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Treball Final de Grau

Design of a Calcium Ammonium Nitrate production plant

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Portem un nou món als nostres cors, que esta creixent en aquests instants...

B.D.

Hi ha molta gent a qui agrair aquest treball, i tot i no mostrar-ho sempre, espero que es donin per eludits.

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SUMMARY

In this work, the feasibility of building an ammonium nitrate production plant will be analysed. To do this we will divide work into 4 chapters. In the first it will be decided which product to make, in what amount, and where. Then it will be necessary to justify which process will be used, what does imply and if it can be improved. Equipment that will be used during the process must be designed, as well as estimate the required industrial services, equipment control or legislation. Finally, the economic viability of the plant and the amortization capacity of the necessary investments will be analysed.

Keywords: Equipment design, economic viability, market analysis, justification of the production process, minimum required services, implementation of improvements.

RESUM

En aquest treball s'analitzarà la viabilitat de construir una planta de producció de nitrat d'amoni. Per fer-ho es dividirà en treball en 4 capítols. En el primer es decidirà quin producte fabricar, en quina quantitat, i a quina zona. Després caldrà justificar quin procés es farà servir, que implica i si es pot millorar. Cal dissenyar els equips que es faran servir durant el procés, així com estimar els serveis industrials requerits, control dels equips o legislació. Finalment, s'analitzarà la viabilitat econòmica de la planta i la capacitat d'amortització de les inversions necessàries.

Paraules clau: Disseny d'equips, viabilitat econòmica, anàlisi de mercat, justificació del procés de producció, serveis requerits mínims, implementació de millores.

1. JUSTIFICATION AND OBJECTIVES

Fertilizers have been one of the undervalued elements of our environment for two centuries. Since prehistory, humans have found ways of cultivating the soil without drowning it, thus allowing healthy products to grow. Unknowingly, what they were doing was to let the soil reappear with nutrients and let crops grow stronger. These techniques, however, are often slow and do not allow us to take advantage of the soil as much as we would like.

That is why with the scientific study of the plant world, the soil and the relationship that is produced between them can feed crops with the necessary products so that they always grow strong and healthy, even in periods of the year that are not propitious for this. With the invention of fertilizer, plant products have multiplied their production by supplying the world's population.

This is why in this project a nitrogen-based fertilizer plant production will be designed. To accomplish this, the following points have to be done:

- Market analysis of the product: The product has to be analysed in order to know if it viable to build a production plant in the area.
- Process Selection: It's a must to fins the most optimal process to carry out the plant, and a way to improve it.
- Process Design: once the process is selected, all equipment, service, instruments have to be calculated and designed.
- Economic analysis: If a project doesn't have an economic viability it won't be done. It's a need to know beforehand if the project will have an economic solvency.

2. MARKET ANALYSIS

2.1 HISTORICAL DATA OF THE PRODUCT

Ammonium nitrate was discovered by a German scientific named Johann R. Glauber on 1659 and called it *“Nitram Flammans”.*

At the beginning of 19th Century, Justus Von Liebig considered “Father of agricultural chemistry”, started to study and define plants composition and their relation with the ground. Those studies were very popular and they match the industrial revolution and a massive exodus from farms to cities. New industrial potencies found themselves with the need to feed a huge mass of population, with less people working on food farming, and that’s how fertilizer industry began.

Even though the great agriculture industrial potential, it didn’t take much for governments to see the destruction power that ammonium nitrate had at determinate conditions. Since then to now ammonium nitrate has been the main components on explosive war materials. So, the origin of agricultural industry matches the modern death industry as well.

In Spain, the fifties will mark the start of a great development in the fertilizers industry. Specially, the nitrogen sector grew exorbitantly. From the 3500 tons of nitrogen produced during the fifties, to 90 000 tons on the sixties and over 500 000 on the seventies. Nowadays, Spain is one of the main nitric fertilizer producers with a production that exceeds the 1 000 000 tons of nitrogen.

It is worth mentioning pioneer industries in the sector like EIASA (Sabiañanigo), NICAS (Valladolid) I Hidro-Nitro (Monzón) that were plants of raw materials like ammonia using hydrogen electrolysis.

2.2 WHAT IS AMMONIUM NITRATE?

Ammonium nitrate is an inorganic fertilizer that presents equitable fractions. By one side, nitric nitrogen that acts immediately and by the other side, ammoniac nitrogen that has an expended delivery over time.

2.2.1 Ammonium nitrate types

Ammonium nitrate can't be used directly at pure state due to its high hygroscopicity it fastly absorbs water from the atmosphere and loses part of its properties. That's why is commonly used in granule form and previously coated. That's why there exist different type of nitrates in the fertilizer industry.

Types	N %
Ammonium Nitrate	33,5
Ammonium Sulphate Nitrate	26,0
Ammonium Calcium Nitrate	27,0

Table 1:Ammonium nitrate types

2.2.2 Ammonium nitrate properties

2.2.2.1 Physic properties

- Physic state: Due that can't be used in pure form it will be seen as granules
- Colour: White
- Odour: Odourless
- Granulomere: 1.5-3 mm
- Density: 1.3 kg/l

- Solubility: at 20 ºC, 190 KgNA/100l H2O
- Higroscopicity: at 20ºC is 33.1
- Acidification index: 60
- Salinity index: 105

2.2.2.2 Chemical properties:

- Easily releases ammonia in presence of alkaline salts
- It's a strong oxidation agent that can cause violent explosions in presence of organic matter, some metals, phosphorus or sulphurs.

2.2.3 Current uses

Currently in Spain, ammonium nitrates consumption achieves the 14% of total nitrogen fertilizers and production is over the 19.5%. It's production is concentred in three main factories: Sagunt, Valencia; Puerto llano, Ciudad Real; I Avilés, Avilés. In total they achieve over a 1 000 000 tons of ammonium nitrate production

A couple decades ago, ammonium nitrate started to had several production problems due to restrictions, especially because of antiterrorists laws and industrial security. It has been substituted gradually for calcium ammonium nitrate (CAN). It contains nearly a 27% of nitrogen and it is also distributed through the nitric and ammoniac form

2.2.4 Competitive products

Apart from ammonium nitrate, different products are used as nitrogen source for fertilizers

- Ammonium sulphate
- Urea
- Ammonium Nitrosulphate
- Potassium Nitrate

Product	N (%)	N-type	Chem formula	Solubility
Urea	46	ammoniac and nitric	CO(NH2)2	105
Ammonium Sulphate	21	Nitric	(NH4)2SO4	75,4
Ammonium Nitro-sulphate	26	Ammoniac and nitric	H12N4O7S	98
Potassium nitrate	13	Nitric	KNO3	31,6
Ammonium Nitrate	33,5	ammoniac and nitric	NH4NO3	196.2

Table 2: Competitive products

From this table there are three reasons we can extract to explain why is ammonium nitrate one of the bests fertilizers. First of all, is one of the products with more percentage of nitrogen, which means less kg of fertilizer per hectare. It also has both nitrogen dispositions, ammoniac and nitric ones, making it a very reliable nitrogen source for the crops. Finally, it has a great solubility in water favouring a better assimilation to the ground.

2.3 NATIONAL CONSUMPTION AND PRODUCTION

To determine the ammonium nitrate consumption in spain, United Nations data from imports and exports has been taken. From all ammonium nitrate types described above, only ammonium nitrate pure and calcium ammonium nitrate are statistically relevant.

AMMONIUM NITRATE				
Year	**Production (t)**	**Exports**	**Imports**	**Consumption**
1992	54.766	12.649	37.751	79.868
1993	90.700	1.900	31.500	120.300
1994	83.400	2.600	36.700	117.500
1995	51.900	3.300	109.800	158.400
1996	66.800	1.600	106.000	171.200

1997	130.700	1.700	61.100	190.100
1998	286.000	15.000	64.000	335.000
1999	286.000	10.000	97.000	373.000
2000	284.000	29.400	65.600	320.200
2001	422.700	27.000	57.000	452.700
2002	417.038	70.000	36.000	383.038
2003	370.132	12.927	206.158	563.363
2004	243.521	11.037	168.256	400.740
2005	164.802	26.844	130.834	268.792
2006	141.281	12.634	138.019	266.666
2007	118.935	2.438	80.810	197.307
2008	94.250	11.399	110.353	193.204
2009	81.393	4.106	82.553	159.840
2010	94.562	6.927	104.961	192.596
2011	86.606	7.887	90.788	169.507
2012	85.608	15.314	53.312	123.606
2013	48.638	23.793	53.731	78.576
2014	28.965	29.681	68.339	67.623
2015	32.167	38.088	59.922	54.001
2016	29.631	31.221	35.057	33.467

Table 3: Ammonium Nitrate production, consumption, exports and imports [1]

As can be observed in table X, ammonium nitrate had high demand at the beginning of the millennium, with almost a 300% more demand and production that in the nineties with a production record of 442 700 tones on 2001. The world around this product changed completely around this year. Since the twin towers attack, production and commercial legislation about this product went radically restrictive, even banning it in a bunch of countries.

As the product restrictions appeared, the ammonium nitrate industry had to change in order to comply the legislation. A new product really similar to the ammonium nitrate appeared to the market, and results that spain has great raw material reserves of the new product addes to ammonium nitrate. Calcium ammonium nitrate, that is basically ammonium nitrate mixed with limestone before being granulated, started to be produced on 2002 and it definitely increased the ammonium nitrate industry value. With the years, pure ammonium nitrate is not produced anymore in the fertilizer industry.

CALCIUM AMMONIUM NITRATE				
Year	**Production (t)**	**Exports**	**Imports**	**Consumption**
1992				
1993				
1994				
1995				
1996				
1997				
1998				
1999				
2000				
2001				
2002	638.796	303.833	172.854	507.817
2003	719.886	313.289	227.716	634.313
2004	746.323	186.159	177.623	737.787
2005	868.236	214.818	274.047	927.465

2006	718.359	13.249	384.734	1.089.844
2007	609.440	57.475	90.993	642.958
2008	679.887	130.466	159.609	709.030
2009	720.169	280.733	169.628	609.064
2010	689.149	192.728	232.496	728.917
2011	689.565	189.651	292.726	792.640
2012	742.348	286.107	201.661	657.902
2013	705.932	248.258	261.380	719.054
2014	669.687	195.266	360.551	834.972
2015	682.114	233.599	357.116	805.631
2016	741.534	333.065	247.120	655.589

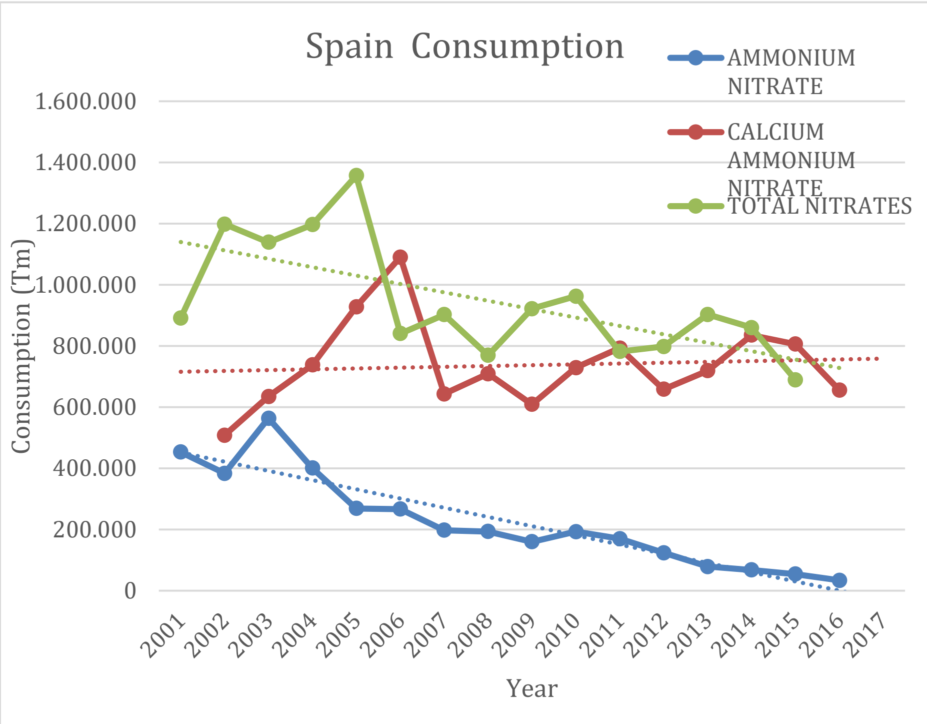
Table 4: Calcium Ammonium Nitrate production, consumption, exports and imports [1]

At 2002, CAN production started, increasing for a 50% the production of ammonium nitrate that had at that time. Exports started to exceed imports, changing the paradigm and making Spain top 5 on the ammonium nitrate industry in the world, behind other European countries like French or Holland.

2.3.1 Demand estimate

Since 2002 a constant decrease on pure ammonium nitrate consumption is offset by the calcium ammonium nitrate consumption, increasing almost a 100% from 2002 to 2006. But then CAN consumption was stabilized between a fork of 650 000 and 800 000 tons, while pure AN continued to decrease. That’s because with the ammonium nitrate decrease, urea, another nitrogen fertilizer, started to rise especially on east countries where legislation is less restrictive.

As can be seen in graph below, pure AN decrease and CAN increase consumption rate are not equitable, making the overall consumption rate to decrease. But is reasonably to think that as pure AN consumption stabilizes close to 0 tons per year in the future, overall consumption will stabilize with CAN consumption, that has a small consumption increase rate of almost 6% in last decade. Lineal demand estimate is 798 000 tons of CAN consumption in 2020



Graph 1 Consumption evolution in Spain

2.3.2 Main consumers

Nitrate consumers belong to the agricultural sector, which has slightly increase consumption in last years. Areas with more consumption are Castilla Leon and Andalucía, with great quantity of crops. Traditionally, they produce cereals and olive, type of crops that need a lot of nitrogen to grow strong.

COMUNIDAD AUTONOMA	2012/13 Consume (t)	2013/14 Consume (t)	2014/15 Consume (t)	2015/16 Consume (t)	2016/17 Consume (t)
ANDALUCÍA	236.380	250.154	252.701	229.855	277.748
ARAGÓN	94.460	109.277	94.280	99.978	103.706
ASTURIAS	4.151	4.979	3.197	3.334	4.043
BALEARES	3.907	2.488	3.371	2.790	2.471
CANTABRIA	3.927	3.380	3.553	2.906	2.185
CT. LA MANCHA	92.262	106.935	85.618	97.149	90.896
CASTILLA LEÓN	236.058	246.570	269.185	245.111	236.493
CATALUÑA	52.730	54.636	51.337	60.015	52.411
EXTREMADURA	30.921	37.239	36.681	40.099	47.170
GALICIA	18.634	23.705	27.114	25.992	20.094
MADRID	3.535	5.924	4.270	6.510	10.075
MURCIA	45.895	45.767	45.641	38.955	48.839
NAVARRA	24.279	25.808	27.140	25.593	18.391
LA RIOJA	13.562	12.966	15.178	15.895	15.266
C. VALENCIANA	84.391	89.129	78.488	74.634	74.037
PAIS VASCO	12.324	13.482	12.459	14.042	12.222
CANARIAS	3.806	3.082	3.474	4.312	3.669
TOTAL	**961.222**	**1.035.521**	**1.013.687**	**987.170**	**1.019.716**

Table 5: Consumption evolution in Spain per area[2]

2.4 CAPACITY, PRODUCT, AND PLANT LOCATION

In spain there are three plants that produce nitrogen fertilizer in nitrate form. Currently, all three plants are producing calcium ammonium nitrate. Due to the previously exposed information, a pure ammonium nitrate plant for agricultural use is completely not viable for our project.

That's why the product selected to produce in this project will be calcium ammonium nitrate 27% mass on nitrogen.

The three main plants are part of the Fertiberia S.A. group and they used to produce pure ammonium nitrate but since the legislation change, all of them started to produce CAN.

- Plant on Sagunt, València. The facilities have almost 1200 terrain hectares and 350 000 tons of nitric acid are produced as intermediate product for the production of 500 000 tons of CAN-27 equivalent. Plant has been active since 1988.
- Plant on Puerto Llano, Ciudad Real. The oldest plant that remains active in Spain of nitrate fertilizers. It produces around 200 000 tons of CAN-27 with a similar quantity of nitric acid and ammonia.
- Plant on Avilés, Asturias. Active since the seventies, this plant has 1800 hectares to produce 200 000 tons of nitric acid and 250 000 tons of CAN-27.

Observing table 4, it can be seen that national production generally exceeds consumption, so the introduction of a new production plant in Spain is not viable. That's why the object of this project is to design a production plant of 200 000 tons of CAN substituting the Puerto Llanos plant, where ammonia and acid nitric are supplied by the same installations.

Puerto Llano is also selected because is really close to the main nitrogen fertilizers demand areas, and has good infrastructure connections with the pourts in the south of the country.

3. AMMONIUM NITRATE PROCESS SELECTION AND PROCESS DESIGN

3.1 PROCESS COMPARISON

From bibliography, the following processes have actually been designed for pure ammonium nitrate production. Since the only difference with calcium ammonium nitrate production is the addition of limestone, the comparison between them for the CAN production is acceptable.

3.1.1 Carnit Process

Block diagram is attached on appendix 1 fig 1.

The Carnit process for production of concentrated AN solution requires no external heat supply. The reaction of ammonia and nitric acid occurs in a recycle flow loop where the pressure is higher than the vapour pressure of the solution. The recycle solution, which is slightly ammoniac, supplies heat for the final concentration and for production of export steam. The free ammonia in the production off-take is neutralized before pressure reduction and subsequent concentration steps.

A couple of titanium reactors are used, both steps operate at 185ºC and 700-800 kPa, and the obtained solution is evaporated through two descendent film evaporators where it gets concentrated to 84% and 97.5% respectively. Then, it gets granulated in a prilling tower to be dried and sifted. The obtained granules are coated with additives to improve their physicochemical properties

These conclusions have been reached

- Advantages:

- Uses the whole process steam
- Limits the decomposition of the ammonium nitrate

➢ Disadvantages:

- Operates at an elevated pressure, increasing the costs
- Uses 2 titanium reactors increasing highly the process cost
- Requires additional steam

3.1.2 UCB Process

Block diagram is attached on appendix 1 fig 2

In the UCB process, a heat exchanger in the pressure reactor uses a part of the heat of reaction to make steam.

In this process ammonia and 52% to 63% nitric acid are preheated and sprayed into the sump of the reactor. The reactor pressure is about 4.5 bar; the temperature is 170 to 180°C and the pH is kept between 3 and 5 by controlling the ratio of reactants. This pH range reduces the amount of nitrogen that is lost in the process steam. A 75% to 80% solution leaves the reactor and is concentrated to 95% in a falling film evaporator.

The heat of reaction generates 1) process steam in the reactor and 2) 5.5 bar pure steam. The process steam is used to preheat boiler feed water and nitric acid as well as operate the falling film evaporator. The pure steam is fed to the plant steam header.

The solution that leaves the evaporator is fed into a granulator and then sifted. The sieved product is coated with stabilizers and then cooled for final disposal.

These conclusions have been reached

➢ Advantages:

- Uses the whole steam generated in the evaporation phase.
- Limits the decomposition of the ammonium nitrate

➢ Disadvantages:

- Operates at an elevated pressure, increasing the costs
- Requires additional steam

3.1.3 StamiCarbon Process

Block diagram is attached on appendix 1 fig 3

The Stamicarbon process is another process that works under pressure. In this process 60% nitric acid, preheated ammonia and a small quantity of sulfuric acid are introduced at the lower end of the reaction loop. The reactor operates at 4 bar and 178°C. The initial ammonium nitrate solution has a concentration of 78%.

The steam that leaves the top of the separator is used to concentrate the solution to 95% in a vacuum evaporator. Excess steam is condensed, and ammonia is recovered from the condensate so it can be returned to the reactor. In a second evaporator, the concentration can be increased to a range of 98% to 99.5% by using fresh steam. Then, ammonium nitrate is granulated, screened, cooled and coated.

These conclusions have been reached

- Advantages:
  - Uses the whole steam generated in the evaporation phase.
  - Limits the decomposition of the ammonium nitrate

- Disadvantages:
  - Operates at an elevated pressure, increasing the costs
  - Requires additional steam

3.1.4 UHDE Process

Block diagram is attached on appendix 1 fig 4

This reaction takes place in an already formed ammonium nitrate solution that passes through the reactor by natural or forced circulation.

The reactor works under 0.5-1.2 bar and 130-150ºC to avoid ammonium nitrate to reach its boiling point. After the neutralization phase, the solution feeds a flash separator folowed by an evaporator that concentrateds the ammonium nitrate up to 97% in weight.

The concentrated solution passes to the granulation process in a granulator tower, where the produced granules are dried in a rotary drum dryer. The dry granules are screened, cooled and conditioned with surfactants

These conclusions have been reached

- Advantages:
  - Uses the whole steam process generated.
  - Limits the decomposition of the ammonium nitrate.
  - The air flow used to cool the product is used in the dryer, reducing the air use.
  - Limits the loss of ammonia.
  - Low reactor costs.
  - Simplest process operation.

- Disadvantages:
  - Requires additional steam production.

3.1.5 NSM /Norsk Hydro Process

Block diagram is attached on appendix 1 fig 5

In the NSM process (see Figure 10.5) the reactor pressure is about 4.5 bar and the temperature is between 170 and 180°C. The results from this is a 70-80% ammonium nitrate solution. Final concentration of the 95% up to 99.5% is carried out with steam in a special vacuum evaporator. The granulation process is similar to the explained above.

These conclusions have been reached

- Advantages:
  - Some process steam is made with the nitric water.
  - Minimum ammonium nitrate or ammonia emissions.

- Disadvantages:
  - Operates at an elevated pressure, increasing the costs.
  - Requires additional steam production.

3.1.6 Stengel Process

Block diagram is attached on appendix 1 fig 6

The Stengel process is used to produce anhydrous ammonium nitrate directly. In this process ammonia and 58% nitric acid are preheated with fresh steam and fed into a packed vertical tube reactor at 3.5 bar and 240°C. The mixture of and steam is expanded into a vacuum in a centrifugal separator. After stripping with hot air, a 99.8% melt is discharged onto a cooled steal belt, solidified and then broken up or granulated. Finally, the solid is screened, big rocks are triturated again and dust feeds the separator.

These conclusions have been reached

- Advantages:
  - Uses the whole steam generated.
  - No evaporation needed

- Disadvantages:
  - Requires high amount of additional steam.
  - High pressure needed

3.2 COMPARISON

Process	Pressure (bar)	Reaction Temperature (ºC)	Number of reactors	Evaporation stages	Can use process steam
Carnit	7-8	185	2	2	Yes
UCB	4.5	170-180	1	1	Yes
StamiCarbon	4	178	1	2	Yes
UHDE	1	140	1	1	Yes
NSM	4.5	170-180	1	1	Yes
Stengel	3.5	240	1	1	Yes

Table 6: Processes comparison

With the data recollected and summarized in this table above, it can be said that UHDE process is the best or one of them to produce CAN because it works at low temperature and pressure, and it has low equipment investment since not much is required in comparison with others.

3.3 UHDE DESCRIPTION:

The production process comprises three main unit operations:

-Neutralisation

-Evaporation

-Granulation

Ammonia is stored in a liquid state approximately at 1000kPa. It vaporizes reducing the pressure to 700kPa and overheating it to 60ºC before feeding the reactor. 60% Acid nitric is also preheated to 66ºC and pressurized to 600kPa before entering the neutralizer.

Both ammonia and nitric acid should be fed in stoichiometric ratio but due to measurement and control reasons we will operate with a 10% nitric excess. The reaction is done at 140ºC and 100kPa in acid conditions by the following exothermically reaction:

$NH3 + HNO3 \rightarrow NH4NO3 + 1345$ kJ/kg

Acid condition has been chosen because otherwise the nitrogen losses would considerably increase due to free ammonia in the AN solution and the process vapours. Acid is distributed into recirculating AN solution by injection nozzles. Then they are mixed in the phase I of the reactor. The ammonia sprayer distributes the gas through holes in the reactor tubes. To maintain the temperature increase in a lower rate, 5% of concentrated NA from the flash will be returned into the reactor. That makes the reactor leave a 64% in weight ammonia nitrate.

The hot solution that left the reactor now feeds a flash evaporator that operates at 45kPa through an orifice. At this point the process steam is separated from the ammonium nitrate solution and used to preheat ammonia and nitric acid. The solution is fed into a lung tank.

The stabilized solution goes to another evaporation stage where its concentrated up to 97% and its ready to enter the granulation phase. The 97% solution will be fed into a pug mill granulator simultaneously with limestone that will be the filler. Hot granules go to a drying drum where they are dried with hot air. Then they are screened, cooled in a fluid bed cooler and finally they will be coated with some anti-caking substance.

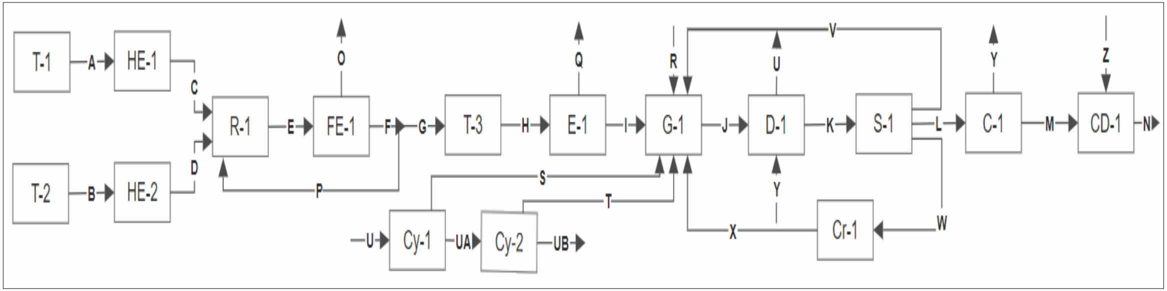
A significant feature of the Uhde process is that the offgas from the fluid bed cooler is used for drying the product in the dryer. This is a significant energy saving feature and enables the plant to run autothermally for nearly all CAN grade. This feature also effectively halves the amount of air that must be processed in the air treatment section. Process air from the cooler and dryer is treated through some cyclones to reduce the amount of dust. A combination of cyclones and a wet scrubber are used to reduce the emissions

Mass and Energy balance are shown in the nexts oages. To do them, a 25 000 kg of CAN has been assumed with a composition of 78% Ammonium nitrate and 22% limestone, so our final composition has 27% nitrogen in weight.

BLOCK DIAGRAM AND MASS BALANCE FOR THE CALCIUM AMMONIUM NITRATE PRODUCTION PROCESS USING UHDE

	A	B	C	D	E	F	G	H	I	J	K	L	M
NH3	4 168.63		4 168.63										
HNO3		15 864.53		15 864.53	416.08								
AN					20 647.38	20 606.09	19 575.78	19 575.78	19 380.02				
CaCO3													
CAN										25 147.78	25 125.12	24 848.75	24 846.26
H2O		10 142.90		10 142.90	10 220.45	1 550.99	1 473.45	1 473.45	723.74	777.77	25.15	24.87	24.87
CoAg													
TOTAL	**4 168.63**	**26 007.43**	**4 168.63**	**26 007.43**	**31 283.91**	**22 157.08**	**21 049.23**	**21 049.23**	**20 103.76**	**25 925.55**	**25 150.27**	**24 873.62**	**24 871.13**

	N	O	P	Q	R	S	T	U	UA	UB	V	W	X	Y	Z
NH3															
HNO3		416.08													
AN		41.29	1 030.30	195.76											
CaCO3					5 466.19										
CAN	24 850.00					23.89	1.19	25.15	1.26	0.06	25.12	251.25	251.25	2.49	
H2O	25.00	8 669.45	77.55	749.71	54.50	1.20	0.06	1.26	0.06	0.00	0.03	0.25	0.25	0.00	3.87
CoAg	125.00														125.00
TOTAL	**25 000.00**	**9 126.82**	**1 107.85**	**945.47**	**5 518.80**	**25.09**	**1.25**	**26.41**	**1.32**	**0.07**	**25.15**	**251.50**	**251.50**	**2.49**	**128.87**

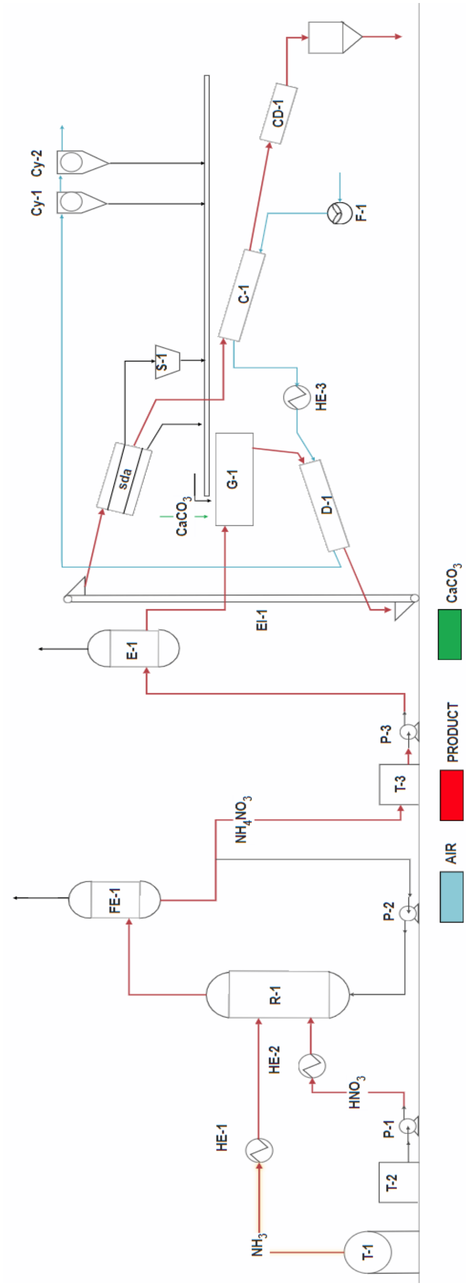


LEGEND			
STREAMS		EQUIPMENT	
A,C	Ammonia	T-1, 2,3	Tanks
B, D	Nitric acid	HE-1,2	Heat exchangers
E	66% AN solution	R-1	Reactor
F, G, P, H	93% AN solution	FE-1	Flash evaporator
I	96.4% AN solution	E-1	evaporator
J	97% Wet CAN granules	G-1	granulator
K, L,M	99.9% Dried CAN granules	D-1	Dryer
V, S, T, X	CAN dust rejected	S-1	Screener
W	CAN oversized rejected	Cy-1,2	Cyclones
N	Final product 99.4% CAN	Cr-1	Crusher
Z	Coating Agent	C-1	Cooler
Y,U,UA,UB	Air	CD-1	Coating drum
R	Limestone		
Q, O	Vapour		

EQUIPMENT	FLOW (kg/h))	HEAT (kJ/h)
AMMONIA HEATER HE-1		
Ammonia gas	4168.63	307 853
NITRIC ACID HEATER HE-2		
Nitric acid 61%	26 007.43	2 457 720
REACTOR R-1		
Ammonium nitrate 66%	31 383.91	-16 621 109
FLASH EVAPORATOR FE-1		
Ammonium nitrate 93%	22 157.08	4 079 000
EVAPORATOR E-1		
Ammonium nitrate 96.4%	20 103.76	1 153 096
GRANULATOR G-1		
Calcium ammonium nitrate granulated	25 926	-3 228 972
DRYER D-1		
Dried CAN granules	25 150	78 716
COOLER C-1		
Cooled CAN granules	24 871.13	-5 631 194

Table 7: Energy balance table

From both balances now are known compositions streams, and heat exchanged in every operation. Following diagram shows all connections and operations on the plant.



T-1
NH_3
HE-1
T-2
P-1
HNO_3
HE-2
R-1
FE-1
P-2
NH_4NO_3
T-3
P-3
E-1
El-1
G-1
$CaCO_3$
sda
S-1
D-1
HE-3
C-1
F-1
CD-1
Cy-1
Cy-2
AIR
PRODUCT
$CaCO_3$

3.4 PYNCH ANALYSIS

To maximize energy efficiency in the Neutralization and Evaporation stages, a complete pinch analysis is made. The Streams selected are, as cold ones:

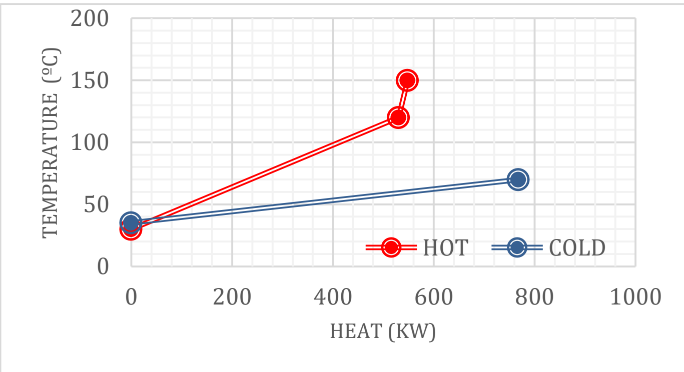
- Ammonia
- Nitric Acid
- And as hot ones:
- 95% Vapour from Flash Evaporator
- 79% Vapour from Evaporator

Cold and hot pinch has been calculated, as well as minimum service heat

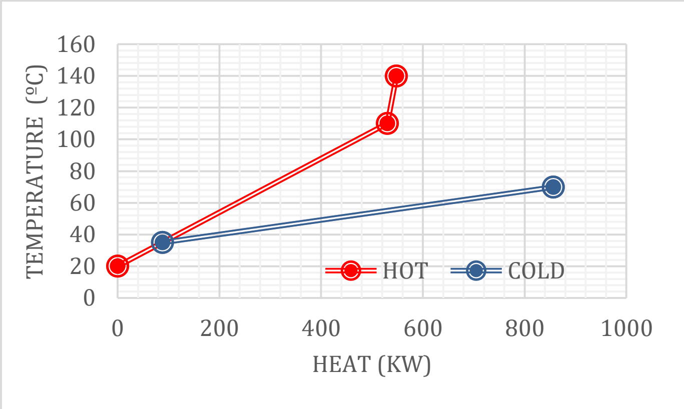
Hot pinch temperature	45 ºC
Cold pinch temperature	25 ºC
Minimum heat requirement	308.32 kW
Minimum cold requirement	88.39 kW

Table 8: Pinch analysis results

Hot and cold curves were designed

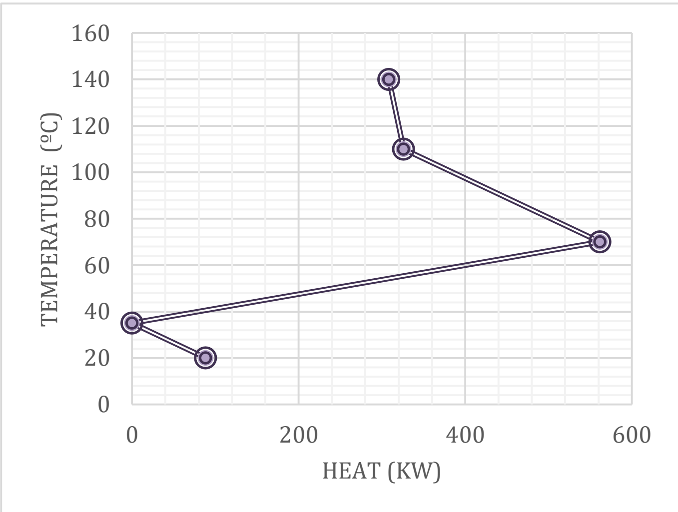


Graph 2: Compounds curves



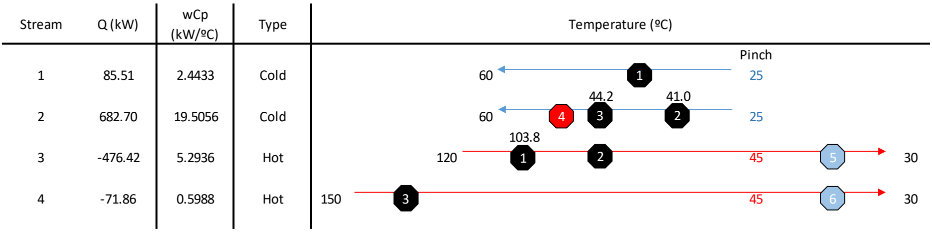
Graph 3: Displaced compunds curves

In this curve service requirements can be obtained graphically. As well as pinch point, and the great compound curve.



Graph 4: Great compound curve

With obtained values the heat exchanger net will be made. In the following diagram all exchanger heat units can be seen, as well as the temperature they will make any stream reach. Stream connections and service exchangers can also be seen.



Graph 5: Analysis pinch results. Heat exchangers position

The six heat exchangers needed are now determined from figure above.

HE-1 recovering heat between stream 1 and 3

HE-2 recovering heat between stream 2 and 3

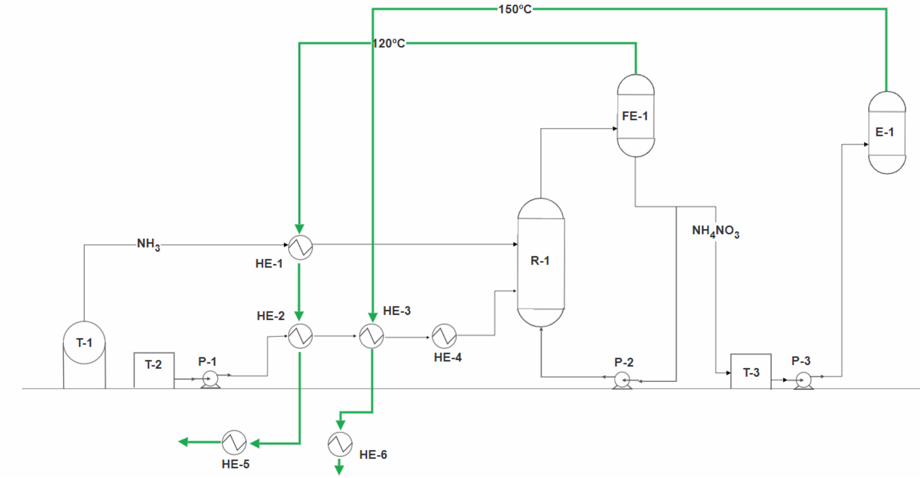
HE-3 recovering heat between stream 2 and 4

HE-4 heater for stream 2 to achieve 60 ºC

HE-5 cooler for stream 3 to achieve 30 ºC

HE-6 cooler for stream 4 to achieve 30 º

With this new exchangers disposition, a 70% of the energy needed initially is saved passing from 1322 kW of energy needed to 396.71. But 2 extra heat exchangers will be needed.



Graph 6: New Heat exchanger system

4. MAIN PROCESS EQUIPMENT DESIGN

4.1 REACTION DESIGN

In this chapter a complete analysis of the chemical reaction between ammonia and nitric acid to produce ammonium nitrate will be done. Conditions of the reactor will be studied as well in order to determine the specifications to design it.

4.1.1 Chemical reaction

The reaction to obtain liquid ammonium nitrate at standard pressure with UHDE process is:

$$NH_3 + HNO_3 \rightarrow NH_4NO_3 + \Delta H_r^{\circ}$$

$$\Delta H_r^{\circ} = 1082.625 \ kJ/kg$$

The reaction occurs between ammonia gas, that was vaporized from the tank and heated to a temperature of 60 ºC and a pressure of 600 kPa. The nitric acid is previously mixed in the zone I of the reactor with recirculated ammonium nitrate and enters at the temperature of 60 ºC and 100 kPa. [4]

With this conditions, 10% excess of nitric acid is added so a 66% ammonium nitrate is achieved with this reaction conditions.

4.1.2 Reaction Heat

Ammonium nitrate formation is a high exothermic reaction that generates almost 74 kJ for each mole of formation which highly needs to be removed. That was calculated following the next equation

$$\Delta H^{\circ}_{r\,413K} = \Delta H^{\circ}_{r\,298K} + \int_{298}^{413} \Delta Cp\, dT$$

The point on those calculations is to know the specific heat variation with temperature, which in this reaction was considered constant due to the lack of information. If this heat is not removed ammonium nitrate and nitric acid could decompose resulting in nitrogen loses obviously not wanted.

If temperature hits over 180 ºC the decomposition of ammonium nitrate to nitrous oxide will take place, having an exothermically enthalpy 5 time bigger than ammonium nitrate production, uncontrolling the decomposition.

4.1.3 Equilibrium and kinetics reaction

4.1.3.1 Equilibrium of the reaction

The constant of equilibrium of this reaction at 25 ºC has been evaluated through Van't Hoff equation [1]. Knowing K at 25 ºC let you calculate in with other temperatures and see how much does it vary.

$$\Delta G^{\circ} = -RT\ lnK$$

Equilibrium Constant	Value
$K_{(25ºC)}$	1.75E+16
$K_{(140ºC)}$	2.20E+14

Table 9: Equilibrium constant variation

It can be seen that this reaction is extremely irreversible and equilibrium can be neglected. Even though it decreases with the temperature, it doesn't affect enough to consider it.

4.1.3.2 Kinetics of the reaction

The reaction between ammonia and nitric acid is considered to be instantaneously (in the range of milliseconds) so reactions kinetic will also be neglected to what material and energetic balance and design specifications refers. Because of that, any reactor designed for de ammonium nitrate obtaining won't be designed depending on the time of residence but depending on the heat transfer surface.

4.1.4 Efficiency

If reactants maintain the quality specified in the calculations, the efficiency of this reaction should be 100% and this will be supposed during the whole project

4.1.5 Reaction feed and effluent

In this table composition of every feed or effluent stream can be seen

Stream	Total Flow (kg/h)	AN		H_2O		HNO_3		NH_3	
		% (p/p)	Flow	% (p/p)	Flow	% (p/p)	Flow	% (p/p)	Flow
C	4 169	-	-	-	-	-	-	4 169	100
D	26 007	-	-	10 143	39	15 865	61	-	-
P	1 108	1 030	93	78	7	-	-	-	-
E	31 284	20 647	66	10 220	33	416	1	-	-

Table 10: Value and composition of stream entering/leaving reactor

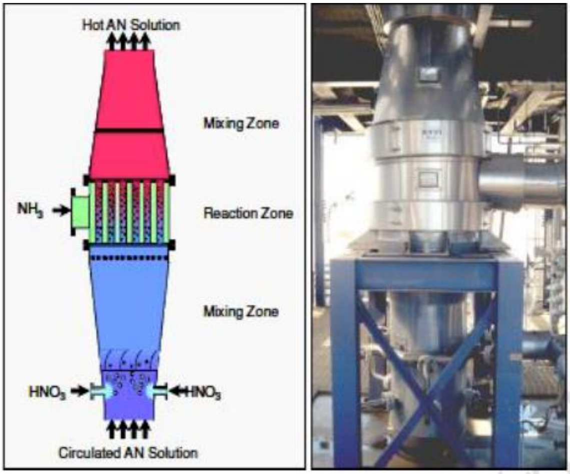
Where stream C and D are respectively the ammonia and nitric acid flow. P stream is the recirculation from the flash evaporator liquid.

E is the effluent of the reaction

4.1.6 Reactor design

The UHDE process to produce ammonium nitrate uses an upflow reactor similar to a heat exchanger with perforated tubes is used. It works with continuous flow. Due to the presence of corrosive substances, stainless steel 302 will be used for the reactor.

UHDEs reactor is divided in three stages, stage I and III are the mixing ones, cold and hot respectively, and stage II is where the reaction takes part.



Graph 7: UHDE’s Reactor

Ammonium nitrate previously heated is introduce at the stage I of the reactor with a pipe of 2.5’’, where is mixed with the ammonium nitrate recirculated that travels in a 0.5’’ pipe. They are mixed in astatic mixer and create an acid solution that enters the reaction zone II. Ammonia enters directly that zone through a 10-inch pipe.

Acid solution passes the reaction zone through 1’’ pipes that go all along the vertical of the reactor. They have 0.25’’ holes every 3’’ long where the ammonia sprayed reacts and forms the ammonium nitrate. It helps to distribute all the contact points of the reaction and also the heat generated so it makes it safer. The reactor operates at 100 kPa and 140 ºC, and pH must be precisely controlled to ensure the optimal conditions for the process.

All heat created in the reaction that is not used to heat reactants, will be removed with a cooling jacket to make sure reaction doesn’t surpass the 160 ºC or parallel reactions for nitrogen dioxide may start to appear contaminating the effluent.

4.1.7 Reactors volume and dimensions

Reactors effective volume (zone II) has not been calculated in function of the time of residence as normally. Since the reaction time is close to 0 volume is being calculated through the heat exchange surface needed to dispel the reactions energy. This energy is approximately 4618 kW and heating water through the cooling jacket to 65 ºC will require a mass flow of 99 329.33 kg H_2O per hour. Knowing the shape of the reactor and its area of exchange, the volume needed can be calculated.

The volume calculated is 31.8 m^3 of reaction zone. An additional 20% was added as a security factor in case pressure and heat could increase dramatically. For the mixture zones we are assuming a 30% of the reaction zone.

For the reaction zone a relation of 3:2 height-diameter is assumed with cylindrical shape. Mixture zones will have truncated cone shape where the largest diameter is equal to the cylinder diameter and the smaller one is assumed to be 1 m.

Reactor Zone	Application	Volume (m^3)	Diameter (m)	Height (m)
I	Cold mixture	9.54	3/0.75	0.77
II	Neutralization	31.8	3	4.5
III	Solution discharge	9.54	3/0.75	0.77

Table 11: reactor dimensions

With this values the overall volume of the reactor is calculated to be 50.88 m^3 and the total height is 6.04 m

4.1.8 Reactor tubes

The reactor used by the UHDE process is an up flow reactor similar to a heat exchanger with perforated tubes. Through this tubes ammonium nitrate mixture and produces circulates to the top of the reactor while ammonia is flowing outside of them reacting inside the wholes the tubes have.

Assuming 1s of time of residence, total volume of pipe needed can be calculated if volumetric flow is known and this equation can be used

$$N_t = \frac{V}{\frac{\pi\, D^2{}_{pipe}\; height}{4}}$$

With 1'' of diameter the reactor will have a total of 1947 tubes displayed in a square position with a pinch of 1.5''.

4.1.9 Construction Materials

Reactor will be constructed with 304 stainless steel due to the high corrosive materials we are using. Since the possibility to use sea water for the cooling jacket is open, the same steel will be used to construct it.

4.1.10 Couplings

Coupling	Nominal diameter (mm)
Coupling for the ammonia entrance	125
Coupling for the nitric acid entrance	60
Coupling for the ammonium nitrate recirculated entrance	15
Coupling for the ammonium nitrate produced exit	80
Coupling for the water entrance	150

Table 12: Reactors couplings

4.2 DESIGN OF MAIN PROCESS EQUIPMENT

In this chapter the results of the design calculations will be shown. For it, the mass and energy balance have been used as well as the main thermodynamic properties. All calculations are in appendix 6 and datasheets are in appendix 7

4.2.1 Storage

In this project, 3 main storage unit has been designed. For raw materials and for final product. An extra tank for safety reasons has been designed an introduced in the middle of the process.

Tank number	Product	Pressure (kPa)	Height (m)	Diameter (m)	Capacity (m3)	Weight (t)	Material
1	Ammonia	1050	-	6.53	1167.22	5.35	AISI 304L
2	Nitric acid	100	20.23	13.49	2893	45	AISI 304L
3	Ammoniu m nitrate	100	9.82	4.91	1185.73	2.89	AISI 304L

Table 13: Storage design results

4.2.2 Heat exchanger

HE Number	Functi on	Type	Heat flow (kW)	Products	Number of tubes
1	Heater	Shell& Tubes	85.51	Ammonia/ Flash vapour	119
2	Heater	Shell& Tubes	311.25	Nitric acid / Flash vapour	40
3	Heater	Shell& Tubes	62.87	Nitric acid / Evaporators vapour	5
4	Heater	Shell& Tubes	308.2	Nitric acid / @5bar steam	16
5	Cooling	Shell& Tubes	79.4	Vapour flash / Water	77
6	Cooling	Shell& Tubes	9	Evaporators vapour	3
7	Heater	Shell& Tubes	850	Air / @5 bar steam	60

Table 14: heat exchanger design results

4.2.3 Mass and energy simultaneously transfer equipment

Different equipment used to concentrate, dry and cool in the production process

4.2.3.1 Flash evaporator FE-1

This equipment uses the pressure reduction of a fluid to evaporate the most volatile components of it. The feed, effluent from the reactor R-1, has two phases: one is rich in water and the other is rich in ammonium nitrate. It operates at 45 kPa and 120 ºC, reducing both temperature and pressure, helping the separation without the need of extra heat.

It is composed of a vapour area and liquid area. The first one is 3.04 m height and the second one 3.22, making a total of 6.26 meter height of column. Its diameter is 1.86 making a relation h/D of 3.35 approx.

4.2.3.2 Evaporator E-1

This unit function is to concentrate ammonium nitrate solution from 93 to 96.4% and make it ready to granulate. To make it, 5 bar water steam circulates throught the pipes to heat the solution. Unit operates at 150 ºC and 100kPa. With 0.8 m as total diameter and 2.42 height meters it generates 320 kW heat for the solution concentration.

The design also has an internal tube to facilitate natural convection in the inside of the reactor of 0.16 m.

4.2.3.3 Rotatory dryer D-1

It will dry the ammonium nitrate granules to a 0.1% moisture. Hot air from the cooler but preheated at 150 ºC will flow in counter current to do it. The drum will have a 4.8 m diameter and 9.6 m large. Power needed to make the drum work I 13.75 Horsepower

4.2.3.4 Rotatory cooler

A unit designed to cool the dried and screened ammonium nitrate granules. Air at atmosphere conditions will be used to cool the product through a 4.8 and 9.6 meter of diameter and length respectively. 13.75 Horsepower are used to power the equipmente.

4.2.4 Mixing equipment

In this project, two liquid-solid mixers are used, the pugmill granulator and the coating drum.

4.2.4.1 Granulator

The granulator equipment is formed by two parts, a pugmill mixer with a cooling jacket, that will be in charge of cooling the ammonium nitrate below fusion point, forming an intimate agglomeration with the limestone dust that is feed into the pugmill as well. The design standards are taken from FEECO International, for the feed mas flow a 4 meter diameter and 12 meter length pugmill is used.

Paddles are distributed on two rotating axes that goes through the mixer length. Each axe has 4 paddle with 90º separation between each other centre. They are distributed like a helical screw so the mass is forced to advance through the mixer. More or less, 40 paddles are distributed in each meter length

Cooling jacket of 3.72 m length is used for the bottom half of the pugmill

Finally, the mass agglomeration is cut into 1.5 mm of diameter balls

Graph 8: A mixer container plus granulator pipes.

4.2.4.2 Coating drum

Coating drum is used to apply a really thin layer of an external product to help it resists the packaging, transport, store and use of the final product. It is applied with a sprinkler at the entrance of the drum, in liquid form at 45, but it dries and get solid at 30ºC at the granules surface itself.

The drum will have a 2.67 m diameter and a total length of 10.5 m and will use 11 Horsepower to spin the drum.

4.2.5 Pumps

This equipment has the function to pump different fluids during the process, specially to surpass heights since the plant is designed to use gravity to move the fluids.

Pump Number	Type	Product	Flow (kg/h)	Power (HP)
1A	Centrifugal pump	Nitric acid	4168.6	5.98
1B	Centrifugal pump	Nitric acid	4168.6	5.98
2A	Centrifugal pump	Ammonium nitrate	1107.85	0.15
2B	Centrifugal pump	Ammonium nitrate	1107.85	0.15
3A	Centrifugal pump	Ammonium nitrate	21049.23	5.73
3B	Centrifugal pump	Ammonium nitrate	21049.23	5.73

Table 15: Value and composition of stream entering/leaving reactor

Every pump is duplicated in a parallel pipe in case any problem could occur with the pump, the production didn't stop.

4.2.6 Fans

Fan Number	Product	Flow (kg/h)	Power
1	Air	80445.63	30.7
2	Air	80445.63	30.7

Table 16: Value and composition of stream entering/leaving reactor

This equipment is a powered machine used to create flow within a fluid, in this case the air used to cool and dry. There are two fans, before cooling operation and before drying operation.

4.3 INSTRUMENTATION AND CONTROL

Industrial process demands an exhaustive control on the products used and produced, and on the unit operations used during the process. Operations are really diverse and there are parameters like pressure, flow or temperature that must be controlled.

Control systems can be defined as systems that can control variables comparing its value or condition with the predefined status and take an action depending on the deviations calculated. They are done automatically, so no human intervention should be required to adjust the process variables.

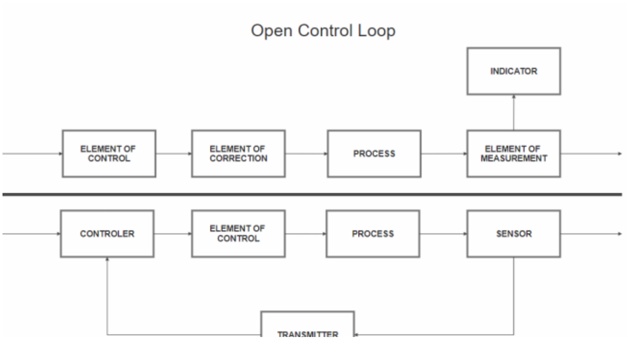
It way of work depend on the control loop defined. There are two types:

Open control loop is a type of continuous control system in which the output has no influence or effect on the control action of the input signal.

Closed control loop is a set of mechanical or electronic devices that automatically regulates a process variable to a desired state or set point without human interaction.

4.3.1 Control loop elements

Control loops have an indeterminate number of elements depending on how many variables are to measure and how to do it, but generally there are only four types of elements.



Graph 9: Types of control loops

4.3.1.1 Sensors

Those elements detect changes on the controlled variable value. The better the change is detected and the response sent, the better the measurement and control will be done.

4.3.1.2 Transmitters

As its name says, those elements are in charge to transmit the value of the controlled variable to the controller or any other receiving element.

4.3.1.3 Controllers

The main thinkers on the control loop. They compare the value of the input value to the set point, calculate a deviation and send an output to the element of control in order to adjust values.

4.3.1.4 Control elements

The final element of the loop used to perform a change on the controlled variable. Control valves will be used in this project

4.3.2 Control Loops designation

Control loops designation have been done following the ANSI/ISA-5.1-1984(R1992) summarized in the following table.

Table 1 — Identification Letters

	FIRST-LETTER (4)		SUCCEEDING-LETTERS (3)		
	MEASURED OR INITIATING VARIABLE	MODIFIER	READOUT OR PASSIVE FUNCTION	OUTPUT FUNCTION	MODIFIER
A	Analysis (5,19)		Alarm		
B	Burner, Combustion		User's Choice (1)	User's Choice (1)	User's Choice (1)
C	User's Choice (1)			Control (13)	
D	User's Choice (1)	Differential (4)			
E	Voltage		Sensor (Primary Element)		
F	Flow Rate	Ratio (Fraction) (4)			
G	User's Choice (1)		Glass, Viewing Device (9)		
H	Hand				High (7, 15, 16)
I	Current (Electrical)		Indicate (10)		
J	Power	Scan (7)			
K	Time, Time Schedule	Time Rate of Change (4, 21)		Control Station (22)	
L	Level		Light (11)		Low (7, 15, 16)
M	User's Choice (1)	Momentary (4)			Middle, Intermediate (7,15)
N	User's Choice (1)		User's Choice (1)	User's Choice (1)	User's Choice (1)
O	User's Choice (1)		Orifice, Restriction		
P	Pressure, Vacuum		Point (Test) Connection		
Q	Quantity	Integrate, Totalize (4)			
R	Radiation		Record (17)		
S	Speed, Frequency	Safety (8)		Switch (13)	
T	Temperature			Transmit (18)	
U	Multivariable (6)		Multifunction (12)	Multifunction (12)	Multifunction (12)
V	Vibration, Mechanical Analysis (19)			Valve, Damper, Louver (13)	
W	Weight, Force		Well		
X	Unclassified (2)	X Axis	Unclassified (2)	Unclassified (2)	Unclassified (2)
Y	Event, State or Presence (20)	Y Axis		Relay, Compute, Convert (13, 14, 18)	
Z	Position, Dimension	Z Axis		Driver, Actuator, Unclassified Final Control Element	

NOTE: Numbers in parentheses refer to specific explanatory notes in Section 5.1.

ANSI/ISA-S5.1-1984 (R 1992) 21

Graph 10: ANSI/ISA-5.1-1984(R1992)Normative

According to this table, first letter is used to refer the instrument of control, and second letter to the equipment involved. First number assigned refers to the unit on the plant. Second number to the loop number.

Description	Denomination
LT	Level transmitter
FT	Flow transmitter
TT	Temperature transmitter
PT	Pressure transmitter
LSL	Low sensor level
LSH	high sensor level

Description	Denomination
TI	Temperature indicator
PI	Pressure indicator

Description	Denomination
LAL	Low level alarm
LAH	High level alarm
TAH	High temperature alarm
FAH	High flow alarm
PAL	Low pressure alarm
PAH	High pressure alarm

Description	Denomination
LC	Level controller
FC	Flow controller
TC	Temperature controller
PC	Pressure controller

Description	Name
T	Tank
P	Pump
E	Evaporator
FE	Flash Evaporator
R	Reactor
HE	Heat exchanger
D	Dryer
C	Cooler

Table 17: Letter designations for p&ID diagrams

4.3.3 Process control loops and P&ID

4.3.3.1 Height level control on tanks T-2 and T-3

The objective of this loop is to maintain the height level of T-2 and T-3 between two values. The lowest security height value that can be accepted and the highest one. In this case, two sensors will be used, one for each value. The low sensor level will be called (LSL) and the high rank one will be called (LSH), and both will send a signal to the level controller (LC). Control elements will be automatic valves. If LSH is activated, the valve in the tanks feed will close to prevent level from increasing above the maximum. If LSL is activated discharge valve will be closed.

Additionally, as extra security, a level transmitter (LT) will send a signal to a high level alarm (LAH) or low level alarm (LAL) that will be activated in case that sensors fail and will act into the automatic valves.

Since the P&ID are the same only T-2 will be shown

4.3.3.2 Pressure control on ammonia tank T-1

The objective is to maintain pressure on T-1 constant and stable. In this tank there is a pressure transmitter (PT) that send a sign to two alarms in case that high or low limit are surpassed. It is also connected to a pressure controller (PC) that send a sign to two automatic valves. If high pressure is detected the feed valve is closed

4.3.3.3 Temperature control on reactor and evaporator

The objective is to control temperature on R-1 and E-1 to maintain it on set point. Both control loops are made with a cascade loop, where two variables are measured but only one is controlled. In the reactor (for example), temperature inside the shell and cooling water temperature are measured (TT1) and (TT2). Each measure is sent into a temperature controller (TC) that acts into an automatic valve in the cooling system.

Since both P&ID are the same only reactors one will be shown.

4.3.3.4 Pressure control on reactor, evaporator and flash evaporator

The objective is to control pressure and maintain it stable at set point. To do it, a pressure transmitter (PT) measures pressure inside the equipment and send a sign to a pressure controller (PC). The controller acts opening or closing a control valve on the vapours exit, reducing or increasing the pressure.

Since reactor, evaporator and flash evaporator have the same P&ID only the reactors one will be shown.

4.3.3.5 Temperature and flow control on heat exchangers

Control loops is made of a temperature transmitter (TT) that measures outer temperature of fluid of interest (nitric acid, for example) and a flow transmitter (FT) that measures flow of the fluid to exchange (water in nitric acids example). Those signs are send to the flow controller (FC) that will open or close the valve in the exchanger entrance (water entrance in this example) regulating heat exchange between fluids

Since all HE P&ID are the same only the one from HE-1 will be shown.

4.3.3.6 Temperature control on dryer

This is the most complex control loop in the process. Granule temperature is an indicator of the solids moisture. It's made of a transmitter temperature (TT) that measures the exit granules temperature. It is connected with two alarms, (TAH) and (TAL). The transmitter temperature is send to a temperature controller (TC) that acts to an automatic valve that will regularize the heat exchanger HE-7, reducing or increasing the air temperature at the dryer entrance.

4.3.3.7 Control of pump flow

The objective of this loop is to control pump flow of all pump. A level transmitter in the tanks before send signals to a level controller. If tank level is below the minimum, an automatic valve before the pump closes so the tank can increase the level. The pump does receive and order to shut down if this happens. In case the level gets restored, the valve will open and the pump turn on again.

4.3.4 Industrial Services

Several industrial services were considerate. Vapour generation, water treatment, refrigeration water, compressed air generation and power consumption. No design of this equipment will be done since they will be selected from preliminary data.

4.3.4.1 Refrigeration water

In this process cooling water is used in the reactor and in the granulator. 99 329 kg/h of water are introduced in the reactors cooling jacket at 25 ºC and leaves at 65 ºC absorbing 16 621 109 kJ/h, then is introduced into the granulator cooling jacket and is heated into 72.77 ºC absorbing 3 228 971 kJ/h.

So a cooling tower to remove 5514 kW are needed. VENTUM Modupol 3100/09 is selected.

4.3.4.2 Vapour generation

Vapour is used as heater exchanger 4 and 7, and additionally it is used to produce vacuum on the flash evaporator. 1674 kg/h of water steam at 5bar is used on heat exchangers and an approximation of 200 kg/h are used on flash evaporator.

1874 kg of steam per hour will be produced in an ATTSU HH 2000 boiler.

4.3.4.3 Compressed air

From other works compressed in the bibliography, an estimated 3.8l/min at 600/700 kPa of compressed air will be needed for this amount of automatic valves. An air compressor Atlas Copco model LF 3-10

4.4 SAFETY, INDUSTRIAL HYGIENE AND ENVIRONMENT

Main laws affecting the project preamble have been summarized.

Ley 21/2013, de 9 de diciembre, de evaluación ambiental.

Environmental assessment is indispensable for the protection of the environment. It facilitates the incorporation of the sustainability criteria in the strategic decision making, through the evaluation of the plans and programs. And through the evaluation of projects, ensures adequate prevention of the specific environmental impacts that can be generated, while establishing effective mechanisms of correction or compensation.

Ley 26/2007, de 23 de octubre, sobre la responsabilidad medioambiental.

It responds to Directive 2004/35/EC of the European Parliament and of the Council, of 21 April 2004, on environmental responsibility in relation to the prevention and reparation of environmental damages, that this law transposes, incorporating to our order Legal an administrative regime of environmental responsibility of an objective and unlimited nature based on the principles of prevention and that "polluter pays". It is, in fact, an administrative regime to the extent that it establishes a whole set of administrative powers with which the public administration must ensure compliance with the law and the application of the liability regime that it incorporates. It thus separates from the classical civil responsibility in which the conflicts between the causer of the damage and the injured one are settled in judicial seat.

Ley 42/2007, Del 13 de diciembre, sobre el patrimonio natural y la biodiversidad.

The law establishes that the competent administrations will ensure that the management of natural resources is produced with the greatest benefits for the present generation, without diminishing its potentiality to satisfy the needs and aspirations of the Future generations, ensuring the maintenance and conservation of heritage, biodiversity and natural resources existing throughout the country, irrespective of their ownership or legal regime, taking into account their orderly use and to the restoration of its renewable resources. The principles that inspire this Law focus, from the perspective of the consideration of the natural heritage itself, in the maintenance of essential ecological processes and basic vital systems, in the preservation of biological diversity, genetic, populations and species, and the preservation of the variety, uniqueness and beauty of natural ecosystems, geological diversity and landscape.

Ley 9/2014, del 31 de junio, sobre la seguridad industrial en establecimientos, instalaciones y productos.

This intervention by the public administration in industrial safety has been carried out mainly in two areas: on the one hand, establishing compulsory technical specifications for establishments, installations and products through the so-called industrial safety regulations and, on the other hand, regulating an industrial safety management system involving group of private agents whose activity is subject to certain prescriptions, conditions and limitations because it affects security.

Real Decreto Legislativo 1/2016, de 16 de diciembre, Ley de prevención y control integrados de la contaminación.

In order to make effective the prevention and integrated control of pollution, European regulations made the implementation of the facilities included in its scope subject to obtaining a written permit, which must be granted in a coordinated manner when several procedures are involved in the procedure. competent authorities. This permit sets the environmental conditions that are required for the operation of the facilities and, among other aspects, specify the emission limit values for polluting substances, which will be based on the best available techniques and taking into consideration the technical characteristics of the installation, its geographical implantation and the local conditions of the environment. To this end, and to facilitate the application of the above measures, the Directive established a system of exchange of information between the European Commission and the Member States on the main polluting emissions and the sources responsible for them, as well as on the best techniques available

Ley 31/1995, de 8 de noviembre, de prevención de Riesgos Laborales.

From the recognition of the right of workers in the workplace to the protection of their health and integrity, the Law establishes the various obligations that, in the indicated area, will guarantee this right, as well as the actions of public administrations that may affect positively in achieving that objective.

When this Law is inserted in the specific field of labour relations, it is configured as a minimum legal reference in a double sense: the first, as a law that establishes a legal framework from which the regulatory standards will fix and specify the most technical aspects of preventive measures; and, the second, as a basic support from which collective bargaining can develop its specific function. In this regard, the Law and its regulatory standards constitute labour legislation, in accordance with article 149.1. 7.ª of the Constitution.

Order of March 9, 1971, approving the General Ordinance on Safety and Hygiene at Work.

The provisions of this Ordinance will adjust the minimum mandatory protection of persons included in the scope of the Social Security System, in order to prevent accidents and occupational diseases and to achieve the best conditions of hygiene and well-being in the centres and posts of work in which said people develop their activities.

Real Decreto 506/2013, de 28 de junio, sobre productos fertilizantes.

This royal decree aims to establish the basic regulations on fertilizer products and the necessary rules of coordination with the autonomous communities. The purposes of this royal decree are:

a) Regulate the aspects of Regulation (EC) No. 2003/2003 of the European Parliament and of the Council of 13 October 2003, concerning fertilizers, whose implementation and development have been entrusted to the Member States.

b) Define and classify fertilizer products, other than "EC fertilizers", that can be used in agriculture and gardening.

c) Guarantee that the nutritional riches and other characteristics of the fertilizer products are adjusted to the requirements of this royal decree.

d) Prevent risks to health and the environment through the use of certain products.

e) Regulate the registration of fertilizer products for the registration of certain products. LEGISLACIÓN CONSOLIDADA DEL BOLETIN OFICIAL DEL ESTADO Page 5

f) Update the procedure for registration in the Register of fertilizer products, prior to the placing on the market of certain products.

g) Establish the procedure for updating the annexes of this royal decree.

Ley 4/2007, de 8 de marzo, de Evaluación Ambiental en Castilla-La Mancha.

The purpose of this law is to establish the regulation of the Environmental Impact Assessment of Projects and the Environmental Evaluation of Plans and Programs, public or private, in order to prevent, avoid or lessen their negative effects on the environment, and allow to the administrative body that has to authorize the knowledge of their environmental repercussions.

The Environmental Evaluation of Plans and Programs aims to promote sustainable development, achieve a high level of protection of the environment and contribute to a better environmental integration of the preparation and adoption of plans and programs that are carried out in Castilla-La Mancha and that they can have significant effects on the environment, thus establishing a coordination channel between the environmental administration and the administrations responsible for the planning and execution of the different sectoral policies.

5. ECONOMIC EVALUATION

Any engineering project can't be done or have any utility if it's not economically viable. In this chapter the viability of a calcium ammonium nitrate production plant will be analysed. All calculations are detailed in the appendix 8.

5.1 TOTAL FIXED INVESTMENT

Needed capital for the project execution, estimated in 42 235 415 €. It is composed by total fixed capital and total working capital

5.2 ECONOMIC ANALYSIS

Cost of CAN manufacture is 54 042 070 € assuming 100% of plant capacity implementation. 1 year of implementation and 10 years of economic life for this project will be assumed.

5.2.1 Global economic balance

CAN sale price has been fixed in 0.35 €/kg, making a raw profit of 7 557 930 euros without taxes and assuming 100% of design capacity. Once standard 30% taxes have been applied 5 290 551 € are the net profit the plant would produce. It's been supposed that all raw materials are imported.

5.2.2 Economic profitability

Economic profitability is 9.79% and has been calculated using the following data

FIXED CAPITAL		
Direct costs		
Detail		**Cost (€)**
Equipment purchase	35.0%	7 225 013
Equipment installation	8.0%	1 651 432
Instrumentation	4.0%	825 716
Pipes	8.0%	1 651 432
Electric installation	4.0%	825 716
Buildings and structures	10.0%	2 064 289
Ground	4.0%	825 716
Auxiliary equipment of the process	10.0%	2 064 289
Total direct cost		17 133 602
Indirect costs		
Design&Engineering	10.0%	2 064 289
Contractors payments	2.0%	412 858
Construction expenses	5.0%	1 032 145
Total indirect cost		3 509 292
TOTAL		**24 771 473**
WORKING CAPITAL		
Raw material inventory		3 596 502
Product inventory		4 295 462.58
InProcess materials		143 182.09
Receivable		5 133 333.33
Cash available		4 295 462.58
TOTAL		17 463 943
TOTAL		**42 235 415.26**

MANUFACTURING COST	
Direct manufacturing cost	
Raw material	43 158 026
Workforce cost	1 020 600
Industrial services	4 315 803
Maintenance	342 672
Supervision	122 472
Miscellaneous materials	34 267
Total direct cost	48 993 840
Indirect manufacturing cost	
Depreciation	1 713 360
Insurance	247 715
Taxes	247 715
General expenses	342 922
Total indirect cost	2 551 711
TOTAL MANUFACTURING COST	**51 545 551**
GENERAL COSTS	
Administrative expenses	153 090.00
Selling expenses	1 232 000.00
Financial expenses	495 429.45
I+D	616 000.00
TOTAL	**2 496 519.45**
TOTAL	**54 042 070.37**

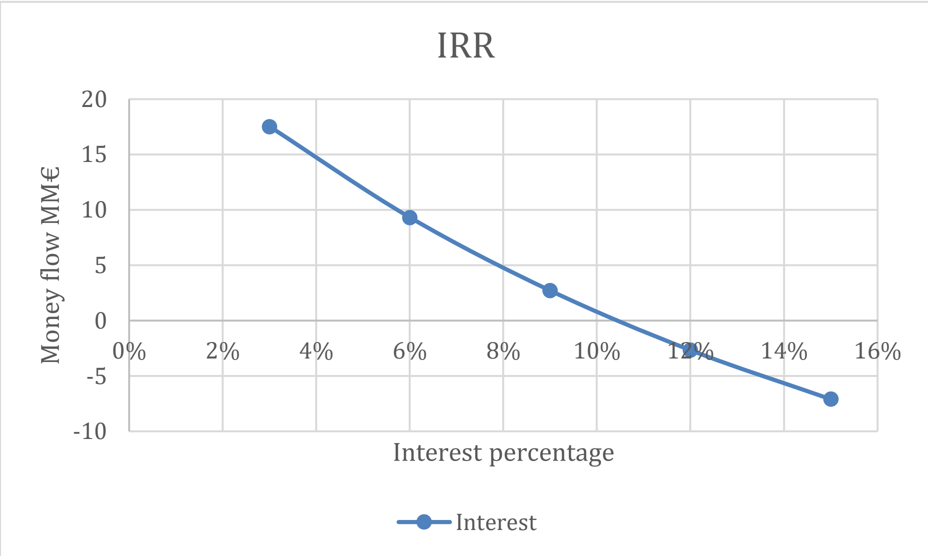
Table 18: Fixed capital, Working capital, Manufacturing cost and General costs estimation

5.2.3 Pay out time

Time to recover the capital of this project is estimated in 3.5 years assuming the plant operates at 100% capacity

5.2.4 IRR

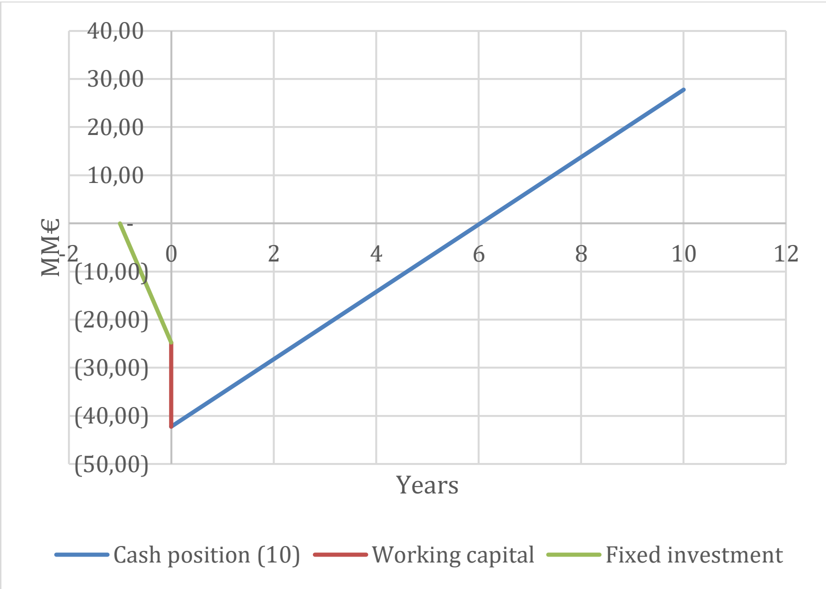
As the graph confirms, 10.44% rate effective interest is the maximum we can expect to pay, in order to return the money within the 10 years of economic life.



Graph 11: Internal rate of return

5.2.5 Cash position

Indicates the time when debts are paid and profits start to show up.



6. CONCLUSIONS

After doing all this project, the conclusions are the following.

- It Is no viable to build an ammonium nitrate production plant in Spain. Pure ammonium nitrate has too many restrictions to be a solid product to be sold or used. It's also not a good idea because Spain produces more calcium ammonium nitrate, the substitute of pure ammonium nitrate, that what it consumes, making the country one of the biggest exporters in Europe.
- UHDE process seems to be by far the simplest, making it a good choose for a production plant. It can also be improved via a pinch analysis and save up to a 70% of heat exchangers energy.
- Design can be simple enough so no especial requirements are made. Industrial services are not so high and there are not many legal restrictions for producing CAN.
- Economically, the plant is viable having an almost 10% of profitability.

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ACRONYMS

A:Heat transfer area (m)

Q: Total heat transferred (kJ/h)

U: Heat transfer global coefficient (W/m^2 ºC)

ΔT_{LMTD}: Logarithmic mean temperature difference

P_D: Design pressure

P_{op}: Operational pressure, 100

P_h: Hydrostatic pressure

E_w: Thickness of the wall

P_D: Design pressure (N/mm^2)

D_i: Internal diameter (mm)

E: Welding factor

S: Elastic limit,

Ec: Thickness of the wall by corrosion

Q: Volumetric flow (m^3/s)

Ac: Cross sectional Area (m^2)

v: Velocity

V: Design Volume (m^3)

M: Consumption (kg/h)

Θ: Storage time (d)

P: Density (kg/m^3)

g: gravity acceleration (m/s^2)

h: Liquid height

$T_{1,2}$: Hot fluid entrance and exit temperature

$t_{1,2}$: Cold fluid entrance and exit temperature

Do: Outer diameter (m)

Di: Inner diameter (m)

R_t: Tube side soiling

R_s: Shell side soiling

$H_{c,t}$: Tube side convection heat transfer coefficient (W/m^2.ºC)

$H_{c,s}$: Shell side convection heat transfer coefficient (W/m^2.ºC)

K: Material thermic conductivity,

G: Mass flux (kg/m^2.s)

M: Mass flow (kg/s)

Atcsa: Tube cross sectional Area (m^2)

Nt: Tube numbers

Pr: Prandlt number

K: Conductivity (w/m.K)

l_b: Baffle spacing,

Dp: Pitch diameter

Re: Reynolds number

D_e: Equivalent diameter (m)

μ: Vapour viscosity (kg/m.s)

$\rho_{G:}$ Gas density

$\rho_{L:}$ Liquid density

K: Constant of separation

liquid retention volume (m^3)

Q_l: Volumetrically liquid flow at operational conditions (m^3/s)

Tr: Residence time

N_f: Number of fins

P: Engine Power (Hp)

D: Dryer diameter (m)

L: dryer length (m)

η: Engine efficiency

B: Prassure at the exit of the sprinkle

A: Requiered area (m^2)

T: Mass flow (t/h)

C: Empiric capacity

Q_1: Correction factor for material density

Q_2: Correction factor for net shape

Q_3: Correction factor for particle shape (1 for spherical particle)

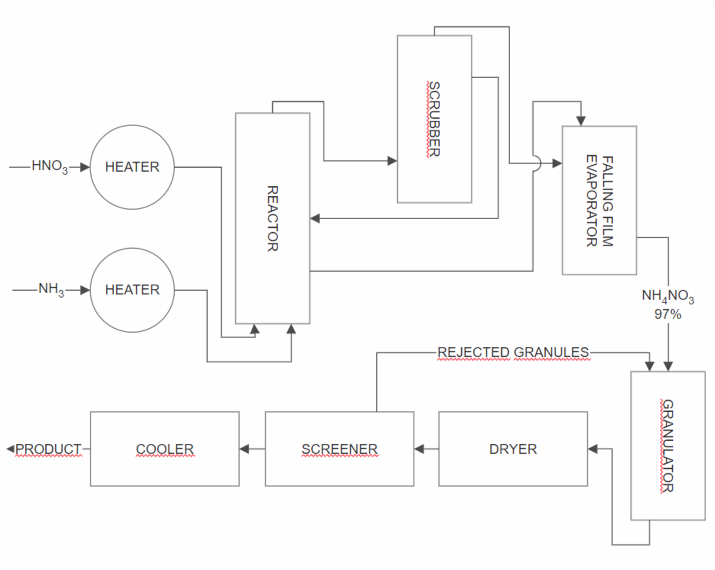
Q_4: Correction factor for open area

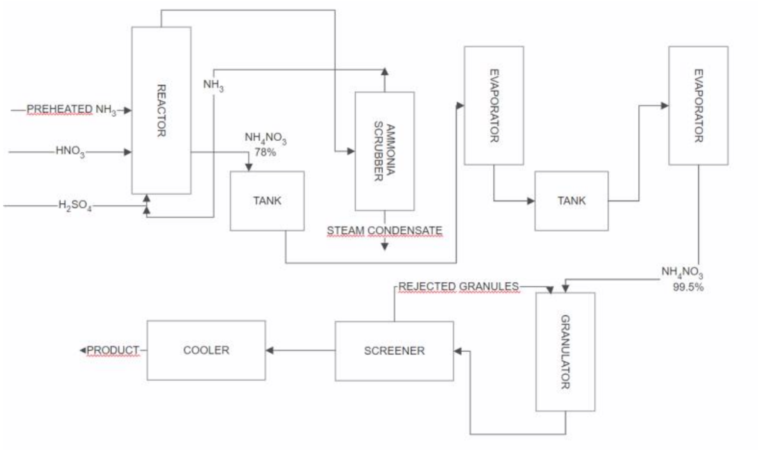
Q_5: Correction factor for moisture screening (1 for dry screening)

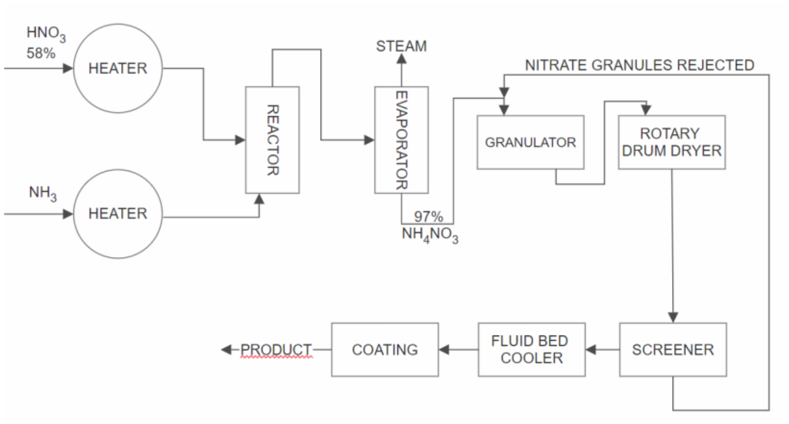
Q_6: Correction factor for material moisture (1 for dried material)

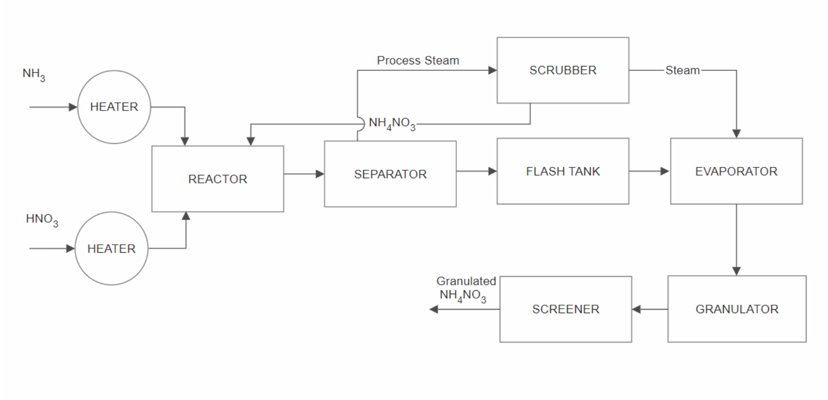
APPENDICES

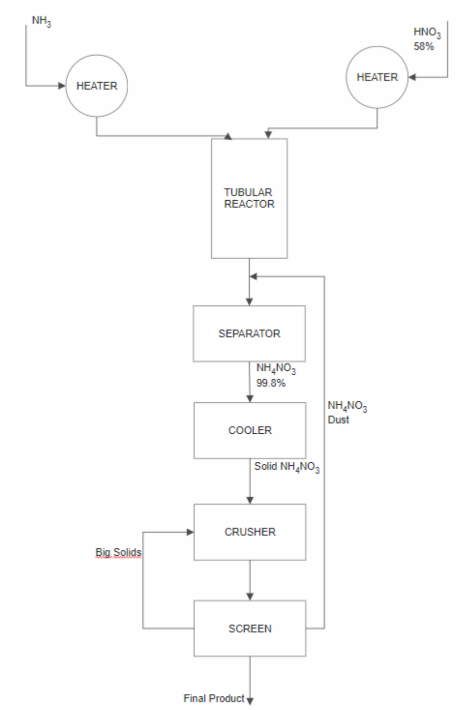
APPENDIX 1: PROCESSES DIAGRAM




PREHEATED NH3
HNO3
H2SO4
REACTOR
NH3
NH4NO3 78%
TANK
AMMONIA SCRUBBER
STEAM CONDENSATE
EVAPORATOR
TANK
EVAPORATOR
NH4NO3 99.5%
REJECTED GRANULES
GRANULATOR
SCREENER
COOLER
PRODUCT


HNO3 58%
HEATER
NH3
HEATER
REACTOR
STEAM
EVAPORATOR
97% NH4NO3
NITRATE GRANULES REJECTED
GRANULATOR
ROTARY DRUM DRYER
SCREENER
FLUID BED COOLER
COATING
PRODUCT

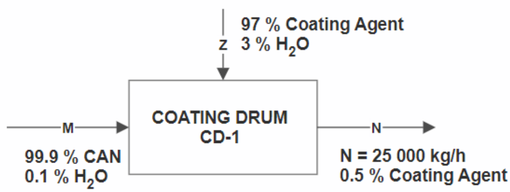

NH3
HEATER
HNO3
HEATER
REACTOR
Process Steam
NH4NO3
SEPARATOR
SCRUBBER
Steam
FLASH TANK
EVAPORATOR
GRANULATOR
SCREENER
Granulated NH4NO3


NH3
HEATER
HNO3 58%
HEATER
TUBULAR REACTOR
SEPARATOR
NH4NO3 99.8%
COOLER
NH4NO3 Dust
Solid NH4NO3
CRUSHER
Big Solids
SCREEN
Final Product

APPENDIX 2: MASS BALANCE

a) Mass Balance on Coating Drum CD-1

Mass of Coating Agent needed for final product is determined. We know from the patent that the optimal use of CoAg is 0.25-0.5% of product weight. We took maximum.



- CoAg Mass Balance

$$0.97\ Z = 0.005\ x\ 25\ 000$$
$$Z = 128.87\ kg/h$$

- Global Mass Balance

$$M + Z = N$$
$$M = 24\ 871.13\ kg/h$$

- CAN Mass Balance

$$0.999\ M = N_{CAN}\ x\ 25\ 000$$
$$N_{CAN} = 0.9940$$

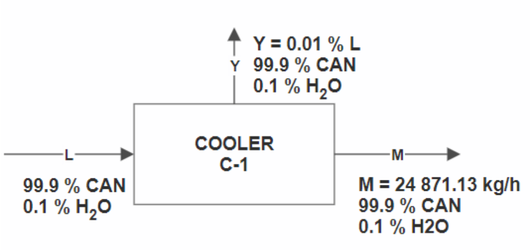
- Water Mass Balance

$$0.001\ M + 0.003\ Z = N_{H_2O}\ x\ 25\ 000$$
$$N_{H_2O} = 0.001$$

Stream	Flow (kg/h)	CAN (kg/h)	H_2O (kg/h)	CoAg (kg/h)
M	24 871.13	24 846.26	24.87	-
Z	128.87	-	3.87	125.00
N	25 000.00	24 850.00	25.00	125.00

b) Mass Balance on Cooler C-1

It's considered that the air stream "Y" drags 0.01% of dust material from "L"



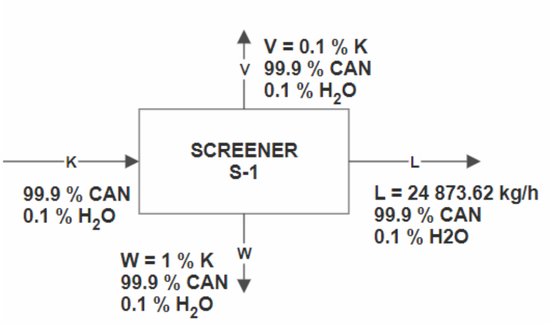
❖ Global Mass Balance

$$L = Y + M = 0.0001\,L + 24\,871.13$$
$$L = 24\,873.62\ kg/h$$
$$Y = 0.0001\,L = 2.49\ kg/h$$

Stream	Flow (kg/h)	CAN (kg/h)	H_2O (kg/h)
L	24 873.62	24 848.75	24.87
Y	2.49	2.49	0.00
M	24 871.13	24 846.26	24.87

c) Mass Balance on Screener S-1

In this operation, 0.1% of initial flow recirculate as fine dust, and 1% as thick rocks.



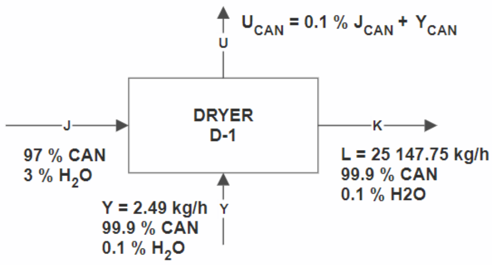
❖ Global Mass Balance

$$K = V + W + L = 0.001\,L + 0.01\,L + 24\,873.62$$
$$K = 25\,150.27\ kg/h$$
$$V = 0.001\,K = 25.15\ kg/h$$
$$W = 0.01\,K = 251.50\ kg/h$$

Stream	Flow (kg/h)	CAN (kg/h)	H_2O (kg/h)
K	25 150.27	25 125.12	25.15
W	251.50	251.25	0.25
V	25.15	25.12	0.03
L	24 873.62	24 848.75	24.87

d) Mass Balance on Dryer D-1

In this case it is assumed that air stream "U" will drag 0.1% of containing CAN on "J" stream. We also assume that there are no loses on stream "Y". Of all the water dragged in air stream "U", only 5% of CAN dust mass will be considered moisture of the same. The rest of water will be neglected in the mass balance calculations.



- CAN Mass Balance

$$0.97\,J = 0.001\,x\,0.97\,J + 0.999\,x\,25\,147.75$$
$$J = 25\,925.55\,kg/h$$
$$U_{CAN} = 0.001\,J_{CAN} + 2.48 = 25.15\,kg/h$$

- Global Mass Balance

$$J + Y = U + K$$
$$U = 777.77\,kg/h$$

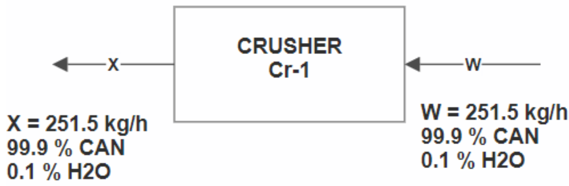
Even though water mass dragged from stream “J” is 752.62 kg/h, we will assume that most of it will become air moisture, so for our calculations, the water mass associated with the CAN will be 5% of 25.15 kg/h.

For the cyclones design all water contained will be considerate

Stream	Flow (kg/h)	CAN (kg/h)	H_2O (kg/h)
J	25 925.55	25 147.78	777.77
U	26.41	25.15	1.26
Y	2.49	2.49	0.00
K	25 150.27	25 125.12	25.15

e) Mass Balance on Crusher Cr-1

This operation does not affect the mass balance



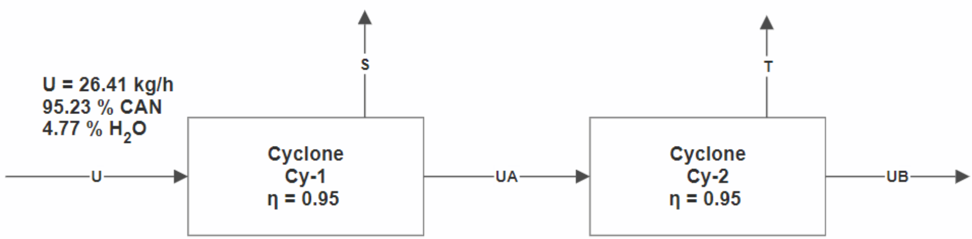
❖ Global Mass Balance

$$X = W = 251.5\ kg/h$$

Stream	Flow (kg/h)	CAN (kg/h)	H_2O (kg/h)
W	251.50	251.25	0.25
X	251.50	251.25	0.25

f) Mass Balance on Cyclones Cy-1,2

We assume an efficiency of 95% on each cyclone. As we considered that the water in this calculations is the CANs moisture, and that all dust is mostly the same size, concentrations can be looked at the same.



❖ Global Mass Balance

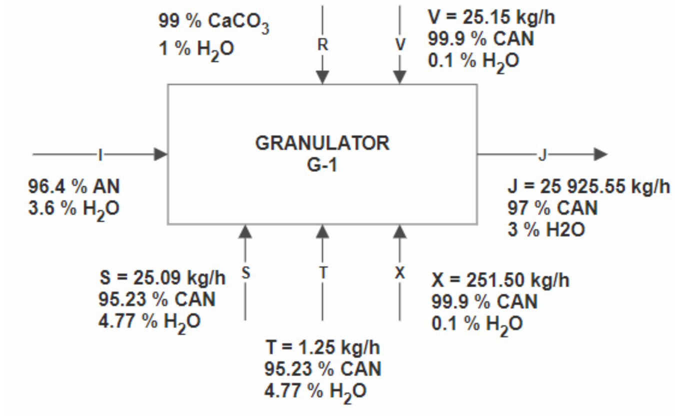
$$U = S + UA$$
$$S = 0.95\ U = 25.09\ kg/h$$
$$UA = 1.32\ kg/h$$

$$UA = T + UB$$
$$T = 0.95\ UA = 1.25\ kg/h$$
$$UB = 0.066\ kg/h$$

Stream	Flow (kg/h)	CAN (kg/h)	H_2O (kg/h)
U	26.41	25.15	1.26
S	25.09	23.89	1.20
UA	1.32	1.26	0.06
T	1.25	1.19	0.06
UB	0.07	0.06	0.00

g) Mass Balance on Granulator G-1

This is the operation that makes CAN. It means that now we have 2 more compounds in our balance, Ammonium Nitrate (AN) and Calcium Carbonate or Limestone. It's important to emphasize that our CAN has to be made out of 78% AN and 22% Limestone to achieve the N% needed in our final product.



- $CaCO_3$ Mass Balance

$$0.22\ x\ 0.97\ J = 0.22\ x\ 0.999\ (X + V) + 0.78\ x\ 0.9523\ (S + T) + 0.99\ R$$
$$R = 5\ 518.80\ kg/h$$

- Global Mass Balance

$$J = I + R + V + X + S + T$$
$$I = 20\ 103.76\ kg/h$$

- AN Mass Balance

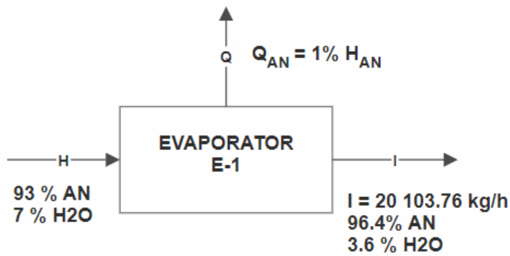
$$0.78\ x\ 0.97\ J = 0.78\ x\ 0.999\ (X + V) + 0.78\ x\ 0.9523\ (S + T) + \frac{\%I_{AN}\ I}{100}$$
$$\%I_{AN} = 96.4$$

Stream	Flow (kg/h)	CAN (kg/h)	H_2O (kg/h)	AN (kg/h)*	$CaCO_3$ (kg/h)*
I	20 103.76	-	721.74	19 380.13	-
R	5518.80	-	54.50	-	5466.19
V	25.15	25.12	0.03	19.60	5.53
S	25.09	23.89	1.20	18.64	5.26
T	1.25	1.19	0.06	0.93	0.26
X	251.50	251.25	0.25	195.97	55.27
J	25 925.55	25 147.78	777.77	19 615.27	5532.51

*It should be noticed that in R,V,S,T,X,J those columns are the product of the composition of CAN and they should not be counted in a "Total" sum

h) Mass Balance on Evaporator E-1

In this operation we know that in stream "Q" we drag 1% of the AN from "H".



❖ AN Mass Balance

$$0.93\ H = 0.01\ x\ 0.93\ H + 0.97\ x\ 20\ 103.76$$
$$H = 20\ 103.76\ kg/h$$

❖ Global Mass Balance

$$H = I + Q$$
$$Q = 945.47\ kg/h$$

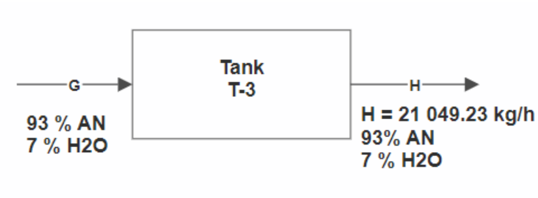
Applying the 1% drag

$$Q_{AN} = 0.01\ x\ 0.93\ H = 195.76\ kg/h$$

Stream	Flow (kg/h)	AN (kg/h)	H_2O (kg/h)
H	21 049.23	19 575.78	1 473.45
Q	945.47	195.76	749.71
I	20 103.76	19 380.02	723.74

i) Mass Balance on Tank T-3

This operation does not affect our mass balance



- Global Mass Balance

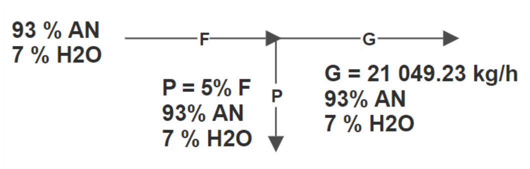
$$H = G$$

$$G = 21\ 049.23\ kg/h$$

Stream	Flow (kg/h)	CAN (kg/h)	H_2O (kg/h)
G	21 049.23	19 575.78	1 473.45
H	21 049.23	19 575.78	1 473.45

j) Mass Balance on Separator Node

We return to the reactor 1kg of every 20. That means a 5%.



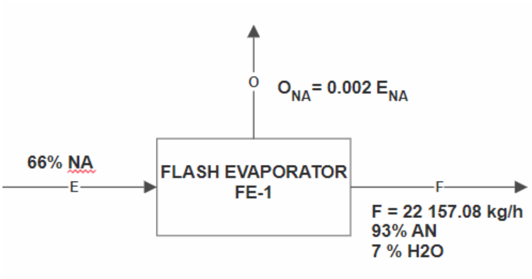
❖ Global Mass Balance

$$F = G + P = 21\,049.23 + 0.05\,F$$
$$F = 22\,157.08\;kg/h$$
$$P = 1107.85\;kg/h$$

Stream	Flow (kg/h)	AN (kg/h)	H_2O (kg/h)
F	22 157.08	20 606.08	1 551.00
P	1107.85	1030.30	77.55
G	21 049.23	19 575.78	1 473.45

k) Mass Balance on Flash Evaporator FE-1

In this operation we will solve the mass balance in two steps. First, we will calculate the AN needed at the entrance of the evaporator, knowing that 0.2% of the AN is lost in the evaporation. We also know from the patent that the entrance steam has 66% AN. With this we will solve the reactor balance to know the composition of the entrance stream.



- AN Mass Balance

$$0.66\,E = 0.002\ x\ 0.66\,E + 0.93\ x\ 22\,157.08$$
$$E = 31\,283.91\ kg/h$$
$$E_{AN} = 20\,647.38\ kg/h$$
$$O_{AN} = 41.29\ kg/h$$

From the mass balance on the reactor we know the exactly composition on “E”

- Global Mass Balance

$$E = O + F$$
$$O = 9126.83\ kg/h$$

- HNO_3 Mass Balance

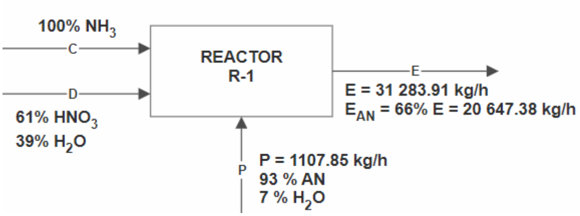
Knowing that all nitric acid must be eliminated

$$E_{HNO_3} = O_{HNO_3} = 416.08\ kg/h$$

Stream	**Flow (kg/h)**	**AN (kg/h)**	**H_2O (kg/h)**	**HNO_3**
E	31 283.91	20 647.38	10 220.45	416.08
O	9 126.83	41.29	8 669.45	416.08
F	22 157.08	20 606.09	1 550.99	-

I) Mass Balance on Reactor

Since AN on stream “E” was calculated, and recirculated too, AN to produce is now known. It is said in the patent that 10% nitric acid is used with respect to ammonia.



- Balance for AN produced

$$NH_4NO_{3\,PROD} = 0.66\,E - 0.93\,P = 19\,617.08\,kg/h$$

- Stoichiometric determination of NH_3 consumption

$$NH_3 = 19\,617.08\,kg\,AN\,x\,\frac{1\,kmol\,AN}{80\,kg\,AN}\frac{1\,kmol\,NH_3}{1\,kmol\,AN}\frac{17\,kg\,NH_3}{1\,kmol\,NH_3}$$
$$= 4168.63\,kg\,NH_3/h$$

- Stoichiometric determination of HNO_3 consumption and excess

$$HNO_3 = 19\,617.08\,kg\,AN\,x\,\frac{1\,kmol\,AN}{80\,kg\,AN}\frac{1\,kmol\,HNO_3}{1\,kmol\,AN}\frac{63\,kg\,HNO_3}{1\,kmol\,HNO_3}$$
$$= 15\,448.45\,kg\,HNO_3/h$$
$$HNO_3 = 15\,448.45 + 0.1\,x\,4168.63 = 15\,864.53\,kg\,HNO_3/h$$

- Stream “D” calculation

$$\frac{15\,864.53}{0.61} = 26\,007.43\,kg\,HNO_3/h$$

Stream	Flow (kg/h)	AN (kg/h)	H_2O (kg/h)	HNO_3	NH_3
C	4 168.63	-	-	-	4 168.63
D	26 007.43	-	10 142.90	15 864.53	-
P	1 107.85	1 030.30	77.55	-	-
E	31 283.91	20 647.38	10 220.45	416.08	-

APPENDIX 3: ENERGY BALANCE

a. Energy Balance on Ammonia Heater HE-1

Heat needed to heat ammonia from 25 to 60ºC will be calculated

- Needed heat

$$Q_{NH_3} = w_{NH_3} Cp_{NH_3} \Delta T = 4168.63 \frac{kg}{h} * 2.11 \frac{kJ}{kg\ K} * (333 - 298)$$
$$= 307\ 853.33\ kJ/h$$

b. Energy Balance on Nitric Heater HE-2

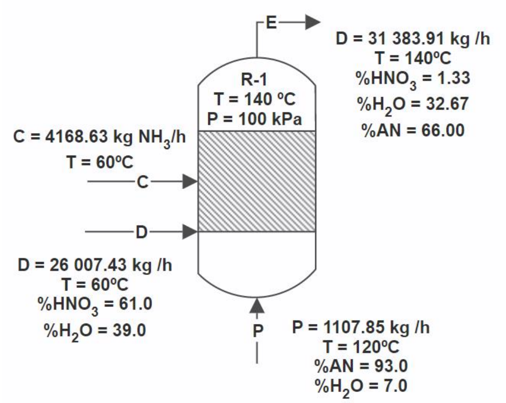
Heat needed to heat nitric acid at 61% from 25 to 60ºC will be calculated

- Needed heat

$$Q_{HNO_3} = w_{HNO_3} Cp_{HNO_3} \Delta T = 26\ 007.43 \frac{kg}{h} * 2.70 \frac{kJ}{kg\ K} * (333 - 298)$$
$$= 2\ 457\ 720.00\ kJ/h$$

c. Energy Balance on Reactor R-1

Reaction heat and energy needed to get reactants to 140ºC will be calculated. Finally, water consumption to refrigerate the reactor to make it isothermal will be figured.



❖ Reaction heat at 25ºC

$$NH_3 + HNO_3 \rightarrow NH_4NO_3$$

$$\Delta H_{f\ NH_3} = -45.90\ kJ/mol$$

$$\Delta H_{f\ HNO_3} = -207.36\ kJ/mol$$

$$\Delta H_{f\ NH_4NO_3} = -339.87\ kJ/mol$$

$$\Delta H^{\circ}_{r\ 298K} = \Delta H^{\circ}_{p} - \Delta H^{\circ}_{r} = -86.61\ kJ/mol$$

❖ Reaction heat at 140ºC

$$\Delta H^{\circ}_{r\ 413K} = \Delta H^{\circ}_{r\ 298K} + \int_{298}^{413} \Delta Cp\ dT$$

$$Cp_{NH_3} = 0.03587 \frac{kJ}{mol\ K}$$

$$Cp_{HNO_3(g)} = -0.065422 \frac{kJ}{mol\ K}$$

$$Cp_{HNO_3(l)} = -0.111087 \frac{kJ}{mol\ K}$$

$$Cp_{NH_4NO_3} = -0.258735 \frac{kJ}{mol\ K}$$

$$\Delta Cp = 0.111772 \frac{kJ}{mol\ K}$$

$$\Delta H^{\circ}_{r\ 413K} = -86.61 + \int_{298}^{413} 0.111772\ dT = -73.76\ kJ/mol$$

Since the Ammonium Nitrate production 20 647.38 kg/h

$$Q_{r\ 413K} = -73.76 \frac{kJ}{mol\ AN} \frac{1000\ mol\ AN}{1\ kmol\ AN} \frac{1\ kmol\ AN}{80\ kg\ AN} \frac{20\ 647.38\ kg\ AN}{h}$$
$$= -19\ 036\ 884.36 \frac{kJ}{h}$$

- Total heat operation

Needed heat to heat all reactants, including recirculation and water to 140ºC will be calculated.

$$Q_T = Q_{r\ 413K} + Q_{NH_3} + Q_{HNO_3} + Q_{NH_4NO_3} + Q_{H_2O}$$

Ammonia:

$$Q_{NH_3} = w_{NH_3} Cp_{NH_3} \Delta T$$
$$= 4168.63 \frac{kg\ NH_3}{h} \frac{1\ kmol\ NH_3}{17\ kg\ NH_3} \frac{1000\ mol}{1\ kmol} 0.035875 \frac{kJ}{mol\ K} (413 - 333) K$$

$$Q_{NH_3} = 703\ 762.83\ kJ/h$$

Nitric acid:

In this case 2 nitric acid heat must be considered to calculate. Achieving the boiling temperature point for all nitric acid that reacts, since it will be reacting in liquid state. Then all non-reacting nitric acid will achieve the temperature of 140ºC and change from liquid to gas state.

Reacting acid:

$$Q_{HNO_{3\ (r)}} = w_{HNO_3} Cp_{HNO_3(l)} \Delta T = 643\ 395.08\ kJ/h$$

Non reacting acid:

$$Q_{HNO_3\,(nr)} = w_{HNO_3}[Cp_{HNO_3(l)}\Delta T_1 + \ \Delta H_{vaporization} + Cp_{HNO_3(g)}\Delta T_2]$$

$$= 416.08\frac{kg\ HNO_3}{h}\frac{1\ kmol\ HNO_3}{63\ kg\ HNO_3}\frac{1000\ mol}{1\ kmol}[0.111087\frac{kJ}{mol\ K}(356-333)K$$

$$+ 38.6\frac{kJ}{mol} + 0.065422\frac{kJ}{mol\ K}(413-356)K$$

$$Q_{HNO_3\,(nr)} = 296\,434.25\ kJ/h$$

$$Q_{HNO_3} = Q_{HNO_3\,(r)} + Q_{HNO_3\,(nr)} = 939\,829.33\ kJ/h$$

Recirculate Ammonium Nitrate:

$$Q_{NH_4NO_3} = w_{NH_4NO_3}Cp_{NH_4NO_3}\Delta T = 6662.43\ kJ/h$$

Present water in the Reactor:

Water introduced with nitric acid:

$$Q_{H_2O_D} = w_{H_2O}[Cp_{H_2O\,(l)}\Delta T_1 + \ \Delta H_{vaporization} + Cp_{H_2O\,(g)}\Delta T_2] =$$

$$= 10\,142.9\frac{kg\ H_2O}{h}\frac{1\ kmol\ H_2O}{18\ kg\ H_2O}\frac{1000\ mol}{1\ kmol}[0.0753\frac{kJ}{mol\ K}(373-333)K$$

$$+ 44.0\frac{J}{mol} + 0.0365\frac{kJ}{mol\ K}(413-373)K$$

$$Q_{H_2O_D} = 759\,032.88\ kJ/h$$

Recirculated water:

$$Q_{H_2O_P} = w_{H_2O}Cp_{H_2O(l)}\Delta T = 6488.35\ kJ/h$$

$$Q_{H_2O} = Q_{H_2O_P} + Q_{H_2O_D} = 765520.88\ kJ/h$$

Total Heat:

$$Q_T = -19\,036\,884.36\frac{kJ}{h} + 703\,762.83\frac{kJ}{h} + \ 939\,829.33\frac{kJ}{h} + 6662.43\frac{kJ}{h}$$

$$+ 765\,520.88\frac{kJ}{h}$$

$$Q_T = -16\,621\,108.89\ kJ/h$$

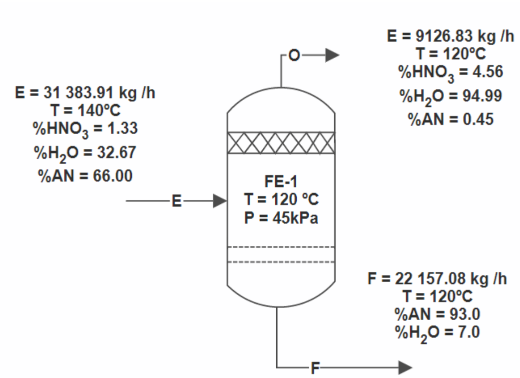
- Cold water mass calculation

  Assuming we use water at 25ºC and 100kPa

$$m_{H_2O} = \frac{|Q_T|}{Cp_{H_2O\,(l)}(T_2 - T_1)} = 99\,329.34\; kg/h$$

d. Energy Balance on Flash Evaporator FE-1

Energy needed to concentrate the AN nitrate from 66 to 93% will be determined. Additionally, all nitric acid non reaction will be assumed to leave through stream "O"



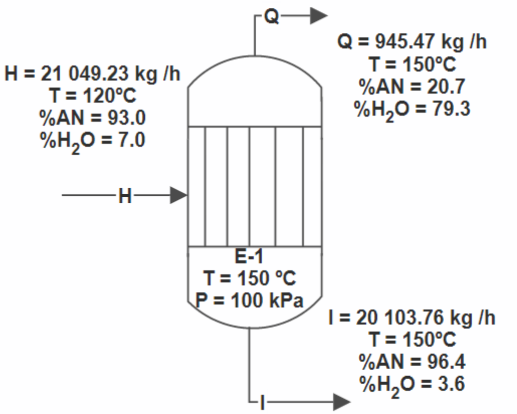
Since some thermodynamic properties are lacking those calculations were done with the simulator DWSIM 5.7 that determined the flow enthalpies.

Stream	E	O	F
HNO_3	416.08	416.08	-
H_2O (kg/h)	10 220.45	8 669.45	1 550.99
AN (kg/h)	20 647.38	41.29	20 606.09
Flow (kg/h)	31 283.91	9 126.82	22 157.08
ΔH (kJ/h)	-1 605 490.26	1 574 834.52	-7 259 324.12

$$Q_T = \Delta H_{exit} - \Delta H_{feed}$$
$$Q_T = 4\,078\,999.34\; kJ/h$$

e. Energy Balance on Evaporator E-1

Energy needed to concentrate the AN nitrate from 93 to 96.4% will be determined.



Since we lack some thermodynamic properties those calculations were done with the simulator DWSIM 5.7 that determined the flow enthalpies.

Stream	H	Q	I
H_2O (kg/h)	1 473.45	749.71	723.74
AN (kg/h)	19 575.78	195.76	19 380.02
Flow (kg/h)	21 049.23	945.47	20 103.76
ΔH (kJ/h)	-6 896 359.22	218 299.57	-8 267 755.40

$$Q_T = \Delta H_{exit} - \Delta H_{feed}$$

$$Q_T = 1\ 153\ 096.61\ kJ/h$$

- Steam needed

$$Q_T = m_v \lambda$$

  - ✓ λ=2085 kJ/kg
  - ✓ 5 bar
  - ✓ 160ºC

$$m_v = 553.03\ kg/h$$

f. Energy Balance on Granulator G-1

To which this operation concerns, energy balance will be calculated as a mixing tank where Ammonium Nitrate(l) and Calcium Carbonate(s) are fed and Calcium Ammonium Nitrate is obtained as a result. Final temperature is being calculated here supposing this granulator operates adiabatically.

All streams will be neglected except for the AN feed, the CaCo3 feed and the CAN exit since they have low energetically value.

- Energy global balance

$$Q_t = Q_R + Q_I = 0$$

Stream R:

$$Q_R = w_R Cp_R \Delta T = 57.69\ kmol\ R\ \frac{1000\ mol\ R}{1\ kmol\ R} 0.08229 \frac{kJ}{mol\ K}(358 - 298)C$$

Stream I:

$$Q_{I_1} = w_I Cp_I \Delta T = 282.35\ kmol\ I\ \frac{1000\ mol\ I}{1\ kmol\ I} 0.23268 \frac{kJ}{mol\ K}(378 - 423)K = -2\ 956\ 373.91\ kJ/h$$

$$Q_{I_2} = w_I(-\lambda_{fus}) = \left(282.35\ kmol\ I \frac{1000\ mol}{1\ kmol}\right)\left(-\frac{6.4kJ}{mol}\right) - 3\ 811\ 725.00\ kJ/h$$

$$Q_{I_3} = w_I Cp_I \Delta T = 282.35\ kmol\ i\ \frac{1000\ mol\ I}{1\ kmol\ I} 0.23268 \frac{kJ}{mol\ K}(358 - 378)K = -1\ 313\ 972.19\ kJ/h$$

$$Q_t = -3\ 228\ 971.81 \frac{kJ}{h}$$

- Cold water mass calculation

Assuming we use water at 65ºC and 100kPa

$$m_{H_2O} = \frac{|Q_T|}{Cp_{H_2O\,(l)}(T_2 - T_1)} = 99\ 329.34\ kg/h$$

g. Energy Balance on Dryer D-1

In this balance experimental equations from bibliography will be used to calculate enthalpy's. The air used to dry has also been used to cool at the very end of the process. Final solid temperature was estimated in order to calculate mass air flow needed in the cooler.

- Water mass balance

$$(Y * y_2) - (U * y_1) = (K * x_2) - (J * x_1)$$

From Mass Balance and Energy balance in the cooler we already obtained that:

- ✓ $Y = U = 80\,445.63\ kg\ air/h$
- ✓ $K \approx J = 25\,140\ kg\ dried\ product/h$
- ✓ $x_2 = \frac{25.15\ kg\ Water}{25\,125.12\ kg\ DP} = 0.001;\ x_1 = \frac{777.77\ kg\ Water}{25\,925.55\ kg\ DP} = 0.031$
- ✓ $y_1 = \frac{752.62\ kg\ Water}{80\,445.63\ kg\ air} = 0.009$

From water mass balance we isolate:

$$y_2 = 1x10^{-8}$$

- Energy Balance

$$H_{G_2}Y + H_{S_1}J = H_{G_1}U + H_{S_2}K + Q$$

Those experimental equations were extracted from bibliography

$$H_G = (0.24 + 0.46y)T + 597.2y\ [\frac{kcal}{kg}]$$

$$H_S = (C_{ps} + C_{pl}x)T\ [\frac{kcal}{kg}]$$

$$C_{ps} = 0.774\frac{kcal}{kg\ C} = Specific\ heat\ of\ dried\ prodcut$$

$$C_{pl} = 1.000\ \frac{kcal}{kg\ C} = Specific\ heat\ of\ liquid\ to\ evaporate$$

Substituting on energy balance

$$33.12 * 80\,445.63\ + 25\,147.78 * 70.04$$
$$= 29.34 * 80\,445.63 + 81.375 * 25\,150.27 + Q$$

$$Q = 18\,831.77\,\frac{kcal}{h} = 78\,716.80\,\frac{kJ}{h}$$

Some energy was lost due to the imperfection of drying system

h. Energy Balance on Cooler C-1

Energy removed from AN granulates before stocking them will be calculated

- Heat removed to air

$$Q = m * Cp * \Delta T = 24\,873.52\,kg/h\,\frac{258.735\,kJ\,mol}{80\,kg\,mol\,K}\,(25 - 95)$$

$$Q = -5\,631\,193.92\,kJ/h$$

- Needed Air

$$m_{air} = \frac{|Q|}{Cp\,\Delta T} = \frac{5\,631\,193.92}{1 * (95 - 25)} = 80\,445.63\,kg\,air/h$$

APPENDIX 4: PINCH ANALYSIS

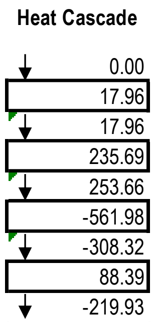
Four streams were selected for the analysis, 2 from the reactors feed and both of the vapours result from the evaporators.

Stream	Product	Type	Inlet T (ºC)	Outlet T (ºC)	MassFlow (kg/h)	Cp (kJ/kg ºC)	Q (kW)
1	NH3	Cold	25	60	4168.63	2.11	85.51
2	HNO3	Cold	25	60	26007.43	2.70	682.70
3	0.95 Vapour	Hot	120	30	9126.83	2.09	-476.42
4	0.79 Vapour	Hot	150	30	945.47	2.28	-71.86

Displaced temperatures were calculated with a ΔT_{min} = 20 ºC

Stream	Type	wCp (kW/ºC)	Design Temperature		Displaced Temperature	
			Inlet T (ºC)	Outlet T (ºC)	Inlet T (ºC)	Outlet T (ºC)
1	Cold	2.44	25	60	35	70
2	Cold	19.51	25	60	35	70
3	Hot	5.29	120	30	110	20
4	Hot	0.60	150	30	140	20

Temperature Intervals	ΔT ºC	ΣmCp (kW/ºC)	Q (kW)	
140.00				
	30.00	0.5988	17.96	Surplus
110.00				
	40.00	5.8924	235.69	Surplus
70.00				
	35.00	-16.0565	-561.98	Shortage
35.00				
	15.00	5.8924	88.39	Surplus
20.00				



From the heat cascade pinch temperatures and service requirements are calculated numerically. So instead of needing to waste nearly 1320 kW cooling or heating, now the system only needs 396.71 kW.

APPENDIX 5: REACTOR DESIGN

- Removed heat

$$Q_T = -16\ 621\ 108.89\ kJ/h$$

- Mass of cooling water needed

Assuming water enters at 25 ºC and leaves at 65 ºC

$$m_{H_2O} = \frac{|Q_T|}{Cp_{H_2O\ (l)}(T_2 - T_1)} = 99\ 329.34\ kg/h$$

- Reactors Volume

Volume will be calculated as a function of heat transfer surface

$$Q = U\ A\ \Delta T_{LMTD}$$

Where

A: Heat transfer area (m)

Q: Total heat transferred (kJ/h)

U: Heat transfer global coefficient (W/m² ºC)

ΔT_{LMTD}: Logarithmic mean temperature difference

From bibliography is extracted that the design standards are between 667.83 and 1619.58 W/m² ºC. So a value between those numbers will be assumed.

- We take as temperature variation the reactors one (which doesn't vary because of the water heat remove) and the water itself (entrances-exits).

$$\Delta T_{LMTD} = \frac{115 - 75}{LN(\frac{115}{75})} = 93.58\ ºC$$

- Heat transfer area

$$A = \frac{4\ 617\ 808 \frac{J}{s}}{1392.38 \frac{W}{m^2 ºC}\ 93.58\ ºC} = 35.44\ m^2$$

As a design security factor, a 20% extra area will be applied

$$A = 42.53\ m^2$$

All heat transfer goes along the side of the cylinder

$$A = A_L = 2\pi r h$$

From standards we know

$$\frac{h}{D} = 1.5$$

$$A = \frac{2\pi D}{2} 1.5D$$

$$D = 3\ m; h = 4.5\ m$$

- Reactors volume

$$V_R = \frac{\pi D^2 1.5D}{2} = 31.8\ m^3$$

- Mixing areas volume

A 30% of reacting volume is assumed for the mixing areas volume.

$$V_{mix} = 9.54\ m^3$$

- Reactor tubes

Knowing the volumetric flow and that having a residence time that about 1s is more than enough for this reaction:

$$N_t = \frac{4.44\ m^3}{\frac{\pi\ 0.0254^2 m^2\ 4.5\ m}{4}} = 1947.21\ tubes\ \approx 1947\ tubes$$

1947 tubes will be used in a square arrange

- Design pressure

$$P_D = P_{op} + P_h$$

Where:

P_D: Design pressure
P_{op}: Operational pressure, 100 kPa
P_h: Hydrostatic pressure

$$P_h = \rho g h = 1.95 * 9.81 * 4.5 = 86\ Pa$$
$$P_D = P_{op} + P_h = 100.086\ kPa$$

As a design security factor, 20% extra pressure will be calculated

$$P_D = 115.11\ kPa$$

- Reactor lateral thickness

$$E_w = E + E_c = \frac{P_D Di}{2\ S.E. - 1.2 P_D} + E_c$$

Where:

E_w: Thickness of the wall
P_D: Design pressure (N/mm^2)
D_i: Internal diameter (mm)

E: Welding factor

S: Elastic limit, 220 N/mm²

*Ec: Thickness of the wall, 4*E*

$$E_w = 4.96\ mm$$

- Cooling jacket

Thickness (D) of the jacket will be calculated

$$\dot{Q} = A\ v$$

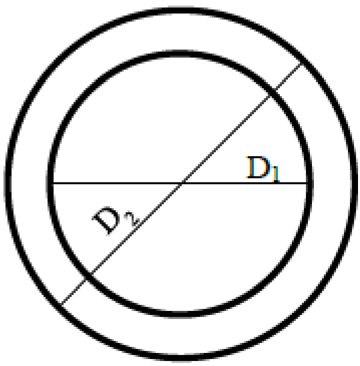
Q: Volumetric flow (m^3/s)

A: Cross sectional Area (m^2)

v: Velocity

$$\dot{Q} = \frac{m_{H_2O}}{\rho} = \frac{99\ 329.33\ kg}{h}\frac{m^3}{1000\ kg}\frac{h}{3600\ s} = 2.75x10^{-2}m^3/s$$

Assuming the ideal velocity of water flow is 1.5 m/s



$$A = 1.84\ m^2 = Rings\ area$$

$$A = 1.84\ m^2 = \frac{\pi}{4}(D_2^2 - D_1^2)$$

$$D_2 = \sqrt{\frac{4A}{\pi} + D_1^2} = 3.004\ m$$

The thickness of the cooling jacket is about 4mm but 10mm will be taken.

APPENDIX 6: MAIN EQUIPMENT DESIGN

Main equations and calculations needed for the sizing of process equipment will be detailed here.

a) Storage containers

The calculation of the nitric acid storage tank is carried out as a demonstrative way for the rest.

a.1. Nitric acid tank T-1

Data:

Material	Nitric acid
Consumption (kg/h)	26 007.43
Density (kg/m^3)	1 510.00
Storage time (d)	7.00
Temperature (ºC)	25.00
Pressure	100.00

a.1.1. Design volume

$$V = \frac{M\ \theta\ 24}{\rho} \qquad \text{Eq.1}$$

Where:

V: Design Volume (m^3)

M: Consumption (kg/h)

Θ: Storage time (d)

P: Density (kg/m^3)

$$V = 2893\ m^3$$

a.1.2. Diameter calculation

$$V = \frac{\pi D^2}{4} h \qquad \text{Eq.2}$$

$$\frac{h}{D} = 1.5 \qquad \text{Eq.3}$$

Where

D: Tank diameter (m)

h: Tank height

Substituting *Eq.3* into *Eq.2*

$$D = 13.49\ m\ ; H = 20.23\ m$$

a.1.3. Wall thickness

$$t = E + E_c = \frac{P_D Di}{2\ S.E. - 1.2 P_D} + E_c \qquad \text{Eq. 4}$$

Where:

t: Wall thickness

P_D: Design pressure

S: Resistance to the materials traction,7000 bar for 304-SS

E: Welding factor, 0.85

Ec: Over thickness for corrosion, 3 mm

a.1.3.1.Design pressure

$$P_D = P_{op} + P_h \qquad \text{Eq. 5}$$

Where:

P_D: Design pressure (kPa)

P_{op}: Operational pressure, 100 kPa

P_h: Hydrostatic pressure (kPa)

$$VP_h = \rho g h = 1321 * 9.81 * 20.23 = 262.16\ kPa \qquad \text{Eq. 6}$$

$$P_D = P_{op} + P_h = 362.16\ kPa$$

g: gravity acceleration (m/s^2)

h: Liquid height

As a design security factor, 20% extra pressure will be calculated

$$P_D = 265.92\ kPa$$

Substituting on *Eq. 4* wall thickness is obtained

$$t = E + E_c = \frac{P_D Di}{2\,S.E. -1.2P_D} + E_c = 6.66\ mm$$

This is slightly superior than ¼'' plate

a.1.4. Roof and base thickness

From bibliography is assumed that roof thickness is 50% more than wall thickness

$$t_r = t_b = t + 0.5t = 10\ mm$$

b) Heat exchangers

Heat exchanger design will be done as a demonstrative way

b.1. Heat exchanger HE-3

Design for heat exchanger 1 will be done. Tubes and shell exchanger will be chosen to heat ammonia gas from 25 to 60 ºC

Tubes		**Shell**	
Product	NH3	Product	Vapour
Flow (kg/h)	4168.63	Flow (kg/h)	9126.83
Cp (J/g K)	2.11032	Cp (J/g K)	2.09
Viscosity (kg/m s)	10E-5	Viscosity (kg/m s)	1.44E-5
Conductivity (w/m ºC)	0.02958	Conductivity (w/m ºC)	0.0298
Density (kg/m3)	0.6	Density (kg/m3)	2.670
t1 (ºC)	25	T1 (ºC)	120
t2 (ºC)	60	T2 (ºC)	103.8
Pressure (kPa)	600	Pressure (kPa)	100

b.1.1. Heat transfer area

$$Q = U\ A\ \Delta T_{LMTD} f \qquad \textit{Eq. 7}$$

Where:

A: Heat transfer area (m^2)

Q: Total heat transferred (kW)

U: Overall heat transfer coefficient (W/m^2 ºC)

ΔT_{LMTD}: Logarithmic mean temperature difference (ºC)

f: Correction factor

b.1.1.1.Log mean temperature difference

$$\Delta T_{LMTD} = \frac{(T_1 - t_2) - (T_2 - t_1)}{LN\left(\frac{(T_1 - t_2)}{(T_2 - t_1)}\right)} \quad \textit{Eq. 8}$$

Where:

$T_{1,2}$: Hot fluid entrance and exit temperature

$t_{1,2}$: Cold fluid entrance and exit temperature

Applying values:

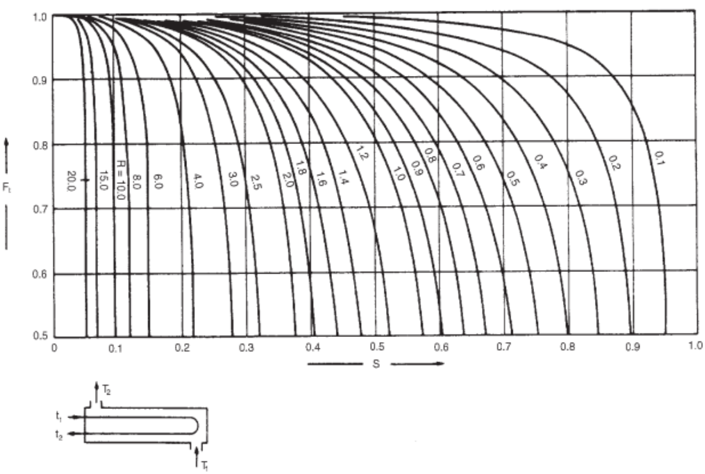
$$\Delta T_{LMTD} = 69.00\ ºC$$

b.1.1.2.Correction factor calculation

$$S = \frac{t_2 - t_1}{T_1 - t_1}; R = \frac{T_1 - T_2}{t_2 - t_1} \quad \textit{Eq. 9}$$

Applying on *Eq. 9* we obtain

$$S = 0.37; R = 0.46$$



Graph 12: Temperature correction factor, with 1 shell pass and 2 tubes pass

From the graphic we assume that

$$f = 1$$

From bibliography, we extract that overall heat transfer coefficient varies between 10-500 W/m2. 50 W/m2 will be taken as starter value because of both components are gas.

$$A = 4.95\ m^3$$

A 20% security factor will be taken, A=5.95 m3

b.1.2. Number of tubes

Tube length (m)	2
Do (m)	0.04
Ao (m2)	0.2512
Tube Cross-sectional area (m2)	0.000873618
Cross-flow area As (m2)	0.017943165
Di	0.03336

For the outside diameter a standard 40 mm tube has been taken. First two numbers have been supposed in order to calculate the results, then values may need to be iterated.

$$A_t = \pi D_o L = 0.2512\ m^2 \quad \textit{Eq. 10}$$

$$N_t = \frac{A}{A_t} = 119 \quad \textit{Eq. 11}$$

b.1.3. Bundle tube calculation

The bundle tube has been designed in a triangle arrangement and “U” shape. Its diameter is calculated with the following equation

$$D_b = D_o \left(\frac{N_t}{k_1}\right)^{\frac{1}{n_1}} \quad \textit{Eq. 12}$$

Where:

Db: Bundel diameter (m)

Do: Outside diameter (m)

Nt: Number of tubes

k_1: Constant for triangular arrangement, 0.156

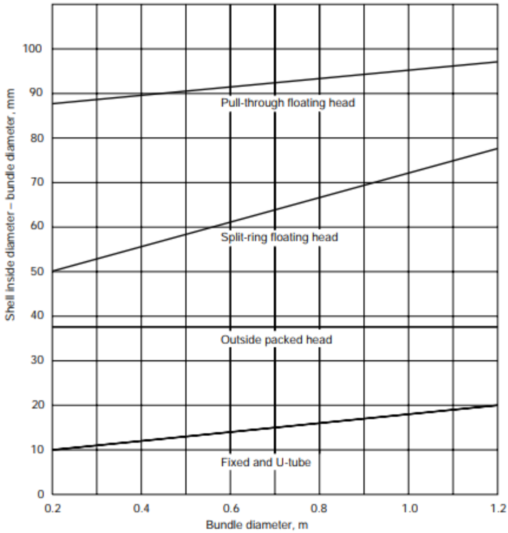
n_1: Constant for triangular arrangement, 2.291

Replacing *Eq. 12*

$$D_b = 655\ mm$$

b.1.4. Shell diameter calculation

From the diagram below the next equation is obtained.



Graph 13: Shell diameter - Bundle diameter

$$D_s - D_b = 15\ mm \qquad \textit{Eq. 13}$$

$$D_s = 670\ mm$$

b.1.5. Baffle (B) and baffle spacing (l_b)

Baffle is assumed 25% and baffle spacing is considered 0.5 Ds

b.1.6. Overall heat transfer coefficient (U)

To reach this point, U was supposed 0.25 kW/m ^{2}ºC. Now it must be verified, where the result of the following equation has to be lesser than the one we supposed.

$$\frac{1}{U} = \frac{D_o}{D_i + h_{c,t}} + \frac{D_o}{D_i} * R_t + D_o \ln\left[\frac{(D_o/D_i)}{k}\right] + R_s + \frac{1}{h_{c,s}} \qquad \textit{Eq. 14}$$

Where:
Do: Outer diameter (m)
Di: Inner diameter (m)
R_t: Tube side soiling 1.7e-4 m.ºC/W
R_s: Shell side soiling 1e-4 m.ºC/W
$H_{c,t}$: Tube side convection heat transfer coefficient (W/m^2.ºC)
$H_{c,s}$: Shell side convection heat transfer coefficient (W/m^2.ºC)
K: Material thermic conductivity, SS304-15 W/m.ºC

b.1.6.1.Mass flux on tube side

$$G = \frac{M}{A_{tcsa} N_t} \qquad \text{Eq. 15}$$

Where:
G: Mass flux (kg/m^2.s)
M: Mass flow (kg/s)
Atcsa: Tube cross sectional Area (m^2)
Nt: Tube numbers
Replacing on *Eq. 15*

$$G = 11.14 \frac{kg}{m^2 s}$$

b.1.6.2.Reynolds number on tube side

$$Re = \frac{D_i G}{\mu} \qquad \text{Eq. 16}$$

Where:
Re: Reynolds number
D_i: Inner diameter (m)
μ: nitric acid viscosity (kg/m.s)
Replacing on *Eq. 16*

$$Re = 44\,553.53$$

b.1.6.3.Prandlt number in the side of tubes

$$Pr = \frac{\mu C_p}{k} \qquad \text{Eq. 17}$$

Where:
Pr: Prandlt number
K: Conductivity (w/m.K)

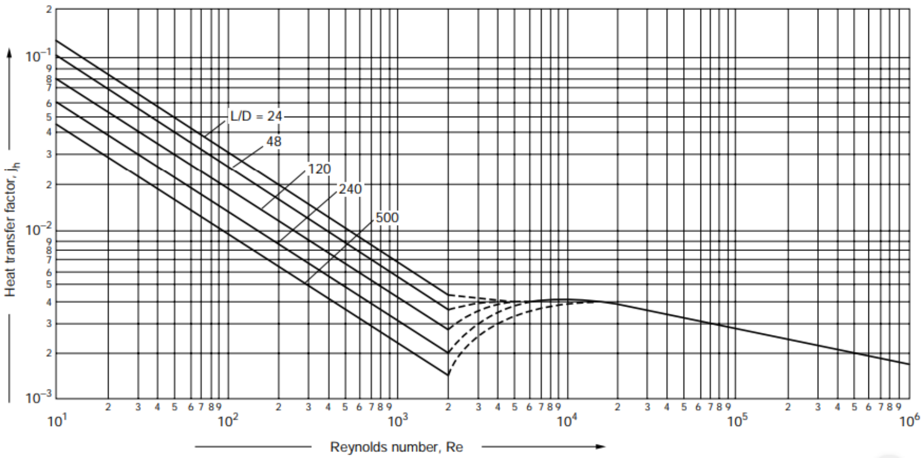
$$Pr = 0.713428$$

b.1.6.4.Tube side convection heat transfer energy

$$h_{c,t} = \frac{k}{D_i} j_h Re Pr^2 \qquad \text{Eq. 18}$$

Where the only new value is j_h, a constant extracted from the graph below in function of the Reynolds number. It is j_h=0.0036

$$h_{c,t} = \frac{127.22\ W}{mºC}$$



Graph 14: Heat transfer-reynolds

b.1.6.5.Mass flux on shell side

$$G = \frac{M}{A_s} \quad \textit{Eq.19}$$

$$A_s = \frac{\left(D_p - D_o\right)}{D_p} l_b D_s \quad \textit{Eq. 20}$$

Where:

G: Mass flux (kg/m^2.s)

M: Mass flow (kg/s)

As: Cross-flow area (m^2)

Dp: Pitch diameter, 1.25 D_o

D_o: Outside diameter

l_b: Baffle spacing, 0.2 Ds

Ds: Shell diameter

Replacing on *Eq. 19*

$$G = 141.29 \frac{kg}{m^2 s}$$

b.1.6.6.Reynolds number on shell side

$$Re = \frac{D_e G}{\mu}$$ *Eq.21*

$$D_e = \frac{1.1}{D_o} * (D_p^2 - 0.92\ D_O^2)$$ *Eq. 22*

Where:
Re: Reynolds number
D_e: Equivalent diameter (m)
μ: Vapour viscosity (kg/m.s)
Replacing on *Eq. 21 and 22*

$$Re = 399\ 433$$

b.1.6.7.Prandlt number in the shell sides

$$Pr = \frac{\mu C_p}{k}$$ *Eq.23*

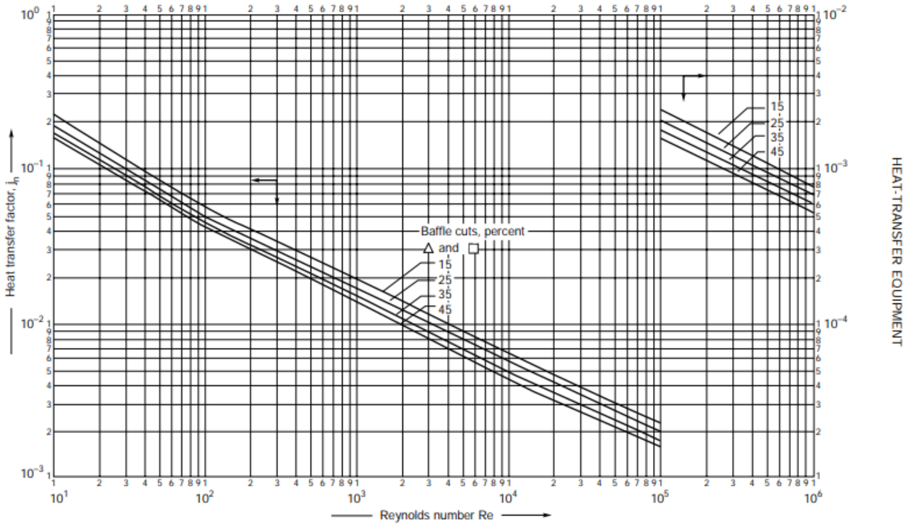
Where:
Pr: Prandlt number
K: Conductivity (w/m.K)

$$Pr = 1.009$$

b.1.6.8.Tube side convection heat transfer energy

$$h_{c,s} = \frac{k}{D_e} j_h Re Pr^2$$ *Eq.24*

Where j_h, a constant extracted from the graph below in function of the Reynolds number and the baffle (B=0.25). It is j_h=0.0036



Graph 15: Heat transfer-reynolds

$$h_{c,s} = \frac{295.60\ W}{m^{\circ}C}$$

Resolving *Eq. 14 now*

$$U = \frac{48.36\ W}{m^2{}^{\circ}C}$$

As the result is lesser than the value that was supposed, we can accept the results of the exchanger

b.1.7. Shell thickness

Resolving *Eq. 4*

$$t = 8.69\ mm$$

c) Design of mass and energy simultaneously transfer equipment

For this equipment, DWSIM 5.1 has been used to simulate the stream flows results. Simulation results are attached.

c.1. Flash evaporator FE-1

Used to separate the effluent of the reactor into a rich water vapour stream, and a rich liquid ammonium nitrate stream. All nitric acid is supposed to evaporate.

c.1.1. Report

DWSIM 5.7 Simulation Results Report

Simulation File: Flash Evaporator Simulation FE-1
Date created: 27/04/2019 0:19:19

Liquid		
Temperature	120	C
Pressure	45	kPa
Mass Flow	22 157.08	kg/h
Molar Flow	258.59	kmol/h
Volumetric Flow	11.41	m3/h
Mixture Density	1811.26	kg/m3
Mixture Molar Weight	79.89	kg/kmol
Mixture Specific Enthalpy	-327.63	kJ/kg
Mixture Specific Entropy	-3.03	kJ/[kg.K]
Mixture Molar Enthalpy	-28 072.72	kJ/kmol
Mixture Molar Entropy	-242.16	kJ/[kmol.K]
Mixture Thermal Conductivity	0.00012	W/[m.K]
Mixture Mass Fraction		
Ammonium Nitrate	0.9300	
Water	0.0700	
Nitric acid	0.0000	
Vapour		
Temperature	120	C
Pressure	45	kPa
Mass Flow	9126.83	kg/h
Molar Flow	573.30	kmol/h
Volumetric Flow	35 103.19	m3/h
Mixture Density	0.26	kg/m3
Mixture Molar Weight	18.53	kg/kmol
Mixture Specific Enthalpy	172.55	kJ/kg
Mixture Specific Entropy	0.88	kJ/[kg.K]

Mixture Molar Enthalpy	3197.94	kJ/kmol
Mixture Molar Entropy	16.33	kJ/[kmol.K]
Mixture Thermal Conductivity	0.031356	W/[m.K]
Mixture Mass Fraction		
Ammonium Nitrate	0.0045	
Water	0.9499	
Nitric acid	0.4560	
Feed		
Temperature	140	C
Pressure	100	kPa
Mass Flow	31 283.91	kg/h
Molar Flow	831.89	kmol/h
Volumetric Flow	16 075.60	m3/h
Mixture Density	1.95	kg/m3
Mixture Molar Weight	37.61	kg/kmol
Mixture Specific Enthalpy	-51.32	kJ/kg
Mixture Specific Entropy	0.05	kJ/[kg.K]
Mixture Molar Enthalpy	-1930.06	kJ/kmol
Mixture Molar Entropy	1.74	kJ/[kmol.K]
Mixture Thermal Conductivity	0.021563	W/[m.K]
Mixture Mass Fraction		
Ammonium Nitrate	0.6600	
Water	0.3267	
Nitric acid	0.0133	
FE-1 (Flash Evaporator)		
Separation Temperature	120	C
Separation Pressure	45	kPa

c.1.2. Gas velocity inside the equipment

$$u = K\sqrt{\frac{\rho_L - \rho_G}{\rho_g}}$$ *Eq. 25*

Where

u: Gas velocity

$\rho_{G:}$ Gas density

$\rho_{L:}$ Liquid density

K: Constant of separation, 0.2

$$u = 16.64\ m/s$$

c.1.3. Separator cross-flow area

$$A = \frac{Q_g}{u}$$ *Eq. 26*

Where

A: Cross flow area(m^2)

u: gas velocity(m/s)

Qg: Volumetric gas flow at operational conditions (m^3/s)

$$A = 0.59\ m^2$$

c.1.4. Internal diameter

$$D = \sqrt{\frac{4A}{\pi}} = 1.86\ m$$ *Eq. 27*

c.1.5. Liquid retention volume

$$V_l = 60 Q_l T_r$$ *Eq. 28*

Where

V_l: liquid retention volume (m^3)

Q_l: Volumetrically liquid flow at operational conditions (m^3/s)

Tr: Residence time, 10 minutes assumed

$$V_l = 1.9\ m^3$$

c.1.6. Liquid height

$$h_l = \frac{V_l}{A}$$ *Eq. 29*

The liquid zone will have a height of approximately 3.22 m

c.1.7. Feed nozzle Diameters

This value of this is chosen from a fork between maximum and minimum diameter calculated depending on standard values.

$$D_{min} = \sqrt{\frac{4Q}{\pi V_{max}}}$$ *Eq. 30*

$$D_{max} = \sqrt{\frac{4Q}{\pi V_{min}}}$$ *Eq. 31*

Where
Q: Feed volumetric flow at conditional operation (m^3/s)
Vmin/max: Maximum or minimum velocity m^3
Dmin/max: Maximum or minimum diameter for feed nozzles m

c.1.7.1. Maximum and minimum velocity

$$V_{min} = \frac{45}{\rho_{feed}}$$ *Eq. 32*

$$V_{max} = \frac{60}{\rho_{feed}}$$ *Eq. 33*

We conclude that V_{min} = 32.22 m/s; V_{max} = 42.97 m/s and applying results to *Eq. 30 and 31*

$$D_{min} = 0.32\ m; D_{max} = 0.37m$$

c.1.8. Effluents diameter discharge

The vapour nozzle diameter and the liquid exit are calculated the same way as the feed nozzle entrance.

c.1.8.1. Vapour nozzle

$$D_{min} = 0.32\ m; D_{max} = 0.37m$$

c.1.8.2. Liquid discharge

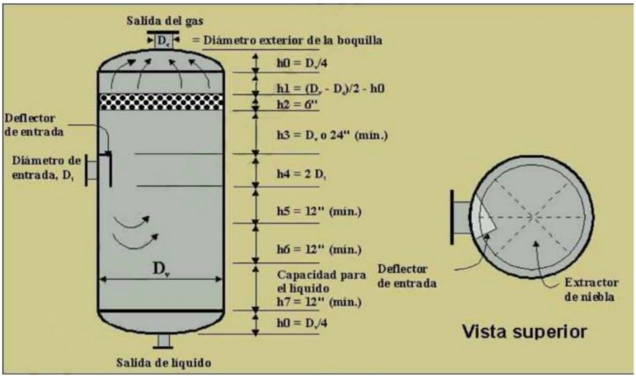
$$D_{min} = 0.34\ m; D_{max} = 0.40m$$

c.1.9. Total height

To calculate the total height, the figure above will be used as reference.

Flash Evaporator Height	
h0	0.22

h1	0.29
h2	0.15
h3	0.86
h4	0.70
h5	0.30
h6	0.30
h7	3.22
h8	0.22
Total height	**6.26**



Graph 16 Flash evaporator height relations

c.2. Evaporator E-1

An evaporator to concentrate the ammonium nitrate solution from 93 to 96.4%. A vertical tube with internal calendar

Product	AN 93%	Product2	Vapour
Flow (kg/h)	21049.23	Flow (kg/h)	553
t1	120	T1	151.85
t2	150	T2	
Pressure/kPa)	100	Pressure/kPa)	500
Latent heat /kJ/kg)	73.22	Latent heat /kJ/kg)	2085.36
Density(kg/m3)	1281.84	Density(kg/m3)	2.668

c.2.1. Heat transfer area

$$A = \frac{Q}{U\Delta T}$$ *Eq. 34*

Where

Q: Heat flow (J/s)

U: Overall heat transfer coefficient (W/m2.ºC)
A: Heat transfer area (m2)
ΔT: Temperature variation (ºC)

The usage of U=1200 W/m2.ºC is recommended for this products and pressures. Replacing

$$A = 8.90\ m^2$$

Assuming a 20% security factor new area is:

$$A = 10.68\ m^2$$

c.2.2. Number of tubes calculation

Tube length (m)	0.5
Do (m)	0.0254

Using *Eq. 11 described before*

$$N_T = 268$$

c.2.3. Bundle tube diameter

Using *Eq. 12 described before*

$$D_b = 0.642\ m$$

c.2.4. Central tube diameter

Central tube is responsible to transport concentrate solution to the evaporators exit. It must be between 20 and 40% of bundles diameter. In this project 25% was selected so D_{ct}=0.16 m

c.2.5. Shell diameter

In this type of equipment, shell diameter is the sum of central tube and bundle tube, so D_s=0.802 m

c.2.6. Liquid height

$$h_l = 1.2 D_b$$

Where

h_l: Liquid height (m)
D_b: bundle tube diameter (m)

c.2.7. Liquid width

$$I = 2(h_l D_s - h_l^2)^{0.5} \qquad \textit{Eq. 35}$$

Where

h_l: Liquid height (m)
Ds: Shelter diameter (m)

c.2.8. Steam velocity

Since the steam velocity can't be very high, or it would drag more AN from the other stream than expected, u_{max} will be calculated and compared. In case the velocity calculated exceeds the maximum one, new design specifications will have to be calculated

$$u = \frac{2m}{\rho_{vap} IL} \quad \text{Eq. 36}$$

$$u_{max} = 0.2\left(\frac{\rho_L - \rho_{vap}}{\rho_{vap}}\right)^{0.5} \quad \text{Eq. 37}$$

Where

u: vapour velocity (m/s)

u_{max}: vapours max velocity (m/s)

m: Vapours mass flow (kg/m3)

$$u_{max} = 4.38 m/s > u = 0.73 m/s$$

c.2.9. Evaporation camera height

$$h_e = 2.5\, L = 1.25$$

c.2.10. Total height

$$h_t = h_e + h_l + \frac{D_s}{2} = 2.42m$$

c.3. Rotatory dryer

Ammonium nitrate		**Air**	
Flow (kg/h)	25140	Flow (kg/h)	80445.63
t1 (ºC)	85	T1 (ºC)	138
t2 (ºC)	95	T2 (ºC)	90
Pressure (kPa)	100	Pressure (kPa)	100
Entrance humidity (kgW/kg D.S.)	0.031	Entrance humidity (kgW/kg D.A.)	1.00E-07
Exit humidity (kgW/kg D.S.)	0.001	Exit humidity (kgW/kg D.A.)	0.009
Entrance enthalpy (kcal/kg)	68.425	Entrance enthalpy (kcal/kg)	33.12
Exit enthalpy (kcal/kg)	74.91	Exit enthalpy (kcal/kg)	30.86

c.3.1. Dryer diameter

$$D = \left(\frac{4m_a}{\pi u(1-f)}\right)^{0.5} \quad \text{Eq. 38}$$

Where

D: Dryer diameter (m)

m_a: Air mass low (kg/s)

u: Solid velocity

f: Fill factor

Solid velocity is considered 1.4 m/s for <12 mm granules. Fill factor is recommended to be between 10 and 15%. 12% was chosen.

$$D = 4.8\ m$$

c.3.2. Dryer length

Length in those equipments are considered 2D

$$L = 2D = 9.6\ m$$

c.3.3. Residence time

$$\theta = \frac{0.23L}{\Delta X\ N\ D} + 0.6\left(\frac{\beta\ L\ G}{F}\right)$$

Eq. 39

Where

Θ: Residence time (min)

L: dryer length (m)

ΔX: slope (m/m), 0.08

N: RPM

D: Dryer diameter (m)

β: Granule size factor

G: Mass air velocity (kg/h.m^2)

F: Dried air flux (kg/h.m^2)

Rotatory driers normally spin at 4-5 RPM. The slope goes in a fork of between 0-0.08m. ΔX=0.04 m is chosen.

c.3.3.1. Granule size factor

$$\beta = 5D_p^{-0.5}$$

Eq. 40

Where

β: Granule size factor

Dp: Particle diameter (1500micrometers)

$$\beta = 0.129$$

c.3.3.2. Air mass velocity

$$G = \frac{4m_a}{\pi D^2}$$

Eq. 41

Where

G: Air mass velocity (kg/h.m^2)

D: Dryer diameter

m_a: Mass air flow

$$G = 4435.2$$

c.3.3.3. Air dry flux

$$F = G\left(\frac{Y_1 - Y_2}{X_1 - X_2}\right) \quad \text{Eq. 42}$$

Where

F: Air dry flux (kg/h.m²)

G: Mass air velocity (kg/h.m²)

X_1: Solid entrance enthalpy (kg water/kg dried solid)

X_2: Solid exit enthalpy (kg water/kg dried solid)

Y_1: Air exit enthalpy (kg water/kg dried air)

Y_2: Air entrance enthalpy (kg water/kg dried air)

$$F = 6359.84\,\frac{kg}{h\,m^2}$$

$$\theta = 5.12\,min$$

c.3.4. Number of fins

$$N_f = 4\pi D = 60 \quad \text{Eq. 43}$$

Where

N_f: Number of fins

D: Dryer diameter (m)

c.3.5. Fins height

$$10H_f = D \quad \text{Eq. 44}$$

Where

H_f: Fins height (m)

D: Dryer diameter (m)

$$H_f = 0.48m$$

c.3.6. Determination of engine power

$$P = \frac{5 + 0.11\,L\,D}{\eta} \quad \text{Eq. 45}$$

Where

P: Engine Power (Hp)

D: Dryer diameter (m)

L: dryer length (m)

η: Engine efficiency

Applying a 20% security factor

$$P = 13.75\,Hp$$

c.3.7. Thickness of the drum

Using *Eq. 4.*

$$t = 5.028\ mm$$

c.4. Rotatory cooler

To what the design refers, rotatory cooler and rotatory dryer are exactly the same. Since the same air flow from the cooler is used into the dryer, they will have the same variables results.

Ammonium nitrate		**Air**	
Flow (kg/h)	24873.62	Flow (kg/h)	80445.63
t1 (ºC)	95	T1 (ºC)	25
t2 (ºC)	25	T2 (ºC)	95
Pressure (kPa)	100	Pressure (kPa)	100

c.4.1. Cooler diameter

$$D = \left(\frac{4m_a}{\pi u(1-f)}\right)^{0.5}$$ *Eq. 46*

Where

D: Cooler diameter (m)

m_a: Air mass flow (kg/s)

u: Solid velocity

f: Fill factor

Solid velocity is considered 1.4 m/s for <12 mm granules. Fill factor is recommended to be between 10 and 15%. 12% was chosen.

$$D = 4.8\ m$$

c.4.2. Cooler length

Length in those equipment is considered 2D

$$L = 2D = 9.6\ m$$

c.4.3. Residence time

In this equipment the residence time is valued into 10min. It depends on the material to cool.

c.4.4. Number of fins

$$N_f = 4\pi D = 60$$ *Eq. 47*

Where

N_f: Number of fins

D: Cooler diameter (m)

c.4.5. Fins height

$$10H_f = D$$ *Eq. 48*

Where

H_f: Fins height (m)

D: Cooler diameter (m)

$$H_f = 0.48m$$

c.4.6. Determination of engine power

$$P = \frac{5 + 0.11\,L\,D}{\eta}$$ *Eq. 49*

Where

P: Engine Power (Hp)

D: Cooler diameter (m)

L: dryer length (m)

η: Engine efficiency

Applying a 20% security factor

$$P = 13.74\ Hp$$

c.4.7. Thickness of the drum

Using *Eq. 4.*

$$t = 5.028\ mm$$

d) Mixer units

d.1. Granulator

Granulator is composed of two parts. The first part is where the mix occurs, and will be done in a pugmill mixer. In the mixer, liquid ammonium nitrate, limestone, and recycled AN granules are fed in order to mix them making an intimate agglomeration solid past.

It also has a cooling jacket to absorb the energy total energy needed to cool the mix mass to 85ºC.

Since all granulator equipment are already sold with its design done, specifications will be taken from FEECO international.

d.1.1. Diameter and length

The feed mass flow is about 29 925 kg/h. To carry out all that mass product, pug mill diameter will be 4m. Length is considered to be 3*D in order to let the paddles work and mix the products enough.

d.1.2. Paddles

Paddles are distributed on two rotating axes that goes through the mixer length. Each axe has 4 paddle with 90º separation between each other centre. They are distributed like an helical screw so the mass is forced to advance through the mixer. More or less, 40 paddles are distributed in each meter length.

d.1.3. Cooling jacket

The cooling jacket has been designed to absorb 3 228 971 kJ/h of heat from the mix. Since the granulator is supposed to be half filled, the jacket will only be at half shell. Water used will be recirculated from the reactors cooling jacket.
First, final temperature must be calculated first

$$w_m = \frac{Q}{C_p(T_f - T_i)} \qquad \textit{Eq. 50}$$

Isolating Tf:

$$T_f = 72.77\ ºC$$

Calculating the heat transfer area:
A 1200 W/m² ºC will be supposed

$$Q = UA\ \Delta T_{MLTD} \qquad \textit{Eq. 51}$$

Where

$$\Delta T_{LMTD} = \frac{\Delta T_2 - \Delta T_1}{LN\left(\frac{\Delta T_2}{\Delta T_1}\right)} = 38.34\ ºC$$

$$A = 19.5\ m^2$$

Plus, a 20% security factor

$$A = 23.4\ m^2$$

Lateral area of the jacket is

$$A = \pi RL$$

Knowing that only bottom half of the shell will have any fluid, cooling jacket length need to remove enough heat is

$$L = 3.72\ m$$

d.2. Rotatory coating drum

Ammonium nitrate		**Coating**	
Flow (kg/h)	24871.13	Flow (kg/h)	128.87
t1 (ºC)	25	T1 (ºC)	25
Pressure (kPa)	100	Pressure (kPa)	100

This equipment is in charge to spray the coating product into the final ammonium nitrate product.

d.2.1. Conditioner diameter

$$D = \left(\frac{4m_{AN}}{\pi u(1-f)}\right)^{0.5} \qquad \text{Eq. 52}$$

Where

D: Conditioner diameter (m)

m_{AN}: Ammonium nitrate mass low (kg/s)

u: Solid velocity (m/s)

f: Fill factor

Solid velocity is considered 1.4 m/s for <12 mm granules. Fill factor is recommended to be between 10 and 15%. 12% was chosen.

$$D = 2.67\ m$$

d.2.2. Conditioner length

Length in those equipment is considered 4D

$$L = 4D = 10.69\ m$$

d.2.3. Residence time

In this equipment the residence time is valued into 15min. It depends on the material to cool.

d.2.4. Number of fins

$$N_f = 4\pi D = 33 \qquad \text{Eq. 53}$$

Where

N_f: Number of fins

D: Conditioner diameter (m)

d.2.5. Fins height

$$10H_f = D \qquad \text{Eq. 54}$$

Where

H_f: Fins height (m)

D: Conditioner diameter (m)

$$H_f = 0.26m$$

d.2.6. Determination of engine power

$$P = \frac{5 + 0.11\ L\ D}{\eta} \qquad \text{Eq. 55}$$

Where
P: Engine Power (Hp)
D: Dryer diameter (m)
L: dryer length (m)
η: Engine efficiency

Applying a 20% security factor

$$P = 11.10\ Hp$$

d.2.7. Thickness of the drum
Using *Eq. 4.*

$$t = 3.77\ mm$$

d.2.8. Sprinkler design

$$P = \frac{0.0000256BM}{\rho_L} \qquad \text{Eq. 56}$$

Where

P: Power required (Hp)

B: Preassure at the exit of the sprinkle, 14.5 psi

M: Coating agent mass flow (kg/h)

P_C: Coating agent density (kg/m^3)

$$P = 0.94\ Hp$$

e) Screen design
e.1. Big granules rejecter screener

e.1.1. Screening area

$$A = \frac{T}{C\ Q_1 Q_2 Q_3 Q_4 Q_5 Q_6} \qquad \text{Eq. 57}$$

Where:

A: Requiered area (m^2)

T: Mass flow (t/h)

C: Empiric capacity

Q_1: Correction factor for material density

Q_2: Correction factor for net shape

Q_3: Correction factor for particle shape (1 for spherical particle)

Q_4: Correction factor for open area

Q_5: Correction factor for moisture screening (1 for dry screening)

Q_6: Correction factor for material moisture (1 for dried material)

e.1.1.1.Correction factor for open area

Luz malla (mm)	Diámetro borde (mm)	Superficie útil de pasaje (%)	n° pulgadas francesas
0,076	0,05	36,2	220
0,114	0,06	42,4	160
0,128	0,07	41,6	140
0,141	0,09	37,1	120
0,153	0,1	36,2	110
0,158	0,12	32,4	100
0,189	0,12	37,1	90
0,514	0,18	53,9	40
1,01	0,22	66,9	22 ½
1,54	0,6	48,3	13
2,49	0,6	64,6	9
2,97	1	56	7
4	1	69,3	5 ½
5,94	1	73,2	4
8,26	1	79,6	3
10,01	1,1	81	2 ½

Graph 17: Correction factor for open area

$$Q_4 = \frac{\%\ Superficie\ util\ de\ pasaje}{50} \qquad \text{Eq. 58}$$

$$Q_4 = 1.12$$

$$A = 1.97\ m^2$$

e.1.2. Screening diameter

$$D = \sqrt{\frac{4A}{\pi}} \qquad \text{Eq. 59}$$

$$D = 1.58\ m$$

e.2. Dust granules rejecter screener

e.2.1. Screening area

$$A = \frac{T}{C\ Q_1 Q_2 Q_3 Q_4 Q_5 Q_6} \qquad \text{Eq. 60}$$

Where:

A: Required area (m^2)

T: Mass flow (t/h)

C: Empiric capacity

Q_1: Correction factor for material density

Q_2: Correction factor for net shape

Q_3: Correction factor for particle shape (1 for spherical particle)

Q_4: Correction factor for open area

Q_5: Correction factor for moisture screening (1 for dry screening)

Q_6: Correction factor for material moisture (1 for dried material)

e.2.1.1.Correction factor for open area

$$Q_4 = \frac{\%\ Superficie\ util\ de\ pasaje}{50} \qquad \text{Eq. 61}$$

$$Q_4 = 1.338$$

$$A = 1.84m^2$$

e.2.2. Screening diameter

$$D = \sqrt{\frac{4A}{\pi}} \qquad \text{Eq. 62}$$

$$D = 1.53\ m$$

f) Transport equipment

f.1. Bucket elevator

Used to elevate the stream exiting the dryer to the screener, located on the top of the granulator system

Ammonium nitrate	
Flow (kg/h)	25150.23
density (kg/m3)	1360
Elevation height (m)	10

ELEVATOR CAPACITY SELECTION				
CAPACITY BPH (*MTPH*)	PULLEY DIAMETER INCHES (*mm*)	BELT SPEED		BUCKET & SPACING INCHES (*mm*)
		FPM (*M/S*)	RPM	
500 (13)	10 *(254.0)*	314 *(1.59)*	109	6x4 *(152.4x101.6)* @ 12" *(304.8)*
750 (20)	10 *(254.0)*	314 *(1.59)*	109	6x4 *(152.4x101.6)* @ 6" *(152.4)*
1,000 *(27)*	16 *(406.4)*	414 *(2.10)*	93	9x6 *(228.6x152.4)* @ 20" *(508.0)*
2,000 *(54)*	16 *(406.4)*	414 *(2.10)*	93	9x6 *(228.6x152.4)* @ 10" *(254.0)*
3,000 *(81)*	16 *(406.4)*	414 *(2.10)*	93	9x6 *(228.6x152.4)* @ 7" *(177.8)*
	24 *(609.6)*	478 *(2.43)*	73	12x6 *(304.8x152.4)* @ 10" *(254.0)*
4,000 *(108)*	24 *(609.6)*	478 *(2.43)*	73	12x6 *(304.8x152.4)* @ 8" *(203.2)*
	30 *(762.0)*	544 *(2.76)*	67	12x6 *(304.8x152.4)* @ 9" *(228.6)*
5,000 *(136)*	30 *(762.0)*	544 *(2.76)*	67	12x6 *(304.8x152.4)* @ 7" *(177.8)*
	36 *(914.4)*	630 *(3.20)*	65	12x7 *(304.8x177.8)* @ 12" *(304.8)*
6,000 *(163)*	36 *(914.4)*	630 *(3.20)*	65	12x7 *(304.8x177.8)* @ 10" *(254.0)*
7,500 *(204)*	36 *(914.4)*	630 *(3.20)*	65	12x7 *(304.8x177.8)* @ 8" *(203.2)*
	36 *(914.4)*	630 *(3.20)*	65	16x7 *(406.4x177.8)* @ 11" *(266.7)*
10,000 (272)	36 *(914.4)*	630 *(3.20)*	65	16x7 *(406.4x177.8)* @ 8.5" *(215.9)*
	42 (*1066.8*)	642 *(3.26)*	57	16x8 *(406.4x203.2)* @ 11.5" *(292.1)*
12,000 *(326)*	42 (*1066.8*)	642 *(3.26)*	57	16x8 *(406.4x203.2)* @ 10" *(254.0)*
15,000 *(408)*	48 *(1219.2)*	718 *(3.65)*	56	20x8 *(508.0x203.2)* @ 10.5" *(266.7)*
20,000 *(544)*	48 *(1219.2)*	718 *(3.65)*	56	(2) 16x8 *(406.4x203.2)* @ 13" *(330.2)*
22,500 *(612)*	48 *(1219.2)*	718 *(3.65)*	56	(2) 16x8 *(406.4x203.2)* @ 12" *(304.8)*
25,000 *(680)*	48 *(1219.2)*	718 *(3.65)*	56	(2) 16x8 *(406.4x203.2)* @ 10.5" *(266.7)*
28,000 *(762)*	48 *(1219.2)*	718 *(3.65)*	56	(2) 16x8 *(406.4x203.2)* @ 9.5" *(241.3)*
30,000 *(816)*	48 *(1219.2)*	718 *(3.65)*	56	(2) 16x8 *(406.4x203.2)* @ 8.5" *(215.9)*

Graph 18: Elevator capacity

Third row is selected, the 27 MTPH.

Bucket has:

- ✓ 9x6 Dimension
- ✓ 226.6 mm length
- ✓ 152.4 mm proyection
- ✓ 152.4 mm profundity
- ✓ Gross capacity: 5.26 l/bucket

f.1.1. High weight per bucket

$$B = fC\rho \qquad \text{Eq. 63}$$

Where

B: High weight (kg/bucket)

f: Filling factor

C: Gross capacity (m^3/bucket)

d: Density (kg/m^3)

Filling factor is recommended to be 0.75

$$B = 3.35\ kg/bucket$$

f.1.2. Bucket velocity

$$v_C = \frac{M}{B} \quad \text{Eq. 64}$$

Where

v_c: Bucket velocity (buckets/s)

M: Mass flow (kg/s)

B: High weight (kg/bucket)

$$v_C = 2.1\ buckets/s$$

f.1.3. Tangential speed

$$v = E v_c \quad \text{Eq. 65}$$

Where

v: tangential velocity (m/s)

E: Bucket spacing (m)

v_c: Bucket velocity (bucket/s)

$$v = 1.067\ m/s$$

f.1.4. Drum diameter

$$D_d = 2\frac{v^2}{g} \quad \text{Eq. 66}$$

Where:

Dd: Drum diameter /m)

g: Gravity acceleration (m/s^2)

v: Tangential velocity (m/s)

$$D_d = 0.23\ m$$

f.1.5. Length of the band

$$L_b = 2H + D_d \pi \qquad \textit{Eq. 67}$$

Where

L_b: Length of the band (m)

H: Elevation height (m)

Dd: Drum diameter (m)

$$L_b = 20.72\ m$$

f.1.6. Number of buckets

$$N_b = \frac{L_b}{E} \qquad \textit{Eq. 68}$$

Where

N_b: Number of buckets

L_b: Lenght of band (m)

E: Bucket space (m)

$$N_b = 41\ buckets$$

f.1.7. Drum strength

$$F = \frac{M(H + H_o)}{3.6v} \qquad \textit{Eq. 69}$$

Where

F: Drum strength (CV)

M: Mass flow (TM/h)

H: Elevation height (m)

Ho: Height factor correction, 7.6 m

v: Tangential velocity (m/s)

$$F = 115\ CV$$

f.1.8. Elevator power

$$P = \frac{Fv}{75\eta} \qquad \text{Eq. 70}$$

Where

P: Power (CV)

F: Drum strength (CV)

v: Tangential velocity (m/s)

n: motor efficiency, 0.8

$$P = 2.045\ CV$$

f.2. Conveyor belts

g) Pumps Design

Pump P-1 will be done as an example of pump design calculations. It pumps nitric acid from T-2 to R-1

Nitric acid			
M (kg/h)		26007	
density (kg/m3)		1510	
Q (m3/s)		0.004784216	
Specific weight (kN/m3)		13.394	
Viscosity (m2/s)		0.000000546	
Pipe 1		**Pipe 2**	
Pipe 1 lenght	2	Pipe 2 lenght	8
Diameter (m)	0.102	Diameter (m)	0.102
Velocity (m/s)	0.58538133	Velocity (m/s)	0.58538133
Pressure (kPa)	100	Pressure (kPa)	200
Height (m)	0	Height (m)	2
Roughness (m)	0.000015	Roughness (m)	0.0000015

g.1. In pipe 1 (suction pipe)

g.1.1. Relative roughness

$$R_r = \frac{D}{E} \qquad \text{Eq. 71}$$

Where

Rr: Relative roughness

D: Pipe diameter

E: Roughness

$$R_r = 6800$$

g.1.2. Velocity charge

$$V_c = \frac{V^2}{2g} \qquad \text{Eq. 72}$$

Where

Vc: Velocity charge (m)

V: Velocity (m/s)

g: gravity (m/s2)

$$V_c = 0.01746$$

g.1.3. Reynolds number

$$Re = \frac{VD}{\gamma} \qquad \text{Eq. 73}$$

Where

Re: Reynolds number

V: velocity (m/s)

D: Diameter (m)

Gamma: viscosity (m^2/s)

$$Re = 1.09x10^5$$

g.1.4. Friction factor

$$f = \frac{0.25}{\left[\log\left(\frac{1}{3.7\left(\frac{D}{E}\right)} + \frac{5.74}{N_R^{0.9}}\right)\right]^2} = 0.0184 \qquad \text{Eq. 74}$$

g.1.5. Energy loss

Kinetic Energy Factors	
Type of fitting or configuration	**e_v**
Elbow, 45°	0.35
Elbow, 90°	0.75
Tee	1
Return bend	1.5
Coupling	0.04
Union	0.04
Gate valve (wide open)	0.17
Gate valve (half open)	4.5
Glove valve (wide open)	6
Globe valve (half open)	9.5
Angle valve (wide open)	2
Check valve (ball)	70
Check valve (swing)	2
Water meter (disk)	7
Rounded entrance to pipe	0.05
Sudden contraction	0.45(1-B)*
Sudden expansion	$(1/B-1)^2$
Expansion into infinite reservoir	1**
Orifice	$2.7(1-B)(1-B^2)/B^2$

*B= (smaller cross-sectional area)/(larger cross-sectional area)
**for this case, use the upstream value of <v>

Graph 19: Kinetic Energy Factor

From figure above we can suppose e_v from different configurations and equipments on the pipe. To calculate the pipe itself energy losses from friction;

$$e_v = \frac{V^2}{gR_H} L\, f \qquad \text{Eq. 75}$$

Where

e_v: Kinetic energy factor

V: Velocity (m/s)

G: Gravity acceleration (m/s^2)

R_H: Hydraulic radius

L: Pipe length

f: Friction factor

$$e_v = 0.026$$

Equipment	e_v	Energy loss (m)
Pipe	0.026	0.0004
Globe valve	6	0.1048

Where the energy loss is calculated

$$h = V_c * e_v \qquad \text{Eq. 76}$$

Total energy loss on pipe 1:

$$h_{L1} = \sum h_e$$

g.2. In pipe 2 (impulsion pipe)

g.2.1. Relative roughness

$$R_r = \frac{D}{E} \qquad \text{Eq. 77}$$

Where

Rr: Relative roughness

D: Pipe diameter

E: Roughness

$$R_r = 68000$$

g.2.2. Velocity charge

$$V_c = \frac{V^2}{2g} \qquad \text{Eq. 78}$$

Where

Vc: Velocity charge (m)

V: Velocity (m/s)

g: gravity (m/s2)

$$V_c = 0.01746$$

g.2.3. Reynolds number

$$Re = \frac{VD}{\gamma} \qquad \text{Eq. 79}$$

Where

Re: Reynolds number

V: velocity (m/s)

D: Diameter (m)

Gamma: viscosity (m^2/s)

$$Re = 1.09x10^5$$

g.2.4. Friction factor

$$f = \frac{0.25}{\left[\log\left(\frac{1}{3.7\left(\frac{D}{E}\right)} + \frac{5.74}{N_R^{0.9}}\right)\right]^2} = 0.0184 \qquad \text{Eq. 80}$$

g.2.5. Energy loss

From figure X we can suppose e_v from different configurations and equipments on the pipe. To calculate the pipe itself energy losses from friction;

$$e_v = \frac{V^2}{gR_H} L\, f \qquad \text{Eq. 81}$$

Where

e_v: Kinetic energy factor

V: Velocity (m/s)

G: Gravity acceleration (m/s^2)

R_H: Hydraulic radius

L: Pipe length

f: Friction factor

$$e_v = 0.104$$

Equipment	e_v	Energy loss (m)
Pipe	0.104	0.0017
Globe valve	6	0.1048
Standard elbow (2)	0.75	0.01310

Where the energy loss is calculated

$$h = V_c * e_v \qquad \text{Eq. 82}$$

Total energy loss on pipe 1:

$$h_{L2} = \sum h_e$$

g.3. Total energy losses

$$h_L = H_{L1} + H_{L2} = 0.225\ m \qquad \text{Eq. 83}$$

g.4. Total charge on pump

$$h_A = \frac{P_2 - P_1}{\gamma} + (z_2 - z_1) + \frac{v_2^2 - v_1^2}{2g} + h_L \qquad \text{Eq. 84}$$

Where

P2: Pressure on pipe 2

P1: Pressure on pipe 1

gamma: Specific weight

z2: Pipe 2 height

z1: Pipe 1 height

V2: velocity on pipe 2

V1: velocity on pipe 1

h_L: Total energy loss

$$h_A = 52.2$$

g.5. Power added to the fluid

$$P_A = h_A \gamma Q \qquad \text{Eq. 85}$$

Where

P_A: Power added to fluid

gamma: Specific weight

Q: Volumetric flow

$$P_A = 4.48\ HP$$

g.6. Power needed

$$P_T = \frac{P_A}{\eta} \qquad \text{Eq. 86}$$

Where

P_A: Power added to fluid

$$P_T = 5.75\ HP$$

h) Fan design

Fan F-1 will be the responsible to provide air mass flow to the cooler C-1

Air	
Flow (kg/h)	80445.63
T1 (ºC)	95
density (kg/m3)	1.18
Discharge pressure (kPa)	102.7317005
Suction pressure (kPa)	101.3527515

h.1. Total pressure drop

$$\Delta P_T = P_2 - P_1 \qquad \text{Eq. 87}$$

Where

P2: Discharge pressure

P1: Suction pressure

$$\Delta P_T = 1.3789\ kPa$$

h.2. Velocities pressure

$$P_V = \rho V_a^2 \quad \text{Eq. 88}$$

Where

Pv: Pressure of velocity

p: density

Va: average velocity, estimed 0.8 m/s

$$P_V = 0.00075\ kPa$$

h.3. Operation pressure

$$P_O = \Delta P_T - P_V = 1.3782\ kPa \quad \text{Eq. 89}$$

h.4. Fan pressure

$$H = \frac{P_O}{\rho_{gas}} = 1.17\ kPa \quad \text{Eq. 90}$$

h.5. Power added to fluid

$$P_A = mH \quad \text{Eq. 91}$$

Where

P_A: Power added to fluid (HP)

m: Mass flow (kg/m3)

H: Fan pressure (kPa)

$$P_A = 26.1\ HP$$

h.6. Power needed

$$P_T = \frac{P_A}{n}$$ *Eq. 92*

Where

P_T: Total power needed (HP)

P_A: Power added to fluid (HP)

n: Efficiency, 0.85

i) Cyclone design

Both cyclones are designed to separate ammonium nitrate dust from the air, to recuperate product and to avoid emissions to the atmosphere. Most recommended cyclone type is 2D2D, that means that both length of the cone and tube are 2 times inlet diameter.

i.1. Diameter determination

In order to determine diameter, some relation-tables will be used.

	Cyclone Type					
	High Efficiency		Conventional		High Throughput	
	(1)	(2)	(3)	(4)	(5)	(6)
Body Diameter, D/D	1.0	1.0	1.0	1.0	1.0	1.0
Height of Inlet, H/D	0.5	0.44	0.5	0.5	0.75	0.8
Width of Inlet, W/D	0.2	0.21	0.25	0.25	0.375	0.35
Diameter of Gas Exit, D_e/D	0.5	0.4	0.5	0.5	0.75	0.75
Length of Vortex Finder, S/D	0.5	0.5	0.625	0.6	0.875	0.85
Length of Body, L_b/D	1.5	1.4	2.0	1.75	1.5	1.7
Length of Cone, L_c/D	2.5	2.5	2.0	2.0	2.5	2.0
Diameter of Dust Outlet, D_d/D	0.375	0.4	0.25	0.4	0.375	0.4

Graph 20: Cyclone design relations

Maximum velocity recommended inlet, is 50 m/s. Isolating, using table X relations diameter can be deduced.

$$V_i = \frac{Q}{WH} = \frac{M}{\rho WH}$$ *Eq. 93*

Where

Vi: Inlet velocity (m/s)

Q: Volumetric flow (m3/s)

M: Mass flow (kg/s)

W: Width of the inlet (m)

H: Height of the inlet (m)

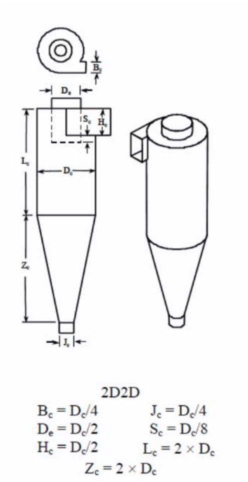
From relations above

$$V_i = \frac{Q}{WH} = \frac{M}{\rho\ 0.25 D_c\ 0.5 D_c}$$

Dc: Inlet diameter (m)

$$D_c = 1.71\ m$$

The most standard cyclone design type is 2D2D, so with the picture below all measurements can be calculated.



Graph 21: 2D2D Cyclone

i.2. Effective turn

Number of effective turns is the number of revolutions the gas spinswhile passing through the cyclone outer vortex

$$N_e = \frac{1}{H}\left(L_b + \frac{L_c}{2}\right) \qquad \text{Eq. 94}$$

Where

Lb: Length of the tube (m)

Lc: Length of the cone

H: Height of the inlet

Ne: Number of turns inside the device

$$N_e = 6$$

i.3. Gas residence time

$$\theta = \frac{\pi D_c N}{V_i} = 0.65 \ s \qquad \text{Eq. 95}$$

i.4. Power requierement

$$W_f = Q\Delta P \qquad \text{Eq. 96}$$

Where

Q: Volumetric flow

Wf: final power requierement

P: Pressure drop

i.4.1. Pressure drop

$$\Delta P = \frac{\alpha \rho V_i^2}{2} \qquad \text{Eq. 97}$$

Where

$$\alpha = 16\frac{HW}{D_e^2} = 6.84 \qquad \text{Eq. 98}$$

$$\Delta P = \frac{\alpha \rho V_i^2}{2} = 2.47 \ kPa$$

$$W_f = Q\Delta P = 45kW$$

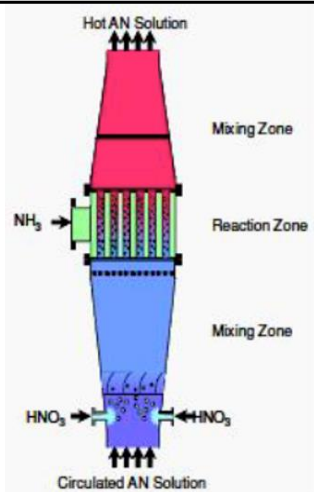
APPENDIX 7: DATASHEETS

REACTOR R-1 DATASHEET				
Project: Calcium ammonium nitrate production plant				Date: June 2019
Location: Sagunt, València				Serie: P-1
Equipment service: Ammonium nitrate production via ammonia and nitric acid neutralization				
Type: Multitubular reactor with cooling jacket			Vertical	Connected
UNIT PERFORMANCE				
	Stream C	Stream D	Stream P	Stream E
	Ammonia	Nitric acid	AN recirculation	Ammonium nitrate
Mass flow (kg/h)	4168.63	26007.43	1107.85	31283.91
Composition (% p/p)				
Ammonia	100.00	-	-	
Nitric acid	-	60.00	1.33	
Ammonium nitrate	-	-	66.00	93.00
Water	-	40.00	32.67	7.00
temperature (ºC)	60.00	60.00	140.00	120.00
Pressure (kPa)	600.00	200.00	100.00	45.00

DESIGN DATA

	Zone 1	Zone 2	Zone 3
High Diameter (m)	3	3	3
Low Diameter (m)	0.75	3	0.75
Height (m)	0.77	4.5	0.77
Thickness (mm)	4.96	4.96	4.96
Volume (m^3)	9.54	31.8	9.54

Tube bundle	
Nº of tubes: 1947	Nominal Diameter: 1"
Pitch arrengement: square1 1.25". 0.25" holes every 3"	
Lenght: 4.5m	Material: Stainless steel 304 type
Heat transfer area	
Heat removed: 16 621 108.89 kJ/h	Needed heat transfer area: 42.53 r
Overall heat transfer coefficient: 1245 $W/m^2.ºC$	
Cooling jacket diameter: 3.04 m	



Couplings	
Detail	Diameter (mm)
Ammonia entrance	125
Nitric acid entrance	60
Ammonium nitrate recirculated entrance	15
Ammonium nitrate produced exit	80
Water entrance	150
All couplings are made of Stainles Steel 304 type	

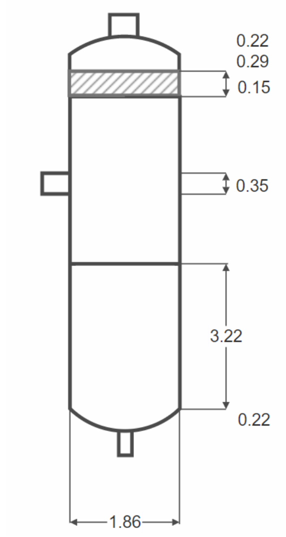
COMMENTS

FLASH EVAPORATOR FE-1		
Project: Calcium ammonium nitrate production plant		Date: June 2019
Location: Sagunt, València		Serie: FE-1
Equipment service: Effluent separation from the reactor		
Type: Low pressure liquid-vapour separator	Vertical	Connected

UNIT PERFORMANCE			
	FEED	VAPOUR	LIQUID
Mass flow (kg/h)	31283.91	9126.83	22157.08
Composition (% p/p)			
Nitric acid	1.33	4.56	-
Ammonium nitrate	66.00	0.45	93.00
Water	32.67	94.99	7.00
temperature (ºC)	140.00	120.00	120.00
Pressure (kPa)	100.00	45.00	45.00

DESIGN DATA

Pressure design (kPa): 0.50	
Design temperature (ºC): 170	
Torispherical head design	
Vapour data	
Gas velocity (m/s): 16.64	
Density (kg/m3): 0.26	
Volumetric flow (m^3/s): 9.75	
Liquid data	
Volumetric flow (m^3/s): 3.17E-3	
Liquid volume (m^3): 1.9	
MECHANIC DESIGN	
Tank height (m): 6.26	
Tank diameter (m): 1.86	
Thickness (mm): 5.32	
Material: Stainless Steel 406 type	
Tank volume (m^3): 3.63	
COUPLINGS	
Detail	Diameter (m)
Feed	0.08
Vapour exit	0.508
Liquid exit	0.0508



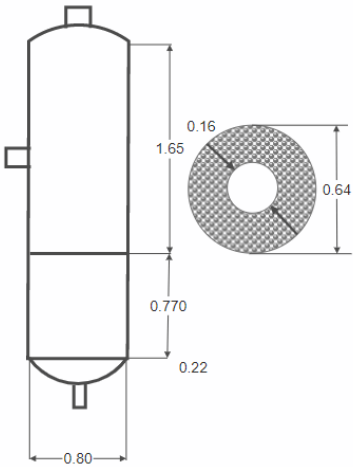
All couplings are made of Stainles Steel 304 type

COMMENTS

TUBES EVAPORATOR E-1		
Project: Calcium ammonium nitrate production plant		Date: June 2019
Location: Sagunt, València		Serie: E-1
Equipment service: Concentration of the ammonium nitrate solution		
Type: Short tube with intern space evaporator	Vertical	Connected

UNIT PERFORMANCE			
	FEED	VAPOUR	LIQUID
Mass flow (kg/h)	21049.23	945.47	20103.76
Composition (% p/p)			
Ammonium nitrate	93.00	20.71	96.40
Water	7.00	79.29	3.60
Temperature (ºC)	120.00	150.00	150.00
Pressure (kPa)	45.00	100.00	100.00

DESIGN DATA
Pressure design (kPa): 1.2
Design temperature (ºC): 170
Torispherical head design
Heat exchange area (m^2): 10.68
Gas velocity (m/s): 0.73
Density (kg/m3): 2.668
Overall heat transfer coefficient ($W/m^2 \cdot ºC$)
Nº of tubes: 268
Intern tubes diameter (m): 0.0254
Lenght of tubes (m): 0.5
Internal tube diameter (m): 0.16



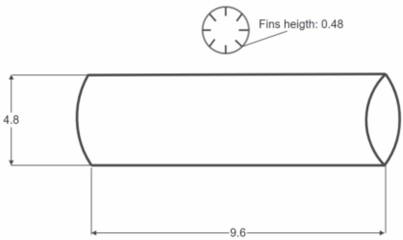
MECHANICAL DESIGN
Tank height (m): 2.42
Tank diameter (m): 0.8
Thickness (mm): 5.32
Material: Stainless Steel 406 type
Tank volume (m^3): 1.21

COUPLINGS	
Detail	Diameter (m)
Feed	0.0508
Vapour exit	0.0508
Liquid exit	0.0508
All couplings are made of Stainles Steel 304 type	

COMMENTS

ROTATORY DRYER D-1			
Project: Calcium ammonium nitrate production plant			Date: June 2019
Location: Sagunt, València			Serie: D-1
Equipment service: Dryer for the calcium ammonium nitrate dryer			
Type: Rotatory dryer		Horitzontal	Connected
UNIT PERFORMANCE			
	FEED	EXIT	AIR
Mass flow (kg/h)	25925.55	25150.27	80445.63
Composition (% p/p)			
Calcium ammonium nitrate	97.00	99.90	0.00
Water	3.00	0.10	0.90
Temperature (ºC)	85.00	95.00	138 / 90
Pressure (kPa)	100.00	100.00	100.00

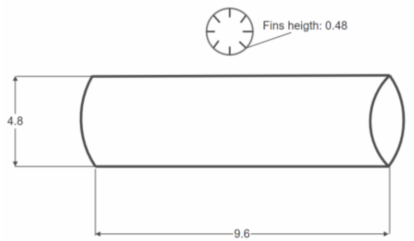
DESIGN DATA
Pressure design (kPa): 1.2
Design temperature (ºC): 150
Residence time (min): 5.12
Fill factor: 12%
Slope (m/m): 0.08
Velocity (RPM): 5
Average diameter of the prills (mm): 1.5
Entrance humidity (kgW/kg D.S.): 0.03
Exit humidity (kgW/kg D.S.): 0.01
Entrance humidity (kgW/kg D.A.): 0
Exit humidity (kgW/kg D.A.): 0.009
MECHANICAL DESIGN
Dryer diameter (m): 4.8
Dryer length (m): 9.6
Number of fins: 60
Fins height (m): 0.48
Material: Stainless Steel 304 type
Thickness (mm): 5.03
MECHANICAL DRIVE
Power (HP): 13.75
Efficiency: 0.85



COMMENTS

ROTATORY COOLER C-1			
Project: Calcium ammonium nitrate production plant			Date: June 2019
Location: Sagunt, València			Serie: C-1
Equipment service: Dryer for the calcium ammonium nitrate dryer			
Type: Rotatory dryer		Horitzontal	Connected
UNIT PERFORMANCE			
	FEED	EXIT	AIR
Mass flow (kg/h)	25925.55	25150.27	80445.63
Composition (% p/p)			
Calcium ammonium nitrate	99.90	99.90	0.00
Water	0.10	0.10	0.05
Temperature (ºC)	95.00	25.00	95 / 25
Pressure (kPa)	100.00	100.00	100.00

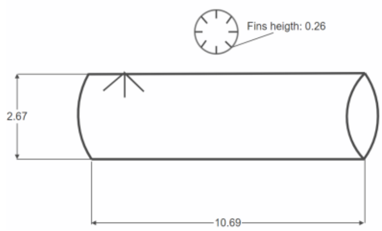
DESIGN DATA
Pressure design (kPa): 1.2
Design temperature (ºC): 115
Residence time (min): 10
Fill factor: 12%
Slope (m/m): 0.08
Velocity (RPM): 5
Average diameter of the prills (mm): 1.5
MECHANICAL DESIGN
Dryer diameter (m): 4.8
Dryer length (m): 9.6
Number of fins: 60
Fins height (m): 0.48
Material: Stainless Steel 304 type
Thickness (mm): 5.03
MECHANICAL DRIVE
Power (HP): 13.75
Efficiency: 0.85



COMMENTS

ROTATORY COATING DRUM CD-1		
Project: Calcium ammonium nitrate production plant		Date: June 2019
Location: Sagunt, València		Serie: CD-1
Equipment service: Dryer for the calcium ammonium nitrate dryer		
Type: Rotatory dryer	Horitzontal	Connected

UNIT PERFORMANCE		
	FEED	COATING AGENT
Mass flow (kg/h)	24871.13	128.87
Composition (% p/p)		
Coating Agent	0	97
Calcium ammonium nitrate	99.9	0
Water	0.01	3
Temperature (ºC)	25	25
Pressure (kPa)	100	100

DESIGN DATA	
Pressure design (kPa): 1.2	
Design temperature (ºC): 50	
Residence time (min): 15	
Fill factor: 12%	
Slope (m/m): 0.08	
Velocity (RPM): 5	
Average diameter of the prills (mm): 1.5	
MECHANICAL DESIGN	
Dryer diameter (m): 2.67	
Dryer length (m): 10.69	
Number of fins: 33	
Fins height (m): 0.26	
Material: Stainless Steel 304 type	
Thickness (mm): 5.03	
MECHANICAL DRIVE	
Power (HP): 11.10	
Efficiency: 0.85	
Sprinkle power demand (HP): 0.94	

COMMENTS

STORAGE TANK T-1		
Project: Calcium ammonium nitrate production plant		Date: June 2019
Location: Sagunt, València		Serie: T-1
Equipment service: Ammonia storage		
Type: Spherical tank	Spherical	Connected

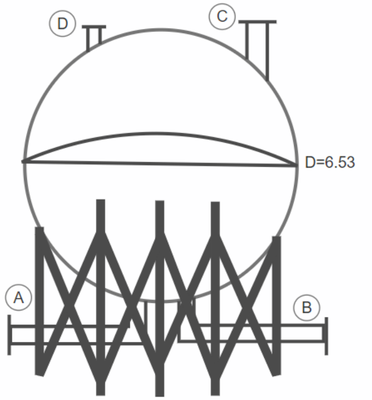
UNIT PERFORMANCE			
Storaging tank for 10 bar ammonia			
Posicion:	Vertical	Density (kg/m3)	600
Diameter (m)	6.53	Empty tank weight (t)	5.35
Height (m)	-	Water-filled tank weight (t)	1167.2164
Capacity (m3)	1167.2164	Operational weight (t)	700

DESIGN DATA

Container	
Product	Ammonia
Operational temperature (ºC)	25
Fluid pressure (kPa)	1050
Container pressure (kPa)	1150
Upper area	-
Bottom	-
Wall thickness	9.32 mm

Couplings		
Mark	size	Dexcription
A	0.06	Discharge coupling
B	0.06	Charge coupling
C	0.06	Purge coupling
D	0.06	Pressure relief vent

Design details	
Design normative	ASME
Material	Stainless Steel 304
Desnity (kg/m3)	7980
Isolation	No
Welding factor	0.85
Lateral area (m2)	-



COMMENTS

STORAGE TANK T-2			
Project: Calcium ammonium nitrate production plant			Date: June 2019
Location: Sagunt, València			Serie: T-2
Equipment service: Nitric acid storage			
Type: vertical tank		Vertical	Connected

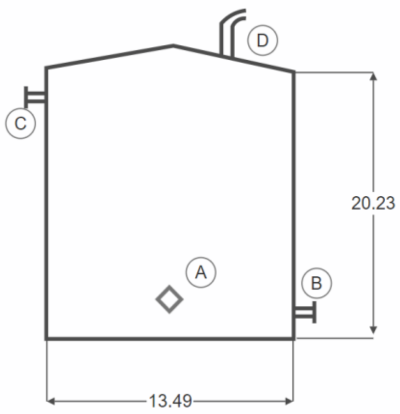
UNIT PERFORMANCE			
Storaging tank for 60% nitric acid			
Posicion:	Vertical	Density (kg/m3)	1510
Diameter (m)	13.49	Empty tank weight (t)	45
Height (m)	20.23	Water-filled tank weight (t)	2893
Capacity (m3)	2893	Operational weight (t)	4368

DESIGN DATA

Container	
Product	Nitric acid
Operational temperature (ºC)	25
Fluid pressure (kPa)	100
Container pressure (kPa)	362.16
Upper area	Conic (10mm)
Bottom	Flat (10mm)
Wall thickness	6.66 mm

Couplings		
Mark	size	Dexcription
A	1.5 m	Manhole
B	0.06 m	Discharge coupling
C	0.06 m	Charge coupling
D	0.1 m	Pressure relief vent

Design details	
Design normative	ASME
Material	Stainless Steel 304
Desnity (kg/m3)	7980
Isolation	No
Welding factor	0.85
Lateral area (m2)	857



COMMENTS

SAFETY TANK T-3		
Project: Calcium ammonium nitrate production plant		Date: June 2019
Location: Sagunt, València		Serie: T-2
Equipment service: safety tank		
Type: Vertical tank	Vertical	Connected

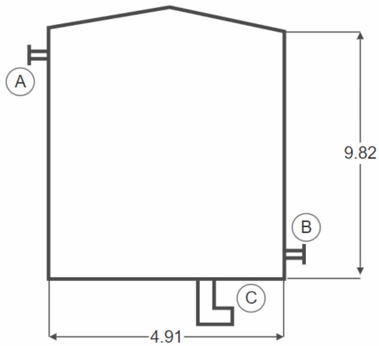
UNIT PERFORMANCE			
Storaging tank for 60% nitric acid			
Posicion:	Vertical	Density (kg/m3)	1360
Diameter (m)	4.91	Empty tank weight (t)	45
Height (m)	9.82	Water-filled tank weight (t)	185.73
Capacity (m3) (~12h)	185.73	Operational weight (t)	253

DESIGN DATA

Container	
Product	Ammonium nitrate
Operational temperature (°C)	120
Fluid pressure (kPa)	100
Container pressure (kPa)	362.16
Upper area	Conic (10mm)
Bottom	Flat (10mm)
Wall thickness	6.66 mm

Couplings		
Mark	size	Dexcription
A	0.1	Charge coupling
B	0.1	Discharge coupling
C	0.2	Purge

Design details	
Design normative	ASME
Material	Stainless Steel 304
Desnity (kg/m3)	7980
Isolation	No
Welding factor	0.85
Lateral area (m2)	151



COMMENTS

HEAT EXCHANGER HE-1 DATASHEET		
Project: Calcium ammonium nitrate production plant		Date: June 2019
Location: Sagunt, València		Serie: HE-1
Equipment service: Heat ammonia using flash vapour		
Type: Multitubular reactor with cooling jacket	Horitzontal	Connected

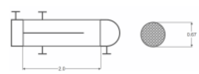
UNIT PERFORMANCE

	Shell side		Tubes side	
	Vapour		Ammonia	
Mass flow (kg/h)	9126.83		4168.63	
	Entrance	Exit	Entrance	Exit
Gas	-	-	-	-
Liquid	-	-	-	-
Vapor	9126.83	9126.83	4168.63	4168.63
Specific heat (kJ/kg.ºC)	2.09		2.11	
Molecular weight	-		17.00	
Temperature (entrance/exit)	120.00	103.80	25.00	60.00
Pressure (kPa)	100		600	
Heat exchanged (kW): 85.51	LMTD (ºC): 69.00		OHTC(U, W/m2.ºC): 50	

HEAT EXCHANGER DESIGN

		Shell	Tubes
Pressure Design (kPa)		120	720
Design temperature (ºC)		140 / 30	
Number of steps		1	2
Couplings	Entrance		
	Exit		

FIGURE



TUBES

Number of tubes: 119	Nominal diameter (m): 0.04	Length (m): 2	Square pitch (in): 1.5"
Nº BWG: 14	Roughness (mm): 4.15	Stainless steel type 304	

SHELL

Shell Diameter (m): 0.67	Roughness (mm): 8.69	Shell cover: Thermal isolation

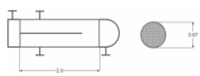
BAFFLES

Percentage of cut: 25%	Baffle spacing (mm): 134

TUBES BOUNDLE

Tubular boundle	Diamater (m): 0.655	Type of heading: Floating heading

COMMENTS

HEAT EXCHANGER HE-2 DATASHEET				
Project: Calcium ammonium nitrate production plant				Date: June 2019
Location: Sagunt, València				Serie: HE-2
Equipment service: Heat nitrc acid using flash vapour				
Type: Multitubular reactor with cooling jacket			Horitzontal	Connected
UNIT PERFORMANCE				
	Shell side		Tubes side	
	Vapour		Nitric acid	
Mass flow (kg/h)	9126.83		26007.43	
	Entrance	Exit	Entrance	Exit
Gas	-	-	-	-
Liquid	-	-	26007.43	26007.43
Vapor	9126.83	9126.83	-	-
Specific heat (kJ/kg.ºC)	2.09		2.70	
Molecular weight	-		17.00	
Temperature (entrance/exit)	103.80	45.00	25.00	41.00
Pressure (kPa)	100		200	
Heat exchanged (kW): 311.25	LMTD (ºC): 37.40		OHTC(U, W/m2.ºC): 800	
HEAT EXCHANGER DESIGN			**FIGURE**	
	Shell	Tubes		
Pressure Design (kPa)	120	240		
Design temperature (ºC)	140 / 30			
Number of steps	1	2		
Couplings: Entrance				
Couplings: Exit				
TUBES				
Number of tubes: 40	Nominal diameter (m): 0.1	Length (m): 2	Square pitch (m): 0.125	
Nº BWG: 14	Roughness (mm): 4.15	Stainless steel type 304		
SHELL				
Shell Diameter (m): 1.014	Roughness (mm): 8.69	Shell cover: Thermal isolation		
BAFFLES				
Percentage of cut: 25%		Baffle spacing (mm): 203		
TUBES BOUNDLE				
Tubular boundle	Diamater (m): 0.999	Type of heading: Floating heading		
COMMENTS				

HEAT EXCHANGER HE-3 DATASHEET		
Project: Calcium ammonium nitrate production plant		Date: June 2019
Location: Sagunt, València		Serie: HE-3
Equipment service: Heat nitric acid with evaporators vapour		
Type: Multitubular reactor with cooling jacket	Horitzontal	Connected

UNIT PERFORMANCE				
	Shell side		Tubes side	
	Vapour		Nitric acid	
Mass flow (kg/h)	945		26007.43	
	Entrance	Exit	Entrance	Exit
Gas	-	-	-	-
Liquid	-	-	26007.43	26007.43
Vapor	945.00	945.00	-	-
Specific heat (kJ/kg.ºC)	2.28		2.70	
Molecular weight	-		63.00	
Temperature (entrance/exit)	150.00	45.00	41.00	44.20
Pressure (kPa)	100		200	
Heat exchanged (kW): 62.87	LMTD (ºC): 31.08		OHTC(U, W/m2.ºC): 800	

HEAT EXCHANGER DESIGN			
		Shell	Tubes
Pressure Design (kPa)		100	200
Design temperature (ºC)		170 / 30	
Number of steps		1	2
Couplings	Entrance		
	Exit		

FIGURE

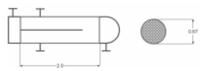
TUBES			
Number of tubes: 5	Nominal diameter (m): 0.1	Length (m): 2	Square pitch (m): 0.125
Nº BWG: 14	Roughness (mm): 4.15	Stainless steel type 304	

SHELL		
Shell Diameter (m): 0.404	Roughness (mm): 4.38	Shell cover: Thermal isolation

BAFFLES	
Percentage of cut: 25%	Baffle spacing (mm): 81

TUBES BOUNDLE		
Tubular boundle	Diamater (m): 0.389	Type of heading: Floating heading

COMMENTS

HEAT EXCHANGER HE-4 DATASHEET							
Project: Calcium ammonium nitrate production plant							Date: June 2019
Location: Sagunt, València							Serie: HE-4
Equipment service: Heat nitric acid with @5bar steam							
Type: Multitubular reactor with cooling jacket						Horitzontal	Connected
UNIT PERFORMANCE							
				Shell side		Tubes side	
				Water steam		Nitric acid	
Mass flow (kg/h)				403.74		26007.43	
				Entrance	Exit	Entrance	Exit
Gas				-	-	-	-
Liquid				-	-	26007.43	26007.43
Vapor				403.74	403.74	-	-
Specific heat (kJ/kg.ºC)				2.33		2.70	
Molecular weight				18.00		63.00	
Temperature (entrance/exit)				151.90	138.50	44.20	60.00
Pressure (kPa)				500		200	
Heat exchanged (kW): 308.2			LMTD (ºC): 92.13			OHTC(U, W/m2.ºC): 400	
HEAT EXCHANGER DESIGN						**FIGURE**	
		Shell		Tubes			
Pressure Design (kPa)		100		200			
Design temperature (ºC)		170 / 30					
Number of steps		1		2			
Couplings	Entrance						
	Exit						
TUBES							
Number of tubes: 16		Nominal diameter (m): 0.1		Length (m): 2		Square pitch (m): 0.125	
Nº BWG: 14		Roughness (mm): 4.15		Stainless steel type 304			
SHELL							
Shell Diameter (m): 0.674		Roughness (mm): 4.38		Shell cover: Thermal isolation			
BAFFLES							
Percentage of cut: 25%				Baffle spacing (mm): 135			
TUBES BOUNDLE							
Tubular boundle		Diamater (m): 0.660		Type of heading: Floating heading			
COMMENTS							

HEAT EXCHANGER HE-5 DATASHEET

Project: Calcium ammonium nitrate production plant		Date: June 2019
Location: Sagunt, València		Serie: HE-5
Equipment service: Cool flash evaporators vapour		
Type: Multitubular reactor with cooling jacket	Horitzontal	Connected

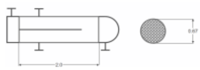
UNIT PERFORMANCE

	Shell side		Tubes side	
	Water		Flash vapour	
Mass flow (kg/h)	5698.85		9126.83	
	Entrance	Exit	Entrance	Exit
Gas	-	-	-	-
Liquid	5698.85	5698.85	-	-
Vapor	-	-	9126.83	9126.83
Specific heat (kJ/kg.ºC)	4.18		2.09	
Molecular weight	18.00		-	
Temperature (entrance/exit)	26.50	38.50	45.00	30.00
Pressure (kPa)	100		100	
Heat exchanged (kW): 79.404	LMTD (ºC): 92.13		OHTC(U, W/m2.ºC): 400	

HEAT EXCHANGER DESIGN

		Shell	Tubes
Pressure Design (kPa)		120	120
Design temperature (ºC)		60 / 30	
Number of steps		1	2
Couplings	Entrance		
	Exit		

FIGURE



TUBES

Number of tubes: 77	Nominal diameter (m): 0.05	Length (m): 2	Square pitch (m): 0.125
Nº BWG: 14	Roughness (mm): 4.15	Stainless steel type 304	

SHELL

Shell Diameter (m): 0.582	Roughness (mm): 4.38	Shell cover: Thermal isolation

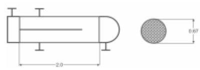
BAFFLES

Percentage of cut: 25%	Baffle spacing (mm): 116

TUBES BOUNDLE

Tubular boundle	Diamater (m): 0.567	Type of heading: Floating heading

COMMENTS

HEAT EXCHANGER HE-6 DATASHEET				
Project: Calcium ammonium nitrate production plant				Date: June 2019
Location: Sagunt, València				Serie: HE-6
Equipment service: Cool evaporators vapour to				
Type: Multitubular reactor with cooling jacket			Horitzontal	Connected
UNIT PERFORMANCE				
	Shell side		Tubes side	
	Water		Evaporators vapour	
Mass flow (kg/h)	5698.85		945.47	
	Entrance	Exit	Entrance	Exit
Gas	-	-	-	-
Liquid	-	-	-	-
Vapor	5698.85	5698.85	945.47	945.47
Specific heat (kJ/kg.ºC)	4.18		2.28	
Molecular weight	18.00		-	
Temperature (entrance/exit)	25.00	26.50	45.00	30.00
Pressure (kPa)	100		100	
Heat exchanged (kW): 9	LMTD (ºC): 10.32		OHTC(U, W/m2.ºC): 1200	
HEAT EXCHANGER DESIGN			**FIGURE**	
	Shell	Tubes		
Pressure Design (kPa)	120	120		
Design temperature (ºC)	50 / 30			
Number of steps	1	2		
Couplings – Entrance				
Couplings – Exit				
TUBES				
Number of tubes: 3	Nominal diameter (m): 0.05	Length (m): 2	Square pitch (m): 0.0625	
Nº BWG: 14	Roughness (mm): 4.15	Stainless steel type 304		
SHELL				
Shell Diameter (m): 0.169	Roughness (mm): 4.38	Shell cover: Thermal isolation		
BAFFLES				
Percentage of cut: 25%		Baffle spacing (mm): 34		
TUBES BOUNDLE				
Tubular boundle	Diamater (m): 0.154	Type of heading: Floating heading		
COMMENTS				

HEAT EXCHANGER HE-7 DATASHEET		
Project: Calcium ammonium nitrate production plant		Date: June 2019
Location: Sagunt, València		Serie: HE-7
Equipment service: Heat dried air with @5bar steam		
Type: "U" type shell and tubes heat exchanger	Horitzontal	Connected

UNIT PERFORMANCE

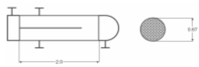
	Shell side		Tubes side	
	Water steam		Air	
Mass flow (kg/h)	1270		80445.63	
	Entrance	Exit	Entrance	Exit
Gas	-	-	-	-
Liquid	-	-	80445.63	80445.63
Vapor	1270.00	1270.00	-	-
Specific heat (kJ/kg.ºC)	2.33		1.00	
Molecular weight	18.00		-	
Temperature (entrance/exit)	151.90	138.00	95.00	138.00
Pressure (kPa)	500		100	

Heat exchanged (kW): 950	LMTD (ºC): 25.77	OHTC(U, W/m2.ºC):1200

HEAT EXCHANGER DESIGN

		Shell	Tubes
Pressure Design (kPa)		100	200
Design temperature (ºC)		170 / 30	
Number of steps		1	2
Couplings	Entrance		
	Exit		

FIGURE



TUBES

Number of tubes: 60	Nominal diameter (m): 0.1	Length (m): 2	Square pitch (m): 0.125
Nº BWG: 14	Roughness (mm): 4.15	Stainless steel type 304	

SHELL

Shell Diameter (m): 1.215	Roughness (mm): 4.38	Shell cover: Thermal isolation

BAFFLES

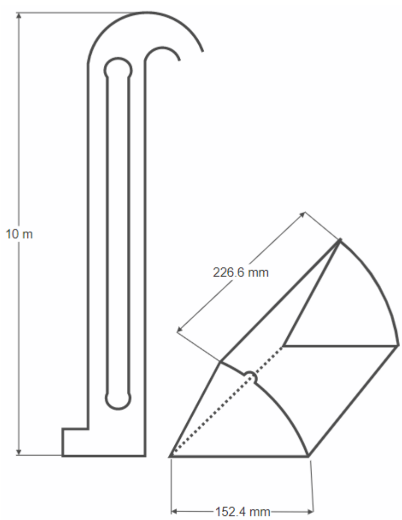
Percentage of cut: 25%	Baffle spacing (mm): 243

TUBES BOUNDLE

Tubular boundle	Diamater (m): 1.200	Type of heading: Floating heading

COMMENTS

ELEVATOR EI-1 DATASHEET		
Project: Calcium ammonium nitrate production plant		Date: June 2019
Location: Sagunt, València		Serie: EI-1
Equipment service: Pump nitric acid to reactor		
Type: centrifugal pump	Vertical	Connected
UNIT PERFORMANCE		
	Calcium ammonium nitrate	
Total Flow (kg/h)	25150.23	
Ammonium nitrate (% p/p)	99.9	
Water (% p/p)	0.01	
Temperature (ºC)	95	
Pressure (kPa)	100	
DESIGN DATA		
Pressure of design (kPa): 120		
Temperature of design (ºC): 115		
Tipe: Vertical		
Prill diameter average (mm): 1.5		
Aparent density (kg/m3): 1360		
Heaight elevation (m): 10		
Fullfil factor: 0.75		
Tangential speed (m/s): 1.067		
ELEVATOR MECHANICAL DESIGN		
Height (m): 10		
Drum diameter (m):0.23		
Numbers of buckets: 41		
bucket spacing (mm): 508		
Thickness (mm): 3.28		
BUCKET MECHANICAL DESIGN		
Capacity (l): 5.26		
Length (mm): 226.6		
Proyection (mm): 152.4		
Profundity (mm): 152.4		
Mass capacity (kg):3.35		
MECHANICAL OPERATION		
Elevator power (CV): 2.045		
Efficiency: 0.8		
COMMENTS		



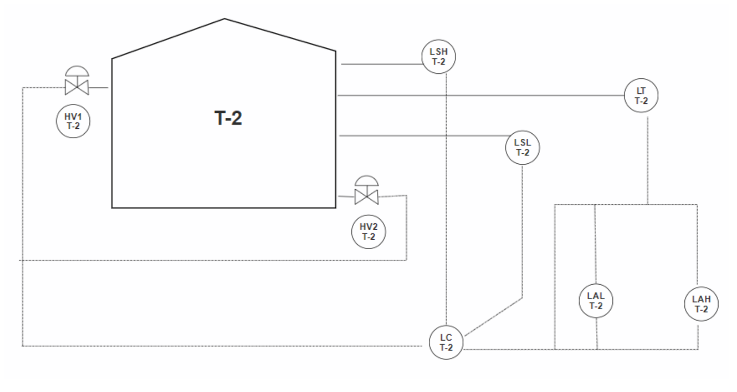
PUMP P-1 DATASHEET		
Project: Calcium ammonium nitrate production plant		Date: June 2019
Location: Sagunt, València		Serie: P-1
Equipment service: Pump nitric acid to reactor		
Type: centrifugal pump	Horizontal	Connected
UNIT PERFORMANCE		
Product	Nitric acid	
Mass flow (kg/h)	4168.6	
Volumetric flow /m3/s)	4.78E-03	
Viscosity (Cp)	5.46E-07	
Specific weight (kN/m3)	13.394	
Suction pressure (kPa)	100	
Impulsion pressure (kPa)	200	
Operation temperature (ºC)	25	
DESIGN DATA		
Design temperature (ºC)	40	
Total energy loss (m)	0.225	
Total charge on pump	52.2	
MECHANICAL OPERATION		
Power (Hp)	5.98	
Efficiency	0.78	
Material	Stainless Steel 304	
COMMENTS		

PUMP P-2 DATASHEET		
Project: Calcium ammonium nitrate production plant		Date: June 2019
Location: Sagunt, València		Serie: P-2
Equipment service: Pump ammonium nitrate to R-1		
Type: centrifugal pump	Horizontal	Connected
UNIT PERFORMANCE		
Product	Ammonium nitrate	
Mass flow (kg/h)	1107.85	
Volumetric flow /m3/s)	1.70E-04	
Viscosity (Cp)	1.70E-05	
Specific weight (kN/m3)	16.87	
Suction pressure (kPa)	45	
Impulsion pressure (kPa)	100	
Operation temperature (ºC)	120	
DESIGN DATA		
Design temperature (ºC)	150	
Total energy loss (m)	0.254	
Total charge on pump	21.8	
MECHANICAL OPERATION		
Power (Hp)	0.15	
Efficiency	0.78	
Material	Stainless Steel 304	
COMMENTS		

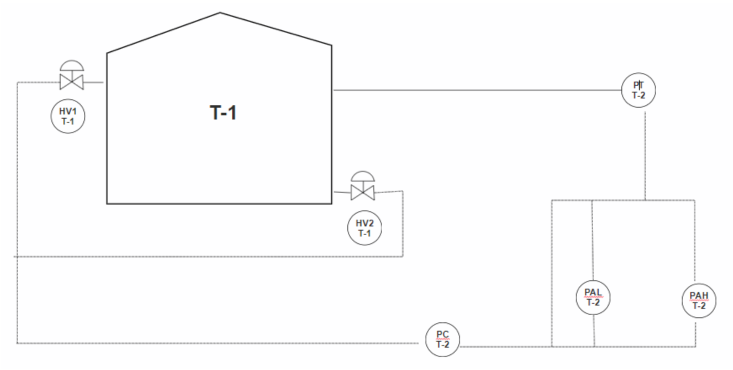
PUMP P-3 DATASHEET		
Project: Calcium ammonium nitrate production plant		Date: June 2019
Location: Sagunt, València		Serie: P-3
Equipment service: Pump ammonium nitrate to evaporator E-1		
Type: centrifugal pump	Horizontal	Connected
UNIT PERFORMANCE		
Product	Ammonium nitrate	
Mass flow (kg/h)	21049.23	
Volumetric flow /m3/s)	3.40E-03	
Viscosity (Cp)	1.70E-05	
Specific weight (kN/m3)	16.85	
Suction pressure (kPa)	100	
Impulsion pressure (kPa)	200	
Operation temperature (ºC)	120	
DESIGN DATA		
Design temperature (ºC)	150	
Total energy loss (m)	0.225	
Total charge on pump	52.2	
MECHANICAL OPERATION		
Power (Hp)	5.73	
Efficiency	0.78	
Material	Stainless Steel 304	
COMMENTS		

APPENDIX 8: P&ID

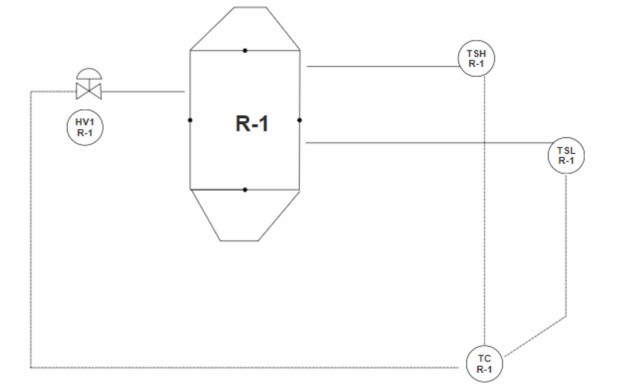
P&ID TANK 2 T-2	
ITEMS	NAME
LSH T-2	High level sensor
LT T-2	Level transmissor
LSL T-2	Low level sensor
HV2 T-2	Hand valve
LAL T-2	low alarm level
LAH T-2	High alarm level
LC T-2	Level controller
HV1 T-2	Hand valve



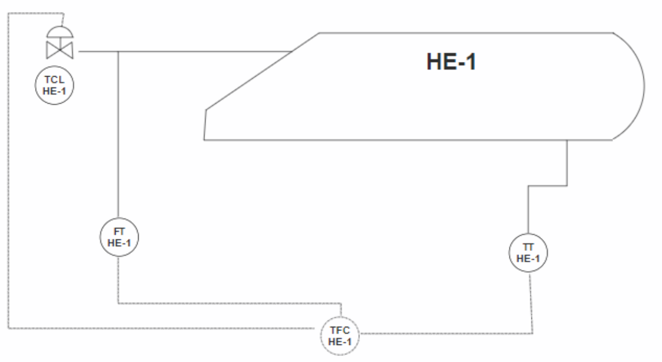
P&ID TANK 1 T-1	
ITEMS	NAME
PAL T-1	low alarm pressure
PT T-1	Pressure transmetter
HV2 T-1	Hand valve
PAH T-1	High alarm pressure
PC T-1	Pressure controler
HV1 T-1	Hand valve



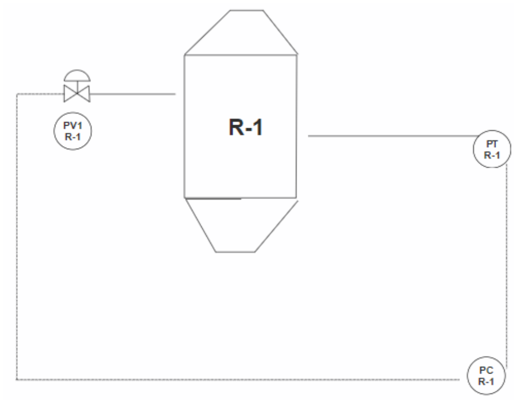
P&ID REACTOR R-1	
ITEMS	NAME
TSH R-1	Low temperature sensor
TSL R-1	High temperature sensor
TC R-1	Temperature controller
HV1 R-1	Hand valve



P&ID HEAT EXCHANGER HE-1	
ITEMS	NAME
TT HE-1	Temperature transmitter
TFC HE-1	Temperature and Flow Controller
FT HE-1	Flow transmitter
TCL HE-1	Hand valve



P&ID REACTOR R-1	
ITEMS	NAME
PT	Pressure transmitter
PC	Pressure controller
PVC R-1	Automatic valve



APPENDIX 9: ECONOMIC ANALYSIS

a) Total investment estimation
All cash needed for the CAN plant installation

a.1. Total fixed capital
Total fixed capital is calculated using an already implemented plant, knowing its fixed costs, year of installation and cost index. Index cost in 2019 is estimated 630 (first trimester estimation).

$$C_{Fa} = C_{Fb} * \left(\frac{w_A}{w_B}\right)^{0.6} * \left(\frac{I_a}{I_b}\right) \qquad \textit{Eq. 99}$$

Where

C_{Fa}: 2019 CAN fixed capital (€)

C_{Fb}: 2015 AN fixed capital (€)

CP_a: 2019 CAN capacity (t/year)

CP_b: 2015 AN capacity (t/year)

I_a: 2019 Index cost

I_b: 2015 Index cost

Replacing on *Eq.99*

$$C_{Fa} = 20\ 642\ 894.00€$$

Year	Fixed Capital	Cost Index	Capacity (t/year)
2015	4 699 657	571	20 000

Fixed capital can be also divided into direct and indirect costs. They are divided into different items that are calculated based on the total fixed capital percentatge as shown in the following table.

FIXED CAPITAL		
Direct costs		
Detail		**Cost (€)**
Equipment purchase	35.0%	7 225 013
Equipment instalation	8.0%	1 651 432
Instrumentation	4.0%	825 716
Pipes	8.0%	1 651 432
Electric instalation	4.0%	825 716
Buildings and structures	10.0%	2 064 289
Ground	4.0%	825 716
Auxiliar equipment of the process	10.0%	2 064 289
Total direct cost		17 133 602
Indirect costs		
Design&Engineering	10.0%	2 064 289
Contractors payments	2.0%	412 858
Construction expenses	5.0%	1 032 145
Total indirect cost		3 509 292
TOTAL		**24 771 473**

a.2. Working Capital

a.2.1. Raw Material inventory

Considerd a Month of raw materials

Material	Consume (kg/month)	Product cost (€/kg)	Monthly cost
NH3	2 779 086.67	0.361	1 002 694
HNO3	17 338 286.67	0.150	2 593 808
Total cost			3 596 502

a.2.2. Product inventory

Its considered a month on the product manufacture cost. 4 295 462.58 €

a.2.3. InProcess materials

Its considered a day on the product manufacture cost. 143 182.09 €

a.2.4. Receivable

Its considered a month on the total annual sales. 5 133 333.33 €

a.2.5. Cash available

Its considered a month on product manufacture cost. 4 295 462.58 €

b) Annual sales estimation

b.1. Annually production (kg/year): 200 000 000

b.2. Sale price (€/kg): 0.308

b.3. Annual sales (€): 61 600 000

c) Product total cost estimation

Percentage method is used to estimate values

c.1. Total manufacturing cost

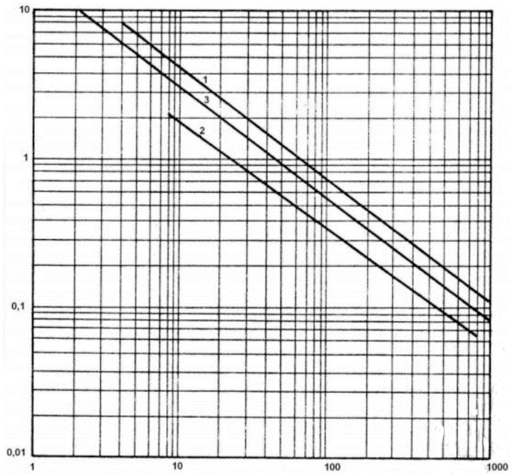
c.1.1. Direct manufacturing cost

c.1.1.1. Raw materials

Material	Consume (kg/year)	Product cost (€/kg)	year cost
NH3	33 349 040	0.361	12 032 334
HNO3	208 059 440	0.150	31 125 692
Total cost			43 158 026

c.1.1.2. Workforce cost

With the help of the following graph, number of workers can be estimated for a 600 ton/day. 3 stages are determined, of 8 hours each.



Graph 22

$$(h - m) * 600 * \frac{3}{8} = Minimum\ number\ of\ workers \qquad \text{Eq. } 100$$

From this equation, a minimum of 27 workers are needed. Their salary will be 3 time the interprofesional minimum salary with 14 monthly payments resulting in a total of 1 020 600 €/year

c.1.1.3. Industrial services

Its considered a 10% on the raw materials cost. 4 315 803 €

c.1.1.4. Maintenance

Its considered a 2% on the direct fixed cost. 342 672 €

c.1.1.5. Supervision

Its considered a 12% on the direct workforce cost. 122 472 €

c.1.1.6. Miscellaneous materials

Its considered a 10% of the maintenance cost. 34 267 €

c.1.2. Indirect manufacturing cost

c.1.2.1. Depreciation

Considering 10 years of equipment life, its value is equal to 10% of total direct cost. 1 713 360 €

c.1.2.2. Insurance

Its considered a 1% of the total fixed capital. 247 715 €

c.1.2.3. Taxes

Its considered a 1% of the total fixed capital. 247 715 €

c.1.2.4. General expenses

Its considered a 30% of the total direct workforce cost plus supervision. 342 922 €

c.2. General cost

c.2.1. Administrative expenses

Its considered a 30% of the total direct workforce cost. 153 090 €

c.2.2. Selling expenses

Its considered a 2% of the total annual sales. 1 232 000 €

c.2.3. Financial expenses

Its considered a 2% of the total fixed cost. 495 429 € €

c.2.4. I+D

Its considered a 1% of the total annual sales. 616 000 €

d) Economical evaluation

d.1. Economical balance

Anual production (t/year)	200 000
Sale price (€/t)	0.308
Total sales (€)	61 600 000
Total production cost (€)	54 042 070
Gross profit (€)	7 557 930
Income tax, 30%	2 267 379
Net profit (€)	5 290 551

d.2. Projects economic profitability

$$R_N = \frac{Net\ profit * 100}{Total\ manufacturing\ cost}$$ *Eq. 101*

$$R_N = 9.79\%$$

d.3. Pay out time

$$V = \frac{Total\ fixed\ capital}{(net\ profit + depreciation)} = 3.54$$ *Eq. 102*

d.4. Internal rate of return (IRR)

For a 10 years' economic life

$$NPV = \sum_{t=1}^{T} \frac{Net\ profit_t}{(1+r)^t} - Total\ fixed\ capital \qquad \text{Eq. 103}$$

Where

r: Discount rate

t: Time periods

When NPV=0, isolating r we calculate the IRR, the maximum interest rate that can be accepted.

d.5. Cash position

Used to know how long will it take to pay debts

$$\begin{aligned}(cp)_{10} &= (net\ profit + depreciation) * 10 \\ &\quad - Working\ capital - Fixed\ capital \\ &= 27\ 803\ 694\ €\end{aligned} \qquad \text{Eq. 104}$$