Drying Process Optimization and Efficiency of Aluminum Fluoride (AlF_3) Plant

Hanifah Inas Nastiti[1], Ryan Anindya Affan[1], Elly Agustiani[1*]

***Abstract*−** **Aluminum Fluoride (AlF_3) is a substantive material used to reduce the melting point temperature of the Aluminum from 1500°C to 600-850°C. The production applies a wet process using raw materials of Fluosilicic Acid and Aluminum Hydroxide with a by-product of Silica Dioxide. In this case, AlF_3 products are expected to have a maximum H_2O content of 2.6%. However, in the production process, the H_2O content reached 3% due to the non-optimum drying process. Therefore, the optimization process was carried out by increasing the dry air temperature of the recycle from stage 2 to stage 1 in the drying process, so that the mass transfer of H_2O from AlF_3 crystals to the air can be maximized. After the optimization, it was found that the H_2O content has met the quality standard of 1.8%.**

***Keywords*−Aluminum fluoride, Fluosilicic acid, Aluminum hydroxide, Drying process**

I. INTRODUCTION

Currently, the Indonesian government pays more attention to the development and expansion of the metal industry sector in Indonesia to meet both domestic and foreign needs to strengthen and stabilize the economic growth. However, the management of the metal industry has not yet achieved independence, one of which is the aluminum refining industry. The demand for aluminum for the domestic industry currently reaches 600,000-800,000 tons per year, but the amount that can be met by PT Y, the largest Aluminum industry in Asia, is only around 104,000 tons per year. It is estimated that by 2025, the demand will reach 2 million tons/year, especially since PT Y is preparing to increase its production capacity to 400,000 tons/year [1].

It is known that the Aluminum demand is quite high, so that, the fulfillment of aluminum needs must be carried out [2]. However, in the production process, aluminum requires a high melting temperature of around 1200-1500°C. This has an impact on energy consumption and large costs. Therefore, a substantive material is needed to reduce the melting point temperature to around 600-850°C with the addition of AlF_3 compounds so that it can reduce the production costs and the production process runs more efficiently [3]. However, to meet this high demand, only PT X is currently operating to produce Aluminum Fluoride using wet process with Fluosilicic Acid and Aluminium Hydroxide as raw material. The specifications of each raw material can be seen in Table 1. and Table 2.

Optimization and efficiency process at the Aluminum Fluoride plant was carried out, so that, it is expected the production can run optimally and becomes one of the sectors that can boost the development of Indonesian industry, especially in the metal industry sector. In this case, the optimization and efficiency processes were carried out by evaluating the production process that has been running at the Aluminum Fluoride factory of PT X, where the data were collected.

[1] Department of Industrial Chemical Engineering, Institut Teknologi Sepuluh Nopember, Kampus ITS Sukolilo, Surabaya 60111, Indonesia. E-mail: elly@chem-eng.its.ac.id

TABLE 1.
SPECIFICATION OF ALUMINUM HYDROXIDE

Parameter	Information
Molecular Formula	$Al(OH)_3$
Molecular Weight (g/mol)	78
form	Solid, white
Melting Point (°C)	300
Bulk Density (kg/m^3)	1150
$Al(OH)_3$ content	Minimum of 98.5%
SiO_2 level	Maximum of 1.5%

TABLE 2.
SPECIFICATIONS OF FLUOSILICIC ACID

Parameter	Information
Molecular Formula	H_2SiF_6
Molecular Weight (g/mol)	144.08
form	Liquid, colorless
Melting Point (°C)	-30
Specific Gravity	1.15
H_2SiF_6. levels	Minimum of 18%
P_2O_5 level	Minimum of 0.025%
H_2O level	Maximum of 82%

II. OPTIMIZATION METHOD

This optimization process was carried out to increase the level of H_2O released from $AlF_3.3H_2O$ crystals by comparing the calculation of the mass balance and energy balance before and after the optimization process, so that the H_2O content in the product is in accordance with the predetermined specifications. This drying process consisted of 2 stages. The operating temperature of stage 1 is 200°C, while stage 2 is 500°C. This operating temperature condition produced a product with an H_2O content of 3%. This optimization process was carried out by increasing the recycle temperature from stage 2 to

Figure 1. Location of Aluminum Fluoride Factory

250ºC using steam in the heater so that more H_2O was released at stage 1. Therefore, the mass of H_2O released from $AlF_3.3H_2O$ crystals can increase. This further lightened the drying load on stage 2. Furthermore, the recycle air temperature was increased to 250ºC so that the output temperature of $AlF_3.0.5H_2O$ became 300ºC.

III. RESULTS AND DISCUSSION

Process existing

3.1 Process Description

In the production process, Aluminum Fluoride is made using raw materials of Fluosilicic Acid and Aluminum Hydroxide. The specifications for the Aluminum Fluoride product can be seen in Table 3 according to the specification that defined by PT X, refers to SNI 06-2603-1992. In this case, the quality of the product must be maintained. From the PT. X data [3], it is known that there was a discrepancy between the H_2O content of the product and the qualified specifications. Based on the material balance calculation, there was also an imbalance between the production capacity of AlF_3 which should be 1708.3 kg/hour but the existing process produce 1728.3 kg/hour capacity.

The process of making Aluminum Fluoride in this factory applies a wet process which consists of the following several stages:

1) *Preparation Unit*
2) *Reaction Unit*
3) *Separation of SiO_2 Unit*
4) *Crystallization Unit*
5) *Separation of $AlF_3.3H_2O$ Unit*
6) *Drying Unit*
7) *Cooling and Packaging Unit*

In general, the process in the manufacture of Aluminum Fluoride is shown in Figure 2.

A. Preparation Unit

H_2SiF_6 from the Phosphoric Acid Factory from PT X is stored in storage tanks. Then, it is pumped to the second storage tank (preheated tank). In this second storage tank, H_2SiF_6 is preheated in a Heat Exchanger before being reacted with $Al(OH)_3$. The temperature in the Heat Exchanger is further maintained in the range of 78ºC-80ºC. When the temperature of H_2SiF_6 has reached 75ºC-78ºC, it will be sent to the reactor. However, if the temperature has not reached 75ºC, it will be returned to the preheated tank to be flowed back to the Heat Exchanger so that the temperature before the reaction is reached. $Al(OH)_3$ from the storage warehouse with a maximum H_2O content of 1.3% is then sent to the $Al(OH)_3$ Silo using a bucket elevator. To avoid dust from escaping from the silo, the equipment is installed with an exhaust fan and filtered by a filter from the $Al(OH)_3$ silo.

TABLE 3.
SPECIFICATION OF ALUMINUM FLUORIDE

Parameter	Information
Molecular Formula	AlF_3
Molecular Weight (g/mol)	83.98
form	Powder, white
Melting Point (ºC)	1290
Bulk Density (kg/m^3)	770
AlF_3 levels	Minimum of 97%
SiO_2 level	Minimum of 0.2%
P_2O_5 level	Minimum of 0.02%
Fe_2O_3 content	Maximum of 0.07%
H_2O level	Maximum of 2.8%

B. Reaction Unit

The reaction between H_2SiF_6 and $Al(OH)_3$ occurs in the reactor at a temperature of 90ºC with a maximum temperature of 99ºC for 13 minutes. The reactor is equipped with an agitator so that there is no precipitation from the remaining of the reaction products. The product formed of the reaction is exothermic. The amount of $Al(OH)_3$ required for the reaction is calculated according to the concentration of H_2SiF_6 entering the reactor. The following reaction occur in the reactor:

$$H_2SiF_{6(l)} + 2Al(OH)_{3(s)} \rightarrow 2AlF_{3(aq)} + SiO_{2(s)} + 4H_2O_{(l)}$$

Fluosilicic Acid	Aluminum Hydroxide	Aluminum Fluoride	Silicon Dioxide	Dihydrogen Oxide

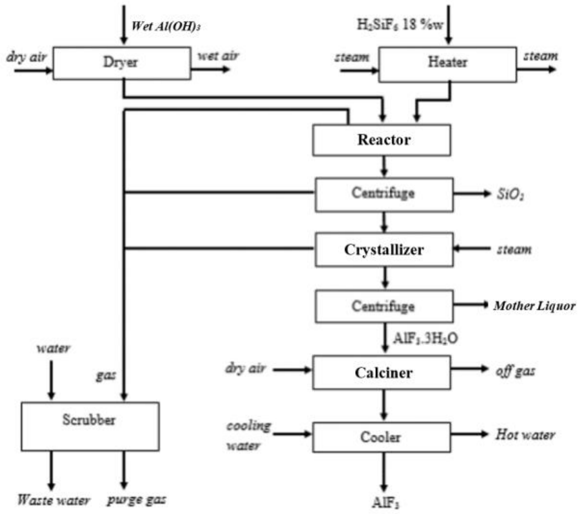


Figure 2. Block Diagram of Aluminum Fluoride Manufacturing Process using Wet Process

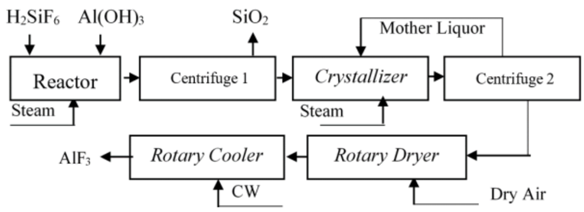


Figure 3. Flowchart of AlF_3 Production Process

C. Separation of SiO_2 Unit

In order to obtain good product quality, the silica contained in the reaction product must be separated immediately and the moisture content of the silica must also be decreased. After the reaction, it flows into the centrifuge. In the centrifuge, AlF_3 will be separated from SiO_2. This separation is done based on the density. There is a significant difference in density between AlF_3, H_2O, and SiO_2, where the highest density is in SiO_2 which is 2,650 kg/m^3, while the density of AlF_3 and H_2O is 770 and 1000 kg/m^3.

D. Crystallization Unit

In the crystallization process, the slurry from the centrifuge will be crystallized. The crystallizer is a batch that lasts for 4 hours so that 4 crystallizers are used in parallel. Before entering the crystallizer, the slurry will be accommodated in the AlF_3 distributor to be flowed into the crystallizer through the rotary valve. The function of the AlF_3 distributor is to regulate the purpose of the slurry flow so that there is no overflow/spill on the crystallizer. In this process, the slurry is in direct contact with the steam from the bottom of the crystallizer. The steam used is saturated steam (wet steam). With increasing solid porosity, it is expected that the product will have low bulk density. In addition, the crystallizer is equipped with an agitator or stirrer so that the product does not harden during heating. Based on the solubility curve [4], at a temperature of 90ºC the concentration crystals formed during crystallization is 140 mol/m^3. After the process is complete, it will be put in a holding tank.

E. Separation of $AlF_3.3H_2O$ Unit

This process aims to separate $AlF_3.3H_2O$ using saturated solution (mother liquor) which will later be recycled back to the crystallizer. The separation is carried out using a centrifugal type centrifuge so that the separation is based on density. Solid $AlF_3.3H_2O$ will be separated from mother liquor at the operating temperature of 80ºC. Mother liquor contains unreacted raw material and some uncrystallized AlF_3. Mother liquor will be further put in the vessel since some of it will be recycled to the crystallizer, while the other part is purged to waste water treatment. Recycle serves as an initiator of crystal formation in the crystallizer. The separated crystals will enter the hopper and then flow to the drying stage.

F. Drying Unit

In this process, the reduction of water content in AlF_3 is divided into 2 stages [5], namely the first stage is to reduce the water content of $AlF_3.3H_2O$ to AlF_3. H_2O and the second stage is to reduce the water content in AlF_3. H_2O to become AlF_3. This process is carried out on a rotary dryer. At this stage, the water content of the AlF_3 crystals will also be reduced in both free and hydrate forms to obtain the desired product specifications. The moisture content will be reduced to a maximum of 2.6%w. This process uses hot dry water with a temperature of 600ºC which is heated using a burner as a water vapor carrier. The operating condition temperature in the first stage is 250ºC, while in the second stage is 600ºC. This drying process takes place in direct contact with countercurrent flow in the rotary dryer.

$$AlF_3.3H_2O \rightarrow AlF_3.\ 0.5\ H_2O + 2.5\ H_2O$$
$$AlF_3.\ 0.5\ H_2O \rightarrow AlF_3 + 0.5\ H_2O$$

G. Cooling and Packing Unit

The AlF_3 solid that comes out of the rotary dryer has a temperature of about 500ºC. So it must be refrigerated before the packaging. Meanwhile, the cooling process uses a rotary cooler type, so that the cooling water does not directly contact the product. The product temperature after cooling process is 40ºC. The product is packaged in sacks/bags for 1 ton. Therefore, a weight tool is used in the packaging process.

3.2 Material Balance

Based on the calculations results from the material balance of the Aluminum Fluoride plant, it was found that in order to obtain a production capacity of 12,600 tons/year (1708.33 kg/hour), it requires H_2SiF_6 and $AlOH_3$ of 8346.588 kg/hour and 1652.37 kg/hour, respectively in each production [6][7].

Process Optimization

3.3 Optimization

Product quality is important in a production process. AlF_3 products produced at this factory are expected to be in accordance with the specifications set by the factory, which include having a purity of minimum 94%, SiO_2 of maximum 0.2%, H_2O of maximum 0.26%, and LOI of maximum 0.85%. In practice, there are still problems related to product quality, in which the water content in AlF_3 products exceeds the predetermined standard (3% of H_2O). This mismatch of water content can be caused by the non-optimal drying process in the rotary dryer. In the production process, anhydrous AlF_3 compound is obtained from its hydrate form in the form of $AlF_3.3H_2O$ (trihydrate) by going through a drying process. The drying process is carried out by direct contact with $AlF_3.3H_2O$ and dry air using a counter current flow type.

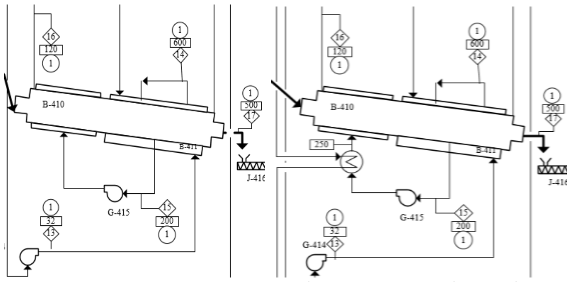


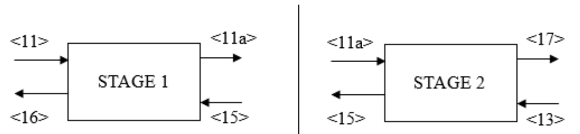
Figure 4. Process Flow Diagram of Drying Unit Before (left) and After (right) Optimization

It is known that there is a mismatch between the H_2O content in the manufactured AlF_3 product and the product quality standards. Figure 3. shows a flow diagram of the production process where there is a drying unit. The mismatch of H_2O levels in the product can be caused by the non-optimal release of H_2O from $AlF_3.3H_2O$ crystals in the rotary dryer during the drying process. Therefore, it is necessary to optimize the drying process to obtain H_2O content in accordance with the product specifications.

Based on the data from PT X's Aluminum Fluoride unit [3], it is known that there were problems that occur, namely the quality of the product where the H_2O content is not in accordance with the product specifications. In this case, it was found that the H_2O content in the product reaches 3%. This can be caused by the drying process, which is not optimal, so that there is H_2O content in the AlF_3 crystals that is not evaporated. The calculation of material balance can be seen in Figure 5.

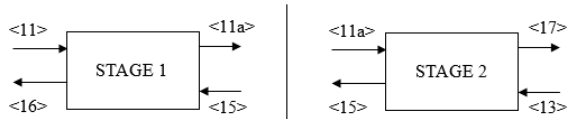
The dry air temperature condition that is fed to the rotary dryer after being heated in the burner is 500ºC (stage 2) and the recycled dry air resulting from stage 2 is fed to stage 1 with a temperature of 200ºC. At these operating temperature conditions, the total mass flow of the product obtained was 1728.83 kg/hour, which indicates that it exceeded the expected capacity of 1708.33 kg/hour (based on the calculation of the production capacity of 41 tons/day). This occurred due to the presence of excess water content in the product. The mass of H_2O that is evaporated from $AlF_3.3H_2O$ was 1169.21 kg/hour, which requires 6507.5 kg/hour of dry air to evaporate the H_2O.

Based on Figure 6. it can be seen that at stage 1, streams 11, 11a, 15, and 16 are $AlF_3.3H_2O$ crystals, $AlF_3.0.5H_2O$ crystals, recycle air, and exhaust air, respectively. In stage 1 with an operating temperature of 250^oC after the optimization (increasing temperature using heater [8]), the mass of H_2O removed was 897.159 kg/hour. In stage 2, the mass of H_2O removed was 291.51 kg/hour. With a stage 1 operating temperature of 250^oC, dry air mass of 5536.47 kg/hour is required with a humidity of 0.0011 kg H_2O/kg Dry Air, it can reduce the H_2O content of 1188.21 kg/hour so that the H_2O content in the product is 30.75 kg/hour



Input (kg/jam)		Output (kg/jam)		Input		Output	
Stream <11>		Stream <11a>		Stream <11a>		Stream <17>	
AlF_3	10,515	AlF_3	10,515	AlF_3	10,515	AlF_3	1674,17
$AlF_3.3H_2O$	2733,14	$AlF_3.0.5H_2O$	1841,9	$AlF_3.0.5H_2O$	1841,9	H_2O	51,250
H_2O	150,97	H_2O	144,01	H_2O	144,01		
Stream <15>		Stream <16>		Stream <13>		Stream <15>	
Dry Air	6507,5	Dry Air	6507,5	Dry Air	6507,5	Dry Air	6507,5
H_2O	1169,2	H_2O	11|76,2	H_2O	6,95	H_2O	1169,2
Humidity	0,1797	Humidity	0,181	Humidity	0,011	Humidity	0,1797
H_2O removed = 879,159 kg/jam				H_2O removed = 271,01 kg/jam			
Total	**10574,8**	**Total**	**10574,8**	**Total**	**9405,54**	**Total**	**9405,54**

Figure 5. Mass Balance of Stage 1 and 2 Rotary Dryer Before Optimization (Problem Condition)



Input (kg/jam)		Output (kg/jam)		Input		Output	
Stream <11>		Stream <11a>		Stream <11a>		Stream <17>	
AlF_3	10,515	AlF_3	10,515	AlF_3	10,515	AlF_3	1674,17
$AlF_3.3H_2O$	2733,14	$AlF_3.0.5H_2O$	1841,9	$AlF_3.0.5H_2O$	1841,9	H_2O	30,750
H_2O	149,928	H_2O	144,01	H_2O	144,01		
Stream <15>		Stream <16>		Stream <13>		Stream <15>	
Dry Air	5536,5	Dry Air	5536,5	Dry Air	5536,5	Dry Air	5536,5
H_2O	1188,7	H_2O	1194,6	H_2O	5,92	H_2O	1188,7
Humidity	0,215	Humidity	0,216	Humidity	0,011	Humidity	0,215
H_2O removed = 897,159 kg/jam				H_2O removed = 291,509 kg/jam			
Total	**9622,14**	**Total**	**9622,14**	**Total**	**8433,47**	**Total**	**8433,47**

Figure 6. Mass Balance Stage 1 and 2 Rotary Dryer Expected Condition (After Optimization)

(1.8%wt; specification standard). This data is obtained based on material and energy balance calculation [9][10].

3.4 Effect of the Optimization Process

The optimization process carried out affected both the production process and the economic analysis. After the optimization, the final product of AlF_3 has met the standard and material balance can be achieved at a production capacity of 1708.3 kg/hour. Therefore, based on the evaluation and calculations carried out, a comparison of conditions before and after the optimization can be obtained, both in terms of the production process (material balance) and evaluation of the economic analysis as shown in Table 4.

TABLE 4.
COMPARISON OF CONDITIONS BEFORE AND AFTER OPTIMIZATION

Parameter	*Before Optimization*	*After Optimization*	Unit
Mass Flow	1728.3	1708.33	kg/hour
%H_2O at <17>	3	1.8	%wt
H_2O mass <17>	51.25	30.75	kg/hour
Mass of AlF_3 <17>	1674.17	1674.17	kg/hour
Mass of SiO_2 <17>	3.4167	3.4167	kg/hour
Dry Air Mass	6507.5	5536.47	kg/hour
Humidity<13>	0.00107	0.00107	kg
Humidity<15>	0.1797	0.215	H_2O/kg
Humidity<16>	0.181	0.216	*Dry Air*
H_2O Removed	1169.21	1188.21	kg/hour
IRR	37.82	36.97	%
POT	3.29	3.36	year
BEP	34	35	%

3.5 Economic Analysis

Economic analysis was carried out to determine the feasibility of a factory. In the case of this economic analysis an evaluation was carried out by considering several things as follows:

1) *Internal Rate of Return* (IRR)
2) *Payout Time* (POT)
3) *Break Event Points* (BEP)

The calculation of the economic analysis was carried out using the discounted cash flow method, in which the cash flow value was projected at the present time. The followings are the assumptions used in the calculation.

1) Capital, consists of 30% of own capital and 70% of loan capital
2) Bank interest is 10% per year
3) Inflation rate is 3.5% per year
4) The construction period is 2 years, with the first year using 50% of own capital and 50% of loan capital. As for the second year using the remaining capital owned.
5) Loan repayment is within 10 years.
6) Production capacity at
   a) First year = 60%
   b) Second year = 80%
   c) Third year = 100%
7) Income tax of:
   a) Up to IDR 50,000,000 = 10%
   b) IDR 50,000,000 – IDR 100,000,000 = 15%
   c) More than IDR 100,000,000 = 30%

Based on these data, calculations were made to obtain the IRR, POT, and BEP values. IRR is defined as a certain interest rate on conditions when all revenues will still cover the entire amount of capital issued. Based on the calculation, the IRR value is 37.82%. The IRR value obtained is greater than the interest from bank loans. Furthermore, the POT value is known through the calculation of accumulated cashflow and the payback period, which is 3.29 years (before tax) and 4.06 years (after tax).

BEP is the break-even point when the total production costs are equal to the sales results, so that the total production capacity at that point can be known. BEP calculation involves several parameters including Fixed Cost (FC), Semi Variable Cost (SVC), Variable Cost (VC), and Total Sales (S). Based on the calculation, it can be obtained that the BEP value is 34% at a production capacity of 432,159,814 kg/year.

The optimization process on the drying unit has an influence on the economic analysis, including the IRR, POT, and BEP values. The optimization process was carried out by adding a heater to the drying unit to increase the recycle temperature from stage 2 so that it will reduce the IRR value to 36.97%. The payback period (POT) increased to 3.36 years (before tax) and 4.14 years (after tax). The optimization process will also increase the BEP value to 35% at a capacity of 439,232,519 kg/year.

TABLE 5.
FIX COST, VARIABLE COST, SEMI VARIABLE COST, AND TOTAL SALES FOR EACH UNIT OF PRODUCT PRODUCED

No	Information	Amount (Rp)
1	Fix Cost (FC)	IDR3,286
	- Depreciation	IDR2,629
	- Property tax	IDR394
	- Insurance	IDR263
2	Variable Cots (VC)	IDR5,892
	- Raw material	IDR4,450
	- Utilities	IDR1,258
	- Royalties	IDR184
3	Semi Variable Cost (SVC)	IDR9,225
	- Employee salary	IDR628
	- Supervision	IDR94
	- Maintenance & Repair	IDR1,840
	- Operating Supplies	IDR276
	- Laboratory	IDR276
	- General Expenses	IDR4,318
	- Plant Overhead Cost	IDR1,793
4	Total Sales (S)	IDR30,000

IV. CONCLUSION

Optimization and efficiency are carried out in the drying process by changing the operating conditions of the recycle air temperature from stage 2 to 250ºC using a heater. Therefore, the H_2O content in the AlF_3 product does not exceed the predetermined standard (<2.6%). Based on the calculation results, the percentage of H_2O contained in the product is obtained. In this way, the factory can reduce off-specification products so as not to repeat the drying process (saving cost and production time). The optimization of the process carried out has an influence on the economic analysis of the factory, where before the optimization, the IRR value is 37.82%; POT of 3.29 years (before tax) and 4.06 years (after tax); and BEP of 34%. After the optimization, the IRR value is 36.97% and POT is 3.36 years (before tax) and 4.14 years (after tax); and BEP of 35%. From the economic analysis, the existing process give better value than after optimization but not specific, the IRR value increased 0.85%: POT only increased 0.07 years before tax and 0.08 years after tax; and BEP increased only 1%. However, the optimization still need to be done even the H_2O content is only excess 0.2% from the specification because when the H_2O content of the AlF_3 product does not meet specification, it will affect the whole process, including production capacity and the qualified standard of the product, product is not in anhydrous form but is still in hydrate form.

SUPPLEMENTARY MATERIAL

Process Flow Diagrams (PFD) of Aluminum Fluoride Plant from Fluosilicic Acid and Aluminum Hydroxide can be seen in Figure 7 (before the optimization) and Figure 8 (after the optimization).

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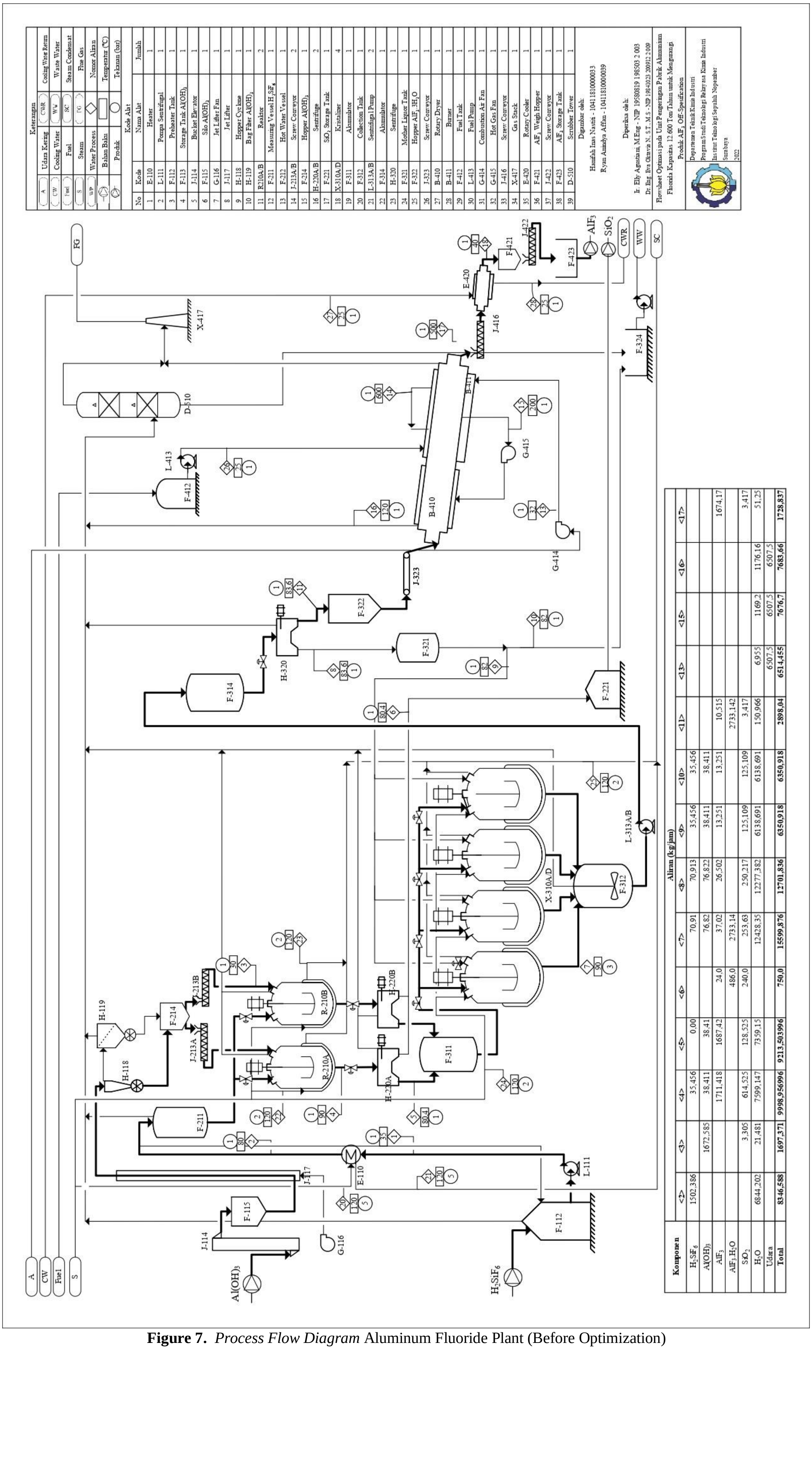
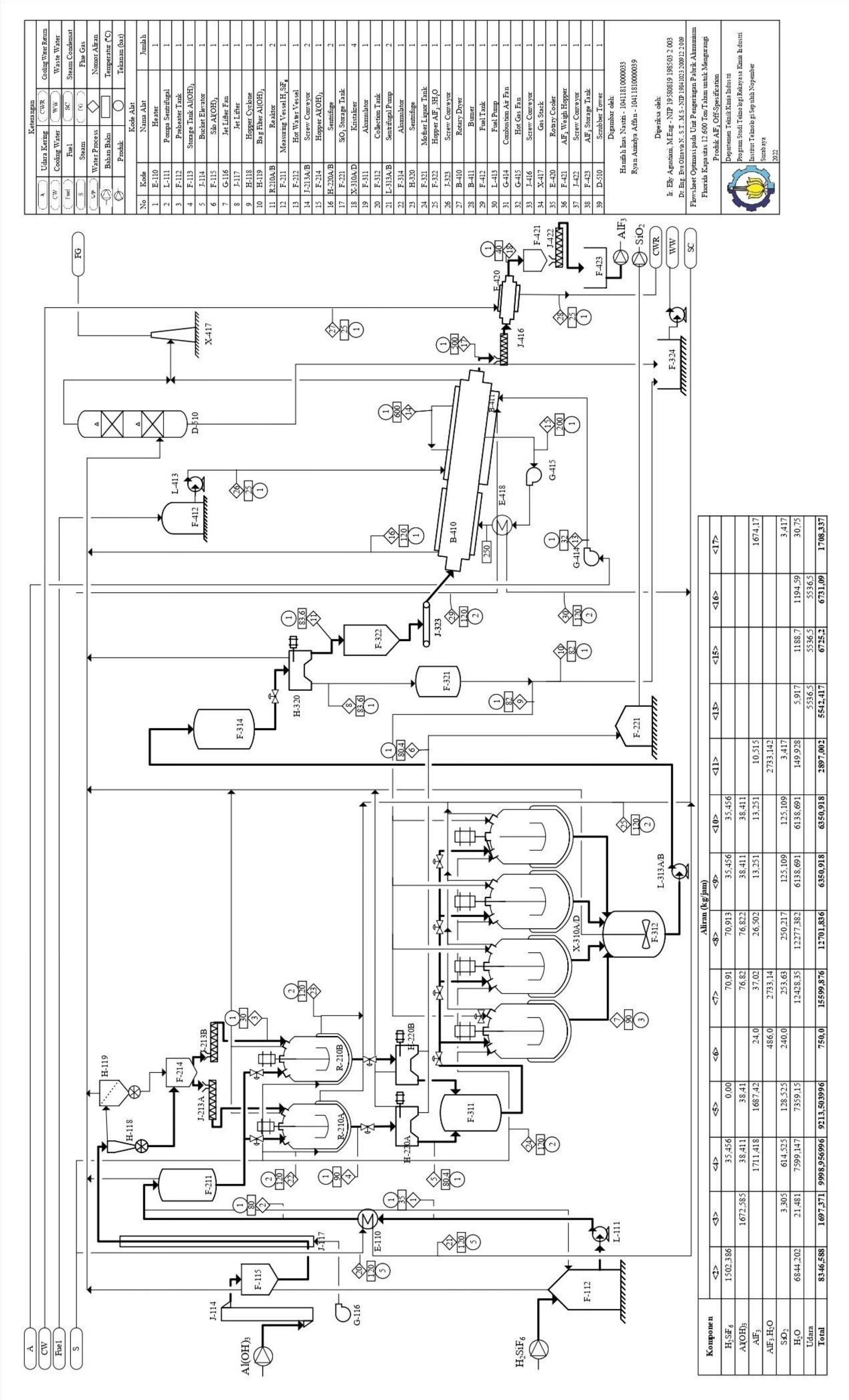


Figure 7. *Process Flow Diagram* Aluminum Fluoride Plant (Before Optimization)



Komponen	Aliran (kg/jam)													
	<2>	<3>	<4>	<5>	<6>	<7>	<8>	<9>	<10>	<11>	<13>	<15>	<16>	<17>
H_2SiF_6	1502,386		35,456	0,00		70,91	70,913	35,456	35,456					
$Al(OH)_3$		1672,585	38,411	38,41		76,82	76,822	38,411	38,411					
AlF_3			1711,418	1687,42	24,0	37,02	26,502	13,251	13,251	10,515				1674,17
$AlF_3.H_2O$					486,0	2733,14				2733,142				
SiO_2		3,305	614,525	128,525	240,0	253,63	250,217	125,109	125,109	3,417				3,417
H_2O	6844,202	21,481	7599,147	7359,15		12428,35	12277,382	6138,691	6138,691	149,928	5,917	1188,7	1194,59	30,75
Udara											5536,5	5536,5	5536,5	
Total	**8346,588**	**1697,371**	**9998,956996**	**9213,503996**	**750,0**	**15599,876**	**12701,836**	**6350,918**	**6350,918**	**2897,002**	**5542,417**	**6725,2**	**6731,09**	**1708,337**

Figure 8. *Process Flow Diagram* Aluminum Fluoride Plant (After Optimization)