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Optimization Of Furnace Efficiency In High Vacuum Units: Analyzing Heat Absorption And Loss Methods For Enhanced Fuel Utilization

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ABSTRACT: One of the operating units of PT. Y, which functions to separate fractions based on differences in boiling routes. Serves to separate fractions based on differences in boiling routes and under vacuum pressure conditions in the High Vacuum Unit (HVU). This is because the feed in this operation contains long residues that consist of long hydrocarbon chain components or have a high boiling point. One of the leading equipment used in this unit is a furnace. The efficiency of furnaces in the High Vacuum Unit (HVU) is critical because furnace efficiency is paramount as it directly influences operational costs and energy consumption in the separation process. The study addresses the problem of optimizing furnace efficiency, which is crucial for reducing fuel usage, particularly fuel gas, thereby enhancing the overall economic viability of the operation. The research employs a methodology that analyzes heat absorbed and heat loss within the furnace system. By measuring these parameters, the study identifies areas for improvement in thermal efficiency. Optimization involves adjusting fuel inputs and operational settings to minimize waste while maintaining effective heating capabilities. The optimization results show a significant decrease in fuel gas usage by 2,14%, compared to the average consumption level recorded in July 2024. In addition, fuel oil usage was optimized to 3 tons per day (T/D). These adjustments improved the furnace's efficiency and contributed to a more sustainable operation. The findings of this optimization study have broader implications for energy efficiency and cost savings in operations. By improving furnace performance, PT. Y can achieve lower operational costs and reduce its environmental footprint through decreased fuel consumption. This aligns with the industry trend towards sustainability and efficient resource management, benefiting the company and society.

Keywords: Furnace, Efficiency, Optimization, Fuel Gas.

INTRODUCTION

This research aims to optimize furnace efficiency in crude oil processing through a fraction separation method based on differences in boiling point under vacuum pressure(Zhao et al., 2022). The current research gap is the lack of optimization related to furnace efficiency, thus affecting the production of end products such as LVGO, MVGO, and HVGO as diesel gasoline blends, as well as FCC unit suppliers with polypropylene and LNG(Yan et al., 2024). High Vacuum Unit is one of the operational units of PT. Y. Processing at the High Vacuum Unit is carried out by the oil fraction separation method based on the difference in boiling points under vacuum pressure conditions. This is because the feed used is a long residue with a long hydrocarbon chain with a high boiling point. To facilitate the separation process, the feed is slightly preheated and then reheated in a Furnace to increase the temperature to 340-360ºC before the feed flows into the vacuum distillation column (Anonim, 2024).

One of the essential tools found in the High Vacuum Unit process is the Furnace because, in this Furnace, heat transfer occurs when fuel is combustion from the burner to the High Vacuum Unit supply feed(Chen et al., 2024). If this tool does not work, the feed cannot be processed in this unit because the heat exchanger load as a preheater to heat the feed and the distillation column as a means of separating the fraction into products will be greater where the feed used is long residue (heavy fraction with long hydrocarbon chains). This will impact the products produced, namely not being able to produce LVGO products for blending components with diesel fuel and MVGO & HVGO as Fluidized Catalytic Cracking (FCC) unit feed with polypropylene and LPG. Therefore, 20% of the national diesel demand and production of 120 T/D polypropylene and 350 T/D liquid petroleum Gas (LPG) will not be achieved.

One parameter that influences Furnace's efficiency is the fuel used. Excessive fuel consumption can reduce the thermal efficiency of the heater, which can also lead to wasted operating costs. Excessive should be prevented as it can lead to energy waste. Based on Indonesian Energy Outlook 2009 data, fossil fuel energy production has decreased over the past decade from 346 million BBL in 2009 to 283 million in 2018. Therefore, it is necessary to save fuel energy in Furnace (Hassan Al-Haj, 2010).

The use of energy from non-renewable energy sources contributes to increased exhaust emissions from both domestic and non-domestic activities, which in turn exacerbates global warming and its impacts. Consumption of energy from these sources with conventional technologies releases more CO2, which damages the environment and accelerates global climate change. Electricity energy provision often relies on fuel oil through electric generators or turbines, which causes air pollution due to CO2 emissions from burning these fuels (Walas, n.d.).

The Furnace uses heat energy resulting from the fuel combustion reaction. Oil, gas, or solid fuels can be used as fuel. The liquid flowing in the furnace pipes absorbs the heat generated during combustion(Shao et al., 2024; Xie et al., 2024). This requests its operating temperature (Connolly, n.d.). Convection and radiation sections are essential in the Furnace's heating process. The liquid first enters the convection section and then the radiation section. About 70% of the energy is transferred to the liquid in the radiation section and 30% in the convection section. The convection section tubes sometimes have fins to enhance convection heat transfer, as shown in Figure 1. The following is a schematic of the process that occurs in the Furnace (Baukal, 2013).

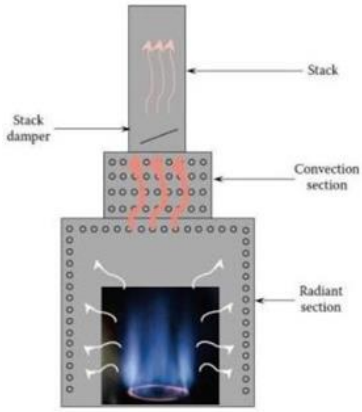

Figure 1. Furnace Process Schematic

A furnace is a hydrocarbon and petrochemical process device that heats liquids in tube sections for further processing(López-Palenzuela et al., 2024; Pavlidis & Chkalova, 2024). The furnace consists of a combustion chamber with one or more burners and a series of tubes through which the process fluid flows. Furnace play an important role in atmospheric and vacuum distillation, thermal reforming, and high-temperature gas processing(Long et al., 2024; Wu et al., 2024). Furnaces are commonly used in various fired heaters, processing, and evaporation applications. Multiple types of purification furnaces are required to process liquids with a temperature of 1500oF and an actual condition of 1100oF at a pressure of 1600 psig (Kern, n.d.).

In a furnace or heater, fuel combustion in an open space releases heat and transfers it to liquid in the pipes running along the walls and ceiling of the combustion chamber. Heat transfer occurs through radiation convention and reflection from the refractory walls that limit space. The furnace has many types from various aspects. As for the stove being reviewed in the form of double cabin with horizontal tubes, it has 16 burners installed on the end wall (flame parallel to the tube position), uses dual fuel (fuel gas and fuel oil), uses balanced draft (induced draft fan & forced draft fan), and also uses vacuum operating conditions in operation (operating pressure below atmospheric pressure)(Brahma et al., 2024; Sampaio Brasil et al., 2024). The furnace illustration can be seen in Figure 2 below(Lu et al., 2024; Wang et al., 2024).

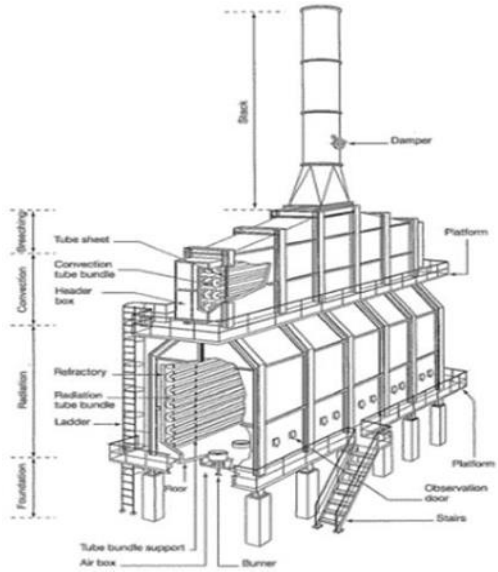

Figure 2. Furnace illustration

Fuel usage is one of the parameters that affect the working efficiency of the furnace. Efficiency is one of the critical parameters that determine the feasibility and performance of the tool. To determine the furnace's efficiency, the heat absorbed and heat loss method uses the following equation(Nelson, n.d.).

Furnace efficiency is critical in measuring the performance of the furnace. Furnace efficiency calculations must be carried out regularly to determine the furnace's performance and avoid long-term damage that can cause maintenance, thus affecting production and refinery costs. The feed that enters the furnace differs from the specifications and can burden the performance (duty) of the furnace; it will be more severe if the furnace's efficiency is low to calculate the furnace's efficiency. Calculating the furnace's efficiency can be done using two methods, and the scheme can be seen in Figure 3 below.

- **Heat Absorbed Method**

$$n = \frac{Heat\ Absorbed\ by\ the\ Fluid}{Total\ Furnace\ inlet\ heat}\ x\ 100\%$$

- **Heat Loss Method**

$$n = \frac{Total\ Furnace\ inlet\ heat - \Sigma\ Heat\ Loss}{Total\ Furnace\ inlet\ heat}\ x\ 100\%$$

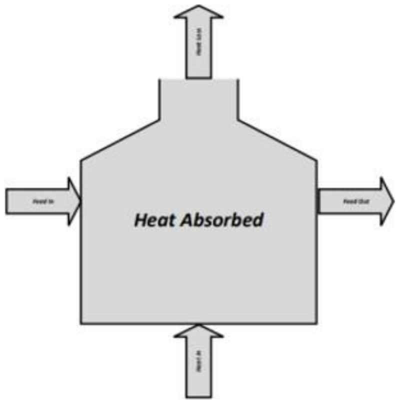

Figure 3. Furnace Efficiency Schematic

The heat-absorbed method focuses on the amount of heat energy successfully absorbed by the material in the furnace. This is important to ensure the material reaches the desired temperature for further processing. Evaluating heat absorbed involves analyzing the heat transfer rate in the furnace and the heat transfer efficiency between the heating element and the material. The heat loss method is a technique used to calculate the amount of heat energy lost from the furnace during the heating process. This loss can occur through the furnace walls' convection with the surrounding air. The heat that enters the furnace is carried and generated by the fuel, and the heat is generated from the combustion process that occurs in the furnace. The amount of fuel is adjusted to the heat requirement used to heat the feed (Correa, 2023).

The justification for this research is the rising cost of fuel and increasingly severe environmental concerns. Using fossil energy not only causes increased carbon dioxide emissions but also brings negative impacts to the global climate. Therefore, improving the furnace's efficiency is crucial to reducing operational costs and greenhouse gas emissions. The specific objectives of this study were to enhance the ability of the furnace to absorb and distribute heat effectively and to understand how variations in temperature, fuel type, and operating pressure can affect furnace efficiency. Thus, this research is expected to make a real contribution to improving the operational efficiency of the furnace at PT. Y significantly reduces operational costs and promotes environmental sustainability.

METHOD

The method used in this research is trial and error, and the methods used as research variables include working methods and analysis methods. Research variables need to be determined first before starting the research. These variables include independent variables (x) and dependent variables (y), which have a close relationship with each other. Independent variables are free to be regulated or controlled where these variables will affect the results. The independent variables used in this study are mass flow fuel gas (T/D), Coil Inlet Temperature (°C), and Coil Outlet Temperature (oC). At the same time, the dependent variable is a variable whose value depends on the independent variable being processed. The independent variables in this study are total heat in and out of the furnace, heat loss, and furnace efficiency.

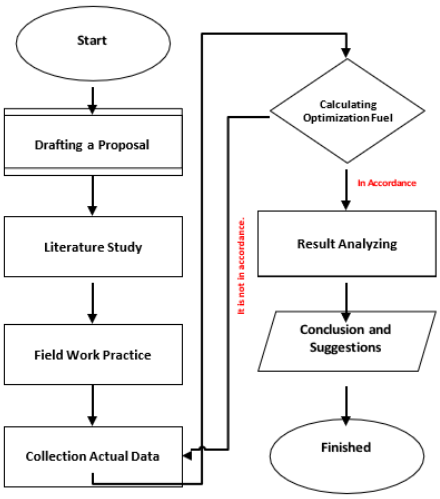

Figure 4. Flowchart of Working Method

Figure 4 shows a flow chart of the work method that illustrates the stages from the beginning to the end of the research. This work method consists of preparation, implementation, and completion stages. In the implementation stage, a literature study of journals related to the research was conducted. Furthermore, a field data search was carried out, and then the data was processed using Microsoft Excel and analyzed to produce conclusions as part of the completion stage. This analysis method reviews the optimization value of gas fuel usage.

RESULT AND DISCUSSION

The optimization calculations conducted to enhance Furnace F-1's efficiency focus on achieving the best possible outcomes for heating feeds, ensuring both high thermal efficiency and reduced fuel gas costs(Liang et al., 2024; Lutsenko & Borovik, 2024). To begin this process, a furnace efficiency calculation determines the percentage efficiency. The following data is required for this calculation.

Table 1. Furnace Specification Data

Furnace Specification Data		
Parameters	**Specification**	**Unit**
Type	Double cabin	-
Total Duty per heater	46,27 (proses) & 0,53 (steam) = 46,8	Mmkcal/hr
Material	Carbon Steel	-
System Type	Balanced Draft	-
Tube Arrangement	Horizontal	-
Pressure Inlet	3,73 - 9,513	Kg/cm^{2}A
Pressure Outlet	0,753 - 2,93	Kg/cm^{2}A
Around Burner Wall Temp.	792	^{o}C
Shielded Wall Temp.	714	^{o}C
Stack Temperature	180 - 210	^{o}C
Inlet Temperature (CIT)	(148).). -	^{o}C

Furnace Specification Data		
Parameters	**Specification**	**Unit**
	272	
Outlet Temperature (COT)	350 - 418	^{o}C
Num. of Burner	16 (for fuel oil and gas)	Burner
Location Burner	End wall	-
Efficiency	85	%

Table 2. Feed and Fuel Operating Condition Data

Date	*Flow Feed* (T/D)	*Fuel Gas* (T/D)	*Fuel Oil* (T/D)	CIT (^{o}C)	COT (^{o}C)	*Stack Temperature* (^{o}C)
01/07/2024	5442	23,30	21	256	351	215
02/07/2024	5970	38,90	9	256	348	214
03/07/2024	5959	37,30	12	253	346	216
04/07/2024	5959	36,80	12	255	349	217
05/07/2024	5959	36,90	12	254	347	217
06/07/2024	5959	39,80	6	254	349	214
07/07/2024	5971	40,30	6	253	347	213
08/07/2024	5967	40,00	6	251	346	217
09/07/2024	5966	40,30	6	251	344	214
10/07/2024	5966	40,30	6	251	344	214
11/07/2024	5966	40,30	6	251	344	215
12/07/2024	5961	40,30	12	249	347	215
13/07/2024	5962	36,20	12	252	346	215
14/07/2024	5954	38,40	6	251	346	215
15/07/2024	5952	39,70	6	249	345	216
16/07/2024	5956	41,50	3	252	346	213
17/07/2024	5967	41,00	3	249	342	214
18/07/2024	5970	42,00	3	249	343	215
19/07/2024	5970	41,00	3	249	343	214
20/07/2024	6036	41,00	3	248	343	216
21/07/2024	6103	42,10	3	248	343	214
22/07/2024	6103	42,10	3	248	343	213
23/07/2024	5965	42,10	3	248	343	215
24/07/2024	5962	43,50	3	248	344	213
25/07/2024	5740	41,60	3	249	344	214
26/07/2024	5768	40,80	3	249	345	212
27/07/2024	5759	40,10	3	250	345	214
28/07/2024	5748	39,70	3	253	346	216
29/07/2024	5776	39,70	3	253	344	216
30/07/2024	5112	40,60	3	236	346	213
31/07/2024	5112	40,60	3	236	346	215
Average	**5870**	**39,62**	**6**	**250,03**	**345,32**	**214,65**

Table 1. above is used as a reference to find the furnace's efficiency, while table 2. is used to calculate the heat absorbed by the feed. Fur fuel gas and oil data are used to calculate the heat entering the furnace, namely sensible heat and fuel combustion. CIT, COT, and stack temperature data are used to calculate the outgoing heat carried by the feed.

Table 3. Operating Condition Data and Fuel Oil Design

Parameters	Average (Actual)	Design (min./max.)	Unit
Flow Fuel Oil	6	(3 - 24)	(T/D)
	551,156		lb/hr
Temp. Inlet Fuel Oil	139,7	-	^oC
	283,46		^oF
Pressure Inlet Fuel Oil	5,928	(2 - 6)	kg/cm^2
SG 60/60	0,9033	0,8 - 0,9	-
API Gravity	25,148	-	-
Pour Point	110	-	-
Ash Content	0,4	-	%wt
Water Content	0,1	0,1	%wt
Sulphur Content	0,25	0,23	%wt

Table 4. Operating Condition Data and Fuel Gas Design

Parameters	Average (Actual)	Design (min. / max.)	Unit
Flow Fuel Gas	40,3	(3 - 24)	T/D)
	3.701,929		lb/hr
Temp. Inlet Fuel Gas	32	-	^oC
	89,6		^oF
Pressure Inlet Fuel Gas	1,5	(0,6 - 1,6)	kg/cm^2

Table 3 calculates the heat absorbed by the furnace, while Table 4 calculates the sensible heat and heat of fuel gas combustion.

Table 5. ASTM Distillation Data

ASTM Distillation Data		
%Volume	**Temperature**	**Unit**
IBP	212	^oC
10 %vol	313	^oC
50 %vol	350	^oC
Rec. at 350 ^oC	24% vol	-
Pour Point	110	^oF
Flash Point	220	^oF
Water Content	0,1	%vol (0,05 max)

Table 6. Composition Data Fuel Gas

Component	Composition
Methane (C_1)	30,000
Ethylene (C_2=)	14,800
Ethane (C_2)	11,400
Propylene (C_3=)	7,500
Propane (C_3)	1,700

Component	Composition
Iso Buthane (iC_4)	1,000
N-Buthane	0,300
1 - C_4"	0,200
1 - C_4" trans	0,100
1 - C_4" Cis	0,200
Iso Pentane	0,100
n-Pentane (C_5H_{12})	0,100
Total Penthylene	0,000
Hexane Plus	0,000
Carbon Dioxide (CO_2)	4,000
Carbon Monoxide (CO)	4,300
Oxygen (O_2)	0,600
Hydrogen (H_2)	5,800
Nitrogen (N_2)	17,900
Total	**100,000**

Table 5. The above is used to calculate the EFV distillation value and heat absorbed by the feed, while Table 6 shows that it is used to calculate the LHV and sensible heat and heat of combustion of the fuel gas.

Table 7. Combustion Air Data

Parameters	Average (Actual)	Design (min./max.)	Unit
Inlet Temperature	29	(28 - 31)	^oC
Outlet Temperature	129	-	^oC
Excess Air	27,09	-	%
Flow Rate	28800	120.000	kg/hr

Table 8. Steam Atomizing Data

Parameters	Average (Actual)	Design (min./max.)	Unit
Inlet Temperature	289	-	^oC
	552,2	-	^oF
Outlet Temperature	310	-	^oC
	590	-	^oF
Pressure	7,6	7,5 - 8,5	kg/cm^2
Mass Flow	8,892	-	T/D
	816,813		lb/hr

Table 7. above is used to calculate the combustion air inlet heat, while Table 8. is used to calculate the heat generated from steam atomizing. The data used is average for one month for tables 1-4 and 7-8. In tables 5-6, the data used is sample data on July 9, 2024.

Then, we will use these data to find the heat balance, calculate the efficiency percentage, and produce a heat balance in the furnace operating conditions on July 9, 2024.

Table 9. Heat Balance on July 9, 2024

No.	Heat Type	Amount of Heat (BTU/hr)	
		Heat In	Heat Out
1.	Fuel Oil Sensible Heat	60,349,01	
2.	Fuel Oil Combustion Heat	9.977.922,71	
3.	Sensible Heat of Fuel Gas	41.489,45	
4.	Heat of Combustion Fuel Gas	53.061.445,47	
5.	Sensible heat of Combustion Air	3.392.979,03	
6.	The heat of Steam Atomizing	1.017.136,42	
7.	Water Vapor Sensible Heat	13.739,48	
8.	Feed Absorbed Heat		59.600.385,93
9.	Heat Loss Carried by Flue Gas		4.371.729,00
10.	Heat Loss Through Fired Heater Wall		625.675,08
11.	Unknown Heat Loss		2.967.271,55
	Total	**67.565.061,56**	**67.565.061,56**

Furnace efficiency on July 9, 2024, can be calculated using the formula below.

- **Heat Absorbed Method**

$$n = \frac{Heat\ Absorbed\ by\ the\ Fluid}{Total\ Furnace\ inlet\ heat}\ x\ 100\%$$

η = 88,21%

- **Heat Loss Method**

$$n = \frac{Total\ Furnace\ inlet\ heat - \Sigma\ Heat\ Loss}{Total\ Furnace\ inlet\ heat}\ x\ 100\%$$

η = 88,21%

Then, the efficiency data during the operation of July 2024 can be seen in Table 10 below. Table 10. Furnace Efficiency Data from Date 01-30 July

Date	*Flow Feed* (T/D)	*Fuel Gas* (T/D)	*Fuel Oil* (T/D)	Efficiency (%)
01/07/2024	5442	23,30	21	83,61
02/07/2024	5970	38,90	9	85,86
03/07/2024	5959	37,30	12	86,93
04/07/2024	5959	36,80	12	86,26
05/07/2024	5959	36,90	12	86,67
06/07/2024	5959	39,80	6	85,64
07/07/2024	5971	40,30	6	85,11
08/07/2024	5967	40,00	6	86,47
09/07/2024	**5966**	**40,30**	**6**	**88,21**
10/07/2024	5966	40,30	6	86,14
11/07/2024	5966	40,30	6	85,21
12/07/2024	5961	40,30	12	85,44
13/07/2024	5962	36,20	12	85,92
14/07/2024	5954	38,40	6	86,08
15/07/2024	5952	39,70	6	84,27
16/07/2024	5956	41,50	3	84,16

17/07/2024	5967	41,00	3	84,53
18/07/2024	**5970**	**42,00**	**3**	**83,03**
19/07/2024	5970	41,00	3	84,76
20/07/2024	6036	41,00	3	83,87
21/07/2024	6103	42,10	3	83,93
22/07/2024	6103	42,10	3	86,41
23/07/2024	5965	42,10	3	84,19
24/07/2024	5962	43,50	3	84,15
25/07/2024	5740	41,60	3	83,13
26/07/2024	5768	40,80	3	83,67
27/07/2024	5759	40,10	3	87,56
28/07/2024	5748	39,70	3	84,63
29/07/2024	5776	39,70	3	84,46
30/07/2024	5112	40,60	3	84,83
31/07/2024	5112	40,60	3	84,39
Average	**5870**	**39,62**	**6**	**85,10**

It can be seen from Table 10. Above, the highest furnace efficiency was 88,21% on July 08, 2024, and the lowest efficiency was 83,03% on July 19, 2024, with an average efficiency for one month of 85,10%. If reviewed based on the furnace efficiency specification data, the minimum efficiency is 85%. This indicates that the furnace operation during July is classified or included as excellent and feasible because the efficiency value exceeds the minimum design limit. However, it would be even better if the furnace efficiency value was close to 100%.

When considering other parameters, we find that the average fuel gas flow rate is 39.62 T/D, higher than the minimum design of 30 T/D. This suggests further research into reducing fuel gas use in the furnace. The foundation for this optimization process relies on fuel usage (39,62 T/D), CIT (249 oC), and COT (343 oC) averages recorded in July. These figures are then analyzed using the same steps and methods as in the previous calculation, resulting in an efficiency of 80,33%. Detailed information can be found in Table 11 below.

Table 11. Optimization Process Calculation Base

Fuel Type	Unit	Calculation Base	
		Before Optimization	After Optimization
Fuel Gas	lb/hr	560,3416	X
Fuel Oil		3636,4053	3143,4244
Total Fuel		4196,7451	Y
Efficiency	%	80,31	Z

This optimization process aims to reduce the fuel gas flow rate (x) and total fuel consumption (y) while increasing efficiency (z) after optimization. By minimizing fuel usage, the operational costs for furnaces are expected to decrease while maintaining high efficiency. A significant or optimal efficiency indicates that the furnace's combustion and heat transfer processes are functioning effectively. When these processes operate well, the feed's output temperature (COT) can reach a high level within design limits, ensuring that the fraction separation process in the fractionation column performs efficiently and produces high-quality products.

The optimization procedure mirrors the calculation method used to determine furnace efficiency. However, in this case, the fuel gas flow rate variable was adjusted by decreasing it by 0,2 from the baseline value and incorporating this into the furnace efficiency calculation. This optimization effort resulted in 30 trials, detailed in Table 12 below.

Table 12. Trial and Error Data on Fuel Usage in the Furnace

Trial	Decrease in Fuel Gas	Mass Flow (lb/hr)			Eff (%)	Fuel Gas Saved (lb/hr)
		Fuel Oil	Fuel Gas	Total	Min. 83,6%; Max. 100%	
0	0	560,3416	3636,4035	4196,7451	80,32	33,6827
1	0,08	1929,0448	3602,7208	5531,7655	81,06	42,8687
2	0,16	826,7335	3593,5348	4420,2683	81,25	52,0546
3	0,24	1102,3113	3584,3489	4686,6602	81,44	70,4264
4	0,32	1102,3113	3565,9771	4668,2884	81,82	88,7983
5	0,40	1102,3113	3547,6052	4649,9165	82,20	107,1702
6	0,48	551,1557	3529,2333	4080,3890	86,67	125,5420
7	0,55	551,1557	3510,8615	4062,0171	82,98	143,9139
8	0,63	551,1557	3492,4896	4043,6453	83,37	162,2857
9	0,71	551,1557	3474,1178	4025,2734	83,77	180,6576
10	0,79	551,1557	3455,7459	4006,9016	84,17	199,0294
11	0,87	551,1557	3437,3741	3988,5297	84,58	217,4013
12	0,95	1102,3113	3419,0022	4521,3135	84,99	235,7731
13	1,03	1102,3113	3400,6304	4502,9417	85,40	254,1450
14	1,11	551,1557	3382,2585	3933,4142	85,82	272,5169
15	1,19	551,1557	3363,8867	3915,0423	86,24	290,8887
16	1,27	275,5778	3345,5148	3621,0926	86,67	309,2606
17	1,35	275,5778	3327,1429	3602,7208	87,10	327,6324
18	1,43	275,5778	3308,7711	3584,3489	87,54	346,0043
19	1,51	275,5778	3290,3992	3565,9771	87,98	364,3761
20	1,58	275,5778	3272,0274	3547,6052	88,42	382,7480
21	1,66	275,5778	3253,6555	3529,2333	88,87	401,1198
22	1,74	275,5778	3235,2837	3510,8615	89,32	419,4917
23	1,82	275,5778	3216,9118	3492,4896	89,78	437,8635
24	1,90	275,5778	3198,5400	3474,1178	90,24	456,2354
25	1,98	275,5778	3180,1681	3455,7459	90,71	474,6073
26	2,06	275,5778	3161,7962	3437,3741	91,18	492,9791
27	**2,14**	**275,5778**	**3143,4244**	**3419,0022**	**91,66**	**511,3510**
28	2,22	275,5778	3125,0525	3400,6304	92,14	529,7228
29	2,30	275,5778	3106,6807	3382,2585	92,63	548,0947
30	2,38	275,5778	3088,3088	3363,8867	93,12	548,0947

Table 12 above shows that 2,14% less fuel gas must be used than the average usage in July 2024 of 3143,4244 lb/hr to achieve the ideal furnace efficiency (91,66%). Trial 27 has outstanding thermal efficiency, which allows for the achievement of optimal efficiency. This indicates that the overall heat loss, which is unknown, is insignificant. The total heat loss for trials 28-30 is unknown, but the results could be better. The furnace system itself is not separated, so this is not feasible in a system. As a result, unidentified heat loss must exist.

After the optimization process is carried out, the results of the heat balance calculation in Table 13 and the efficiency calculation are as follows.

Table 13. Heat Balance After Optimization

No.	Heat Type	Amount of Heat (BTU/hr)	
		Heat In	Heat Out
1.	Fuel Oil Sensible Heat	31.273,56	
2.	Fuel Oil Combustion Heat	4.999.512,21	
3.	Sensible Heat of Fuel Gas	38.078,11	
4.	Heat of Combustion Fuel Gas	50.766.696,45	
5.	Sensible heat of Combustion Air	2.904.140,20	
6.	The heat of Steam Atomizing	977.506,48	
7.	Water Vapor Sensible Heat	11.312,07	
8.	Feed Absorbed Heat		54.746.257,34
9.	Heat Loss Carried by Flue Gas		4.251.103,03
10.	Heat Loss Through Fired Heater Wall		680.463,18
11.	Unknown Heat Loss		50.695,54
	Total	**59.728.519,09**	**59.728.519,09**

- **Heat Absorbed Method**

$$n = \frac{Heat\ Absorbed\ by\ the\ Fluid}{Total\ Furnace\ inlet\ heat}\ x\ 100\%$$

$$\eta\ =\ 91{,}66\%$$

- **Heat Loss Method**

$$n = \frac{Total\ Furnace\ inlet\ heat - \Sigma\ Heat\ Loss}{Total\ Furnace\ inlet\ heat}\ x\ 100\%$$

$$\eta = 91{,}66\%$$

The optimization process can be seen in Table 14 below.

Table 14. Furnace Optimization Results

Fuel Type	Unit	Calculation Base		Percentage Increase or Decrease (%)
		Before Optimization	After Optimization	
Fuel Gas	lb/hr	560,3416	560,3414	0,0000
Fuel Oil		3636,4053	3143,4244	(-) 4,9298
Total Fuel		4196,7451	3703,7660	(-) 4,9297
Efficiency	%	80,31	91,66	(+) 11,35

CONCLUSION

The results of the calculation of the efficiency furnace carried out in July 2024 showed that on July 09, 2024, with a gas flow rate of 40,3 T/D, the maximum efficiency was 88,21%, and the minimum efficiency was 83,03% on July 18, 2024, with a gas flow rate of 41 T/D. Judging from the results calculation, fuel, especially fuel gas, is still used with an average of 39,62 T/D for one month.

Further research can still be done to reduce the mass flow rate of fuel gas back to the minimum design limit of 30 T/D.

Our research to reduce fuel gas usage has yielded promising results. The data shows that the average monthly fuel gas usage is 39.62 T/D. By optimizing the gas mass flow amount to the design minimum of 30 T/D, we can significantly decrease to 34.22 T/D, representing a 2.14% reduction from the average gas mass flow. Gas should be used instead of oil to reduce the dwindling availability of fossil fuels. Gas is cleaner burning, cheaper to sell, and more readily available.

This research shows that significant fuel savings and efficiency improvements can be achieved in high-vacuum units through gas mass flow rate optimization(Li et al., 2024). The study's results are relevant to the manufacturing industry and contribute to global efforts to save energy and reduce greenhouse gas emissions. Industries should consider adopting these optimization methods to reduce fuel consumption and operating costs. Implementing real-time monitoring systems and control automation can improve the effectiveness of fuel-saving programs.

Future studies can focus on real-time monitoring and automatic adjustment to further improve furnace efficiency, and a detailed analysis of the interactions between process parameters and environmental conditions will help create more robust optimization strategies(Mazari, 2024; Vaidyanathan et al., 2024). Thus, this research directly answers questions about fuel consumption reduction and offers a broad vision and practical steps for implementation in the field.

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