



# **Analysis of Overheating Combustion Temperature in Stress Relief Furnace Machine**

## **Final Project**

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## Statement of Authenticity of Final Project

I, the undersigned, certify that the contents of part or all of my Final Project entitled: " Analysis of Overheating Combustion Temperature in Stress Relief Furnace Machine" is my **own work, completed without the use of materials that are not permitted, and is not the work of other parties which I acknowledge as my own work.** All references cited or referred to have been written in full in the bibliography. If it turns out that my statement is not true, I am willing to accept sanctions in accordance with applicable regulations.

Batam, 13 Januari 2026



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# Approval sheet

The Final Project is structured to fulfill one of the requirements for  
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# Analysis of Overheating Combustion Temperature in Stress Relief Furnace Machine

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**Abstract**— The oil and gas industry faces challenges in controlling the heat treatment process of pipe joints using stress relief furnaces to maintain material quality and durability after production. This process aims to eliminate residual stresses and enhance the pipe's structure after forging (swaging). However, there is a problem regarding excessive temperature control. Excessive temperatures can cause material damage, such as cracking or decreased mechanical performance, which affects the quality of the final product. The purpose of this study is to analyze and identify the primary causes of quality issues in the heat treatment process using a systematic approach, and to provide recommendations for process improvements that reduce the risk of material failure. This study employs the Root Cause Analysis (RCA) method, using a Fishbone diagram, to identify the root cause of the problem, and Failure Mode and Effects Analysis (FMEA) to assess potential failures related to overheating. The results indicate that poorly controlled firing temperatures are the primary cause of material failure, and the FMEA analysis reveals several critical points in the process that pose high risk. Based on these findings, recommendations are made to enhance temperature control, refine operating procedures, and improve operator training to minimize the risk of damage and improve overall product quality.

**Keyword:** Combustion, Fishbone Pup Joint, Stress Relief Furnace, Temperature, PFMEA

## I. INTRODUCTION

In metal manufacturing, particularly in the oil and gas industry, short pipe joints (pup joints) connect and attach pipe assemblies such as casing and tubing. Made of high-strength carbon steel, these short pipe joints require heat treatment, using a stress relief machine, to reduce residual stresses resulting from the swaging and welding processes. This process is performed using a Stress Relief Furnace with an automatic firing system and temperature control. Temperature accuracy and stability are key factors in ensuring the material's mechanical properties remain within specifications. [1], [2]

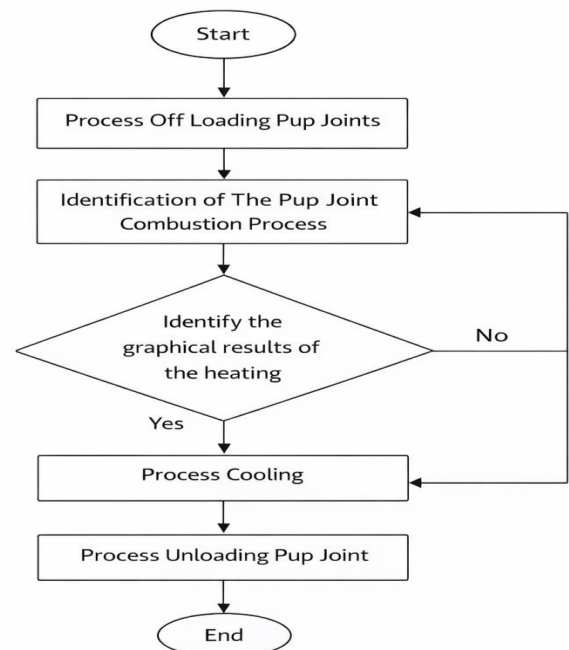
The heating process in a stress relief furnace typically uses temperatures between 555°C and 605°C, depending on the pipe type. A common problem in this process is overheating, which occurs when the firing temperature exceeds the specified limit. This condition can cause changes in the material's microstructure, decreased tensile and yield strength, dimensional distortion, and reduced product quality and reliability. [3], [4].

Previous research has shown that furnace temperature instability is generally caused by a combination of factors, such as errors in the combustion temperature control system, uncalibrated temperature sensors (pyrometers), and operator errors in inputting process parameters. Analytical methods such as FMEA and Root Cause Analysis are widely used to identify the root causes of industrial heating system failures. [5].

However, studies specifically analyzing overheating phenomena in stress relief furnaces under real-world industrial operating conditions are limited. Therefore, this study aims to analyze the factors causing overheating and formulate recommendations for improvements to enhance the stability, quality, and reliability of the stress relief process.

## METHOD

The following is a flowchart that describes the structured process flow for operating a stress relief furnace machine on a pup joint.



**Figure 1.** Flowchart Of The Stress Relief Furnace Process.

## 2.1 Flowchart Process

In completing the project “Analysis of Over Heat Combustion Temperature in the Stress Relief Furnace Machine”, a flow chart is needed to support the workflow to be carried out. The following is an explanation of the flowchart.

### A. Process Off Loading Pup Joints

This is the initial process where the pipe is on the conveyor, in the area around the machine, until the pipe enters the machine and the coil will move forward automatically according to the previously set program commands.

### B. Identification Off the Pup Joints Combustion Process

This process begins when the pipe joint is placed inside the machine (coil), where the coil and pyrometer sensor begin to heat according to the temperature and time set in the program based on the Mill Test Certificate (MTC). The aim is to relieve internal stresses in the pipe material.

### C. Heating Process (Yes & No)

The During this process, the operator monitors the combustion temperature graph on the stress relief machine to detect any signs of overheating.

If the temperature readings are OK (Y), the cooling process proceeds.

If overheating occurs (No), the short pipe connection is cooled first and then reprocessed from the heating stage.

### D. Cooling Process

In this process, the pipe material is left on the conveyor to reduce its temperature for 15 minutes before proceeding to the next process.

### E. Process Unloading Pup Joint

Finally, during the unloading process, where the rollers automatically move backwards, the material is marked as evidence that it has undergone a stress relief process.

## 2.2 Material And Equipment

The following are the tools and materials used in the process of operating the stress relief machine.

### A. Stress Relief Furnace

A stress relief furnace is a heating machine used for stress relief heat treatment, which reduces residual stresses in pipe materials after the fabrication process (forging). This is achieved by heating the pipe joint using a heating coil, which generally heats gradually to a temperature of 555-605°C, depending on the material type. A diagram of the machine is shown in Figure 15. Stress Relief Furnace Machine.

### B. Pup Joints

Pup Joints are the primary material processed in this research. Pup joints are short pipes used as connections in piping systems. Pup points are made of carbon steel and come in sizes ranging from 2 7/8 to 16 inches. The stress relief process of pup joints is carried out by considering the pipe material, optimal heating temperature, duration on pipe wall thickness, and steel type. The pipe images are shown in Figures 16 and 17.

### C. Infrared pyrometer.

An infrared pyrometer is a non-contact temperature measuring instrument used in stress relief machines to measure the temperature of a material during the heating process. This instrument operates by using infrared radiation emitted by the heated material's surface, then converting it into a temperature value. The use of an infrared pyrometer allows for rapid and continuous temperature measurement without direct contact, making it particularly suitable for high-temperature furnace environments. The following temperature specifications are based on procedures established by the American Petroleum Institute (API) technical standards.

**Table 1.** Spesification Temprature Material.

NO	Size Pup Joints (Inch)	Steel Grade	Temp Target	Temp Range	Out the spech (Overheat Combustion)
1	Pup Joint 2 7/8	L80 13CR PSL 3	625°C	605°C - 645°C	>645°C
2	Pup joint 3 ½	TN 95 CR 13 S	575°C	555°C - 595°C	>595°C
3	Pup Joints 16	N80 Q	580°C	555°C - 605°C	>605°C

In the stress relief process, infrared pyrometers play a crucial role in maintaining the heating temperature within specified parameters to minimize residual stress in the material. Measurement accuracy is significantly affected by surface emissivity, measurement distance and angle, environmental conditions, and sensor calibration. Incorrect temperature readings can lead to overheating or suboptimal heating, which can result in reduced mechanical material properties, distortion, and reduced quality of the stress relief results.

## 2.3. Data Collection and Testing Techniques

Data collection for this study involved direct observation of the firing process of shorted pipe joints in a stress relief furnace. Observations included pre- and post-firing data, including temperature parameters and heating graphs from monitors. Sampling was conducted over a one-month period, beginning in January 2025, before the corrective action, and again in February 2025, after the corrective action process, using standard production materials to ensure consistent results.

Testing was conducted by comparing overheating conditions in the months before and after the corrective action, specifically to identify overheating or temperature deviations from established standards. Test results were analyzed based on temperature graphs and supported by root cause analysis using a Fishbone Diagram if differences in the firing process were identified.

## II. RESULT AND DISCUSSION

After describing the research design and procedures in the previous sub-chapter, this section will present the findings or results of the data obtained in the field, which will then be analyzed and discussed.

### 3.1 Fishbone Diagram

In Figure 2, in completing the project “Analysis of Overheated Combustion Temperature in Stress Relief Furnace Machine”. A Fishbone Diagram (Ishikawa Diagram) is a management tool used to systematically identify, analyze, and organize various potential causes of a problem. By identifying these factors, further analysis can be carried out to find the root cause and design solutions to prevent excessive combustion temperature at the pup joint effectively.[6],[7].The following is an explanation of the fishbone diagram.

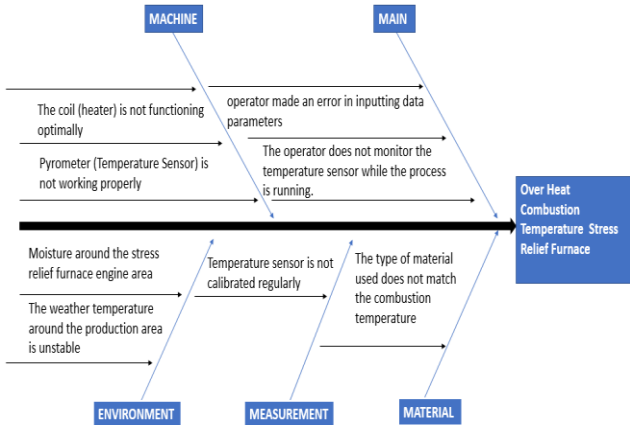


Figure 2. Fishbone Diagram.

#### A. Main

Human error refers to mistakes made by humans while performing a specific task or process. In this context, the main power errors can include installation errors and maintenance errors. Examples include an operator mode error when entering data parameters and the operator not monitoring the temperature sensor while the process is running.

#### B. Material

The material aspect relates to the quality and characteristics of the materials used in the combustion process, including the type of material used, which does not match the combustion temperature. Material incompatibility in this process causes combustion failure.

#### C. Environment

Environmental aspects refer to the environmental conditions surrounding the combustion process that can affect engine performance and reliability. This includes maintenance around the stress relief furnace engine area and unstable weather temperatures around the production area.

#### D. Machine

Machine factors contribute to the problem due to poorly maintained machines and inefficient use of material handling equipment. For example, the heater ins are not functioning optimally, and the pyrometer (temperature sensor) is not working properly.

#### E. Measurement

The cause of the overheating problem was identified in the Main Engine and Power Supply, based on direct observation and data collection. The fishnet diagram results indicated that operator errors in data parameter input due to a lack of understanding and monitoring of the temperature sensors during the process, as well as inadequate machine maintenance, contributed to the overheating problem.

These factors directly contributed to the overheating problem. The table below details these observations.

Table 2. Fishbone Table.

No	Factor	Potential	Contributor (Yes/No)
1	Machine	Sensor Pyrometer is not working properly	Yes
		The coil (heater) is not functioning optimally	No
2	Man Power	Operator made an error in inputting data parameters (Initial Power)	Yes
		The operator does not monitor the temperature sensor while the process is running.	No
3	Material	The type of material used does not match the combustion temperature	No
4	Environment	Moisture around the stress relief furnace engine area.	No
		The weather temperature around the production area is unstable	No
5	Measurement	Temperature sensor is not calibrated regularly.	No

Based on the verification results, the author concluded that overheating in the Stress Relief Furnace was caused by two potential factors: machine factors and human factors. The following is an explanation of these two potential factors (YES) and an explanation of the potential factors that did not contribute (NO) in Table 2.

#### 1. Machine (Yes)

The pyrometer sensor on a stress relief machine is a non-contact temperature measuring instrument used to monitor and control materials during the heating process. This sensor works by detecting infrared radiation emitted by the surface of the heated material in the furnace and then converting it into a temperature signal that is used as input to the control system.

The pyrometer can measure temperatures lower or higher than the actual temperature due to systematic errors, resulting in inaccurate input to the temperature controller. If the sensor reading is higher than the actual temperature, the controller will continue to add heat to the system, causing the actual temperature to exceed a predetermined point. Errors at this stage can result in deviated temperature readings, resulting in overheating, leading to process instability, serious defects in product quality and durability, and decreased material mechanical properties, particularly tensile strength, which weakens the material. [7].

This analysis revealed that the problem was caused by poorly maintained machinery, excessively high surface emissivity values during parameter setting, and suboptimal sensor calibration. Furthermore, the pyrometer sensor had passed its calibration date (data expiration date) according to the maintenance department. The following sensors were overdue for calibration.



Figure 3. Sensor pyrometer not calibrate.

2. **Man Power (Yes)**

Untrained Operators: Untrained operators can make errors in the setup process [8]. Operators make errors in entering data parameters (Initial Power). These errors will impact the engine's output power, leading to disruptions or inefficiencies in the combustion process. This is a contributing factor to overheating during the voltage reduction process. This condition results in inconsistent process results, reduced material quality, and increased risk of equipment damage. The following is a display of the combustion temperature settings.

Order	Customer	Material	Order	Customer	Material
7372790-01	ARMCO OFFSHORE	3.00 Thickness [mm]	730 811E 1820	Order	ARMCO OFFSHORE
			3.51 Steel Grade		
			1.80 L30C P18 2		

Description	Unit	Production Mode	Status	Real	Accepted	Current Set	Current Catalog
Target Temperature	°C	Auto	Cycle Finished	300.000	425.000	625.000	625.000
Maximum Temperature	°C	Auto	Cycle Finished	600.000	640.000	640.000	640.000
Minimum Temperature	°C	Auto	Cycle Finished	600.000	600.000	600.000	600.000
Soaking Time	min	Auto	Cycle Finished	0.000	0.000	0.000	0.000
Pipe Inside coil	mm	Auto	Cycle Finished	0.000	200.000	200.000	200.000
Short Circuit Spike Position	mm	Auto	Cycle Finished	0.000	10.000	10.000	10.000
Impinger Position	mm	Auto	Cycle Finished	0.000	0.000	0.000	0.000
Initial Power	%	Auto	Cycle Finished	0.000	12.000	12.000	12.000
Target Temperature for Initial Power	°C	Auto	Cycle Finished	300.000	600.000	600.000	600.000
Initial Power Time out	min	Auto	Cycle Finished	0.000	300.000	300.000	300.000
Reverse Short Circuit Spike/Impinger Temperature	°C	Auto	Cycle Finished	300.000	300.000	300.000	300.000
Reverse Short Circuit Spike/Impinger Time out	min	Auto	Cycle Finished	0.000	300.000	300.000	300.000
Transformer Ratio		Auto	Cycle Finished	0.000000	0.000000	0.000000	0.000000
Pipe Diameter	in	Auto	Cycle Finished	3.000	3.000	3.000	3.000

Figure 4. Display Stress Relief Parameter Settings.

Based on this analysis, the author recommends that leaders hold internal briefings to discuss work procedures. This will help them better understand the procedures and reduce the likelihood of similar incidents. The author has attached a briefing attendance form that discusses the implementation of the Stress Reduction procedures.

3. **Material (No)**

In Industrial environments, pipe materials used for stress relief are typically selected based on their appropriate thermal properties—thermal conductivity, heat capacity, temperature resistance, surface properties (emissivity), and insulation, if required. These properties are subject to material certification. If the material meets specifications, it will not be a dominant factor in overheating, as is the case with carbon steel and stainless pipes [9].

Based on the analysis does not provide a strong indication that material factors directly contribute to excessive combustion temperatures in stress relief furnaces.

4. **Environment (NO)**

The humidity around the stress relief furnace and the temperature around the production area were unstable. This indicates that humidity does not cause overheating; instead, it prevents the temperature from rising too quickly. Therefore, under normal conditions, humidity does not cause overheating. The humidity and temperature around the stress relief furnace were within normal limits, and the company implemented the Five Steps before completion [10].

The analysis showed no strong indication that environmental factors directly contributed to the excessive combustion temperature in the stress relief furnace.

5. **Measurement (NO)**

Temperature sensors that are not regularly calibrated are a problem in the Measurement category because they have the potential to produce inaccurate data. This can lead to errors in the production process, reduced product quality, and non-compliance with quality standards [2].

Based on the analysis, it shows that without calibration, sensor performance is far from ideal, in companies prioritizing routine calibration is important to ensure the sensor remains accurate. This should be done according to the scheduled time [7].

3.2 **Process Failure Mode and Effect Analysis (PFMEA)**

PFMEA is a systematic method used to identify, analyze, and mitigate potential failure risks in systems, processes, products, and services before they occur [11]. PFMEA is a structured procedure to identify and prevent as many causes of failure as possible. PFMEA is used to identify the source and root cause of quality problems [12]. PFMEA is conducted by recognizing and evaluating potential failure risks and their impact on the product, such as the potential for failure due to excessive combustion temperatures in a stress relief machine [13]. In practice, PFMEA is conducted by: Analyzing failure modes (how a process can fail). Assessing the impact through three main indicators: Severity (S) – the severity of the impact of the failure. Occurrence (O) – the likelihood of the failure occurring. Detection (D) – the ability to detect the failure before it reaches the customer. These three values are used to calculate: Risk Priority Number (RPN) = S × O × D. RPN is used as a basis for determining the priority of process improvements and controls to avoid potential failures of this project. As a guide, I determined the RPN value listed in Figure 18. Description of the PFMEA Assessment Table

Table 3. Failure Mode and Effect Analysis (PFMEA)

Failure Mode and Effect Analysis (PFMEA)									
Analysis of Over Heat Combustion Temperature in Stress Relief									
Process/Product Name: Furnace Machine					Prepared By: Tio Anugrah Iskandar				
Responsible: Tio Anugrah Iskandar					PFMEA Date (Orig.): 5-Jan-25 (Rev.): 15-Mar-25				
Process Step/Input	Potential Failure Mode	Potential Failure Effects	S/M And Factor	Potential Causes	Current Controls	Action Recommended	Resp.	Actions Taken	RPN
What is the process step, change or feature under investigation?	In what ways could the step, change or feature go wrong?	What is the impact on the customer if this failure is not prevented or corrected?	What factors cause this problem to occur?	What causes the step or feature to go wrong? (how could it occur?)	What controls exist that either prevent or detect the failure?	What are the recommended actions for reducing the occurrence of the cause or improving detection?	Who is responsible for making sure the actions are completed?	What actions were completed (and when) with respect to the RPN?	RPN
SEVERITY (1-10)	SEVERITY (1-10)	SEVERITY (1-10)	SEVERITY (1-10)	SEVERITY (1-10)	SEVERITY (1-10)	SEVERITY (1-10)	SEVERITY (1-10)	SEVERITY (1-10)	SEVERITY (1-10)
OCURRENCE (1-10)	OCURRENCE (1-10)	OCURRENCE (1-10)	OCURRENCE (1-10)	OCURRENCE (1-10)	OCURRENCE (1-10)	OCURRENCE (1-10)	OCURRENCE (1-10)	OCURRENCE (1-10)	OCURRENCE (1-10)
DETECTION (1-10)	DETECTION (1-10)	DETECTION (1-10)	DETECTION (1-10)	DETECTION (1-10)	DETECTION (1-10)	DETECTION (1-10)	DETECTION (1-10)	DETECTION (1-10)	DETECTION (1-10)
Combustion Temperature Overheating	The pyrometer sensor is not working properly	Unusable process, defective results, uncontrolled temperature exceeds normal temperature, product is rejected	Machine	Pyrometer temperature sensor is not working, stress relief machine area is unstable	Perform routine calibration on the pyrometer sensor, perform maintenance on the voltage-reliefing furnace	Perform routine calibration on the pyrometer sensor, perform maintenance on the voltage-relief furnace machine.	Maintenance	Check the sensor regularly, perform calibration according to schedule.	7 5 3 105
Combustion Temperature Overheating	The operator enters incorrect parameters (initial power) due to a lack of understanding of procedures.	The process is not correct, the results are not up to standard.	Man	Operators do not understand procedures, lack of training to refresh knowledge	Conduct routine training, provide orientation regarding routine procedures	Operator training on SR parameter data procedures, stricter supervision in data input & parameter interlock	Production	Training is conducted regularly for operators	5 4 4 80

3.3 **Data analysis in PFMEA Table**

- 1. The pyrometer sensor is not working properly.

Table 3. presents part of a Failure Mode and Effect Analysis (PFMEA) used to identify and evaluate potential failures in the pipe joint widening process in a Stress Relief Furnace due to excessively high combustion temperatures caused by a malfunctioning pyrometer sensor.

In the pipe heating process of the Stress Relief Furnace, there is a potential for failure due to suboptimal sensor readings. Overheating occurs when the temperature inside the furnace exceeds a predetermined temperature limit. Errors at this stage can cause process instability, serious defects in the quality and durability of the resulting product, and can reduce material strength (yield strength, tensile strength), causing the material to weaken. Distortion causes structural damage to the pipe material, making it susceptible to leaks. It also causes wear on furnace components and reduces operational efficiency, which can be fatal.[14] The following graph shows the results of a 4 1/2" pup joint material with type L80 13CR PSL 3, subjected to overheat, resulting in material rejection.

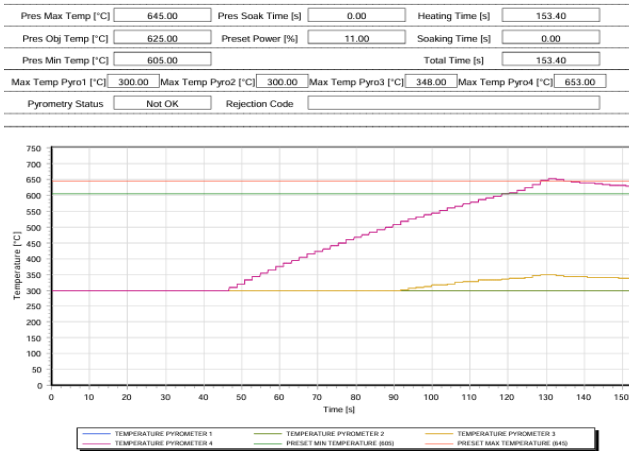


Figure 5. Display Graphic Overheating Temperature. (Not Good)

The following are the results of material experiencing overheating:



Figure 6. Material Pup Joint overheat combustion (NG)

Based on the rejection results, the author explains that the results were Good (OK) following standard procedures. The firing temperature remained within the stress relief standard operating procedure (SOP) range.

The heating graph remained stable and consistently below the maximum temperature. The heating time was within the required heating time. If all parameters are met, the product is declared OK or Acceptable. The following graph shows the results for 4 1/2" L80 13CR PSL 3 pipe fittings.

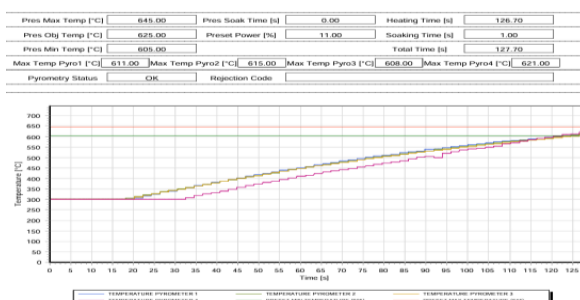


Figure 7. Display Graph Heating Temperature (Ok)

The following are the results for the corrected pup joint material.



Figure 8. Material Pup Joint after combustion (Ok)

Based on standard procedures, the results of the OK and Reject criteria indicate no visual difference in material impact. The specifications are based on the results of the flaring chart, which uses temperatures within the procedures established by the American Petroleum Institute (API) technical standards.

During the production process, observations of the work process revealed a large number of defects in pipe joints that affected the quality of the final product and required reheating. The high number of defects resulted in a decrease in the quality of daily output, which could cause significant service disruptions, especially in customer interactions that questioned production consistency. On the PFMEA severity scale of 1-10, this failure mode was rated 8[15].

The potential cause of this failure was identified as a primary cause, as the pyrometer sensor failed to function optimally, resulting in the pipe firing temperature exceeding the specified target. This could cause serious defects in the pipe material, affecting the quality and durability of the resulting product. This indicates a high probability of failure due to its relationship to the machine's controls and processes. Therefore, based on the PFMEA occurrence scale of 1–10, this failure mode was assigned an occurrence score of 6,[3].

In terms of detection, the existing control system includes routine sensor calibration and periodic furnace machine maintenance. This system allows failures to be detected with a reasonable degree of reliability, although not always before they impact the process. Therefore, the detection value on the PFMEA scale is 6. Based on the severity, occurrence, and detection values, the initial Risk Priority Number (RPN) is calculated as Severity (8) × Occurrence (6) × Detection (4) = 192.

Recommended actions to mitigate the potential causes of this failure include routine pyrometer sensor calibration and preventive maintenance. The parties responsible for implementing these actions are maintenance technicians and company management.

The corrective actions taken included routine machine maintenance and routine sensor calibration. After these actions were taken, the severity was assigned a value of 7 (minor disruptions that do not involve direct customer interaction), the frequency was assigned a value of 5 (moderate, generally

The pyrometer sensor calibration process on the stress relief machine is crucial. Pyrometer sensor calibration is the process of adjusting and verifying the accuracy of the pyrometer temperature measurement by comparing it to a reference standard with a higher level of accuracy, such as a blackbody calibrator.

The reference instrument used is a blackbody calibrator, a standard device that produces stable and accurate temperatures with uniform heat radiation, ensuring high accuracy. The resulting temperature is stable and traceable, making it suitable for calibrating non-contact temperature measuring instruments, such as pyrometers. During the calibration process, the pyrometer is pointed at a blackbody set at a specific temperature (600°C), in accordance with the standard (ASTM E1256) Standard Guide for the Selection and Installation of Infrared Thermometers. The pyrometer reading is then compared to the blackbody temperature. The following is a data check sheet after three weeks of calibration in January 2025.

**Table 4.** Check sheet Calibration Pyrometer.

Minggu	Suhu Blackbody Calibrator (°C)	Suhu sensor Pyrometer (°C)	Deviasi (°C) Toleran ±2°C	Status Sensor
1	600	602	+2	Ok
2	600	602	+2	Ok
3	600	604	+4	Ng

Here's how to read the check sheet table:

Deviation = Pyrometer reading - Blackbody temperature. If the deviation is within tolerance ( $\pm 2^\circ\text{C}$ ), it's OK. If the deviation exceeds tolerance, it's NG (not suitable).

**Table 5.** Check List Calibration Pyrometer

No	Inspection Items.	First Week	Second Week	Third Week	Status
1	Physical Condition of Pyrometer	Ok	Ok	Ok	Normal
2	Pyrometer Lens: Clean	Ok	Ok	Ok	Normal
3	Blackbody Calibrator Available	Ok	Ok	Ok	available for use
4	Cables and Connectors	Ok	Ok	Ok	Normal
5.	Emissivity Settings: Appropriate	Ok	Ok	Ok	Normal

Based on the verification results, the author concluded that, during the first week, the pyrometer remained fairly accurate at low temperatures. The second week remained the same as the previous week, and in the third week, the temperature difference increased, even higher. The following is a checklist for the calibration of the stress relief furnace.

A checklist was used to ensure that the instrument conditions and calibration method were correct before measurements were taken. A check sheet was used to record the results of comparing the pyrometer temperature with a blackbody calibrator. From the three weeks of data, it was clear that the measurement deviation was increasing, especially at high temperatures, so recalibration of the pyrometer was recommended. The following image shows the calibrated sensor.



**Figure 9.** The sensor has been calibrated.

associated with processes similar to the previous process that experienced occasional failures, but not on a significant scale), and the detection was assigned a value of 3 (a fairly high probability that the current control system would detect the failure mode). Thus, the final risk score (RPN) was calculated as Severity (7)  $\times$  Frequency (5)  $\times$  Detection (3) = 105.

## 2. Operator made an error in inputting data parameters (Initial Power)

Table 3 presents the PFMEA analysis section used to identify and mitigate potential failures in the pipe heating process in the Stress Relief Furnace due to operator error in inputting initial power parameters.

In the pipe heating process in the Stress Relief Furnace, there is a potential failure caused by human error when inputting process parameters, specifically the initial power setting. This parameter input error causes the heating process to fail to meet established specifications. As a result, the firing temperature becomes uncontrolled and the process becomes unstable, resulting in heating results that do not meet the specified quality standards. This condition can reduce the quality of the final product, lead to inconsistent heating results, and increase the likelihood of non-standard (out-of-specification) products being rejected.[14]

During production, mechanical engineering observations indicated that operator input errors were causing inconsistent heating. This required readjustment. The result was reduced heating quality and disruption to the production flow. Based on the PFMEA severity scale of 1 to 10, this failure mode was given a score of 6. This score indicates a moderate impact on product quality but a low likelihood of causing major customer damage.[15].

The potential cause of this failure was identified as a primary cause, as the pyrometer sensor failed to function optimally, resulting in the pipe firing temperature exceeding the specified target. This could cause serious defects in the pipe material, affecting the quality and durability of the resulting product. This indicates a high probability of failure due to its relationship to the machine's controls and processes. On the PFMEA severity scale of 1-10, this failure mode is rated 5.[3].

In terms of detection, existing controls include written work procedures, supervisory oversight, and regular briefings on operating procedures. However, this system was not fully capable of preventing parameter input errors before the process began. Therefore, a detection score of 5 was assigned, indicating that the failure had a moderate chance of being detected. Based on these values, the initial Risk Priority Number (RPN) was calculated as Severity (6)  $\times$  Occurrence (5)  $\times$  Detection (5) = 150.

Recommended actions to mitigate the potential causes of this problem include operator training on parameter input for the Stress Reducer Furnace and training on Stress Relief parameter procedures to prevent input errors. The technicians and all management employees are responsible for ensuring these actions are implemented correctly.

Corrective actions taken include regular and periodic operator training to enhance understanding of furnace operating procedures. The author hereby encloses attendance records for training conducted with leaders and operators of the Stress Relief Machine. These are as follows:

Figure 10. Briefing absence form.

The training, titled "Strainer Procedure Training" (S/R), covered calculations and filling out temperature calculation forms, as well as reviewing other work procedures. as follows.

Figure 11. Stress Relief Temperature Calculation Form

This temperature calculation form, which is part of the training material, has been approved by the operator, manager, and QA. After the corrective actions were implemented, the impact was positive, and the severity score decreased to 5, indicating a reduced or minor failure impact. The occurrence score decreased to 4, reflecting a decrease in error frequency due to increased operator competency. The detection score was set at 4 because the training increased operator awareness and enhanced operator knowledge and skills. Therefore, the final RPN is calculated as Severity (5) × Occurrence (4) × Detection (4) = 80.

The purpose of this data collection was to obtain accurate information regarding the number of defective products produced during that period. This data was then used as a basis for analyzing the quality level of the production process, identifying the factors causing defective products, and determining the necessary corrective measures to reduce the reject rate in the future.

Table 6. Number Of Failed Pup Joint Products Before Action.

Production Time	Good (pcs)	Reject (pcs)	Total (pcs)	% Reject
2 <sup>nd</sup> Week of January 2025	60	40	100	40%
3 <sup>rd</sup> Week of January 2025	40	50	90	55.56%
4 <sup>th</sup> Week of January 2025	50	30	80	37.50%
5 <sup>th</sup> Week of January 2025	65	55	120	45.83%
1 <sup>st</sup> Week of February 2025	54	42	96	43.75%
Total	269	217	486	44.65%

Based on the data in Table 6 above collected before the corrective action was taken, the number of defective pup joint pipe products was recorded for five weeks, starting from the 1st week of January 2025 to the 5th week of January 2025. The data shows that the rejection rate varies each week, with the highest percentage occurring in the 3rd week of January 2025 at 55.56% and the lowest in the 4th week of January 2025 at 37.50%. Overall, the average rejection rate before the corrective action was 44.65%. This high rejection percentage indicates instability in the production process that needs to be immediately identified and corrected to meet the expected quality standards [15].

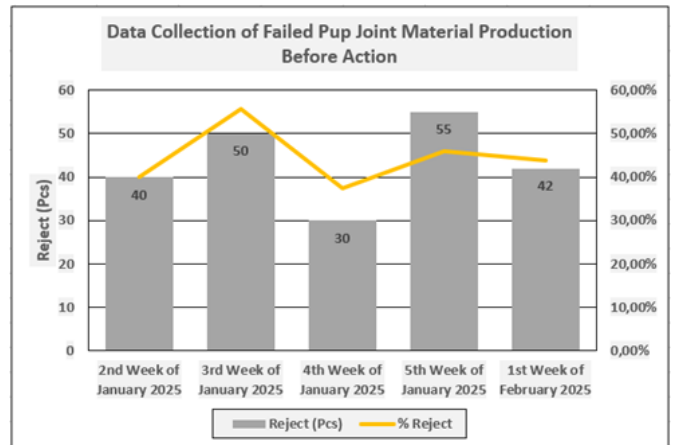


Figure 12. Production reject percentage per week Before Action.

Based on the Pareto Diagram in Figure 12 before corrective action is taken, it shows the number of rejected product pieces and the percentage of rejects in the production process with a period of five weeks from the 1st week of January 2025 to the 5th week of January 2025. The highest number of rejects occurred in the 5th week of January 2025 as many as 55 pieces with a percentage (45.83%), while the lowest occurred in the 4th week of January 2025 as many as 30 pieces with a percentage (37.5%).

Fluctuations in the number and percentage of rejects each week indicate instability in the production process of the pup joint pipe combustion process on the stress relief furnace machine. This needs to be analyzed further to find the root of the problem and prevent recurring defects.

A. Data collection

Data collection in this study was conducted through direct observation in the production area, specifically during the pipe firing process using a stress relief furnace. At this stage, each product experiencing defects (rejects) was recorded and classified according to the type and number of defects. The recording process was conducted routinely for five consecutive weeks, starting from the first week of January 2025 to the fifth week of January 2025.

### B. Identify Causes

Defects in pipe joint materials are caused by the following primary factors: excessive heat during the heating process in the stress relief furnace. This leads to serious defects in the quality and durability of manufactured products. High temperatures can reduce the material's strength (yield strength, tensile strength), thereby weakening the material. Distortion causes structural damage to the pipe material, making it susceptible to leaks. This also causes wear and tear on furnace components, which can be fatal and detrimental to both the company and its customers.

### C. Process Improvement

After identifying the cause of overheating in the combustion temperature of the pup joint pipe in the stress relief furnace, recommended actions to prevent overheating include calibrating each temperature sensor at least once a month.

Performing routine preventative maintenance on the valves (coils) and control system, following furnace operating procedures (SOPs) (starting from loading, starting, heating, cooling, and unloading the pipe) are also recommended. Operator training regarding procedures and temperature parameters for operating the stress relief furnace is also standardized.

### D. Monitoring After Improvement

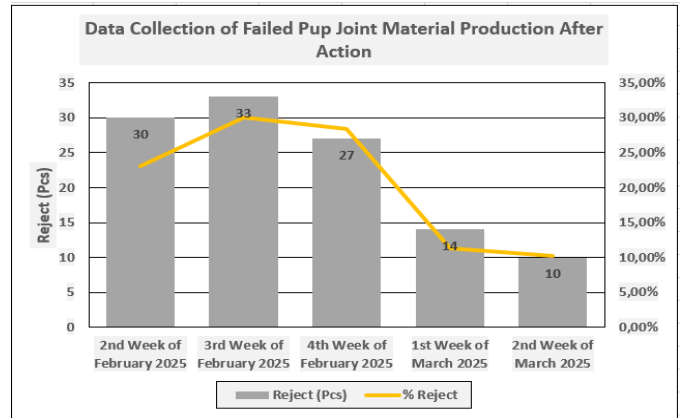
After corrective actions and evaluation of the overheat combustion problem in the Stress Relief Furnace (SRF) machine, production data was collected to monitor the effectiveness of the improvements that had been implemented.

Data collection was carried out by recording the number of defective products (rejects) in the pup joint pipe combustion process for five consecutive weeks, namely from the fourth week of January 2025 to the fourth week of February 2025.

**Table 7.** Number of failed Pup joint products After Corrective Action.

Production Time	Good (pcs)	Reject (pcs)	Total (pcs)	% Reject
2 <sup>nd</sup> Week of February 2025	100	30	130	23.08%
3 <sup>rd</sup> Week of February 2025	77	33	110	30.00%
4 <sup>th</sup> Week of February 2025	68	27	95	28.42%
1 <sup>st</sup> Week of March 2025	110	14	124	11.29%
2 <sup>nd</sup> Week of March 2025	88	10	98	10.20%
Total	443	114	557	20.47%

From the data collected after the corrective actions, it was found that the total production failures during the five-week period (early February to early March 2025) had the highest percentage in the third week of February 2025, at 30.00%, and the lowest in the second week of March 2025, at 10.20%. The average percentage of production failures per week before the corrective action, measured prior to this five-week period, was 20.47%. This demonstrates a decrease in material rejection issues in the production process of flaring joints on the stress relief machine, as evidenced by a decrease in the percentage. This suggests the corrective action was successful, and the company must consistently apply this method to prevent a recurrence of these problems in future production cycles.



**Figure 13.** Production reject percentage per week After Corrective Action.

Based on the Pareto Diagram in Figure 13, after corrective actions were taken, shows a significant decrease in the number of rejected products and the percentage of rejects in the production process during the five weeks from the second week of February 2025 to the second week of March 2025. With the highest number of defects in pup joint production in the 3rd week of February 2025, amounting to 33 pcs, and the lowest number of defects occurring in the 2nd week of March 2025, amounting to 10 pcs, the results of this data indicate that the corrective actions taken were successful in reducing the level of defects in the production process.

## IV. Conclusion

Based on the results of the research study, "Overheating Combustion Temperature Analysis in a Stress Relief Furnace," several important insights were successfully obtained. First, the study identified the primary causes of defects using the PFMEA method. The primary defects occurring during the short-joint pipe firing process in the stress relief furnace, namely the firing or heating process, were identified. The primary causes of these defects were related to suboptimal pyrometer sensors. Second, oxidized or degraded coil insulation results in decreased performance during the process, and a lack of training regarding the procedure. The study prioritized risks based on the RPN value. The PFMEA analysis revealed that the firing or heating process had the highest Risk Priority Number (RPN), indicating that these factors require special attention in process improvement efforts. Third, by applying the PFMEA method, this study successfully achieved its objective of identifying, analyzing, and providing recommendations for improving the causes of overheated combustion in the short-joint pipe firing process in the stress relief furnace. It is also hoped that the company will conduct routine maintenance, calibration, and training so that the implementation of these proposed improvements can significantly reduce the rate of defects and improve the quality of the short- joint pipe material (pup joint).

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### Attachment

A. Attachment – Stress Relief Furnace Machine



Figure 15. Stress Relief Furnace Machine



Figure 16. Pup Joints Size 16 Inch




Figure 17. Pup Joints Size 2 7/8 Inch

B. Attachment – Description PFMEA

Severity(S)			Occurrence (O)			Detection (D)		
Rating	Category	Description	Rating	Category	Description	Rating	Category	Description
1	Very Low	No noticeable effect on product performance or process	1	Very Rare	No noticeable effect on product performance or process	1	Almost Certain	No noticeable effect on product performance or process
2	Low	Very minor effect, no impact on quality	2	Rare	Very minor effect, no impact on quality	2	Very High	Very minor effect, no impact on quality
3	Low	Slight process disturbance, easily corrected	3	Low	Slight process disturbance, easily corrected	3	High	Slight process disturbance, easily corrected
4	Low-Moderate	Minor quality reduction, still acceptable	4	Low	Minor quality reduction, still acceptable	4	Moderate-High	Minor quality reduction, still acceptable
5	Moderate	Product performance is reduced, minor rework required	5	Moderate	Product performance is reduced, minor rework required	5	Moderate	Product performance is reduced, minor rework required
6	Moderate	Noticeable quality degradation, function is affected	6	Moderate	Noticeable quality degradation, function is affected	6	Moderate-Low	Noticeable quality degradation, function is affected
7	High	Product does not meet specification	7	High	Product does not meet specifications	7	Low	Product does not meet specifications
8	Very High	Serious damage, significant loss of material strength	8	Very High	Serious damage, significant loss of material strength	8	Very High	Serious damage, significant loss of material strength
9	Critical	Potential failure of main function	9	Almost Certain	Potential failure of main function			
10	Extremely Critical	Safety risk or total system failure	10	Certain	Safety risk or total system failure			

Figure 18. Description of PFMEA Table Assessment

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