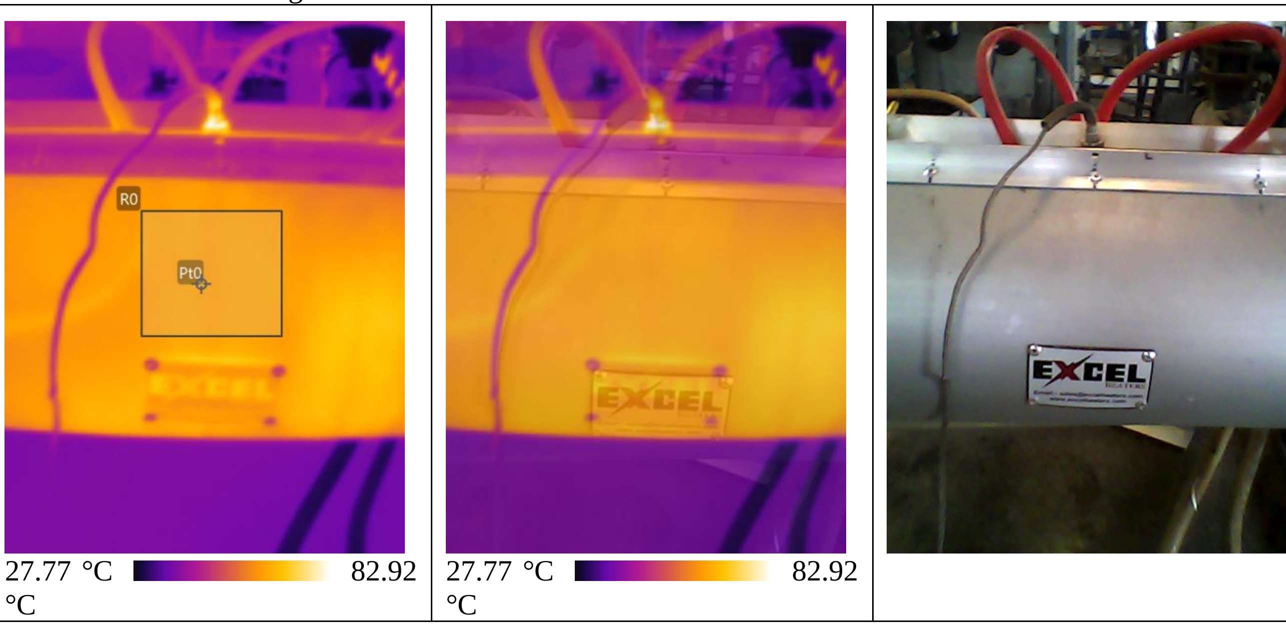

Fig. 2.21 Induction Heater Surface Cover

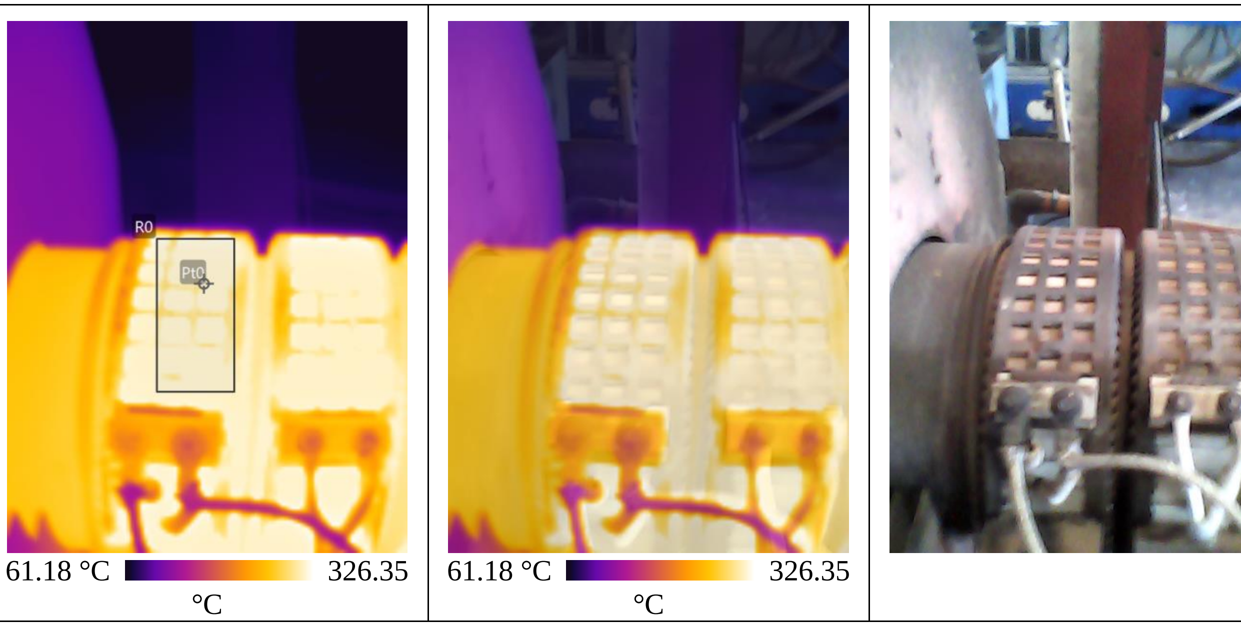

Fig. 2.22 Ceramic Heater Suface Cover

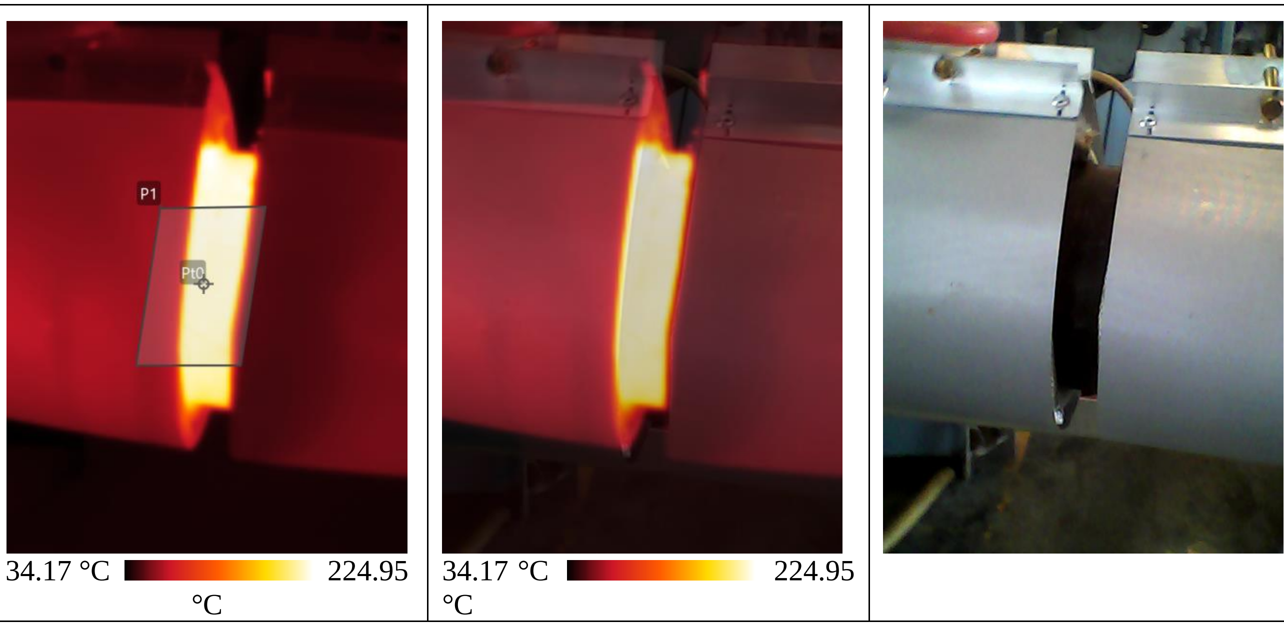

Fig. 2.23 Induction Heater Surface

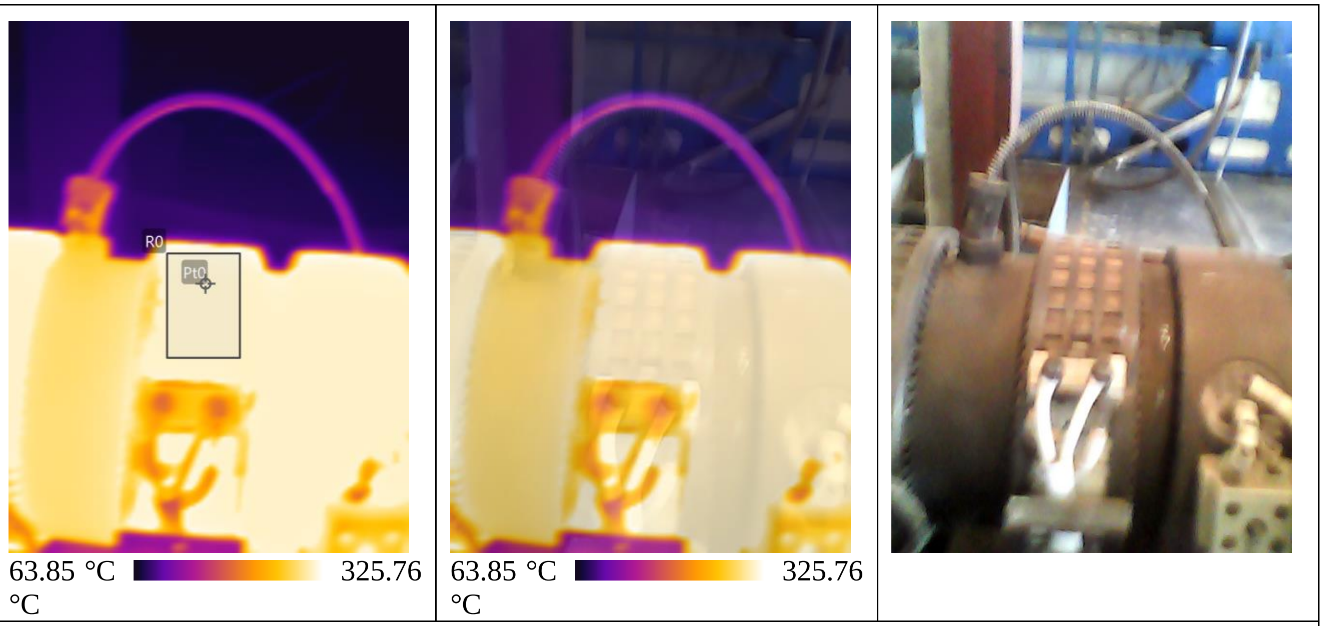

Fig. 2.24 Ceramic Heater Surface

Thermal analysis using a thermal imager has revealed that ceramic heaters emit more heat radiation. The recorded temperatures exceeded 310°C, with specific measurements of 221°C, 325°C, and 328°C. The temperature of the induction heater found near to 120-150 ºC.

4. Conclusion

1. Electrical Analysis: The following table 3 summarizes the unit consumption (kWh) and time (minutes) to produce 122 kg.

Table 3 Comparative Analysis of Units and Time for 122 kg production for both heaters.

Sr. No	Process	Induction Heater		Ceramic Heater	
		Time (Min.)	Unit Consumption (Kwh)	Time (Min.)	Unit Consumption (Kwh)
I	Heating Cycle	12	3.546	20	7.053
II	Die setting cycle	20	6.447	69	10.345
III	Thread setting cycle	45	4.262	54	8.09
IV	Production Cycle	46	7.84	60	14.207
	Total	122	22.095	203	39.695

The thread and die setting cycles are not part of production and are ignored since they are manual processes. Thus, by avoiding these cycles above table 3 is summarized and presented below in table 4 and table 5, considering only the heating cycle and production cycle.

Table 4 Comparative Analysis of Units and Time for Heating cycle and Production cycle

Sr. No	Process	Unit Saving (Kwh)	Time Saving (Minute)
I	Heating Cycle	3.507	8
II	Production Cycle	6.367	14
	Total	9.874	22

Table 5 Comparative Analysis of Units and Time for Heating cycle and Production cycle in

Sr. No	Process	Unit Saving (Kwh)	Unit Saving in %	Time Saving (Minute)	Time Saving in %
I	Heating Cycle	3.507	50%	8	40%
II	Production Cycle	6.367	45%	14	23%
	Total	9.874	47%	22	32%

2. Thermal Analysis: Thermal analysis can be understood through the thermography report.

Heat: Using a thermal imager, it was found that ceramic heaters emit more heat, with temperatures over 310°C (221, 325, and 328°C).

Induction heater temperatures ranged from 120 to 150°C.

3. Heating time Analysis : In case of induction heater, the heating cycle time (12 minute) is less as compared to ceramic heater (20 minute).

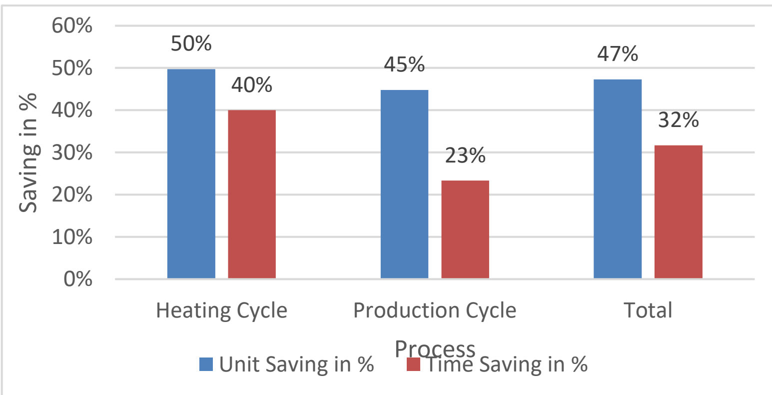

Fig. 25 % Saving

For induction heaters, the cooling period after completing the production cycle is around 5-6 hours, compared to 1-2 hours for ceramic heaters. Thus, ceramic heaters have more heat losses, longer heating times, and extended cooling periods. The case study found significant percentage savings with induction heaters over ceramic heaters.

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