INDEX

1. INTRODUCTION

The aim of this project is to revamp the monomer recovery unit of a polymerization plant of polyvinyl chloride (PVC). Although the polymer is the main product obtained and commercialized, the project focuses on the monomer (vinyl chloride) recuperation.

The design is a real case of a plant located in the chemical complex in Tarragona and therefore, site conditions from the area have been considered. The project consists on designing the three recovery lines for the non-reacted monomer which, has been obtained from different equipment within the process. The vinyl chloride has to be recuperated and reused successfully. During the decision-making process, at the time of doing tasks such as choosing equipment, materials, sizing, etc.., economic viability has been taken into account. Otherwise, all the design process might not be useful for the company.

Further design has been done regarding the specific equipment for each recovery unit. Knowing the conversion of 90% and the total annual production of PVC, it is then trivial to obtain the quantity of monomer (vinyl chloride) that has to be recovered from the process. By doing such recovery, substantial economical savings are achieved due to the costs of raw materials that might not be required.

Initial planning has been done to achieve successfully the objectives mentioned above before the death line. Moreover, it has been required a distribution task considering a teamwork of two engineers and the time available to do such purposes.

2. PRELIMINARY STAGE

2.1. Project description

The increasing demand of Polyvinyl Chloride entail a continuous expansion of the plant and, consequently, of the monomer recovery unit. These successive re-designs of this unit made it very complicated to run.

The current unit has a lack of homogeneity between the equipment that performs it. There are a lot of operational problems that disturbs the functionality of the whole process. Thus, it is important to find a design that provides simplicity to the process since this will absolutely improve the plant efficiency. The design should be flexible and must take in consideration future production growth as well.

The final results of this project must supply definitive solutions of the several problems generated by the present recovery unit.

2.2. Project scope

As explained in introduction, this project studies the revamping of a monomer recovery plant of a PVC synthesis process. Therefore, the project scope is about this non-react monomer recovery unit. This plant part consists of the equipment listed below:

- Separation tank in which monomer is collected.
- A liquid ring compressor for compressing the monomer.
- Shell-tube heat exchanger to adapt the compressor service water temperature.
- Flash separator to separate the compressed monomer from service water.
- Another shell-tube heat exchanger to adjust recovered monomer temperature to be stored.
- A centrifugal pump responsible of sending waste water to treatment.

- A tank to storage the recovered monomer.

The project also includes the following objectives:

- Viability analysis of the chosen alternative in comparison with other ones.
- All specifications of the designed equipment will be given.
- The economical viability of the project will be check.
- Environment impact will be analysed.
- A safety study will be carried out with a description of the used elements for this purpose.
- And finally, the project will comprise a maintenance strategy.

The following diagrams are excluded:

- Layout diagram
- Electric diagram
- Isometric diagram

2.3. Historical record

The plan was first run in 1976, with two reactors of 80 m^3 and a relatively low production. As the years passed by, many changes have taken place in the production process. Moreover, the recovery process of vinyl chloride in the production plants of PVC has evolved during the last forty years.

At first, the recovery phase of VCM was another step to carry out in the reactor (charge, warming, reaction, recuperation, discharge and cleaning). Such was its length and difficulty that in the end, it was removed in order to maximize the production. To cut off time of all the non-reaction phases has a very positive incidence in the capacity of the plant.

For this purpose, pressured tanks were installed so that all the mass contained in the reactors could be discharged when necessary. Finally, the discharge operations and the recovery in these tanks (BDT's or blow down tank), were made simultaneously.

Afterwards, stripping columns were installed in order to increase the purity of the final product (PVC). In the polymerization suspension process porous particles are formed. Inside these particles, it remains an amount of residual monomer hard to eliminate. However, one can remove it by making vacuum and injecting vapour afterwards. Such process favours the removal of the undesirable monomer inside the particles.

The installation of stripping columns meant an important advancement in the recovery of this VCM trapped and also did mean a huge improvements in the quality products.

As the old techniques suffered changes, so the recovery system did. Due to new techniques rising up, the plan suffered successive revamps. Such changes had left obsolete the old recovery systems that were used up until that moment. In the first installation conformed by three compressors and a vacuum pump all oversized for two reactors, new equipment was installed in order to cover the needs that came out.

The first important change was in 1989 when a new automatized reactor was acquired in order to increase the productivity. The existent recovery system at that moment was kept but it was no longer oversized and so, overlap problems began to happen. As a result, delay issues came out, tough at the beginning they were not very relevant.

The installation of the first BDT's improved the productivity of the plant but increased the losses due to the delays in the recovery process. Overlap problems started to be very frequent during these operations. Even the facts, the old recovery system was kept.

In 1992 when the stripping column was first run, specific compressors for the process were acquired. Such compressors had specific characteristics for the process such as continuous operation and low flow. The second stripping column was also acquired with its own compressor package.

The enlargement project of the plant in 2001 meant the acquirement of a new reactor, stripping columns, BDT'S for each reactor, two compressors and an important debottlenecking of the System.

The coexistence of all those Systems provoked considerable operability troubles. The operation gets very complicated and it is the main target to design a new System that fits the current needs and simplifies the operation.

2.4. Bibliographic study

2.4.1. General process

Polymerization of vinyl chloride is exclusively done via a free radical mechanism, but there are four different industrial processes: suspension, emulsion, microsuspension and mass system.

The suspension process for manufacturing polyvinyl chloride is the most important method to produce a variety of general purpose and highly sophisticated grades of PVC; it presents the 80% of worldwide production. The engineering advantages of suspension polymerization include low conversion cost when water is the suspending agent, excellent heat transfer due to the high heat capacity of water and the low slurry viscosity, particle morphology control, and low levels of additives in the polymer. There are some disadvantages to suspension process. The suspending agents can become incorporated in the surface of the particles affecting properties such as particles fusion. The water may contain contaminants, such as metal ions, that adversely affect thermal stability. Monomer soluble in the water face can polymerize and the resulting polymer will have properties different from that made in the particles.

The weight ratio of the continuous water phase to the discontinuous monomer phase varies from 1:1 to 4:1. Agitation is required during the process since large agglomerates with several undesirable properties can be formed. They settle at faster rates than the rest of particles and are harder to suspend with agitation, they can become sites for runaway reactions, they can adhere to reactor surfaces and they can not take up stabilizer and other compounding ingredients well.

The steps of a typical suspension process include a PVC reactor, a blow down tank, a stripper, a separation unit, and finally a fluid-bed dryer.

In the PVC batch reactor, is required a suspension system preparation. First of all, water, vinyl chloride monomer, some of suspending agents and additives (if necessary) are introduced to the reactor, the temperature is brought up to 50-70ºC. Vinyl chloride is dispersed in the water continuous phase with the suspending agents (polyvinyl acetate, cellulosic derivates, etc) and agitation to form droplets. Afterwards, a vinyl chloride-soluble initiator is introduced to the reactor in order to begin polymerization reaction. Most common initiators are perester, percarbonate, peroxide, etc. Once all the compounds are in the reactor, exothermical polymerization takes place in every monomer droplet (150 µm). Normally, the reactor is in about 5 bars of pressure and the generated heat shall be evacuated to keep the temperature constant. Usually polymerization is conducted up to 75% conversion in the outlet stream.

The stream out of the reactor is sent into a blow down tank with agitation, in order to maintain operational the following steps. At the exit of this unit, conversion is about the 90% of the introduced monomer.

From this tank and the following one, the greater part of the non-react vinyl chloride (the remaining 10%, approximately) is conducted to a monomer recovery unit (RVCM).

Afterwards, the main stream enters to an agitated tank called slurry tank. The slurry is compounded mainly by water and PVC, but there is some of VCM contained in the grain's pores. From this unit, slurry is brought in a stripper in order to separate the unwanted monomer from the product. To do it, steam is fed up from the bottom, at 15 bars, and slurry is entered by the head. The process of VCM absorption by water takes place at 105ºC and about 0,3-1 bar. So, there are two outlet streams: water with around 10% of VCM and purer slurry. The first stream, water, is sent to a heat exchanger to low temperature to 40ºC, and then the fluid is deposited in a tank for a subsequent treatment. At this temperature (≈40ºC) all the residual VCM is vapour, so the atmosphere of the tank shall be conducted to another RVCM.

The second stream, slurry, continues with the purification process. The next step is a new tank where composition is approximately 70% water and 30% PVC. So the following goal is to remove the maximum percentage of water from the resin, and it is done by centrifugation. If the wastewater contains more than 1 ppm of monomer, it is sent to another monomer recovery unit.

The slurry before the last stage contains 30% water and 70% PVC. In a fluid-bed dryer, the remaining water is evaporated from the resin using air at 400ºC. The used air passes by a cyclone where solid particles of PVC are removed and later it is freed to the atmosphere at 40ºC. The final product must not contain more than 0.3% of water.

2.4.2. Recovery unit

As quoted above, the plant is in need of a recovery unit to recuperate the non-react monomer from different sections of the process; there are three lines from different parts: blown down tanks, strippers and vents (reactor). In the current unit, every line consists of, at least, a holding tank to separate the VCM gas-vapour mixture from the liquid water. This tank has also the role of assuring feed to the next equipment. The next stage is where monomer recovery takes place; in this case it consists of a compression process. After VCM is compressed, a new separation step in a separator-tank is carried out. Finally there is a heat exchanger to condense the compressed VCM and a tank to store it as a compressed liquid; both devices are common for the three recovery lines.

2.4.3. Recovery process alternatives

The current plant uses liquid ring compressors as a strategy for monomer recovery, but there are some other alternatives to this equipment which shall be studied. In this section, one can find some possibilities regarding types of compressors that may be used. Different options have been taken into account during the decision-making process, but some others, such as membranes have been ruled out from the beginning considering plant requirements.

Table 2.4.1. Compressor comparative.

POSITIVE-DISPLACEMENT

Type	OPERATION CHARACTERISTICS	RANGE OF APPLICATIONS	TYPE	PRESSURE RANGES
Rotary Compressors	- Capacities of 100.000 m^3/h. - Piston speeds 700-850 (ft/min). - It may be stationary or portable. - Lower maintenance issues.	- Low power level applications: - Petroleum and chemical plant service for continuous operation. - Commercial applications.	**Helical Screw**	Used in higher pressure air an process gas services.
			Lobe	Profile 1) up until 12 psi. Profile 2) up until 22psi.
			Scroll	-
			Vane	Profile 1) 29 psi for bulk material movement. Profile 2) 190: psi for oil-injected machines.
			Liquid ring	From atmospheric pressure of surroundings, to a higher pressure.

POSITIVE-DISPLACEMENT				
Type	OPERATION CHARACTERISTICS	RANGE OF APPLICATIONS	TYPE	PRESSURE RANGES
Reciprocating Compressors	- Discharges pressures from vacuum-60. - They are manufactured in a variety of different configurations	- Household, home workshop and smaller job site types.		

DYNAMIC PROCESS GAS COMPRESSORS

TYPE	OPERATION CHARACTERISTICS	RANGE OF APPLICATIONS
Centrifugal compressors	When supplied with a variable-speed driver, centrifugal compressors offer significant flexibility of operating without appreciable loss of efficiency.	In applications in which l pressure requirements mak compressors.
Axial-flow compressors	High efficiencies; around 90% polytropic at their design conditions	Can be found in medium t pumping stations, and withi

Given are the conditions in the monomer recovery unit of VCM, one can come to the conclusion that liquid ring compressor is the one that best suits the process requirements. Non-reacted monomer reaches the collector tank at about atmospheric pressure. Besides, sometimes the monomer solution might have some PVC particles, this kind of compressors can deal with this inconvenient although other types can not. Below is provided a further explanation of liquid ring compressor.

2.4.4. Liquid ring compressor

Liquid ring compressors require a fluid, preferably water, as auxiliary or service liquid. This liquid has the task of compressing the gas to be conveyed, sealing off the various discharge chambers from each other, lubricating the shaft seals and absorbing the compression energy as heat.

Due to the intensive contact between the gas being conveyed and the operating fluid, there is only a very slight rise in gas temperature- no chemical reaction is taking place- so that one can almost describe it as an isothermal compression. During operation there is a continuous loss of some operating fluid which leaves the liquid ring compressor with the gas conveyed. The service liquid can be extracted from the gas in a separator. It is then possible to recirculate the operating fluid into the liquid ring compressor. A heat exchanger in the circulatory system ensures that the heat absorbed from the operating fluid is led off. As the liquid ring compressors do not have any metal parts which move against each other there is a high level of reliability in service with a minimum of maintenance required. Since the compression is achieved with contact-free components there is also no local rise in temperature. The liquid ring compressors therefore provide the greatest possible safety in the compression of inflammable substances being conveyed. Because of the variety of gases and vapours to be conveyed and the various types of operating fluids employed, the liquid ring compressor components are adapted to the operational requirements. Gland packing is used as the simplest form of shaft seals. Shaft seals of the ground joint type in single and double form made by well-known manufacturers are also employed.

Liquid ring compressors can also operate in situations where there is a non-atmospheric intake pressure. As long as the operating limits are adhered to, intake pressures in the vacuum range are nothing unusual. For intake pressures above atmospheric pressure there are single-stage special solutions which are employed to ensure an economical compression of the gases being conveyed.

2.4.5. Vacuum pump

As it could be seen in above sections, liquid ring compressors deal with inlets flow at nearly atmospheric pressure. This condition cannot be assured for vents line where VCM from slurry tanks and reactors degassing is conveyed. In this case VCM does not reach the holding tank due to pressure difference and so it must be scavenged by a pump.

The approach for pump selection takes the same line as in compressor case. But there are two possibilities regarding to vacuum pump: dry and liquid ring vacuum pump. In the following table one can find a comparative between both alternatives:

Table 2.4.2. Dry and liquid ring vacuum pump comparative.

	AVANTAGES	DESAVANTAGES
LIQUID RING VACUUM PUMP	- Simpler design - Little increase in temperature of discharged gas - No damage from liquid small particulates in the process fluid - Maintenance and rebuilding are simple - Slow rotational speed, maximizing operating life - No lubricating liquid in the vacuum chamber to be contaminated - Accommodation of both condensable vapours and noncondensables, while operating as both vacuum pump and condenser.	- Mixing of the evacuated gas with the sealing liquid - Risk of cavitation requires a portion of process load to be noncondensable under operating conditions - High power requirement to form and maintain the liquid ring, resulting in large motors - Achievable vacuum is limited by vapour pressure of sealant fluid at the operating temperature
DRY VACUUM PUMP	- Rugged rotor design - Noncontact design facilitated by timing gears - High rotational speed reduces the ratio of gas slip to displacement increases net pumping capacity and reduces ultimate pressure - Multiple stage provides inlet pressure below 1-mm Hg abs. while discharging to atmosphere - No contamination of evacuated gas - Due to lack condensation, pump can be fabricated of standard inexpensive cast iron	- Cannot handle particulate matter, nor large slugs of liquid - May require a silencer - May discharge gases at high temperature - Most difficult to repair a gas purge for cooling or to protect the bearings and seals from the process gas - Due to high operating temperature some process gases may polymerize

As a result of this comparison, liquid ring vacuum pump seems to be the suitable pump to be used in this process due to that dry vacuum pumps are not useful for processes with solid particles. Besides, since the VCM is used as the main process product, temperature control is required in order to avoid polymerization. Liquid ring vacuum pump and compressor, due to the fact that compression is done using water as a sealing fluid one can consider isothermic the process of compression.

2.4.6. Alternatives in the service liquid arrangement

Liquid ring equipment, either compressor or pump, has three different configurations which are briefly explained along with the one chosen for the process.

- One through

Used where service liquid is plentiful contamination is not a problem and maximum gas discharge cleanliness is required. The benefits are the simplicity, the lowest initial cost and the purest discharge.

- Partial recirculation

Used where service liquid is available and contamination problems are minimal. The benefits are the simplicity the low initial cost and the reduced service liquid consumption.

- Total recirculation

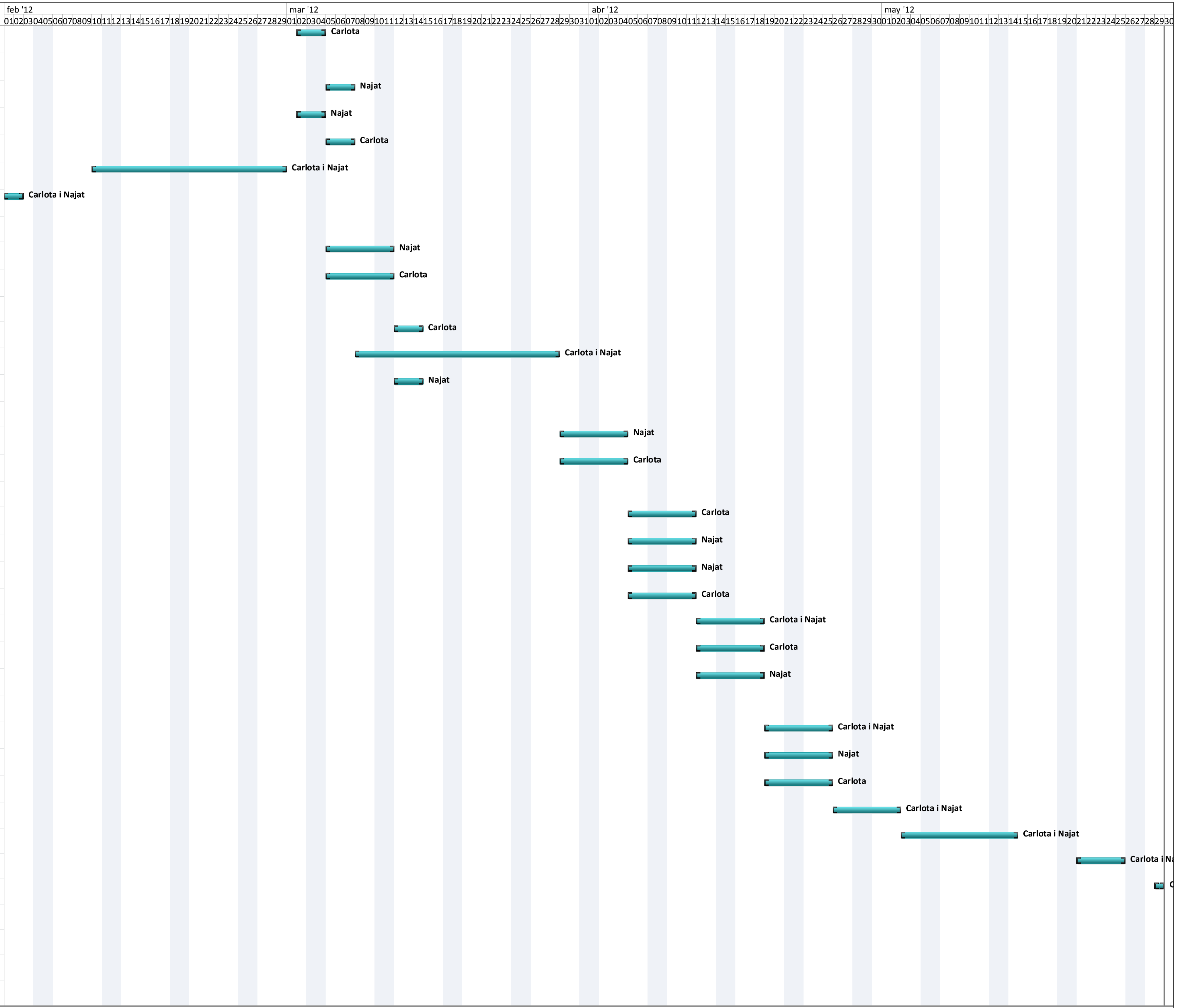
Used where gases and liquids are toxic or hazardous, and when environmental contamination is a concern. The benefits are the service liquid contained and separated from non-hazardous coolant systems, low service liquid usage, the fact that allows recovery of condensable inlet gases and the containing and isolation of seal liquid from non-hazardous coolant systems.

Due to the fact that VCM is a concern regarding its environmental impact, the configuration used in the recovery unit is the total recirculation configuration.

2.5. Initial project planning

In this section, gant diagram is provided showing the planning that has been followed during the execution of the project. It must be pointed out that in the end, the project was not handed out the 11th of May, instead it was delivered the 29th of may. Such change relies on the fact that accurate formate of the report had not been completed within the first death line.

Id	Nombre de tarea
1	**INTRODUCTION**
2	**PRELIMINARY STAGE**
3	Project description
4	Project scope
5	Historical record
6	Bibliographic study
7	Inicial project planning
8	**PROJECT DEVELOPMENT BASIS**
9	Design basis
10	Basic data for the engineering
11	**BASIC ENGINEERING DEVELOPMENT**
12	Diagrams making
13	Basic design
14	Descriptions
15	**SAFETY IN PROCESS DESIGN**
16	Process safety
17	Occupational safety
18	**ENVIRONMENTAL ANALYSIS**
19	Emissions to the environment
20	Solid waste
21	Energy and natural resources consumption
22	**INSTALLATION MAINTENANCE**
23	Breakdown maintenance
24	Preventive maintenance
25	Predictive maintenance & Proactive maintenance
26	**ECONOMIC STUDY**
27	Cost estimation
28	Project viability
29	Sensitivity analysis
30	**FINAL REPORT MAKING**
31	**REPORT CORRECTION**
32	**EXAMS PERIOD**
33	**SUBMITION**
34	
35	
36	
37	



3. PROJECTE DEVELOPMENT BASIS

3.1. Design basis

3.1.1. Feed specifications

The vinyl chloride recovery unit has as input stream the monomer solutions taken from different equipment of the process. As a consequence of this fact, the feed stream does not have steady specifications. However, one can consider that the solution contains VCM, water and some inert compounds. The vinyl chloride in such solution can be assumed to have the same specifications as the one used in PVC manufacturing process.

The monomer used in the polymer manufacturing has the specifications listed below:

Table 3.1.1. Recoverd monomer specificactions.

Item	Units	Nominal value	Tolerance	
			Max.	**Min.**
Aspect	-	Colorless and unturbid		
VCM purity	%			99,95%
Acidity/alkalinity	ppm		2,00	
Iron	ppm		0,50	
Acetylene	ppm		2,00	
Water	ppm		100	
Non-volatile	ppm		500	
Methyl chloride	ppm		500	
1,3-Butadyene	ppm		12,0	
Ethyl chloride	ppm		30,0	
Ethylene + Buthene + Propene	ppm		5,00	
1-CPY + Dichloro-compounds	ppm		500	

Apart from the 100 ppm, there is some water in equilibrium with the VCM entered to the recovery system; the exact amount must be calculated separately at every stream conditions. Beside, this water has approximately the same conditions that the demineralized water (Section 3.2.1.4).

Inert compounds contained in the input stream have three different sources: initiators decomposition, nitrogen used in the tank degassing and oxygen introduced accidentally in the process. When working under vacuum conditions, it is possible to have accidental entrance oxygen. In spite of the facts, the total amount of inert would not be higher than 5%.

3.1.2. Capacity, operative flexibility and service factor

The global recovery capacity of the designed plant must be the addition of the three compression systems. As the total capacity can be from zero to the maximum capacity, one can consider that all the recovery lines work at the same rate that the biggest one of them i. e. BDT line (Table 3.2.1). Thus, the maximum total capacity of the whole unit designed then is 9,12 t/h.

Operational flexibility is very high since it is possible to work with a flow from zero to the maximum capacity (0-9,12 t/h).

Service factor (time percentage in which plant can be working) is different for each one of the three cases. In the first system monomer is extracted from the high pressure blown down tanks. Considering five-hours cycles, in which the content of 4 batch reactors must be recovered in a period of time of 1 hour for each one, service factor is obtained as:

$$\frac{\text{1h/reactor} \times 4\ \text{Reactors}}{\text{5h}} = 80\%$$

The second system is to recover the VCM environment left in low pressure tanks (slurry tanks and reactors degassing). The recovery from the slurry tanks can be considered a continuous process and the reactor degassing a punctual one. But in general, as a continuous process, it must have exactly the same service factor than the whole plant to ensure the uninterrupted functionality of the process. Chemical industry standard service factor is 90%.

Finally, the third system has the responsibility of recovering the monomer stripped from slurry. For the same reasons just mentioned in the last section, as the stripping column works continuously in parallel with other equipment, then stripper has a service factor of 90% as well.

3.1.3. Products specifications

The recovered monomer will be re-used in the main process of polymerization, thus must have the specifications listed on table 3.1.1. However, in this kind of plants, due to the presence of air and oxygen, very explosive peroxides can be formed. It is then necessary a continuous monitoring and a limitation of the oxygen content. Therefore, in RVCM storage tanks, oxygen content must be lower than 5%. There is no limitation referring to inert compounds since removing systems of these substances is available in storage tanks. By pressure control, inert compounds excess is sent to a vents treatment plant where membrane technology is used.

3.1.4. Conditions of raw material and products at battery limit

The battery limit indicates the location up to which the plant to be studied ends. In this case, the unit encompasses all the equipment from collectors to RVCM storage tanks. The following tables expose inlet/outlet conditions of every product:

Table 3.1.2. VCM fed to each recovery line

	Flow (t/h)	Pressure at origin (bara)	Inlet pressure to RVCM (bara)	Temperature (ºC)
BDT	3,040	6	1	70
Vents	0,766	1	0,5	70
Strippers	0,768	1,5	1	34

Table 3.1.3. Recovered monomer conditions.

	Flow (t/h)	Pressure (bar)	Temperature (ºC)
Global stream	<9,12	5	36

It should be noted that the values of pressures given in table 3.1.2 represent the pressures measured at the very fist moment when the equipment is opened. What happen next is that this value decreases as the flow begins the expansion along the pipe. This water has the same specifications of demineralized water, which can be found in section 3.2.1.4.

3.1.5. Standards applied and other design criteria

Design temperature calculation will be done as follows:

$$\text{Design temperature} = \text{Maximum operational temperature} + 15ºC \qquad 3.1.1$$

If the result is lower than 60ºC, then design temperature will be 60ºC. For design pressure calculation, when:

- Maximum operational pressure ≤ 10 barg

$$\text{Design pressure} = \text{Maximum operational pressure} + 1\ \text{barg} \qquad 3.1.2$$

- Maximum operational pressure ≥ 10 barg

$$\text{Design pressure} = \text{Maximum operational temperature} \times 110\% \qquad 3.1.3$$

In case that the equipment to be designed has a pressure safety valve, a rupture disk or both elements, design pressure must be that in which safety element works.

When the equipment works under vacuum conditions, design pressure will be absolute vacuum.

3.2. Basic data for the engineering

3.2.1. Utilities

3.2.1.1. Steam

Table 3.2.1. Vapour characteristics.

	Pressure (barg)	**Quality**
Medium pressure vapor (MS)	12	Saturated
Low pressure vapor (LS1)	8	Saturated
Low pressure vapor (LS2)	2-2,4	Saturated

3.2.1.2. Condensate

Table 3.2.2. Condensate characteristics.

	Pressure (barg)	Quality
Medium pressure condensate (CM)	12	Saturated
Low pressure vapor condensate (CL1)	8	Saturated
Low pressure vapor condensate (CL2)	2,4	Saturated

3.2.1.3. Electrical energy

Table 3.2.3. Motors characteristics.

	Tension	Phase number
Motors with a potency equal or lower than 200 kW	380 V – 50 Hz	3
Motors with a potency higher than 200 kW	6000 V – 50 Hz	3
Electric lighting	220 V	1

3.2.1.4. Service water

Table 3.2.4. Service water.

Tower water (TW)	
Input Temperature	27 °C max (18°C in winter)
Exit temperature	37 °C max
Entrance Pressure	8 barg max
Allowed loss pressure	0.7 bar
Quality	Soft water with anticorrosive agents and antifouling.
PH	7,8-8,2
Cold water (CHW)	
Input Temperature	5 °C max
Exit temperature	8 °C max
Entrance Pressure	5 barg max
Quality	Demineralized water with additives.
Continuous addition water in the reactors ACA (CIW)	
Pressure	18 barg
Temperature	5 °C max
Quality	Demineralized water.
Seal water (SW)	
Pressure	15 barg
Temperature	5 °C max
Quality	Demineralized water.
Pressure	7,2 barg

Process demineralized water (PW)	
Temperature	45-50 °C (máx = 70 °C)
Quality	Demineralized water.
Network demineralized water (ADW1)	
Pressure	6.9 bar g
Temperature	Environmental
pH	5 – 6
Chlorides	2.3 ppm
SiO2	0.2 ppm
Conductivity	1.5 – 20 μ Siemens.
Total solids	7.8 ppm
Crude water (CW)	
Pressure	6 barg
Temperature	Environmental
Quality	River's water (*Ebre*)
Fire water (FW)	
Pressure	9 barg
Temperature	Environmental
Quality	Crude water

- Pressured demineralized water (ADW2):
- Specifications of pressured demineralized water are just the same as ADW1 but at 7 barg.

3.2.1.5. <u>Fuels</u>

Table 3.2.5. Natural gas.

Pressure	2.5 bar g
Temperature	> 8 °C
Lower calorific power	10300 kcal/Nm³
Quality:	90.6 % mole Methane
	7.9 % mole Ethane
	0.5 % mole Nitrogen

3.2.1.6. <u>Air</u>

Table 3.2.6. Air.

Instrumental air (IA)	
Pressure	6 barg max.

Pressure	4 barg min.
Temperature	35-40 °C.
Dew Temperature	-10 °C
Quality	Dry
Plant air (PA)	
Pressure	6 barg max.
Pressure	4 barg min.
Temperature	35-40 °C.
Quality	Dumped
Breathable air (RA)	

3.2.1.7. Nitrogen

Table 3.2.6. Nitrogen.

Medium Pressure nitrogen (MIG)	
Pressure	14 bar g max.
Temperature	Environmental
Dew Temperature	-40 °C.
Purity	99.99 %
Quality	Oil-free
Low pressure nitrogen (LIG)	
Pressure	8 bar g max.
Temperature	Environmental
Dew Temperature	-40 °C.
Purity	99.99 %
Quality	Oil-free
Emergency nitrogen	From bottles

3.2.2. Energy prices

Table 3.2.7. Energy prices.

Natural gas	1,97	euros/mmBtu
Electrical energy	0,06	euros/kWh
Vapor	0,016	euros/ kg
Nitrogen	0,09	euros/Nm³
Air	0,015	euros/ Nm³
Crude water	0,53	euros/ m³
Demineralized water	1,69	euros/ m³
Cooling water	0,095	euros/ m³

3.2.3. Site data

3.2.3.1. Meteorological and geological data

Table 3.2.8. Meteorological and geological data.

Barometric pressure	1740-780 mmHg	
Air temperature	Max. 36ºC, Min. -5ºC and Annual average 16ºC.	
Relative dampness	20-98%	
Design temperature for electrical equipment and instrument	45ºC	
Winds		
Pressure	h < 30 m	P = 100 kg/m^2
	h > 30 m	P = 125 kg/m^2
Frequency	> 104 km/h	20 days/year
Maximum speed:	130 - 140 km/h	
Predominant direction:	SE to NW and NW to SE (at the same day)	
Charge due to snowfall:	40 kg/m^2	
Rainfalls		
Annual average	515 l/m^2	
Maximum	64 l/m^{2}h	
External corrosion	There are no special requirements (industrial environmental)	
Seismic data	MSK grade VI	

3.2.3.2. Elevation and land structure

- Elevation: 23 m above sea level.
- Charge capacity: 2 kg/cm^2.

3.2.4. Standards and design codes

- The design codes used for recipients will be API 620 for Low Pressure tanks, ASME VIII div. 1 for pressured recipients and TEMA R for heat exchangers (if applies)
- Regarding the pipes designs, ASTM ANSI B31-3 will be used.
- In the case of pumps and compressors, the design code will be DIN or the standards supplies for special pumps.

- For instrumentation the design codes will be API 550 and ISA

3.2.4.1. Electricity

- Electrical equipment according to ATEX (Explosive Atmospheres).

3.2.4.2. Insulating materials

For temperatures equal or lower than 60ºC, isolation is not required except for the following cases:

- Temperatures higher than 60 ºC: As a personal protection measure or isolation for heating according the process requirements.
- For temperatures equal or lower than 12 ºC. Isolation for cooling.

API 505 must be used as a principle of area and equipment selection classification. Area classification: Class 1 Zone 2

3.2.4.3. Others

Table 3.2.9. Design codes.

Equipment	Design codes
Valves	DIN
Bridles	DIN
Agitators	Supplier standards
Electrical material	CENELEC and LOW TENSION REGULATIONS API 505 must be used as a principle of area and equipment selection classification. Area classification: Class 1 Zone 2
Civil work	DIN and Spanish regulations.

3.2.5. Unit system

Except for specific cases, the international metric system is the one used.

Table 3.2.10. Units system.

Magnitude		Unit
Length		mm or m
Volume		m3
Weight		kg
Flow:	Liquids	kg/h, t/h, m3/h
	Vapour	kg/h, t/h, m3/h
	Gases	Nm3/h (standard conditions)
Temperature		ºC
Pressure		barg, mm water column
Viscosity		Cp
Heat		kcal
Energy		kcal
Power		kcal/h, W, kW

3.2.6. Pipes, equipment and instrument codification

- **Equipment codification**

The equipment will be identified using the following codes: X 0 0 00 AB

- First character alphanumeric will be referred to the equipment type considering the list presented below.
- The second character corresponds to the unit which the equipment belongs. In our case it will always make reference to the unit 0 (PVC fabrication unit).
- The third character it is also numeric and it refers to the section. In our process it will always be referred to the section 1 (raw materials, polymerization and recuperation zone).
- The digits 4 and 5 are referred to the serial number (see list below)
- The last character it is used to identify the redundant equipment and it is distinguished using and alphabetic character.

Table 3.2.11. Equipment.

Type	Code	Serial number
Agitator	AG	Same than recipient
Vent/compressor	C	From 12
Heat exchanger	E	From 33
Filter	F	From 17

Mixer	MZ	From 00
Pump	P	From 46
Reactor	R	From 04
Column	T	From 00
Tank or recipient	TK	From 53
Separator	S	From 23
Others	X	From 00

- **Flanged connection identification**

The flanged connection code for recipients it is compound for a letter followed by a number. The letter is referred to the service while the number distinguishes flanged connections dedicated to the same service. For instance: A1, A2 and A3 would be the flanged connection codes of three recipients dedicated to the process or service entrances.

Table 3.2.12. Flanged connection identification

Type	Code
Product Entrances (process or services).	A
Product Exit (process or services)	B
Shared flange connection for various services	C
Vents	E
Manhole and handhole	H
Analysis (ph)	J
Downcomer	L
Indicator, Transistor, Controller or level interrupter	N
Indicator, Transistor, Controller or pressure interrupter	P
Sample	S
Indicator, Transistor, Controller or temperature interrupter	T
Drainage	V
Supports	W
Others	X

- **Lines identification**

The lines will be identified with the following code compounded for six characters:

100 TW 01 5 02 F42

- The first group refers to the pipe diameter in mm.
- The second corresponds to the fluid code.
- The third to the section number (in the position always 01).

- The fourth number from the PID.
- The fifth is a lineal serial number (inside PID).
- The last is referred to the line specification.

- **Valve identification**

- It is compound for four characters (for example B W A 3'').
- The first is referred to the valve type.
- The second is referred to the connection type.
- The third is an identification letter.
- The last is referred to the valve diameter in inches.

- **Instrument identification**

- It is compound also for the four characters (for example TIC 5 0 70).
- The first group indicates the ISA instrument code.
- The second refers whether it is a process (5) or service (6) instrument.
- The third refers to the section which the instrument belongs. In the service used it will always be 0 because it is referred to installations that give service to four polymerizations.
- The last group of two numbers indicate a serial number included between 50 and 99.

- **Electrical motors identification**

The motors will be identified with three characters (for example P M 0101). First character refers to the equipment type (see table 3.2.11). The second it is always letter M meaning motor. The four numeric characters are referred to the equipment item.

4. BASIC ENGINEERING DEVELOPMENT

4.1. Descriptions

4.1.1. Project functional description

VCM recovery process initiates when non-reacted VCM arrives at VCM recovery unit. Depending on its origin, it can arrive through three different collectors which are Blow Down Tank 6’’-VCM-01-1-04-F42, strippers 6’’-VCM-01-1-06-F42 and vent 6’’-VCM-01-1-01-F42. Due to the fact that each origin has different conditions, there are different operation characteristics between BDT, strippers line and vent line. However, such differences do not affect the recovery process itself which is the same in all lines.

When VCM non-reacted arrives at the recovery unit, holding tanks contain the incoming product at a pressure of 1 bar in order to avoid operability issues. Therefore, holding tanks TK-0154A, TK-0154B & TK-0154C correspond to 6’’-VCM-01-1-01-F42, 6’’-VCM-01-1-04-F42 & 6’’-VCM-01-1-01-F42 respectively.

4.1.1.1. BDT & Strippers line

In BDT and strippers line, VCM in holding tanks TK-0154B & TK-0154C is suctioned and compressed up to 7 bar by liquid ring compressor C-0113B & C-0113C respectively. Afterwards, VCM is held in separators S-0125B (BDT line) & S-0125C (strippers line) at a temperature of 50ºC and 56ºC respectively. VCM to storage will be separated from service water and recirculated VCM. Such recirculated products are sent back to compressor suction. Heat exchangers E-0135B & E0135C put the service water from separator temperature (50ºC & 56ºC) to suction temperature that 36ºC in both lines. Finally, VCM vapor is condensed and storage in tank TK-0155.

4.1.1.2. Vent line

In case of vent line, VCM in holding tank TK0154A is first suctioned by a vacuum pump C-0112 from 0,5bar or less up to 1bar. Compressed VCM is held in S-0124 at a temperature of 66ºC. Afterwards, VCM treated is separated in S-0124 from recirculated VCM and service water. Recirculated service water, is cooled in heat exchanger E-0134 from separator temperature until suction temperature (36ºC). Treated VCM goes to compressor C-0113A which compresses it from 1bar to 7bar, from separator S-0125A VCM vapor is obtained. Heat exchanger E-0135A puts service water at suction temperature.

Eventually, VCM vapor from each line is condensed in E-0136. Storage tank TK-0155 contains VCM recovered from the three lines.

4.1.2. Installation description

VCM to be recovered reach recovery unit by three different 6-in pipes. Installation is performed basically by: three holding tanks, three separators, one liquid ring vacuum pump, three liquid ring compressors and a storage tank.

Flow enters in holding tanks installed at the entrance of recovery unit. These are vessels of 10,5-cubic-meter with a diameter of 2,23 m and a height of 4,25m with ellipsoidal bottom and head. At vessels head there is a 6-in pipe outlet and PSV for safety purposes. At the bottom there is a 4-in pipe to drain the waste water contented in the tank. In vent line there is a centrifugal pump (P-0147AB) that sucks out the liquid because of the low pressure inside the vessel. Pump suction and impulsion lines are 4-in pipes.

The particularity of vent line, as quoted above, is vacuum pump to extract VCM. 6-in pipe leads the flow to suction vacuum pump C-0112. Inlet vacuum pump joins with by-passed service water (2’’pipe) and by-passed VCM (3’pippe). Compressed VCM & service water reach the separator S-0124 (1 m^3, 0,84 m of diameter and 1,8 m of height) through a 2-in pipe. In separator, VCM is separated from service water. In the separator head, we find installed a PSV, a hose connection and an outlet pipe that separates , this stream in two using a Straight Tee: the mentioned by pass and a new 6-in pipe outlet. At the bottom there is a 3-in pipe dedicated to water recirculation. Heat exchanger is installed in order to obtain the desired suction temperature. This separator has also an ellipsoidal head and bottom.

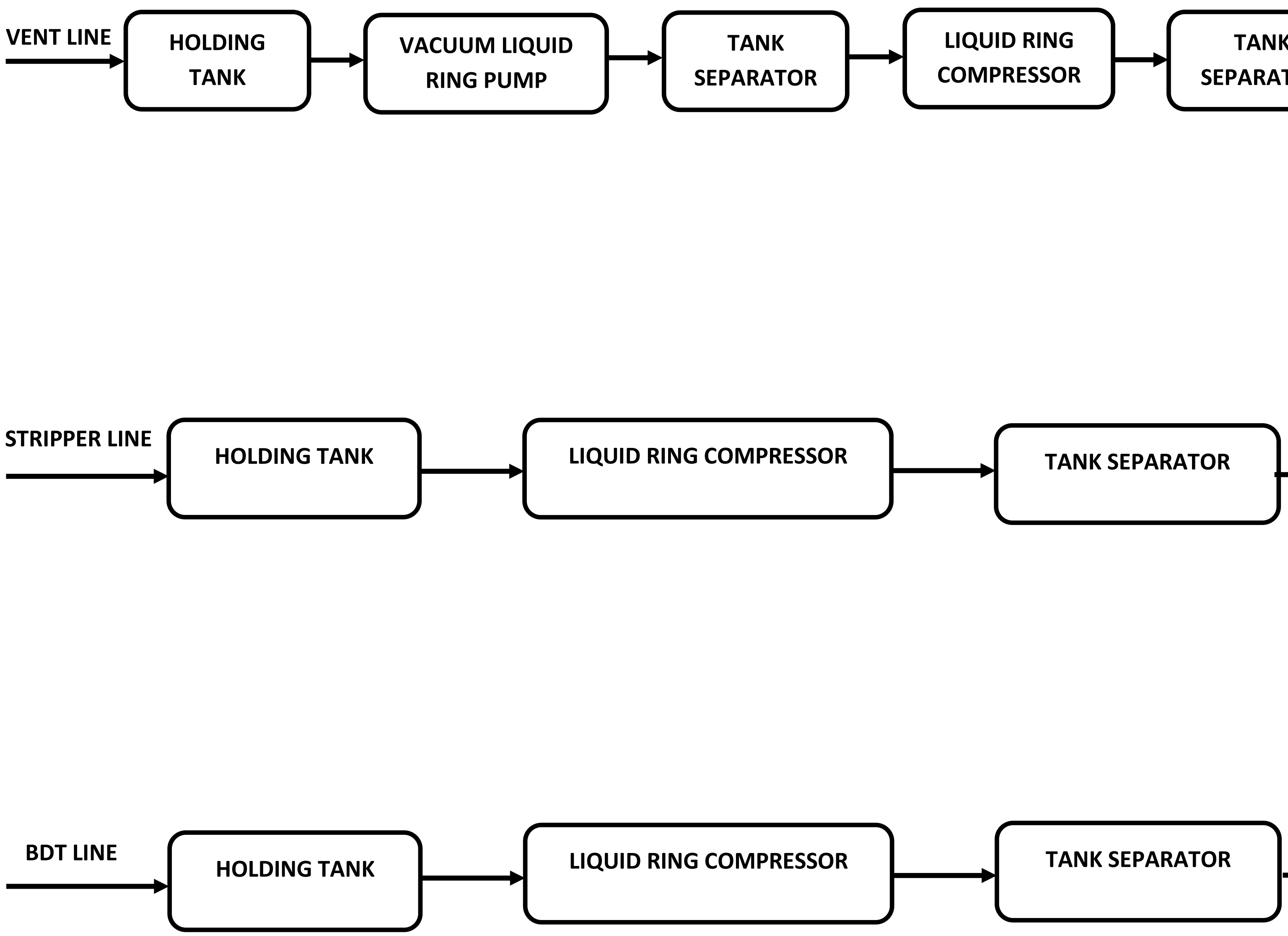
Apart from this difference, left stages are the same for all lines. The three VCM stream at about 1 bar reach liquid ring compressor through a 6-in pipe where the pressure is increased to 7 bar. In the inlet compressor, as in vacuum pump case, VCM stream gathers with by-passed service water (3'') and by-pass of VCM (3'' and 7 m). The outlet of compressor is a 4-in pipe, which enters to the separator (the second one for vent line). Separators have similar characteristics to separator detailed above (PSV's, hose connection and drains) although dimensions are different: 3,5 m^3, 1,26 m of diameter and 2,5 m of height.

The three lines are driven through 3-in pipes of 30 meters until they join. Afterwards, pipe of 32 m with same diameter sends the flow to condenser. The condensed outlet flow circulates trough a 10-in pipe to reach a 32,4 m^3 storage tank (2,74 m of diameter and 5,5 m of height).

4.2. Diagram making

4.2.1. Blocks diagram

In the monomer recovery unit there are three differentiable lines. Every line has basically the following stages: holding tank, compressor and/or pump and separator. The three lines gather at a condensation step and finally the global stream is stored in tank.


VENT LINE
HOLDING TANK
VACUUM LIQUID RING PUMP
TANK SEPARATOR
LIQUID RING COMPRESSOR
STRIPPER LINE
HOLDING TANK
LIQUID RING COMPRESSOR
TANK SEPARATOR
BDT LINE
HOLDING TANK
LIQUID RING COMPRESSOR
TANK SEPARATOR

4.2.2. Process Flow Diagram

In Sheets 1 and 2, main equipment of recovery unit can be found. Holding tanks and auxiliary equipment are omitted in this diagram since no change in mass or energy takes place in them. Two sheets are attached to represent both situation of plant operating: when vent line is operative and when it is not. This line is frequently shutdown because it is only used for reactor degassing.

4.2.3. Process Control Diagram

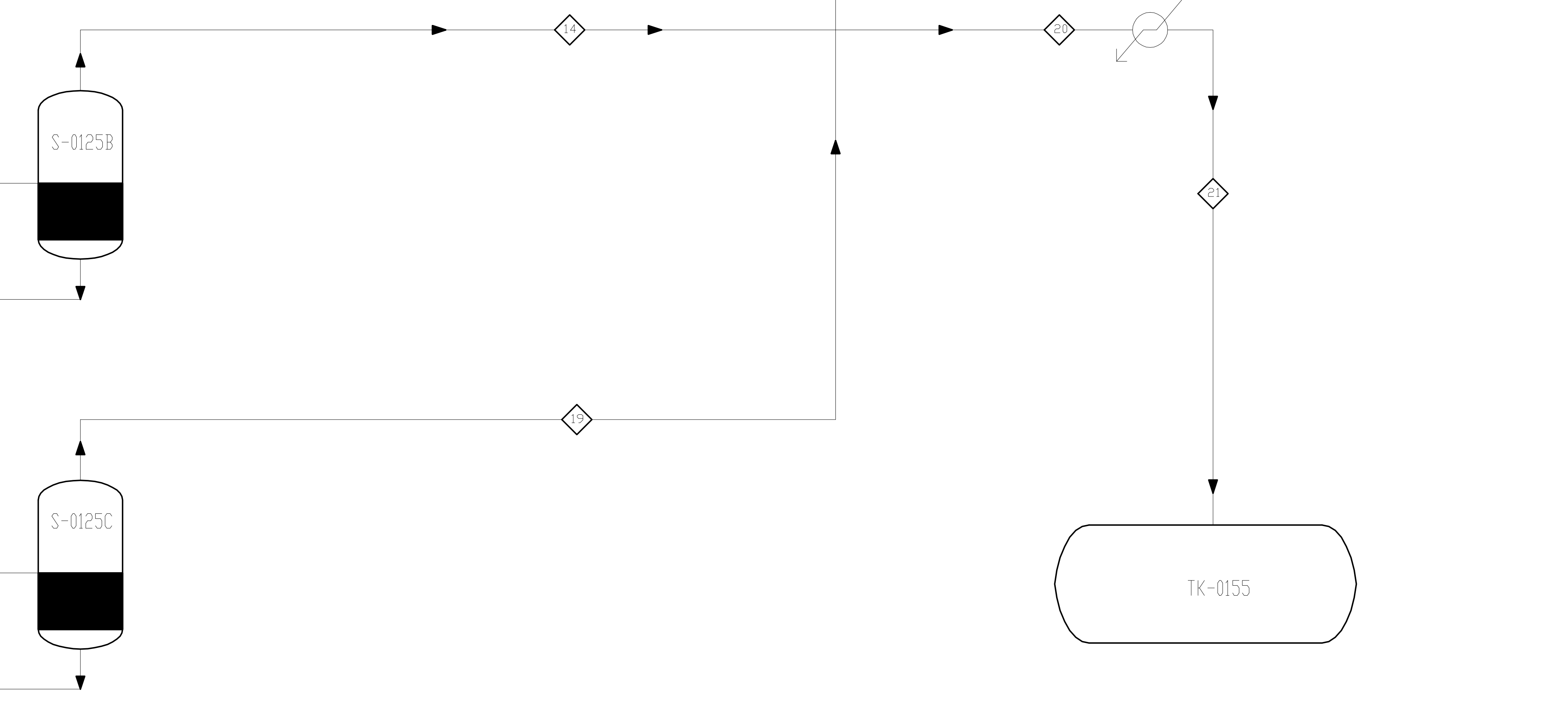
Sheet 3 illustrates control strategy used and explained in section 4. It shows all control instrumentation which compounds the control system.

4.2.4. Plot Plan

In Sheet 4 PVC site is illustrated. Such sheet shows the building, utility runs and the equipment layout, the position of roads and other construction of the existing. VCM recovery unit can be situated in the site and therefore, battery limit of the project design can be appreciated.

4.2.5. Piping and Instrumentation Diagram

Sheet 5 shows the piping and the process flow together with the installed equipment and instrumentation.



…T Line			Stripper Line					Storage	
12	13	14	15	16	17	18	19	20	21
6	6	6	1	7	6	6	6	6	5
55	36	55	34	43	43	36	43	56	36
26777	26777	2450	780	27180	26410	26410	770,8	3991	3991
1,00	1,00	0,008	0,02	0,972	1,00	1,00	0,004	0,007	0,007
0,00	0,00	0,992	0,98	0,028	0,00	0,00	0,996	0,993	0,993

NOTES

H&G Industrial Design Services

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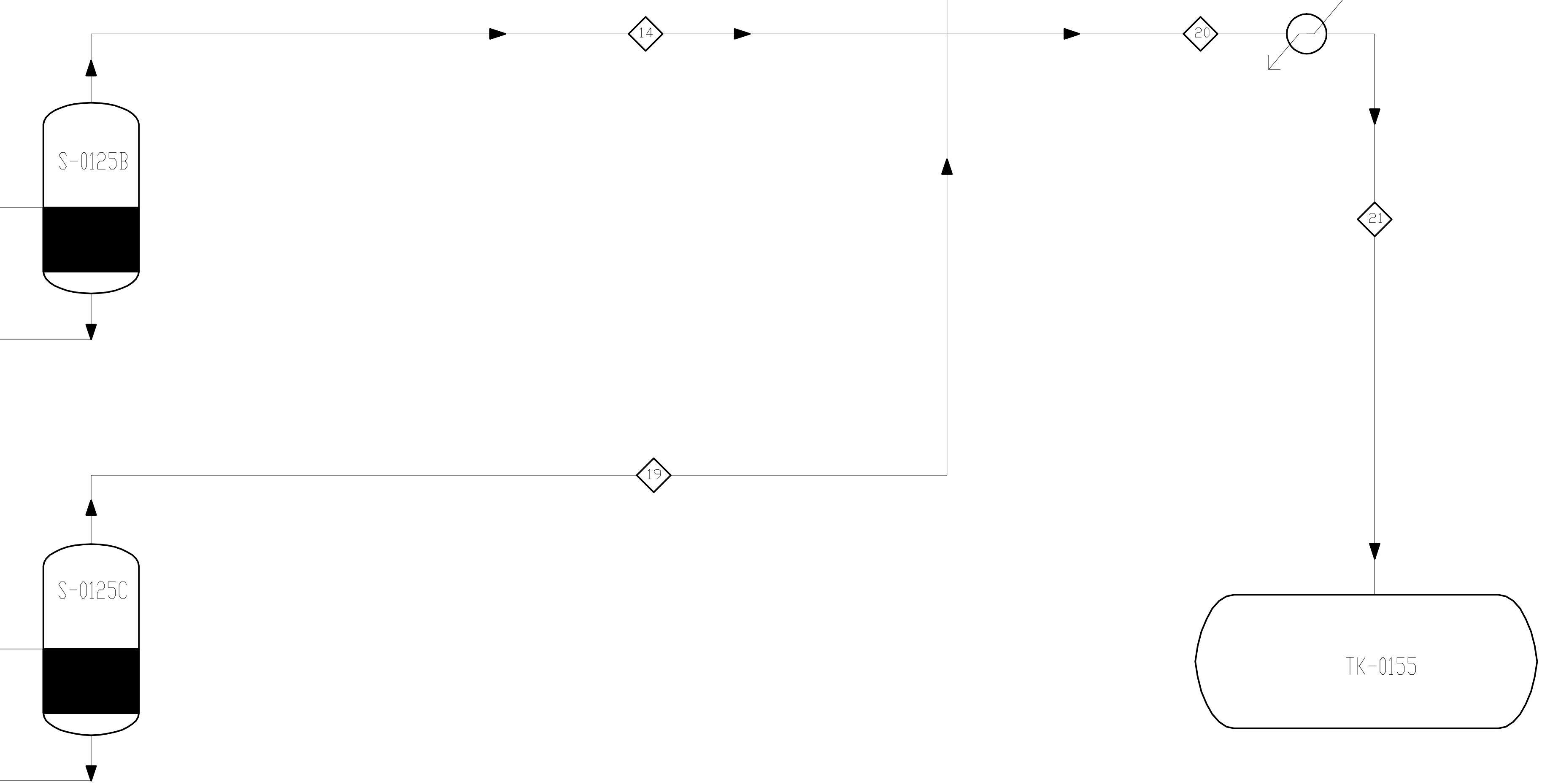
SCALE
CHECKED BY: CARLOTA HERNANDEZ
DATE 28/04/2012
APPROVED BY: MANUEL TIERNO
DATE 08/05/2012

PROCESS FLOW DIAGRAM

PROJECT
REVAMPING OF A VCM RECOVERY UNT

SHEET NUM. 1

POSITION | SECTION



	Stripper Line						Storage	
14	15	16	17	18	19		20	21
6	1	7	6	6	6		6	5
55	34	43	43	36	43		55	36
7 2450	780	27180	26410	26410	770,8		3221	3221
0,008	0,02	0,972	1,00	1,00	0,004		0,007	0,007
0,992	0,98	0,028	0,00	0,00	0,996		0,993	0,993

NOTES

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DATE 08/05/2012

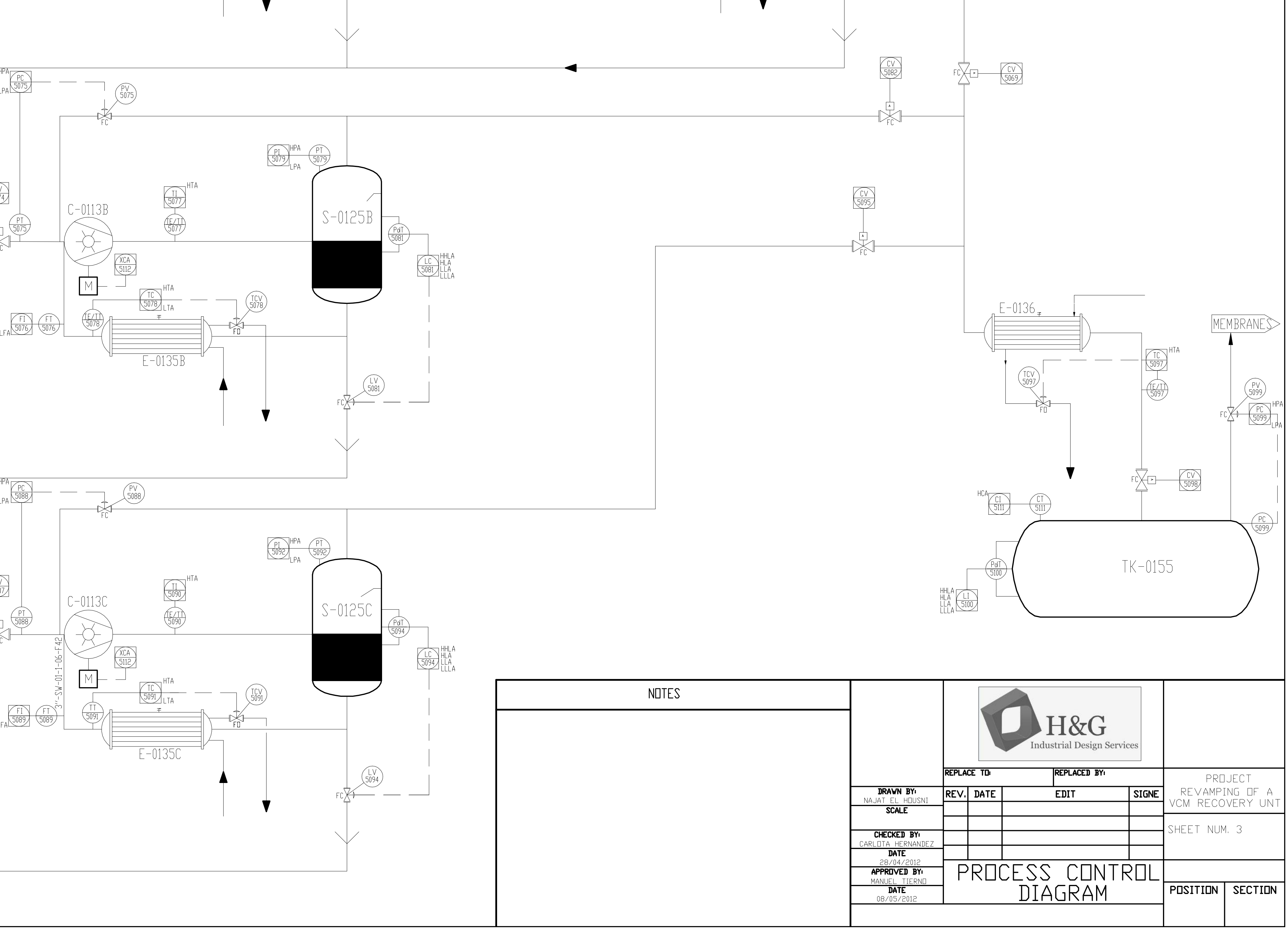
PROCESS FLOW DIAGRAM*

* Vent line off

PROJECT REVAMPING OF A VCM RECOVERY UNT

SHEET NUM. 2

POSITION | SECTION



NOTES

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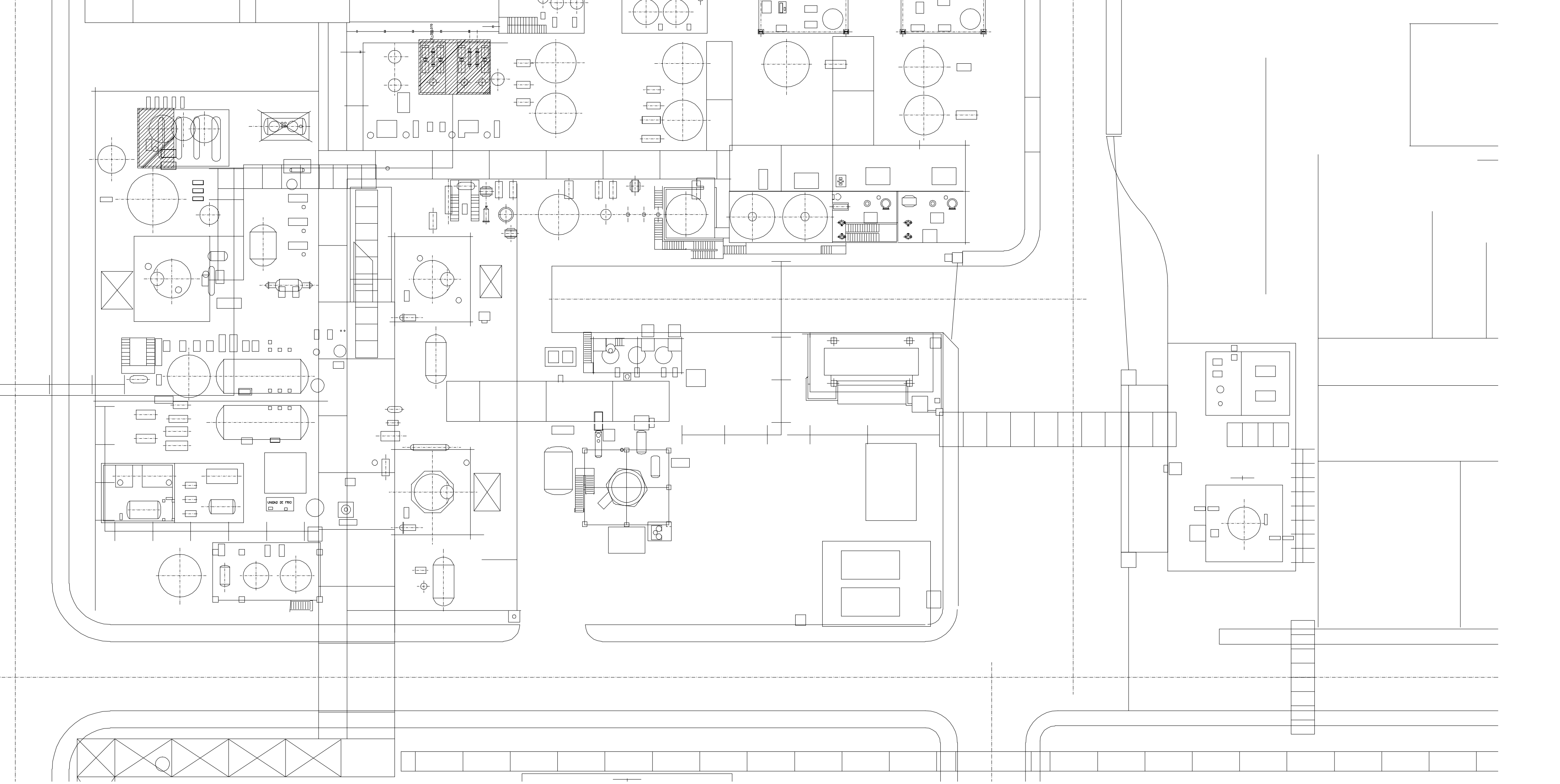
DATE 08/05/2012

PROCESS CONTROL DIAGRAM

PROJECT
REVAMPING OF A VCM RECOVERY UNT

SHEET NUM. 3

POSITION	SECTION



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SCALE	REV.	DATE	EDIT	SIGNE
CHECKED BY: CARLOTA HERNANDEZ				SHEET NUM. 4
DATE 28/04/2012				
APPROVED BY: MANUEL TIERNO	PLOT PLAN			POSITION
DATE 08/05/2012				SECTION

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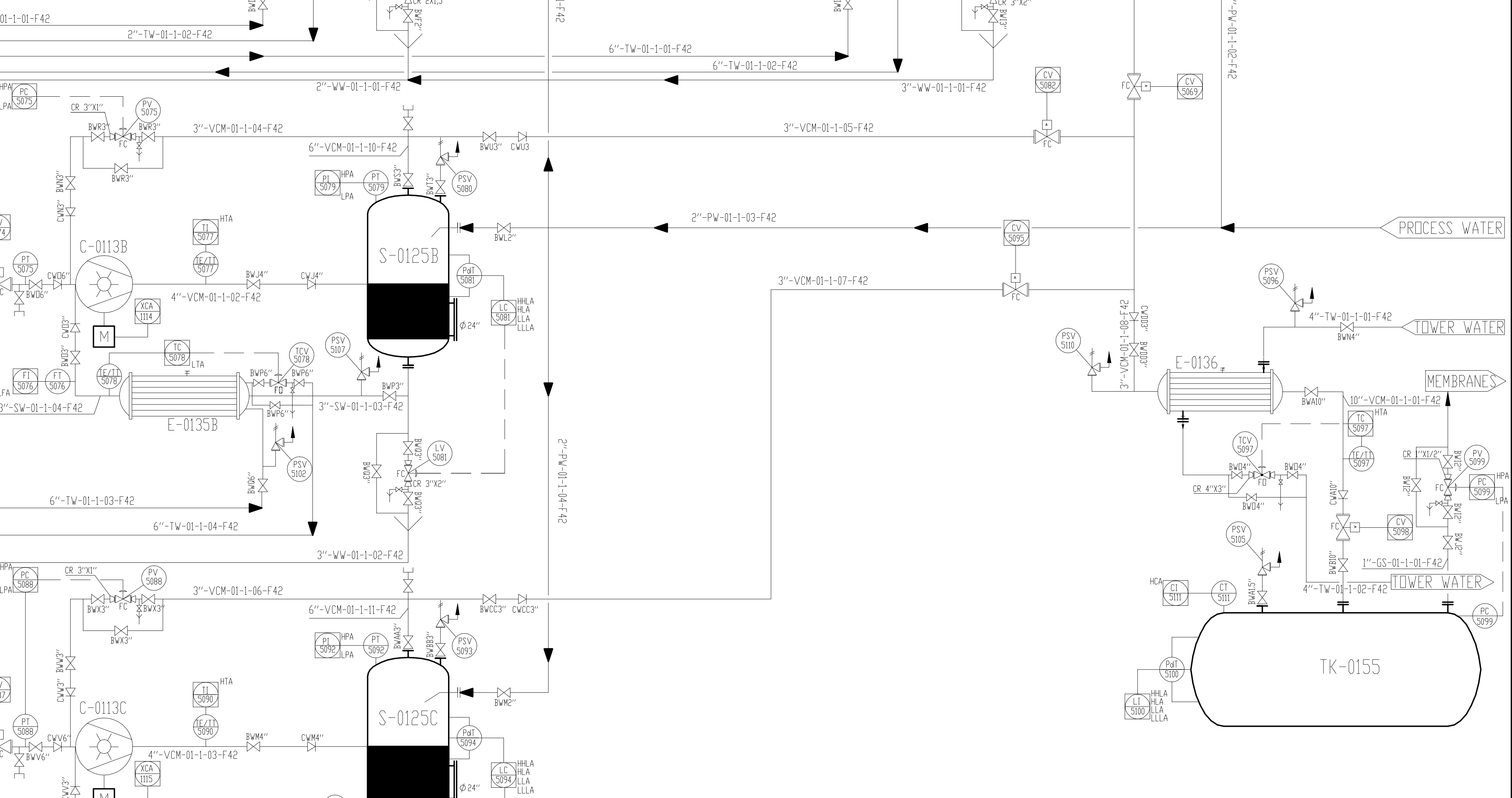

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	SCALE					SHEET NUM. 5
	CHECKED BY: NAJAT EL HOUSNI					
	DATE 28/04/2012	PIPING & INSTRUMENT DIAGRAM				
	APPROVED BY: MANUEL TIERNO					POSITION
	DATE 08/05/2012					SECTION

4.3. Basic design

4.3.1. Pipe design

In this section process pipelines are being designed according to ASTM ANSI B31-3 code. Piping was been arranged considering economy, accessibility for operation, maintenance, construction and safety. Besides, to ensure these goals, the minimum distance between pipelines is 50 mm and relative elevations of pipe ways were set to provide sufficient clearance between lines at intersections. Drains and all low points have a minimum elevation of 250 mm.

Moreover, to reduce pressure drop through pipes, fitting is only installed when required. Regarding fitting types, in this process all direction changes are done using 90 degree elbows. For pipe size adjustment, to install a control valve for instance, reducers are available. In some positions there are straight tees installed, for example to make a by-pass line.

4.3.1.1. Pipe and fitting sizing

Following table sums-up all information about every stream from the recovery unit:

Table 4.3.1. Pipelines characteristics.

	Pipe ID	From	To	Stat	Q (kg/h)	ρ (kg/m3)	P (bar)	T (ºC)
VENT LINE	6''-VCM-01-1-01-F42	-	TK-0154A	Gas	1501	0,843	0,50	70
	6''-VCM-01-1-02-F42	TK-0154A	C-0112	Gas	1134	0,843	0,50	70
	4''-WW-01-1-01-F42	P-0147AB	Water treatment	Liquid	-	982	3,0	70
	4''-WW-01-1-02-F42	TK-0154A	P-0147AB	Liquid	-	982	0,5	70
	4''-WW-01-1-03-F42	Drain point		Liquid	-	982	982	70
	3''-VCM-01-1-01-F42	S-0124	C-0112	Gas	1501	2,28	1,0	66
	2''-VCM-01-1-01-F42	C-0112	S-0124	Gas/liquid	8634	984	1,0	66
	2''-SW-01-1-01-F42	S-0124	E-0134	Liquid	7787	984	1,0	66
	2''-SW-01-1-02-F42	E-0134	C-0112	Liquid	7787	997	0,95	36
	2''-TW-01-1-01-F42	Cooling tower	E-0134	Liquid	87293	998	1,5	27
	2''-TW-01-1-02-F42	E-0134	Cooling tower	Liquid	87293	998	1,5	33
	2''-WW-01-1-01-F42	Drain point		Liquid	-	984	984	66
	6''-VCM-01-1-08-F42	S-0124	-	Gas	-	-	-	-
	6''-VCM-01-1-03-F42	S-0124	C-0113A	Gas	847,0	2,28	1,0	66
	2''-PW-01-1-01-F42	Process water	S-0124	Liquid	-	1000	1,0	25
	3''-VCM-01-1-02-F42	S-0125A	C-0113A	Gas	1936	4,08	1,0	66
	4''-VCM-01-1-01-F42	C-0113A	S-0125A	Gas/liquid	28714	992	7,0	50
	3''-SW-01-1-01-F42	S-0125A	E-0135A	Liquid	26777	992	6	66
	3''-SW-01-1-02-F42	E-0135A	C-0113A	Liquid	26777	997	5,9	36
	3''-WW-01-1-01-F42	Drain point		Liquid	-	992	992	66
	6''-TW-01-1-01-F42	Cooling tower	E-0135A	Liquid	87293	998	1,5	27

	Pipe ID	From	To	Stat	Q (kg/h)	ρ (kg/m3)	P (bar)	T (ºC)
	6''-TW-01-1-02-F42	E-0135A	Cooling tower	Liquid	87293	998	1,5	33
	3''-VCM-01-1-03-F42	S-0125A	E-0136	gas	770,0	4,08	6	36
	3''-VCM-01-1-09-F42	S-0125A	-	gas	-	-	-	36
	2''-PW-01-1-02-F42	Process water	S-0125A	Liquid	-	1000	1	25
BDT	6''-VCM-01-1-04-F42	-	TK-0154B	Gas	3835	2,01	1,0	70
	6''-VCM-01-1-05-F42	TK-0154B	C-0113B	Gas	3438	2,01	1,0	70
	4''-WW-01-1-04-F42	TK-0154B	Water treatment	Liquid	398	989	1,0	70
	4''-WW-01-1-05-F42	Drain point		Liquid	-	989	989	70
	3''-VCM-01-1-04-F42	S-0125B	C-0113B	Gas	-	13,7	1,0	55
	4''-VCM-01-1-02-F42	C-0113B	S-0125B	Gas/liquid	29838	997	7,0	55
	3''-SW-01-1-03-F42	S-0125B	E-0135B	Liquid	26777	989	6,0	55
	3''-SW-01-1-04-F42	E-0135B	C-0113B	Liquid	26777	989	5,9	36
	3''-WW-01-1-02-F42	Drain point		Liquid	-	989	989	55
	6''-TW-01-1-03-F42	Cooling tower	E-0135B	Liquid	87293	998	1,5	27
	6''-TW-01-1-04-F42	E-0135B	Cooling tower	Liquid	87293	998	1,0	33
	3''-VCM-01-1-05-F42	S-0125B	E-0136	gas	3060	13,7	6,0	36
	3''-VCM-01-1-10-F42	S-0125B	-	gas	-	-	-	36
	2''-PW-01-1-03-F42	Process water	S-0125B	Liquid	-	1000	1,0	25
STRIPPERS LINE	6''-VCM-01-1-06-F42	-	TK-0154C	Gas	792,9	2,42	1,0	34
	6''-VCM-01-1-07-F42	TK-0154C	C-0113C	Gas	780,5	2,42	1,0	34
	4''-WW-01-1-06-F42	TK-0154C	Water treatment	Liquid	12,45	-	1,0	34
	4''-WW-01-1-07-F42	Drain point		Liquid	-	997	998	34
	3''-VCM-01-1-06-F42	S-0125C	C-0113C	Gas	2668	14,3	1,0	43

	Pipe ID	From	To	Stat	Q (kg/h)	ρ (kg/m3)	P (bar)	T (ºC)
STRIPPERS LINE	4''-VCM-01-1-03-F42	C-0113C	S-0125C	Gas/liquid	29445	994	7,0	43
	3''-SW-01-1-05-F42	S-0125C	E-0135C	Liquid	26777	994	6,0	43
	3''-SW-01-1-06-F42	E-0135C	C-0113C	Liquid	26777	997	5,9	43
	3''-WW-01-1-03-F42	Drain point		Liquid	-	994	994	43
	6''-TW-01-1-05-F42	Cooling tower	E-0135C	Liquid	87293	998	1,5	27
	6''-TW-01-1-06-F42	E-0135C	Cooling tower	Liquid	87293	998	1,0	33
	3''-VCM-01-1-07-F42	S-0125C	E-0136	gas	769,4	14,3	6,0	36
	3''-VCM-01-1-11-F42	S-0125C	-	gas	-	-	6,0	36
	2''-PW-01-1-04-F42	Process water	S-0125A	Liquid	-	1000	1,0	25
STORAGE	3''-VCM-01-1-08-F42	-	E-0136	Liquid	4600	13,8	6,0	52
	10''-VCM-01-1-01-F42	E-0136	TK-0155	Liquid	4600	25,4	5,0	36
	4''-TW-01-1-01-F42	Cooling tower	E-0136	Liquid	31892	997	1,5	27
	4''-TW-01-1-02-F42	E-0136	Cooling tower	Liquid	31892	997	1,0	33
	1''-GS-01-1-01-F42	TK-0155	Membranes	Gas	-	-	5,0	36

4.3.1.2. Pipe and fitting ratio

Table 4.3.2. Pipe & fitting ratio.

Pipe ID	90º*	Tee	Reducers	Pipe ID	90º	Tee	Reducers
6''-VCM-01-1-01-F42	-	3	-	3''-VCM-01-1-04-F42	1	3	2
6''-VCM-01-1-02-F42	3	-	-	4''-VCM-01-1-02-F42	-	-	-
4''-WW-01-1-01-F42	-	1	-	3''-SW-01-1-03-F42	1	-	-
4''-WW-01-1-02-F42	1	1	-	3''-SW-01-1-04-F42	1	-	-
4''-WW-01-1-03-F42	-	-	-	3''-WW-01-1-02-F42	-	3	2
3''-VCM-01-1-01-F42	1	3	2	6''-TW-01-1-03-F42	3	-	-
2''-VCM-01-1-01-F42	-	-	-	6''-TW-01-1-04-F42	3	3	-
2''-SW-01-1-01-F42	1	-	-	3''-VCM-01-1-05-F42	3	-	-
2''-SW-01-1-02-F42	1	-	-	3''-VCM-01-1-10-F42	-	1	-
2''-TW-01-1-01-F42	3	-	-	2''-PW-01-1-03-F42	2	1	-
2''-TW-01-1-02-F42	3	3	2	6''-VCM-01-1-06-F42	-	3	-
2''-WW-01-1-01-F42	-	3	2	6''-VCM-01-1-07-F42	3	-	-
6''-VCM-01-1-08-F42	-	1	-	4''-WW-01-1-06-F42	-	3	-
6''-VCM-01-1-03-F42	3	-	-	4''-WW-01-1-07-F42	-	1	-
2''-PW-01-1-01-F42	2	1	-	3''-VCM-01-1-06-F42	1	3	2
3''-VCM-01-1-02-F42	1	3	2	4''-VCM-01-1-03-F42	-	-	-
4''-VCM-01-1-01-F42	-	-	-	3''-SW-01-1-05-F42	1	-	-
3''-SW-01-1-01-F42	1	-	-	3''-SW-01-1-06-F42	1	-	-
3''-SW-01-1-02-F42	1	-	-	3''-WW-01-1-03-F42	-	3	2
3''-WW-01-1-01-F42	-	3	2	6''-TW-01-1-05-F42	3	-	-
6''-TW-01-1-01-F42	3	-	-	6''-TW-01-1-06-F42	3	3	-
6''-TW-01-1-02-F42	3	3	-	3''-VCM-01-1-07-F42	3	-	-
3''-VCM-01-1-03-F42	3	-	-	3''-VCM-01-1-11-F42	-	1	-
3''-VCM-01-1-09-F42	-	1	-	2''-PW-01-1-04-F42	2	1	-
2''-PW-01-1-02-F42	2	1	-	3''-VCM-01-1-08-F42	1	-	-
6''-VCM-01-1-04-F42	-	3	-	10''-VCM-01-1-01-F42	1	-	-
6''-VCM-01-1-05-F42	3	-	-	4''-TW-01-1-01-F42	3	-	-
4''-WW-01-1-04-F42	-	3	-	4''-TW-01-1-02-F42	3	3	-
4''-WW-01-1-05-F42	-	1	-	1''-GS-01-1-01-F42	-	3	2

4.3.2. Instrumentation and control design

In this section, instrumentation and control design is accomplished. When specifying instrumentation and control schemes some targets must be achieved. First of all, safe plant operation to keep the process variables within known safe operating limits, to detect dangerous situations and finally provide interlocks and alarms to prevent dangerous operating procedures. Secondly product output design has to be achieved as well as the product quality within the specified quality standards. Finally, the lowest cost operation commensurate with the other objectives.

- Pressure control in holding tank

For pressure control in tanks TK-0154-A, TK-0154B, TK-0154C, proportional integrating and derivative feedback control (PID) is installed. Measured variable is pressure while manipulated variable is inlet flow rate. If pressure rises, globe valve closes and vice versa, therefore, action of controller is reverse. If control fails, valve will work as “fail closed” so that back flow to the PVC process, can be avoided.

- Level control in holding tank

Proportional feedback control (P) in tanks TK-0154B and TK-0154C is installed. Measured variable is level using differential pressure measurement while manipulated variable is flow rate. If level rises, globe valve opens and vice versa and so action of controller is direct. If control fails, valve will work as “fail open” so that overpressure can be avoided. In case of tank TK-0154-A, manipulated variable is pump’s motor rotor. If level rises, rpm of pump’s rotor rise as well so actuating of controller is direct.

- Level control in tank separator

To do such purpose, proportional feedback control (P) is installed in separators S-0124, S-0125A, S-0125B and S-0125C. Measured variable is level using a differential pressure measurement while flow at drain point is the manipulated variable. If level rises, globe valve opens and vice versa, therefore, control will have a direct action. If control fails, valve will work as “fail open” so that overpressure can be avoided.

- Suction pressure

In compressors C-0112, C-0113A, C-0113B, C-0113C proportional integrating and derivative feedback control (PID) is installed in by-passed VCM line. Measured variable is inlet pressure while the manipulated variable is recirculated flow rate. If pressure line is lower than SP, valve opens. Therefore, controller has reversed actuating. If control fails, valve will work as “fail open” because cavitation has to be avoided in this equipment.

- Water service liquid temperature at suction

For suction temperature control, it is necessary proportional integrating and derivative control (PID) in heat exchangers E-0134, E-0125A and E-0135C. Control valve is installed in the refrigeration line; more specifically in heat exchanger exit. Measured variable is outlet service water temperature while manipulated variable is tower water flow rate. If temperature rises, valve opens. Therefore, this control has direct actuating. If control fails, valve will work as “fail open” so that increasement in temperature suction can be avoided.

- Temperature control for storage

For storage temperature control in heat exchanger E-0136 proportional integrating and derivative control (PID) is installed. Control valve is installed in the refrigeration line; more specifically in heat exchanger exit. Measured variable is outlet service water temperature while manipulated variable is tower water flow rate. If temperature rises, valve opens. Therefore, this control has direct actuating. If control fails, valve will work as “fail open” so that increasement in temperature suction can be avoided.

4.3.2.1. Instrument and signal ratio

In this section, signals and alarms ratios as well as signals and transmitters ratio are described. Tables 4.3.3, 4.3.5 and 4.3.7 show signals and transmitters ratio of Vent, BDT and strippers line respectively while tables 4.3.4, 4.3.6 and 4.3.8 show signals and alarms ratios respectively. Notice that analogic indicator is used for all transmitters while digital indicator is used for all alarms.

- Vent line ratios

Table 4.3.3. Signals and transmitters ratios installed in vent line.

Signal	Name	Description	SP	Type
AI-5050	PT-5051	Pressure transmitter TK-0154A	1,00 bar	Bourdon
AI-5051	PdT-5053	Level transmitter TK-0154A	20,0%	Differential P.
AI-5052	PT-5055	Pressure transmitter C-0112	0,50 bar	Bourdon
AI-5053	FT-5056	Flow transmitter C-0112	$1{,}13\cdot10^{3}$(kg/h)	Mass
AI-5054	TT-5058	Inlet temperature transmitter C-0112	36,0ºC	Thermocouple

Signal	Name	Description	SP	Type
AI-5055	TE/TT-5057	Outlet temperature transmitter C-0112	55,1ºC	Thermocouple
AI-5056	PdT-5061	Level transmitter S-0124	50,0%	Differential P.
AI-5057	PT-5059	Pressure transmitter S-0124	1,00 bar	Bourdon
AI-5058	PT-5063	Pressure transmitter C-0113A	0,50 bar	Bourdon
AI-5059	FT-5062	Flow transmitter C-0113A	847(kg/h)	Mass
AI-5060	TT-5065	Inlet temperature transmitter C-0113A	36,0ºC	Thermocouple
AI-5061	TE/TT-5064	Outlet temperature transmitter C-0113A	66,0ºC	Thermocouple
AI-5062	PdT-5068	Level transmitter S-0125A	50,0%	Differential P.
AI-5063	PT-5066	Pressure transmitter S-0125A	7,00 bar	Bourdon

Table 4.3.4. Signals and alarms ratios installed in vent line.

Signal	Name	Description	SP	Type
DI-5050	HPA-5051	High pressure alarm TK-0154A	1,25 bar	-
DI-5051	LPA-5051	Low pressure alarm TK-0154A	0,75 bar	-
DI-5051	HHLA-5053	High high level alarm TK-0154A	90,0%	-
DI-5052	HLA-5053	High level alarm TK-0154A	80,0%	-
DI-5053	LLA-5053	Low level alarm TK-0154A	20,0%	-
DI-5054	LLLA-5053	Low low level alarm TK-0154A	10,0%	-
DI-5055	HPA-5055	High pressure alarm C-0112	0,70 bar	-
DI-5056	LPA-5055	Low pressure alarm C-0112	0,30 bar	-
DI-5057	LFA-5056	Low flow alarm C-0112	565(kg/h)	-
DI-5058	HTA-5057	High out temperature alarm C-0112	66,1ºC	-
DI-5059	LTA-5058	Low inlet temperature alarm C-0112	28,8ºC	-
DI-5060	HPA-5059	High pressure alarm S-0124	1,25 bar	-
DI-5061	LPA-5059	Low pressure alarm S-0124	0,75 bar	-
DI-5062	HHLA-5061	High high level alarm S-0124	90,0%	-
DI-5063	HLA-5061	High level alarm S-0124	80,0%	-
DI-5064	LLA-5061	Low level alarm S-0124	20,0%	-
DI-5065	LLLA-5061	Low low level alarm S-0124	10,0%	-
DI-5066	HPA-5063	High pressure alarm C-0113A	1,30 bar	-
DI-5067	LPA-5063	Low pressure alarm C-0113A	0,70 bar	-
DI-5068	HPA-5066	High pressure alarm S-0125A	7,30 bar	-
DI-5069	LPA-5066	Low pressure alarm S-0125A	6,70 bar	-

Signal	Name	Description	SP	Type
DI-5070	LFA-5062	Low flow alarm C-0113A	423(kg/h)	-
DI-5071	LTA-5065	Low temperature alarm C-0113A	60,0ºC	-
DI-5072	HTA-5064	High out temperature alarm C-0113A	40,0ºC	-
DI-5053	HHLA-5068	High high level alarm S-0125A	90,0%	-
DI-5074	HLA-5068	High level alarm S-0125A	80,0%	-
DI-5075	LLA-5068	Low level alarm S-0125A	20,0%	-
DI-5076	LLLA-5068	Low low level alarm S-0125A	10,0%	-

- BDT line ratios

Table 4.3.5. Signals and transmitters ratios installed in BDT line.

Signal	Name	Description	SP	Type
AI-5064	PT-5071	Pressure transmitter TK-0154B	1,00 bar	Bourdon
AI-5065	PdT-5073	Level transmitter TK-0154B	20,0%	Differential P.
AI-5066	PT-5075	Pressure transmitter C-0113B	1,00 bar	Bourdon
AI-5067	FT-5076	Flow transmitter C-0113B	$3,44\cdot10^{3}$(kg/h)	Mass
AI-5068	TT-5078	Inlet Temperature transmitter C-0113B	36,0ºC	Thermocouple
AI-5069	TE/TT-5077	Outlet Temperature transmitter C-0113B	56,0ºC	Thermocouple
AI-5070	PdT-5081	Level transmitter S-0125B	50,0%	Differential P.
AI-5071	PT-5079	Pressure transmitter S-0125B	7,00 bar	Bourdon

Table 4.3.6. Signals and alarms ratios installed in BDT line.

Signal	Name	Description	SP	Type
DI-5077	HPA-5071	High pressure alarm TK-0154B	1,25 bar	-
DI-5078	LPA-5071	Low pressure alarm TK-0154B	0,75 bar	-
DI-5079	HHLA-5073	High high level alarm TK-0154B	90,0%	-
DI-5080	HLA-5073	High level alarm TK-0154B	80,0%	-
DI-5081	LLA-5073	Low level alarm TK-0154B	20,0%	-
DI-5082	LLLA-5073	Low low level alarm TK-0154B	10,0%	-
DI-5083	HPA-5075	High pressure alarm C-0113B	1,25 bar	-
DI-5084	LPA-5075	Low pressure alarm C-0113B	0,75 bar	-
DI-5085	LFA-5076	Low flow alarm C-0113B	$1,72\cdot10^{3}$(kg/h)	-
DI-5086	HTA-5077	High out temperature alarm C-0113B	66,0ºC	-
DI-5087	LTA-5078	Low inlet temperature alarm C-0113B	46,0ºC	-

Signal	Name	Description	SP	Type
DI-5088	HHLA-5081	High high level alarm S-0125B	90,0%	-
DI-5089	HLA-5081	High level alarm S-0125B	80,0%	-
DI-5083	LLA-5081	Low level alarm S-0125B	20,0%	-
DI-5090	LLLA-5081	Low low level alarm S-0125B	10,0%	-
DI-5091	HPA-5079	High pressure alarm S-0125B	7,30 bar	-
DI-5092	LPA-5079	Low pressure alarm S-0125B	6,70 bar	-

- Strippers line ratios

Table 4.3.7. Signals and transmitters ratios installed in strippers line.

Signal	Name	Description	SP	Type
AI-5072	PT-5084	Pressure transmitter TK-0154C	1,00 bar	Bourdon
AI-5073	PdT-5086	Level transmitter TK-0154C	0,20%	Differential P.
AI-5074	PT-5088	Pressure transmitter C-0113C	1,00 bar	Bourdon
AI-5075	FT-5089	Flow transmitter C-0113C	780(kg/h)	Mass
AI-5076	TT-5091	Inlet Temperature transmitter C-0113C	36,0ºC	Thermocouple
AI-5077	TE/TT-5090	Outlet Temperature transmitter C-0113C	50,0ºC	Thermocouple
AI-5078	PdT-5094	Level transmitter S-0125C	20,0%	Differential P.
AI-5079	PT-5092	Pressure transmitter S-0125C	7,00 bar	Bourdon

Table 4.3.8. Signals and alarms ratios installed in strippers line.

Signal	Name	Description	SP	Type
DI-5093	HPA-5084	High pressure alarm TK-0154C	1,25 bar	-
DI-5094	LPA-5084	Low pressure alarm TK-0154C	0,75 bar	-
DI-5095	HLA-5086	High high level alarm TK-0154C	90,0%	
DI-5096	HLA-5086	High level alarm TK-0154C	80,0%	
DI-5097	LLA-5086	Low level alarm TK-0154C	20,0%	-
DI-5098	LLLA-5086	Low low level alarm TK-0154C	10,0%	-
DI-5099	HPA-5088	High pressure alarm C-0113 C	1,25 bar	-
DI-5100	LPA-5088	Low pressure alarm C-0113 C	0,75 bar	-
DI-5101	LFA-5089	Low flow alarm C-0113 C	390(kg/h)	-
DI-5102	HTA-5090	High out temperature alarm C-0112	60,0ºC	-
DI-5103	LTA-5091	Low inlet temperature alarm C-0112	40,0ºC	-
DI-5104	HHLA-5094	High high level alarm S-0125C	90,0%	-

Signal	Name	Description	SP	Type
DI-5105	HLA-5094	High level alarm S-0125C	80,0%	-
DI-5106	LLA-5094	Low level alarm S-0125C	20,0%	-
DI-5107	LLLA-5094	Low low level alarm S-0125C	10,0%	-
DI-5108	HPA-5092	High pressure alarm S-0125C	7,25 bar	-
DI-5109	LPA-5092	Low pressure alarm S-0125C	0,75 bar	-

- Storage line ratios

Table 4.3.9. Signals and transmitters ratios installed in storage line.

Signal	Name	Description	SP	Type
AI-5080	TE/TT-5097	Temperature transmitter E-0136	36ºC	Thermocouple
AI-5081	PdT-5100	Level transmitter TK-0155	80%	Differential P.
AI-5082	CT-5101	Composition transmitter TK-0155	0,001%	Multivariable
AI-5083	PT-5099	Pressure transmitter TK-0155	5 bar	Bourdon

Table 4.3.10. Signals and alarms ratios installed in storage line.

Signal	Name	Description	SP	Type
DI-5110	HTA-5097	High temperature alarm E-0136	40ºC	-
DI-5111	HHLA-5100	High high level alarm TK-0155	90%	-
DI-5112	HLA-5100	High level alarm TK-0155	80%	-
DI-5113	LLA-5100	Low level alarm TK-0155	20%	-
DI-5114	LLLA-5100	Low low level alarm TK-0155	10%	-
DI-5115	HCA-5101	High O_2 composition alarm TK-0155	0,001%	-
DI-5116	HPA-5099	High pressure alarm TK-0155	5,5 bar	-
DI-5117	LPA-5099	Low pressure alarm TK-0155	4,5 bar	-

4.3.2.2. Controllers ratio

In this section, controlers ratio is provided:

Table 4.3.11. Controllers ratio design.

Name	Controlled Variable	Manipulated Variable	Element	Effect	Acti
VENT LINE					
PC 5051	Pressure TK-0154A	Inlet flow rate in TK-0154A	PV 5051	Primary	Inve
LC-5053	Level TK-0154A	Outlet flow rate in TK-0154A	Motor	Primary	Dire
PC 5055	Pressure C-0112	Inlet flow rate in C-0112	PV 5055	Primary	Inve
TCV 5058	Outlet temperature E-0134	Outlet TW flow rate E-0134	TCV 5058	Primary	Dire
LC 5061	Level S-0124	Drain flow rate S-0124	LV 5061	Primary	Dire
PC 5063	Pressure C-0113A	Inlet flow rate in C-0113A	PV 5063	Primary	Inve
TCV 5065	Outlet temperature E-0135A	Outlet TW flow rate E-0135A	TCV 5065	Primary	Dire
LC 5068	Level S-0125A	Drain flow rate S-0125A	LV 5068	Primary	Dire
BLOWN DOWN TANK LINE					
PC 5071	Pressure TK-0154B	Inlet flow rate in TK-0154B	PV 5071	Primary	Inve
LC-5073	Level TK-0154B	Outlet flow rate TK-0154B	LV 5073	Primary	Dire
PC 5075	Pressure C-0113B	Inlet flow rate in C-0113B	PV 5075	Primary	Inve
TCV 5078	Outlet temperature E-0135B	Outlet TW flow rate E-0135B	TCV 5078	Primary	Dire
LC 5081	Level S-0125B	Drain flow rate S-0125B	LV 5081	Primary	Dire
STRIPPERS LINE					
PC 5084	Pressure TK-0154C	Inlet flow rate in TK-0154C	PV 5084	Primary	Inve
LC-5086	Level TK-0154C	Outlet flow rate in TK-0154C	PV 5086	Primary	Dire
PC 5088	Pressure C-0113C	Inlet flow rate in C-0113C	PV 5088	Primary	Inve
TCV 5058	Outlet temperature E-0135C	Outlet TW flow rate E-0135C	TCV 5058	Primary	Dire
LC 5094	Level S-0125C	Drain flow rate S-0125C	LV 5094	Primary	Dire
TCV 5097	Outlet temperature E-0136	Outlet TW flow rate E-0136	TCV 5097	Primary	Dire
STORAGE LINE					
PC 5100	Pressure TK-0155	Outlet flow rate in TK-0155	PV 5099	Primary	Dire
TC 5097	Outlet temperature E-0136	Outlet TW flow rate E-0136	TCV 5097	Primary	Dire

4.3.2.3. Alarms and interlock system

In this section, interlock system is described below.

Table 4.3.12. Interlock and alarms ratio in vent line

Signal	Name	Description	SP	Order
HPA-5051	Interlock 1	High pressure TK-0154A	1,50 bar	Stop system
LPA-5051	Interlock 4	Low pressure TK-0154A	0,70 bar	Stop system
HHLA-5053	Interlock 7	High level TK-0154A	90,0%	Run pump P-0147AB
LLLA-5053	Interlock 10	Low level TK-0154A	10,0%	Stop pump P-0147AB
HPA-5055	Interlock 13	High pressure	0,70 bar	Stops vacuum pump C-0112
LPA-5055	Interlock 14	Low pressure	0,30 bar	Stops vacuum pump C-0112
LFA-5065	Interlock 15	No flow	0,00 kg/s	Stops vacuum pump C-0112
HPA-5063	Interlock 16	Pressure increase	1,40 bar	Stops compressor C-0113A
LPA-5063	Interlock 19	Pressure decrease	0,70 bar	Stops compressor C-0113A
LFA-5062	Interlock 22	No flow	0,00 kg/s	Stops compressor C-0113A
HPA-5059	Interlock 25	Pressure increase S-0124	1,30 bar	Stops system
HPA-5059	Interlock 26	Pressure decrease S-0124	0,90 bar	Stops system
LPA-5066	Interlock 29	Pressure increase S-0125A	7,30 bar	Stops system
LPA-5066	Interlock 30	Pressure decrease S-0125A	50 bar	Stops system
LLLA-5061	Interlock 33	No level in S-0124	10,0%	Stops system
LLLA-5068	Interlock 34	No level in S-0125A	10,0%	Stops system
HHLA-5061	Interlock 37	Level increase in S-0124	90,0%	Stops system
HHLA-5068	Interlock 38	Level increase in S-0125A	90,0%	Stops system

Table 4.3.13. Interlock and alarms ratio in BDT line

Signal	Name	Description	SP	Order
HPA-5071	Interlock 2	High pressure TK-0154B	1,50 bar	Stop system
LPA-5071	Interlock 5	Low pressure TK-0154B	0,70 bar	Stop system
HHLA-5073	Interlock 8	High level TK-0154B	90,0%	Stop system
LLLA-5073	Interlock 11	Low level TK-0154B	10,0%	Stop system
HPA-5075	Interlock 17	Pressure increase	1,40 bar	Stops compressor C-0113B
LPA-5075	Interlock 20	Pressure decrease	0,70 bar	Stops compressor C-0113B
LFA-5076	Interlock 23	Flow decrease	0,00 kg/s	Stops compressor C-0113B

HPA-5079	Interlock 27	Pressure increase S-0125B	7,30 bar	Stops system
LPA-5079	Interlock 31	Pressure decrease S-0125B	5,00 bar	Stops system
LLLA-5081	Interlock 35	Level decrease in S-0124B	10,0%	Stops system
HHLA-5081	Interlock 39	Level increase in S-0124B	90,0%	Stops system

Table 4.3.14. Interlock and alarms ratio in Strippers line

Signal	Name	Description	SP	Order
HPA-5084	Interlock 3	High pressure TK-0154C	1,50 bar	Stop system
LPA-5084	Interlock 6	Low pressure TK-0154C	0,60 bar	Stop system
HHLA-5086	Interlock 9	High level TK-0154C	80,0%	Stop system
LLLA-5086	Interlock 12	Low level TK-0154C	20,0%	Stop system
HPA-5088	Interlock 18	Pressure increase	1,40 bar	Stops compressor C-0113C
LPA-5088	Interlock 21	Pressure decrease	0,70 bar	Stops compressor C-0113C
LFA-5089	Interlock 24	Flow decrease	0,00 kg/s	Stops compressor C-0113C
HPA-5092	Interlock 28	Pressure increase S-0125C	7,30 bar	Stops system
LPA-5092	Interlock 32	Pressure decrease S-0125C	5,00 bar	Stops system
LLLA-5094	Interlock 36	No level in S-0124C	0,00%	Stops system
HHLA-5094	Interlock 40	Level increase in S-0124C	90,0%	Stops system

Table 4.3.15. Interlock and alarms ratio in Storage zone

Signal	Name	Description	SP	Order
HHLA-5001	Interlock 41	Level increase TK-0155	90%	Stop system
HPA-5099	Interlock 42	Pressure decrease TK-0155	3 bar	Stop system

4.3.3. Equipment design

4.3.3.1. Liquid ring device

In this section the liquid ring compressors needed in the recovery unit are being designed. There are two considerations to take into account while doing such task. The first one, the service or sealing liquid chosen is water. And the second is that the gas to convey is a saturated mixture of water-VCM, due to the water used in polymerization process.

Moreover, as it was mentioned in section 2, a liquid ring vacuum pump is required in the vents recovery line. In essence the same relationships apply for the design of both equipment, thus the pump will also be calculated in this section. Design will take place following procedure described in ref. 9.

4.3.3.1.1. Inlet flow rate calculation

The gas being compressed is already saturated in suction state, so no further evaporation will take place when the gas enters the compressor. Consequently, the inlet volumetric flow rate in this case is greater by the volumetric flow rate of the service water than when compressing dry gases.

If the gas-vapor mixture entering to the compressor or pump is at a higher temperature than the service water, as in this case, it is cooled down when it comes in contact with the service water. Upon reaching saturation vapor pressure, the vapor condenses to bring about an increase in the inlet volumetric flow rate.

Since the vapor pressure rises with temperature, the mixture can contain high vapor content at elevated temperatures. In such cases, it may be useful to examine the possibility of vapor condensation ahead the equipment.

For a saturated mixture the partial pressure of the vapor is equal to the vapor pressure of water at the mixture temperature, so the partial pressure of VCM (PVCM) can be obtained by using the following form:

$$\mathrm{P_{tot}} = \mathrm{P_{VCM}} + \mathrm{P_{V,S}} \tag{4.3.1}$$

Considering ideal gases, the vapour mass flow required is then calculated by using the adaptation of Ideal Gases Equation State shown below:

$$\dot{\mathrm{m}}_{\mathrm{Wa}} = \dot{\mathrm{m}}_{\mathrm{VCM}} \times \frac{\mathrm{M_{Wa}}}{\mathrm{M_{VCM}}} \times \frac{\mathrm{P_{V,S}}}{\mathrm{P_{VCM}}} \tag{4.3.2}$$

Once calculated the vapour mass flow rate, total inlet volume flow rate can be found as:

$$S = \dot{V}_{tot} = \frac{83{,}15 \times \left[\frac{\dot{m}_{Wa}}{M_{Wa}} + \frac{\dot{m}_{VCM}}{M_{VCM}}\right] \times T_S}{P_S} \qquad (4.3.3)$$

Since operating conditions do not match with those of catalogues, the required inlet volumetric flow rate must to be converted to the conditions used by the catalogue[1]. But, it is first needed to select a preliminary pump/compressor because dimensions need to be used in previous calculations.

Selected is the equipment, equation x.x can be used to adapt to catalogue specifications:

$$S = S_L \times \lambda_I \times \lambda_{II} \qquad (4.3.4)$$

λ_I express the influence of the service water temperature and λ_{II} the level of vapor condensation in the pump or compressor. These parameters are equal to 1 if operating and catalogue conditions are the same; otherwise, they can be found as:

$$\lambda_{I,1} = \frac{P_S \times (0{,}27 \times \ln P_S - 0{,}0783) - 1{,}05 \times P_{V,D}}{P_S \times (0{,}27 \times \ln P_S - 0{,}0783) - 1{,}05 \times 17{,}04} \qquad (4.3.5)$$

$$\lambda_{I,2} = \frac{P_S \times (0{,}35 \times \ln P_S - 0{,}1) - P_{V,D}}{P_S \times (0{,}35 \times \ln P_S - 0{,}1) - 17{,}04} \qquad (4.3.6)$$

$$\lambda_{II} = \frac{[0{,}75 \times P_S \times (\ln P_S - 0{,}2877)]^E}{[0{,}75 \times P_S \times (\ln P_S - 0{,}2877)]^E - 0{,}75 \times P_{V,S}} \qquad (4.3.7)$$

$$E = \left[0{,}082 \times \frac{h}{d} + 0{,}793\right] \times \left[\frac{P_{V,D}}{17{,}04}\right]^{0{,}0369} \qquad (4.3.8)$$

There are several forms to calculate λI depending of the number of pump/compressor stage: λI,1 for single stage equipment and λI,2 for two-stage ones. However, it is always advisable to use λI,1 for compressors regardless the number of stages.

Once the definitive pump/compressor is selected, there are two adjustments to choose if required by the pump selected under operating conditions instead the required inlet volumetric flow rate:

[1] Catalogue conditions: Service liquid: water; T_A= 20ºC; T_B=15ºC; P=14,7psia

- Bypass control: a pipe fitted between the gas outlet line of the separator and the discharge nozzle on the pump/compressor. The return flow can be adjusted by means of a bypass valve in order to maintain the suction pressure.
- Controlling the service water temperature: changing the water service temperature, inlet volumetric flow rate of the pump/compressor can be reduced due to the λI effect in order to a better matching between the required inlet volumetric flow rate and that of the selected equipment.

The first choice is already considered in plant design to ensure the required inlet flow rate. The following table shows conditions and requirements of the three recovery lines:

Table 4.3.16. Conditions and requirements for recovery system lines.

Line	Q (kg/h)	Inlet P (bar)	Outlet P (bar)	Inlet T (ºC)	Outlet T (ºC)	Condensed vapor (kg/h)	Service water T (ºC)	Evacuated Heat (kJ/s)
Vent	766	0,5	1	70	67	287	36	268,5
		1	7	67	50	76,6	36	127,0
BDT	3040	1	7	70	55	377	36	585,4
Strippers	768	1	7	34	43	11,1	36	82,5

In table below results of such designs are exposed. Since every line must be able, if required, to replace the other lines, biggest dimensions (BDT line) will be assumed for whole unit.

Table 4.3.17. Selected equipment.

Line	Device	Selection	Required Inlet flow (m^3/h)*	Service water (m^3/h)
Vent	Liquid ring vacuum pump	PUMP 2BE4 30	5000	7,5
	Liquid ring compressor	NASH2500	2500	26,4
BDT	Liquid ring compressor	NASH2500	2500	26,4
Strippers	Liquid ring compressor	NASH2500	2500	26,4

* At catalogue conditions.

4.3.3.2. Control and safety valve design

For valve sizing and selection, ref. 7 for control valve and ref. 8 for safety valve were used.

4.3.3.2.1. Control valve sizing

For control valve sizing, a pressure drop of 10% is assumed for liquid and 25% for gases. Regarding control valve type, the used one is a Single-Ported Globe Style Valve. The Flow Characteristic of the chosen control valve is equal percentage, which means that flow capacity increases exponentially with valve trim travel. Equal increments of valve travel produce equal percentage changes in the existing C_v.

Control valve in Vent line and Strippers line were oversized at the same way as the whole line. Anyway both results, provisional and definitive sizes, are shown in following results table, where important parameters are also exposed.

4.3.3.2.1.1. Sizing valve for liquid

Following is a step-by-step procedure used for the sizing of control valves for liquid flow:

$$\mathrm{Cv} = \frac{\mathrm{q}}{0{,}865 \cdot \mathrm{F_p} \cdot \sqrt{\frac{(\mathrm{P_{inlet}} - \mathrm{P_{outlet}})}{\mathrm{G_f}}}} \tag{4.3.9}$$

Where Fp is the piping geometry factor that is required if any fitting such as reducers, elbows, or teed will be directly attached to the inlet and outlet connections of the control valve that is to be sized.

$$\mathrm{F_P} = \left[1 + \frac{\sum \mathrm{K}}{0{,}00214}\left(\frac{\mathrm{C_v}}{\mathrm{d_v}^2}\right)^2\right]^{-1/2} \tag{4.3.10}$$

Where d is an assumed valve size to initiate calculation and C_v is the valve sizing coefficient at 100-percent travel for the assumed valve size.

$$K = K_1 + K_2 + K_{B1} - K_{B2} \tag{4.3.11}$$

In the above equation, the ΣK term is the algebraic sum of the velocity head loss coefficients of all of the fittings that are attached to the control valve. In this case, since pipe diameter is the same for valve inlet and outlet then terms KB1 and KB2 are dropped from the equation. Terms K_1 and K_2 express the head loss caused by reducers when valve diameter is different from pipe diameter.

$$K = 1{,}5 \cdot \left(1 - \frac{d_v{}^2}{D^2}\right)^2 \tag{4.3.12}$$

Table 4.3.18. Control valve sized for liquid streams

Valve	Q m³/h	P bar	T ºC	ρ_f kg/m³	D STD in	AP	G_f	K	Fp	Cv cal.	d_v in	Cv
TCV 5058	8,69	1,5	33	998	2,067	0,15	0,996	$3{,}36\cdot10^{-1}$	0,96	27,1	1 ½	35,8
TCV 5065	87,5	1,5	33	998	6,065	0,15	0,996	$6{,}82\cdot10^{-4}$	1,0	261	6	394
TCV 5078	87,5	1,5	33	998	6,065	0,15	0,996	$6{,}82\cdot10^{-4}$	1,0	261	6	394
TCV 5091	87,5	1,5	33	998	6,065	0,15	0,996	$6{,}82\cdot10^{-4}$	1,0	261	6	394
LV 5061	7,91	1	66	984	2,067	0,1	0,983	$3{,}36\cdot10^{-1}$	0,96	30,0	1 ½	35,8
LV 5073	55,5	1	70	989	4,026	0,1	0,988	$2{,}49\cdot10^{-4}$	1,0	201	4	224
LV 5086	55,5	1	34	998	4,026	0,1	0,996	$2{,}49\cdot10^{-1}$	1,0	202	4	224
LV 5068	7,64	6	50	992	3,068	0,6	0,99	$8{,}80\cdot10^{-1}$	0,88	42,6	2	59,7
LV 5081	27,1	6	55	989	3,068	0,6	0,988	$4{,}96\cdot10^{-1}$	0,94	42,6	2	59,7
LV 5094	9,82	6	43	994	3,068	0,6	0,993	$8{,}80\cdot10^{-1}$	0,88	42,6	2	59,7
TCV 5097	32	1,5	37	997	4,026	0,15	0,995	$2{,}97\cdot10^{-4}$	0,96	98,8	3	136

4.3.3.2.1.2. Sizing valve for compressible fluid

Following is a procedure for control valve for gases according to ISA standard.

$$Cv = \frac{q}{2120 \cdot F_p \cdot P_{inlet} \cdot Y \cdot \sqrt{\frac{x}{M \cdot T \cdot Z}}} \tag{4.3.13}$$

Where:

$$x = \frac{\Delta P}{P_{inlet}} \tag{4.3.14}$$

$$k = \frac{C_p}{C_v} \quad (4.3.15)$$

$$Y = 1 - \frac{x}{3 \cdot F_k \cdot x_T} \quad (4.3.16)$$

$$F_k = k/1{,}4 \quad (4.3.17)$$

F_p is obtained as in control valve for liquid procedure. To determine q_{max} and ΔP_{max} the following expressions is used:

$$q_{max} = 0{,}865 \cdot F_L \cdot Cv \cdot \sqrt{\frac{P_1 - F_F \cdot P_s}{G_f}} \quad (4.3.18)$$

$$\Delta P_{max} = {F_L}^2 \cdot (P_{inlet} - F_F \cdot P_s) \quad (4.3.19)$$

Where FL is a tabulated value provided by manufacturer, FF can be found as:

$$F_F = 0{,}96 - 0{,}28 \cdot \sqrt{\frac{P_s}{P_c}} \quad (4.3.20)$$

Table 4.3.19. Control valves sized for gas streams.

Valve	Q m^3/h	P bar	T ºC	ρ_g kg/m^3	D STD in	AP	Gg	K	XT	Y	Cv cal.	d_v in	Cv
PV5071	1906	1	70	2	6,065	0,75	$2{,}0 \cdot 10^{-3}$	$6{,}8 \cdot 10^{-4}$	0,78	0,55	274	6	394
PV5084	327,4	1	34	2,4	6,065	0,75	$2{,}0 \cdot 10^{-3}$	0,869	0,78	0,49	274	6	394
PV5051	1780	5	70	0,80	6,065	0,38	$8{,}0 \cdot 10^{-4}$	$6{,}8 \cdot 10^{-4}$	0,72	0,51	249	6	394
PV5055	370,8	1	66	2,3	3,068	0,75	$2{,}3 \cdot 10^{-3}$	0,496	0,69	0,49	52,8	2	59,7
PV5063	188,8	6	50	14	3,068	4,5	$1{,}4 \cdot 10^{-2}$	0,880	0,80	0,56	4,36	1	4,91
PV5075	223,5	6	55	14	3,068	4,5	$1{,}4 \cdot 10^{-2}$	1,20	0,80	0,55	4,36	1	4,91
LV5088	53,94	6	43	14	3,068	4,5	$1{,}4 \cdot 10^{-2}$	0,896	0,80	0,35	4,36	1	4,91
PV5099	53,94	5	36	14	1,049	4,5	0,0023	0,896	0,72	0,35	2,02	0,5	2,41

4.3.3.2.2. Safety valves sizing

Safety valves were only installed at critical equipment such as heat exchangers, tanks and separators. In the first case (HE), SV was installed at both inlet streams (cooling water and fluid).

Regarding valves sizing, when it is for the protection a vessel, two different safety situations were studied. The first one assuming an external fire and, consequently an evaporation of the liquid contained in the vessel. First of all, the wet area of the vessel shall be calculated, it depends on the geometry of the recipient but in general for a cylindrical tank, this area includes the bottom of the tank and the wet part of the shell (liquid height). Then, the absorbed heat is obtained:

$$Q = 21000 \cdot A_w^{0,82} \tag{4.3.21}$$

Thus, the flow to be discharged is:

$$W = \frac{Q}{\lambda} \tag{4.3.22}$$

Where W is the flow to be discharged and λ is the evaporation enthalpy of the liquid. In this case the equation that shall be used to obtain orifice area is for gases discharge:

$$A = \frac{W}{387,2 \cdot C \cdot P_{set} \cdot K \cdot K_1 \cdot K_2}\sqrt{\frac{ZT}{M}} \tag{4.3.23}$$

The second situation takes place when outlet valve is closed and inlet valve is breakdown. In this case, flow rate to be discharged is the same that the entering flow rate to vessel. Thus using the equation above for gases valve orifice is obtained. If the flow to be discharged is a liquid the following expression will be used:

$$A = \frac{W}{5042 \cdot K \cdot K_P \cdot K_3 \cdot K_V\sqrt{(P - P_b) \cdot G_f}} \tag{4.3.24}$$

Obtained are valve orifices, they must be standardized using manufacturer's catalogue.

Table 4.3.20. PSV sizing results.

PSV ID	First scenario				Second scenario			Valve
	Aw (cm^2)	W (kg/h)	A (cm^2)	A STD (cm^2)	W (kg/h)	A (cm^2)	A STD (cm^2)	
PSV 5067	5,40	2316	2,39	3,245	3040	3,135	3,245	3K4
PSV 5080	5,40	2316	2,39	3,245	3040	3,135	3,245	3K4
PSV 5093	5,40	2316	2,39	3,245	3040	3,135	3,245	3K4
PSV 5060	14,0	5063	15,9	18,4	3040	9,573	11,85	2L3
PSV 5072	14,0	5063	15,9	18,4	3040	9,573	11,85	2L3
PSV 5085	14,0	5063	15,9	18,4	3040	9,573	11,85	2L3
PSV 5052	8,85	3474	13,2	18,4	766	2,911	3,245	3L4
PSV 5105	31,0	12706	16,03	18,4	4600	5,803	0,710	3''L4''
PSV 5101	-	8676	1,37	1,98	-	-	-	1½''F2''
PSV 5106	-	7787	1,33	1,98	-	-	-	1½''F2''
PSV 5102	-	7787	1,23	1,265	-	-	-	1''E2''

PSV ID	First scenario				Second scenario			Valve
	Aw (cm^2)	W (kg/h)	A (cm^2)	A STD (cm^2)	W (kg/h)	A (cm^2)	A STD (cm^2)	
PSV 5103	-	7787	1,23	1,265	-	-	-	1''E2''
PSV 5104	-	7787	1,23	1,265	-	-	-	1''E2''
PSV 5107	-	7787	0,763	1,265	-	-	-	1''E2''
PSV 5108	-	7787	0,763	1,265	-	-	-	1''E2''
PSV 5109	-	7787	0,763	1,265	-	-	-	1''E2''
PSV 5096	-	31892	5,05	5,06	-	-	-	2''H3''
PSV 5110	-	4600	0,512	0,71	-	-	-	1''D2''

4.3.3.3. Centrifugal pump design

As mentioned in previous sections, vent line holding tank cannot discharge the content of liquid because of the low pressure inside tank. Thus liquid phase has to be suctioned by a centrifugal pump and impelled at a minimum pressure of 3 bar. In this section this pump (P-0147AB) is being designed:

First of all, total pressure drop shall be calculated, this is the sum of the drop produced by pipe friction and the drop produced by fitting.

$$h_{L\,friction} = f \cdot \frac{L}{D_i} \cdot \frac{v^2}{2 \cdot g} \tag{4.3.25}$$

$$h_{Lfitting} = K \cdot \frac{v^2}{2 \cdot g} \tag{4.3.26}$$

Where K is a characteristic coefficient that depends on fitting type:

$$K = f \cdot \frac{Le}{D} \tag{4.3.27}$$

Table 4.3.21. Fitting constants and equivalent lengths.

Fitting	Le/D	K
Ball valve	8	
Globe valve	340	
90° Elbow	30	
Straight Tee	20	
Equipment inlet		1
Equipment outlet		0,5

Table 4.3.22. Head loss results.

f	L (m)	$H_{Lfriction}$ (m)	$H_{Lfitting}$ (m)	H_{Total} (m)
0,019	6	0,810	0,210	1,02

Once pressure drop calculation is finished, the next step is a mechanical energy balance in the line. For this purpose Bernoulli equation is used and pump head is obtained.

$$\frac{P_1}{\rho \cdot g} + z_1 + \frac{v^2}{2 \cdot g} - h_{L\,total} + h_B = \frac{P_2}{\rho \cdot g} + z_2 + \frac{v^2}{2 \cdot g} \quad (4.3.28)$$

Using this value a manufacturer catalogue a centrifugal pump is being selected. Finally, required NPSH (Net positive suction head), i.e. head to be provided by the pump to convey the fluid through the pipe to the final point, is calculated and compared with selected pump NSPH.

$$NPSH = \frac{P_1}{\rho \cdot g} + z_1 - H_S + \frac{P_v}{\rho \cdot g} \quad (4.3.29)$$

Table 4.3.23. Pump design results.

Pump	**H_B (m)**	**Efficiency**	**$NPSH_{Pump}$ (m)**	**$NPSH_{Calculated}$ (m)**	**Cavitation**
2CR 32-06-2	20	76%	6,87	10,19	No

4.3.3.4. <u>Heat exchanger design</u>

Heat exchangers will be designed using Kern's method. Heat exchangers have been designed for the three recovery process lines as well as the storage section.

Since strippers and the second section of vent line are oversized using operational conditions of BDT line, heat exchangers in BDT and stripper lines and the second section of vent line, have the same design. In case of first section of vent's line, different design has been done. Appendix 1 show the procedure followed.

Heat exchangers from process lines as well as operational conditions are displayed in table 4.3.24.

Table 4.3.24. Heat exchanger design conditions.

Conditions/HE	**VENT LINE**		**BDT LINE**	**STRIPPERS LINE**	**STORAGE**
	E-0134	**E-0135A**	**E-0135B**	**E-0135C**	**E-0136**
$M_{service\ water}$ (kg/h)	7500	7500	26400	9750	4570

Conditions/HE	VENT LINE		BDT LINE	STRIPPERS LINE	STORAGE
$T_{in,cold}$(ºC)	27	27	27	27	27
$T_{out,cold}$(ºC)	33	33	33	33	33
m_{water} (kg/h)	37200	8680	87300	22560	31800
$T_{in,hot}$(ºC)	66	43	56	50	56
$T_{out,hot}$(ºC)	36	36	36	36	36

*This flow rate value belongs to VCM vapor.

4.3.3.5. Vessel design

Vessels have been designed as vertical cylindrical vessel with ellipsoidal head except storage tank which has horizontal position. Material used is SA-516 Gr 60. Recipients at 7bar have been design using ASME code for pressurized vessels. On the other hand, vessels at 1 bar have been design tensional state equations at which vessels are submitted.

In table 4.3.25 design conditions are displayed. It has to be mentioned that 3mm of extra material has been added. Extra material will act as a sacrifice anode in order to avoid several damages in vessels caused by corrosion.

Table 4.3.25. Design conditions.

Line	Vessel	P (bar)	T (ºC)
BDT	TK-0154B	1	70
	S-0125B	7	56
VENT	TK-0154A	1	70
	S-0124	1	43
	S-0125A	7	56
STRIPPERS	TK-0154C	1	70
	S-0125C	7	56
STORAGE	TK-0155	5	36

4.3.4. Specification sheets

In this section, specification sheets of equipment designed are provided.

PROJECT	REVAMPING OF A VCM RECOVERY UNIT	**ESPECIFICATION**	NUM.	
			SHEET NUM.	1 / 1
COMPANY		**LIQUID RING VACUUM PUMP**	DATE	
FACTORY			PREPARATED	
PLANTA		H&G Industrial Design Services	CHECKED	
			APPROVED	
ITEM	**C-0112**		NUM. UNITS	1
SERVICE	FLUID SUCTION FROM TK-0154A TO S-0124			

GENERAL				
FLOW RATE			kg/h	1.134
COMPOSITION				
	Water		%	32,42
	VCM		%	67,58
INLET TEMPERATURE			ºC	70
INLET PRESSURE			bar	0,5
DISCHARGE PRESSURE			bar	1
SEAL LIQUID				
TYPE OF SEAL LIOQUID				Water
FLOW RATE			kg/h	7.500
TEMPERATURE			ºC	37,00
PRESSURE			bar	1,00
COOLING MEDIA				
COOLING LIQUID				Water
TEMPERATURE			ºC	25,00
TEMPERATURE RISE			ºC	11,00
DESIGN DATA				
NUMBER OF STAGES				1
POWER			kW	75,00
SERVICE LIQUID SYSTEM				Total reciculation system
Notes				

1–2	PROJECT	REVAMPING OF A VCM RECOVERY UNIT	**ESPECIFICATION**	NUM.	
				SHEET NUM.	1 / 1
3	COMPANY		**LIQUID RING COMPRESSOR**	DATE	
4	FACTORY			PREPARATED	
5–6	PLANTA		H&G Industrial Design Services	CHECKED	
				APPROVED	
7	**ITEM**	**C-0113A**		NUM. UNITS	3
8	**SERVICE**	FLUID SUCTION FROM S-0124 TO S-0125A			

9	**GENERAL**			
10	FLOW RATE		kg/h	847
11	COMPOSITION			
12		Water	%	90,44
13		VCM	%	9,557
14	INLET TEMPERATURE		ºC	70,00
15	INLET PRESSURE		bar	1
16	DISCHARGE PRESSURE		bar	7
17	**SEAL LIQUID**			
18	TYPE OF SEAL LIOQUID			Water
19	FLOW RATE		kg/h	26.400
20	TEMPERATURE		ºC	37,00
21	PRESSURE		bar	1,00
22	**COOLING MEDIA**			
23	COOLING LIQUID			Water
24	TEMPERATURE		ºC	25,00
25	TEMPERATURE RISE		ºC	11,00
26	**DESIGN DATA**			
27	NUMBER OF STAGES			1
28	POWER		kW	330,0
26	**SERVICE LIQUID SYSTEM**			Total reciculation system
27	**Notes**			
28				
29				
30				
31				
32				

PROJECT	REVAMPING OF A VCM RECOVERY UNIT	**ESPECIFICATION**	NUM.	
			SHEET NUM.	1 / 1
COMPANY		**LIQUID RING COMPRESSOR**	DATE	
FACTORY			PREPARATED	
PLANTA			CHECKED	
			APPROVED	
ITEM	**C-0113B**		NUM. UNITS	3
SERVICE	FLUID SUCTION FROM TK-0154B TO S-0125B			

GENERAL			
FLOW RATE		kg/h	2.828
COMPOSITION			
	Water	%	14,06
	VCM	%	85,94
INLET TEMPERATURE		ºC	70,00
INLET PRESSURE		bar	1
DISCHARGE PRESSURE		bar	7
SEAL LIQUID			
TYPE OF SEAL LIOQUID			Water
FLOW RATE		kg/h	26.400
TEMPERATURE		ºC	37,00
PRESSURE		bar	1,00
COOLING MEDIA			
COOLING LIQUID			Water
TEMPERATURE		ºC	25,00
TEMPERATURE RISE		ºC	11,00
DESIGN DATA			
NUMBER OF STAGES			1
POWER		kW	330,0
SERVICE LIQUID SYSTEM			Total reciculation system

Notes

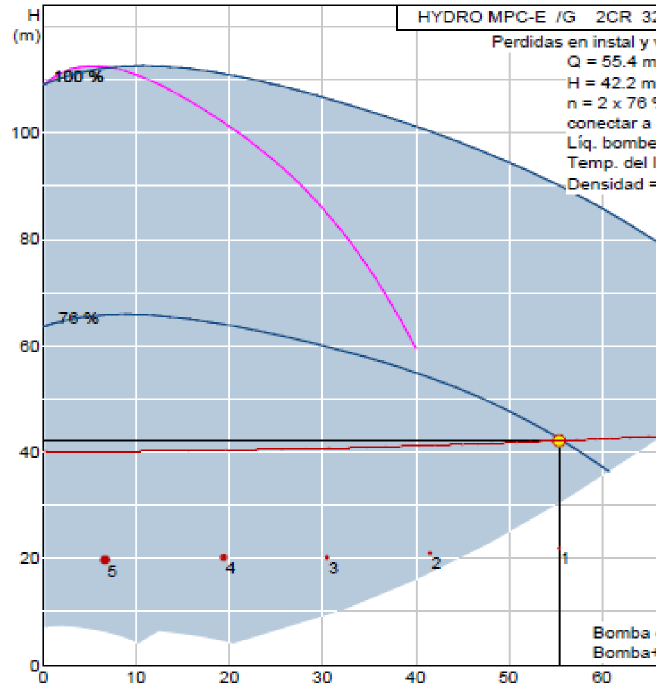
#					
1	PROJECT	REVAMPING OF A	**ESPECIFICATION**	NUM.	
2		VCM RECOVERY UNIT		SHEET NUM.	1 / 1
3	COMPANY		**LIQUID RING**	DATE	
4	FACTORY		**COMPRESSOR**	PREPARATED	
5	PLANTA		H&G Industrial Design Services	CHECKED	
6				APPROVED	
7	**ITEM**	**C0113C**		NUM. UNITS	3
8	**SERVICE**	FLUID SUCTION FROM TK-0154C TO S-0125C			

9	**GENERAL**				
10	FLOW RATE			kg/h	780
11	COMPOSITION				
12		Water		%	1,60
13		VCM		%	98,40
14	INLET TEMPERATURE			ºC	70,00
15	INLET PRESSURE			bar	1
16	DISCHARGE PRESSURE			bar	7
17	**SEAL LIQUID**				
18	TYPE OF SEAL LIOQUID				Water
19	FLOW RATE			kg/h	26.400
20	TEMPERATURE			ºC	37,00
21	PRESSURE			bar	1,00
22	**COOLING MEDIA**				
23	COOLING LIQUID				Water
24	TEMPERATURE			ºC	25,00
25	TEMPERATURE RISE			ºC	11,00
26	**DESIGN DATA**				
27	NUMBER OF STAGES				1
28	POWER			kW	330,0
26	**SERVICE LIQUID SYSTEM**				Total reciculation system
27	**Notes**				
28					
29					
30					
31					
32					

1	Nº OF PUMPS 2	RUN: SPARE:	
2	SERVICE	Impulsion to waste water	
3		treatment	
4			
5	FLUID PUMPED	H_2O	
6	OPER.TEMP	70	ºC
7	DENSITY	982,4	kg/m3
8	VISCOSITY	0,40870	cP
9	VAPOR PRESS.	0,312	bar
10	NORM.CAPACITY	55	m3/h
11	MAX.CAPACITY	80	m3/h
12			
13	**SUCTION CONDITIONS**		
14	TOTAL SUCT.PR.,	0,988	kg/cm^2g
15	NPSH (m.w.c.)	70	m
16			
17	**DISCHARGE CONDITIONS**		
18	LIQUID HEAD	1,99	kg/cm^2g
19	TOTAL DISCH.PR,	3,059	kg/cm^2g
20	DIFF.PRESSURE	1	kg/cm^2
21	DIFF.HEAD (m.w.c.)	10	m
22	**PUMP REQUIREMENTS**		
23	TYPE PUMP	Centrifugal	
24	ESTIMATED EFF.	76	%
25	ESTIMATED Rot.freq.	50	s-1
26	ESTIMATED Power	11	kW
27	TYPE DRIVER	-	
28	STEAM (abs.)	- kg/cm^2g	ºC
29	ELECTRICITY	V: 3x400 PH: 50	Hz
30		PE	
31			
32	**PUMP MATERIALS**		
33	CASE	Galvanized steel	
34	IMPELLER		
35	SHAFT		
36	SHAFT SLEEVE		
37	SEAL/PACKING		
38	PISTON		
39			
40			

41	**NOZZLES**				
42		Mark	Nº	Dia.	Rating
43	Suction				
44	Discharge				

Pump Curve



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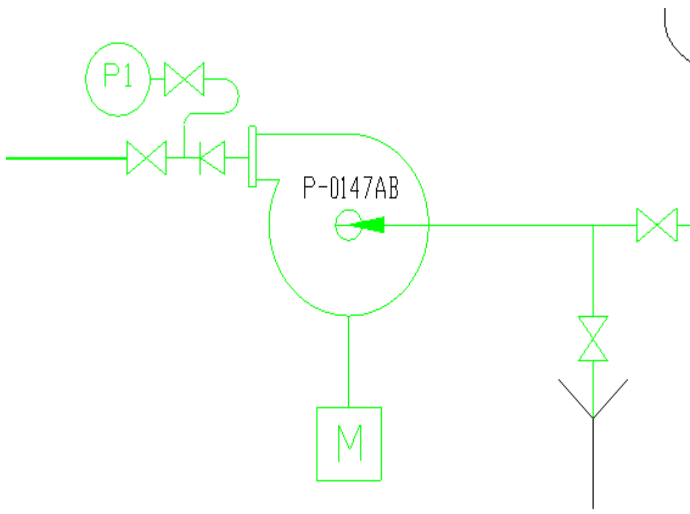

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REV.	*DATE*	*PREP.*	*APPR.*

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1	PROJECT	REVAMPING OF A	SPECIFICATION	NUM.	
2		VCM RECOVERY UNIT		SHEET NUM.	1/1
3	COMPANY		**CONTROL valve**	DATE	
4	FACTORY			PREPARETED	
5	PLANT			CHECKED	
6				APPROVED	
7					

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8	**ITEM**				
9	REFERENCIA P&ID		TCV 5097		
10	SERVICIO				
11	DIAMETRO LINEA	inch	4		
12	PHASE		Liquid		
13	VAPORIZATION	(SI/NO)	No		
14	FLOW NORMAL	m3/h	32		
15	FLOW MAXIMUM	m3/h	119		
16	NORMAL PRESSURE DROP	bar	0,150		
17	MAX. PRESSURE DROP	bar	1,02		
18					
20	INLET PRESSURE	bar	1,50		
21	INLET TEMPERATURE	ºC	37		
22					
23	**GAS PHASE**				
24	DENSITY	kg/m3			
25	VISCOSITY	cP			
26	MOLECULAR WEIGHT				
27	Cp/Cv RATIO				
28	Z COMPRESSIBILITY FACTOR				
29					
30	**LIQUID PHASE**				
31	DENSITY	kg/m3	996,63		
32	VISCOSITY	cP	0,012		
33	VAPOR PRESSURE	bar	0,063		
34					
35					
36	**VÁLVULA**				
37	CALCULATED Cv		98,8		
38	INSTALLED Cv		136		
39	ESTANQUEIDAD REQUERIDA		-		
40	FAIL OPEN/FAIL CLOSE		FO		
41					

42	Notas
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13	VAPORIZATION	(SI/NO)	No		
14	FLOW NORMAL	m3/h	1779,83		
15	FLOW MAXIMUM	m3/h			
16	NORMAL PRESSURE DROP	bar	0,375		
17	MAX. PRESSURE DROP	bar			
18					
20	INLET PRESSURE	bar	0,50		
21	INLET TEMPERATURE	ºC	70		
22					
23	**GAS PHASE**				
24	DENSITY	kg/m3	0,843		
25	VISCOSITY	cP	0,01186		
26	MOLECULAR WEIGHT		62,5		
27	Cp/Cv RATIO		1,01		
28	Z COMPRESSIBILITY FACTOR		1,00		
29					
30	**LIQUID PHASE**				
31	DENSITY	kg/m3			
32	VISCOSITY	cP			
33	VAPOR PRESSURE	kg/cm2a			
34					
35					
36	**VÁLVULA**				
37	CALCULATED Cv		249		
38	INSTALLED Cv		394		
39	ESTANQUEIDAD REQUERIDA		-		
40	FAIL OPEN/FAIL CLOSE		FC		
41					
42	Notas				
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1	PROJECT	REVAMPING OF A	SPECIFICATION	NUM.	
2		VCM RECOVERY UNIT		SHEET NUM.	1/1
3	COMPANY		**CONTROL valve**	DATE	
4	FACTORY			PREPARETED	
5	PLANT		H&G Industrial Design Services	CHECKED	
6				APPROVED	
7					

8	**ITEM**					
9	REFERENCIA P&ID			PV 5055		
10	SERVICIO					
11	DIAMETRO LINEA		inch	3		
12	PHASE			Gas		
13	VAPORIZATION		(SI/NO)	No		
14	FLOW	NORMAL	m3/h	370,821		
15	FLOW	MAXIMUM	m3/h			
16	NORMAL PRESSURE DROP		bar	0,750		
17	MAX. PRESSURE DROP		bar			
18						
20	INLET PRESSURE		bar	1,00		
21	INLET TEMPERATURE		ºC	66		
22						
23	**GAS PHASE**					
24	DENSITY		kg/m3	0,843		
25	VISCOSITY		cP	0,012		
26	MOLECULAR WEIGHT			62,5		
27	Cp/Cv RATIO			1,01		
28	Z COMPRESSIBILITY FACTOR			1,00		
29						
30	**LIQUID PHASE**					
31	DENSITY		kg/m3			
32	VISCOSITY		cP			
33	VAPOR PRESSURE		kg/cm2a			
34						
35						
36	**VÁLVULA**					
37	CALCULATED Cv			52,8		
38	INSTALLED Cv			59,7		
39	ESTANQUEIDAD REQUERIDA			-		
40	FAIL OPEN/FAIL CLOSE			FC		
41						
42	Notas					
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1	PROJECT	REVAMPING OF A	SPECIFICATION	NUM.	
2		VCM RECOVERY UNIT		SHEET NUM.	1/1
3	COMPANY		CONTROL valve	DATE	
4	FACTORY			PREPARETED	
5	PLANT		H&G Industrial Design Services	CHECKED	
6				APPROVED	
7					

8	**ITEM**				
9	REFERENCIA P&ID		TCV 5058		
10	SERVICIO				
11	DIAMETRO LINEA	inch	2		
12	PHASE		Liquid		
13	VAPORIZATION	(SI/NO)	No		
14	FLOW NORMAL	m3/h	9		
15	FLOW MAXIMUM	m3/h	32		
16	NORMAL PRESSURE DROP	bar	0,150		
17	MAX. PRESSURE DROP	bar	1,05		
18					
20	INLET PRESSURE	bar	1,50		
21	INLET TEMPERATURE	ºC	37		
22					
23	**GAS PHASE**				
24	DENSITY	kg/m3			
25	VISCOSITY	cP			
26	MOLECULAR WEIGHT				
27	Cp/Cv RATIO				
28	Z COMPRESSIBILITY FACTOR				
29					
30	**LIQUID PHASE**				
31	DENSITY	kg/m3	997,92		
32	VISCOSITY	cP	0,012		
33	VAPOR PRESSURE	bar	0,050		
34					
35					
36	**VÁLVULA**				
37	CALCULATED Cv		27,1		
38	INSTALLED Cv		35,8		
39	ESTANQUEIDAD REQUERIDA		-		
40	FAIL OPEN/FAIL CLOSE		FO		
41					
42	Notas				
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1	PROJECT	REVAMPING OF A	**SPECIFICATION**	NUM.	
2		VCM RECOVERY UNIT		SHEET NUM.	1/1
3	COMPANY		**CONTROL VALVE**	DATE	
4	FACTORY			PREPARETED	
5	PLANT		H&G Industrial Design Services	CHECKED	
6				APPROVED	
7					

8	**ITEM**					
9	REFERENCIA P&ID			LV 5061		
10	SERVICIO					
11	DIAMETRO LINEA		inch	2,00		
12	PHASE			Liquid		
13	VAPORIZATION		(SI/NO)	No		
14	FLOW	NORMAL	m3/h	7,91		
15	FLOW	MAXIMUM	m3/h	22,74		
16	NORMAL PRESSURE DROP		bar	0,10		
17	MAX. PRESSURE DROP		bar	0,53		
18						
20	INLET PRESSURE		bar	1,00		
21	INLET TEMPERATURE		ºC	66		
22						
23	**GAS PHASE**					
24	DENSITY		kg/m3			
25	VISCOSITY		cP			
26	MOLECULAR WEIGHT					
27	Cp/Cv RATIO					
28	Z COMPRESSIBILITY FACTOR					
29						
30	**LIQUID PHASE**					
31	DENSITY		kg/m3	984,34		
32	VISCOSITY		cP	0,43		
33	VAPOR PRESSURE		bar	0,26		
34						
35						
36	**VÁLVULA**					
37	CALCULATED Cv			30,00		
38	INSTALLED Cv			35,80		
39	ESTANQUEIDAD REQUERIDA			-		
40	FAIL OPEN/FAIL CLOSE			FC		
41						

42	Notas
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1	PROJECT	REVAMPING OF A	SPECIFICATION	NUM.	
2		VCM RECOVERY UNIT		SHEET NUM.	1/1
3	COMPANY		**CONTROL valve**	DATE	
4	FACTORY			PREPARETED	
5	PLANT		H&G Industrial Design Services	CHECKED	
6				APPROVED	
7					

8	**ITEM**					
9	REFERENCIA P&ID			LV 5063 / LV5075 / LV5088		
10	SERVICIO					
11	DIAMETRO LINEA		inch	3		
12	PHASE			Gas		
13	VAPORIZATION		(SI/NO)	No		
14	FLOW	NORMAL	m3/h	223,479		
15	FLOW	MAXIMUM	m3/h			
16	NORMAL PRESSURE DROP		bar	4,500		
17	MAX. PRESSURE DROP		bar			
18						
20	INLET PRESSURE		bar	6,00		
21	INLET TEMPERATURE		ºC	55		
22						
23	**GAS PHASE**					
24	DENSITY		kg/m3	13,693		
25	VISCOSITY		cP	0,011		
26	MOLECULAR WEIGHT			62,5		
27	Cp/Cv RATIO			1,01		
28	Z COMPRESSIBILITY FACTOR			1,00		
29						
30	**LIQUID PHASE**					
31	DENSITY		kg/m3			
32	VISCOSITY		cP			
33	VAPOR PRESSURE		kg/cm2a			
34						
35						
36	**VÁLVULA**					
37	CALCULATED Cv			4,2		
38	INSTALLED Cv			4,91		
39	ESTANQUEIDAD REQUERIDA			-		
40	FAIL OPEN/FAIL CLOSE			FC		
41						
42	Notas					
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1	PROJECT	REVAMPING OF A	SPECIFICATION	NUM.	
2		VCM RECOVERY UNIT		SHEET NUM.	1/1
3	COMPANY		**CONTROL valve**	DATE	
4	FACTORY			PREPARETED	
5	PLANT		H&G Industrial Design Services	CHECKED	
6				APPROVED	
7					

8	**ITEM**					
9	REFERENCIA P&ID			TCV 5065 / TCV 5078 / TCV 5091		
10	SERVICIO					
11	DIAMETRO LINEA		inch	6		
12	PHASE			Liquid		
13	VAPORIZATION		(SI/NO)	No		
14	FLOW	NORMAL	m3/h	87		
15	FLOW	MAXIMUM	m3/h	337		
16	NORMAL PRESSURE DROP		bar	0,150		
17	MAX. PRESSURE DROP		bar	0,98		
18						
20	INLET PRESSURE		bar	1,50		
21	INLET TEMPERATURE		ºC	33		
22						
23	**GAS PHASE**					
24	DENSITY		kg/m3			
25	VISCOSITY		cP			
26	MOLECULAR WEIGHT					
27	Cp/Cv RATIO					
28	Z COMPRESSIBILITY FACTOR					
29						
30	**LIQUID PHASE**					
31	DENSITY		kg/m3	997,92		
32	VISCOSITY		cP	0,012		
33	VAPOR PRESSURE		bar	0,050		
34						
35						
36	**VÁLVULA**					
37	CALCULATED Cv			152,4		
38	INSTALLED Cv			260,619		
39	ESTANQUEIDAD REQUERIDA			-		
40	FAIL OPEN/FAIL CLOSE			FO		
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42	Notas					
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1	PROJECT	REVAMPING OF A	**SPECIFICATION**	NUM.	
2		VCM RECOVERY UNIT		SHEET NUM.	1/1
3	COMPANY		**CONTROL VALVE**	DATE	
4	FACTORY			PREPARETED	
5	PLANT		H&G Industrial Design Services	CHECKED	
6				APPROVED	
7					

8	**ITEM**					
9	REFERENCIA P&ID			LV 5068 / LV81 / LV5094		
10	SERVICIO					
11	DIAMETRO LINEA		inch	3,00		
12	PHASE			Liquid		
13	VAPORIZATION		(SI/NO)	No		
14	FLOW	NORMAL	m3/h	27,06		
15	FLOW	MAXIMUM	m3/h	106,82		
16	NORMAL PRESSURE DROP		bar	0,60		
17	MAX. PRESSURE DROP		bar	4,23		
18						
20	INLET PRESSURE		bar	1,00		
21	INLET TEMPERATURE		ºC	55		
22						
23	**GAS PHASE**					
24	DENSITY		kg/m3			
25	VISCOSITY		cP			
26	MOLECULAR WEIGHT					
27	Cp/Cv RATIO					
28	Z COMPRESSIBILITY FACTOR					
29						
30	**LIQUID PHASE**					
31	DENSITY		kg/m3	989,47		
32	VISCOSITY		cP	0,52		
33	VAPOR PRESSURE		bar	0,16		
34						
35						
36	**VÁLVULA**					
37	CALCULATED Cv			43		
38	INSTALLED Cv			60		
39	ESTANQUEIDAD REQUERIDA			-		
40	FAIL OPEN/FAIL CLOSE			FC		
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42	Notas					
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1	PROJECT	REVAMPING OF A VCM RECOVERY UNIT	SPECIFICATION	NUM.	
2				SHEET NUM.	1/1
3	COMPANY		CONTROL valve	DATE	
4	FACTORY			PREPARETED	
5	PLANT		H&G Industrial Design Services	CHECKED	
6				APPROVED	
7					

8	**ITEM**					
9	REFERENCIA P&ID			PV 5071 / PV5084		
10	SERVICIO					
11	DIAMETRO LINEA		inch	6		
12	PHASE			Gas		
13	VAPORIZATION		(SI/NO)	No		
14	FLOW	NORMAL	m3/h	1905,82		
15	FLOW	MAXIMUM	m3/h			
16	NORMAL PRESSURE DROP		bar	0,750		
17	MAX. PRESSURE DROP		bar			
18						
20	INLET PRESSURE		bar	1,00		
21	INLET TEMPERATURE		ºC	70		
22						
23	**GAS PHASE**					
24	DENSITY		kg/m3	2,012		
25	VISCOSITY		cP	0,012		
26	MOLECULAR WEIGHT			62,5		
27	Cp/Cv RATIO			1,01		
28	Z COMPRESSIBILITY FACTOR			1,00		
29						
30	**LIQUID PHASE**					
31	DENSITY		kg/m3			
32	VISCOSITY		cP			
33	VAPOR PRESSURE		kg/cm2a			
34						
35						
36	**VÁLVULA**					
37	CALCULATED Cv			274,3		
38	INSTALLED Cv			394		
39	ESTANQUEIDAD REQUERIDA			-		
40	FAIL OPEN/FAIL CLOSE			FC		
41						
42	Notas					
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1	PROJECT	REVAMPING OF A	**SPECIFICATION**	NUM.	
2		VCM RECOVERY UNIT		SHEET NUM.	1/1
3	COMPANY		**CONTROL VALVE**	DATE	
4	FACTORY			PREPARETED	
5	PLANT		H&G Industrial Design Services	CHECKED	
6				APPROVED	
7					

8	**ITEM**					
9	REFERENCIA P&ID			LV 5073 / LV 5086		
10	SERVICIO					
11	DIAMETRO LINEA		inch	4,00		
12	PHASE			Liquid		
13	VAPORIZATION		(SI/NO)	No		
14	FLOW	NORMAL	m3/h	55,46		
15	FLOW	MAXIMUM	m3/h	134,11		
16	NORMAL PRESSURE DROP		bar	0,10		
17	MAX. PRESSURE DROP		bar	0,47		
18						
20	INLET PRESSURE		bar	1,00		
21	INLET TEMPERATURE		ºC	70		
22						
23	**GAS PHASE**					
24	DENSITY		kg/m3			
25	VISCOSITY		cP			
26	MOLECULAR WEIGHT					
27	Cp/Cv RATIO					
28	Z COMPRESSIBILITY FACTOR					
29						
30	**LIQUID PHASE**					
31	DENSITY		kg/m3	989,47		
32	VISCOSITY		cP	0,41		
33	VAPOR PRESSURE		bar	0,31		
34						
35						
36	**VÁLVULA**					
37	CALCULATED Cv			201		
38	INSTALLED Cv			224		
39	ESTANQUEIDAD REQUERIDA			-		
40	FAIL OPEN/FAIL CLOSE			FC		
41						
42	Notas					
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PROJECT	REVAMPING OF A VCM RECOVERY UNIT	**SPECIFICATION**	NUM.	
			SHEET NUM.	1/1
COMPANY		**SAFETY VALVE**	DATE	
FACTORY			PREPARETED	
PLANT		H&G Industrial Design Services	CHECKED	
			APPROVED	
			NUM. UNITS	1

ITEM		
P&ID REFERENCE		PSV-5052
SERVICE		Protection
PROTECTED EQUIPMENT		TK-0154A
EQUIPMENT DESIGN PRESSURE	kg/cm2g	1,53
SIZING ESCENARIO		External Fire
PHASE		Gas
SET PRESSURE	kg/cm2g	1,53
SET PRESSURE + OVERPRESSURE	kg/cm2g	1,68
SET TEMPERATURE + OVERPRESSURE	ºC	70,00
BACKPRESSURE	kg/cm2g	1,02
MAXIMUM BACKPRESSURE	%	
PRESIÓN DE ENTRADA	kg/cm2g	0,5099
TEMPERATURA ENTRADA	ºC	70
GAS		
FLOW	kg/h	3.473,0
DENSITY	kg/m3	2,012
VISCOSITY	cP	1,2E-05
MOLECULAR WEIGHT		62,50
Cp/Cv RATIO		1,0064
COMPRESIBILITY FACTOR Z		1,00
LIQUID		
FLOW	kg/h	
DENSITY	kg/m3	
VISCOSITY	cP	
VAPOR PRESSURE	kg/cm2a	
VALVE		
CALCULATED AREA	mm2	1.320
REQUIRED SIZE	mm2	1.840 **3L4**

Notes

PROJECT	REVAMPING OF A VCM RECOVERY UNIT	**SPECIFICATION**	NUM.	
			SHEET NUM.	1/1
COMPANY		**SAFETY VALVE**	DATE	
FACTORY			PREPARETED	
PLANT		H&G Industrial Design Services	CHECKED	
			APPROVED	
			NUM. UNITS	3

ITEM		
P&ID REFERENCE		PSV-5060/PSV-5072/PSV-5085
SERVICE		Protection
PROTECTED EQUIPMENT		S-0124, TK-0154B and TK-0154C
EQUIPMENT DESIGN PRESSURE	kg/cm^2g	2,039
SIZING ESCENARIO		External Fire
PHASE		Gas
SET PRESSURE	kg/cm^2g	2,039
SET PRESSURE + OVERPRESSURE	kg/cm^2g	2,243
SET TEMPERATURE + OVERPRESSURE	ºC	70
BACKPRESSURE	kg/cm2g	1,019
MAXIMUM BACKPRESSURE	%	
PRESIÓN DE ENTRADA	kg/cm^2g	1,0197
TEMPERATURA ENTRADA	ºC	70
GAS		
FLOW	kg/h	5.063
DENSITY	kg/m^3	2,012
VISCOSITY	cP	1,19E-05
MOLECULAR WEIGHT		62,50
Cp/Cv RATIO		1,0064
COMPRESIBILITY FACTOR Z		1,00
LIQUID		
FLOW	kg/h	
DENSITY	kg/m^3	
VISCOSITY	cP	
VAPOR PRESSURE	kg/cm^2a	
VALVE		
CALCULATED AREA	mm^2	1.594,28
REQUIRED SIZE	mm^2	1.840,00 **2L3**

NotEs

Industrial Design Services

NUM. UNITS

ITEM		
P&ID REFERENCE		PSV-5067/PSV-5080/PSV-5093
SERVICE		Protection
PROTECTED EQUIPMENT		S-0125A, S-0125B and S-0125C
EQUIPMENT DESIGN PRESSURE	kg/cm^2g	8,15
SIZING ESCENARIO		Inlet flow valve failure/breakdown and closed outlet flov
PHASE		Gas
SET PRESSURE	kg/cm2g	8,15
SET PRESSURE + OVERPRESSURE	kg/cm2g	8,97
SET TEMPERATURE + OVERPRESSURE	ºC	66
BACKPRESSURE	kg/cm2g	1,02
MAXIMUM BACKPRESSURE	%	
INLET PRESSURE	kg/cm2g	7,14
INLET TEMPERATURE	ºC	66
GAS		
FLOW	kg/h	3.040
DENSITY	kg/m3	13,69
VISCOSITY	cP	1,17E-05
MOLECULAR WEIGHT		62,50
Cp/Cv RATIO		1,0064
COMPRESIBILITY FACTOR Z		1,00
LIQUID		
FLOW	kg/h	-
DENSITY	kg/m3	-
VISCOSITY	cP	-
VAPOR PRESSURE	kg/cm2a	-
VALVE		
CALCULATED AREA	mm2	313,40
REQUIRED SIZE	mm2	324,50 **3K4**

Notes

PROJECT	REVAMPING OF A VCM RECOVERY UNIT	**SPECIFICATION**	NUM.	
			SHEET NUM.	1/1
COMPANY		**SAFETY VALVE**	DATE	
FACTORY			PREPARETED	
PLANT		H&G Industrial Design Services	CHECKED	
			APPROVED	
			NUM. UNITS	1

ITEM		
P&ID REFERENCE		PSV-5096
SERVICE		Protection
PROTECTED EQUIPMENT		Lines: 4''-TW-01-1-01-F42
EQUIPMENT DESIGN PRESSURE	kg/cm2g	2,54842
SIZING ESCENARIO		Thermal expansion
PHASE		Liquid
SET PRESSURE	kg/cm2g	2,54842
SET PRESSURE + OVERPRESSURE	kg/cm2g	2,80326
SET TEMPERATURE + OVERPRESSURE	ºC	27
BACKPRESSURE	kg/cm2g	1,01937
MAXIMUM BACKPRESSURE	%	
PRESIÓN DE ENTRADA	kg/cm2g	1,530
TEMPERATURA ENTRADA	ºC	27
GAS		
FLOW	kg/h	
DENSITY	kg/m3	
VISCOSITY	cP	
MOLECULAR WEIGHT		
Cp/Cv RATIO		
COMPRESIBILITY FACTOR Z		
LIQUID		
FLOW	kg/h	31.892
DENSITY	kg/m3	1.000
VISCOSITY	cP	0,01
VAPOR PRESSURE	kg/cm2a	0,0364
VALVE		
CALCULATED AREA	mm2	504,679
REQUIRED SIZE	mm2	506,00 **2H3**

Notes

PROJECT	REVAMPING OF A VCM RECOVERY UNIT	**SPECIFICATION**	NUM.	
			SHEET NUM.	1/1
COMPANY		**SAFETY VALVE**	DATE	
FACTORY			PREPARETED	
PLANT		H&G Industrial Design Services	CHECKED	
			APPROVED	
			NUM. UNITS	1

ITEM			
P&ID REFERENCE		PSV-5101	
SERVICE		Protection	
PROTECTED EQUIPMENT		Line: 2''-TW-01-1-01-F42	
EQUIPMENT DESIGN PRESSURE	kg/cm2g	2,548	
SIZING ESCENARIO		Thermal expansion	
PHASE		Liquid	
SET PRESSURE	kg/cm2g	2,548	
SET PRESSURE + OVERPRESSURE	kg/cm2g	2,803	
SET TEMPERATURE + OVERPRESSURE	ºC	27,00	
BACKPRESSURE	kg/cm2g	1,01937	
MAXIMUM BACKPRESSURE	%		
PRESIÓN DE ENTRADA	kg/cm2g	1,5296	
TEMPERATURA ENTRADA	ºC	27	
GAS			
FLOW	kg/h		
DENSITY	kg/m3		
VISCOSITY	cP		
MOLECULAR WEIGHT			
Cp/Cv RATIO			
COMPRESIBILITY FACTOR Z			
LIQUID			
FLOW	kg/h	8676	
DENSITY	kg/m3	1.000	
VISCOSITY	cP	0,01	
VAPOR PRESSURE	kg/cm2a	0,0364	
VALVE			
CALCULATED AREA	mm2	137,29	
REQUIRED SIZE	mm2	198,00	**1 1/2F2**

Notes

PROJECT	REVAMPING OF A VCM RECOVERY UNIT	**SPECIFICATION**	NUM.	
			SHEET NUM.	1/1
COMPANY		**SAFETY VALVE**	DATE	
FACTORY			PREPARETED	
PLANT		H&G Industrial Design Services	CHECKED	
			APPROVED	
			NUM. UNITS	1

ITEM		
P&ID REFERENCE		PSV-5105
SERVICE		Protection
PROTECTED EQUIPMENT		TK-0155
EQUIPMENT DESIGN PRESSURE	kg/cm2g	62,35
SIZING ESCENARIO		External Fire
PHASE		Gas
SET PRESSURE	kg/cm2g	62,35
SET PRESSURE + OVERPRESSURE	kg/cm2g	
SET TEMPERATURE + OVERPRESSURE	ºC	36,00
BACKPRESSURE	kg/cm2g	1,02
MAXIMUM BACKPRESSURE	%	
PRESIÓN DE ENTRADA	kg/cm2g	0,5099
TEMPERATURA ENTRADA	ºC	36
GAS		
FLOW	kg/h	3.473,0
DENSITY	kg/m3	25,351
VISCOSITY	cP	1,1E-05
MOLECULAR WEIGHT		62,50
Cp/Cv RATIO		1,0064
COMPRESIBILITY FACTOR Z		1,00
LIQUID		
FLOW	kg/h	
DENSITY	kg/m3	
VISCOSITY	cP	
VAPOR PRESSURE	kg/cm2a	
VALVE		
CALCULATED AREA	mm2	1.603
REQUIRED SIZE		1.840 3L4

Notes

PROJECT	REVAMPING OF A VCM RECOVERY UNIT	**SPECIFICATION**	NUM.	
			SHEET NUM.	1/1
COMPANY		**SAFETY VALVE**	DATE	
FACTORY			PREPARETED	
PLANT		H&G Industrial Design Services	CHECKED	
			APPROVED	
			NUM. UNITS	3

ITEM		
P&ID REFERENCE		PSV-5102/PSV-5103/PSV-5104
SERVICE		Protection
PROTECTED EQUIPMENT		Line: 6''-TW-01-1-03-F42/ 6''-TW-01-1-05-F42/ 6''-TW-01-1-01-F42
EQUIPMENT DESIGN PRESSURE	kg/cm2g	2,54842
SIZING ESCENARIO		Thermal expansion
PHASE		Liquid
SET PRESSURE	kg/cm2g	2,54842
SET PRESSURE + OVERPRESSURE	kg/cm2g	2,80326
SET TEMPERATURE + OVERPRESSURE	ºC	27,00
BACKPRESSURE	kg/cm2g	1,01937
MAXIMUM BACKPRESSURE	%	
PRESIÓN DE ENTRADA	kg/cm2g	1,52957
TEMPERATURA ENTRADA	ºC	27
GAS		
FLOW	kg/h	
DENSITY	kg/m3	
VISCOSITY	cP	
MOLECULAR WEIGHT		18,02
Cp/Cv RATIO		
COMPRESIBILITY FACTOR Z		
LIQUID		
FLOW	kg/h	7787
DENSITY	kg/m3	1.000
VISCOSITY	cP	0,01
VAPOR PRESSURE	kg/cm2a	0,0364
VALVE		
CALCULATED AREA	mm2	123,22
REQUIRED SIZE	mm2	126,50 **1E2**

Notes

PROJECT	REVAMPING OF A VCM RECOVERY UNIT	**SPECIFICATION**	NUM.	
			SHEET NUM.	1/1
COMPANY		**SAFETY VALVE**	DATE	
FACTORY			PREPARETED	
PLANT		H&G Industrial Design Services	CHECKED	
			APPROVED	
			NUM. UNITS	3

ITEM		
P&ID REFERENCE		PSV-5106
SERVICE		Protection
PROTECTED EQUIPMENT		Line: 2''-SW-01-1-01-F42
EQUIPMENT DESIGN PRESSURE	kg/cm2g	2,03874
SIZING ESCENARIO		Thermal expansion
PHASE		Liquid
SET PRESSURE	kg/cm2g	2,03874
SET PRESSURE + OVERPRESSURE	kg/cm2g	2,27561
SET TEMPERATURE + OVERPRESSURE	ºC	66,00
BACKPRESSURE	kg/cm2g	1,01937
MAXIMUM BACKPRESSURE	%	
PRESIÓN DE ENTRADA	kg/cm2g	1,03874
TEMPERATURA ENTRADA	ºC	66,00
GAS		
FLOW	kg/h	
DENSITY	kg/m3	
VISCOSITY	cP	
MOLECULAR WEIGHT		
Cp/Cv RATIO		
COMPRESIBILITY FACTOR Z		
LIQUID		
FLOW	kg/h	7786,57
DENSITY	kg/m3	1.000
VISCOSITY	cP	0,01
VAPOR PRESSURE	kg/cm2a	0,2670
VALVE		
CALCULATED AREA	mm2	133,35
REQUIRED SIZE	mm2	198,00 **1 1/2F2**

Notes

PROJECT	REVAMPING OF A VCM RECOVERY UNIT	**SPECIFICATION**	NUM.	
			SHEET NUM.	1/1
COMPANY		**SAFETY VALVE**	DATE	
FACTORY			PREPARETED	
PLANT			CHECKED	
			APPROVED	
			NUM. UNITS	3

ITEM		
P&ID REFERENCE		PSV-5107/PSV-5108/PSV-5109
SERVICE		Protection
PROTECTED EQUIPMENT		Lines: 3''-SW-01-1-01-F42/ 3''-SW-01-1-03-F42/ 3''-SW-01-1-05-F42
EQUIPMENT DESIGN PRESSURE	kg/cm2g	2,548
SIZING ESCENARIO		Thermal expansion
PHASE		Liquid
SET PRESSURE	kg/cm2g	8,155
SET PRESSURE + OVERPRESSURE	kg/cm2g	9,003
SET TEMPERATURE + OVERPRESSURE	ºC	55,00
BACKPRESSURE	kg/cm2g	1,019
MAXIMUM BACKPRESSURE	%	
PRESIÓN DE ENTRADA	kg/cm2g	7,155
TEMPERATURA ENTRADA	ºC	55,00
GAS		
FLOW	kg/h	
DENSITY	kg/m3	
VISCOSITY	cP	
MOLECULAR WEIGHT		
Cp/Cv RATIO		
COMPRESIBILITY FACTOR Z		
LIQUID		
FLOW	kg/h	7787
DENSITY	kg/m3	1.000
VISCOSITY	cP	0,01
VAPOR PRESSURE	kg/cm2a	0,16073
VALVE		
CALCULATED AREA	mm2	76,305
REQUIRED SIZE	mm2	126,50 **1E2**

Notes

PROJECT	REVAMPING OF A VCM RECOVERY UNIT	**SPECIFICATION**	NUM.	
			SHEET NUM.	1/1
COMPANY		**SAFETY VALVE**	DATE	
FACTORY			PREPARETED	
PLANT		H&G Industrial Design Services	CHECKED	
			APPROVED	
			NUM. UNITS	1

ITEM		
P&ID REFERENCE		PSV-5110
SERVICE		Protection
PROTECTED EQUIPMENT		Lines: 3''-VCM-01-1-08-F42
EQUIPMENT DESIGN PRESSURE	kg/cm2g	6,237
SIZING ESCENARIO		Thermal expansion
PHASE		Liquid
SET PRESSURE	kg/cm2g	6,237
SET PRESSURE + OVERPRESSURE	kg/cm2g	6,728
SET TEMPERATURE + OVERPRESSURE	ºC	55,00
BACKPRESSURE	kg/cm2g	1,02
MAXIMUM BACKPRESSURE	%	
PRESIÓN DE ENTRADA	kg/cm2g	5,099
TEMPERATURA ENTRADA	ºC	55
GAS		
FLOW	kg/h	
DENSITY	kg/m3	
VISCOSITY	cP	
MOLECULAR WEIGHT		
Cp/Cv RATIO		
COMPRESIBILITY FACTOR Z		
LIQUID		
FLOW	kg/h	4.600
DENSITY	kg/m3	13,82
VISCOSITY	cP	1,1E-05
VAPOR PRESSURE	kg/cm2a	0,1607
VALVE		
CALCULATED AREA	mm2	51,17
REQUIRED SIZE	mm2	71,00 **1D2**

Notes

1	ITEM No.: **E-0134**					
2	Service:					
3	Type: Shell & Tubes	Position: Horizontal	Total surface / unit:		5,024	(m^2)
4	No. Shell:					
5	**PERFORMANCE OF UNIT**					
6			**Shell side**		**Tube side**	
7			**Inlet**	**Outlet**	**Inlet**	**Outlet**
8	Fluid name: service water		Service water		Tower water	
9	Fluid total flow	kg/h	75000		8680	
10	Vapour	kg/h				
11	Liquid	kg/h	75000	75000	8680	8680
12	Steam	kg/h				
13	Water	kg/h				
14	Temperature	°C	43	36	27	33
15	Density (L/V)	kg/m^3	994,5	996,9	999,6	997,3
16	Viscosity (L/V)	cP	0,636	0,727	0,876	0,773
17	Vapour molecular weight					
18	Specific heat (L/V)	kcal/kg.°C	0,999	0,999	1,001	0,999
19	Thermal conductivity (L/V)	kcal/h.m.°C	0,441	0,44	0,437	0,439
20	Latent heat	kcal/kg				
21	Inlet pressure	kg/cm^2	7,13		1,32	
22	Velocity (allowable / calculated)	m/s	0,51	0,51	1,4	1,4
23	Pressure drop (allowable / calculated)	kg/cm^2	7,13	6,88	1,32	1,03
24	Fouling resistance	h.m^2.°C/kcal	$1{,}16\cdot10^{-4}$		$1{,}16\cdot10^{-4}$	
25	**Heat exchanged:**	(kcal/h)	52479			
26	**Heat transfer rate** (kcal/h.m2.°C)	Fouled: 1373,7	Clean: 1419			

27	**CONSTRUCTION PER SHELL**					
28	Codes:		**Shell side**	**Tube side**		
29	Design pressure	kg/cm^2				
30	Design temperature	°C				
31	No. of passes	2	2 1	2 2 2 2		
32	Stress relief					
33	Radiograph.					
34	Corrosion allowance	mm				

35		Service	Mark	Dia.	Rating
36					
37					
38					
39	Nozzles				
40					
41					
42					
43					
44					

45	**MATERIALS**			
46		Dia.	Thick. (mm.)	Spec. Mat.
47	Shell:			
48	Channel:			
49	Tubesheets:			
50	Baffles: nº / mat.	4		
51	Baffles spacing:	84,6	mm.	
52				
53	Tubes:			
54	Nº	16 6		
55	OD	3/4	inches	
56	BWG:			
57	Length	4570	mm.	
58	Pitch:	25,4	mm.	□◇△◁
59				
60				
61				
62				
63				
64	NOTES:			

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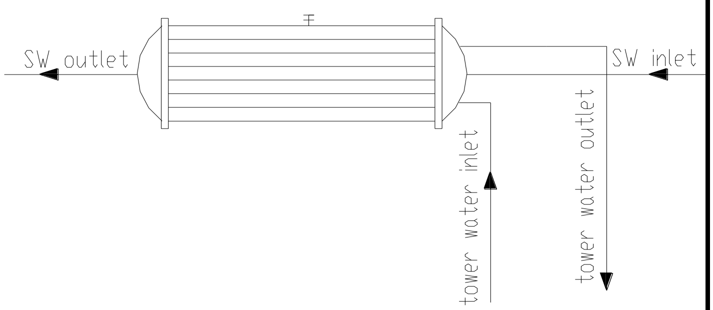

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1	ITEM No.: **E-0135A / E-0135B / E-0135C**					
2	Service:					
3	Type: Shell & Tubes	Position: Horizontal	Total surface / unit:		33,32	(m^2)
4	No. Shell:					
5	**PERFORMANCE OF UNIT**					
6			**Shell side**		**Tube side**	
7			**Inlet**	**Outlet**	**Inlet**	**Outlet**
8	Fluid name: service water		Service water		Tower water	
9	Fluid total flow	kg/h	26400		87295,9	
10	Vapour	kg/h				
11	Liquid	kg/h	26400	26400	87295,9	87295,9
12	Steam	kg/h				
13	Water	kg/h				
14	Temperature	°C	56	36	27	35
15	Density (L/V)	kg/m^3	989,01	996,9	999,6	997,3
16	Viscosity (L/V)	cP	0,5069	0,7274	0,8764	0,7727
17	Vapour molecular weight					
18	Specific heat (L/V)	kcal/kg.°C	0,9996	0,9994	1,0007	0,9995
19	Thermal conductivity (L/V)	kcal/h.m.°C	0,4401	0,4401	0,4378	0,4399
20	Latent heat	kcal/kg				
21	Inlet pressure	kg/cm^2	7,12		1,32	
22	Velocity (allowable / calculated)	m/s	2,4	2,4	0,79	0,79
23	Pressure drop (allowable / calculated)	kg/cm^2	7,12	6,62	1,32	1,01
24	Fouling resistance	$h.m^2.°C/kcal$	$1{,}16 \cdot 10^{-4}$		$1{,}16 \cdot 10^{-4}$	
25	**Heat exchanged:**	(kcal/h)	501154			
26	**Heat transfer rate** (kcal/h.m2.°C)	Fouled: 1926,8	Clean: 1331,18			

27	**CONSTRUCTION PER SHELL**					
28	Codes:		**Shell side**	**Tube side**		
29	Design pressure	kg/cm^2				
30	Design temperature	°C				
31	No. of passes	2	1	2		
32	Stress relief					
33	Radiograph.					
34	Corrosion allowance	mm				

35	Nozzles	Service	Mark	Dia.	Rating	
36						
37						
38						
39						
40						
41						
42						
43						
44						

45	**MATERIALS**			
46		Dia.	Thick. (mm.)	Spec. Mat.
47	Shell:			
48	Channel:			
49	Tubesheets:			
50	Baffles: nº / mat.	2		
51	Baffles spacing:	152	mm.	
52				
53	Tubes:			
54	Nº	98 6		
55	OD	1	inches	
56	BWG:			
57	Length	4876	mm.	
58	Pitch:	31,8	mm.	□◇△◁
59				
60				
61				
62				
63				
64	NOTES:			

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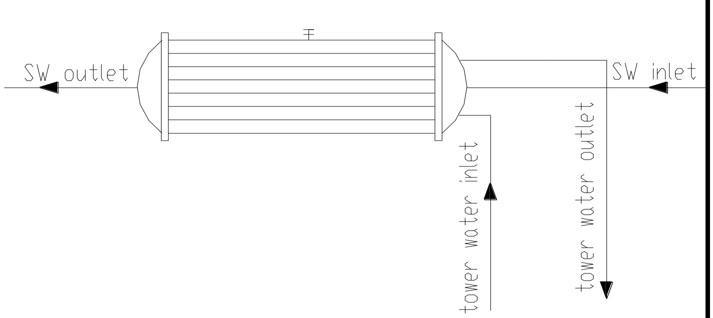

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Industrial Design Services

HEAT EXCHANGER DATA SHEET

1	ITEM No.: **E-0136**					
2	Service:					
3	Type: Shell & Tubes	Position: Horizontal	Total surface / unit:		26,81	(m^2)
4	No. Shell:					
5	**PERFORMANCE OF UNIT**					
6			**Shell side**		**Tube side**	
7			**Inlet**	**Outlet**	**Inlet**	**Outlet**
8	Fluid name: service water		Tower water		Vinyl chloride	
9	Fluid total flow	kg/h	31895		4574	
10	Vapour	kg/h			4574	
11	Liquid	kg/h	31895	31895		4574
12	Steam	kg/h				
13	Water	kg/h				
14	Temperature	°C	27	37	56	39
15	Density (L/V)	kg/m^3	999,6	997,3	36,24	1574,4
16	Viscosity (L/V)	cP	0,636	0,727	0,346	0,0108
17	Vapour molecular weight					
18	Specific heat (L/V)	kcal/kg.°C	1,0007	0,9995	$8{,}74\cdot10^{-3}$	6,094
19	Thermal conductivity (L/V)	kcal/h.m.°C	0,4378	0,4399	$5\cdot10^{-6}$	0,345
20	Latent heat	kcal/kg			1121,46	
21	Inlet pressure	kg/cm^2	7,11		1,22	
22	Velocity (allowable / calculated)	m/s	3,86	3,86	2,69	2,69
23	Pressure drop (allowable / calculated)	kg/cm^2	7,11	6,78	1,22	1,03
24	Fouling resistance	$h.m^2.°C/kcal$	$1{,}16\cdot10^{-4}$		$2{,}3\cdot10^{-4}$	
25	**Heat exchanged:**	(kcal/h)	318925			
26	**Heat transfer rate** (kcal/h.m2.°C)	Fouled: 575,94	Clean: 615			
27	**CONSTRUCTION PER SHELL**					
28	Codes:		**Shell side**	**Tube side**		
29	Design pressure	kg/cm^2				
30	Design temperature	°C				
31	No. of passes	2	1	2		
32	Stress relief					
33	Radiograph.					
34	Corrosion allowance	mm				

35	Nozzles	Service	Mark	Dia.	Rating		
36							
37							
38							
39							
40							
41							
42							
43							
44							

45	**MATERIALS**			
46		Dia.	Thick. (mm.)	Spec. Mat.
47	Shell:			
48	Channel:			
49	Tubesheets:			
50	Baffles: nº / mat. 2			
51	Baffles spacing: 193		mm.	
52				
53	Tubes:			
54	Nº	137 6		
55	OD	3/4	inches	
56	BWG:			
57	Length	3440	mm.	
58	Pitch:	25,4	mm.	□◇△◁
59				
60				
61				
62				
63				

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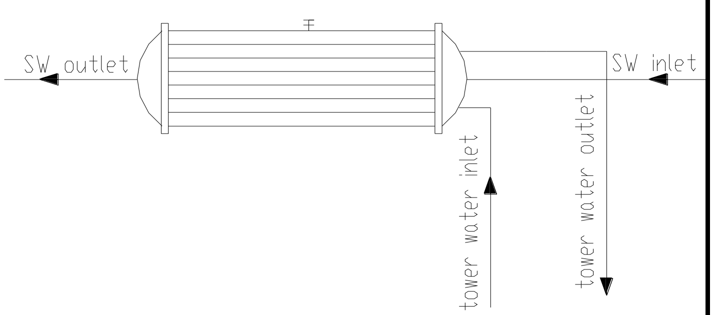

64 NOTES:

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Industrial Design Services

VERTICAL TANK DATA SHEET

No.	Section	Description			Value	Unit
1	GENERAL	Item:	TK-0155			
2	GENERAL	Service:	storage			
3	GENERAL	Type of roof:	elipsoidal			
4	GENERAL	Capacity	$32\ m^3$			
5	OPER. COND	Operating Pressure			5,96	kg/cm2
6	OPER. COND	Operating Temperature			39	ºC
7	OPER. COND	Liquid Density			1574,4	kg/m^3
8	OPER. COND	Inlet flow			2,905	m3/h
9	OPER. COND	Outlet flow				m3/h
10	DDESIGN DATA	Design Pressure (eff.)			6,23	kg/cm2
11	DDESIGN DATA	Vacuum (abs.)				bar
12	DDESIGN DATA	Design Temperature			59	ºC
13	DDESIGN DATA	Corr. Allow.			3	mm
14	DDESIGN DATA	Courses:				Nº
15	DDESIGN DATA	Joint Eff.				
16	DDESIGN DATA	Code:				
17	DDESIGN DATA	Radiograph:			85	%
18	DDESIGN DATA	Stress Relieve:	Yes	Parts:		
	DDESIGN DATA		No			
19	DDESIGN DATA	Insulation:	Yes			thick mm.
	DDESIGN DATA		No			
20	DDESIGN DATA	Fireproofing:	Yes			
	DDESIGN DATA		No			
22	DDESIGN DATA	Paint:	Yes	Parts:		
	DDESIGN DATA		No			
23	DDESIGN DATA	Wt. Empty:			2,36	kg
24	DDESIGN DATA	Wt. Full of product:			17.210,00	kg
25	DDESIGN DATA	Wt. Full of water:			19.361,00	kg
26	DDESIGN DATA	Hidrostatic Test (eff.)				kg/cm2 g
27	M ATERIALS		Thick. (mm.)		Mat´l Class	
28	M ATERIALS	Roof	12		SA516	
29	M ATERIALS	Shell course	12			
30	M ATERIALS	8				
31	M ATERIALS	7				
32	M ATERIALS	6				
33	M ATERIALS	5				
34	M ATERIALS	4				
35	M ATERIALS	3				
36	M ATERIALS	2				
37	M ATERIALS	1				
38	M ATERIALS	Bottom				
39	M ATERIALS	Perimetral ring				
40	NOZZLES	Service	Mark	No.	Dia.	Rating
41	NOZZLES		A			
42	NOZZLES		B			
43	NOZZLES		C			
44	NOZZLES		D			
45	NOZZLES		E			
46	NOZZLES		F			
47	NOZZLES		G			
48	NOZZLES		H			
49	NOZZLES		I			
50	NOZZLES		J			
51	NOZZLES		K			
52	NOZZLES		L			
53	NOZZLES		M			
54	NOZZLES		N			

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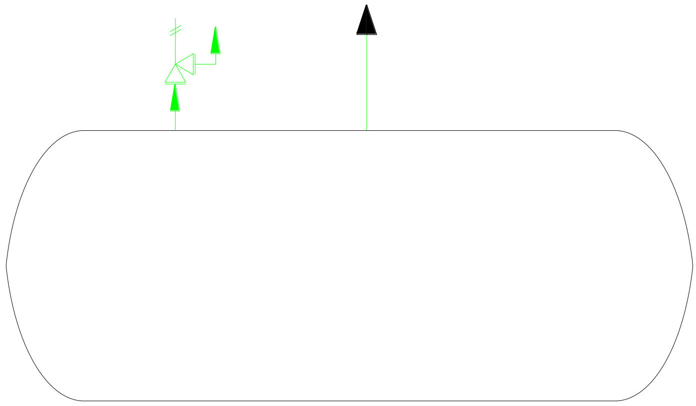

55	NOTES:			
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H&G Industrial Design Services

VERTICAL TANK DATA SHEET

No.	Section	Item	Value	Unit
1	GENERAL	Item: S-0125A		
2		Service: Separator		
3		Type of roof: elipsoidal		
4		Capacity $32\ m^3$		
5	OPER. COND	Operating Pressure	10,2	kg/cm2
6		Operating Temperature	43	ºC
7		Liquid Density	1574,4	kg/m^3
8		Inlet flow	2,905	m3/h
9		Outlet flow		m3/h
10	DDESIGN DATA	Design Pressure (eff.)	10,2	kg/cm2
11		Vacuum (abs.)		bar
12		Design Temperature	53	ºC
13		Corr. Allow.	3	mm
14		Courses:		Nº
15		Joint Eff.		
16		Code:		
17		Radiograph:	85	%
18		Stress Relieve: Yes / No	Parts:	
19		Insulation: Yes / No		thick mm.
20		Fireproofing: Yes / No		
22		Paint: Yes / No	Parts:	
23		Wt. Empty:	0,39	kg
24		Wt. Full of product:	5.293,00	kg
25		Wt. Full of water:	5.954,00	kg
26		Hidrostatic Test (eff.)		kg/cm2 g

			Thick. (mm.)	Mat´l Class
27	M ATERIALS		Thick. (mm.)	Mat´l Class
28		Roof	4	SA516
29		Shell course	4	
30		8		
31		7		
32		6		
33		5		
34		4		
35		3		
36		2		
37		1		
38		Bottom	4	
39		Perimetral ring		

No.	Section	Service	Mark	No.	Dia.	Rating
40	NOZZLES	Service	Mark	No.	Dia.	Rating
41			A			
42			B			
43			C			
44			D			
45			E			
46			F			
47			G			
48			H			
49			I			
50			J			
51			K			
52			L			
53			M			
54			N			

55 NOTES:
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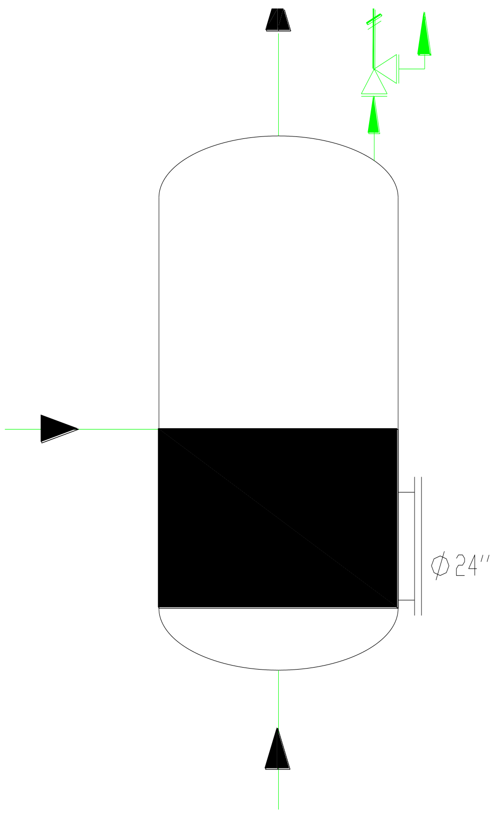

H&G Industrial Design Services

VERTICAL TANK DATA SHEET

No.	Section	Description		Value	Unit
1	GENERAL	Item:	S-0125B, S-0125C, S-0124		
2		Service:	Separator		
3		Type of roof:	elipsoidal		
4		Capacity	$32\ m^3$		
5	OPER. COND	Operating Pressure		7,13	kg/cm2
6		Operating Temperature		56	ºC
7		Liquid Density		1574,4	kg/m^3
8		Inlet flow		0,87	m3/h
9		Outlet flow			m3/h
10	DDESIGN DATA	Design Pressure (eff.)		8,15	kg/cm2
11		Vacuum (abs.)			bar
12		Design Temperature		86	ºC
13		Corr. Allow.		3	mm
14		Courses:			Nº
15		Joint Eff.			
16		Code:			
17		Radiograph:		85	%
18		Stress Relieve:	Yes	Parts:	
			No		
19		Insulation:	Yes		thick mm.
			No		
20		Fireproofing:	Yes		
			No		
22		Paint:	Yes	Parts:	
			No		
23		Wt. Empty:		0,06	kg
24		Wt. Full of product:		2.182,00	kg
25		Wt. Full of water:		2.454,00	kg
26		Hidrostatic Test (eff.)			kg/cm2 g

No.	Section	Description		Thick. (mm.)	Mat´l Class
27	M ATERIALS			Thick. (mm.)	Mat´l Class
28		Roof		10	SA516
29		Shell course		10	
30			8		
31			7		
32			6		
33			5		
34			4		
35			3		
36			2		
37			1		
38		Bottom		10	
39		Perimetral ring			

No.	Section	Service	Mark	No.	Dia.	Rating
40	NOZZLES	Service	Mark	No.	Dia.	Rating
41			A			
42			B			
43			C			
44			D			
45			E			
46			F			
47			G			
48			H			
49			I			
50			J			
51			K			
52			L			
53			M			
54			N			

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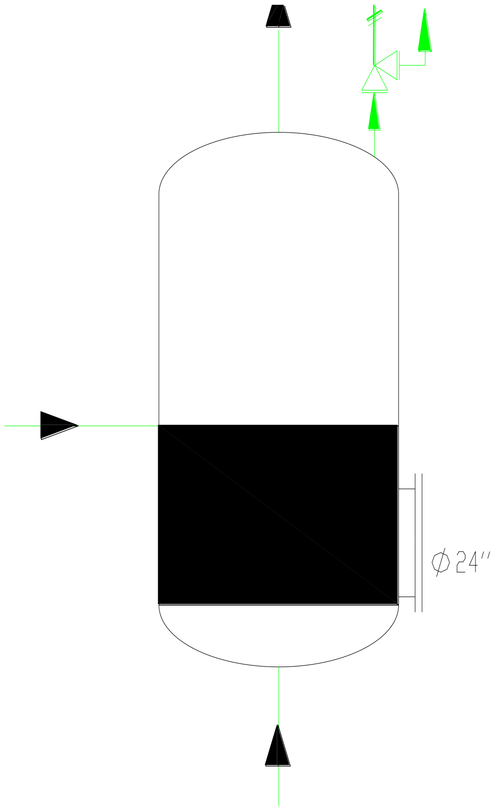

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55	NOTES:
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Industrial Design Services

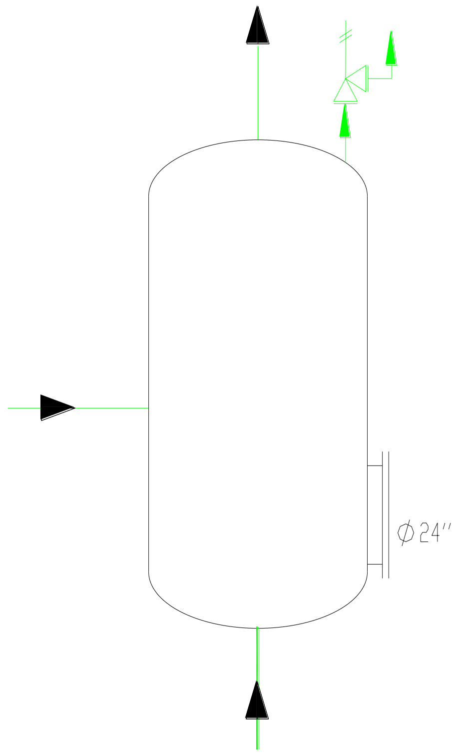
VERTICAL TANK DATA SHEET

No.	Section	Description		Value	Unit
1	GENERAL	Item:	TK-0154A, TK-0154B, TK-0154C		
2		Service:	Holding tanks		
3		Type of roof:	elipsoidal		
4		Capacity	$32\ m^3$		
5	OPER. COND	Operating Pressure		1,019	kg/cm2
6		Operating Temperature		56	ºC
7		Liquid Density		36	kg/m^3
8		Inlet flow		2,905	m3/h
9		Outlet flow			m3/h
10	DDESIGN DATA	Design Pressure (eff.)		1,019	kg/cm2
11		Vacuum (abs.)			bar
12		Design Temperature		76	ºC
13		Corr. Allow.		3	mm
14		Courses:			Nº
15		Joint Eff.			
16		Code:			
17		Radiograph:		85	%
18		Stress Relieve:	Yes	Parts:	
			No		
19		Insulation:	Yes		thick mm.
			No		
20		Fireproofing:	Yes		
			No		
22		Paint:	Yes	Parts:	
			No		
23		Wt. Empty:		0,67	kg
24		Wt. Full of product:		11.088,00	kg
25		Wt. Full of water:		12474	kg
26		Hidrostatic Test (eff.)			kg/cm2 g

No.	Section	Description		Thick. (mm.)	Mat´l Class
27	M ATERIALS			Thick. (mm.)	Mat´l Class
28		Roof		4	SA516
29		Shell course		4	
30			8		
31			7		
32			6		
33			5		
34			4		
35			3		
36			2		
37			1		
38		Bottom		4	
39		Perimetral ring			

No.	Section	Service	Mark	No.	Dia.	Rating
40	NOZZLES	Service	Mark	No.	Dia.	Rating
41			A			
42			B			
43			C			
44			D			
45			E			
46			F			
47			G			
48			H			
49			I			
50			J			
51			K			
52			L			
53			M			
54			N			

SKETCH



No.	
55	NOTES:
56	
57	
58	
59	

REV.		DATE	PREP.	APPR.
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REV.		DATE	PREP.	APPR.

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Industrial Design Services

5. SAFETY IN PROCESS DESIGN

In this section an exhaustive safety study is carried out to identify hazard products and installation. Since the project is a revamping of an already existing unit, there are no changes in preventive and response plan. This section is being developed using the following Spanish Regulations:

- Ley 31/1995, de 8 de noviembre (BOE de 10/11/95) de Prevención de Riesgos Laborales.
- Ley 54/2003, de 12 de diciembre, de reforma del marco normativo de la prevención de riesgos laborales.
- Real Decreto 1254/1999, de 16 de julio, por el que se aprueban medidas de control de los riesgos inherentes a los accidentes graves en los que intervengan sustancias peligrosas.
- Decreto 1254/1999, de 16 de julio, por el que se aprueban medidas de control de los riesgos inherentes a los accidentes graves en los que intervengan sustancias peligrosas.
- Real Decreto 1196/2003, de 19 de septiembre, por el que se aprueba la Directriz Básica de Protección Civil para el control y planificación ante el riesgo de accidentes graves en los que intervienen sustancias peligrosas.
- Real Decreto 2267/2004, de 3 de diciembre, por el que se aprueba el Reglamento de seguridad contra incendios en los establecimientos industriales.

5.1. Process safety

5.1.1. Preliminary hazard analysis

5.1.1.1. Hazardous products and equipment

The only hazardous product in this process is VCM because dangerous fire and explosion may take place when it is exposed to heat or flame. This product is highly flammable and forms explosive mixtures with air. Vapors are heavier than air and may travel to the source of ignition and flash back. Tanks and separator with VCM atmosphere may explode in heat of fire. In section 3 of appendix the Material Safety Data Sheet (MSDS) of this product can be found.

Tanks and separators with VCM atmosphere are the most hazardous equipment of the unit. Therefore, in storage tank TK-0155 it is installed an oxygen detector, to reduce the probability of hazardous situation.

Following is a qualitative hazard analysis which focuses on deviations from desired operating conditions that could potentially harm personnel, the environment, or the installation.

5.1.1.1.1. Hazard and operability study

A Hazard and Operability (HAZOP) study is a structured and systematic examination of a planned or existing process or operation in order to identify and evaluate potential hazards and operability problems. The HAZOP analysis technique uses a systematic process to identify possible deviations from normal operations and ensure that appropriate safeguards are in place to help prevent accidents. It uses special adjectives combined with process conditions to systematically consider all credible deviations from normal conditions. The adjectives, called guidewords, are a unique feature of HAZOP analysis.

Table 5.1. HAZOP sheet.

Project: *Revamping of VCM recovery unit*			***Node: TK-0154A, TK-0154B and TK-0154C***	
			Node descriptions: Holding tank	
Guide word	***Deviation***	***Causes***	***Consequences***	**Corrective actio**
More	Temperature	1. External fire 2. Pressure control failure 3. Inlet flow increase	1. Pressure increase	1. High pressur 2. Installation P
Less	Temperature	1. Low weather temperature	1. Frozen water in tank	
More	Pressure	1. Inlet flow increase 2. External fire 3. Pressure control failure 4. Level control failure 5. Centrifugal pump failure 6. Control valve breakdown 7. Instrumentation air failure	1. Level increase 2. Temperature increase 3. Inundation 4. Tank rupture	1. High pressur 2. Interlock 1,2, 3. PSV
Less	Pressure	1. No inlet flow 2. Pressure control failure 3. Level control failure 4. Pipe obstruction/rupture 5. Control valve breakdown 6. Instrumentation air failure	1. Liquid vaporization 2. Tank rupture	1. Low pressure 2. Low level ala 3. Interlock 4,5,

Project: *Revamping of VCM recovery unit*			***Node: TK-0154A, TK-0154B and TK-0154C*** ***Node descriptions: Holding tank***	
Guide word	***Deviation***	***Causes***	***Consequences***	**Corrective actio**
No	Level	1. No inlet flow 2. Leak 3. Level control failure 4. Pipe obstruction/rupture 5. Valve breakdown 6. Instrumentation air failure	1. Pressure decrease 2. Pump cavitation 3. Damages in pump	1. Low low leve 2. Low level ala 3. Low pressure 4. Interlock 7,8,
More	Level	1. Pump failure 2. Inlet flow increase 3. Level control failure 4. Valve breakdown 5. Instrumentation air failure	1. Inundation 2. Pressure increase 3. Tank rupture	1. High high lev 2. High level ala 3. PSV 4. Auxiliary pun
Less	Level	1. No inlet flow 2. Leak 3. Level control failure 4. Pipe obstruction/rupture 5. Valve breakdown 6. Instrumentation air failure	1. Pressure decrease 2. Pump cavitation 3. Damages in pump 4. Tank vacuum	1. Interlock 10, 2. Low low leve 3. Low level ala 4. Low pressure
No	Flow	1. Pipe obstruction/rupture 2. Pressure controller failure 3. Valve breakdown 4. Instrumentation air failure	1. Pressure decrease 2. Pump cavitation 3. Damages in pump	1. Low pressure
Less	Flow	1. Pipe obstruction/rupture 2. Valve breakdown 3. Instrumentation air failure	1. Pressure decrease 2. Pump cavitation 3. Damages in pump	1. Low pressure

Project: *Revamping of VCM recovery unit*			***Node: TK-0154A, TK-0154B and TK-0154C*** ***Node descriptions: Holding tank***	
Guide word	***Deviation***	***Causes***	***Consequences***	**Corrective actio**
More	Flow	1. Valve breakdown 2. Instrumentation air failure	1. Pressure increase 2. Inundation 3. Tank rupture	1. High pressur 2. PSV

Table 5.1. HAZOP sheet (continuation).

Project: *Revamping of VCM recovery unit*			***Node: C0112*** ***Node descriptions: Liquid ring vacuum pu***	
Guide word	***Deviation***	***Causes***	***Consequences***	**Corrective acti**
More	Temperature	1. External fire 2. Heat exchanger E0134 failure 3. Temperature controller failure 4. Pressure controller failure 5. Valve breakdown 6. Instrumentation air failure	1. Pressure increase 2. Vaporization 3. Cavitation in pump 4. Damages in pump	1. High temper 2. High pressur 3. Installation P
Less	Temperature	1. Low weather temperature 2. Heat exchanger E0134 failure 3. Temperature controller failure 4. Valve breakdown 5. Instrumentation air failure	1. Frozen water 2. Pump rupture	1. Low tempera
More	Pressure	1. External fire 2. Pressure controller failure 3. Valve breakdown 4. Instrumentation air failure 5. Temperature increase	1. Pressure increase	1. High pressur 2. Interlock 13
Less	Pressure	1. Pipe/bypass obstruction/rupture 2. Pump failure 3. Pressure controller failure 4. Valve breakdown 5. Instrumentation air failure	1. Pressure decrease 2. Cavitation in pump 3. Damages in pump	1. Low pressur 2. Low level ala 3. High level al 4. Interlock 14

Project: *Revamping of VCM recovery unit*			**Node: C0112**	
			Node descriptions: Liquid ring vacuum pu	
Guide word	**Deviation**	**Causes**	**Consequences**	**Corrective acti**
No	Flow	1. Pipe/bypass obstruction/rupture 2. Pressure controller failure 3. Valve breakdown 4. Instrumentation air failure	1. Pressure decrease 2. Cavitation in pump 3. Damages in pump	1. Low pressur 2. Interlock 15
Less	Flow	1. Pressure controller failure 2. Valve breakdown 3. Instrumentation air failure	1. Pressure decrease 2. Cavitation in pump 3. Damages in pump	1. Low pressur
More	Flow	1. Pressure controller failure 2. Valve breakdown 3. Instrumentation air failure	1. Pressure increase 2. Temperature increase	1. High pressur 2. PSV

Table 5.1. HAZOP sheet (continuation).

Project: *Revamping of VCM recovery unit*			***Node: C0113A, C0113B and C***	
			Node descriptions: Liquid rin	
Guide word	***Deviation***	***Causes***	***Consequences***	***Corre***
More	Temperature	1. External fire 2. Heat exchanger E-0135A/ E-0135B/ E-0135C failure 3. Temperature controller failure 4. Pressure controller failure 5. Valve breakdown 6. Instrumentation air failure	1. Pressure increase 2. Vaporization 3. Damages in compressor	1. Hig ala 2. Hig 3. Ins
Less	Temperature	1. Low weather temperature 2. Heat exchanger E-0135A/ E-0135B/ E-0135C failure 3. Temperature controller failure 4. Valve breakdown 5. Instrumentation air failure	1. Frozen water 2. Compressor rupture	1. Lov ala
More	Pressure	1. External fire 2. Pressure controller failure 3. Valve breakdown 4. Instrumentation air failure 5. Temperature increase	1. Pressure increase	1. Hig 2. Int
Less	Pressure	1. Pipe/bypass obstruction/rupture 2. Compressor failure 3. Pressure controller failure 4. Valve breakdown 5. Instrumentation air failure	1. Pressure decrease 2. Cavitation in compressor 3. Damages in compressor	1. Lov 2. Lov 3. Int

Project: *Revamping of VCM recovery unit*			***Node: C0113A, C0113B and C***	
			Node descriptions: Liquid rin	
Guide word	***Deviation***	***Causes***	***Consequences***	**Corre**
No	Flow	1. Pipe/bypass obstruction/rupture 2. Pressure controller failure 3. Valve breakdown 4. Instrumentation air failure	1. Pressure decrease 2. Cavitation in compressor 3. Damages in compressor	1. Lo 2. Int
Less	Flow	1. Pressure controller failure 2. Valve breakdown 3. Instrumentation air failure	1. Pressure decrease 2. Cavitation in compressor 3. Damages in compressor	1. Lo
More	Flow	1. Pressure controller failure 2. Valve breakdown 3. Instrumentation air failure	1. Pressure increase 2. Temperature increase	1. Hi 2. PS

Table 5.1. HAZOP sheet (continuation).

Project: *Revamping of VCM recovery unit*			***Node: S-0124, S-0125A, S-0125B and S-01***	
			Node descriptions: Separator	
Guide word	**Deviation**	**Causes**	**Consequences**	**Corrective actio**
More	Temperature	1. External fire 2. Level control failure 3. Inlet flow increase	1. Pressure increase	1. Installation PSV 2. High pressure a
Less	Temperature	1. Low weather temperature	1. Frozen water in tank	-
More	Pressure	1. Inlet flow increase 2. External fire 3. Level control failure 4. Valve breakdown 5. Instrumentation air failure	1. Level increase 2. Temperature increase 3. Inundation 4. Tank rupture	1. High pressure 2. Interlock 25, 3. PSV
Less	Pressure	1. No inlet flow 2. Level control failure 3. Pipe obstruction/rupture 4. Valve breakdown 5. Instrumentation air failure	1. Liquid vaporization 2. Inundation 3. Tank rupture	1. Low pressure 2. Low level alar 3. Interlock 29, 4. High level ala
No	Level	1. No inlet flow 2. Leak 3. Level control failure 4. Pipe obstruction/rupture 5. Valve breakdown 6. Instrumentation air failure	1. Pressure decrease	1. Low low 2. Low leve 3. Low pre 4. Interloc and 36.

Project: *Revamping of VCM recovery unit*			***Node: S-0124, S-0125A, S-0125B and S-01*** ***Node descriptions: Separator***	
Guide word	**Deviation**	**Causes**	**Consequences**	**Corrective actio**
More	Level	1. Inlet flow increase 2. Level control failure 3. Valve breakdown 4. Instrumentation air failure	1. Inundation 2. Pressure increase 3. Tank rupture	1. High level ala 2. High high lev 3. Interlock 37, 4. PSV
Less	Level	1. No inlet flow 2. Leak 3. Level control failure 4. Pipe obstruction/rupture 5. Valve breakdown 6. Instrumentation air failure	1. Pressure decrease 2. Tank vacuum	1. Low low leve 2. Low level ala 3. Low pressure
No	Flow	1. Pipe obstruction/rupture 2. Valve breakdown 3. Instrumentation air failure	1. Pressure decrease	1. Low pressure
Less	Flow	1. Pipe obstruction/rupture 2. Valve breakdown 3. Instrumentation air failure	1. Pressure decrease	1. Low pressure
More	Flow	1. Valve breakdown 2. Instrumentation air failure	1. Pressure increase 2. Inundation 3. Tank rupture	1. High pressure 2. PSV

Table 5.1. HAZOP sheet (continuation).

Project: *Revamping of VCM recovery unit*			***Node: TK-0155*** ***Node descriptions: Storage tank***	
Guide word	***Deviation***	***Causes***	***Consequences***	**Corrective a**
More	Temperature	1. External fire 2. Level control failure 3. Inlet flow increase	1. Pressure increase	1. Installation P 2. High pressure
Less	Temperature	1. Low weather temperature	1. Frozen water in tank	
More	Pressure	1. Inlet flow increase 2. External fire 3. Level control failure 4. Valve breakdown 5. Instrumentation air failure	1. Level increase 2. Temperature increase 3. Inundation 4. Tank rupture	1. High pressure 2. Interlock 41 3. PSV
Less	Pressure	1. No inlet flow 2. Level control failure 3. Pipe obstruction/rupture 4. Valve breakdown 5. Instrumentation air failure	1. Liquid vaporization 2. Tank rupture	1. Low pressure 2. Low level alar
No	Level	1. No inlet flow 2. Leak 3. Level control failure 4. Pipe obstruction/rupture 5. Valve breakdown 6. Instrumentation air failure	1. Pressure decrease	2. Installat 3. Low low 4. Low leve 5. Low pre

Project: *Revamping of VCM recovery unit*			***Node: TK-0155*** ***Node descriptions: Storage tank***	
Guide word	***Deviation***	***Causes***	***Consequences***	**Corrective a**
More	Level	1. Inlet flow increase 2. Level control failure 3. Valve breakdown 4. Instrumentation air failure	1. Inundation 2. Pressure increase 3. Tank rupture	1. High high lev 2. High level ala 3. Interlock 42 4. PSV
Less	Level	1. No inlet flow 2. Leak 3. Level control failure 4. Pipe obstruction/rupture 5. Valve breakdown 6. Instrumentation air failure	1. Pressure decrease 2. Tank vacuum	1. Low low level 2. Low level alar 3. Low pressure
No	Flow	1. Pipe obstruction/rupture 2. Valve breakdown 3. Instrumentation air failure	1. Pressure decrease	1. Low pressure
Less	Flow	1. Pipe obstruction/rupture 2. Valve breakdown 3. Instrumentation air failure	1. Pressure decrease	1. Low pressure
More	Flow	1. Valve breakdown 2. Instrumentation air failure	1. Pressure increase 2. Inundation 3. Tank rupture	1. High pressure 2. PSV

5.1.1.1.2. HAZOP conclusions

Some conclusions have been extracted from HAZOP attached above, these are:

- Warning alarms for all critical variables will be installed for operating intervention.
- Interlocks are being designed to prevent serious accidents such as tank explosion. Interlocks intervene when control fails and/or no operational solution is available. In section 4 process interlocks are listed and explained.
- Overpressure protection has been installed, if interlock cannot solve the situation, PSV intervene. The required safety valves were been designed at section 4.

These conclusions have been illustrated in the P&ID sheet.

5.1.2. ATEX zone

According to ATEX 1999/92/CE the zone defines the probability of hazardous material being present in an ignitable concentration in the surrounding atmosphere:

- Zone 0: Location where an explosive concentration of a flammable gas or vapor mixture is present continuously or during long periods.
- Zone 1: Location where an explosive concentration of a flammable or explosive gas or vapor mixture is likely to occur in normal operation.
- Zone 2: Location in which an explosive concentration of a flammable or explosive gas or vapor mixture is unlikely to occur in normal operation and, if it does occur, will exist only for a short time.

In this case recovery unit can be considered as Zone 1, since VCM is a flammable substance which may be present in normal conditions.

5.1.3. Overpressure protection

As explained above, for critical equipment protection is achieved by installing a pressure safety valve in tanks TK-0154A, TK-0154B, TK-0154C and TK-0155 and separators S-0124, S-0125A, S-0125B and S-0125C. To protect heat exchangers (E-0134, E-0135A, E0135B and E-0135C) two PSV are installed: one in shell-side fluid inlet and the other in tube-side fluid inlet. In all cases, before PSV acts there are some other safety measures such as alarms and interlock systems that let this safety device as the last solution to avoid explosion.

5.1.4. Auto Protection Planning

It is a reasonable assumption that every industry will, at some point, experience some type of crisis or emergency. Emergency preparedness and planning activities will help to minimize human, property, and economic losses due to any hazardous event. Therefore, main targets of this planning are:

- Prevent, when possible, occurrence of emergent situations.
- Safely control of the events that may cause emergency.
- Protect human life, health and environment.
- Minimize damage to installation and environment uncovered

The protection planning has been done taking into account an exhaustive hazard analysis, identifying accident and assessing hazard levels. From this study, conclusions have been extracted regarding material and personal means. Therefore, an Auto Protection Guidebook was elaborated. Depending on emergency class, there is an organizational structure to response. Roles are disturbed to cover all necessary personal requirements even in abnormal working days. The internal Auto Protection Planning works coordinately with the exterior one, so that situation management is performed optimally.

5.1.4.1. Protection means

In the plant there are available the following material protective means:

- Fix chemical extinguishing systems such as deluge system, monitors and hydrants and mobile extinguishers.
- Air contamination analyzers which take samples from 30 different points from the plant every 20 minutes. Therefore contaminants concentration can be monitored.
- Mobile flammable atmosphere detectors are available.
- Foam firefighting protection system.
- Alarm system with acoustic warning.
- Self-contained and semi-self-contained breathing equipment.
- Fireproof and Protective clothing to deal with substances leaks.

5.1.4.2. Emergency Response Guidebook

1. It is the responsibility of all employees to report immediately all incidents or conditions that supose a threat to life or property.
2. The Director of Crisis Management is responsible for assessing the level of the emergency and for making the correct decisions and unleashing the appropriate actions. Plant responsible will assume this task if Director of Crisis Management is absent.
3. If it is possible routine operations will be shutdown by the unit chief focusing on emergency response.
4. The response team is the personal of the affected unit. So in emergency situation this team has the obligation of deal with the situation having been already prepared with the required protection equipment.
5. Such response team will go to the incident scene to try to solve the emergency cause.
6. If firemen are absent, firefighting task will be a responsibility of personal of non-affected areas.
7. The intervention will be organized by Director of Crisis Management in order to coordinate actuations.

8. Communication of situation progress will be continuous.
9. If necessary, personal staff will be evacuated from the site.
10. Solved is the emergency, Director of Crisis Management is responsible will communicate End of Emergency.

Following is an evacuation plan:

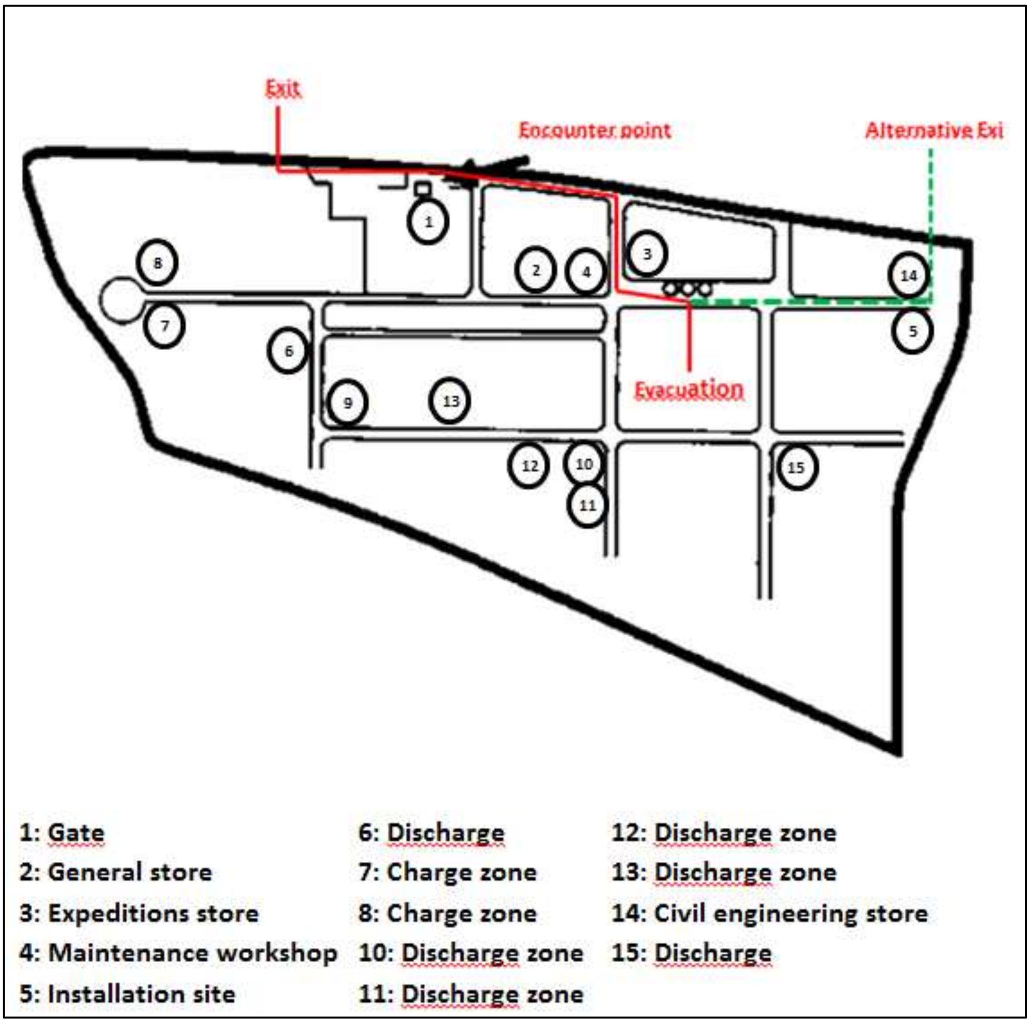

Figure 5.1.4.1. Response planning.

5.2. Occupational safety

5.2.1. Hazard Assessment and Personal Protective Equipment

VCM is a toxic and carcinogenic product, so there are some considerations to take into account to protect employees from hazards by the use of Personal Protective Equipment.

Table 5.2.1. Occupational hazard assessment.

Hazard	Hazard description	Personal Protective Equipment
Impact	Falling/flying objects, heavy tools, etc.	- Hard Hat - Safety shoes
	With fixed object	
Penetration	Sharp objects piercing foot/hand: nails, scrap metal…	Footwear with puncture-resistant soles/steel insert
Compression	Rolling or pinching objects, rolls, carts or vehicles	Safety shoes. For severe exposure use metatarsal guards.
Chemicals	- Exposure: inhalation, ingestion, skin contact, eye contact or injection. - Splashing/spilling liquids, i.e., solvents, oils, paints, corrosives, acids, etc.	- Chemical goggles. Use a face shield plus chemical goggles for severe exposure. - Leather shoes for mild exposures. Rubber boots or shoes with spats for severe exposure.
Electrical	Contact with power lines, conductors, arcing, sparks or static discharges.	Footwear with special conductive/insulated soles
Heat	Flying sparks, flux, and metal from cutting/welding operations	- Leather safety shoes. For severe exposure, use metatarsal guards or spats. - Safety shoes with metatarsal guards or spats
Dust	Flying solid particles (mists or vapors)	Impact goggles or safety glasses with side shields. Use a face shield plus impact goggles or safety glasses for severe exposure.
Light radiation	- Sparks, optical radiation, flying particles, flash burns - Reflected or direct laser beam impact	- Safety glasses with shaded lenses or welding shield. Use face shield plus safety glasses for severe exposure. - Narrow or broad spectrum laser spectacles or goggles.
Water	- Potential for drowning or fungal infections caused by wetness - Wetness/moisture from prolonged exposure	Insulated shoes or boots
	Slipping hazard	Footwear with slip-resistant soles
Temperature	Exposure to extreme hot	Insulated shoes/boots
	Exposure to extreme cold	
Electrical	- Sparks, optical radiation, flying particles - Contact with exposed electrical wires, conductors	- Welding shield or welding helmet worn over safety glasses with side shields. - Hard Hat - Footwear with special conductive/insulated soles

5.2.2. Incidents and accidents

Everybody who suffers an incident/accident has the obligation to communicate it to the area responsible. Such responsible, will make appropriate decisions to minimize and take control of the accident consequences. The information to be given is:

- Site
- Date and time
- Brief explanation of the event

Depending on the level of the accident/incident HR, Health Prevention and Prevention service shall be informed.

- Health Prevention: injury level assessment to take suitable measures.
- Management Centre: a committee will be designed to investigate the causes, assesse consequences and propose appropriate corrective actions.
- Prevention Service: it will manage the information and will participate with the affected area to adopt the corrective measures participating in Committee investigation. It will spread incident/accident and the recommendations to other plant areas. This service has the obligation of corrective actions accomplishment.
- Affected area: the responsible of this section will meet with the affected personal and witnesses to establish the real causes.
- Investigation Committee: this team will meet to gather all obtained information from different parts to establish the final causes of the event and to decide corrective actions to implant. For every corrective measure, a responsible and an execution period of time will be designed.
- When all corrective actions are finished another meeting will take place to assess the effectiveness of the measures and to establish other ones if necessary.

5.2.3. Safety training

Training to the employees must be provided concerning the proper use, maintenance, limitations and storage of the Personal Protective Equipment. Each employee presently involved in operating the process, and each employee before being involved in operating a newly assigned process, will be trained in an overview of the process and in the operating procedures explained in section 8. This initial training must include emphasis on the specific safety and health hazards, emergency operations including shutdown, and safe work practices applicable to the employee's job tasks.

Employees who are engaged in responding to hazardous emergency situations at hazardous waste cleanup sites that may expose them to hazardous substances will be trained in how to respond to such expected emergencies. Moreover, they will receive a refresher training day twice annually where incidents that have occurred in the past year will serve as training examples of any related work.

6. ENVIRONMENTAL ANALYSIS

The environmental impact of PVC products has been investigated in numerous studies, quantified in many life cycle analyses and compared many times to products made from alternative materials. The latest and most comprehensive study was a Review commissioned by the EU. It showed PVC products to be comparable to alternatives in their environmental impact. The strongest aspects of PVC products are performance and cost; PVC products are amongst the lowest cost products for a given performance.

In this section, emissions to the environment are analyzed.

6.1. Emissions to the environment

Several EU Member States and companies set lower maximum levels, typically 1 ppm. Emissions are also covered by the ECVM Industry Charters.

In this section, analysis of solid liquid and air emissions in recovery unit is provided.

6.1.1. Atmosphere emissions

In storage tank TK-0155 is installed a vent system that spontaneously emits gases in order to avoid overpressure.

In order to treat such gases, membranes have been installed so that VCM vapor can be separated from water. Installation of an MTR membrane vapor recovery system allows 90-99% recovery and direct recycles of the vinyl chloride eliminating the need for an HCl scrubber on the incinerator. VCM that can not be recuperated goes to an oxi-cat.

6.1.2. Water spills

In the recovery unit there exists process water spills regarding drains in vessels as well as in control valves.

- Service water obtained manually in drains in vessels TK-0154A, TK-0154B, TK-0154C is sent to waste water treatment.
- Service water obtained in drains in vessels S-0124, S-0125A, S-0125B, S-0125C due to process control, it is also sent to waste water treatment.
- Due to the fact that all control valves need drain, waste water is obtained in all of them. Such waste water it is sent to treatment.
- Tower water is needed in heat exchangers and so tower water split from heat exchanger controllers installed in every unit. Since no cross contamination occurs, no water treatment is required.

6.1.3. Soil emissions

In VCM recovery unit there is no evidence of soil emissions so far.

6.1.4. Acoustic contamination

The only acoustic contamination sources inside the installation are caused by pumps and compressors. If during operation, maximum acoustic contamination level of imission allowed is reached, equipment will be isolated in order to accomplish the law limit.

Catalan Statute 16/2002 currently modified with the decree-law 176/2009 fix maximum imision levels of acoustic contaminations in 60 dB during the night and 70 during the day.

6.1.5. Polluting fumes

Since recovery unit does not have combustion, there is not polluting fumes inside the battery limit.

6.2. Solid waste

Solid waste generation comes from PVC dust, and flanged connections and joints.

- Flanged connections are used to attach a series of pipes or other flanged together. Considering maintenance strategy, the frequency in which these connections will be replaced depends on corrosion damages.
- Oil is required only in centrifugal pump P-0147AB. No lubrication is required in vacuum pump C-0112 and liquid ring compressors C-0113A, C-0113B, C-0113C.
- Joints are changed depending on temperature and pressure cycles. Depending on process conditions, joints lifetime differs from 1 to 10 years.

6.3. Energy and natural resources consumption

- Tower water is used in heat exchanger. From drains in heat exchangers controllers tower water is obtained as well.

Flow rates are shown in table 6.3.1. Since no cross contamination occurs, no water treatment is needed for these consumptions.

Table 6.3.1. Tower water flow rates.

	E-0134	**E-0135B**	**E-0135C**	**E-0135A**	**E-0136**
m(kg/s)	10,33	24,25	2,411	2,083	8,859

- Process water: during the first process start of recovery unit vessles S-0124, S-0125A, S-0125B, S-0125C are filled with process water up until 50% of vessel level.
- Nitrogen is used to clean the installation during the shut down.
- Energy consumption: compress equipment has its energy consumption as well. Values are showed in table 6.3.2

Table 6.3.2. Energy consumption.

	Electricity consumption (kWh)
C-0112	75
C-0113C	330
C-0113A	330
C-0113B	330

It must be pointed out that values in table 6.3.2 show energy consumption in each equipment however, not all equipment is functioning 24h per day 365 days a year. Liquid ring compressor in BDT line (C-0113B) functions with a 5-hour frequency, on the other hand, ring compressor in strippers line (C-0113C) is functioning 24h a day 365 days per year. Finally, liquid ring compressor in vent line (C-0113C) is used punctually.

7. INSTALLATION MAINTENANCE

Maintenance strategy has been implemented to overcome the problems related to equipment breakdown. Different maintenance strategies that have been designed are explained in this section.

7.1. Breakdown maintenance

The approach to maintenance is totally reactive and only act when the equipment needs to be fixed. This strategy has no routine maintenance task and also described as no scheduled maintenance strategy. To rectify the problem, corrective maintenance is performed onto the equipment. Thus, this activity may consist of repairing, restoration or replacement of components. The strategy is to apply the corrective maintenance activity only, which is required to correct a failure that has occurred or is in the process of occurring.

- Change valves when sealing is not proper.
- Change instrumentation when it does not work properly.
- Fix rotative equipment if any breakdown.
- Fix static equipment if any fissure is appreciated.

7.2. Preventive maintenance

This is a time-based maintenance strategy equipment is taken off-line, opened up and inspected. Based on visual inspection, repairs are made and the equipment is then put back on-line. Thus under this equipment maintenance strategy, replacing, overhauling or remanufacturing an items is done at a fixed intervals regardless of its condition at the time.

Preventive maintenance program is design to do the following:

- Reduce equipment failures.
- Reduce the magnitude of equipment failure or repair costs.
- Reduce product loss or production downtime due to equipment failure or repair.

- Reduce deterioration in the productive capacity of equipment.

Different types of preventive equipment maintenance explanation are provided.

7.2.1. Liquid ring compressor and vacuum pump

Periodically check the working conditions of the system by means of the instrumentation on the installation (pressure gauges, vacuum gauges, temperature gauges, ampmeters, etc.) and that the pump/compressor is consistently handling the application for which it was selected.

- The operation of the pump/compressor should be without abnormal vibrations or noises, if any of these problems is noticed, the pump should be stopped immediately, search for the cause and make the necessary corrections.
- Check the pump/motor alignment at least once a year, even if no abnormalities have been noticed.
- If there is a deterioration of the pump/compressor performance, which is not attributable to changes in system demands, the pump/compressor must be stopped and proceed with necessary repairs or replacement.
- If the mechanical seals are fitted with external flushing and/or quenching lines their pressures, temperatures and flows must be checked constantly.
- During operation it must be avoided to have sudden and frequent variations from high to low vacuum.
- Particular attention should be put on the quantity of the service liquid flow.

7.2.2. Vessels

- When recovery unit is being shut down proceed with cleaning.
- Detection of leaks in the connections between the tanks and piping and instruments implemented.

- Annual Review of thicknesses has to be done.
- Verify the thickness with liquid penetrant and non-destructive testing on pipes or tanks.
- Inspect any loss of steam, cracks, leaks, etc.
- During the life of the equipment, inspections set by industry are done. Such inspections are carried out in order to check integrity of the installation. Person designed for this purposes can be a inspector from the plant staff orelse from an entity authorized by these purposes.
- Hydrostatic testing is performed.

7.2.3. Valves

- Look for media leaks at the leak port.
- Actuate valves looking for indicator movement. In addition to visually inspecting the valve indicator for movement, it is also test and that normally static valves open and close upon demand. This ensures that the valve position indicator is providing an accurate reading.
- Verify pilot pressures are correct, pilot lines are correctly installed and are not leaking.
- Perform general system visual leak inspection; look for other plumbing leaks, especially onto components, cross-threaded nuts, etc., also look for corrosion or discoloration on the valve's exterior.

7.2.4. Piping

Pipelines – no matter what they transport – must have clean inner surfaces and be in good operating condition to work efficiently and cost-effectively. Moreover, a clean pipeline is a precondition for high-quality in-line inspection results.

- All inspections are performed by an API 570-certified survey engineer and an NDT specialist using the most appropriate inspection method.
- Anomalies are assessed in accordance with applicable design code (e.g. ASME B31.3, ASME B31.4) and ASME B31G.
- Special attention is paid in zones where leaks are more likely to happen: joints, flanged connections.

7.2.5. Instrumentation

- Calibration

Instrumentation devices needs to be calibrated from time to time to make sure they show the right value. The interval is different from different devices, brands and styles. Some suppliers give up to 10 years warranty on the device they sell to stay true, others are less.

- Control

Part of an instrumentation preventive maintenance program is to check your loop response. Part of the loop response problem can be design issues. If a maximum flow may be achieved at 75% open and the range will therefore be 0-75% for the corresponding 0-1000kg/h, instead of 0-100%.

- Physical Instrumentation Checks

All instrumentation should be checked physically. A physical inspection route for instrumentation equipment will pinpoint physical problems and identify problems earlier.

7.2.6. Storage

According to the article VI of “Reglamento de Almacenaje de Productos Químicos aprobado por el Real Decreto 668/1980 de 8 de febrero del Ministerio de Industria y Energía” during inspection, it shall be verified:

- If between inspections period has not changed anything that could alter the level of security in which the project was first approved. If there have been modifications or extensions such changes must be carried out with its permits.
- Products that are still the same as in the initial project.
- Storage capacities that are still the same.
- Condition of pipes, cementing and drains should be checked visually.
- Continuity of electrical elements in case of the absence of a justifying document has to be check.
- Visual inspection of container's walls has to be done.
- Checks: Pumping equipment operation, alarms, fire, fire extinguishers, fire system.

7.2.7. Electrical elements

Initiating an effective electrical preventive maintenance program to reduce the potential for a serious electrical interruption. The basic rule applying to all electrical apparatus is to keep it clean, keep it dry, keep it tight, and prevent friction.

- Clean Dirt is a common cause of electrical failure. Dirt is the day-to-day accumulation of particulate matter. Weekly cleaning of motor casings and keeping electrical cabinets free of dust by vacuuming. Every maintenance opportunity should include a thorough cleaning of apparatus.
- Humidity: Humidity accelerates the oxidation of metals used in the electrical gear. Oxide build-up increases resistance thus reducing effective contact and the resulting heat can lead to eventual failure.
- Tight: Motion of operating equipment will eventually cause wear and imbalance. Appreciable imbalance tends to create vibrations in equipment and loosen vital connecting parts. Routine maintenance is necessary to detect wear and loosening of parts and connections. This should include a check for tightness of accessible hardware and bolted parts as a simple precautionary measure.

- Friction Free: Electrical equipment that is operating properly has minimum of friction, however, there is always the potential for mechanical breakdown as a result of increased friction. Machinery must be properly lubricated at recommended frequencies. Alignment of machinery components is critical to help reduce friction.

7.2.8. Time based

Maintenance is performed in specific cycles for time-based maintenance planning. Such cycles differ from equipment characteristics and manufacturer.

7.2.8.1. Liquid ring compressor and vacuum pump

Six-Month Intervals:

- If the drive coupling is lubricated, it should be filled with oil or grease in accordance with the coupling manufacturer's guide.
- Check the pump bearing and lubricates.
- Relubricate the drive motor bearings according to the motor manufacturer's instructions.

Twelve-Month Intervals

- Inspect the pump bearings and lubricate.
- Replace the stuffing box packing.

7.2.8.2. Vessels

For vessel inspection API Standard 653, "Tank Inspection, Repair, Alteration, and Reconstruction," will be used. Such code,includes a cap on the maximum interval between external and internal inspections, and provides specific criteria for alternative inspection intervals based on the calculated corrosion rate.

7.2.8.3. Valves

Consider replacing any valve more than 5 years old. If valve replacement is cost prohibitive, basic PM should be increased to twice per year.

7.2.8.4. Piping

API 570, Piping Inspection Code 3rth edition

7.2.8.5. Storage

According to the article VI of “Reglamento de Almacenaje de Productos Químicos aprobado por el Real Decreto 668/1980 de 8 de febrero del Ministerio de Industria y Energía” inspection of all storage areas every five years has to be done.

7.2.8.6. Electrical elements

Frequency, of course, can be varied depending on operating conditions. Manufacturer's recommendations for electrical equipment have been followed.

- If that electrical equipment is exposed to dust or corrosive vapors, which is VCM recovery case, the test frequency may be doubled.
- For equipment subjected to failures the interval between inspections could be reduced by 50 percent.
- If equipment consistently goes through two maintenance cycles without requiring service, the period in between inspections may be increased up to 50 percent.

7.2.9. Condition based

In the case of condition-based maintenance, maintenance activities are always performed when the measuring point of a technical object has reached a particular state, for example, every time a brake pad has been worn away to the minimum thickness permitted.

SCADA system (Supervisory Control And Data Acquisition system) is used. Such system recognizes events that have been predefined. So if perturbation is introduced in the process and predefined values are overreached:.

1. Each time predefined value is exceeded, the SCADA system transfers this in the form of a measurement reading via the PM interface to the R/3 System.
2. The R/3 System generates a measurement document and a malfunction report for the measurement.
3. The R/3 System recognizes measurement that exceeds the threshold value or as the valuation code "Measurement reading not OK".

7.2.10. Performance based

Counter readings maintained have been installed for measuring points at pieces of equipment and functional locations.

Counter to the maintenance plan has been assigned. Maintenance takes place when the counter for the technical object has reached a certain reading. Calculated planned date depends on the counter reading at the time of planning, and the estimated annual performance that has been defined for the counter.

For performance-based maintenance planning, it is important that you enter the current counter reading regularly, even if it has not changed. Otherwise, the system generates call objects (for example, maintenance orders) based on the estimated annual performance entered for the counter, even though the counter reading has not in reality been reached.

7.2.10.1. Measurement document

A data record for a measurement document comprises the following groups of data:

- Measuring point data

This includes measuring point number, measurement position, description, characteristic and unit.

- Measurement result data

This includes the time of the measurement or reading (time stamp) to the exact second, the measurement or counter reading, and any qualitative judgment regarding the result of the measurement.

- Possible additional information (as short and long text)

This includes information about which employee who took the measurement or counter reading, and where necessary, the number of the measurement document from which the measurement or counter reading result has been copied.

7.3. Predictive maintenance

The approach is based on measuring of the equipment condition in order to assess whether an equipment will fail during some future period, and then taking action to avoid the consequences of that failures.

Predictive technologies (i.e. vibration analysis, infrared thermographs, ultrasonic detection, etc.) are utilized to determine the condition of an equipment, and to decide on any necessary repairs.

A part from the predictive technologies, statistical process control techniques, equipment performance monitoring or human senses are also adapted to monitor the equipment condition.

7.4. Proactive maintenance

Proactive maintenance concentrates on the monitoring and correction of root causes to equipment failures.

The proactive maintenance strategy is also designed to extend the useful age of the equipment to reach the wear-out stage by adaptation a high mastery level of operating precision.

8. OPERATION MANUAL

In this section, manual operation for the startup and shut down of recovery unit is provided. Moreover, steady state operation it is also described.

8.1. Previous steps before the startup

Before the starting, check lists have to be done in order to ensure a proper functioning of all equipment in the recovery unit.

In this section it is firstly provided previous steps to be followed during VCM recovery unit check procedure. Secondly, special steps for the liquid ring pump and compressor are listed as well.

8.1.1. VCM recovery unit previous steps

Previous steps to be followed before first recovery unit start-up are listed below:

1. Manual review: in this step all staff working in the unit has to be familiarized with manual operation, product specification step. The goal is to achieve clear understanding of the start-up and continuous plan operation.
2. Visual inspection of the installation: The goal of this step is to ensure that equipment and services are ready to operate:

- Check that zone is clean after installation.
- Check all the labeling of equipment and instrumentation.
- Check equipment and pipe connection.
- Visual inspection of PSV (Pressure Safety Valves).
- Check vent system in storage tank TK-0136.
- Check electrical installation.
- Check fire protection.

- Earthing equipment

3. Visual inspection of equipment:

- Check flanged connections.
- Check valves that might be used.
- Check controllers, measurement instruments installation, set point and operation range.
- Check operating set point and range of actuation.

4. Availability of auxiliary services: auxiliary services conditions have to be check to ensure they are ready to operate:

- Check compress air circuit as well as its accessories.
- Check drains.
- Check water circuit for fire protection.
- Check electrical circuit.
- Check tower water connections as well as its accessories.
- Check process water connections as well as its accessories.
- Check alarm circuit.
- Check reductions as well as safety valves.
- Check products entrance in the recovery unit.

8.1.2. Previous steps of Liquid ring vacuum pump and compressor

In case of liquid ring vacuum pump and compressor, specific checks have to be done before the starting:

- Check if the piping system has been flushed of any foreign particles, welding or impurities.
- Check if all piping and pump obstruction have been removed.

- All connections and piping have to be leak proof, ensure there are no external forces or moments applied to the piping or pump flanges.
- Check if pump and motor are properly lubricated.
- Check pump/motor, compressor/motor alignment.
- Mechanical seal flushing line has to be connected where required.
- All valves in the installation are in the correct position.
- Check all safety guards are in place.
- Pump direction of rotation has to be checked by jogging the motor.
- Check if the pump stop switch is clear and visible.

8.2. Start-up guide

In this section, instructions to be followed during the first start-up after revamping implementations are listed.

- First, air test is done in compressors in order to ensure property functioning of equipment. Afterwards, VCM start-up takes place.
- It has to be mentioned that before the start-up of vent, strippers or BDT line, tower water entrance in heat exchanger E-0136 with valve BWN4'' has to be opened.

8.2.1. Start-up of vent line

Air test of C-0112:

1. Fill up separator S-0124 with process water up until 50% level. Level control LC-5061 in separator has to be set in automatic mode.
2. Open tower water inlet (valve BWD6'') to heat exchanger E-0134.
3. Line up manual valves.
4. Run compressor C-0112 using air to check its functioning.

5. Close entrance and exit air.

Air test of C-0113A:

1. Fill up separator S-0125A with process water up until 50% level. Level control LC-5068 in separator has to be set in automatic mode.
2. Open tower water inlet (valve BWI6'') to heat exchanger E-0135A.
3. Line up manual valves.
4. Run compressor C-0113A using air to check its functioning.
5. Close entrance and exit air.

VCM startup:

1. Open manual valve CV-5050.
2. Pressure control PC-5051 in holding tank TK-0154A has to be set in automatic mode.
3. Suction pressure controller PC-5055 set in manual mode, plus, 100% valve overture PV-5055.
4. Open manual valve CV-5054.
5. Run compressor C-0112.
6. Suction pressure controller PC-5055 set in automatic mode.
7. Suction pressure controller PC-5063 set in manual mode, plus, 100% valve overture PV-5063.
8. Open manual valve CV-5062.
9. Run compressor C-0113A.
10. Suction pressure controller PC-5063 set in automatic mode.
11. When pressure indicator PI-5066 displays a value pressure equals or higher than Set Point in pressure controller PC-5099 open CV-5069 and CV-5098.

8.2.2. Startup of BDT line

Air test of C-0113B:

1. Fill up separator S-0125B with process water up until 50% level. Level control LC-5081 in separator has to be set in automatic mode.
2. Open tower water inlet (valve BWP6'') to heat exchanger E-0135B.
3. Line up manual valves.
4. Run compressor C-0113B using air to check its functioning.
5. Close entrance and exit air.

VCM startup:

1. Open valve CV-5070.
2. Pressure control PC-5071 in holding tank TK-0154B has to be set in automatic mode.
3. Suction pressure controller PC-5075 set in manual mode, plus, 100% valve overture PV-5075.
4. Open manual valve CV-5074.
5. Run compressor C-0113B.
6. Suction pressure controller PC-5075 set in automatic mode
7. When pressure indicator PI-5079 displays a value pressure equals or higher than Set Point in pressure controller PC-5099 open CV-5082 and CV-5098.

8.2.3. Startup of strippers line

Air test of C-0113C:

1. Fill up separator S-0125C with process water up until 50% level. Level control LC-5094 in separator has to be set in automatic mode.
2. Open tower water inlet (valve BWX6'') to heat exchanger E-0135C.
3. Line up manual valves.

4. Run compressor C-0113C using air to check its functioning.
5. Close entrance and exit air.

VCM startup:

1. Open manual valve CV-5083.
2. Pressure control PC-5084 in holding tank TK-0154C has to be set in automatic mode.
3. Suction pressure controller PC-5088 set in manual mode, plus, 100% valve overture PV-5088.
4. Open manual valve CV-5087
5. Run compressor C-0113C
6. Suction pressure controller PC-5088 set in automatic mode
7. When pressure indicator PI-5092 displays a value pressure equals or higher than Set Point in pressure controller PC-5099 open CV-5095 and CV-5098.

8.2.4. Startup of liquid ring compressor and vacuum pump

In this section the step "run compressor/pump" mentioned earlier in 8.2.1, 8.2.2 and 8.2.3 is explained with further details. Steps to be followed are:

1. Verify that the electrical power to the equipment is off.
2. Check the drive coupling alignment. Adjust the driver if necessary. On monoblock units, the alignment is preset, along with the coupling gap.
3. Check the drive coupling hub spacing. The flexible element should be allowed approximately 1/16" of free axial movement. Adjust if necessary. Tighten set screws.
4. Rotate the pump/compressor by hand to ensure that it turns freely. During the time between manufacture and start-up, a slight film of rust may form on the portplates, causing the pump to be hard to turn. If this is the case, fill the pump/compressor with a rust inhibitor and wait until it can be turned by hand.
5. Drain the pump/compressor.

8.3. Shut down guide

Following the listed steps below, plant stops without incidents. Once all steps have been followed, it is necessary to open drains of main equipment and evacuate liquid to waste water treatment.

8.3.1. Shut down of vent line

1. Stop compressor C-0113A.
2. When pressure indicator PI-5066 displays a value pressure equals to controller PI-5099 close CV-5062, CV-5098 and CV-5069.
3. Suction pressure controller PC-5063 set in manual mode, plus, 100% valve overture PV-5063.
4. Stop compressor C-0112.
5. Close CV-5054.
6. Pressure control PC-5051 in holding tank TK-0154A has to be set in manual mode. Valve overture PV-5051 has to be set at 0%.
7. Close valve CV-5050.
8. Close tower water supply.

8.3.2. Shut down of BDT line

1. Stop compressor C-0113B.
2. When pressure indicator PI-5079 displays a value pressure equals to controller PI-5099 close CV-5082, CV-5098 and CV-5074.
3. Suction pressure controller PC-5075 set in manual mode, plus, 100% valve overture PV-5075.
4. Pressure control PC-5071 in holding tank TK-0154B has to be set in manual mode. Valve overture PV-5084 has to be set at 0%.

5. Close valve CV-5070.
6. Close tower water supply.

8.3.3. <u>Shut down of strippers line</u>

1. Stop compressor C-0113C.
2. When pressure indicator PI-5092 displays a value pressure equals to controller PI-5099 close CV-5095, CV-5098 and CV-5087.
3. Suction pressure controller PC-5088 set in manual mode, plus, 100% valve overture PV-5088.
4. Pressure control PC-5084 in holding tank TK-0154C has to be set in manual mode. Valve overture has to be set at 0%.
5. Close valve CV-5083.
6. Close tower water supply.

8.4. <u>Emergency shut down</u>

Should the pump break down leak gas and/or service liquid, immediately disconnect the electrical power following the instructions given:

1. Close, if applicable, the cooling water to the water heat exchanger.
2. Turn off the power to the circulating pump.
3. Where possible, gradually decrease the vacuum level.
4. Turn off motor, radiator and any accessories and flushing circuitry.
5. Make sure the non-return valves, or similar, at suction and discharge lines are leak tight. Should the system be idle for an extended period of time it is recommended to disconnect the electricity to the motor panel, drain all liquids from pump, separator and piping.

Alert the maintenance personnel, at least two people should interfere using precautions, as it is required for the specific installation: pump may be handling dangerous and/or hazardous fluids.

After correction of all the problems that created the emergency situation, it is necessary to carry out all the recommended starting procedures.

8.5. Steady state

In this section, steady state operation of the recovery unit and more specifically of the liquid ring compressor and vacuum pump is provided.

8.5.1. Recovery unit steady state

In steady state, plant operates automatically; set points fixed in lines are showed in the following tables.

Table 8.5.1. Set point values in vent line.

Vent line								
Controller	PC 5051	LC-5053	PC 5055	TCV 5058	LC 5061	PC 5063	TCV 5065	LC 5068
Set Point	1,00 bar	0,50 bar	0,50 bar	36,0ºC	50,0%	1,00 bar	36,0ºC	50,0%

Table 8.5.2. Set point values in BDT line.

BDT line					
Controller	PC 5071	LC-5073	PC 5075	TCV 5078	LC 5081
Set point	1,00 bar	1,00 bar	1,00 bar	36,0ºC	50,0%

Table 8.5.3. Set point values in strippers line.

Strippers line						
Controller	PC 5084	LC-5086	PC 5088	TCV 5058	LC 5094	TCV 5097
Set Point	1,00 bar	1,00 bar	1,00 bar	36,0ºC	50,0%	36,0ºC

Table 8.5.4. Set point values in storage line.

Storage line		
Controller	PC 5100	TC 5097

Set Point	5,5 bar	36ºC

8.5.2. Liquid ring compressor and vacuum pump steady state operation

Once the steady state is reached, the following items must be checked for proper liquid ring compressor and vacuum pump.

- The vacuum level is as desired or adjust the flow-regulating valve to the required vacuum flow and temperature of service liquid and/or cooling liquid are as expected (within 25% tolerance).
- Motor does not draw more amperage than shown on its nameplate.
- The pump-motor assembly does not have abnormal vibrations and noises such as cavitation.
- The operating temperature at full load does not exceed approximately 85°C.
- There are no leaks from mechanical seals, joints and flushing or cooling liquid lines.
- Liquid level in separator is between the minimum and the maximum.

During steady state operation, operation problems might come up. Table 8.5.5. provides solutions of most frequent experienced problems. Solutions for each of them are described.

Table 8.5.5. Causes and solutions for improper operation.

Num.	Causes	Solutions
1.	Defective motor or wired wrong	Check the voltage, the frequency, motor type, wired wrong power consumption, rotation, wiring connections, phase consistency.
2.	Leakage in suction piping	Repair piping; check valves for leakage
3.	Service liquid high temperature	Lower the service liquid temperature; temperature check the level of the service liquid; adjust the cooling liquid flow; adjust the radiator thermostat to lower temperature setting.
4.	Low service liquid flow	Increase the service liquid flow.
5.	Coupling misalignment	Re-align the coupling and the pump/motor assembly.

6.	Faulty bearing	Replace the bearing.
7.	Cavitation	Open the anti-cavitation valve or set the relief valve to a lower vacuum.
8.	High service liquid flow	Reduce the service liquid flow; adjust the bypass valve.
9.	High back pressure	Check the discharge line for obstructions or high friction losses; reduce the back-pressure to maximum 0.1 bar.
10.	Wrong pump/motor assembly	Verify that the base surface is level and that all pump feet are resting on the surface, add spacers if required.
11.	Wrong pump mounting	Remount the pump.
12.	Piping weight resting on pump	Support the piping with hangers or other means.
13.	Inadequate seal lubrication	Check flushing liquid temperature, flow and pressure.
14.	Mineral deposits from hard water	Clean the pump.
15.	Foreign particles in pump	Disassemble the pump to remove the foreign objects.
16.	Low suction pressure	Open the vacuum regulating valve and/or the anti-cavitation valve.
17.	Wrong pump rotation	Reverse the rotation.
18.	Bad gaskets	Replace the defective gaskets.
19.	Wrong motor connections	Check the electrical connections (connectors, fuses, breakers) and the power supply line.
20.	Pump seized	Disassemble and repair the pump.
21.	Pump undersized	Select a pump with higher capacity.
22.	Pump worn-out	Disassemble and repair the pump.
23.	Excessive liquid flow through suction line	Reduce the liquid flow through the pump suction; install a centrifugal separator (cyclone) before the pump.
24.	Instrumentation out of calibration	Check the working characteristics, replace if required.

9. ECONOMIC STUDY

The economic study of a chemical plan has a crucial importance since it let investors know whether the plan is economically viable or not.

9.1. Purchased equipment cost

In order to determine capital cost, equipment prices have to be determined. From bibliography[2], all the equipment prices have been found and, therefore, the purchased equipment cost.

Prices found are from year 2007 and so, due to the inflation, equation 9.1.1 has been used in order to know their current value in 2012.

$$\frac{C_{2012}}{C_{2007}} = \frac{CEPI_{2012}}{CEPI_{2007}} \quad (9.1.1)$$

Term CEPI is the Cost index[3] from each year respectively.

In table 9.1.1. index costs for years 2007 and 2012 can observed.

Table 9.1.1. Index costs.

Year	Index	Purchased cost (M$)
2007	525,4	364,7
2012	592,8	411,5

Finally, euro dollar exchanger index of 1,315€/$4 has been used to figure out the capital investment in euros. The value obtained is 312,5 M€.

9.2. Total installation cost

In order to determine total installation cost, 10% of total capital cost has been considered due to instrumentation.

Table 9.2.1 displays costs considered in determining total cost installation.

[2] http://www.matche.com/EquipCost/Index.htm
[3] Chemical Engineering Review, April 2012.
[4] Money exchange rate consulted the 3rd of May 2012.

Table 9.2.1. Index costs.

Cost	M€
CAF	144.39
DC	488.18
IC	141.57
Unforeseen	88.16
SE	300
TCI	**717.9**

CAF (cost adjustment factor) has been obtained using values displayed in table 9.2.2. Due to the fact that it is not new design but a revamping, adjustment factors regarding installation modification have to be considered.

Table 9.2.2. Adjustment factors.

Item	Comment	Factor
Basic equipment installation	Medium	7,0%
Foundations and structures	Medium alloy	3,0%
Pipes	Low	6,0%
Isolation	Low	3,0%
Electricity and light	Medium-Chemical plan	2,0%
Instrumentation	Medium	8,0%
Non counted	Simple process	1,0%
Buildings	Exterior equipment	12,0%

9.3. Manufacturing costs

The aim of this project is to revamp VCM recovery unit as a part of a PVC production plan. In order to determine the manufacturing cost, no incomes can be considered since VCM is not sold but it is being recirculated to the entrance of PVC process. However, substantial savings as a result of production increase after revamping have been considered as income. Current service plant factor has been considered to be 0,91 in comparison with the service plant factor before revamping of 0,9.

Savings in production fix cost and electricity expenses have been calculated. Annex 2 shows procedures followed. In table 9.3.1 and 9.3.2 savings are showed.

Table 9.3.1. Fix cost savings annually.

Annual production (tn/yr)	Fix cost (€/tn)	Savings (€/yr)
165000	160 €/tn	293333,3
166833,67	158,2€/tn	

Table 9.3.2. Electricity savings annually.

Consumption savings (kWh)	Consumption a year(kWh)	Price (€)	Cost (€)
5,21	869,201	0,06	52152,1

No other variables have been considered during the EBIT, since the differences between VCM unit before and after the revamping have little impact on such variables.

9.4. Project viability

9.4.1. Cash flow

Plan cash flow can be determined from the EBIT amortization and capital investment. It must be pointed out the 15 years study period considered in this calculation. Data necessary to determine cash flow is displayed in table 9.4.1.

Table 9.4.1. Cash Flow data.

EBIT	EAT (M€)	Amortization (M€)	Taxes (M€)
345485	102792	51791	35%

9.4.2. IRR

Using equation 9.1.2, VAN is determined and therefore, the year when the plan will actually get profits, or in other words, when will the initial investment be recuperated.

$$\mathrm{NPV} = -\mathrm{I}_0 + \sum_{i=1}^{n} \frac{\mathrm{CF}_i}{(1+k)^i} \qquad (9.4.1)$$

IRR is defined as the interest that makes the NPV value 0. In this case, it has been found to be 33,8%. It can be concluded that the project revamping of the recovery unit is viable due to short return period and relatively high interest rates.

In figure 9.4.1 evolution of the accumulated cash flow is illustrated. It can be appreciate the year when recovery unit begins to generate profits.

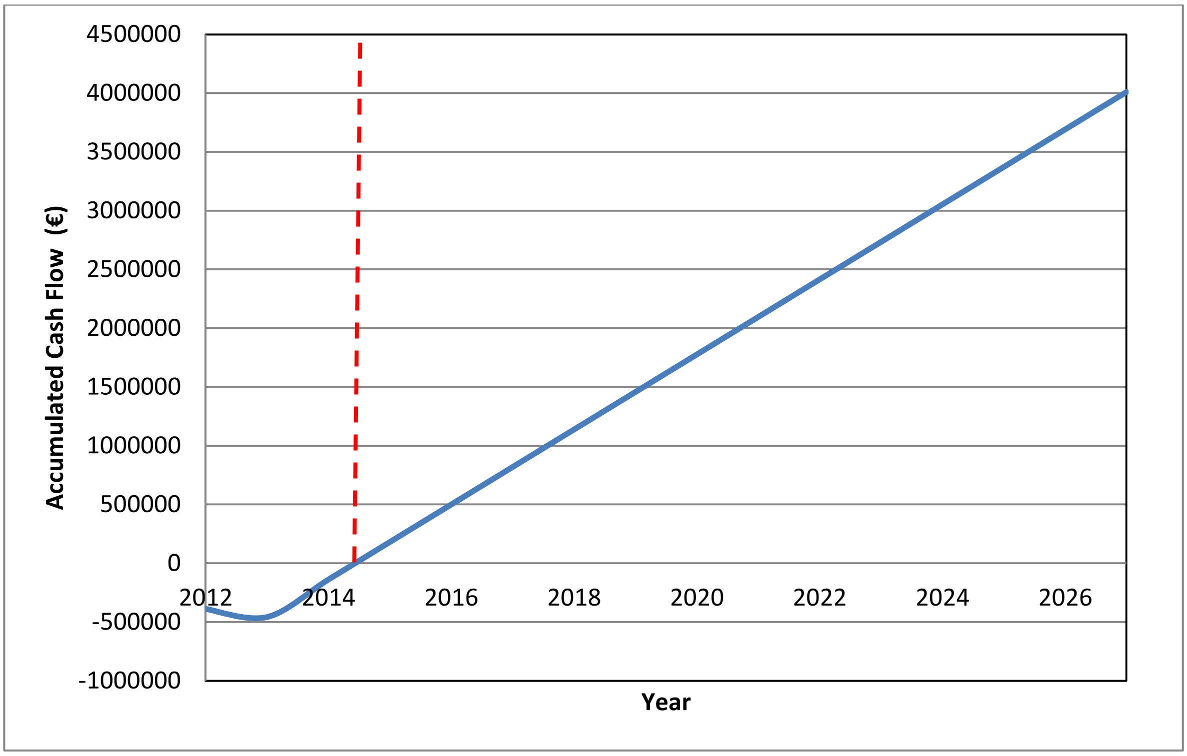

Figure 9.4.1. Evolution of accumulated cash flow.

Payback period for the given investment, which is the length of time required to recover the cost of investment, has been calculated using equation 9.4.2

$$\text{PaybackPeriod} = \frac{I_0}{CF} \quad (9.4.2)$$

In VCM revamping, is going to be of 3,2 years.

9.5. Sensitivity analysis

In this section, sensitivity analysis to investigate the robustness of the economic study has been done. By reporting extensive outputs from sensitivity analysis, investors, are able to consider different scenarios and, as such, can increase the level of confidence in the project.

Different production increase due to revamping improvement has been considered to make the sensitive analysis.

In table 9.5.1 production increase regarding service plan factor can be observed as well as project returns and payback period.

Table 9.5.1. Sensitivity analysis results.

PSF	Production (tn/yr)	TIR	Payback period
0,91	166833	33,8%	3,2
0,913	167566	44,5%	2,56
0,914	167566,3	48,1%	2,4

Little increase in plant service factor implies high return rates and a considerable payback period. Figure 9.5.1 illustrates such conclusion.

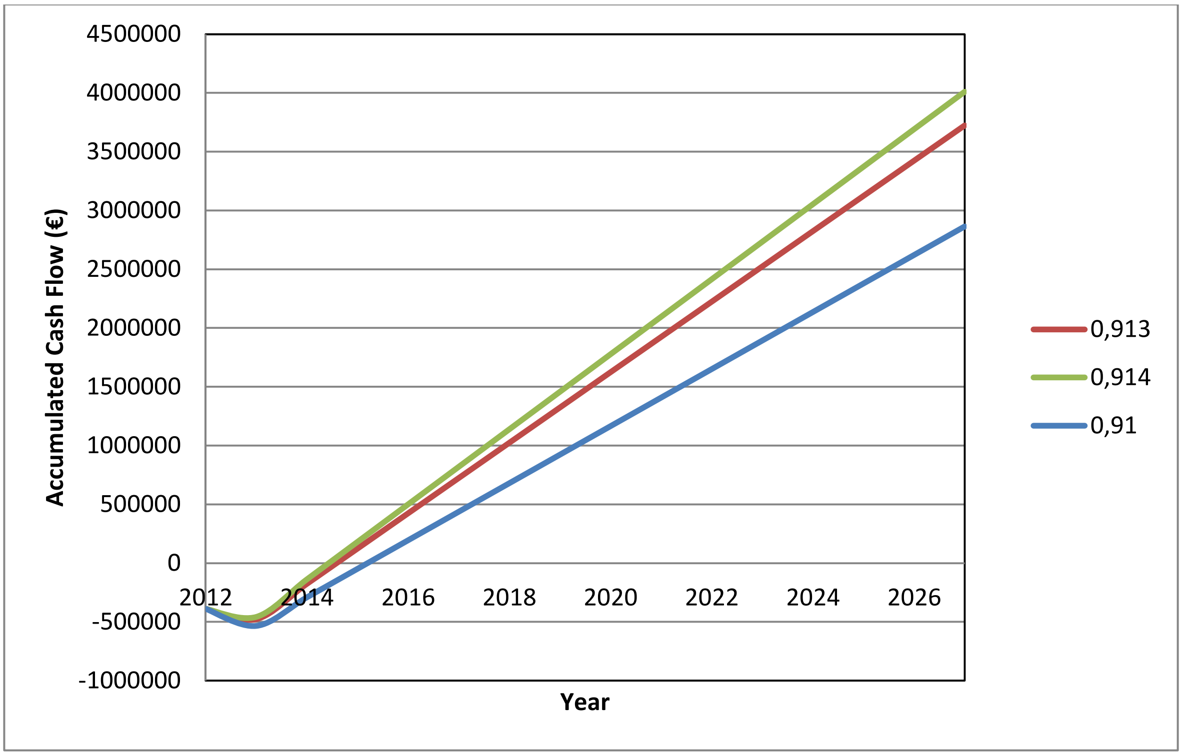

Figure 9.5.1. Sensitivity analysis.

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APPENDIX

1. EQUIPMENT DESIGN

1.1. Heat exchanger design

In order to select the heat exchanger configuration, different factors have to be considered. The dirtiest product is always inside the tubes while the cleanest is in shell. The reason Is because tubes are easier to clean rather than the shell.

- Corrosive fluids are inside tubes for same reason.
- Pressurized fluid is inside the tubes. Tubes are more resistant than shell.
- Aspects that have to be mentioned in heat exchangers design showed in this section:
- In case of the condenser, subcooling of 3ºC has been supposed due to the tubes inundation.

1.1.1. Kern's method

Kern's Method that has been followed to design the heat exchangers. Steps to follow during the heat exchanger design are explained in this section.

First, heat exchange is calculate in the desired conditions.

$$q = m_{hot} \cdot Cp_{hot} \cdot (T_{in,hot} - T_{out,hot}) = m_{cold} \cdot Cp_{cold} \cdot (T_{out,cold} - T_{out,cold}) \qquad (1.1.1)$$

Because it is unknown, calculations begin supposing a global transfer coefficient (U0).

By supposing U0, heat transfer area is easy calculated using equation 1.1.2.

$$A = \frac{Q}{U_o \cdot \Delta T_{LM}} \qquad (1.1.2)$$

Ft factor has to be calculated for correction temperature eq. 1.1.3

$$\Delta T = \Delta T_{LM} \cdot F_T \qquad (1.1.3)$$

Tube side design

Select the tube, diameter, wall thickness, intern diameter and length.

Calculate the tub number of heat exchanger using Area calculated previously and the tube area (a'). Eq (1.1.4).

$$N_T = \frac{A}{L_T \cdot a'} \quad (1.1.4)$$

Once tubes number is determined, tube pass area and velocity in tubes be calculated.

$$a_{pT} = \frac{N_T \cdot a''}{n} \quad (1.1.5)$$

$$V = \frac{m}{\rho \cdot a_{pT}} \quad (1.1.6)$$

Using Reynolds, Prandal correlations as well as Nusselt correlation for turbulent fluids, intern heat coefficient can be determined.

$$h_i = \frac{Nu \cdot k}{D_i} \quad (1.1.7)$$

$$h_{io} = h_i \frac{D_i}{D_o} \quad (1.1.8)$$

Losses in tubes

Finally, losses in tubes due to friction as well as passes changes can be calculated (eq 1.1.9 and 1.1.10).

$$\Delta P_T = f \cdot \frac{L_T \cdot n}{D_i \cdot \left({}^{\mu}/_{\mu_w}\right)^{0.14}} \cdot \frac{\rho \cdot v^2}{2} \quad (1.1.9)$$

$$\Delta P_r = 4 \cdot n \cdot \frac{\rho \cdot v^2}{2} \quad (1.1.10)$$

Shell side design

First, shell side spacing has to be calculated in order to know the pass area in shell side (eq 1.1.11 and 1.1.12).

$$B = \frac{DI}{Z} \quad (1.1.11)$$

$$a_{pC} = \frac{DI \cdot c \cdot B}{P_T} \quad (1.1.12)$$

Once shell area has been determined, velocity in shell side can be calculated using equation 1.1.13.

$$v = \frac{m}{\rho \cdot a_{pC}} \tag{1.1.13}$$

Using Reynolds and Prandal correlations, Kern's Nusselt correlation can be used so that heat transfer coefficient can be determined using equation 1.1.14.

$$h_o = \frac{Nu \cdot k}{D_H} \tag{1.1.14}$$

Wall Temperature

$$q = h_{io} \cdot (t - T_w) = h_o \cdot (T_w - t) \tag{1.1.15}$$

Losses in Shell

$$\Delta P_C = 4 \cdot f \cdot \frac{DI \cdot (N + 1)}{D_H \cdot \left({}^{\mu}/_{\mu_w}\right)^{0,14}} \cdot \frac{\rho \cdot v^2}{2} \tag{1.1.16}$$

Finally, overall clean heat transfer coefficient calculated using equation x.x. and the individual heat transfer coefficient of inside and outside tubes

$$\frac{1}{U_L} = \frac{1}{h_{io}} + \frac{1}{h_o} \tag{1.1.17}$$

Using fouling factors, overall service heat transfer coefficient can be determined.

$$\frac{1}{U_S} = \frac{1}{U_L} + R''_{fc} + R''_{ff} \tag{1.1.18}$$

Eventually, transfer area is recalculated and compared to the previous supposed area. If the difference between suppositions and new calculations is no higher than 15% then the design is correct.

$$A_r = \frac{q}{U_S \cdot \Delta T} \tag{1.1.19}$$

1.2. Vessel design

1.2.1. Shell vessel design

In table 1.2.1 vessels in the VCM process that only need a shell to be save, are shown.

Table 1.2.1. Operating conditions.

Line	Vessel	P (bar)	T (ºC)
BDT	TK-0154B	1	70
VENT	TK-0154A	1	70
	S-0124	1	43
STRIPPERS	TK-0154C	1	70

Such vessels have been designed knowing the tensional state that the vessel is submitted. Equation 1.2.1 is for the cylindrical part while equation 1.2.2 is for the ellipsoidal head.

$$\sigma = \frac{pr}{t} \tag{1.2.1}$$

$$\sigma = \frac{pr}{2 \cdot t} \tag{1.2.2}$$

The term p has been calculated using the ratio between the vessel pressure and the area of a cylinder or an ellipsoid depending on the part of the vessel designed.

Knowing the admissible tension that the material chosen (SA-516) and the pressure at which the tank has to be designed, using equations 1.2.1 and 1.2.2 shell thickens it is then trivial to calculate.

1.2.2. Pressurized vessels

In table 1.2.2 vessels in the VCM process that will be designed following the ASME code are showed.

Table 1.2.2. Operation conditions

Line	Vessel	P (bar)	T (ºC)
BDT	S-0125B	7	56
VENT	S-0125A	7	56

Line	Vessel	P (bar)	T (ºC)
STRIPPERS	S-0125C	7	56
STORAGE	TK-0135	5	36

First of all, pressure and temperature design will be calculated using equations 1.2.3 and 1.2.4.

$$P_d = P_t + 1\text{bar} \quad (1.2.3)$$

$$T_d = T_t + 20\text{ºC} \quad (1.2.4)$$

After doing such calculations, admissible tension can be known using the values obtained in ASME section 8 division II. Thickness of cylinder and ellipsoidal head and bottom is calculated using equations (1.2.5) and (1.2.6)

$$t = \frac{P \cdot D}{2 \cdot S \cdot E - 0{,}2 \cdot P} \quad (1.2.5)$$

$$t = \frac{P \cdot D}{S \cdot E - 0{,}6 \cdot P} \quad (1.2.6)$$

2. ECONOMIC BALANCE

2.1. Purchased cost estimating

In table 2.1.1 specific equipment cost used during the purchased equipment cost calculations are showed.

Table 2.1.1. Equipment cost

		M$ 2007	M$ 2012	M€ 2012
BDT	**Holding tank**	25,30	28,54	21,68
	Separator	7,500	8,462	6,427
	Liquid ring compressor	20,00	22,56	17,13
	HE	25,30	28,54	21,68
VENT	**Vacuum pump**	33,70	38,02	28,88
	Holding tank	18,70	21,09	16,02
	Separator	6,100	6,882	5,227
	HE	13,00	14,66	11,14
	Storage tank	32,20	36,33	27,59
	Condenser	26,70	30,12	22,88

2.2. Total installation cost

Considering 10% cost of instrumentation of the total purchased cost, and adding such quantity to the already known purchased cost, 343794M€ is obtained as Basic equipment cost (BEC).

For VCM recovery unit operation, 42% adjustment factor has been calculated.

Direct Cost (DC) has been determined using equations 2.1.1.

$$\mathrm{DC} = \mathrm{CF} + \mathrm{BEC} \qquad (2.2.1)$$

Indirect Costs (IC) are calculated as the 29% of the Direct Costs.

Eventually, using equation 2.2.2 total installation cost has been calculated.

$$\mathrm{TIC} = \mathrm{DC} + \mathrm{IC} + \mathrm{SE} \qquad (2.2.2)$$

Being SE (startup expenses) the 14% of the total amount of DC and IC.

Table 2.2.1 displays results.

Table 2.2.1. Values of total installation cost.

	CEP	PID	CEB	CF	CI	CD	GPM	CTI
€	312.540	31.254	343.794	144.394	141.574	488.188	300	717.929

2.3. Manufacturing cost

In this section, procedure to calculate VCM recovery unit savings is explained.

Initially, service factor of 0,9 has been considered, after the revamping, it is considered that plant service factor increases up until 0,91.

It must be pointed out that from 1000€/tn of production cost, 160€/tn are fix costs and 840€/tn are variable costs. Knowing the annual production of 165000tn/year, it is then trivial the 26,40·106€/yr value of fix costs obtained.

If production is increased up until 167383,33tn/yr and taking into account that the 26,4·106€/year value of fix costs will not change, it is then known the new fix cost per tone produced 158,2€/tn. Table 2.3.1 results are displayed.

Table 2.3.1. Manufacturing cost data.

Annual production (tn/yr)	Fix cost (€/tn)	Fix cost (€/yr)	Savings (€/tn)	Savings (€/yr)
165000	160 €/tn	$26{,}40\cdot10^{6}$	1,75	293333,3
167383,33	158,2€/tn	$26{,}40\cdot10^{6}$		

2.4. Project rendibility

2.4.1. Cash flow

Cash flow is calculated using equation 2.4.1.

$$\mathrm{CF} = \mathrm{CI} - \mathrm{Taxes} - \mathrm{EBIT} \quad (2.4.1)$$

Table 2.4.1 displays the values used during cash flow calculations of three different scenarios explained in sensitivity analysis section.

Table 2.4.1. Different scenarios considered.

Scenario	Plant service factor (PSF)	EBIT (€)	Income (€)	Cash flow (€)
1	0,91	102792,8	345485	242693
2	0,913	433657	381333	300004
3	0,914	463048	410667	143939,7

2.5. Sensitivity analysis

During the sensitive analysis, same procedure as the one explained in section 2.1 has been followed. In tables 2.5.1 and 2.5.2 results for different plant service factor are showed.

Table 2.5.1. Results for plant service factor of 0,913

Annual production (tn/yr)	Fix cost (€/tn)	Fix cost (€/yr)	Savings (€/tn)	Savings (€/yr)
165000	160 €/tn	26400	2,27	381333,3
167383,33	157,72€/tn	26400		

Table 2.5.2. Results for plant service factor of 0,914

Annual production (tn/yr)	Fix cost (€/tn)	Fix cost (€/yr)	Savings (€/tn)	Savings (€/yr)
165000	160 €/tn	26400	2,45	410666,67
167566,67	157,54€/tn	26400		

3. MATERIAL SAFETY DATA SHEET (MSDS)

MATERIAL SAFETY DATA SHEET		
VINYL CHLORIDE Monochloroethylene, chloroethylene, chloroethene, monochloroethene, Ethylene monochloride, vinyl chlorideM	C_2H_3CL CH_2=CHCL	CAS Nº: 75-01-4 EC N° (EINECS) : 200-831-0 Index N°: 602-023-00-7 UN N°: 1086 Class: 2

First aid data	
Airborne poisoning: Go outdoors, breathe oxygen or have artificial respiration if needed, admit to hospital, place under neurological and liver surveillance. Skin contact: Rinse with a lot of water (warm if possible). Frostbite must be treated as thermal burns.	Eye contact: Rinse with a lot of water for a few minutes, remove contact lenses and see an eye specialist if needed. Do not treat with catecholamines

Fisical data

Relative density (water=1):	0,9121
Relative vapour density(air=1):	2,15
Solubility in freshwater:	1,100 mg/litre at 25°C
Vapour pressure/tension:	340 kPa at 20°C
Olfactory threshold: airborne:	260 to 3,000 ppm
Diffusion coefficient in water:	1,2·10-6 cm2/s at 25°C
Diffusion coefficient in air:	0,106 cm2/s at 25°C
Henry's law constant:	2.73.103 Pa.m3/mol at 25°C
Flash point:	- 78°C
Melting point:	- 153.7°C
Boiling point:	- 13.9°C

T: Toxic F+: Highly flammable

R45 – Can cause cancer.

R12 – Highly flammable.

S45 – In the event of accident or discomfort see a doctor immediately (show him the label if possible).

S53 - Avoid exposure, get special instructions prior to use.

200-831-0 – EC labelling.

Toxicological data

TLV-TWA:	1 ppm (2.6 mg/m3)
VME:	1 ppm (2.6 mg/m3)
MRL inh. (acute exposure):	0.5 ppm (1.3 mg/m3)
MRL inh. (sub acute exposure):	0.03 ppm (0.078 mg/m3)
TEEL 0:	1 ppm (2.6 mg/m3)
TEEL 1:	5 ppm (13 mg/m3)
TEEL 2:	5 ppm (13 mg/m3)
TEEL 3:	75 ppm (195 mg/m3)

Toxicological data (2)
Specific effect
Carcinogenic effects: objectivated, group C1.
Genotoxic effects: Globally toxic.
Effects on fertility: not demonstrated.
Teratogenic effects: unconfirmed.
Mutagenic effects: yes.
Acute human toxicity
Skin contact: irritational lesions and frostbite.
Eye contact: reversible corneal impairment.
Airways (main route): moderate irritation of the bronchial tube. Narcotic effects, depression of central nervous system, dizziness, disorientation, drowsiness, loss of consciousness, death if exposure persists.
Chronic human toxicity
Trophic impairment of skin and bone involving bone destruction of the fingers (other bones also), Raynaud's syndrome and a kind of skin sclerosis (in the event of massive exposure).
Digestive effects: abdominal discomfort, nausea, anorexia, hepatomegaly, and often splenomegaly. Liver impairment comprises initial cytolysis then fibrosis and cirrhosis.
Impairment of blood cell lines.
Impaired breathing.
Peripheral neuropathy.

Ecotoxicological data	
Acute ecotoxicity	
Bacteria (Pseudomonas putida):	CE5 (16h) > 135 mg/L
Bacteria (anaerobic):	CI50 (3.5 days)=40 mg/L
Seaweed (Scenesdesmus quadricauda):	CL3 (8 days)=710 mg/L
Fish (Brachydanio rerio):	CL50(96h) = 210 mg/L
Micro-crustaceans (Daphnia magna): value estimated by TGD	CE50(48h) = 103 mg/L
Chronic ecotoxicity	
PNEC: no data	

Persistence in the environment
Abiotic degradation: Vinyl chloride breaks down quickly in air as it reacts with hydroxyl radicals. Degradation products are hydrogen chloride and formaldehyde chloride.
Volatilisation: Vinyl chloride evaporates quickly from the water surface (half-life: a few hours) or from the soil (main route) Evaporation: half-life is 0.8hours.
Biodegradation
- Soil, aerobic and anaerobic degradation is usually slow.
- Water: non hydrolysable/ not easily biodegradable (16% after 18 days).
Anaerobic biodegradability in water : 80% after 4 weeks.
Standard European behaviour classification: G (Gas)
Octanol/water distribution coefficient: Kow log = 1.58

Persistence in the environment (2)	
Bio concentration factor, log BCF (aquatic organisms):	0.609
Organic carbon/water distribution coefficient, Koc = 8 to 98 litres/kg Mobile in soil and can reach the underground water table by percolation.	

Special risks

Polymerisation

Polymerises easily in sunshine, heat or catalysers: peroxides, ozone, persulfates. To offset this trend during storage and transportation add a small amount of polymerisation inhibitor, (ex: phenol derivative.)

Danger

- Risk of spontaneous increase in pressure or self-ignition by exposure: heat, light, shock or contact, other chemicals.

- If the recipient heats up, pressure will build up and the container may fail followed by an immediate release of flammable vapours accompanies by an explosion and a pressure wave (Uvinyl chlorideE).

- Gas is invisible and can enter sewage system, underground areas or closed premises.
- Heat may destroy the inhibitor.
- Contact the manufacturer.
- Can cause narcotic effects and cause loss of consciousness.

Fire

Explosion limit in % by volume in air: LEL: 4/ UEL: 22
Self-ignition temperature: 472°C
Flash point: - 78°C (in a closed beaker)
Fumes: toxic

Stability and reactivity

- Conditions to avoid:
Combined with water and high temperatures, it can corrode iron and even steel.
Keep away from heat and ignition sources.

- Materials to be avoided:
Oxidisers (exothermal polymerisation possible).
Explodes when in contact with: air.

- Decomposition products are dangerous:
At 450° C it generates acetylene.
If it burns: HCl, CO, CO_2, traces of carbonyl dichloride, phosgene.

- Other reactions:
It reacts with concentrate bases when warm and releases hydrogen chloride.
Reacts violently with oxidisers and metals (copper, aluminium).

Transport

General data:	UN N°: 1086 Class: 2 Labels: 2.1	Land transportation: RID/ADR danger ID N°: 239 Packaging group: - Classification code: 2F	ADN/ADNR danger ID number: 239 Substance ID N°: 1086 Identification code: 2F

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<tr><th colspan="2">Transport (2)</th></tr>
<tr><td colspan="2">Shipping and air freight :
IMDG/IATA packaging group : -</td></tr>
<tr><td colspan="2">Class: 2.1 Marine pollutant: NO
Labels: 2.1+C Forbidden in passenger planes</td></tr>
<tr><th>Manipulation</th><th>Stockage</th></tr>
<tr><td>- Provide ventilation and appropriate evacuation on board.
- Provide showers and eye washers.
- Have respirators available nearby.
- Prohibit all spark and ignition sources.
- Only use the product in a closed system.
- Avoid build-up of electrostatic charges.
- Only use explosion proof equipment.</td><td>Vinyl chloride is stored and transported in liquid form. It can be stored in a pressure vessel (at 3 bars usually) at ambient temperature and often between -10°C and 14°C at low pressure.
- Keep well away from ignition sources.
- Protect against heat. - Provide a dyke.
- Use only electric appliances that can operate in explosive atmospheres.</td></tr>
</table>