KX Low Temperature Digestion Preliminary Engineering

Robert Clegg[1], Laurent Guillaumont[2] and Fabrice Gamel[3]
1. Director of Projects
Sahl Regen, Dakar, Senegal
2. Technology Director
3. Director of Projects
Alteo, Gardanne, France
Corresponding author: rob.clegg@sahlregen.com
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Abstract

The patented KX heat exchanger, supplied by Sahl Regen, in combination with reduction of environmental heat losses, can reduce energy consumption at Alteo's Bayer process by 70% and reduce CO_2 footprint by 93%; as reported at the AQW conference in April 2024 [1]. Since then Alteo Gardanne and Sahl Regen have completed preliminary engineering with two equipment suppliers to improve the cost estimate of the project and establish how to conduct a pilot project to finalise design parameters, such as reboiler design heat transfer coefficient (HTC). This paper provides details on how Alteo and Sahl Regen scoped and delivered the preliminary engineering to replace the existing Digestion section with a new KX low temperature digestion (KX LTD) and reduce environmental heat losses.

Keywords: KX heat exchanger, Decarbonisation, Emissions, Energy, Environmental heat loss.

1. Introduction

The world is facing an existential challenge in climate change where humanity is currently generating more than 40 billion tonnes of carbon dioxide (CO_2) per year. The United Nations has set a goal to achieve Net Zero by 2050 [2–6]. Strategies to achieve this are to replace fossil fuels with renewable energy, or at least reduce CO_2 emissions complemented with CO_2 capture. The economic challenge to industry, and specifically the chemical industry, is the simple conversion to renewable energy has a high capital cost, and often increases operating cost; there is no return on investment. Sahl Regen is working on both how to reduce CO_2 emissions and capture CO_2. Sahl Regen's KX heat exchanger can assist the chemical industry in significantly reducing and replacing their thermal energy consumption with electrical energy. Thus, reducing CO_2 emissions and their operating costs. Now there is an attractive return on investment while contributing to Net Zero by 2050. Sahl Regen is also developing a complementary project in Senegal to capture CO_2 at scale.

Alteo Gardanne, the world's oldest operating alumina refinery, established 130 years ago, has decided to change its process in 2022 for environmental reasons linked to the storage of bauxite residue. The transformation of the plant involved adapting a part of the Bayer process to dissolve alumina hydrate and re-precipitate it in order to control the quality of its product alumina hydrate, the precursor of high-value commercial alumina. The energy crisis of 2022 and the France 2030 program encouraging manufacturers to reduce their carbon emissions have prompted the Gardanne plant to consider new technological solutions to reduce its gas consumption for steam production. This is how Alteo and Sahl Regen came to collaborate on the project to install Sahl Regen's KX heat exchangers in the plant's new process. Sahl Regen possesses access to the patented KX heat exchanger that can recover heat between scaling slurries with approach temperature less than zero degree centigrade (0 °C).

The Digestion section of the Bayer process currently recovers energy by flashing the digestion slurry to generate process steam which is then condensed to heat the incoming digestor feed, either just the spent liquor or the combined spent liquor and bauxite. This is a robust method to exchange heat between two streams in which at least one stream contains abrasive solids in a scaling liquor. The drawback is the generation of a temperature profile that often requires heating of the digestion slurry by more than 20 °C [7, 8]. An advantage of this method of heat recovery is the removal of water from the process to assist in maintaining the refinery's water balance; although there are alternatives that require considerably less energy.

In 2023, Sahl Regen and Alteo Gardanne completed Conceptual Engineering [1] that established how to:

- In Phase 1 – Reduce energy by 30 % and steam by over 40 %, by:
    - Replacing their existing Digestion with heat recovery by flash, with a KX low temperature digestion (KX LTD) with heat recovery with KX heat exchangers
    - Increasing the heat recovery capacity of their spent liquor / pregnant liquor plate heat exchangers
    - Add MVR evaporation to more than compensate for the loss of evaporation in Digestion, thus, enhancing a net positive water balance sufficient to satisfy future net zero solute emissions to the environment
    - Reducing conductive and evaporative heat losses.
- In Phase 2 – Reduce energy by 70 % and steam by 100 % by:
    - Recovering exothermic heat of precipitation with KX heat exchangers
    - Replacing the spent liquor / pregnant liquor plate heat exchangers with KX heat exchangers
    - Recovering low grade heat from calcination into spent liquor.

The next step was to conduct Preliminary Engineering for Phase 1 with equipment suppliers and design a pilot unit to finalise design parameters for the KX heat exchanger's condenser and reboiler. Sahl Regen developed for Preliminary Engineering PFDs for:

- KX LTD, see Figure 1
- MVR Evaporation, see Figure 2
- Spent Liquor / Pregnant Liquor Plate Heat Exchangers, see Figure 3.

2. KX Heat Exchanger

The KX Heat Exchanger is a combination of a condenser and reboiler with an optional vapour compressor between the two, filled with a heat transfer fluid that can be water or any other refrigerant appropriate for the operating temperature. The condenser can be arranged in a similar fashion to conventional tube digestors. The huge advantage of the KX Heat Exchanger is that it can recover heat at low and even negative approach temperatures. The approach temperature is the temperature difference available for heat transfer between an outgoing stream and its facing ingoing stream; a positive approach temperature is normally required to achieve heat recovery in a conventional heat exchanger.

3. Importance of Balancing Heat Input to Heat Loss from a Refinery

Although, as explained in our previous AQW paper [1] we can recover heat with the KX Heat exchanger to the point where we do not require any steam in Digestion. However, to achieve zero steam in Digestion we must reduce or eliminate net heat losses from the system or recover low grade heat loss from elsewhere in the refinery. Without any reduction of heat losses in the refinery then heat input to the refinery will not change.

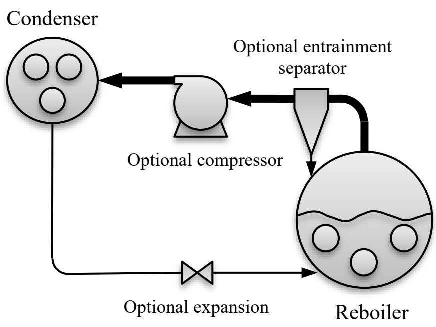

Figure 1. Example of a KX heat exchanger.

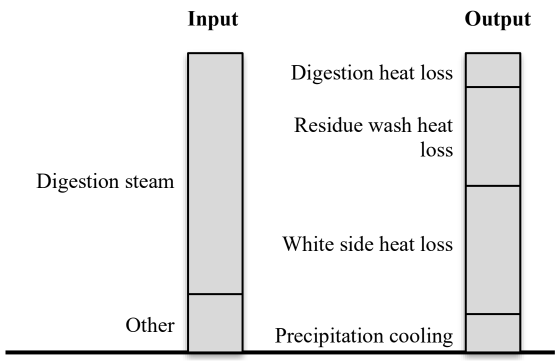

Figure 2. Indicative distribution of alumina refinery heat inputs and outputs.

Figure 3 is the PFD for KX LTD at Alteo Gardanne alumina refinery. It has two hydrate slurry feed tanks with injection of the strong feed liquor from the new MVR Evaporation section of the refinery into the suction of the KX LTD feed pumps. There is a live steam preheater KX LTD feed to ensure optimum temperature to the KX Heat Exchangers after extended refinery shutdowns or during exceedingly cold weather events. There are 6 KX units in series and three Digestion holding vessels to ensure complete dissolution of the hydrate. There is a by-pass arrangement to permit maintenance on any KX unit without shutting down KX LTD. The MVR evaporator condensate tank and distribution system is show on the lower half of this PFD.

Figure 4 is the PFD for the spent liquor tanks and MVR Evaporation section of Alteo Gardanne. Note that the MVR flowsheet is similar to that presented by GEA at the 2024 AQW conference in Dubai [9]. In the top left corner is a plate heat exchanger recovering waste heat from our cogeneration plant. The two plate heat exchangers to the left of the falling film evaporator ensures that the evaporator can operate at a temperature independent of the spent liquor feed temperature.

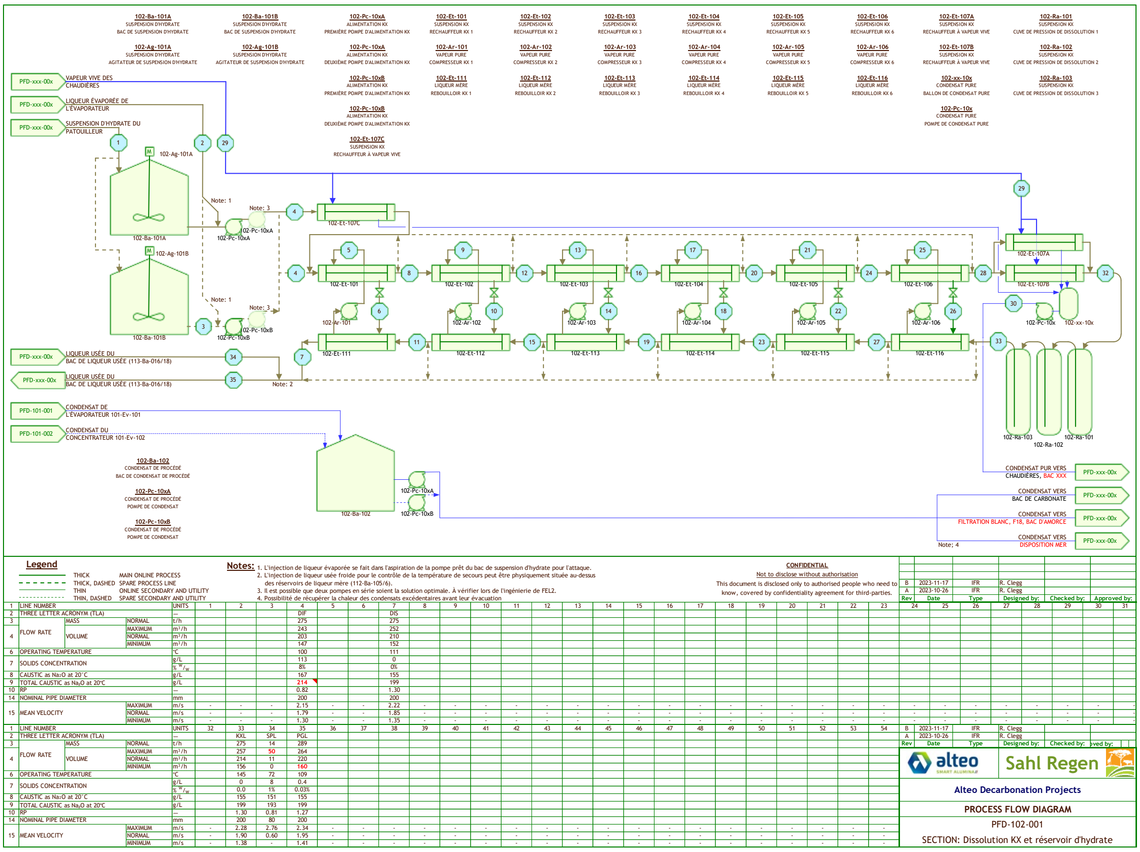

Figure 3. KX LTD PFD for Alteo Gardanne.

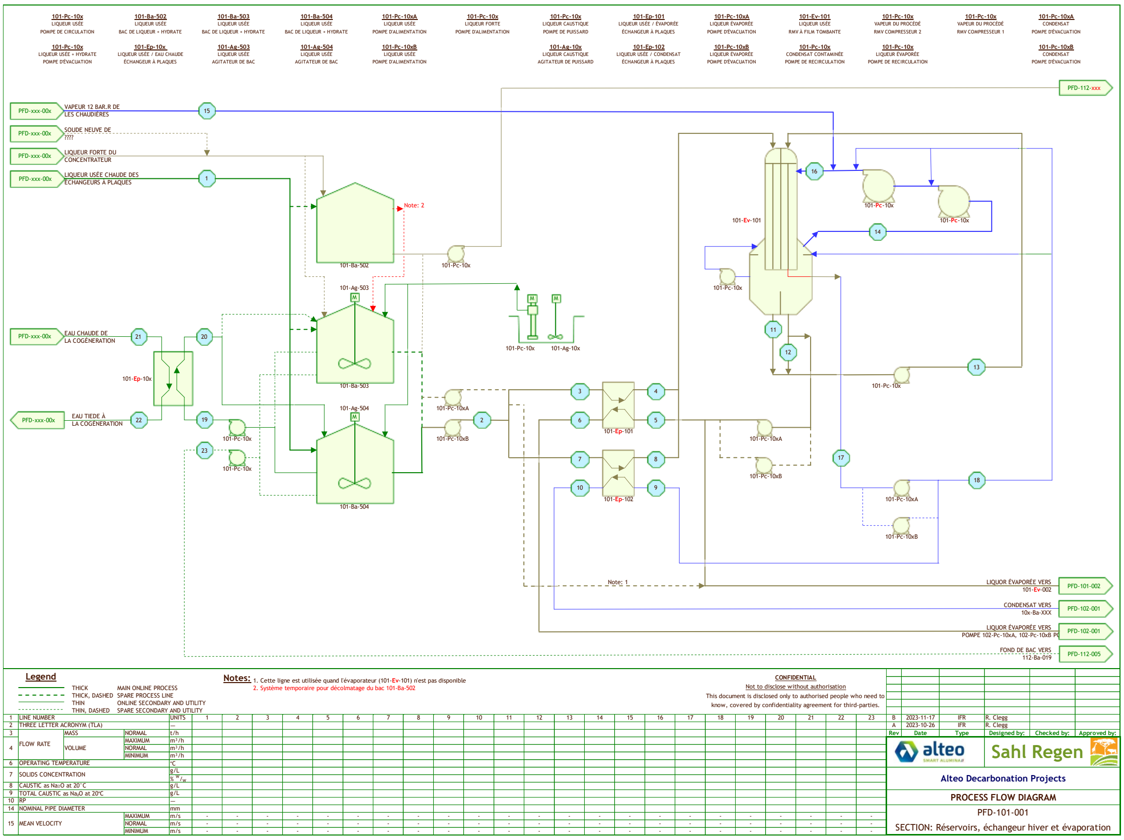

Figure 4. MVR evaporation PFD for Alteo Gardanne.

Figure 5 is the PFD for the addition of supplementary spent liquor / pregnant liquor plate heat exchangers required for the specific requirements of Alteo Gardanne.

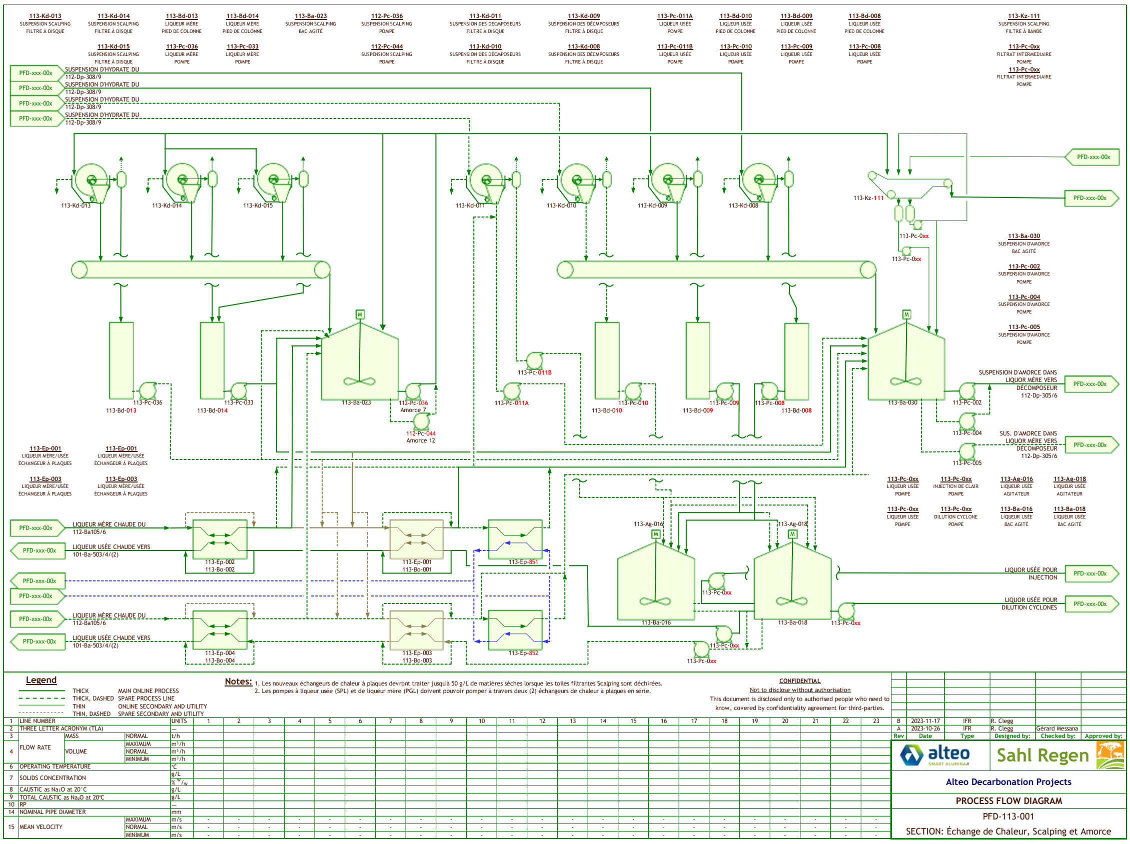

Figure 5. Pregnant liquor / spent liquor plate heat exchangers.

During Preliminary Engineering with the equipment suppliers the main design data required to establish the sizes of the condensers and reboilers of the KX heat exchangers were the heat transfer coefficients (HTC). One of the equipment suppliers was provided the following:

- Condenser design HTC of 800 W/m²·K (possibly underestimated)
- Reboiler design HTC of 600 W/m²·K (possibly overestimated)

The other equipment supplier preferred to use their own internally derived reboiler and condenser design HTCs.

This was sufficient to provide a footprint for KX LTD for Preliminary Engineering, however, to avoid over or under design prior to finalising the design the equipment design we would need operating experience arrangement so as to improve capital cost estimate and establish how to conduct a KX pilot to firm-up design HTCs. One supplier provided a footprint for the KX LTD of 36 m long by 15 m wide, plus 12 m added to the length for maintenance access.

4. Scope for Equipment Suppliers

The equipment suppliers had to have experience in industrial scale vapour compression, condensation and reboilers design. We required them to provide a design that could not only achieve Phase 1 operating condition, but could also with minor modifications also operate under Phase 2 operating conditions. Using Figure 6 and Table 1, we specified to the equipment suppliers two operating conditions:

- “Normal heat recovery” will be the operating conditions in Phase 1 for 100 000 t/y Al_2O_3,

- “Highest heat recovery” are operating conditions required in Phase 2, where the spent liquor/pregnant liquor plate heat exchangers have been replaced with KX heat exchangers and KX heat exchangers are recovering exothermic heat of reaction in the Precipitation section.

The following schematic is the design conditions we required from the equipment suppliers, where:

DIF Digestion feed
KXL KX liquor at digestion temperature
DIS Digestion slurry
SPL Spent liquor (for quench during transition conditions)
PGL Pregnant liquor (turbid, prior to security filtration)

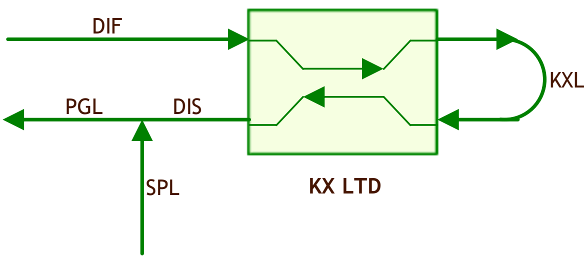

Figure 6. Simplified flowsheet provided to equipment suppliers.

Table 1. Data table for simplified KX Low Temperature Digestion.

1	LINE NUMBER			UNITS	Nominal heat recovery					Highest heat recovery				
2	THREE LETTER ACRONYM (TLA)			—	DIF	KXL	DIS	SPL	PGL	DIF	KXL	DIS	SPL	PGL
3	FLOW RATE	MASS	NORMAL	t/h	275	274	274	14	289	274	274	274	13	287
4		VOLUME	MAXIMUM	m^3/h	243	256	239	50	264	250	256	239	50	262
			NORMAL	m^3/h	203	214	200	11	220	208	214	200	10	219
			MINIMUM	m^3/h	147	155	145	0	160	151	155	145	0	159
6	OPERATING TEMPERATURE			°C	100	145	111	72	109	109	145	111	69	109
7	SOLIDS CONCENTRATION			g/L	113	0	0	8	0.4	1	0	0	8	0.4
				$\% \, ^w/_w$	8%	0.0	0%	1%	0.03%	0.1%	0.0	0%	1%	0.03%
8	CAUSTIC as Na_2O at 20°C			g/L	167	155	155	151	155	155	155	155	151	155
9	TOTAL CAUSTIC as Na_2O at 20°C			g/L	214	199	199	193	199	199	199	199	193	199
10	RP			—	0.82	1.30	1.30	0.81	1.27	1.29	1.30	1.30	0.80	1.28
14	NOMINAL PIPE DIAMETER			mm	200	200	200	80	200	200	200	200	80	200
15	MEAN VELOCITY		MAXIMUM	m/s	2.15	2.27	2.12	2.76	2.34	2.21	2.27	2.12	2.76	2.32
			NORMAL	m/s	1.79	1.89	1.76	0.60	1.95	1.84	1.89	1.76	0.56	1.93
			MINIMUM	m/s	1.30	1.37	1.28	-	1.41	1.34	1.37	1.28	-	1.40

0	2023-11-17	IFU	R. Clegg	J. Fournier	L. Guillaumont
A	2023-10-26	IFR	R. Clegg		
Rev	Date	Type	Designed by:	Checked by:	Approved by:
alteo SMART ALUMINA			Sahl Regen		
Alteo Decarbonation Projects					
PROCESS FLOW DIAGRAM					
PFD-102-001 (Summary Design for KX on Whiteside) SECTION: Dissolution KX et réservoir d'hydrate					

5. Location of KX LTD

Using the footprint provided by the first equipment supplier we were able to identify the optimum location for two KX LTD units and the MVR Evaporator, as indicated in Figure 4. Alteo Gardanne alumina refinery has been operating in the village of Gardanne since 1894. Originally, the main road to Marseille used to run west through the centre of the refinery just north of the existing Digestion building. Today, the refinery land is fully occupied, and Alteo have plans rehabilitate the site and continue to meet modern, strict environmental standards. To this end, we will reduce the footprint of the refinery that uses caustic liquor. Thus, the new KX LTD will be located on a site close to and to the north of the Precipitation section (green site in Figure 4). The MVR Evaporation section will be located close to KX LTD (yellow site in Figure 4). The existing digestion building (blue site in Figure 4) will be demolished and replaced with new offices and R&D laboratory.

As part of the Prefeasibility Engineering, the footprint of the new KX LTD has been defined based on equipment arrangement and size. Figure 4 shows the footprint for 2 by 100 000 t/y Al_2O_3 units including maintenance access. This will require the existing buildings and infrastructure to be demolished and rehabilitated prior to commencing construction. Since the land preparation for the KX LTD and MVR Evaporation will require at least 12 months to complete, we will use this time to build a KX pilot to improve the precision of reboiler and condenser HTCs. This will avoid over or under designing the KX LTD, thus either saving capital or avoiding under performing.

Figure 7. Location of existing digestion and future KX LTD and MVR Evaporation :
Blue square: existing Digestion building (650 000 t/y Al_2O_3)
Green rectangle: future KX LTD building (2×100 000 t/y Al_2O_3)
Yellow shape : future 20 t/h MVR Evaporation section.

6. KX Pilot

To ensure that the KX LTD is not over or under designed we need to improve our confidence in the condenser and reboiler design HTC. To this end, we will build a small condenser reboiler in the existing Digestion section to measure HTC as a function of operating temperature and temperature difference.

The equipment suppliers have proposed design of a KX pilot to improve precision of design HTCs, both condensing and boiling. We, however, have to establish how to best connect the KX pilot to the refinery to provide process liquor at the required temperatures and flows. The nominal flow of the pilot unit will be up to 50 m³/h, while the Digestion units are capable of more than 200 m³/h, and we require to establish condensing and boiling HTCs at temperatures from 85 to 145 °C. Although we do not expect condensing HTC to vary significantly with operating temperature and temperature difference (ΔT), we know it will vary significantly for the boiling HTC. The latter will require a trade-off between compressor power and heat transfer surface area. Hence the importance of the KX pilot.

Fortunately, above the old Digestion control room and Digestion feed pump room there is a large space (Figure 8) that runs between 2nd and 3rd reheaters (A1 and A2) of Digestion units 1 and 2.

Figure 9 below is the PFD indicating how we intend to connect the KX pilot to one of the Digestion units. The tie-ins (TIs) from TI-01 to TI-08 are indicated on the PFD. Note: the Digestion units used to be high temperature units that have been converted to low temperature units; hence D1-D3 flash tanks and A4-A7 are greyed out on the PFD. TI-03 to TI-06 will provide 50 m³/h of Digestion slurry/liquor between 85 and 145°C and return the slurry/liquor to the feed to the first reheater. The drawback of this design is the increase in temperature of the feed to digestion. On the other hand, it is not intended to operate in this configuration for long periods of time. The KX pilot is designed to operate in either condenser or reboiler mode. The KX Pilot PFD is drawn showing the pilot in reboiler mode taking digestion slurry from the last online reheater (A3) and returning the slurry to the first reheater (A0). The vapour vent will control the operating temperature and pressure, while the digestion condensate (EDS) will control the level of heat transfer fluid (HTF) in the reboiler above the reboiler tube.

Figure 8. Existing Digestion area, with the orange rectangle indicating the location for KX Pilot between A1 and A2 of digestion units 1 and 2.

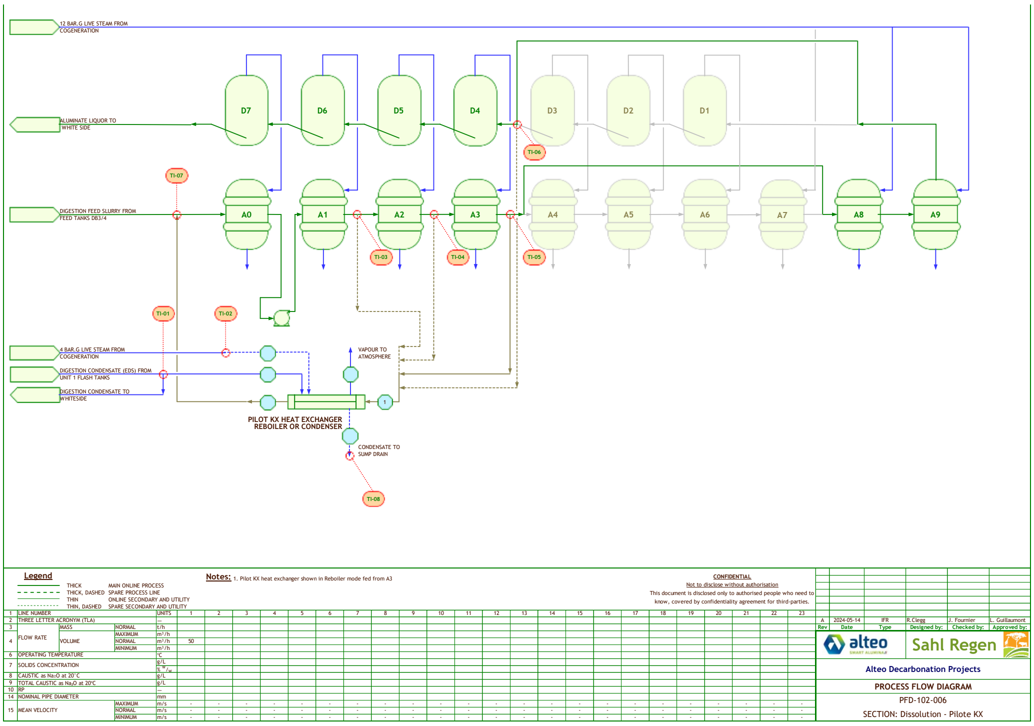

Figure 9. PFD KX Pilot in Digestion.

7. Strategy and Financing to Deliver Phase 1 and Phase 2

Replacing an existing Digestion section no matter how large is exceedingly expensive on a per tonne of alumina production basis. So how can we make this change commercially viable and what are the drivers? In Europe, they are:

- Reducing energy costs
- Reducing CO_2 emissions and associated costs within the European Union Emission Trading Scheme.

Our analysis shows that Phase1 is commercially very attractive for Alteo, however the capital cost is sufficiently high to make committing to the project with “new” technology challenging. Fortunately, in Europe for innovative projects that can reduce CO_2 emission and improve competitiveness of European industries, we can seek grants and no/low interest loans from programs like Décarb’Ind of ADEME in the French program France 2030, Certificat Économie Énergie (CEE) of France’s national electricity provider EDF and the Innovation Fund of the European Union. If successful, this will make our decision to proceed with Phase 1 significantly easier to make.

We at Alteo are taking small incremental steps in the refinery to implement some of the energy recovery modifications like increased spent liquor / pregnant liquor heat recovery to learn how to integrate these modifications to the operating constraints that are specific to the Alteo alumina refinery.

Phase 2 will only be considered and commercially evaluated once Phase 1 is a commercial success. Like Phase 1, Phase 2 could further reduce energy costs significantly. For now, our focus is on Phase1. Phase 2 is for now only an option for the future.

So in summary, our implementation strategy is in 4 phases:

1. Obtain European and French financial support
2. Prepare the land where the KX LTD and MVR Evaporation will be built
3. Install an incremental increase in plate heat exchanger heat recovery capacity
4. Build and operate a KX condenser / reboiler pilot to firm up design HTCs
5. Select vendor for 100 000 t/y Al_2O_3 KX LTD unit and 20 t/h MVR Evaporator
6. Commence construction

8. Conclusions

We at ALTEO and SAHL REGEN have an exciting project, based on a step change in technology to not only reduce CO_2 emissions but also to significantly reduce operating costs. The key to success is to move forward step by step, clearly identifying the key parameters and making the project financially viable.

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