Comparison of technologies for CO_2 capture from cement production – Part 1: Technical evaluation – Supplementary Materials

1 Reference cement kiln

Process flow diagram of the reference cement kiln is given in Figure 1.1. It should be noted that in this figure the lowest cyclone is treated as a part of the calciner.

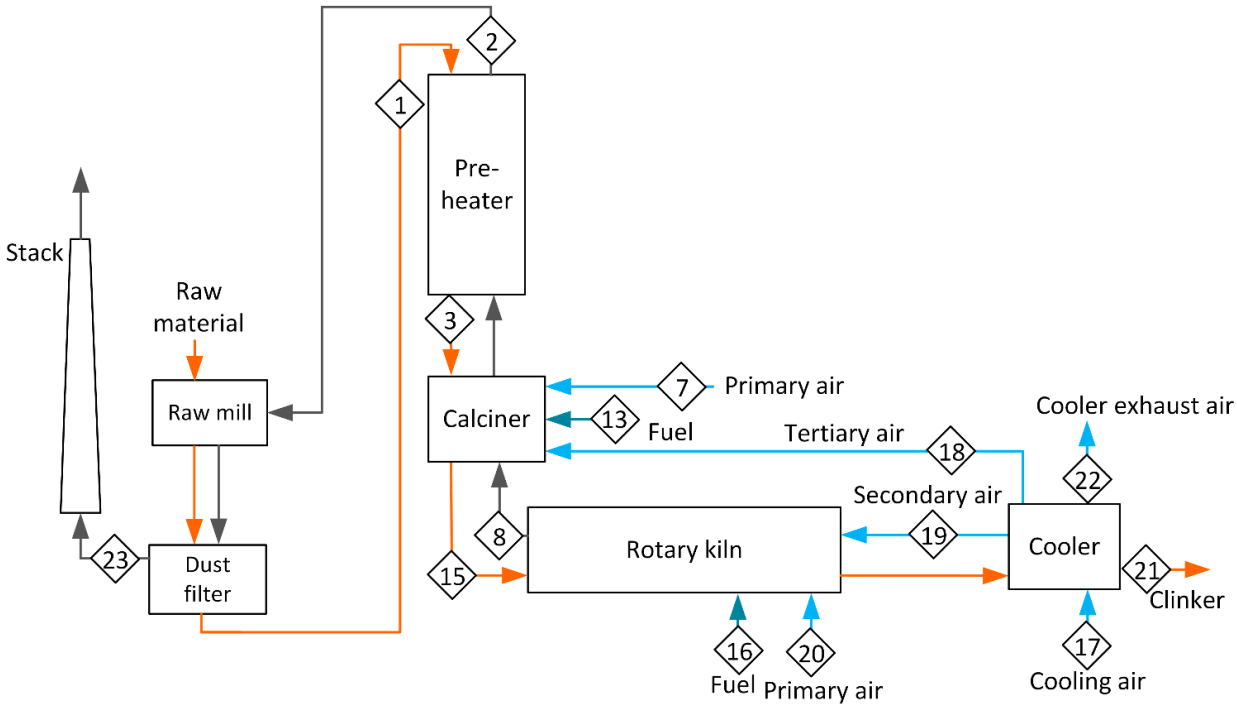

Figure 1.1. Process flowsheet of the reference cement kiln.

1.1 VDZ simulation

Responsible project partner: VDZ

Stream data for solid streams in the reference cement kiln are given in **Error! Not a valid bookmark self-reference.** and data for gaseous streams are given in Table 1.2.

Table 1.1. Stream data for solid streams in the reference cement kiln (solid components present in very small amounts are not included).

#	M	T	Solid phase mass composition [%]														
	[kg/h]	[°C]	AL_2O_3	$CACO_3$	CAO	$CaSO_4$	FE_2O_3	H_2O	$MGCO_3$	MGO	SIO_2	C_3S	C_2S	C_3A	C_4AF	CA	C_2F
1	200025	60	3.26	77.34	0.00	0.00	1.96	1	1.49	0.00	13.83	0.00	0.00	0.00	0.00	0.00	0.00
3	233098	755	2.58	63.59	8.61	0.01	1.55	0	1.23	0.17	14.17	0.83	2.79	0.18	0.14	1.58	1.00
13	8640	50	69% C. 4% H. 0.5%S. 0.48%N. 9%O. 16.5%Ash. 0.5%Moisture. 0.02% Cl														
15	143198	860	0.04	6.24	42.46	0.06	0.01	0	0.12	0.83	14.78	4.29	14.33	0.90	0.74	7.43	4.68
16	5290	60	69% C. 4% H. 0.5%S. 0.48%N. 9%O. 16.5%Ash. 0.5%Moisture. 0.02% Cl														
21	120646	115	0.00	0.00	0.73	0.00	0.00	0	0.00	0.01	0.03	64.31	14.00	10.01	8.57	0.00	0.55

Table 1.2. Stream data for gaseous streams in the reference cement kiln.

#	M gas [kg/h]	M dust [kg/h]	T gas [°C]	Gas phase volumetric composition [%]			
				CO_2	H_2O	O_2	N_2
2	236470	9393	314	31.99	6.18	3.03	58.79
7	2630	0	15	0.00	1.00	21.00	78.00
8	61411	10550	1078	20.14	6.37	1.51	70.51
17	297996	0	15	0	1	21	78
18	94290	2470	1086	0	1	21	78
19	37302	977	1137	0	1	21	78
20	11842	0	15	0	1	21	78
22	166303	4357	285	0	1	21	78
23 A	318192	10 mg/Nm3	130	22	11	7	60
23 B	388098	10 mg/Nm3	110	18	9	10	63

A: Low air leak in raw mill. B: Medium air leak in raw mill.

1.2 PoliMi simulation

Responsible project partner: Politecnico di Milano

Stream data for solid streams in the reference cement kiln are given in **Table *1.3*** and stream data for gaseous streams are given in Table 1.4.

Table 1.3. *Stream data for solid streams in the reference cement kiln (solid components present in very small amounts are not included)*

#	M	T	Solid phase mass composition [%]														
	[kg/h]	[°C]	AL_2O_3	$CACO_3$	CAO	$CaSO_4$	FE_2O_3	H_2O	$MGCO_3$	MGO	SIO_2	C_3S	C_2S	C_3A	C_4AF	CA	C_2F
1	195660	60	3.3	79.3	0	0	2.0	0	1.5	0	13.8	0	0	0	0	0	0
3	229320	743	3.7	66.0	9.3	0	2.2		0	0.8	14.1	0.8	2.8	0.2	0.1	0	0
13	8640	60	69% C, 4% H, 0.5%S, 0.48%N, 9%O, 16.5%Ash, 0.5%Moisture, 0.02% Cl; LHV=27 MJ/kg														
15	137880	852	4.9	6.5	48.8	0.2	2.8	0	0	1.1	14.8	4.5	14.9	0.9	0.8	0	0
16	5400	60	69% C, 4% H, 0.5%S, 0.48%N, 9%O, 16.5%Ash, 0.5%Moisture, 0.02% Cl; LHV=27 MJ/kg														
21	117720	115	0	0	0.8	0.2	0	0	0	1.1	0	64.5	14	9.8	9.6	0	0

Table 1.4. Stream data for gaseous streams in the reference cement kiln.

#	M gas [kg/h]	M dust [kg/h]	T gas [°C]	Gas phase volumetric composition [%]				
				Ar	CO_2	H_2O	O_2	N_2
2	237240	9360	313	0.7	31.9	5.1	3.3	59
7	2520	0	15	0.9	0	1	20.7	77.3
8	61560	10440	1079	0.8	19.7	6.3	1.9	71.2
17	276840	0	15	0.9	0	1	20.7	77.3
18	94320	2520	1137	0.9	0	1	20.7	77.3
19	38880	1080	1137	0.9	0	1	20.7	77.3
20	12240	0	15	0.9	0	1	20.7	77.3
22	143640	4320	285	0.9	0	1	20.7	77.3

2 MEA absorption

Responsible project partner: SINTEF ER.

Process flow diagram for the MEA process is given in Figure 2.1, and process flow diagram for conditioning of CO_2 for transport by pipeline is given in Figure 2.2.

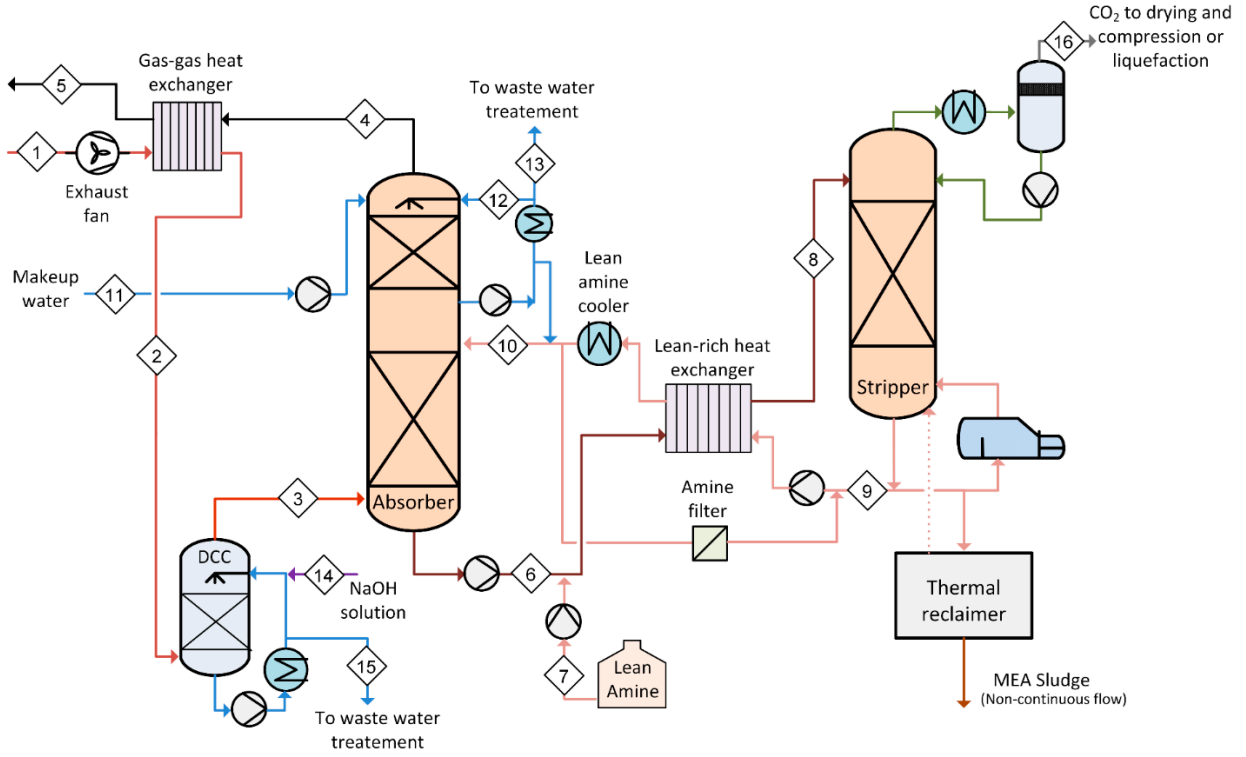

Figure 2.1. Process flowsheet of the MEA process.

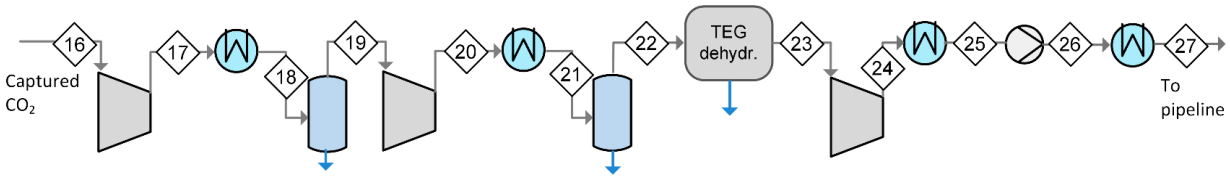

Figure 2.2. Process flowsheet of CO_2 drying and compression for pipeline transport.

The process is designed for medium air leak in the mill, and in the first half of the year it is assumed to be operated with low air leak in the raw mill and in the second half of the year it is assumed to be operated at medium air leak in the raw mill. Stream data for the first half of the year is given in Table 2.1 and stream data for the second half of the year is given in Table 2.2. Stream data for the CO_2 conditioning process is given in Table 2.3.

Table 2.1. Stream data for MEA process designed for medium air leak operated with low air leak in raw mill. For liquid streams, the molar flow and the mole fractions refer to apparent molar flow and mole fractions.

#	Vapor fraction	Temperature [°C]	Pressure [bar]	Molar flow [kmol/h]	Mole fraction					
					MEA	H_2O	CO_2	O_2	N_2	NaOH
1	1.00	110.0	1.01	12769	0.0000	0.0900	0.1800	0.1000	0.6300	0.0000
2	1.00	125.2	1.18	12769	0.0000	0.0900	0.1800	0.1000	0.6300	0.0000
3	1.00	39.8	1.10	12455	0.0000	0.0670	0.1845	0.1025	0.6459	0.0000
4	1.00	66.4	1.02	12941	0.0000	0.2622	0.0177	0.0986	0.6214	0.0000
5	1.00	72.0	1.02	12941	0.0000	0.2622	0.0177	0.0986	0.6214	0.0000
6	0.00	49.3	6.09	62466	0.1155	0.8259	0.0586	0.0000	0.0000	0.0000
7	0.00	30.0	1.01	2	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.01	102.2	2.00	62468	0.1156	0.8258	0.0586	0.0000	0.0000	0.0000
9	0.00	118.4	1.80	60400	0.1196	0.8541	0.0263	0.0000	0.0000	0.0000
10	0.00	40.0	8.22	60400	0.1196	0.8541	0.0263	0.0000	0.0000	0.0000
11	0.00	30.0	1.10	2667	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
12	0.00	28.2	1.10	2913	0.0018	0.9976	0.0007	0.0000	0.0000	0.0000
13	0.00	28.2	3.05	44	0.0018	0.9976	0.0007	0.0000	0.0000	0.0000
14	0.00	28.2	3.13	4	0.0000	0.6897	0.0000	0.0000	0.0000	0.3103
15	0.00	28.2	3.13	314	0.0000	0.9999	0.0001	0.0000	0.0000	0.0000
16	1.00	28.2	1.30	2136	0.0000	0.0300	0.9686	0.0003	0.0011	0.0000

Table 2.2. Stream data for MEA process designed for medium air leak and operated with medium air leak in raw mill. For liquid streams, the molar flow and the mole fractions refer to apparent molar flow and mole fractions.

#	Vapor fraction	Temperature [°C]	Pressure [bar]	Molar flow [kmol/h]	Mole fraction					
					MEA	H_2O	CO_2	O_2	N_2	NaOH
1	1.00	110.0	1.01	12769	0.0000	0.0900	0.1800	0.1000	0.6300	0.0000
2	1.00	125.2	1.18	12769	0.0000	0.0900	0.1800	0.1000	0.6300	0.0000
3	1.00	39.8	1.10	12455	0.0000	0.0670	0.1845	0.1025	0.6459	0.0000
4	1.00	66.4	1.02	12941	0.0000	0.2622	0.0177	0.0986	0.6214	0.0000
5	1.00	72.0	1.02	12941	0.0000	0.2622	0.0177	0.0986	0.6214	0.0000
6	0.00	49.3	6.09	62466	0.1155	0.8259	0.0586	0.0000	0.0000	0.0000
7	0.00	30.0	1.01	2	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.01	102.2	2.00	62468	0.1156	0.8258	0.0586	0.0000	0.0000	0.0000
9	0.00	118.4	1.80	60400	0.1196	0.8541	0.0263	0.0000	0.0000	0.0000
10	0.00	40.0	8.22	60400	0.1196	0.8541	0.0263	0.0000	0.0000	0.0000
11	0.00	30.0	1.10	2667	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
12	0.00	28.2	1.10	2913	0.0018	0.9976	0.0007	0.0000	0.0000	0.0000
13	0.00	28.2	3.05	44	0.0018	0.9976	0.0007	0.0000	0.0000	0.0000
14	0.00	28.2	3.13	4	0.0000	0.6897	0.0000	0.0000	0.0000	0.3103
15	0.00	28.2	3.13	314	0.0000	0.9999	0.0001	0.0000	0.0000	0.0000
16	1.00	28.2	1.30	2136	0.0000	0.0300	0.9686	0.0003	0.0011	0.0000

Table 2.3. Stream data for the CO_2 conditioning process for pipeline transport.

#	Vapor fraction	Temperature [°C]	Pressure [bar]	Molar flow [kmol/h]	Mole fraction					
					MEA	H_2O	CO_2	O_2	N_2	NaOH
17	1.00	146.8	5.20	2136	0.0000	0.0300	0.9686	0.0003	0.0011	0.0000
18	0.98	28.2	5.10	2136	0.0000	0.0300	0.9686	0.0003	0.0011	0.0000
19	1.00	28.2	5.10	2089	0.0000	0.0079	0.9906	0.0003	0.0011	0.0000
20	1.00	149.4	20.38	2089	0.0000	0.0079	0.9906	0.0003	0.0011	0.0000
21	0.99	28.2	19.98	2089	0.0000	0.0079	0.9906	0.0003	0.0011	0.0000
22	1.00	28.2	19.98	2078	0.0000	0.0026	0.9960	0.0003	0.0011	0.0000
23	1.00	29.5	18.98	2073	0.0000	0.0001	0.9984	0.0003	0.0011	0.0000
24	1.00	162.4	80.00	2073	0.0000	0.0001	0.9984	0.0003	0.0011	0.0000
25	0.00	28.2	78.40	2073	0.0000	0.0001	0.9984	0.0003	0.0011	0.0000
26	0.00	36.4	110.40	2073	0.0000	0.0001	0.9984	0.0003	0.0011	0.0000
27	0.00	28.2	110.00	2073	0.0000	0.0001	0.9984	0.0003	0.0011	0.0000

3 Oxyfuel

Responsible project partner: VDZ (core process), SINTEF ER (heat recovery and CPU)

Process flow diagram of the oxyfuel core process and the heat recovery system is given in Figure 3.1. It should be noted that the lowest cyclone is included in the box labelled calciner. Process flow diagrams of the CPU and heat integration are given in Figure 3.2. Note that the streams 18-21 in the CPU are renumbered as C18-C21 for the integration figure. The dashed lines in Figure 3.1 illustrate the heat flow from the CPU to other units.

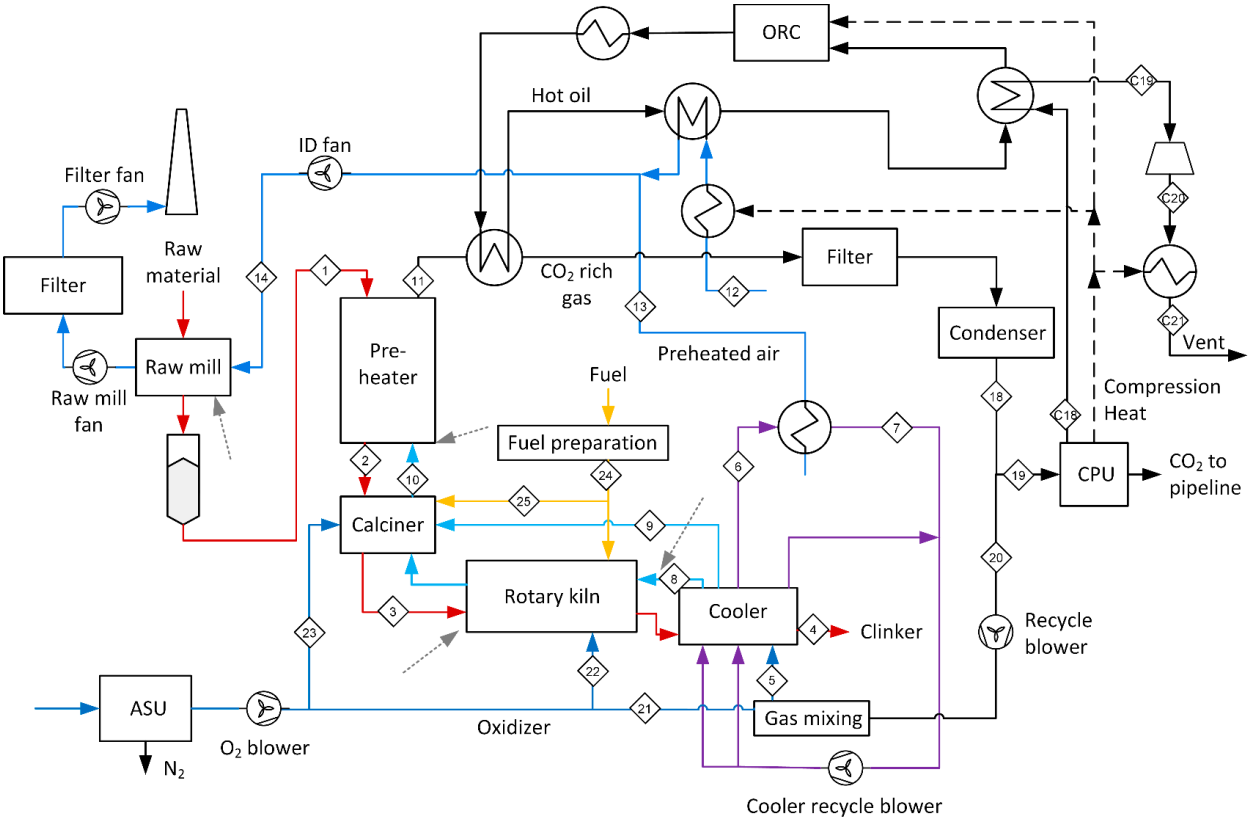

Figure 3.1. Process flowsheet of the core oxyfuel process, the ORC and heat integration system for pipeline transport.

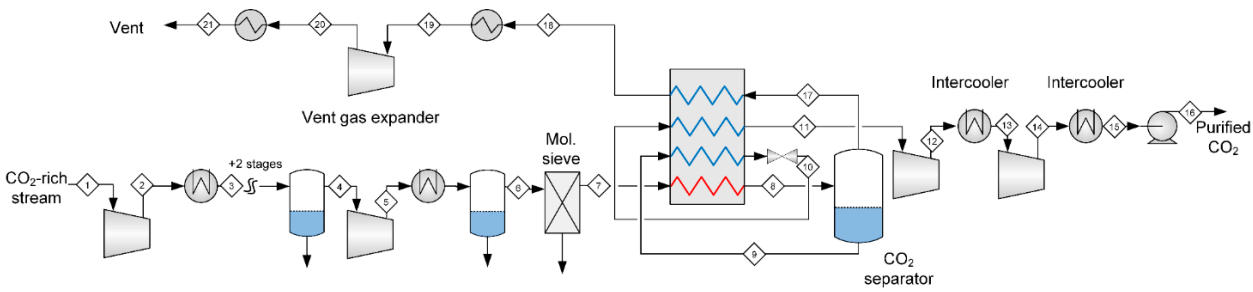

Figure 3.2. Process flowsheet of the CPU for pipeline transport.

Stream data for the core process is given in Table 3.1 - Table 3.3. Dust content in gaseous streams is only provided in streams where this is relevant for the heat balance. Stream data for the CPU is given in Table 3.4.

Table 3.1. Stream data for solid streams in the oxyfuel core process.

#	T [°C]	M [kg/h]	Solid phase mass composition [%]												
			AL_2O_3	$CACO_3$	CAO	$CaSO_4$	FE_2O_3	H_2O	$MGCO_3$	MGO	SIO_2	C_3S	C_2S	C_3A	C_4AF
1	60	200025	3.26	77.34	0	0	1.96	1.0	1.49	0	13.83	0	0	0	0
2	784	233628	2.55	62.84	8.87	0.01	1.53	0	1.20	0.17	14.12	1.2	2.82	0.24	0.19
3	905	147029	0.04	14.10	33.3	0.05	0.01	0	0.10	0.80	14.4	6.0	14.0	1.2	0.90
4	85.5	125078	0.01	0	0.6	0	0	0	0	0.01	0.06	64.7	13.6	9.98	8.69
24	60	6120	69% C. 4% H. 0.5%S. 0.48%N. 9%O. 16.5%Ash. 0.5%Moisture. 0.02% Cl												
25	60	8350	69% C. 4% H. 0.5%S. 0.48%N. 9%O. 16.5%Ash. 0.5%Moisture. 0.02% Cl												

Table 3.2. Stream data for gaseous streams in the oxyfuel core process.

#	V gas [m³/h]	VN gas [m³/h]	VNDry gas [m³/h]	M dust [kg/h]	T gas [°C]	Gas phase volumetric composition [%]				
						AR	CO_2	H_2O	O_2	N_2
5	115747.43	106519.68	103062.08	94	23.6	1.65	64.46	3.24	20.43	10.19
6	256716.41	115050.2	115000.0	5730	338.2	1.65	64.46	3.24	20.43	10.19
7	174706.55	115050.2	115000.0	5730	162.4	1.65	64.46	3.24	20.43	10.19
8	131414.03	28547.28	27620.64	903.5	984.26	1.65	64.46	3.24	20.43	10.19
9	335954.38	77759.37	75235.32	2461.5	906.98	1.65	64.46	3.24	20.43	10.19
10	636537	154118	144067		855	1.2	81	6.5	3.1	8.57
11	397896.67	162812.82	150211.78	9393	394.39	1.18	76.96	7.73	3.34	10.74
12	103407.17	98000	97983.51		15	0.9	0.0	1	21	77.1
13	192331.02	116172.63	115006.12		179.0	0.9	0.0	1	21	77.1
14	364867.61	215162.53	213006.12		190	0.9	0.0	1	21	77.1
18	173172.01	156592.35	150660.72	94	29	1.2	80	3.7	3.54	11.4
19	78273.74	70779.74	68098.64	94	29	1.2	80	3.7	3.54	11.4
20	94898.26	85812.60	82562.07	94	29	1.2	80	3.7	3.54	11.4
21	20579.4	19506	19500		15	3.5	0	0	95	1.5
22	3324	3151	3150		15	3.5	0	0	95	1.5
23	551.9	523	523		15	3.5	0	0	95	1.5

Table 3.3. Air leak stream data in the oxyfuel process.

	V [m³/h]	VN [m³/h]	VNDry [m³/h]	T [°C]	Gas phase volumetric composition [%]				
					AR	CO_2	H_2O	O_2	N_2
Between kiln and cooler	131414.0	28547.3	27620.6	984.26	1.65	64.46	3.24	20.43	10.19
Air leak at preheater tower	5804	5502	5500	15	0.9	0	1	21	77.1
In filter (filter gasin)	351453.9	162862.5	150260.9	316.3	1.2	76.94	7.73	3.35	10.76
In heat exchanger (preheater gas out)	397896.7	162812.8	150211.8	394.39	1.18	76.96	7.73	3.34	10.74
In organic rankine cycle (ORC)	330264.2	163165.3	150560.7	279.73	1.2	76.8	7.73	3.39	10.89
In condencer	298246.5	163266.3	150660.7	225.82	1.2	76.8	7.72	3.39	10.93

Table 3.4. Main stream data for the CPU with pipeline transport in the oxyfuel process.

#	T gas [°C]	p gas [bar]	Molar flow [kmol/h]	Gas phase volumetric composition [%]				
				AR	CO_2	H_2O	O_2	N_2
1	29.00	1.01	3111.63	1.23	80.15	3.92	3.49	11.19
7	30.42	21.34	2989.38	1.28	83.43	0	3.63	11.65
15	28.00	82.32	2307.62	0.35	97.28	0	0.74	1.62
16	36.37	110.00	2307.62	0.35	97.28	0	0.74	1.62
18	20.42	20.91	681.77	4.44	36.53	0	13.42	45.62
19	200.37	20.49	681.77	4.44	36.53	0	13.42	45.62
20	10.00	1.30	681.77	4.44	36.53	0	13.42	45.62
21	70.00	1.30	681.77	4.44	36.53	0	13.42	45.62

4 Chilled ammonia process

Responsible project partner: ETH (core process), SINTEF (compression)

Process flow diagram of the chilled ammonia process is given in Figure 4.1. Process flow diagram for conditioning of CO_2 for transport by pipeline is given in Figure 4.2.

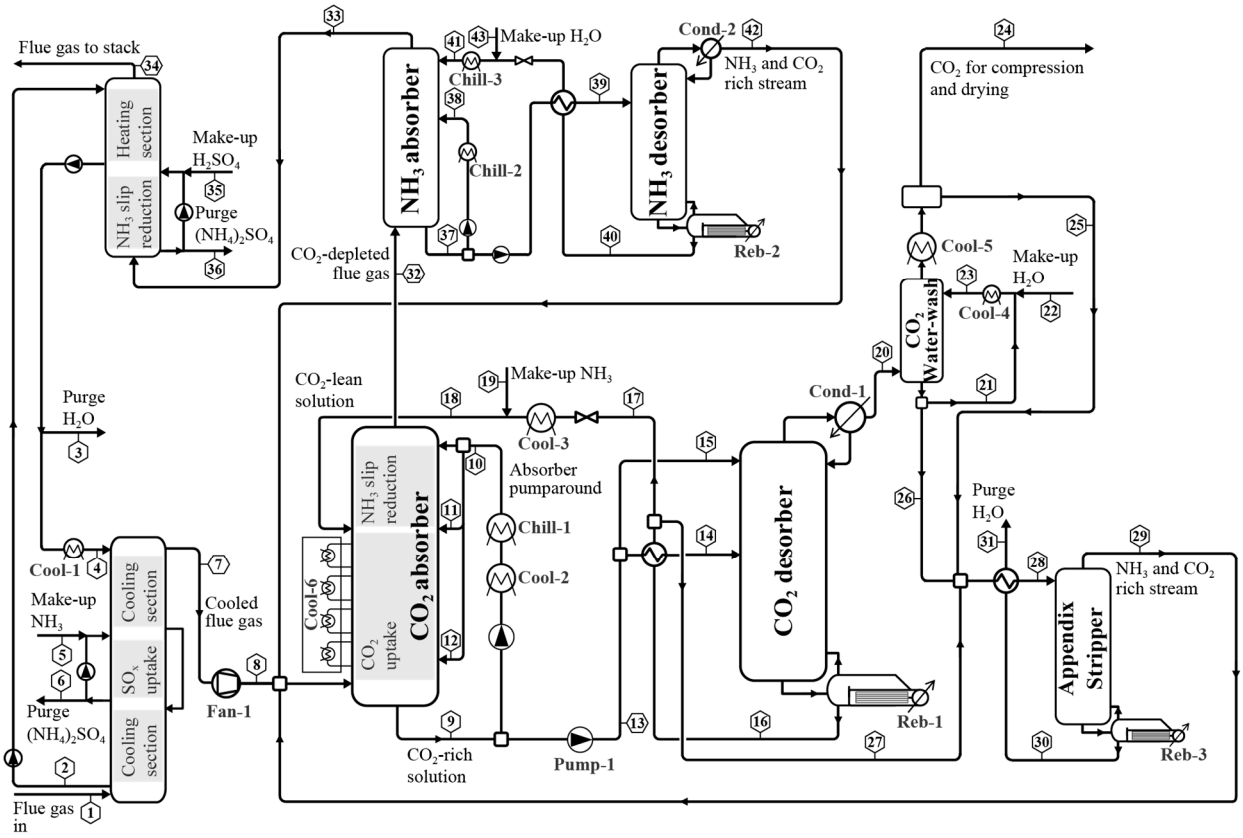

Figure 4.1. Process flowsheet of the chilled ammonia process.

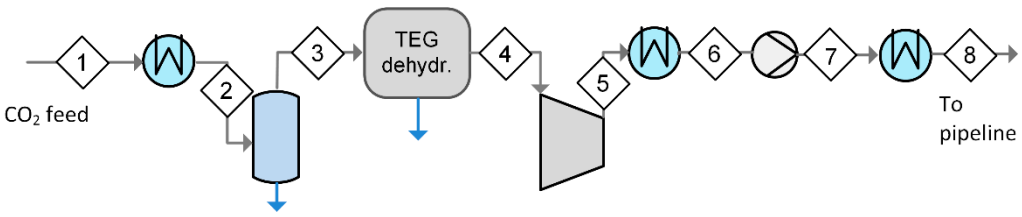

Figure 4.2. Process flowsheet of CO_2 drying and compression for pipeline transport.

The process is designed for medium air leak in the mill, and in the first half of the year it is assumed to be operated with low air leak in the raw mill and in the second half of the year it is assumed to be operated at medium air leak in the raw mill. Stream data for the first half of the year is given in Table 4.1 and stream data for the second half of the year is given in **Error! Reference source not found.**. Stream data for the CO_2 conditioning process is given in Table 4.3. The main energy consumers in the CAP for the first half of the year are listed in Table 4.4 and for the second half of the year in Table 4.5.

Table 4.1. Specifications of the streams of the CAP. Design at medium air leak, operated at low air leak. First ½ of the year.

#	F	T	P	N	H	Composition (mole frac.)												
	[kg/s]	[°C]	[bar]	[kmol/s]	[kJ/s]	H_2O	NH_3	CO_2	NH_4^+	H^+	OH^-	CO_3^{2-}	HCO_3^-	NH_2COO^-	Air	SO_2	$(NH_4)_2SO_4$	H_2SO_4
1	8.84E+01	130	1.1	2.90E+00	-3.19E+05	1.10E-01	0.00E+00	2.20E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.70E-01	200 mg/Nm3	0.00E+00	0.00E+00
2	1.86E+02	48.2	1.01	1.03E+01	-2.93E+06	1.00E+00	0.00E+00	7.94E-05	0.00E+00	8.36E-07	1.88E-11	1.27E-12	8.36E-07	0.00E+00	7.06E-06	0.00E+00	0.00E+00	0.00E+00
3	7.55E-01	34.3	1.01	4.19E-02	-1.19E+04	1.00E+00	0.00E+00	1.44E-05	0.00E+00	3.49E-07	1.85E-11	1.02E-12	3.49E-07	0.00E+00	1.12E-05	0.00E+00	0.00E+00	0.00E+00
4	1.81E+02	21.2	1.01	1.01E+01	-2.88E+06	1.00E+00	0.00E+00	7.94E-05	0.00E+00	7.74E-07	3.22E-12	8.01E-13	7.74E-07	0.00E+00	7.06E-06	0.00E+00	0.00E+00	0.00E+00
5(1)	3.46E-02	20	1.1	1.95E-03	-4.54E+02	7.39E-01	2.61E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6(1)	5.95E-02	20	1.01	1.70E-03	-4.54E+02	8.50E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-01	0.00E+00
7	8.39E+01	22.2	1.01	2.66E+00	-2.69E+05	2.66E-02	0.00E+00	2.41E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.33E-01	0.00E+00	0.00E+00	0.00E+00
8	8.39E+01	29.9	1.1	2.66E+00	-2.68E+05	2.66E-02	0.00E+00	2.41E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.33E-01	0.00E+00	0.00E+00	0.00E+00
9	8.89E+02	24.8	1.05	4.42E+01	-1.29E+07	8.93E-01	4.52E-03	9.41E-05	5.39E-02	4.74E-11	1.22E-08	4.90E-03	1.99E-02	2.42E-02	5.59E-07	0.00E+00	0.00E+00	0.00E+00
10	1.07E+02	12	1.4	5.31E+00	-1.56E+06	8.91E-01	3.24E-03	1.83E-04	5.63E-02	2.19E-11	7.68E-09	7.38E-03	1.84E-02	2.31E-02	5.59E-07	0.00E+00	0.00E+00	0.00E+00
11	0.00E+00	na	na	0.00E+00	na	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	0.00E+00	na	na	0.00E+00	na	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	7.82E+02	25.6	25.4	3.89E+01	-1.14E+07	8.93E-01	4.60E-03	9.20E-05	5.38E-02	4.95E-11	1.25E-08	4.79E-03	2.00E-02	2.42E-02	5.59E-07	0.00E+00	0.00E+00	0.00E+00
14	7.62E+02	137	25.4	3.84E+01	-1.07E+07	8.80E-01	3.35E-02	1.08E-02	3.79E-02	3.43E-09	9.13E-08	2.00E-04	2.72E-02	1.03E-02	5.53E-07	0.00E+00	0.00E+00	0.00E+00
15	1.95E+01	25.6	25.4	9.73E-01	-2.84E+05	8.93E-01	4.60E-03	9.20E-05	5.38E-02	4.95E-11	1.26E-08	4.79E-03	2.00E-02	2.42E-02	5.59E-07	0.00E+00	0.00E+00	0.00E+00
16	7.57E+02	146	25	3.90E+01	-1.07E+07	8.92E-01	4.30E-02	3.15E-03	3.12E-02	3.57E-09	1.64E-07	1.61E-04	2.27E-02	8.19E-03	9.16E-10	0.00E+00	0.00E+00	0.00E+00
17	7.55E+02	29.3	25	3.88E+01	-1.11E+07	9.06E-01	2.03E-02	3.17E-06	3.89E-02	1.23E-11	1.18E-07	4.64E-03	6.24E-03	2.34E-02	9.19E-10	0.00E+00	0.00E+00	0.00E+00
18	7.55E+02	21.2	1.05	3.88E+01	-1.11E+07	9.06E-01	1.94E-02	2.61E-06	4.03E-02	6.61E-12	1.10E-07	5.98E-03	5.36E-03	2.30E-02	9.19E-10	0.00E+00	0.00E+00	0.00E+00
19(1)	1.02E-02	20	1.01	5.72E-04	-1.33E+02	7.39E-01	2.61E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	2.54E+01	59.4	24.5	5.81E-01	-2.28E+05	8.81E-03	2.16E-04	9.91E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.74E-05	0.00E+00	0.00E+00	0.00E+00
21	9.23E+00	56.8	24.5	4.52E-01	-1.34E+05	8.88E-01	4.66E-04	7.70E-03	5.19E-02	4.76E-09	5.39E-10	1.80E-04	4.90E-02	2.56E-03	1.87E-09	0.00E+00	0.00E+00	0.00E+00
22	4.76E-03	20	1.01	2.64E-04	-7.56E+01	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-09	1.49E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	9.23E+00	50	24.5	4.52E-01	-1.34E+05	8.88E-01	3.75E-04	7.56E-03	5.21E-02	3.92E-09	4.21E-10	2.08E-04	4.92E-02	2.49E-03	1.87E-09	0.00E+00	0.00E+00	0.00E+00

#	F	T	P	N	H	Composition (mole frac.)												
	[kg/s]	[°C]	[bar]	[kmol/s]	[kJ/s]	H_2O	NH_3	CO_2	NH_4^+	H^+	OH^-	CO_3^{2-}	HCO_3^-	NH_2COO^-	Air	SO_2	$(NH_4)_2SO_4$	H_2SO_4
24	2.54E+01	35	24.5	5.77E-01	-2.27E+05	2.97E-03	9.25E-07	9.97E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.76E-05	0.00E+00	0.00E+00	0.00E+00
25	2.53E+01	28.2	110	5.76E-01	-2.33E+05	9.57E-01	1.14E-05	1.29E-02	1.48E-02	1.44E-08	2.84E-10	5.25E-06	1.48E-02	2.75E-05	6.49E-09	0.00E+00	0.00E+00	0.00E+00
26	4.06E-02	35	24.5	2.14E-03	-6.22E+02	8.88E-01	4.66E-04	7.70E-03	5.19E-02	4.76E-09	5.39E-10	1.80E-04	4.90E-02	2.56E-03	1.87E-09	0.00E+00	0.00E+00	0.00E+00
27	3.46E-02	56.8	24.5	1.69E-03	-5.03E+02	9.06E-01	2.03E-02	3.17E-06	3.89E-02	1.23E-11	1.18E-07	4.64E-03	6.24E-03	2.34E-02	9.19E-10	0.00E+00	0.00E+00	0.00E+00
28	1.29E+00	29.3	25	6.65E-02	-1.89E+04	9.05E-01	2.38E-02	3.43E-05	3.61E-02	1.80E-10	1.18E-07	1.44E-03	1.32E-02	2.00E-02	1.11E-09	0.00E+00	0.00E+00	0.00E+00
29	1.37E+00	72	24.5	7.02E-02	-1.98E+04	7.05E-01	2.05E-01	8.93E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.86E-09	0.00E+00	0.00E+00	0.00E+00
30	5.50E-01	93.9	1.15	2.73E-02	-5.82E+03	1.00E+00	1.68E-04	2.31E-08	8.38E-06	4.59E-11	5.11E-06	1.21E-07	3.02E-06	1.41E-08	1.00E-30	0.00E+00	0.00E+00	0.00E+00
31	8.17E-01	105	1.25	4.54E-02	-1.27E+04	1.00E+00	1.66E-04	3.63E-10	1.02E-05	1.79E-12	5.77E-06	1.29E-06	1.85E-06	4.35E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	8.17E-01	40.8	1.25	4.54E-02	-1.29E+04	1.32E-02	2.70E-03	3.34E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.51E-01	0.00E+00	0.00E+00	0.00E+00
33	5.81E+01	12.4	1.01	2.05E+00	-3.45E+04	1.78E-02	1.44E-04	3.11E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.51E-01	0.00E+00	0.00E+00	0.00E+00
34	5.80E+01	15.8	1.01	2.05E+00	-3.44E+04	1.08E-01	0.00E+00	2.85E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.64E-01	0.00E+00	0.00E+00	0.00E+00
35	6.17E+01	47.3	1.01	2.25E+00	-8.25E+04	1.00E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-01
36[(1)]	1.47E-02	20	1.1	1.63E-04	na	1.00E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-01	0.00E+00
37[(1)]	1.97E-02	20	1.01	1.63E-04	na	9.84E-01	4.08E-04	4.77E-05	7.91E-03	6.86E-11	2.34E-08	3.35E-04	6.46E-03	7.82E-04	1.61E-05	0.00E+00	0.00E+00	0.00E+00
38	1.18E+01	12.5	1.04	6.41E-01	-1.85E+05	9.84E-01	3.09E-04	4.94E-05	8.02E-03	3.84E-11	1.48E-08	4.47E-04	6.36E-03	7.71E-04	1.61E-05	0.00E+00	0.00E+00	0.00E+00
39	1.18E-04	1.5	1.2	6.41E-06	-1.85E+00	9.84E-01	3.86E-03	3.04E-03	4.62E-03	5.47E-10	3.53E-07	5.91E-05	3.90E-03	5.99E-04	1.60E-05	0.00E+00	0.00E+00	0.00E+00
40	1.18E+01	90.6	1.4	6.43E-01	-1.81E+05	9.99E-01	9.28E-04	1.28E-07	4.00E-05	3.03E-11	5.92E-06	2.01E-06	2.91E-05	9.01E-07	3.68E-25	0.00E+00	0.00E+00	0.00E+00
41	1.14E+01	98.8	1.01	6.33E-01	-1.77E+05	9.99E-01	8.91E-04	3.21E-10	5.86E-05	3.21E-13	5.15E-06	2.19E-05	7.93E-06	1.76E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
42	1.16E+01	15	1.01	6.45E-01	-1.85E+05	2.09E-01	4.09E-01	3.81E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.08E-04	0.00E+00	0.00E+00	0.00E+00
43	3.52E-01	68	1.01	1.28E-02	-2.78E+03	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.49E-09	1.49E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
44	2.18E-01	20	1.01	1.21E-02	-3.46E+03	8.88E-01	3.75E-04	7.56E-03	5.21E-02	3.92E-09	4.21E-10	2.08E-04	4.92E-02	2.49E-03	1.87E-09	0.00E+00	0.00E+00	0.00E+00
45	3.13E-02	32.5	24.5	1.74E-03	-4.96E+02	2.97E-03	9.25E-07	9.97E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.76E-05	0.00E+00	0.00E+00	0.00E+00

[(1)] *Apparent composition*

Table 4.2. Specifications of the streams of the CAP. Design at medium air leak, operated at medium air leak. Second ½ of the year.

#	F	T	P	N	H	Composition (mole frac.)												
	[kg/s]	[°C]	[bar]	[kmol/s]	[kJ/s]	H_2O	NH_3	CO_2	NH_4^+	H^+	OH^-	CO_3^{2-}	HCO_3^-	NH_2COO^-	Air	SO_2	$(NH_4)_2SO_4$	H_2SO_4
1	1.08E+02	110	1.1	3.59E+00	-3.23E+05	9.00E-02	0.00E+00	1.80E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.30E-01	200 mg/Nm^3	0.00E+00	0.00E+00
2	2.24E+02	42.9	1.01	1.24E+01	-3.54E+06	1.00E+00	0.00E+00	7.24E-05	0.00E+00	7.97E-07	1.43E-11	1.18E-12	7.97E-07	0.00E+00	8.13E-06	0.00E+00	0.00E+00	0.00E+00
3	6.81E-01	31.4	1.01	3.78E-02	-1.08E+04	1.00E+00	0.00E+00	1.17E-05	0.00E+00	3.11E-07	1.70E-11	9.70E-13	3.11E-07	0.00E+00	1.18E-05	0.00E+00	0.00E+00	0.00E+00
4	2.20E+02	21.2	1.01	1.22E+01	-3.49E+06	1.00E+00	0.00E+00	7.25E-05	0.00E+00	7.39E-07	3.37E-12	8.00E-13	7.39E-07	0.00E+00	8.13E-06	0.00E+00	0.00E+00	0.00E+00
5(1)	4.07E-02	20	1.1	2.29E-03	-5.33E+02	7.39E-01	2.61E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6(1)	7.00E-02	20	1.01	1.99E-03	-5.93E+02	8.50E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-01	0.00E+00
7	1.04E+02	21.8	1.01	3.36E+00	-2.76E+05	2.61E-02	0.00E+00	1.93E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.81E-01	0.00E+00	0.00E+00	0.00E+00
8	1.04E+02	29.7	1.1	3.36E+00	-2.75E+05	2.61E-02	0.00E+00	1.93E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.81E-01	0.00E+00	0.00E+00	0.00E+00
9	8.61E+02	26	1.05	4.24E+01	-1.24E+07	8.78E-01	6.54E-03	5.72E-05	6.05E-02	3.54E-11	1.37E-08	6.05E-03	1.80E-02	3.05E-02	3.30E-07	0.00E+00	0.00E+00	0.00E+00
10	1.55E+02	9	1.4	7.63E+00	-2.24E+06	8.76E-01	4.29E-03	1.52E-04	6.52E-02	1.14E-11	7.45E-09	1.09E-02	1.55E-02	2.80E-02	3.30E-07	0.00E+00	0.00E+00	0.00E+00
11	0.00E+00	na	na	0.00E+00	na	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	0.00E+00	na	na	0.00E+00	na	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	7.06E+02	26.8	25.4	3.48E+01	-1.01E+07	8.78E-01	6.65E-03	5.61E-05	6.04E-02	3.72E-11	1.40E-08	5.90E-03	1.81E-02	3.05E-02	3.30E-07	0.00E+00	0.00E+00	0.00E+00
14	6.81E+02	138	25.4	3.39E+01	-9.45E+06	8.63E-01	4.04E-02	1.11E-02	4.31E-02	3.38E-09	8.23E-08	2.42E-04	2.96E-02	1.30E-02	3.27E-07	0.00E+00	0.00E+00	0.00E+00
15	2.47E+01	26.8	25.4	1.22E+00	-3.55E+05	8.78E-01	6.66E-03	5.61E-05	6.04E-02	3.72E-11	1.40E-08	5.90E-03	1.81E-02	3.05E-02	3.30E-07	0.00E+00	0.00E+00	0.00E+00
16	6.80E+02	147	25	3.49E+01	-9.52E+06	8.75E-01	5.23E-02	2.94E-03	3.49E-02	3.55E-09	1.61E-07	1.97E-04	2.44E-02	1.01E-02	1.22E-09	0.00E+00	0.00E+00	0.00E+00
17	6.79E+02	30.5	25	3.47E+01	-9.82E+06	8.92E-01	2.78E-02	2.10E-06	4.28E-02	1.05E-11	1.08E-07	5.06E-03	5.74E-03	2.69E-02	1.22E-09	0.00E+00	0.00E+00	0.00E+00
18	6.79E+02	21.2	1.05	3.47E+01	-9.85E+06	8.91E-01	2.69E-02	1.66E-06	4.45E-02	5.02E-12	1.01E-07	6.75E-03	4.79E-03	2.62E-02	1.22E-09	0.00E+00	0.00E+00	0.00E+00
19(1)	3.04E-02	20	1.01	1.71E-03	-3.99E+02	7.39E-01	2.61E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	2.58E+01	54.3	24.5	5.88E-01	-2.31E+05	6.79E-03	1.62E-04	9.93E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.95E-05	0.00E+00	0.00E+00	0.00E+00
21	9.35E+00	52.9	24.5	4.57E-01	-1.36E+05	8.87E-01	3.48E-04	8.95E-03	5.18E-02	4.97E-09	3.86E-10	1.62E-04	4.94E-02	2.12E-03	1.05E-09	0.00E+00	0.00E+00	0.00E+00
22	1.45E-02	20	1.01	8.05E-04	-2.30E+02	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-09	1.50E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	9.37E+00	50	24.5	4.58E-01	-1.36E+05	8.87E-01	3.18E-04	8.89E-03	5.18E-02	4.56E-09	3.50E-10	1.72E-04	4.94E-02	2.09E-03	1.05E-09	0.00E+00	0.00E+00	0.00E+00
24	2.57E+01	35	24.5	5.85E-01	-2.30E+05	2.98E-03	8.62E-07	9.97E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.95E-05	0.00E+00	0.00E+00	0.00E+00
25	2.57E+01	28.2	110	5.83E-01	-2.36E+05	9.59E-01	1.06E-05	1.28E-02	1.41E-02	1.49E-08	2.85E-10	4.73E-06	1.41E-02	2.43E-05	3.41E-09	0.00E+00	0.00E+00	0.00E+00
26	3.70E-02	35	24.5	1.95E-03	-5.66E+02	8.87E-01	3.48E-04	8.95E-03	5.18E-02	4.97E-09	3.86E-10	1.62E-04	4.94E-02	2.12E-03	1.05E-09	0.00E+00	0.00E+00	0.00E+00
27	2.53E-02	52.9	24.5	1.23E-03	-3.67E+02	8.92E-01	2.78E-02	2.10E-06	4.28E-02	1.05E-11	1.08E-07	5.06E-03	5.74E-03	2.69E-02	1.22E-09	0.00E+00	0.00E+00	0.00E+00

#	F	T	P	N	H	Composition (mole frac.)												
	[kg/s]	[°C]	[bar]	[kmol/s]	[kJ/s]	H_2O	NH_3	CO_2	NH_4^+	H^+	OH^-	CO_3^{2-}	HCO_3^-	NH_2COO^-	Air	SO_2	$(NH_4)_2SO_4$	H_2SO_4
28	1.85E+00	30.5	25	9.43E-02	-2.67E+04	8.90E-01	3.27E-02	2.66E-05	3.94E-02	1.74E-10	1.09E-07	1.58E-03	1.30E-02	2.33E-02	1.26E-09	0.00E+00	0.00E+00	0.00E+00
29	1.91E+00	75.4	24.5	9.74E-02	-2.73E+04	6.78E-01	2.31E-01	9.16E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.05E-09	0.00E+00	0.00E+00	0.00E+00
30	8.12E-01	92.9	1.15	4.02E-02	-8.38E+03	1.00E+00	1.75E-04	2.41E-08	8.30E-06	4.41E-11	4.81E-06	1.31E-07	3.22E-06	1.60E-08	1.03E-27	0.00E+00	0.00E+00	0.00E+00
31	1.10E+00	105	1.25	6.09E-02	-1.70E+04	1.00E+00	1.73E-04	2.29E-10	1.07E-05	1.19E-12	5.71E-06	1.63E-06	1.71E-06	4.86E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	1.10E+00	34.3	1.25	6.09E-02	-1.74E+04	1.15E-02	3.53E-03	2.61E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.59E-01	0.00E+00	0.00E+00	0.00E+00
33	7.74E+01	10.5	1.01	2.74E+00	-3.74E+04	1.71E-02	1.93E-04	2.32E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.59E-01	0.00E+00	0.00E+00	0.00E+00
34	7.72E+01	15.1	1.01	2.73E+00	-3.72E+04	8.33E-02	0.00E+00	2.19E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.95E-01	0.00E+00	0.00E+00	0.00E+00
35	8.07E+01	42.4	1.01	2.93E+00	-8.29E+04	1.00E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-01
36[(1)]	2.64E-02	20	1.1	2.93E-04	na	1.00E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-01	0.00E+00
37[(1)]	3.53E-02	20	1.01	2.93E-04	na	9.80E-01	5.80E-04	4.46E-05	9.73E-03	4.97E-11	2.60E-08	5.55E-04	7.29E-03	1.33E-03	1.53E-05	0.00E+00	0.00E+00	0.00E+00
38	1.57E+01	10.8	1.04	8.54E-01	-2.46E+05	8.92E-01	2.78E-02	2.10E-06	4.28E-02	1.05E-11	1.08E-07	5.06E-03	5.74E-03	2.69E-02	1.22E-09	0.00E+00	0.00E+00	0.00E+00
39	1.57E-04	1.5	1.2	8.54E-06	-2.47E+00	9.80E-01	4.56E-04	4.96E-05	9.87E-03	3.05E-11	1.75E-08	7.06E-04	7.15E-03	1.31E-03	1.53E-05	0.00E+00	0.00E+00	0.00E+00
40	1.57E+01	89.6	1.4	8.56E-01	-2.41E+05	9.80E-01	4.89E-03	3.49E-03	5.78E-03	5.10E-10	3.53E-07	8.47E-05	4.68E-03	9.30E-04	1.52E-05	0.00E+00	0.00E+00	0.00E+00
41	1.51E+01	98.8	1.01	8.40E-01	-2.35E+05	9.99E-01	9.27E-04	1.29E-07	4.00E-05	3.03E-11	5.91E-06	2.01E-06	2.92E-05	9.02E-07	3.20E-25	0.00E+00	0.00E+00	0.00E+00
42	1.55E+01	13.9	1.01	8.60E-01	-2.46E+05	9.99E-01	8.86E-04	2.91E-10	5.87E-05	2.97E-13	5.07E-06	2.21E-05	7.63E-06	1.73E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	5.81E-01	68	1.01	2.14E-02	-4.55E+03	2.08E-01	4.26E-01	3.66E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.08E-04	0.00E+00	0.00E+00	0.00E+00
44	3.54E-01	20	1.01	1.96E-02	-5.62E+03	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.49E-09	1.49E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
45	3.16E-02	32.5	24.5	1.75E-03	-5.01E+02	9.80E-01	4.56E-04	4.96E-05	9.87E-03	3.05E-11	1.75E-08	7.06E-04	7.15E-03	1.31E-03	1.53E-05	0.00E+00	0.00E+00	0.00E+00

[(1)] *Apparent composition*

Table 4.3. Stream data for the CO_2 conditioning process for pipeline transport.

#	Vapor fraction	Temperature [°C]	Pressure [bar]	Molar flow [kmol/h]	Mole fraction			
					H_2O	CO_2	O_2	N_2
1	1.00	35.00	24.50	2078.11	0.0030	0.9970	0.0000	0.0000
2	1.00	28.20	24.01	2078.11	0.0030	0.9970	0.0000	0.0000
3	1.00	28.20	24.01	2076.64	0.0023	0.9977	0.0000	0.0000
4	1.00	28.91	22.81	2072.10	0.0001	0.9999	0.0000	0.0000
5	1.00	143.90	80.00	2072.10	0.0001	0.9999	0.0000	0.0000
6	0.00	28.20	78.40	2072.10	0.0001	0.9999	0.0000	0.0000
7	0.00	36.26	110.40	2072.10	0.0001	0.9999	0.0000	0.0000
8	0.00	28.20	110.00	2072.10	0.0001	0.9999	0.0000	0.0000

Table 4.4. Main energy consumers of the CAP. Design at medium air leak, operated at low air leak. First ½ of the year.

Variable	Value
$\dot{Q}_{\mathrm{heat,tot}}$ [MW$_{\mathrm{th}}$]	58.22
$\dot{Q}_{\mathrm{heat,Reb-1}}$ [MW$_{\mathrm{th}}$]	53.68
$T_{\mathrm{Reb-1}}$ [°C]	145
$\dot{Q}_{\mathrm{heat,Reb-2}}$ [MW$_{\mathrm{th}}$]	3.21
$T_{\mathrm{Reb-2}}$ [°C]	99
$\dot{Q}_{\mathrm{heat,Reb-3}}$ [MW$_{\mathrm{th}}$]	1.33
$T_{\mathrm{Reb-3}}$ [°C]	105
$\dot{Q}_{\mathrm{cool,tot}}$ [MW$_{\mathrm{th}}$]	76.74
$\dot{Q}_{\mathrm{cool,Cond-1}}$ [MW$_{\mathrm{th}}$]	0
$T_{\mathrm{out,Cond-1}}$ [°C]	-
$\dot{Q}_{\mathrm{cool,Cond-2}}$ [MW$_{\mathrm{th}}$]	2.42
$T_{\mathrm{out,Cond-2}}$ [°C]	68.0
$\dot{Q}_{\mathrm{cool,Cool-1}}$ [MW$_{\mathrm{th}}$]	9.71
$T_{\mathrm{out,Cool-1}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-2}}$ [MW$_{\mathrm{th}}$]	1.54
$T_{\mathrm{out,Cool-2}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-3}}$ [MW$_{\mathrm{th}}$]	24.08
$T_{\mathrm{out,Cool-3}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-4}}$ [MW$_{\mathrm{th}}$]	0.25
$T_{\mathrm{out,Cool-4}}$ [°C]	50.0
$\dot{Q}_{\mathrm{cool,Cool-5}}$ [MW$_{\mathrm{th}}$]	0.53
$T_{\mathrm{out,Cool-5}}$ [°C]	35.0
$\dot{Q}_{\mathrm{cool,Cool-6}}$ [MW$_{\mathrm{th}}$]	30.41
$T_{\mathrm{out,Cool-6}}$ [°C]	21.2
$\dot{Q}_{\mathrm{chill,tot}}$ [MW$_{\mathrm{th}}$]	4.07
$\dot{Q}_{\mathrm{chill,Chill-1}}$ [MW$_{\mathrm{th}}$]	4.04
$T_{\mathrm{out,Chill-1}}$ [°C]	12.0
$\dot{Q}_{\mathrm{chill,Chill-2}}$ [MW$_{\mathrm{th}}$]	0
$T_{\mathrm{out,Chill-2}}$ [°C]	-
$\dot{Q}_{\mathrm{chill,Chill-3}}$ [MW$_{\mathrm{th}}$]	0.03
$T_{\mathrm{out,Chill-3}}$ [°C]	15.0
$\dot{W}_{\mathrm{aux,tot}}$ [MW$_{\mathrm{el}}$]	3.19
$\dot{W}_{\mathrm{aux,Fan-1}}$ [MW$_{\mathrm{el}}$]	0.67
$\dot{W}_{\mathrm{aux,Pump-1}}$ [MW$_{\mathrm{el}}$]	2.51

Table 4.5. Main energy consumers of the CAP. Design at medium air leak, operated at medium air leak. Second ½ of the year.

Variable	Value
$\dot{Q}_{\mathrm{heat,tot}}$ [MW$_{\mathrm{th}}$]	63.11
$\dot{Q}_{\mathrm{heat,Reb-1}}$ [MW$_{\mathrm{th}}$]	56.50
$T_{\mathrm{Reb-1}}$ [°C]	147
$\dot{Q}_{\mathrm{heat,Reb-2}}$ [MW$_{\mathrm{th}}$]	4.70
$T_{\mathrm{Reb-2}}$ [°C]	99
$\dot{Q}_{\mathrm{heat,Reb-3}}$ [MW$_{\mathrm{th}}$]	1.92
$T_{\mathrm{Reb-3}}$ [°C]	105
$\dot{Q}_{\mathrm{cool,tot}}$ [MW$_{\mathrm{th}}$]	84.17
$\dot{Q}_{\mathrm{cool,Cond-1}}$ [MW$_{\mathrm{th}}$]	0
$T_{\mathrm{out,Cond-1}}$ [°C]	-
$\dot{Q}_{\mathrm{cool,Cond-2}}$ [MW$_{\mathrm{th}}$]	3.42
$T_{\mathrm{out,Cond-2}}$ [°C]	68.0
$\dot{Q}_{\mathrm{cool,Cool-1}}$ [MW$_{\mathrm{th}}$]	9.23
$T_{\mathrm{out,Cool-1}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-2}}$ [MW$_{\mathrm{th}}$]	3.00
$T_{\mathrm{out,Cool-2}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-3}}$ [MW$_{\mathrm{th}}$]	24.57
$T_{\mathrm{out,Cool-3}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-4}}$ [MW$_{\mathrm{th}}$]	0.11
$T_{\mathrm{out,Cool-4}}$ [°C]	50.0
$\dot{Q}_{\mathrm{cool,Cool-5}}$ [MW$_{\mathrm{th}}$]	0.49
$T_{\mathrm{out,Cool-5}}$ [°C]	35.0
$\dot{Q}_{\mathrm{cool,Cool-6}}$ [MW$_{\mathrm{th}}$]	29.02
$T_{\mathrm{out,Cool-6}}$ [°C]	21.2
$\dot{Q}_{\mathrm{chill,tot}}$ [MW$_{\mathrm{th}}$]	7.98
$\dot{Q}_{\mathrm{chill,Chill-1}}$ [MW$_{\mathrm{th}}$]	7.98
$T_{\mathrm{out,Chill-1}}$ [°C]	9.0
$\dot{Q}_{\mathrm{chill,Chill-2}}$ [MW$_{\mathrm{th}}$]	0
$T_{\mathrm{out,Chill-2}}$ [°C]	-
$\dot{Q}_{\mathrm{chill,Chill-3}}$ [MW$_{\mathrm{th}}$]	0
$T_{\mathrm{out,Chill-3}}$ [°C]	-
$\dot{W}_{\mathrm{aux,tot}}$ [MW$_{\mathrm{el}}$]	3.15
$\dot{W}_{\mathrm{aux,Fan-1}}$ [MW$_{\mathrm{el}}$]	0.85
$\dot{W}_{\mathrm{aux,Pump-1}}$ [MW$_{\mathrm{el}}$]	2.30

Table 4.6. Energy consumers of the CAP CO_2 drying and compression for pipeline transport.

Variable	Value
$\dot{Q}_{\mathrm{cool,Cool-C1}}$ [MW_{th}]	0.18
$\dot{Q}_{\mathrm{cool,Cool-C2}}$ [MW_{th}]	7.20
$\dot{Q}_{\mathrm{cool,Cool-C3}}$ [MW_{th}]	0.73
$\dot{W}_{\mathrm{aux,comp-C1}}$ [MW_{el}]	2.30
$\dot{W}_{\mathrm{aux,pump-C1}}$ [MW_{el}]	0.18

5 Membrane-assisted liquefaction

Responsible project partner: SINTEF ER

The process flowsheets for the membrane-assisted CO_2 liquefaction process for pipeline transport is shown in Figure 5.1.

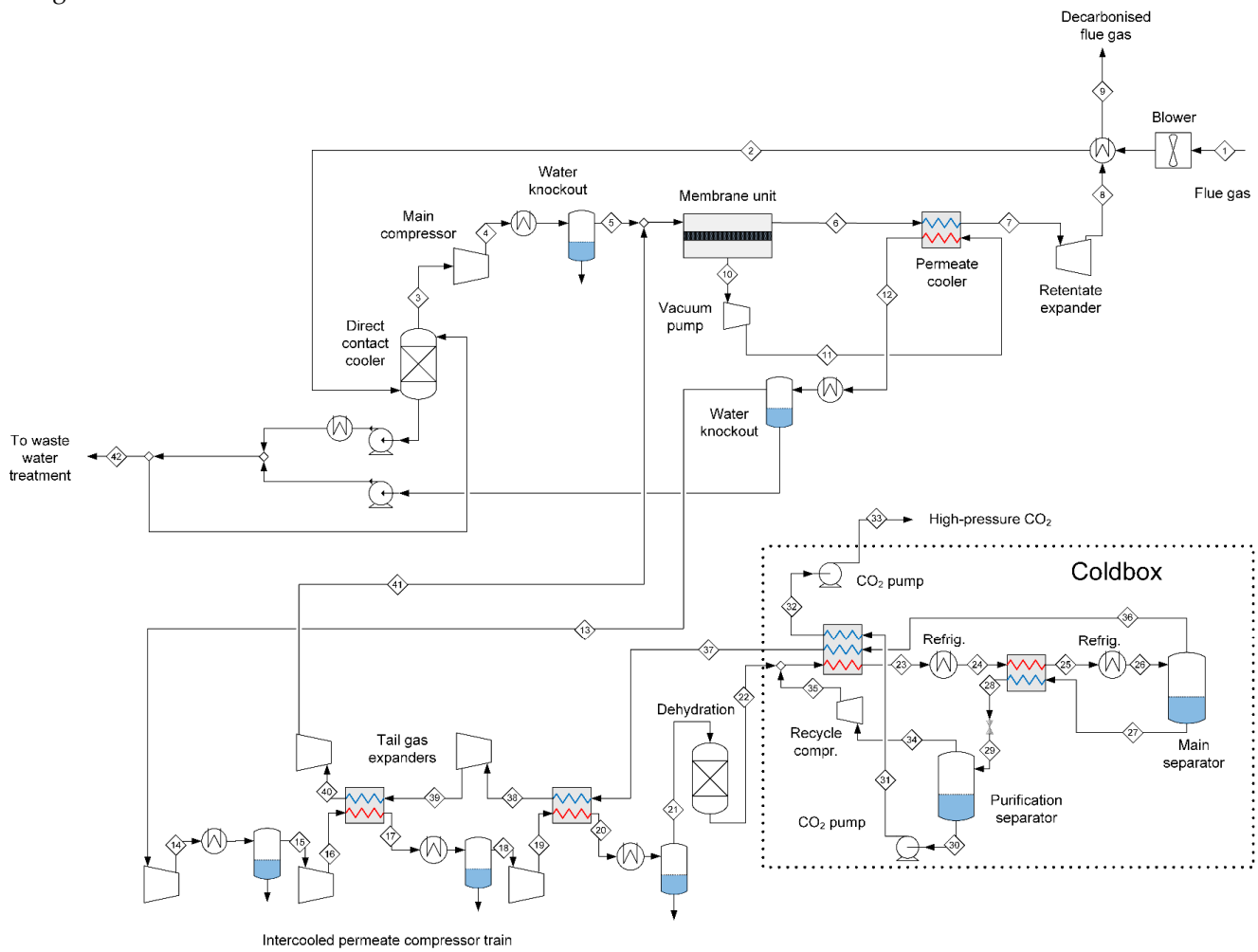

Figure 5.1. Process flowsheet of the membrane-assisted CO_2 liquefaction process, with liquefaction for pipeline transportation.

The process is designed for medium air leak in the mill, and in the first half of the year it is assumed to be operated with low air leak and in the second half of the year it is assumed to be operated with medium air leak. Stream data for the first half of the year is given in Table 5.1 and stream data for the second half of the year is given in Table 5.2.

Table 5.1. Stream data for membrane-assisted CO_2 liquefaction process designed for medium air leak operated with low air leak.

#	Vapor fraction	Temperature [°C]	Pressure [bar]	Molar flow [kmol/h]	Mole fraction			
					H_2O	CO_2	O_2	N_2
1	1.00	130.00	1.01	10362	0.1100	0.2200	0.0700	0.6000
2	1.00	139.32	1.18	10362	0.1100	0.2200	0.0700	0.6000
3	1.00	42.18	1.02	10036	0.0812	0.2270	0.0723	0.6195
4	1.00	28.70	30.75	4171	0.0000	0.6446	0.1192	0.2362
5	1.00	28.00	2.23	9382	0.0172	0.2428	0.0773	0.6627
6	1.00	26.23	2.23	7147	0.0003	0.0308	0.1002	0.8687
7	1.00	106.54	2.09	7147	0.0003	0.0308	0.1002	0.8687
8	1.00	53.62	1.10	7147	0.0003	0.0308	0.1002	0.8687
9	1.00	72.00	1.08	7147	0.0003	0.0308	0.1002	0.8687
10	1.00	26.23	0.23	4068	0.0391	0.6180	0.1137	0.2292
11	1.00	188.86	1.03	4068	0.0391	0.6180	0.1137	0.2292
12	1.00	76.20	1.01	4068	0.0391	0.6180	0.1137	0.2292
13	1.00	28.00	1.01	4060	0.0372	0.6192	0.1140	0.2297
14	1.00	137.00	3.24	4060	0.0372	0.6192	0.1140	0.2297
15	1.00	28.00	3.18	3958	0.0122	0.6352	0.1169	0.2356
16	1.00	137.39	10.17	3958	0.0122	0.6352	0.1169	0.2356
17	1.00	101.93	9.97	3958	0.0122	0.6352	0.1169	0.2356
18	1.00	28.00	9.97	3926	0.0043	0.6403	0.1179	0.2375
19	1.00	138.96	31.89	3926	0.0043	0.6403	0.1179	0.2375
20	1.00	96.25	31.25	3926	0.0043	0.6403	0.1179	0.2375
21	1.00	28.00	31.25	3917	0.0019	0.6418	0.1181	0.2381
22	1.00	28.00	31.25	3909	0.0000	0.6431	0.1184	0.2385
23	0.88	-25.93	30.35	4171	0.0000	0.6446	0.1192	0.2362
24	0.57	-39.15	29.95	4171	0.0000	0.6446	0.1192	0.2362
25	0.54	-42.05	29.55	4171	0.0000	0.6446	0.1192	0.2362
26	0.44	-54.00	29.15	4171	0.0000	0.6446	0.1192	0.2362
27	0.00	-54.00	29.15	2338	0.0000	0.9550	0.0188	0.0262
28	0.01	-42.15	28.75	2338	0.0000	0.9550	0.0188	0.0262
29	0.12	-55.00	8.41	2338	0.0000	0.9550	0.0188	0.0262
30	0.00	-55.00	8.41	2065	0.0000	0.9940	0.0031	0.0030
31	0.00	-51.73	80.00	2065	0.0000	0.9940	0.0031	0.0030
32	0.00	7.33	79.60	2065	0.0000	0.9940	0.0031	0.0030
33	0.00	10.76	110.00	2065	0.0000	0.9940	0.0031	0.0030
34	1.00	-55.00	8.41	273	0.0000	0.6603	0.1380	0.2017
35	1.00	45.03	31.25	273	0.0000	0.6603	0.1380	0.2017
36	1.00	-54.00	29.15	1833	0.0000	0.2486	0.2473	0.5041
37	1.00	7.33	28.57	1833	0.0000	0.2486	0.2473	0.5041
38	1.00	113.96	28.00	1833	0.0000	0.2486	0.2473	0.5041
39	1.00	23.37	8.40	1833	0.0000	0.2486	0.2473	0.5041
40	1.00	112.39	8.23	1833	0.0000	0.2486	0.2473	0.5041
41	1.00	17.15	2.23	1833	0.0000	0.2486	0.2473	0.5041
42	0.00	28.00	5.27	332	0.9999	0.0001	0.0000	0.0000

Table 5.2. Stream data for membrane-assisted CO_2 liquefaction process designed for medium air leak and operated with medium air leak.

#	Vapor fraction	Temperature [°C]	Pressure [bar]	Molar flow [kmol/h]	Mole fraction			
					H_2O	CO_2	O_2	N_2
1	1.00	110.00	1.01	12770	0.0900	0.1800	0.1000	0.6300
2	1.00	110.51	1.18	12770	0.0900	0.1800	0.1000	0.6300
3	1.00	40.11	1.02	12532	0.0728	0.1833	0.1019	0.6420
4	1.00	28.92	33.77	4610	0.0000	0.6008	0.1630	0.2362
5	1.00	28.00	2.50	11801	0.0154	0.1947	0.1082	0.6817
6	1.00	26.93	2.50	9520	0.0002	0.0231	0.1326	0.8441
7	1.00	105.02	2.35	9520	0.0002	0.0231	0.1326	0.8441
8	1.00	43.27	1.10	9520	0.0002	0.0231	0.1326	0.8441
9	1.00	72.00	1.08	9520	0.0002	0.0231	0.1326	0.8441
10	1.00	26.93	0.20	4515	0.0398	0.5749	0.1561	0.2292
11	1.00	209.11	1.03	4515	0.0398	0.5749	0.1561	0.2292
12	1.00	76.90	1.01	4515	0.0398	0.5749	0.1561	0.2292
13	1.00	28.00	1.01	4503	0.0372	0.5765	0.1565	0.2299
14	1.00	141.70	3.34	4503	0.0372	0.5765	0.1565	0.2299
15	1.00	28.00	3.28	4388	0.0119	0.5916	0.1606	0.2359
16	1.00	142.12	10.81	4388	0.0119	0.5916	0.1606	0.2359
17	1.00	102.22	10.60	4388	0.0119	0.5916	0.1606	0.2359
18	1.00	28.00	10.60	4353	0.0041	0.5963	0.1619	0.2378
19	1.00	143.75	34.97	4353	0.0041	0.5963	0.1619	0.2378
20	1.00	94.86	34.27	4353	0.0041	0.5963	0.1619	0.2378
21	1.00	28.00	34.27	4343	0.0018	0.5976	0.1622	0.2383
22	1.00	28.00	34.27	4335	0.0000	0.5987	0.1625	0.2388
23	0.89	-26.40	33.37	4610	0.0000	0.6008	0.1630	0.2362
24	0.62	-39.15	32.97	4610	0.0000	0.6008	0.1630	0.2362
25	0.59	-41.91	32.57	4610	0.0000	0.6008	0.1630	0.2362
26	0.48	-54.00	32.17	4610	0.0000	0.6008	0.1630	0.2362
27	0.00	-54.00	32.17	2376	0.0000	0.9475	0.0260	0.0265
28	0.01	-42.15	31.77	2376	0.0000	0.9475	0.0260	0.0265
29	0.12	-55.00	8.93	2376	0.0000	0.9475	0.0260	0.0265
30	0.00	-55.00	8.93	2083	0.0000	0.9927	0.0043	0.0030
31	0.00	-51.75	80.00	2083	0.0000	0.9927	0.0043	0.0030
32	0.00	8.71	79.60	2083	0.0000	0.9927	0.0043	0.0030
33	0.00	12.27	110.00	2083	0.0000	0.9927	0.0043	0.0030
34	1.00	-55.00	8.93	293	0.0000	0.6256	0.1808	0.1935
35	1.00	48.80	34.27	293	0.0000	0.6256	0.1808	0.1935
36	1.00	-54.00	32.17	2234	0.0000	0.2320	0.3088	0.4592
37	1.00	8.71	31.53	2234	0.0000	0.2320	0.3088	0.4592
38	1.00	118.75	30.90	2234	0.0000	0.2320	0.3088	0.4592
39	1.00	26.84	9.29	2234	0.0000	0.2320	0.3088	0.4592
40	1.00	117.12	9.10	2234	0.0000	0.2320	0.3088	0.4592
41	1.00	21.30	2.50	2234	0.0000	0.2320	0.3088	0.4592
42	0.00	28.00	5.55	249	0.9999	0.0001	0.0000	0.0000

6 Calcium looping – Tail-End configuration

Responsible project partner: PoliMi (core process and steam cycle), SINTEF ER (CPU)

The process flowsheet for calcium looping tail-end process is shown in Figure 6.1, and a process flow diagram of the CPU is given in Figure 6.2.

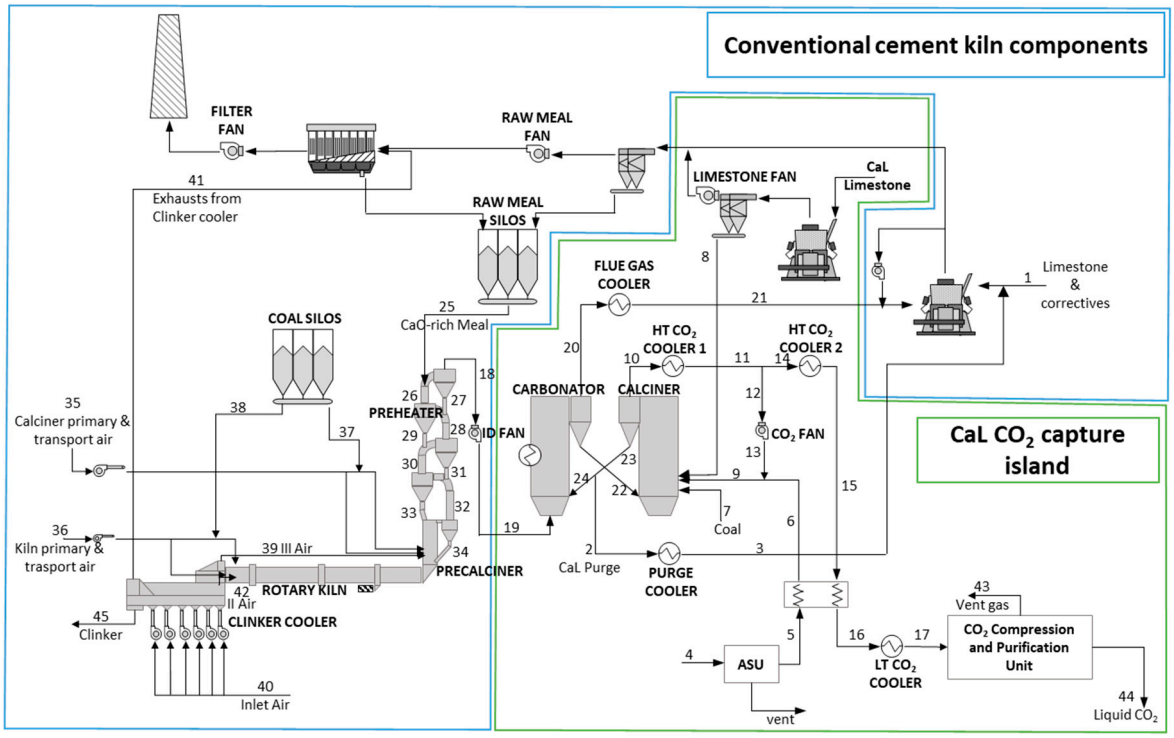

Figure 6.1. Process flowsheet of the tail-end CaL process integration for CO_2 capture in a cement kiln.

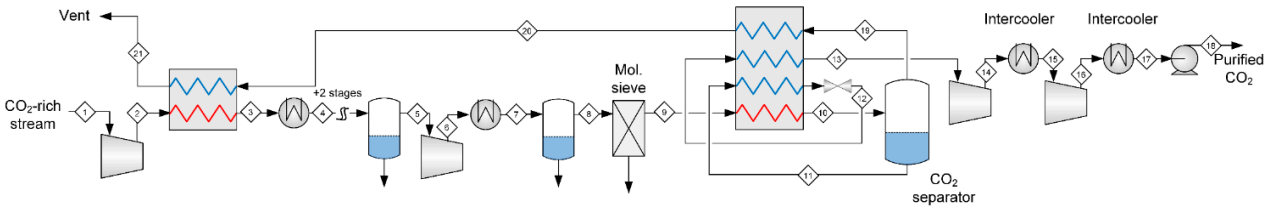

Figure 6.2. Process flowsheet of the CPU for pipeline transport.

Stream data for the core process is given in Table 6.1. Stream data for the CPU is given in Table 6.2.

Table 6.1. Streams properties of CaL cement kiln with IL=50% (s: solid stream, g: gas stream).

Stream (IL50%)		G	m*	T	Mass composition [wt%]												Molar composition [vol%]				
		[kg/s]	[kg/kg$_{CLK}$]	[°C]	Al_2O_3	$CaCO_3$	CaO	Fe_2O_3	$H2O_{(L)}$	$MgCO_3$	MgO	SiO_2	C3S	C2S	C3A	$CaSO_4$	C4AF	Ar	CO_2	H_2O	O_2	N_2
1	s	32.14	0.98	60.0	4.62	66.85	0.00	3.27	0.41	2.47	0.00	22.38	0.00	0.00	0.00	0.00	0.00					
2	s	12.98	0.40	920.1	2.50	0.00	92.72	0.31	0.00	0.00	0.13	3.36	0.00	0.00	0.00	0.99	0.00					
3	s	12.98	0.40	120.0	2.50	0.00	92.72	0.31	0.00	0.00	0.13	3.36	0.00	0.00	0.00	0.99	0.00					
4	g	62.22	1.90	15.0														0.92	0.03	1.034	20.733	77.282
5	g	15.14	0.46	15.0														3.00	0.00	0.00	95.00	2.00
6	g	15.14	0.46	150.0														3.00	0.00	0.00	95.00	2.00
7	s	6.06	0.19	60.0	69% C, 4% H, 0.5% S, 0.48% N, 9% O, 16.5% Ash, 0.5% Moisture, 0.02% Cl; LHV 27.15 MJ/kg																	
8	s	21.25	0.65	60.0	-	100	-	-	-	-	-	-	-	-	-	-	-					
9	g	34.09	1.04	315.5														2.15	40.73	5.64	50.00	1.48
10	g	62.56	1.91	920.1														1.30	81.45	11.28	5.00	0.97
11	g	62.56	1.91	400.0														1.30	81.45	11.28	5.00	0.97
12	g	18.96	0.58	400.0														1.30	81.45	11.28	5.00	0.97
13	g	18.96	0.58	426.9														1.30	81.45	11.28	5.00	0.97
14	g	43.60	1.33	400.0														1.30	81.45	11.28	5.00	0.97
15	g	43.60	1.33	320.0														1.30	81.45	11.28	5.00	0.97
16	g	43.60	1.33	280.9														1.30	81.45	11.28	5.00	0.97
17	g	43.60	1.33	35.0														1.30	81.45	11.28	5.00	0.97
18	g	55.35	1.69	339.4														0.79	20.15	4.13	8.67	66.27
	s	2.16	0.07	339.4	4.02	47.77	26.75	2.43	0.00	1.72	0.06	16.95	0.00	0.01	0.00	0.28	0.00					
19	g	55.35	1.69	60.0														0.79	20.15	4.13	8.67	66.27
	s	2.16	0.07	60.0	4.02	47.77	26.75	2.43	0.00	1.72	0.06	16.95	0.00	0.01	0.00	0.28	0.00					
20	g	41.22	1.26	650.0														0.96	2.46	5.04	10.59	80.95
21	g	41.22	1.26	445.5														0.96	2.46	5.04	10.59	80.95
22	s	78.56	2.40	650.0	2.05	40.90	53.12	0.25	0.00	0.00	0.11	2.76	0.00	0.00	0.00	0.81	0.00					
23	s	77.42	2.37	920.1	2.50	0.00	92.71	0.31	0.00	0.00	0.13	3.36	0.00	0.00	0.00	0.99	0.00					
24	s	64.43	1.97	920.1	2.50	0.00	92.71	0.31	0.00	0.00	0.13	3.36	0.00	0.00	0.00	0.99	0.00					
25	s	45.12	1.38	60.0	4.01	47.62	26.67	2.42	0.29	1.76	0.04	16.91	0.00	0.00	0.00	0.28	0.00					

Stream (IL50%)		G	m*	T	Mass composition [wt%]												Molar composition [vol%]				
		[kg/s]	[kg/kg$_{CLK}$]	[°C]	Al_2O_3	$CaCO_3$	CaO	Fe_2O_3	$H2O_{(L)}$	$MgCO_3$	MgO	SiO_2	C3S	C2S	C3A	$CaSO_4$	C4AF	Ar	CO_2	H_2O	O_2	N_2
26	g	54.42	1.66	522.0														0.79	20.55	3.77	8.51	66.37
	s	8.35	0.26	522.0	4.03	47.82	26.72	2.43	0.00	1.48	0.18	16.95	0.02	0.08	0.00	0.28	0.01					
27	s	51.18	1.57	339.4	4.02	47.77	26.75	2.43	0.00	1.72	0.06	16.95	0.00	0.01	0.00	0.28	0.00					
28	g	54.03	1.65	664.1														0.79	20.72	3.80	8.41	66.28
	s	8.49	0.26	664.1	4.05	48.14	26.58	2.44	0.00	0.00	0.89	16.91	0.15	0.49	0.03	0.29	0.03					
29	s	51.32	1.57	522.0	4.03	47.82	26.72	2.43	0.00	1.48	0.18	16.95	0.02	0.08	0.00	0.28	0.01					
30	g	53.63	1.64	768.6														0.79	20.88	3.82	8.32	66.20
	s	9.18	0.28	768.6	4.16	40.13	30.84	2.50	0.00	0.00	0.93	16.52	0.97	3.25	0.21	0.32	0.17					
31	s	52.02	1.59	664.1	4.05	48.14	26.58	2.44	0.00	0.00	0.89	16.91	0.15	0.49	0.03	0.29	0.03					
32	g	53.24	1.63	860.2														0.79	21.05	3.84	8.21	66.11
	s	12.38	0.38	860.2	4.64	6.48	48.74	2.77	0.00	0.00	1.10	14.86	4.45	14.85	0.94	0.42	0.77					
33	s	55.21	1.69	768.6	4.16	40.13	30.84	2.50	0.00	0.00	0.93	16.52	0.97	3.25	0.21	0.32	0.17					
34	s	38.33	1.17	860.2	4.64	6.48	48.74	2.77	0.00	0.00	1.10	14.86	4.45	14.85	0.94	0.42	0.77					
35	g	0.31	0.01	15.0														0.92	0.03	1.03	20.73	77.28
36	g	3.29	0.10	15.0														0.92	0.03	1.03	20.73	77.28
37	s	1.02	0.03	60.0	69% C, 4% H, 0.5% S, 0.48% N, 9% O, 16.5% Ash, 0.5% Moisture, 0.02% Cl; LHV 27.15MJ/kg																	
38	s	1.47	0.04	60.0	69% C, 4% H, 0.5% S, 0.48% N, 9% O, 16.5% Ash, 0.5% Moisture, 0.02% Cl; LHV 27.15 MJ/kg																	
39	g	26.19	0.80	1049.8														0.92	0.03	1.03	20.73	77.28
	s	0.69	0.02	1049.8	0.00	0.00	0.77	0.00	0.00	0.00	1.14	0.00	64.76	14.10	9.24	0.51	9.48					
40	g	78.47	2.40	15.0														0.92	0.03	1.03	20.73	77.28
41	g	41.31	1.26	298.7														0.92	0.03	1.03	20.73	77.28
	s	1.19	0.04	298.7	0.00	0.00	0.77	0.00	0.00	0.00	1.14	0.00	64.76	14.10	9.24	0.51	9.48					
42	G	10.97	0.34	1137.0														0.92	0.03	1.03	20.73	77.28
	S	0.27	0.01	1137.0	0.00	0.00	0.77	0.00	0.00	0.00	1.14	0.00	64.77	14.10	9.24	0.51	9.48					
43*	G	See stream #21 in Table 6.2																				
44	G	See stream #18 in Table 6.2																				
45	S	32.70	1.00	114.9	0.00	0.00	0.77	0.00	0.00	0.00	1.14	0.00	64.76	14.10	9.24	0.51	9.48					

*CPU vent gas to atmosphere

Table 6.2. Main stream data for the CPU with pipeline transport in the calcium looping tail-end process.

#	Vapor fraction	Temperature [°C]	Pressure [bar]	Molar flow [kmol/h]	Mole fraction			
					H_2O	CO_2	O_2	N_2
1	0.94	35.00	1.01	3897.60	0.0130	0.8145	0.1128	0.0500
9	1.00	30.23	22.59	3457.66	0.0147	0.9180	0.0000	0.0564
17	0.00	28.00	82.32	3216.59	0.0083	0.9610	0.0000	0.0267
18	1.00	37.43	110.00	3216.59	0.0083	0.9610	0.0000	0.0267
19	1.00	-50.00	22.59	241.07	0.0994	0.3448	0.0000	0.4519
20	1.00	20.23	22.59	241.07	0.0994	0.3448	0.0000	0.4519
21	1.00	71.21	1.10	241.07	0.0994	0.3448	0.0000	0.4519

7 Calcium looping – Integrated entrained flow configuration

Responsible project partner: PoliMi (core process and steam cycle), SINTEF ER (CPU)

The process flowsheet for calcium looping integrated entrained flow process is shown in Figure 7.1. The process flow diagram of the CPU is identical to the calcium looping tail-end process and is given in Figure 6.2.

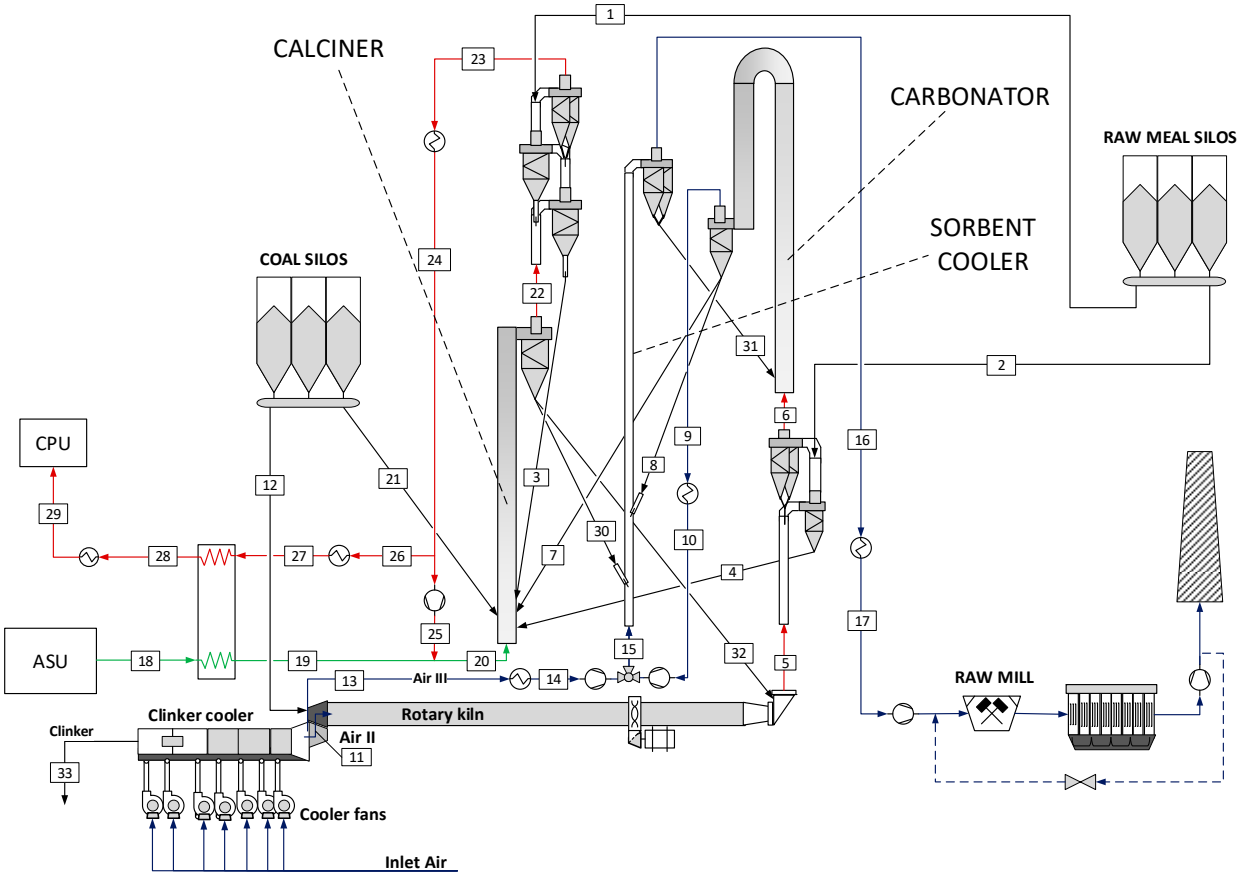

Figure 7.1. Process flowsheet of the integrated CaL process with entrained flow reactors.

Stream data for the core process is given in Table 7.1. Stream data for the CPU is given in Table 7.2.

Table 7.1. Streams properties of integrated CaL cement kiln (s: solid stream, g: gas stream)

Stream	G	V	T	P	Molar composition [vol%]						Mass composition [wt%]										
	[kg/s]	[Nm³/h]	[°C]	[bar]	Ar	CO_2	H_2O	N_2	O_2	$H_2O_{(L)}$	C4AF	C3S	C3A	C2S	CaO	$CaCO_3$	SiO_2	A	F	$MgCO_3$	MgO	$CaSO_4$
1 (s)	33.28	-	60.0	1.00						0.29						79.41	13.41	3.34	2.02	1.53		
2 (s)	18.71	-	60.0	1.00						0.29						79.41	13.41	3.34	2.02	1.53		
3 (s)	35.41	-	883.4	1.00							0.09	0.52	0.11	1.75	5.73	71.01	13.57	3.57	2.12	1.36	0.13	0.04
4 (s)	20.49	-	749.9	1.00							1.37	9.03	1.50	1.96	0.11	68.34	11.54	2.88	1.74	1.32	0.16	0.05
5 (g)	16.75	45,156	1536.4	1.00	0.86	16.21	5.06	71.81	6.07													
5 (s)	2.93	-	1534.2	1.00							9.65	63.62	10.58	13.85	0.77						1.16	0.38
6 (g)	16.81	45,405	434.4	1.00	0.85	16.12	5.58	71.41	6.04													
6 (s)	1.10	-	434.4	1.00							0.21	1.37	0.23	0.30	0.02	77.93	13.16	3.28	1.98	1.51	0.03	0.01
7 (s)	46.12	-	667.9	1.00							0.84	5.04	1.01	13.45	34.82	22.93	13.28	4.73	2.57		1.04	0.28
8 (s)	98.01	-	667.9	1.00							0.84	5.04	1.01	13.45	34.82	22.93	13.28	4.73	2.57		1.04	0.28
9 (g)	13.71	39,445	667.9	1.00	0.97	3.91	6.39	81.81	6.92													
9 (s)	7.59	-	667.9	1.00							0.84	5.04	1.01	13.45	34.82	22.93	13.28	4.73	2.57		1.04	0.28
10 (g)	13.71	39,445	281.7	0.96	0.97	3.91	6.39	81.81	6.92													
10 (s)	7.59		281.7	0.96							0.84	5.04	1.01	13.45	34.82	22.93	13.28	4.73	2.57		1.04	0.28
11 (g)	11.43	30,557	1137.0	1.00	0.92	0.03	1.03	77.28	20.73													
12 (s)	1.12	-	60.0	1.00	69% C, 4% H, 0.5% S, 0.48% N, 9% O, 16.5% Ash, 0.5% Moisture, 0.02% Cl; LHV 27.15 MJ/kg																	
13 (g)	26.19	73,248	1049.8	1.00	0.92	0.03	1.03	77.28	20.73													
13 (s)	0.76	-	1049.8	1.00							9.65	63.62	10.58	13.85	0.77						1.16	0.38
14 (g)	26.19	73,248	281.7	1.00	0.92	0.03	1.03	77.28	20.73													
14 (s)	0.76	-	281.7	1.00							9.65	63.62	10.58	13.85	0.77						1.16	0.38
15 (g)	39.90	112,690	290.5	1.04	0.94	1.36	2.87	78.84	15.99													
15 (s)	8.35	-	290.5	1.04							1.65	10.40	1.88	13.50	31.71	20.84	12.07	4.30	2.34		1.05	0.29
16 (g)	39.90	112,692	622.1	1.00	0.94	1.38	2.89	78.86	15.94													
17 (g)	39.90	112,692	437.2	1.00	0.94	1.38	2.89	78.86	15.94													
18 (g)	12.38	31,356	15.0	1.11	3.00			2.00	95.00													
19 (g)	12.38	31,356	150.0	1.11	3.00			2.00	95.00													
20 (g)	52.33	112,273	361.4	1.11	1.67	62.18	8.74	1.18	26.22													

Stream	G	V	T	P	Molar composition [vol%]						Mass composition [wt%]											
	[kg/s]	[Nm³/h]	[°C]	[bar]	Ar	CO_2	H_2O	N_2	O_2	$H_2O_{(L)}$	C4AF	C3S	C3A	C2S	CaO	$CaCO_3$	SiO_2	A	F	$MgCO_3$	MgO	$CaSO_4$
20 (s)	1.02	-	361.4	1.11								0.01	0.00	0.04	0.14	79.43	13.45	3.36	2.03	1.53	0.00	0.00
21 (s)	4.92	-	60.0	1.00	69% C, 4% H, 0.5% S, 0.48% N, 9% O, 16.5% Ash, 0.5% Moisture, 0.02% Cl; LHV 27.15 MJ/kg																	
22 (g)	76.62	154,734	920.1	1.00	1.27	81.47	11.17	0.94	5.15													
22 (s)	4.18	-	920.1	1.00							0.76	4.44	0.93	14.81	48.60	6.46	14.53	5.21	2.83		1.13	0.31
23 (g)	76.72	155,162	608.8	1.00	1.26	81.24	11.43	0.94	5.14													
23 (s)	1.96	-	608.8	1.00								0.01	0.00	0.04	0.14	79.43	13.45	3.36	2.03	1.53	0.00	0.00
24 (g)	76.72	155,162	400.0	1.00	1.26	81.24	11.43	0.94	5.14													
24 (s)	1.96		400.0	1.00								0.01	0.00	0.04	0.14	79.43	13.45	3.36	2.03	1.53	0.00	0.00
25 (g)	40.40	80,917	415.2	1.11	1.26	81.24	11.43	0.94	5.14													
25 (s)	1.03		415.2	1.11								0.01	0.00	0.04	0.14	79.43	13.45	3.36	2.03	1.53	0.00	0.00
26 (g)	36.32	74,245	400.0	1.00	1.26	81.24	11.43	0.94	5.14													
26 (s)	0.93		400.0	1.00								0.01	0.00	0.04	0.14	79.43	13.45	3.36	2.03	1.53	0.00	0.00
27 (g)	36.32	74,245	320.0	1.00	1.26	81.24	11.43	0.94	5.14													
27 (s)	0.93		320.0	1.00								0.01	0.00	0.04	0.14	79.43	13.45	3.36	2.03	1.53	0.00	0.00
28 (g)	36.32	74,245	283.0	1.00	1.26	81.24	11.43	0.94	5.14													
28 (s)	0.93		283.0	1.00								0.01	0.00	0.04	0.14	79.43	13.45	3.36	2.03	1.53	0.00	0.00
29 (g)	36.32	74,245	35.0	1.00	1.26	81.24	11.43	0.94	5.14													
30 (s)	41.17	-	920.1	1.00							0.76	4.44	0.93	14.81	48.60	6.46	14.53	5.21	2.83		1.13	0.31
31 (s)	147.52	-	622.1	1.00							0.87	5.17	1.04	13.83	38.49	18.21	13.56	4.84	2.63		1.07	0.29
32 (s)	38.32	-	920.1	1.00							0.76	4.44	0.93	14.81	48.60	6.46	14.53	5.21	2.83		1.13	0.31
33 (s)	32.56	-	114.9	1.00							9.65	63.62	10.58	13.85	0.77						1.16	0.38

Table 7.2. Main stream data for the CPU with pipeline transport in the calcium looping integrated entrained flow process.

#	Vapor fraction	Temperature [°C]	Pressure [bar]	Molar flow [kmol/h]	Mole fraction			
					H_2O	CO_2	O_2	N_2
1	0.94	35.00	1.01	3420.00	0.0126	0.8116	0.1147	0.0516
9	1.00	30.32	21.60	3027.47	0.0142	0.9167	0.0000	0.0583
17	0.00	28.00	82.32	2794.23	0.0075	0.9634	0.0000	0.0255
18	1.00	37.13	110.00	2794.23	0.0075	0.9634	0.0000	0.0255
19	1.00	-50.00	21.60	233.24	0.0944	0.3573	0.0000	0.4512
20	1.00	20.32	21.60	233.24	0.0944	0.3573	0.0000	0.4512
21	1.00	70.08	1.12	233.24	0.0944	0.3573	0.0000	0.4512