CEMCAP

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CEMCAP comparative techno-economic analysis of CO_2 capture in cement plants

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SINTEF Energy Research

1 REFERENCE CEMENT KILN

1.1 Process flow diagram

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.

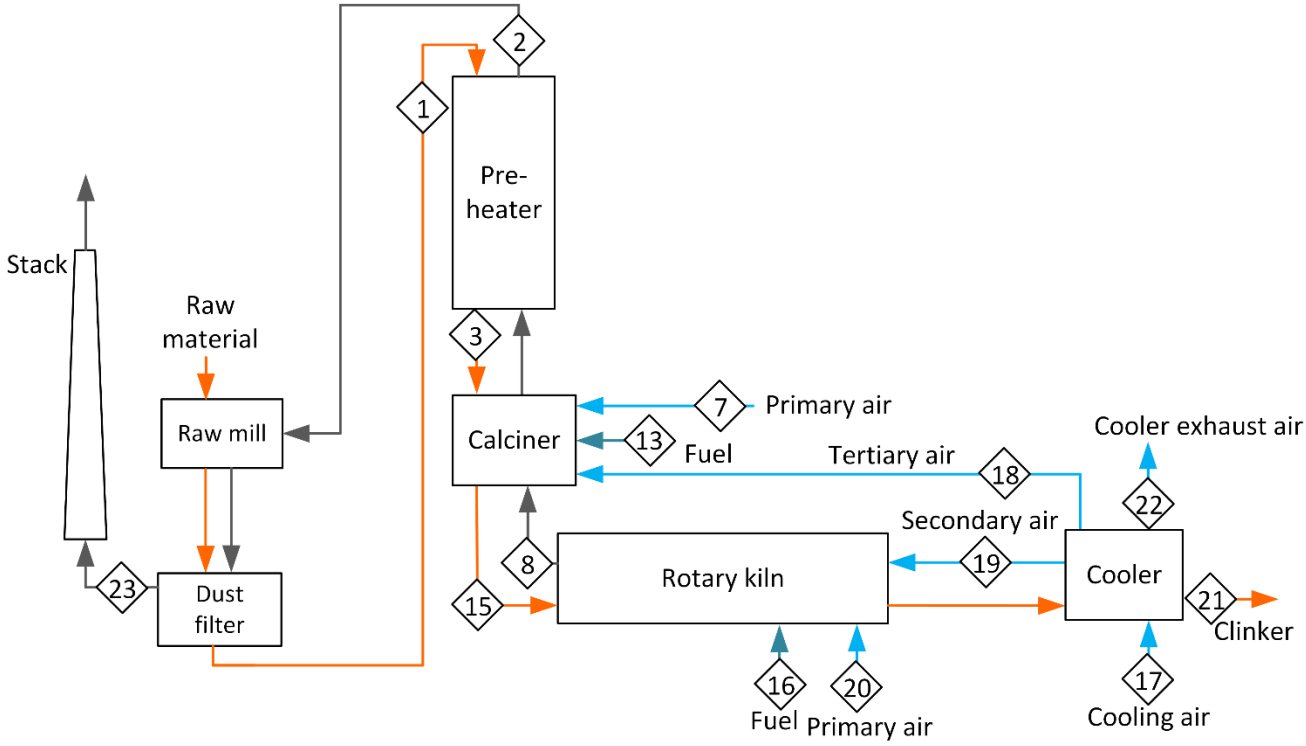

Figure 1.1. Process flowsheet of the reference cement kiln.

1.2 Stream data

Stream data for solid streams in the reference cement kiln are given in Table 1.1 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 [kg/h]	T [°C]	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	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.

2 MEA ABSORPTION

The project partners responsible for the process simulations and for compiling equipment lists for the MEA absorption technology are listed in Table 2.1.

Table 2.1. Responsible project partners for process simulations and compilation of equipment lists for the MEA absorption technology.

	Responsible partner
Process simulations	SINTEF ER
Equipment lists	SINTEF ER

2.1 Process flow diagrams

Process flow diagrams for the MEA process is given in Figure 2.1. Process flow diagrams for conditioning of CO_2 for transport by pipeline is given in Figure 2.2 and for transport by ship is given in Figure 2.3.

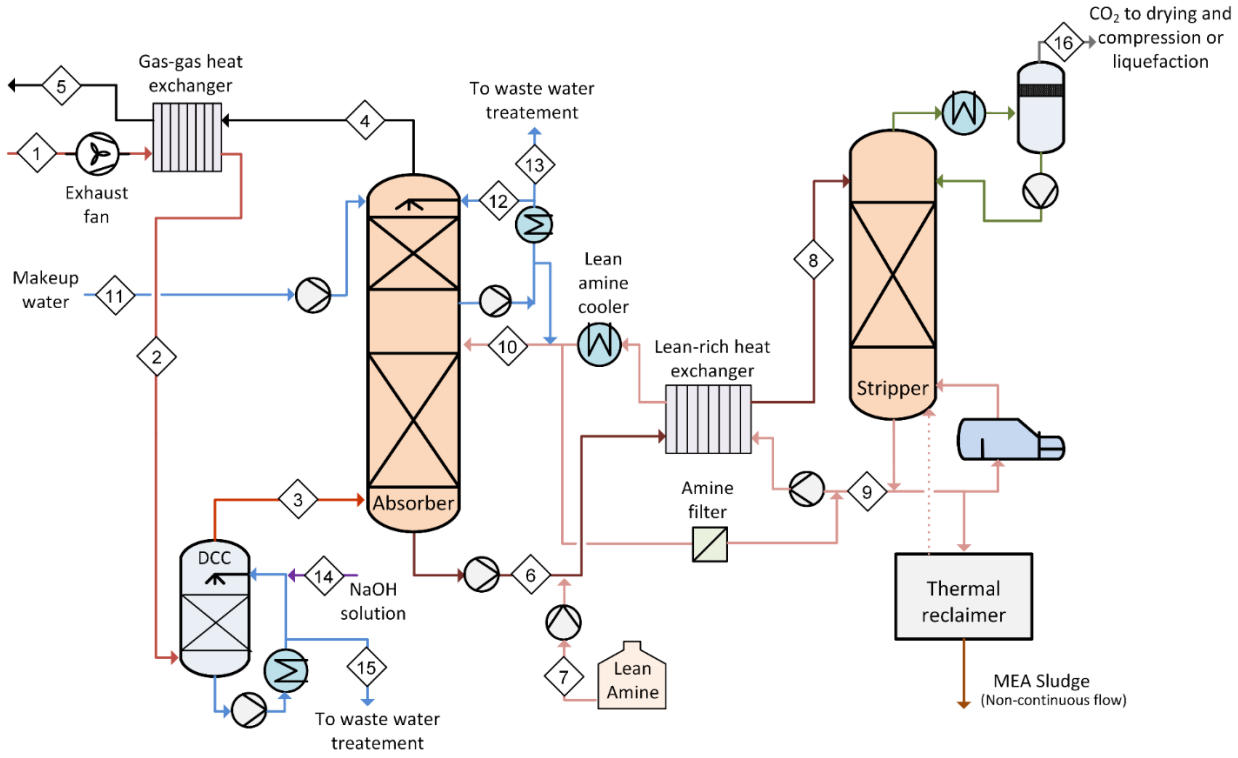

Figure 2.1. Process flowsheet of the MEA process.

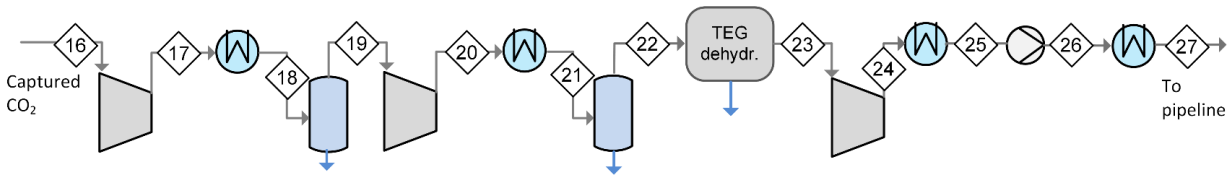

Figure 2.2. Process flowsheet of CO_2 drying and compression for pipeline transport.

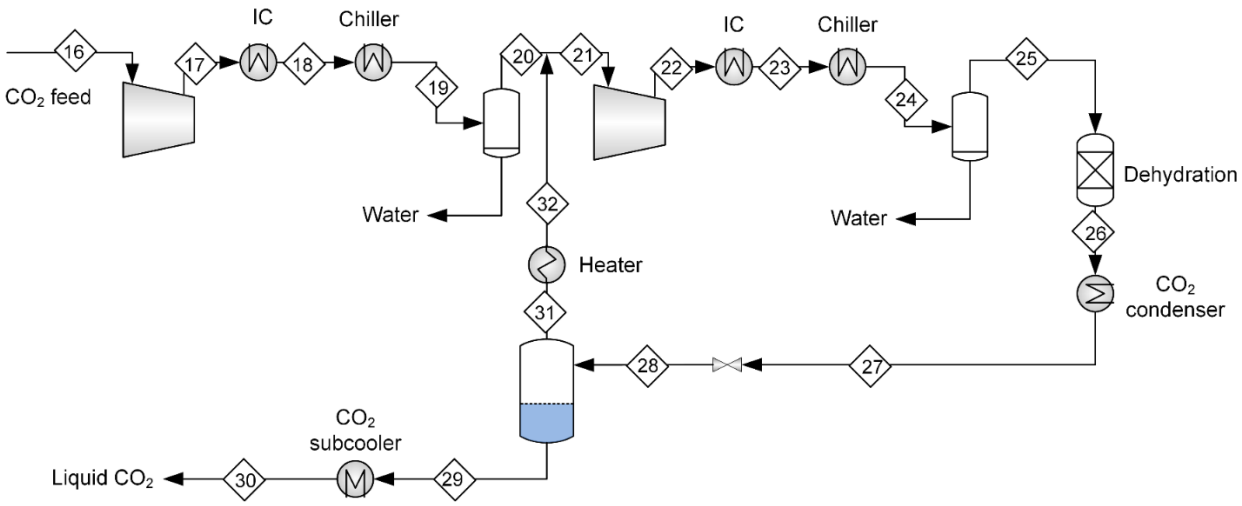

Figure 2.3. Process flowsheet of CO_2 dehydration and liquefaction for ship transport.

2.2 Stream data

2.2.1 Base case

In the base case 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 2.2 and stream data for the second half of the year is given in Table 2.3. Stream data for the CO_2 conditioning process is given in Table 2.4.

Table 2.2. Stream data for MEA process designed for medium air leak operated with low air leak in raw mill.

#	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

#	Vapor fraction	Temperature [°C]	Pressure [bar]	Molar flow [kmol/h]	Mole fraction					
					MEA	H_2O	CO_2	O_2	N_2	NaOH
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 MEA process designed for medium air leak and operated with medium air leak in raw mill.

#	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 2.4. 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

2.2.2 Constant low air leak in mill

Stream data for the MEA process in the case with constant low air leak in the mill is given in Table 2.5. The CO_2 conditioning process is identical to the conditioning process in the base case.

Table 2.5. Stream data for MEA process designed for low air leak and operated with low air leak.

#	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

2.2.3 Optional extent of capture

The energy performance and cost of the MEA process for a case with 60% CO_2 avoided from the flue gas was estimated. It was assumed that 60% of the flue gas was treated and the rest was

bypassed. The energy performance and cost of the process were estimated by scaling the results of the base case. See the base case for stream data.

2.2.4 Ship transport

In the ship transport case, the capture process is identical to the base case. Stream data for the CO_2 conditioning process is given in Table 2.6.

Table 2.6. Stream data for the CO_2 conditioning process for ship 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	159.1	5.85	2137	0.0000	0.0295	0.9691	0.0003	0.0011	0.0000
18	0.98	28.2	5.73	2137	0.0000	0.0295	0.9691	0.0003	0.0011	0.0000
19	0.97	4.0	5.62	2137	0.0000	0.0295	0.9691	0.0003	0.0011	0.0000
20	1.00	4.0	5.62	2077	0.0000	0.0016	0.9970	0.0003	0.0011	0.0000
21	1.00	3.6	5.62	2262	0.0000	0.0014	0.9883	0.0018	0.0085	0.0000
22	1.00	95.5	17.42	2262	0.0000	0.0014	0.9883	0.0018	0.0085	0.0000
23	1.00	28.2	17.07	2262	0.0000	0.0014	0.9883	0.0018	0.0085	0.0000
24	1.00	4.0	16.73	2262	0.0000	0.0014	0.9883	0.0018	0.0085	0.0000
25	1.00	4.0	16.73	2260	0.0000	0.0007	0.9891	0.0018	0.0085	0.0000
26	1.00	4.0	16.23	2258	0.0000	0.0000	0.9897	0.0018	0.0085	0.0000
27	0.00	-39.2	15.83	2258	0.0000	0.0000	0.9897	0.0018	0.0085	0.0000
28	0.08	-51.9	6.90	2258	0.0000	0.0000	0.9897	0.0018	0.0085	0.0000
29	0.00	-51.9	6.90	2073	0.0000	0.0000	0.9986	0.0003	0.0011	0.0000
30	0.00	-54.9	6.50	2073	0.0000	0.0000	0.9986	0.0003	0.0011	0.0000
31	1.00	-51.9	6.90	185	0.0000	0.0000	0.8910	0.0179	0.0910	0.0000
32	1.00	-1.3	5.62	185	0.0000	0.0000	0.8910	0.0179	0.0910	0.0000

2.2.5 Steam import

The stream data for this case is identical to the base case.

2.3 Equipment lists

2.3.1 Base case

Equipment lists for the various sections of the MEA absorption process in the base case are presented in Table 2.7 - Table 2.10.

Table 2.7. Equipment list for the absorption section.

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT
		ID	H Packing	H Column	PRESSURE	TEMPERATURE		COST	COST
Columns		(m)	(m)	(m)	barg	°C		k€2014	k€2014
Direct Contact Cooler	Vertical	6.2	7	14	1.9	153	SS304L	1453	3088
Absorber	Vertical	7.8	20	36	1.9	99	SS304L	5038	7469

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST
Heat Exchangers		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014
Flue gas reheater	P&F	622	59	333.1	2.0	159	SS304L	68	350
DCC cooler	P&F	13 485	13	782.0	3.9	82	SS304L	154	535
Amine wash cooler	P&F	2 530	17	110.1	3.9	97	SS304L	24	214

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT
		Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST	COST
Fans and Compressors		(m3/h)	(kW)	barg	°C		k€2014	k€2014
Exhaust fan before flue gas reheater	FN CENT TURBO	441 305	2 573	2.0	159	SS304L	748	1 048

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT
		Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST	COST
Pumps		(l/s)	(kW)	barg	°C		k€2014	k€2014
DCC Circulating pump	Centrifugal	139	35	3.9	82	SS304L	80	265
Amine water wash pump	Centrifugal	33	8.3	3.9	97	SS316L	54	157
Rich amine pump	Centrifugal	442	276	6.9	77	SS304L	235	687
Water make-up pump	Centrifugal	15	7.4	5.9	58	SS304L	47	120

Table 2.8. Equipment list for the desorption section.

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(m)	(m)	barg	°C		k€2014	k€2014	
Lean amine tank	Vertical	1587	0	3.5	13.9	2.8	147	SS316L	295	771	APEA
MEA storage tank	Vertical	0.144	0	2.0	7.9	1.8	58	CS	47	183	APEA
CO2 reflux accumalator	Vertical	48	44981	5.2	7.3	2.1	56	SS304L	341	779	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		ID	H Packing	H Column	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Columns		(m)	(m)	(m)	barg	°C		k€2014	k€2014	
Regenerator (stripper)	Vertical	5.2	9	13.5	2.8	146	SS316L	1375	2514	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Lean/Rich Heat exchanger	P&F	86 858	10	6 207	9.0	147	SS316L	1558	3819	APEA
Lean amine cooler	P&F	28 172	25	842	9.0	88	SS316L	214	604	APEA
Reflux condenser	S&T	32 252	24	1 483	2.5	124	SS316L	413	836	APEA
Stripper reboiler	Kettle	96 259	11	6187	3.4	156	SS316L	1832	2966	APEA

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Pumps		(l/s)	(kW)	barg	°C		k€2014	k€2014	
Lean Amine makeup pump	Centrifugal	0.04	0.03	6.9	58	SS304L	42	71	APEA
Lean Amine pump	Centrifugal	440.9	354	9.0	147	SS316L	253	711	APEA
Stripper Reflux pump	Centrifugal	13.3	4.48	4.8	56	SS304L	46	119	APEA

DESCRIPTION	TYPE	SIZE	DESIGN	HSS FLOW	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	PRESSURE	TO RECLAIMER		COST	COST	SOURCE
Other Equipment		(l/s) - (kg/h)	barg	kg/h		k€2014	k€2014	
Amine Filter	Charcoal	55.1	9.0		SS304L	46	77	APEA
Amine Filter	Catridge	55.1	9.0		SS304L	46	77	APEA
Thermal reclaimer unit		1584	9.0	14	SS316L	516	828	D4.4/ReCap

Table 2.9. Equipment list for the CO_2 compression section and the cooling tower.

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow In (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	TEMPERATURE (IN)		COST	COST	SOURCE
Compressor train		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
3-stage compressor	Centrigufal, horizontal	44 991	8 916	2.1	86.9	56	SS304L	13 048	14 136	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Intercooler 1	P&F	3 453	35	214	6.0	175	SS304L	45	314	APEA
Intercooler 2	P&F	3 204	36	196	22.3	177	SS304L	41	251	APEA
Intercooler 3	P&F	7 730	38	443	86.9	190	SS304L	111	486	APEA
CO2 cooler after pump	S&T	745	9	62	120.3	64	SS304L	116	474	APEA

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Pumps		(m3/h)	(kW)	barg	°C		k€2014	k€2014	
CO2 pump	Centrifugal	166.9	185.5	120.3	64	CS	307	510	D4.4

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
KO drum after Intercooler 1	Vertical	0.93	11020	2.3	9.1	5.9	56	SS304L	132	365	APEA
KO drum after Intercooler 2	Vertical	0.22	2575	1.4	5.6	21.8	56	SS304L	89	226	APEA

DESCRIPTION	TYPE	SIZE	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	COST	COST	SOURCE
Cooling tower		(l/s)	k€2014	k€2014	
Complete cooling tower, field assembly	Vertical	2264.1	968	1609	APEA

Table 2.10. Equipment list for the TEG dehydration section.

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		ID	H Packing	H Column	PRESSURE	TEMPERATURE		COST - CEMCAP	COST - CEMCAP	SOURCE
Columns		(m)	(m)	(m)	barg	°C		k€2014	k€2014	
TEG absorber	Vertical	1.2	2.4	4.08	21.8	58	SS304L	126	285	APEA
TEG stripper	Vertical	0.2	1.6	2.72	2.0	198	SS316L	12	110	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST - CEMCAP	COST - CEMCAP	SOURCE
Heat Exchangers		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
TEG stripper (reboiler)	Kettle	66	15	3	5.7	198	SS316L	17	89	APEA
TEG stripper (condenser)	P&F	2	20	0.037	2.0	133	SS316L	1	49	APEA
Water Lean TEG Cooler	P&F	15	20	0.55	21.5	67	SS304L	1	49	APEA
Lean/Rich Heat Exchanger	P&F	159	2	58	5.8	198	SS316L	17	168	APEA

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST - CEMCAP	COST - CEMCAP	SOURCE
Pumps		(l/s)	(kW)	barg	°C		k€2014	k€2014	
Water Lean TEG pumps	Centrifugal	0.5	1	21.5	67	SS304L	42	76	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST - CEMCAP	COST - CEMCAP	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
TEG stripper (Condenser flash)	Horizontal	0.00	128	0.5	2.1	2.0	156	SS316L	12	122	APEA

2.3.2 Constant low air leak in mill

Equipment lists for the various sections of the MEA absorption process in the constant low air leak case are presented in Table 2.11 - Table 2.14.

Table 2.11. Equipment list for the absorption section.

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		ID	H Packing	H Column	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Columns		(m)	(m)	(m)	barg	°C		k€2014	k€2014	
Direct Contact Cooler	Vertical	5.8	7	14	1.9	172	SS304L	1268	2400	APEA
Absorber	Vertical	7.4	20	36	1.9	101	SS304L	4633	7020	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Flue gas reheater	P&F	293	75	122.9	2.0	175	SS304L	27	223	APEA
DCC cooler	P&F	15 387	14	813.8	3.9	86	SS304L	160	544	APEA
Amine wash cooler	P&F	2 401	17	100.7	3.9	99	SS304L	22	211	APEA

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Fans and Compressors		(m3/h)	(kW)	barg	°C		k€2014	k€2014	
Exhaust fan before flue gas reheater	FN CENT TURBO	376 759	1 748	2.0	175	SS304L	642	899	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Pumps		(l/s)	(kW)	barg	°C		k€2014	k€2014	
DCC Circulating pump	Centrifugal	137	34	3.9	86	SS304L	80	265	APEA
Amine water wash pump	Centrifugal	30	7.5	3.9	99	SS316L	53	156	APEA
Rich amine pump	Centrifugal	433	271	6.9	80	SS304L	232	684	APEA
Water make-up pump	Centrifugal	13	6.5	5.9	58	SS304L	46	119	APEA

Table 2.12. Equipment list for the desorption section.

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(m)	(m)	barg	°C		k€2014	k€2014	
Lean amine tank	Vertical	1556	0	3.5	13.8	2.8	147	SS316L	295	769	APEA
MEA storage tank	Vertical	0.143	0	2.0	7.9	1.8	58	CS	47	183	APEA
CO2 reflux accumalator	Vertical	47	44589	5.2	7.3	2.1	56	SS304L	341	779	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		ID	H Packing	H Column	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Columns		(m)	(m)	(m)	barg	°C		k€2014	k€2014	
Regenerator (stripper)	Vertical	5.2	9	13.5	2.8	146	SS316L	1375	2514	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Lean/Rich Heat exchanger	P&F	81 297	10	5 822	9.0	147	SS316L	1463	3689	APEA
Lean amine cooler	P&F	31 630	26	904	9.0	91	SS316L	229	627	APEA
Reflux condenser	S&T	31 741	24	1 460	3.8	124	SS316L	738	1161	APEA
Stripper reboiler	Kettle	94 581	11	6074	3.4	156	SS316L	1818	2949	APEA

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Pumps		(l/s)	(kW)	barg	°C		k€2014	k€2014	
Lean Amine makeup pump	Centrifugal	0.04	0.03	6.9	58	SS304L	42	71	APEA
Lean Amine pump	Centrifugal	432.2	347	9.0	147	SS316L	251	708	APEA
Stripper Reflux pump	Centrifugal	13.1	4.41	4.8	56	SS304L	46	119	APEA

DESCRIPTION	TYPE	SIZE	DESIGN	HSS FLOW	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	PRESSURE	TO RECLAIMER		COST	COST	SOURCE
Other Equipment		(l/s) - (kg/h)	barg	kg/h		k€2014	k€2014	
Amine Filter	Charcoal	54.0	9.0		SS304L	45	77	APEA
Amine Filter	Catridge	54.0	9.0		SS304L	45	77	APEA
Thermal reclaimer unit		1553	9.0	14	SS316L	506	812	D4.4/ReCap

Table 2.13. Equipment list for the CO_2 compression section and the cooling tower.

DESCRIPTION	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
	Flow In (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	TEMPERATURE (IN)		COST	COST	SOURCE
Compressor train	(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
3-stage compressor	10 921	8 835	2.1	86.9	56	SS304L	13 043	14 212	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Intercooler 1	P&F	3 421	36	212	6.0	175	SS304L	44	313	APEA
Intercooler 2	P&F	3 175	36	194	22.3	177	SS304L	41	250	APEA
Intercooler 3	P&F	7 663	39	438	86.9	190	SS304L	110	485	APEA
CO2 cooler after pump	S&T	737	9	61	120.3	64	SS304L	115	474	APEA

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Pumps		(m3/h)	(kW)	barg	°C		k€2014	k€2014	
CO2 pump	Centrifugal	165.2	183.6	120.3	64	CS	305	506	D4.4

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
KO drum after Intercooler 1	Vertical	0.93	10921	2.3	9.1	5.9	56	SS304L	132	365	APEA
KO drum after Intercooler 2	Vertical	0.22	2551	1.4	5.6	21.8	56	SS304L	89	226	APEA

DESCRIPTION	TYPE	SIZE	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	COST	COST	SOURCE
Cooling tower		(l/s)	k€2014	k€2014	
Complete cooling tower, field assembly	Vertical	2335.5	991	1633	APEA

Table 2.14. Equipment list for the TEG dehydration section.

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		ID	H Packing	H Column	PRESSURE	TEMPERATURE		COST - CEMCAP	COST - CEMCAP	SOURCE
Columns		(m)	(m)	(m)	barg	°C		k€2014	k€2014	
TEG absorber	Vertical	1.2	2.4	4.08	21.8	58	SS304L	126	285	APEA
TEG stripper	Vertical	0.2	1.6	2.72	2.0	198	SS316L	12	110	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST - CEMCAP	COST - CEMCAP	SOURCE
Heat Exchangers		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
TEG stripper (reboiler)	Kettle	66	15	3	5.7	198	SS316L	18	90	APEA
TEG stripper (condenser)	P&F	2	20	0.037	2.0	133	SS316L	1	49	APEA
Water Lean TEG Cooler	P&F	15	20	0.55	21.5	67	SS304L	1	49	APEA
Lean/Rich Heat Exchanger	P&F	159	2	58	5.8	198	SS316L	17	168	APEA

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST - CEMCAP	COST - CEMCAP	SOURCE
Pumps		(l/s)	(kW)	barg	°C		k€2014	k€2014	
Water Lean TEG pumps	Centrifugal	0.5	1	21.5	67	SS304L	42	76	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST - CEMCAP	COST - CEMCAP	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
TEG stripper (Condenser flash)	Horizontal	0.00	124	0.5	2.0	2.0	156	SS304L	12	121	APEA

2.3.3 Optional extent of capture

A case with 60% CO_2 avoided from the flue gas was evaluated, where it was assumed that 60% of the flue gas was treated and the rest was bypassed. The cost of the process was estimated by scaling the results of the base case. See the base case for equipment lists.

2.3.4 Ship transport

In the ship transport case, the absorption and desorption sections are identical to the base case. Equipment lists for the CO_2 conditioning process is given in Table 2.15 - Table 2.16.

Table 2.15. Equipment list for the CO_2 compression section.

DESCRIPTION	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
	Flow In (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	INLET TEMPERATURE		COST	COST	SOURCE
Compressor train	(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
2-stage compressor	44 968	5 682	2.1	18.9	56	SS304L	8 274	9 273	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Frame		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Intercooler 1	P&F	3 772	35	79	6.7	187	SS304L	18	173	APEA
Intercooler 2	P&F	1 801	35	38	18.9	123	SS304L	10	127	APEA
Chiller 1	P&F	721	15	35	6.7	56	SS304L	9	120	APEA
Chiller 2	P&F	666	3	163	18.5	56	SS304L	35	219	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Q/LMTD	C-value	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Fin		(kW)	(K)	(W/K)	(€2014/(W/K))	barg	°C		k€2014	k€2014	
CO2 condenser	P&Fin	9 840	17	565517	0.13	17.5	-43	SS304L	368	736	D4.4
CO2 subcooler	P&Fin	143	5	31867	0.66	7.7	-60	SS304L	105	211	D4.4
CO2 heater	P&Fin	102	29	3548	3.76	7.7	-57	SS304L	67	133	D4.4

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(m)	(m)	barg	°C		k€2014	k€2014	
Water separator LP	Vertical	1.17	9003	0.3	1.3	6.4	32	SS304L	7	83	APEA
Water separator HP	Vertical	0.03	3008	0.1	0.4	18.1	32	SS304L	4	49	APEA
CO2 separator	Vertical	86.74	497	1.3	5.3	7.7	-57	SS304L	53	278	APEA

DESCRIPTION	TYPE	SIZE				ABSORBENT MASS	DESIGN	DESIGN	MATERIAL	EQUIPMENT	TOTAL DIRECT	COST
		Flow (DESIGN)	Water flow (DESIGN)	ID	Length	TOTAL	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Other Equipment	No. Of trains	(m3/s)	(kg/h)	(m)	(m)	(t)	barg	°C		k€2014	k€2014	
Molecular sieve, single vessel dimensions	2	0.84	29.9	1.33	2.12	0.178	18.1	32	SS304L	89	297	APEA + D4.4

Table 2.16. Equipment list for the refrigeration cycle and cooling tower.

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Frame		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Cooler/condenser1	P&F	14 460	12	455.8	11.8	68.3	SS304L	91	380	APEA
Cooler/condenser2	P&F	1 618	13	46.1	11.8	70.9	SS304L	11	128	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Q/LMTD	C-value	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Fin		(kW)	(K)	(W/K)	(€2014/(W/K))	barg	°C		k€2014	k€2014	
LT Heat Exchanger	P&Fin	160	5	30 977	0.67	9.3	-47.2	SS304L	104	209	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	INLET TEMPERATURE		COST	COST	SOURCE
Fans, Compressors and Expanders		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Cooling media compressor 1	Centrifugal, horizontal	21979	2944	4.1	11.8	-16	SS304L	2685	3517	APEA
Cooling media compressor 2	Centrifugal, horizontal	46802	1967	1.8	4.1	-44	SS304L	3300	4500	APEA
Cooling media compressor 3	Centrifugal, horizontal	187	20	4.9	9.3	-62	SS304L	678	865	APEA
Cooling media compressor 4	Centrifugal, horizontal	1708	254	5.7	11.8	32	SS304L	910	1160	APEA

DESCRIPTION	TYPE	SIZE		EQUIPMENT	DIRECT	COST
		Flow (OP)	Flow (DESIGN)	COST	COST	SOURCE
Cooling tower		(m3/h)	(l/s)	k€2014	k€2014	
Complete cooling tower, field assembly	Vertical	7921	2420.4	1023	1674	APEA

2.3.5 Steam import

The equipment lists of this case are identical to the equipment lists of base case. The direct costs associated with steam generation are included as a part of the operating costs associated with steam.

3 OXYFUEL

The project partners responsible for the process simulations and for compiling equipment lists for the oxyfuel technology are listed in Table 3.1.

Table 3.1. Responsible project partners for process simulations and compilation of equipment lists for the oxyfuel technology.

	Responsible partner
Process simulations	VDZ (core process) SINTEF ER (heat recovery and CPU)
Equipment lists	VDZ, Italcementi, SINTEF ER

3.1 Process flow diagram

Process flow diagrams of the oxyfuel core process and the heat recovery system are given in Figure 3.1 and Figure 3.2, for pipeline and ship transport, respectively. It should be noted that in the figure the lowest cyclone is included in the box labelled calciner. Process flow diagrams of the CPU and heat integration are given in Figure 3.3 for pipeline transport and in Figure 3.4 for ship transport. Note that the streams 18-21 in the CPU are renumbered as C18-C21 for the integration case. The dashed lines in Figure 3.1 and Figure 3.2 illustrate the heat flow from the CPU to other units.

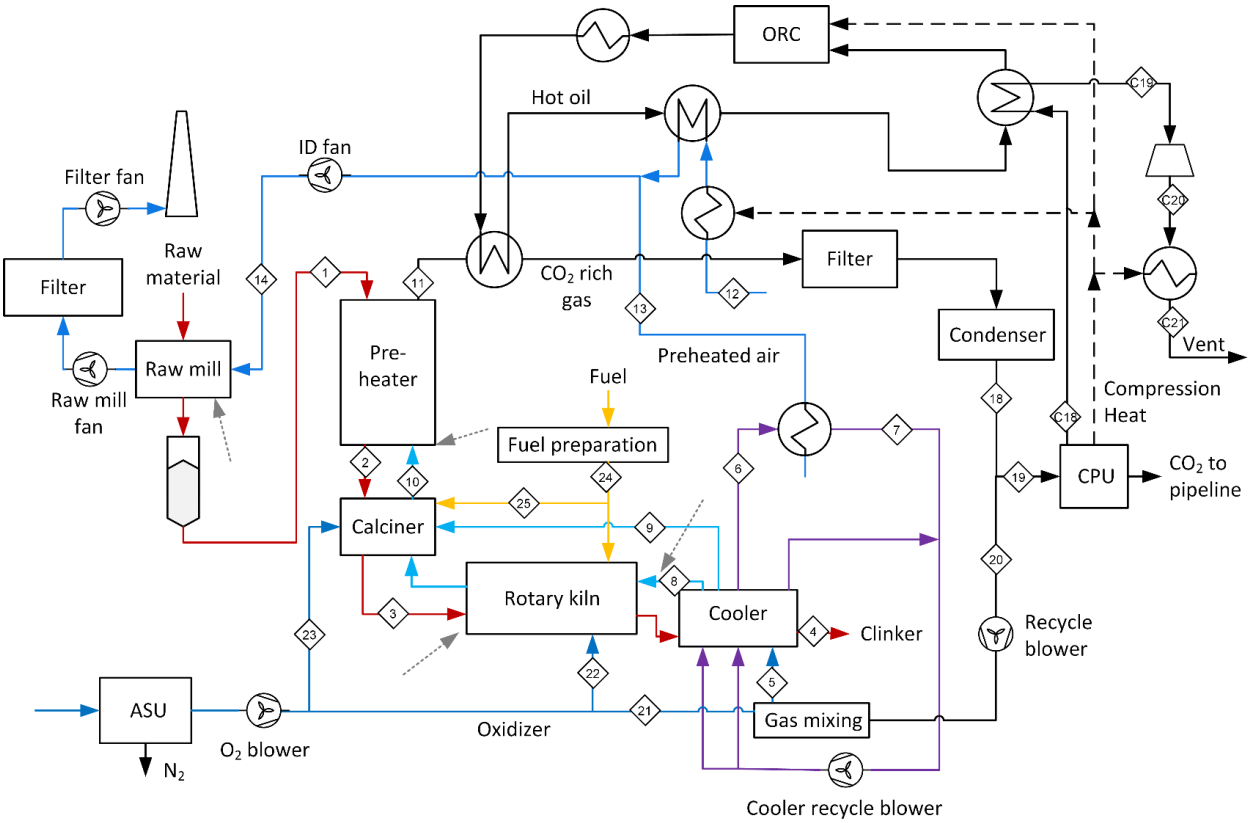

Figure 3.1. Process flowsheet of the core oxyfuel process, the ORC and heat integration system for pipeline transport.

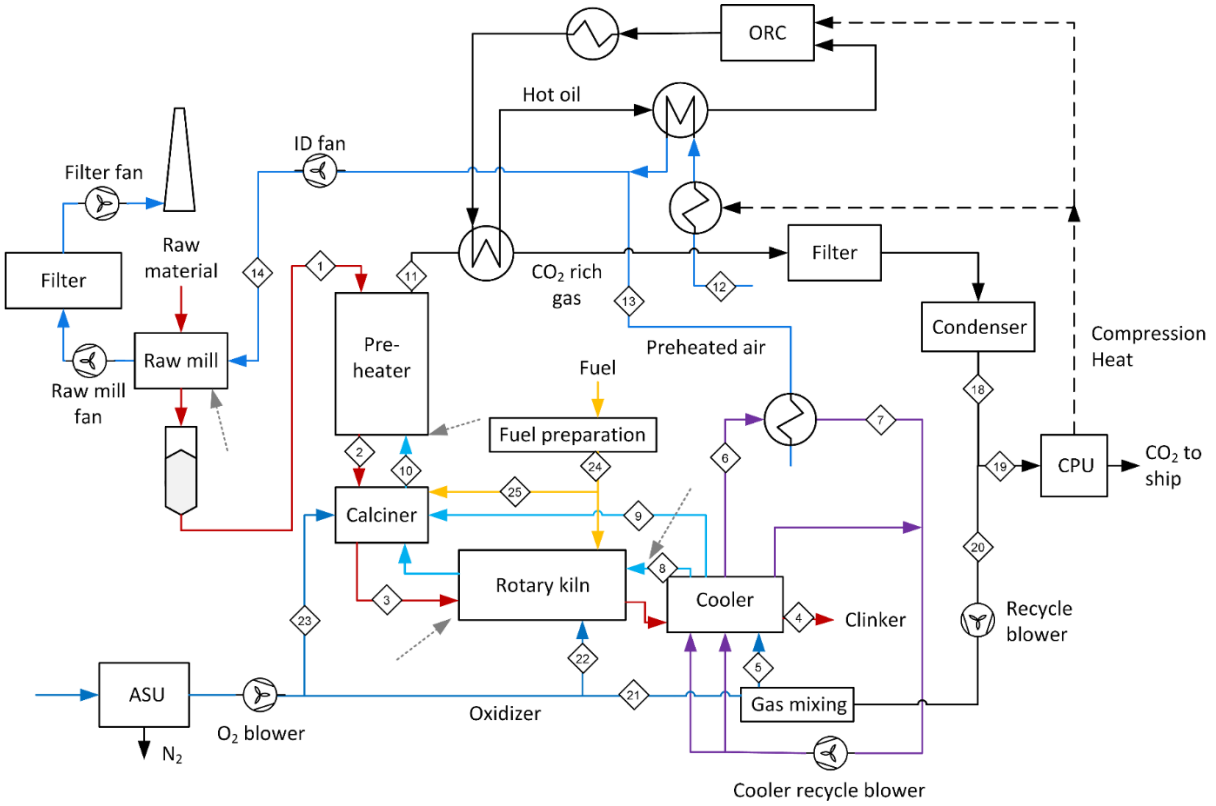

Figure 3.2. Process flowsheet of the core oxyfuel process, the ORC and heat integration system for ship transport.

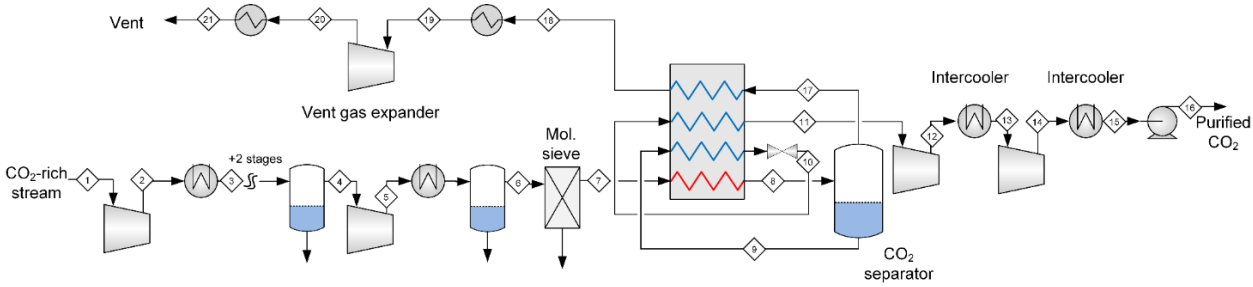

Figure 3.3. Process flowsheet of the CPU for pipeline transport.

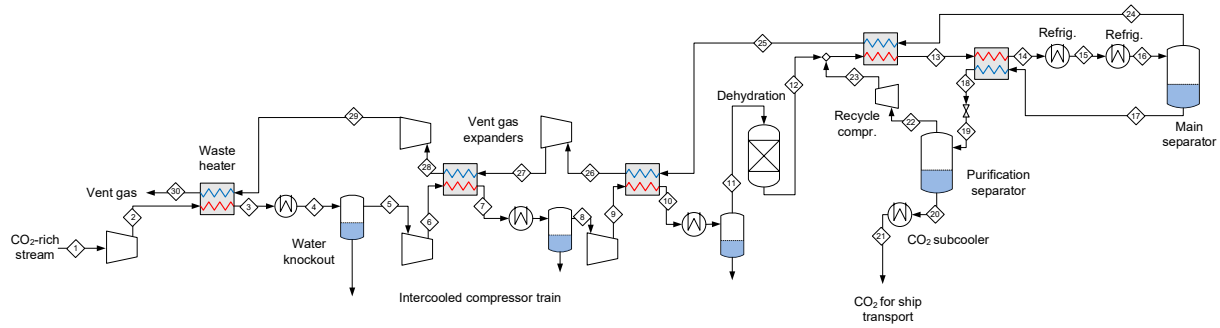

Figure 3.4. Process flowsheet of the CPU for ship transport.

3.2 Stream data

3.2.1 Base case

Stream data for the core process in the base case is given in Table 3.2 - Table 3.4. 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 3.5.

Table 3.2. Stream data for solid streams in the oxyfuel core process in the base case.

#	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 3.3. Stream data for gaseous streams in the oxyfuel core process in the base case.

#	V gas [m^3/h]	VN gas [m^3/h]	VNDry gas [m^3/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 3.4. Air leak stream data in the oxyfuel process in the base case.

	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 3.5. Main stream data for the CPU with pipeline transport in the oxyfuel process in the base case.

#	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

3.2.2 Low air leak in core process

Stream data for the core process in the case with low air leak in the core process is given in Table 3.6 - Table 3.8. 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 3.9.

Table 3.6. Stream data for solid streams in the oxyfuel core process in the case with low air leak in the 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	3.3	77.3	0	0	1.96	1	1.5	0	13.8	0	0	0	0
2	781.7	233858	2.5	63.1	8.8	0	1.5	0	1.2	0.17	14.2	1.2	2.7	0.2	0.2
3	901	147379	0.04	14.7	33.3	0.05	0.02	0	0.1	0.8	14.5	5.8	13.6	1.2	0.9
4	87.1	125091	0	0	0.6	0		0	0	0	0.01	64.6	13.7	10.2	8.3
24	60	6080	69% C. 4% H. 0.5%S. 0.48%N. 9%O. 16.5%Ash. 0.5%Moisture. 0.02% Cl												
25	60	8270	69% C. 4% H. 0.5%S. 0.48%N. 9%O. 16.5%Ash. 0.5%Moisture. 0.02% Cl												

Table 3.7. Stream data for gaseous streams in the oxyfuel core process in the case with low air leak in the core process.

#	V gas [m^3/h]	VN gas [m^3/h]	VNDry gas [m^3/h]	M dust [kg/h]	T gas [°C]	Gas phase volumetric composition [%]				
						AR	CO_2	H_2O	O_2	N_2
5	112645.6	103898.1	100643.8	94	23.0	1.7	66.1	3.1	21.2	7.9
6	261524.3	115049.1	115000.0	5730	341	1.7	66.1	3.1	21.2	7.9
7	178314.5	115049.1	115000.0	5730	165	1.7	66.1	3.1	21.2	7.9
8	128877.4	27844.7	26972.6	881.5	991.1	1.7	66.1	3.1	21.2	7.9
9	329996.2	75845.6	73470.0	2401	915.3	1.7	66.1	3.1	21.2	7.9
10	621437	150883	141098		851	1.2	82	6.4	3.4	6.4
11	383003.8	157727.8	145411.5	9393	390	1.2	79.4	7.8	3.4	8.1
12	103407.17	98000	97983,51		15	0.9	0.0	1	21	77.1
13	194146.2	116167.4	115001.3		183.4	0.9	0.0	1	21	77.1
14	365587.6	215157.2	213001.2		191	0.9	0.0	1	21	77.1
18	166948.9	151255.6	145700.4	94	28.3	1.3	82.9	3.7	3.6	8.5
19	75460.9	68367.5	65856.5	94	28.3	1.3	82.9	3.7	3.6	8.5
20	91487.9	82888.0	79843.8	94	28.3	1.3	82.9	3.7	3.6	8.5
21	20895	19806	19800		15	3.5	0	0	95	1.5
22	3324	3151	3150		15	3.5	0	0	95	1.5
23	651.6	617.6	617.4		15	3.5	0	0	95	1.5

Table 3.8. Air leak stream data in the oxyfuel process in the case with low air leak in the core process.

	V [m^3/h]	VN [m^3/h]	VNDry [m^3/h]	T [°C]	Gas phase volumetric composition [%]				
					AR	CO_2	H_2O	O_2	N_2
Between kiln and cooler	128877.4	27844.7	26972.6	991.1	1.7	66.1	3.1	21.2	7.9
Air leak at preheater tower	3936	3731.1	3730	15	0.9	0	1	21	77.1
In filter (filter gasin)	337670.8	157757.2	145440.6	311	1.2	79.4	7.8	3.4	8.1
In heat exchanger (preheater gas out)	383003.8	157727.8	145411.5	390	1.2	79.4	7.8	3.4	8.1
In organic rankine cycle (ORC)	316942.9	157959.0	145640.4	274	1.2	79.4	7.8	3.5	8.2
In condencer	285903.1	158019.6	145700.4	221	1.2	79.3	7.8	3.5	8.2

Table 3.9. Main stream data for the CPU in the oxyfuel process in the case with low air leak in the core 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	3015.00	1.26	82.83	3.92	3.59	8.39
7	30.77	18.09	2896.55	1.31	86.21	0	3.73	8.73
15	28.00	82.32	2298.79	0.34	97.79	0	0.72	1.14
16	35.89	110.00	2298.79	0.34	97.79	0	0.72	1.14
18	20.77	17.72	597.76	5.07	41.67	0	15.33	37.94
19	184.99	17.37	597.76	5.07	41.67	0	15.33	37.94
20	10.00	1.30	597.76	5.07	41.67	0	15.33	37.94
21	70.00	1.30	597.76	5.07	41.67	0	15.33	37.94

3.2.3 High air leak in core process

Stream data for the core process in the case with high air leak in the core process is given in Table 3.10 - Table 3.12. 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 3.13.

Table 3.10. Stream data for solid streams in the oxyfuel core process in the case with high air leak in the 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	3.3	77.3	0	0	1.96	1	1.5	0	13.8	0	0	0	0
2	788	233311	2.5	62.5	9.0	0.01	1.5	0	1.2	0.17	14.1	1.2	3.0	0.2	0.2
3	909	146700	0.04	13.2	33.5	0.05	0.01	0	0.01	0.8	14.2	6.3	14.7	1.2	1
4	83	125091	0	0	0.5	0	0	0	0	0	0.1	64.8	13.6	9.9	8.8
24	60	6220	69% C. 4% H. 0.5%S. 0.48%N. 9%O. 16.5%Ash. 0.5%Moisture. 0.02% Cl												
25	60	8450	69% C. 4% H. 0.5%S. 0.48%N. 9%O. 16.5%Ash. 0.5%Moisture. 0.02% Cl												

Table 3.11. Stream data for gaseous streams in the oxyfuel core process in the case with high air leak in the core process.

#	V gas [m^3/h]	VN gas [m^3/h]	VNDry gas [m^3/h]	M dust [kg/h]	T gas [°C]	Gas phase volumetric composition [%]				
						AR	CO_2	H_2O	O_2	N_2
5	120658.8	110672.0	106879.7	94	24.6	1.6	62.3	3.4	20.1	12.5
6	251315.2	115051.4	115000.0	5730	335	1.6	62.3	3.4	20.1	12.5
7	171418.1	115051.4	115000.0	5730	160	1.6	62.3	3.4	20.1	12.5
8	135325.9	29660.1	28643.7	939	973	1.6	62.3	3.4	20.1	12.5
9	345088.9	80790.5	78022.2	2558	894	1.6	62.3	3.4	20.1	12.5
10	660222	159272	148785		859	1.2	78	6.6	3.2	10.7
11	420356.1	170064.7	157008.3	9393	402	1.2	74.0	7.7	3.7	13.4
12	103407.17	98000	97983,51		15	0.9	0	1	21	77.1
13	189748.9	116180.9	115013.7		173	0.9	0	1	21	77.1
14	364139.3	215170.8	213013.7		189.1	0.9	0	1	21	77.1
15	372246.2	170134.5	157077.4	9393	324	1.2	74.0	7.7	3.7	13.4
16	349733.9	170619.1	157557.2	94	287	1.2	73.8	7.7	3.7	13.6
17	316744.5	170689.8	157627.2	94	234	1.2	73.7	7.7	3.7	13.7
18	182129.8	164169.6	157627.2	94	29.9	1.2	76.7	4.0	3.9	14.2
19	82322.6	74204.6	71247.4	94	29.9	1.2	76.7	4.0	3.9	14.2
20	99807.1	89964.9	86379.7	94	29.9	1.2	76.7	4.0	3.9	14.2
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	524.9	497.5	497.4		15	3.5	0	0	95	1.5

Table 3.12. Air leak stream data in the oxyfuel process in the case with high air leak in the core process.

	V [m^3/h]	VN [m^3/h]	VNDry [m^3/h]	T [°C]	Gas phase volumetric composition [%]				
					AR	CO_2	H_2O	O_2	N_2
Between kiln and cooler	135325.9	29660.1	28643.7	973	1.6	62.3	3.4	20.1	12.5
Air leak at preheater tower	7883	7472	7470	15	0.9	0	1	21	77.1
In filter (filter gasin)	372246.2	170134.5	157077.4	324	1.2	74.0	7.7	3.7	13.4
In heat exchanger (preheater gas out)	420356.1	170064.7	157008.3	402	1.2	74.0	7.7	3.7	13.4
In organic rankine cycle (ORC)	349733.9	170619.1	157557.2	287	1.2	73.8	7.7	3.7	13.6
In condencer	316744.5	170689.8	157627.2	234	1.2	73.7	7.7	3.7	13.7

Table 3.13. Main stream data for the CPU in the oxyfuel process in the case with high air leak in the core 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	3015.00	1.23	77.02	3.92	3.83	13.99
7	30.77	18.09	2896.55	1.28	80.17	0.00	3.99	14.56
15	28.00	82.32	2298.79	0.37	96.54	0.00	0.87	2.20
16	35.89	110.00	2298.79	0.37	96.54	0.00	0.87	2.20
18	20.77	17.72	597.76	3.96	31.68	0.00	13.20	51.15
19	184.99	17.37	597.76	3.96	31.68	0.00	13.20	51.15
20	10.00	1.30	597.76	3.96	31.68	0.00	13.20	51.15
21	70.00	1.30	597.76	3.96	31.68	0.00	13.20	51.15

3.2.4 No air leak in cooler

Stream data for the core process in the case with no air leak in the cooler is given in Table 3.14 - Table 3.16. 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 3.17.

Table 3.14. Stream data for solid streams in the oxyfuel core process in the case with no air leak in the cooler.

#	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	3.3	77.3	0	0	1.96	1	1.5	0	13.8	0	0	0	0
2	786	233322	2.5	62.7	8.9	0	1.5	0	1.2	0.2	14.1	1.2	2.9	0.2	0.2
3	904	147150	0.04	14.2	33.3	0.05	0.01	0	0.1	0.8	14.4	6	13.9	1.2	0.9
4	87.4	125113	0	0	0.6	0	0	0	0	0	0	64.7	13.7	10.1	8.5
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 3.15. Stream data for gaseous streams in the oxyfuel core process in the case with no air leak in the cooler.

#	V gas [m^3/h]	VN gas [m^3/h]	VNDry gas [m^3/h]	M dust [kg/h]	T gas [°C]	Gas phase volumetric composition [%]				
						AR	CO_2	H_2O	O_2	N_2
5	113745.2	104696.1	101318.6	94	23.6	1.7	65.6	3.2	20.7	8.8
6	267415.6	115050.1	115000.0	5730	345	1.7	65.6	3.2	20.7	8.8
7	183470.4	115050.1	115000.0	5730	167	1.7	65.6	3.2	20.7	8.8
8	130572.0	28058.5	27153.4	888	998.0	1.7	65.6	3.2	20.7	8.8
9	334312.0	76428.2	73962.6	2420	922.0	1.7	65.6	3.2	20.7	8.8
10	630944	152255	142284		854	1.2	81	6.5	3.1	7.6
11	392730.0	160993.0	148471.9	9393	393.2	1.2	77.8	7.8	3.4	9.8
12	103407.17	98000	97983,51		15	0.9	0.0	1	21	77.1
13	194446.5	116168.9	115002.6		184.0	0.9	0.0	1	21	77.1
14	366644.7	215158.8	213002.6		192.3	0.9	0.0	1	21	77.1
15	346662.9	161042.7	148521.1	9393	314.8	1.2	77.8	7.8	3.4	9.8
16	325131.7	161396.0	148870.9	94	277.1	1.2	77.6	7.8	3.4	10.0
17	294000.9	161446.5	148920.9	94	224.3	1.2	77.6	7.8	3.4	10.0
18	170991.5	154720.9	148920.9	94	28.7	1.3	81.0	3.7	3.6	10.4
19	77288.1	69933.8	67312.2	94	28.7	1.3	81.0	3.7	3.6	10.4
20	93703.3	84787.0	81608.6	94	28.7	1.3	81.0	3.7	3.6	10.4
21	20685	19606	19600		15	3.5	0	0	95	1.5
22	3324	3151	3150		15	3.5	0	0	95	1.5
23	524.9	497.5	497.4		15	3.5	0	0	95	1.5

Table 3.16. Air leak stream data in the oxyfuel process in the case with no air leak in the cooler.

	V [m^3/h]	VN [m^3/h]	VNDry [m^3/h]	T [°C]	Gas phase volumetric composition [%]					
					AR	CO_2	H_2O	O_2	N_2	SO_2
Between kiln and cooler	130572.0	28058.5	27153.4	998.0	1.7	65.6	3.2	20.7	8.8	0.01
Air leak at preheater tower	5804	5502	5500	15	0.9	0	1	21	77.1	0
In filter (filter gasin)	346662.9	161042.7	148521.1	314.8	1.2	77.8	7.8	3.4	9.8	0.01
In heat exchanger (preheater gas out)	392730.0	160993.0	148471.9	393.2	1.2	77.8	7.8	3.4	9.8	0.01
In organic rankine cycle (ORC)	325131.7	161396.0	148870.9	277.1	1.2	77.6	7.8	3.4	10.0	0.01
In condencer	294000.9	161446.5	148920.9	224.3	1.2	77.6	7.8	3.4	10.0	0.01

Table 3.17. Main stream data for the CPU in the oxyfuel process in the case with no air leak in the cooler.

#	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	3015.00	1.24	81.09	3.92	3.50	10.23
7	30.77	18.09	2896.55	1.29	84.41	0	3.64	10.65
15	28.00	82.32	2298.79	0.34	97.47	0	0.73	1.45
16	35.89	110.00	2298.79	0.34	97.47	0	0.73	1.45
18	20.77	17.72	597.76	4.64	38.20	0	13.96	43.20
19	184.99	17.37	597.76	4.64	38.20	0	13.96	43.20
20	10.00	1.30	597.76	4.64	38.20	0	13.96	43.20
21	70.00	1.30	597.76	4.64	38.20	0	13.96	43.20

3.2.5 Ship transport

In the ship transport case, the core process is identical to the base case. Main stream data for the CPU is given in Table 3.18.

Table 3.18. Main stream data for the CPU with ship transport in the oxyfuel process in the ship transport case.

#	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
12	27.54	21.11	2988.99	1.28	83.43	0	3.63	11.65
21	-54.94	6.10	2247.82	0.02	99.91	0	0.03	0.04
23	34.31	21.61	1882.08	0.81	94.09	0	1.60	3.50
24	-54.00	19.51	741.65	5.07	33.52	0	14.55	46.86
30	70.00	1.07	741.65	5.07	33.52	0	14.55	46.86

3.3 Equipment lists

3.3.1 Base case

Equipment lists for the various sections of the oxyfuel process in the base case are presented in Table 3.19 - Table 3.21.

Table 3.19. Equipment list for the oxyfuel core process units, fans, compressors, blowers, expanders, exhaust gas recirculation system and air separation unit.

DESCRIPTION	EQUIPMENT COST	DIRECT COST	COST SOURCE
Clinker cooler, kiln hood and sealings	k€2014	k€2014	
Oxyfuel clinker cooler	2944	3655	D4.4
Oxyfuel kiln hood	102	203	D4.4
Rotary kiln inlet sealing	160	160	D4.4
Rotary kiln outlet sealing	160	160	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	INLET TEMPERATURE		COST	COST	SOURCE
Fans, compressors and blowers		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Recycle blower		104388	590	1.8	2.0	57	CS	233	326	D4.4
Cooler recycle blower		192177	1390	1.8	2.0	190	CS	355	496	D4.4
Sealed O2 fan		23390	164	1.8	2.0	56	CS	74	103	D4.4
ORC expander	Turboexpander	248	3454	37.6	1.9	179	CS	1880	2327	APEA

DESCRIPTION	TYPE	Size		EQUIPMENT	DIRECT	COST
		Gas flow (DESIGN)	O2 flow (DESIGN)	COST	COST	SOURCE
Other equipment		(m3/s)	(ton/d)	k€2014	k€2014	
Exhaust gas recirculation system		107	-	70	129	D4.4
Cyclone filter in cooler CO2 recirculation loop		53	-	441	667	APEA
Electrostatic precipitator filter, before ORC cycle	Low voltage	107	-	1013	1616	APEA
Air separation unit (ASU)		-	436	19461	19461	D4.4

Table 3.20. Equipment list for the oxyfuel and waste heat recovery system´s heat exchangers, vessels, electric generator and pumps.

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
FG Condenser/cooling water	P&F	15 099	36	153	1.9	131	SS304L	33	230	APEA
Dirty gas/hot oil, after pre-heater	S&T	18 233	102	2815	1.9	422	SS304L	1376	2240	APEA
Hot oil/air preheat	S&T	6 352	156	112	1.9	342	SS304L	77	287	APEA
Hot oil/ORC boiler	S&T	3 698	46	221	37.6	238	SS304L	198	693	APEA
Hot oil/exhaust preheat (E 105)	S&T	1 182	58	56	1.9	238	SS304L	45	208	APEA
Exhaust reheat/CO2 to stack (E106)	S&T	245	65	118	1.9	98	SS304L	79	277	APEA
ORC Economizer (hot oil/liquid butane)	S&T	13 525	9	1102	37.6	176	SS304L	781	1623	APEA
ORC condenser/cooling water	S&T	12 200	12	1082	1.9	65	SS304L	520	928	APEA
Hot oil cooler/cooling water	P&F	959	14	49	1.9	86	SS304L	24	255	APEA
Gas/gas heat exchanger, after clinker cooler	P&F	7 578	139	1718	1.9	366	SS304L	337	1181	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
Water separator 1	Vertical	5.65	187776	5.8	23.4	1.8	57	SS304L	800	1435	APEA

DESCRIPTION	SIZE		MATERIAL	EQUIPMENT	DIRECT	COST
	Power (DESIGN)	Output (DESIGN)		COST	COST	SOURCE
Electric generators	(kW)	(kVa)		k€2014	k€2014	
ORC generator	3187	3983	CS	3984	4296	APEA

DESCRIPTION	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
	Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Pumps	(l/s)	(kW)	barg	°C		k€2014	k€2014	
ORC pump	69	352	37.6	64	SS304L	156	329	APEA

Table 3.21. Equipment list for the CO_2 purification unit.

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	INLET TEMPERATURE		COST	COST	SOURCE
Fans, Compressors and Expanders		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Compressor 1-4	Centrifugal horizontal	84508	9283	1.8	23.9	57	SS304L	17369	18580	APEA
Compressor 5-6	Centrifugal horizontal	5736	4433	11.1	31.9	50	SS304L	2572	2975	APEA
Vent gas expander	Turboexpander	1444	1302	22.4	1.9	228	SS304L	696	987	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
Water separator 2	Vertical	1.34	38886	3.5	13.8	2.9	56	SS304L	252	592	APEA
Water separator 3	Vertical	0.56	17718	2.7	10.6	5.4	56	SS304L	179	480	APEA
Water separator 4	Vertical	0.26	8022	2.0	8.2	10.7	56	SS304L	117	300	APEA
Water separator 5	Vertical	0.12	3542	1.6	6.2	23.4	56	SS304L	118	258	APEA
Liquid CO2 separator	Vertical	97.88	588	1.5	5.9	23.4	-55	SS304L	99	341	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Frame		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Intercooler 1	P&F	3 087	38	177	2.9	127	SS304L	37	238	APEA
Intercooler 2	P&F	2 543	38	146	5.5	127	SS304L	31	228	APEA
Intercooler 3	P&F	2 395	37	142	10.9	124	SS304L	31	227	APEA
Intercooler 4	P&F	2 445	38	143	23.9	125	SS304L	31	228	APEA
Intercooler 5	P&F	2 488	46	120	31.9	142	SS304L	30	247	APEA
Intercooler 6	P&F	6 817	51	292	91.3	153	SS304L	75	421	APEA

DESCRIPTION	TYPE	SIZE	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Fin		(kW)	barg	°C		k€2014	k€2014	
LT heat exchanger 1 (4 streams)	P&Fin	11 702	23.4	-59	SS304L	849	1 697	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE	COST	COST	SOURCE
Pumps		(m3/h)	(kW)	barg	°C	k€2014	k€2014	
Liquid CO2 pump	Centrifugal	205	197	119.9	56	351	582	D4.4

DESCRIPTION	TYPE	SIZE				ABSORBENT MASS	DESIGN	DESIGN	MATERIAL	MATERIAL	EQUIPMENT	TOTAL DIRECT	COST
		Flow (DESIGN)	Water flow (DESIGN)	ID	Length	TOTAL	PRESSURE	TEMPERATURE		COST	COST	COST	SOURCE
Other Equipment	No. Of trains	(m3/s)	(kg/h)	(m)	(m)	(t)	barg	°C		k€2014	k€2014		
Molecular sieve, single vessel dimensions	2	0.98	143	1.4	2.48	0.849	23.4	58	3A	5	112	339	APEA + D4.4

DESCRIPTION	TYPE	SIZE		EQUIPMENT	DIRECT	COST
		Flow (OP)	Flow (DESIGN)	COST	COST	SOURCE
Cooling tower		(m3/h)	(l/s)	k€2014	k€2014	
Complete cooling tower, field assembly	Vertical	4057	1239.5	588	1045	APEA

3.3.2 Low air leak in core process

Equipment lists for the various sections of the oxyfuel process in the low air leak in core process case are presented in Table 3.22 - Table 3.24.

Table 3.22. Equipment list for the oxyfuel core process units, fans, compressors, blowers, expanders, exhaust gas recirculation system and air separation unit.

DESCRIPTION	EQUIPMENT COST	DIRECT COST	COST SOURCE
Clinker cooler, kiln hood and sealings	k€2014	k€2014	
Oxyfuel clinker cooler	2944	3655	D4.4
Oxyfuel kiln hood	102	203	D4.4
Rotary kiln inlet sealing	160	160	D4.4
Rotary kiln outlet sealing	160	160	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	INLET TEMPERATURE		COST	COST	SOURCE
Fans, compressors and blowers		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Recycle blower		100637	571	1.8	2.0	57	CS	228	320	D4.4
Cooler recycle blower		196146	1390	1.8	2.0	190	CS	356	499	D4.4
Sealed O2 fan		11920	164	1.8	2.0	56	CS	62	87	D4.4
ORC expander	Turboexpander	248	3246	37.6	1.9	179	CS	1785	2230	APEA

DESCRIPTION	TYPE	Size		EQUIPMENT	DIRECT	COST
		Gas flow (DESIGN)	O2 flow (DESIGN)	COST	COST	SOURCE
Other equipment		(m3/s)	(ton/d)	k€2014	k€2014	
Exhaust gas recirculation system		103	-	69	127	D4.4
Cyclone filter in cooler CO2 recirculation loop		54	-	441	667	APEA
Electrostatic precipitator filter, before ORC cycle	Low voltage	103	-	989	1578	APEA
Air separation unit (ASU)		-	436	19461	19461	D4.4

Table 3.23. Equipment list for the oxyfuel and waste heat recovery system´s heat exchangers, vessels, electric generator and pumps.

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
FG Condenser/cooling water	P&F	14 596	36	147	1.9	131	SS304L	32	229	APEA
Dirty gas/hot oil, after pre-heater	S&T	17 681	102	2729	1.9	422	SS304L	1337	2200	APEA
Hot oil/air preheat	S&T	6 266	156	110	1.9	342	SS304L	76	287	APEA
Hot oil/ORC boiler	S&T	3 766	46	225	37.6	238	SS304L	200	694	APEA
Hot oil/exhaust preheat (E 105)	S&T	956	58	45	1.9	238	SS304L	40	167	APEA
Exhaust reheat/CO2 to stack	S&T	218	65	105	1.9	98	SS304L	72	270	APEA
ORC Economizer (hot oil/liquid butane)	S&T	13 777	9	1123	37.6	176	SS304L	799	1642	APEA
ORC condenser/cooling water	S&T	12 000	12	1065	1.9	65	SS304L	511	919	APEA
Hot oil cooler/cooling water	P&F	853	14	46	1.9	85	SS304L	23	257	APEA
Gas/gas heat exchanger, after clinker cooler	P&F	7 723	140	1728	1.9	369	SS304L	339	1183	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
Water separator 1	Vertical	5.58	181934	5.8	23.1	1.8	57	SS304L	796	1431	APEA

DESCRIPTION	SIZE		MATERIAL	EQUIPMENT	DIRECT	COST
	Power (DESIGN)	Output (DESIGN)		COST	COST	SOURCE
Electric generators	(kW)	(kVa)		k€2014	k€2014	
ORC generator	3246	4058	CS	3520	3822	AEPA

DESCRIPTION	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
	Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Pumps	(l/s)	(kW)	barg	°C		k€2014	k€2014	
ORC pump	69	352	37.6	64	SS304L	156	329	APEA

Table 3.24. Equipment list for the CO_2 purification unit.

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	INLET TEMPERATURE		COST	COST	SOURCE
Fans, Compressors and Expanders		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Compressor 1-4	Centrifugal horizontal	81870	8487	1.8	20.1	57	SS304L	17267	18524	APEA
Compressor 5-6	Centrifugal horizontal	6347	4676	10.2	91.3	53	SS304L	2572	2975	APEA
Vent gas expander	Turboexpander	1442	1060	18.8	1.9	213	SS304L	585	937	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
Water separator 2	Vertical	1.25	39292	3.5	13.9	2.9	56	SS304L	253	592	APEA
Water separator 3	Vertical	0.55	18676	2.7	10.8	5.0	56	SS304L	173	475	APEA
Water separator 4	Vertical	0.26	8832	2.1	8.4	9.6	56	SS304L	122	336	APEA
Water separator 5	Vertical	0.12	4094	1.6	6.5	19.7	56	SS304L	113	257	APEA
Liquid CO2 separator	Vertical	97.34	612	1.5	5.9	19.7	-55	SS304L	91	333	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Frame		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Intercooler 1	P&F	2 841	35	177	2.7	121	SS304L	37	237	APEA
Intercooler 2	P&F	2 344	35	148	5.1	120	SS304L	32	228	APEA
Intercooler 3	P&F	2 196	35	138	9.7	120	SS304L	30	224	APEA
Intercooler 4	P&F	2 215	35	138	20.1	121	SS304L	30	225	APEA
Intercooler 5	P&F	2 656	49	119	30.6	148	SS304L	29	247	APEA
Intercooler 6	P&F	7 085	54	291	91.3	157	SS304L	75	421	APEA

DESCRIPTION	TYPE	SIZE	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Fin		(kW)	barg	°C		k€2014	k€2014	
LT heat exchanger 1 (4 streams)	P&Fin	11 748	19.7	-59	SS304L	852	1 704	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE	COST	COST	SOURCE
Pumps		(m3/h)	(kW)	barg	°C	k€2014	k€2014	
Liquid CO2 pump	Centrifugal	198	191	119.9	56	341	566	D4.4

DESCRIPTION	TYPE	SIZE				ABSORBENT MASS	DESIGN	DESIGN	MATERIAL	MATERIAL	EQUIPMENT	TOTAL DIRECT	COST
		Flow (DESIGN)	Water flow (DESIGN)	ID	Length	TOTAL	PRESSURE	TEMPERATURE		COST	COST	COST	SOURCE
Other Equipment	No. Of trains	(m3/s)	(kg/h)	(m)	(m)	(t)	barg	°C		k€2014	k€2014		
Molecular sieve, single vessel dimensions	2	1.14	155	1.6	2.45	0.922	19.7	59	3A	6	130	391	APEA + D4.4

DESCRIPTION	TYPE	SIZE		EQUIPMENT	DIRECT	COST
		Flow (OP)	Flow (DESIGN)	COST	COST	SOURCE
Cooling tower		(m3/h)	(l/s)	k€2014	k€2014	
Complete cooling tower, field assembly	Vertical	3954	1208.1	577	1034	APEA

3.3.3 High air leak in core process

Equipment lists for the various sections of the oxyfuel process in the high air leak in core process case are presented in Table 3.25 - Table 3.27.

Table 3.25. Equipment list for the oxyfuel core process units, fans, compressors, blowers, expanders, exhaust gas recirculation system and air separation unit.

DESCRIPTION	EQUIPMENT COST	DIRECT COST	COST SOURCE
Clinker cooler, kiln hood and sealings	k€2014	k€2014	
Oxyfuel clinker cooler	2944	3655	D4.4
Oxyfuel kiln hood	102	203	D4.4
Rotary kiln inlet sealing	160	160	D4.4
Rotary kiln outlet sealing	160	160	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	INLET TEMPERATURE		COST	COST	SOURCE
Fans, compressors and blowers		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Recycle blower		109788	595	1.8	2.0	57	CS	237	331	D4.4
Cooler recycle blower		188560	1390	1.8	2.0	190	CS	353	494	D4.4
Sealed O2 fan		11920	164	1.8	2.0	56	CS	62	87	D4.4
ORC expander	Turboexpander	248	3043	37.6	1.9	179	CS	483	905	APEA

DESCRIPTION	TYPE	Size		EQUIPMENT	DIRECT	COST
		Gas flow (DESIGN)	O2 flow (DESIGN)	COST	COST	SOURCE
Other equipment		(m3/s)	(ton/d)	k€2014	k€2014	
Exhaust gas recirculation system		114	-	71	132	D4.4
Cyclone filter in cooler CO2 recirculation loop		52	-	441	667	APEA
Electrostatic precipitator filter, before ORC cycle	Low voltage	114	-	1049	1673	APEA
Air separation unit (ASU)		-	436	19461	19461	D4.4

Table 3.26. Equipment list for the oxyfuel and waste heat recovery system´s heat exchangers, vessels, electric generator and pumps.

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
FG Condenser/cooling water	P&F	15 348	36	155	1.9	131	SS304L	33	231	APEA
Dirty gas/hot oil, after pre-heater	S&T	18 595	102	2870	1.9	422	SS304L	1403	2267	APEA
Hot oil/air preheat	S&T	5 335	156	94	1.9	342	SS304L	66	276	APEA
Hot oil/ORC boiler	S&T	3 530	46	211	37.6	238	SS304L	194	688	APEA
Hot oil/exhaust preheat (E 105)	S&T	1 438	58	68	1.9	238	SS304L	52	215	APEA
Exhaust reheat/CO2 to stack	S&T	270	65	130	1.9	98	SS304L	84	282	APEA
ORC Economizer (hot oil/liquid butane)	S&T	12 913	9	1052	37.6	176	SS304L	748	1590	APEA
ORC condenser/cooling water	S&T	11 968	12	1062	1.9	65	SS304L	510	918	APEA
Hot oil cooler/cooling water	P&F	944	14	51	1.9	85	SS304L	25	261	APEA
Gas/gas heat exchanger, after clinker cooler	P&F	7 379	137	1692	1.9	369	SS304L	332	1169	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
Water separator 1	Vertical	5.60	189357	5.9	23.4	1.8	57	SS304L	818	1454	APEA

DESCRIPTION	SIZE		MATERIAL	EQUIPMENT	DIRECT	COST
	Power (DESIGN)	Output (DESIGN)		COST	COST	SOURCE
Electric generators	(kW)	(kVa)		k€2014	k€2014	
ORC generator	3043	3803	CS	3977	4289	APEA

DESCRIPTION	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
	Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Pumps	(l/s)	(kW)	barg	°C		k€2014	k€2014	
ORC pump	69	352	37.6	64	SS304L	156	329	APEA

Table 3.27. Equipment list for the CO_2 purification unit.

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	INLET TEMPERATURE		COST	COST	SOURCE
Fans, Compressors and Expanders		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Compressor 1-4	Centrifugal horizontal	85211	9962	1.8	28.4	57	SS304L	23487	24751	APEA
Compressor 5-6	Centrifugal horizontal	4969	4046	12.2	91.3	47	SS304L	2545	2915	APEA
Vent gas expander	Turboexpander	1391	1572	26.9	1.9	246	SS304L	787	1160	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
Water separator 2	Vertical	1.40	37380	3.4	13.6	3.0	56	SS304L	239	576	APEA
Water separator 3	Vertical	0.56	16247	2.6	10.3	5.9	56	SS304L	168	468	APEA
Water separator 4	Vertical	0.24	7002	2.0	7.8	12.2	56	SS304L	124	306	APEA
Water separator 5	Vertical	0.10	2921	1.5	5.8	27.9	56	SS304L	109	247	APEA
Liquid CO2 separator	Vertical	95.84	541	1.5	5.8	27.9	-55	SS304L	106	332	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Frame		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Intercooler 1	P&F	3 289	40	182	2.7	130	SS304L	38	240	APEA
Intercooler 2	P&F	2 706	39	151	6.0	129	SS304L	32	230	APEA
Intercooler 3	P&F	2 563	40	142	12.4	129	SS304L	31	227	APEA
Intercooler 4	P&F	2 658	40	145	28.4	131	SS304L	34	251	APEA
Intercooler 5	P&F	2 220	42	117	33.5	134	SS304L	29	246	APEA
Intercooler 6	P&F	6 264	49	281	91.3	148	SS304L	72	414	APEA

DESCRIPTION	TYPE	SIZE	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Fin		(kW)	barg	°C		k€2014	k€2014	
LT heat exchanger 1 (4 streams)	P&Fin	11 298	27.9	-55	SS304L	819	1 638	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE	COST	COST	SOURCE
Pumps		(m3/h)	(kW)	barg	°C	k€2014	k€2014	
Liquid CO2 pump	Centrifugal	210	202	119.9	56	359	595	D4.4

DESCRIPTION	TYPE	SIZE				ABSORBENT MASS	DESIGN	DESIGN	MATERIAL	MATERIAL	EQUIPMENT	TOTAL DIRECT	COST
		Flow (DESIGN)	Water flow (DESIGN)	ID	Length	TOTAL	PRESSURE	TEMPERATURE		COST	COST	COST	SOURCE
Other Equipment	No. Of trains	(m3/s)	(kg/h)	(m)	(m)	(t)	barg	°C		k€2014	k€2014		
Molecular sieve, single vessel dimensions	2	0.81	128	1.3	2.52	0.000	19.7	59	3A	0	102	324	APEA + D4.4

DESCRIPTION	TYPE	SIZE		EQUIPMENT	DIRECT	COST
		Flow (OP)	Flow (DESIGN)	COST	COST	SOURCE
Cooling tower		(m3/h)	(l/s)	k€2014	k€2014	
Complete cooling tower, field assembly	Vertical	4074	1244.9	590	1047	APEA

3.3.4 No air leak in cooler

Equipment lists for the various sections of the oxyfuel process in the no air leak in cooler case are presented in Table 3.28 - Table 3.30.

Table 3.28. Equipment list for the oxyfuel core process units, fans, compressors, blowers, expanders, exhaust gas recirculation system and air separation unit.

DESCRIPTION	EQUIPMENT COST	DIRECT COST	COST SOURCE
Clinker cooler, kiln hood and sealings	k€2014	k€2014	
Oxyfuel clinker cooler	2944	3655	D4.4
Oxyfuel kiln hood	102	203	D4.4
Rotary kiln inlet sealing	160	160	D4.4
Rotary kiln outlet sealing	160	160	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN PRESSURE	DESIGN TEMPERATURE	MATERIAL	EQUIPMENT COST	DIRECT COST	COST SOURCE
		Flow (DESIGN)	Power (DESIGN)						
Fans, compressors and blowers		(m3/h)	(kW)	barg	°C		k€2014	k€2014	
Recycle blower		103074	583	2.0	57	CS	231	324	D4.4
Cooler recycle blower		201817	1390	2.0	190	CS	359	503	D4.4
Sealed O2 fan		11920	164	2.0	56	CS	62	87	D4.4
ORC expander	Turboexpander	248	3178	37.6	179	CS	1753	2198	APEA

DESCRIPTION		Size		EQUIPMENT COST	DIRECT COST	COST SOURCE
		Gas flow (DESIGN)	O2 flow (DESIGN)			
Other equipment		(m3/s)	(ton/d)	k€2014	k€2014	
Exhaust gas recirculation system		106	-	69	128	D4.4
Cyclone filter in cooler CO2 recirculation loop		56	-	441	667	APEA
Electrostatic precipitator filter, before ORC cycle	Low voltage	106	-	1005	1603	APEA
Air separation unit (ASU)		-	436	19461	19461	D4.4

Table 3.29. Equipment list for the oxyfuel and waste heat recovery system´s heat exchangers, vessels, electric generator and pumps.

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
FG Condenser/cooling water	P&F	15 029	36	152	1.9	131	SS304L	32	230	APEA
Dirty gas/hot oil, after pre-heater	S&T	17 981	102	2776	1.9	422	SS304L	1361	2225	APEA
Hot oil/air preheat	S&T	6 300	156	111	1.9	342	SS304L	76	287	APEA
Hot oil/ORC boiler	S&T	3 688	46	220	37.6	238	SS304L	198	692	APEA
Hot oil/exhaust preheat (E 105)	S&T	1 099	58	52	1.9	223	SS304L	45	172	APEA
Exhaust reheat/CO2 to stack	S&T	235	65	114	1.9	98	SS304L	78	276	APEA
ORC Economizer (hot oil/liquid butane)	S&T	13 489	9	1099	37.6	176	SS304L	780	1622	APEA
ORC condenser/cooling water	S&T	12 088	12	1072	1.9	65	SS304L	516	925	APEA
Hot oil cooler/cooling water	P&F	945	14	51	1.9	85	SS304L	25	261	APEA
Gas/gas heat exchanger, after clinker cooler	P&F	7 987	137	1832	1.9	373	SS304L	359	1215	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
Water separator 1	Vertical	5.65	188698	5.9	23.4	1.8	57	SS304L	818	1454	APEA

DESCRIPTION	SIZE		MATERIAL	EQUIPMENT	DIRECT	COST
	Power (DESIGN)	Output (DESIGN)		COST	COST	SOURCE
Electric generators	(kW)	(kVa)		k€2014	k€2014	
ORC generator	3178	3972	CS	4029	4342	APEA

DESCRIPTION	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
	Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Pumps	(l/s)	(kW)	barg	°C		k€2014	k€2014	
ORC pump	69	352	37.6	64	SS304L	156	329	APEA

Table 3.30. Equipment list for the CO_2 purification unit.

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	INLET TEMPERATURE		COST	COST	SOURCE
Fans, Compressors and Expanders		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Compressor 1-4	Centrifugal horizontal	83564	9001	1.8	22.5	57	SS304L	17351	18562	APEA
Compressor 5-6	Centrifugal horizontal	5754	4046	11.1	91.3	51	SS304L	2545	2939	APEA
Vent gas expander	Turboexpander	1443	1213	21.1	1.9	223	SS304L	655	1009	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
Water separator 2	Vertical	1.31	37273	3.4	13.6	2.9	56	SS304L	233	570	APEA
Water separator 3	Vertical	0.56	16201	2.6	10.3	5.3	56	SS304L	161	461	APEA
Water separator 4	Vertical	0.26	6982	1.9	7.8	10.3	56	SS304L	106	288	APEA
Water separator 5	Vertical	0.12	2912	1.5	5.8	22.0	56	SS304L	99	237	APEA
Liquid CO2 separator	Vertical	98.36	479	1.5	5.8	22.0	-55	SS304L	88	330	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Frame		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Intercooler 1	P&F	3 000	37	180	2.7	123	SS304L	38	240	APEA
Intercooler 2	P&F	2 473	36	150	5.3	122	SS304L	32	230	APEA
Intercooler 3	P&F	2 324	36	140	10.5	123	SS304L	30	225	APEA
Intercooler 4	P&F	2 363	37	141	22.5	124	SS304L	30	226	APEA
Intercooler 5	P&F	2 525	46	120	31.9	143	SS304L	30	247	APEA
Intercooler 6	P&F	6 863	49	308	91.3	148	SS304L	79	425	APEA

DESCRIPTION	TYPE	SIZE	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Fin		(kW)	barg	°C		k€2014	k€2014	
LT heat exchanger 1 (4 streams)	P&Fin	11 742	22.0	-59	SS304L	851	1 703	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE	COST	COST	SOURCE
Pumps		(m3/h)	(kW)	barg	°C	k€2014	k€2014	
Liquid CO2 pump	Centrifugal	202	195	119.9	56	347	576	D4.4

DESCRIPTION	TYPE	SIZE				ABSORBENT MASS	DESIGN	DESIGN	MATERIAL	MATERIAL	EQUIPMENT	TOTAL DIRECT	COST
		Flow (DESIGN)	Water flow (DESIGN)	ID	Length	TOTAL	PRESSURE	TEMPERATURE		COST	COST	COST	SOURCE
Other Equipment	No. Of trains	(m3/s)	(kg/h)	(m)	(m)	(t)	barg	°C		k€2014	k€2014		
Molecular sieve, single vessel dimensions	2	0.81	128	1.3	2.52	0.761	19.7	59	3A	5	102	328	APEA + D4.4

DESCRIPTION	TYPE	SIZE		EQUIPMENT	DIRECT	COST
		Flow (OP)	Flow (DESIGN)	COST	COST	SOURCE
Cooling tower		(m3/h)	(l/s)	k€2014	k€2014	
Complete cooling tower, field assembly	Vertical	4023	1229.2	584	1041	APEA

3.3.5 Ship transport

Equipment lists for the various sections of the oxyfuel process in the ship transport case are presented in Table 3.31 - Table 3.34.

Table 3.31. Equipment list for the oxyfuel core process units, fans, compressors, blowers, expanders, exhaust gas recirculation system and air separation unit.

DESCRIPTION	EQUIPMENT COST	DIRECT COST	COST SOURCE
Clinker cooler, kiln hood and sealings	k€2014	k€2014	
Oxyfuel clinker cooler	2944	3655	D4.4
Oxyfuel kiln hood	102	203	D4.4
Rotary kiln inlet sealing	160	160	D4.4
Rotary kiln outlet sealing	160	160	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	INLET TEMPERATURE		COST	COST	SOURCE
Fans, compressors and blowers		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Recycle blower		100637	583	1.8	2.0	57	CS	230	322	D4.4
Cooler recycle blower		196146	1390	1.8	2.0	190	CS	356	499	D4.4
Sealed O2 fan		11920	164	1.8	2.0	56	CS	62	87	D4.4
ORC expander	Turboexpander	248	3178	37.6	1.9	179	CS	1753	2198	APEA

DESCRIPTION	TYPE	Size		EQUIPMENT	DIRECT	COST
		Gas flow (DESIGN)	O2 flow (DESIGN)	COST	COST	SOURCE
Other equipment		(m3/s)	(ton/d)	k€2014	k€2014	
Exhaust gas recirculation system		103	-	69	127	D4.4
Cyclone filter in cooler CO2 recirculation loop		54	-	441	667	APEA
Electrostatic precipitator filter, before ORC cycle	Low voltage	103	-	989	1578	APEA
Air separation unit (ASU)		-	436	19461	19461	D4.4

Table 3.32. Equipment list for the oxyfuel and waste heat recovery system´s heat exchangers, vessels, electric generator and pumps.

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
FG Condenser/cooling water	P&F	15 099	36	153	1.9	131	SS304L	33	230	APEA
Dirty gas/hot oil, after pre-heater	S&T	18 233	102	2815	1.9	422	SS304L	1376	2240	APEA
Hot oil/air preheat	S&T	6 352	156	112	1.9	342	SS304L	77	287	APEA
Hot oil/ORC boiler	S&T	3 698	46	221	37.6	238	SS304L	198	693	APEA
Exhaust reheat/CO2 to stack	S&T	511	65	247	1.9	98	SS304L	150	411	APEA
ORC Economizer (hot oil/liquid butane)	S&T	13 525	9	1102	37.6	176	SS304L	781	1623	APEA
ORC condenser/cooling water	S&T	12 010	12	1065	1.9	65	SS304L	511	919	APEA
Hot oil cooler/cooling water	P&F	1 376	14	74	1.9	94	SS304L	34	333	APEA
Gas/gas heat exchanger, after clinker cooler	P&F	7 578	139	1718	1.9	366	SS304L	337	1181	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
Water separator 1	Vertical	5.65	187776	5.8	23.4	1.8	57	SS304L	800	1435	APEA

DESCRIPTION	SIZE		MATERIAL	EQUIPMENT	DIRECT	COST
	Power (DESIGN)	Output (DESIGN)		COST	COST	SOURCE
Electric generators	(kW)	(kVa)		k€2014	k€2014	
ORC generator	3178	3972	CS	3977	4289	APEA

DESCRIPTION	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
	Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Pumps	(l/s)	(kW)	barg	°C		k€2014	k€2014	
ORC pump	69	352	37.6	64	SS304L	156	329	APEA

Table 3.33. Equipment list for the CO_2 purification unit.

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	OPERATING	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	TEMPERATURE	TEMPERATURE		COST	COST	SOURCE
Fans, Compressors and Expanders		(m3/h)	(kW)	barg	barg	°C	°C		k€2014	k€2014	
Compressor 1-3	Centrifugal horizontal	84476	9486	1.8	24.2	29	57	SS304L	17378	18591	APEA
Small recycle compressor	Centrifugal horizontal	5367	1566	7.3	23.7	-52	-57	SS304L	1310	1691	APEA
Vent gas expander 1	Turboexpander	1320	736	20.4	4.8	96	124	SS304L	436	625	APEA
Vent gas expander 2	Turboexpander	5097	653	5.7	1.9	95	123	SS304L	398	695	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
Water separator 2	Vertical	1.59	29344	3.1	12.6	3.6	56	SS304L	214	546	APEA
Water separator 3	Vertical	0.51	10260	2.2	8.9	8.6	56	SS304L	130	361	APEA
Water separator 4	Vertical	0.18	3452	1.5	6.2	23.7	56	SS304L	105	243	APEA
Main CO2 separator	Vertical	173.03	685	1.7	7.0	21.3	-59	SS304L	125	379	APEA
CO2 purification separator	Vertical	94.02	5367	2.0	8.1	7.3	-55	SS304L	98	465	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Frame		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Intercooler 1	P&F	4 046	49	180	3.7	149	SS304L	38	240	APEA
Intercooler 2	P&F	2 710	40	150	8.6	129	SS304L	32	230	APEA
Intercooler 3	P&F	2 829	43	146	23.7	135	SS304L	30	226	APEA
Waste heater 1	P&F	616	49	28	8.8	148	SS304L	7	123	APEA
Waste heater 2	P&F	483	50	21	24.2	149	SS304L	6	121	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Q/LMTD	C-value	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Fin		(kW)	(K)	(W/K)	(€2014/(W/K))	barg	°C		k€2014	k€2014	
LT Heat Exchanger 1	P&Fin	572.9	22	25637	0.77	23.1	-59	SS304L	99	198	D4.4
LT Heat Exchanger 2	P&Fin	7670	8	1016164	0.10	22.7	-59	SS304L	504	1009	D4.4
Refrigerated cooler 1	P&Fin	9328	7	1328868	0.09	22.2	-19	SS304L	583	1165	D4.4
Refrigerated cooler 2	P&Fin	3188	7	430282	0.15	21.7	-59	SS304L	318	635	D4.4
Refrigerated cooler 3	P&Fin	156	3	51747	0.47	7.3	-60	SS304L	121	241	D4.4

DESCRIPTION	TYPE	SIZE				ABSORBENT MASS	DESIGN	DESIGN	MATERIAL	EQUIPMENT	TOTAL DIRECT	COST
		Flow (DESIGN)	Water flow (DESIGN)	ID	Length	TOTAL	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Other Equipment	No. Of trains	(m3/s)	(kg/h)	(m)	(m)	(t)	barg	°C		k€2014		
Molecular sieve, single vessel dimensions	2	0.96	144	1.4	2.50	0.856	20.6	56	3A	105	332	APEA + D4.4

Table 3.34. Equipment list for external refrigeration system.

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Frame		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Cooler/condenser	P&F	18 958	12	594.3	11.8	68	SS304L	118	475	APEA

DESCRIPTION	TYPE	SIZE	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Fin		(kW)	barg	°C		k€2014	k€2014	
LT Heat Exchanger	P&Fin	3 779	9.3	-47	SS304L	420	840	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	INLET TEMPERATURE		COST	COST	SOURCE
Fans, Compressors and Expanders		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Cooling media compressor 1	Centrifugal, horizontal	4444	478	4.9	9.3	-60	SS304L	981	1363	APEA
Cooling media compressor 2	Centrifugal, horizontal	61048	2534	1.8	4.1	-44	SS304L	4398	5740	APEA
Cooling media compressor 3	Centrifugal, horizontal	29175	3902	4.1	11.8	-16	SS304L	2999	3915	APEA

DESCRIPTION	TYPE	SIZE	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	COST	COST	SOURCE
Cooling tower		(l/s)	k€2014	k€2014	
Complete cooling tower, field assembly	Vertical	1598.7	728	1224	APEA

4 CHILLED AMMONIA PROCESS

The project partners responsible for the process simulations and for compiling equipment lists for the chilled ammonia process are listed in Table 4.1.

Table 4.1. Responsible project partners for process simulations and compilation of equipment lists for the chilled ammonia process.

	Responsible partner
Process simulations	ETH (core process) SINTEF ER (CO_2 compression/liquefaction)
Equipment lists	GE

4.1 Process flow diagram

Process flow diagram of the chilled ammonia process is given in Figure 4.1. Process flow diagrams for conditioning of CO_2 for transport by pipeline is given in Figure 4.2 and for transport by ship is given in Figure 4.3.

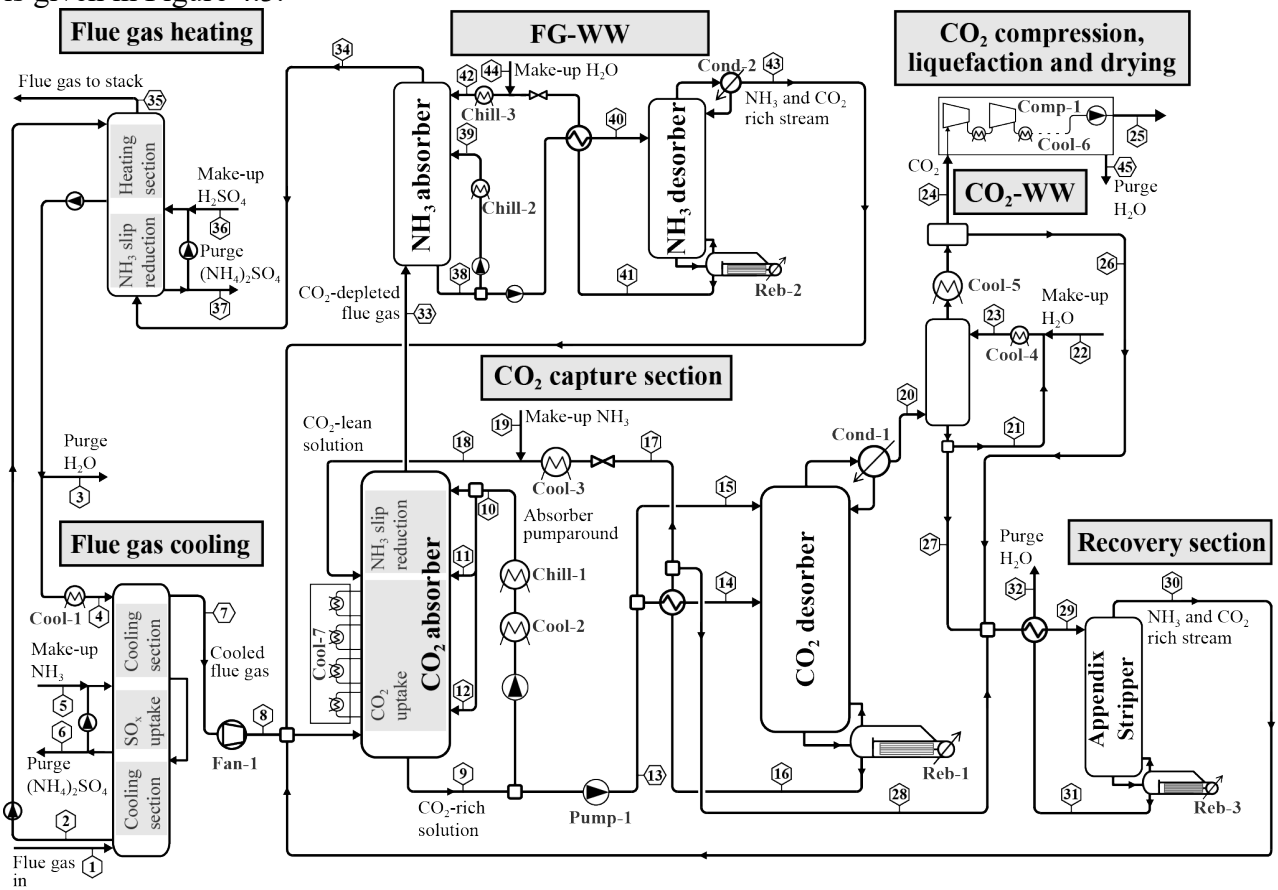

Figure 4.1. Process flowsheet of the chilled ammonia process.

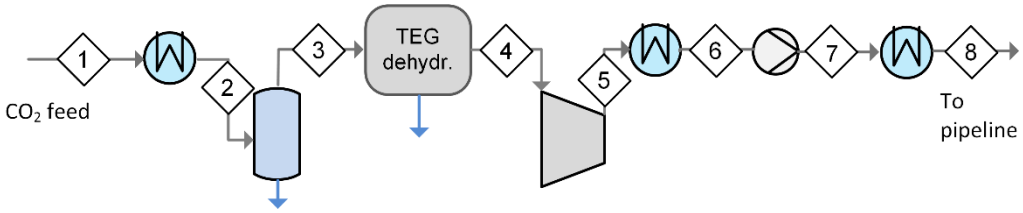

Figure 4.2. Process flowsheet of CO_2 drying and compression for pipeline transport.

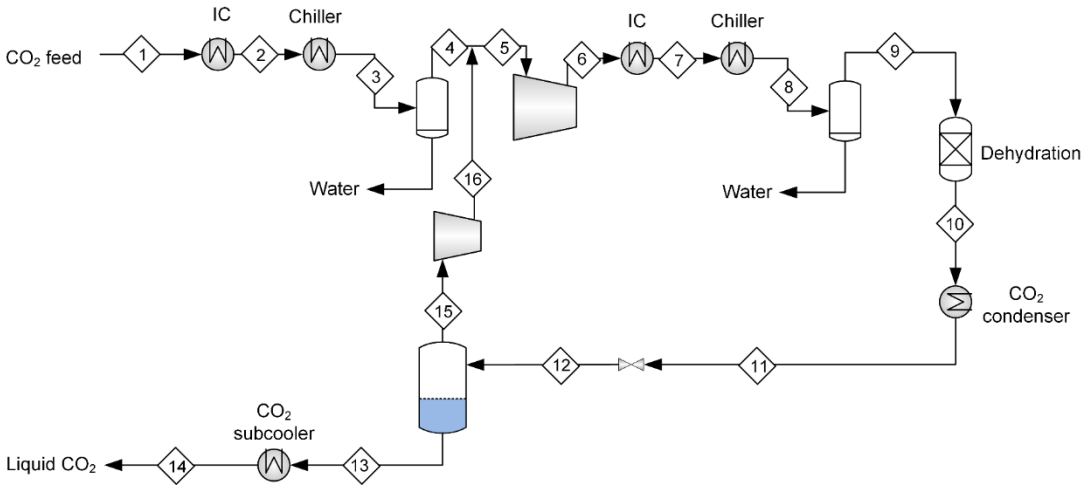

Figure 4.3. Process flowsheet of CO_2 dehydration and liquefaction for ship transport.

4.2 Stream data

4.2.1 Base case

In the base case 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 4.2 and stream data for the second half of the year is given in Table 4.3. Stream data for the CO_2 conditioning process is given in Table 4.4. The main energy consumers in the CAP for the first half of the year are listed in Table 4.5 and for the second half of the year in Table 4.6.

Table 4.2. Specifications of the streams of the CAP applied to the "Base" case defined in CEMCAP. Design at medium air leak, run 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	0.1100	0.0000	0.2200	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.6700	200 mg/Nm^3	0.0000	0.0000
2	1.86E+02	48.2	1.01	1.03E+01	-2.93E+06	1.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	7.55E-01	34.3	1.01	4.19E-02	-1.19E+04	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	1.81E+02	21.2	1.01	1.01E+01	-2.88E+06	1.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5(1)	3.46E-02	20	1.1	1.95E-03	-4.54E+02	0.7390	0.2610	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6(1)	5.95E-02	20	1.01	1.70E-03	-4.54E+02	0.8500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1500	0.0000
7	8.39E+01	22.2	1.01	2.66E+00	-2.69E+05	0.0266	0.0000	0.2410	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7330	0.0000	0.0000	0.0000
8	8.39E+01	29.9	1.1	2.66E+00	-2.68E+05	0.0266	0.0000	0.2410	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7330	0.0000	0.0000	0.0000
9	8.89E+02	24.8	1.05	4.42E+01	-1.29E+07	0.8930	0.0045	0.0001	0.0539	0.0000	0.0000	0.0049	0.0199	0.0242	0.0000	0.0000	0.0000	0.0000
10	1.07E+02	12	1.4	5.31E+00	-1.56E+06	0.8910	0.0032	0.0002	0.0563	0.0000	0.0000	0.0074	0.0184	0.0231	0.0000	0.0000	0.0000	0.0000
11	0.00E+00	na	na	0.00E+00	na	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	0.00E+00	na	na	0.00E+00	na	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	7.82E+02	25.6	25.4	3.89E+01	-1.14E+07	0.8930	0.0046	0.0001	0.0538	0.0000	0.0000	0.0048	0.0200	0.0242	0.0000	0.0000	0.0000	0.0000
14	7.62E+02	137	25.4	3.84E+01	-1.07E+07	0.8800	0.0335	0.0108	0.0379	0.0000	0.0000	0.0002	0.0272	0.0103	0.0000	0.0000	0.0000	0.0000
15	1.95E+01	25.6	25.4	9.73E-01	-2.84E+05	0.8930	0.0046	0.0001	0.0538	0.0000	0.0000	0.0048	0.0200	0.0242	0.0000	0.0000	0.0000	0.0000
16	7.57E+02	146	25	3.90E+01	-1.07E+07	0.8920	0.0430	0.0032	0.0312	0.0000	0.0000	0.0002	0.0227	0.0082	0.0000	0.0000	0.0000	0.0000
17	7.55E+02	29.3	25	3.88E+01	-1.11E+07	0.9060	0.0203	0.0000	0.0389	0.0000	0.0000	0.0046	0.0062	0.0234	0.0000	0.0000	0.0000	0.0000
18	7.55E+02	21.2	1.05	3.88E+01	-1.11E+07	0.9060	0.0194	0.0000	0.0403	0.0000	0.0000	0.0060	0.0054	0.0230	0.0000	0.0000	0.0000	0.0000
19(1)	1.02E-02	20	1.01	5.72E-04	-1.33E+02	0.7390	0.2610	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	2.54E+01	59.4	24.5	5.81E-01	-2.28E+05	0.0088	0.0002	0.9910	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	9.23E+00	56.8	24.5	4.52E-01	-1.34E+05	0.8880	0.0005	0.0077	0.0519	0.0000	0.0000	0.0002	0.0490	0.0026	0.0000	0.0000	0.0000	0.0000
22	4.76E-03	20	1.01	2.64E-04	-7.56E+01	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	9.23E+00	50	24.5	4.52E-01	-1.34E+05	0.8880	0.0004	0.0076	0.0521	0.0000	0.0000	0.0002	0.0492	0.0025	0.0000	0.0000	0.0000	0.0000
24	2.54E+01	35	24.5	5.77E-01	-2.27E+05	0.0030	0.0000	0.9970	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	2.53E+01	28.2	110	5.76E-01	-2.33E+05	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
26	4.06E-02	35	24.5	2.14E-03	-6.22E+02	0.9570	0.0000	0.0129	0.0148	0.0000	0.0000	0.0000	0.0148	0.0000	0.0000	0.0000	0.0000	0.0000

#	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
27	3.46E-02	56.8	24.5	1.69E-03	-5.03E+02	0.8880	0.0005	0.0077	0.0519	0.0000	0.0000	0.0002	0.0490	0.0026	0.0000	0.0000	0.0000	0.0000
28	1.29E+00	29.3	25	6.65E-02	-1.89E+04	0.9060	0.0203	0.0000	0.0389	0.0000	0.0000	0.0046	0.0062	0.0234	0.0000	0.0000	0.0000	0.0000
29	1.37E+00	72	24.5	7.02E-02	-1.98E+04	0.9050	0.0238	0.0000	0.0361	0.0000	0.0000	0.0014	0.0132	0.0200	0.0000	0.0000	0.0000	0.0000
30	5.50E-01	93.9	1.15	2.73E-02	-5.82E+03	0.7050	0.2050	0.0893	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	8.17E-01	105	1.25	4.54E-02	-1.27E+04	1.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
32	8.17E-01	40.8	1.25	4.54E-02	-1.29E+04	1.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
33	5.81E+01	12.4	1.01	2.05E+00	-3.45E+04	0.0132	0.0027	0.0334	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9510	0.0000	0.0000	0.0000
34	5.80E+01	15.8	1.01	2.05E+00	-3.44E+04	0.0178	0.0001	0.0311	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9510	0.0000	0.0000	0.0000
35	6.17E+01	47.3	1.01	2.25E+00	-8.25E+04	0.1080	0.0000	0.0285	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.8640	0.0000	0.0000	0.0000
36(1)	1.47E-02	20	1.1	1.63E-04	na	0.1000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9000
37(1)	1.97E-02	20	1.01	1.63E-04	na	0.1000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9000	0.0000
38	1.18E+01	12.5	1.04	6.41E-01	-1.85E+05	0.9840	0.0004	0.0000	0.0079	0.0000	0.0000	0.0003	0.0065	0.0008	0.0000	0.0000	0.0000	0.0000
39	1.18E-04	1.5	1.2	6.41E-06	-1.85E+00	0.9840	0.0003	0.0000	0.0080	0.0000	0.0000	0.0004	0.0064	0.0008	0.0000	0.0000	0.0000	0.0000
40	1.18E+01	90.6	1.4	6.43E-01	-1.81E+05	0.9840	0.0039	0.0030	0.0046	0.0000	0.0000	0.0001	0.0039	0.0006	0.0000	0.0000	0.0000	0.0000
41	1.14E+01	98.8	1.01	6.33E-01	-1.77E+05	0.9990	0.0009	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
42	1.16E+01	15	1.01	6.45E-01	-1.85E+05	0.9990	0.0009	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
43	3.52E-01	68	1.01	1.28E-02	-2.78E+03	0.2090	0.4090	0.3810	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0008	0.0000	0.0000	0.0000
44	2.18E-01	20	1.01	1.21E-02	-3.46E+03	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45	3.13E-02	32.5	24.5	1.74E-03	-4.96E+02	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

(1) Apparent composition

Table 4.3. Specifications of the streams of the CAP applied to the "Base" case defined in CEMCAP. Design at medium air leak, run 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	0.0900	0.0000	0.1800	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7300	200 mg/Nm^3	0.0000	0.0000
2	2.24E+02	42.9	1.01	1.24E+01	-3.54E+06	1.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	6.81E-01	31.4	1.01	3.78E-02	-1.08E+04	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	2.20E+02	21.2	1.01	1.22E+01	-3.49E+06	1.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5(1)	4.07E-02	20	1.1	2.29E-03	-5.33E+02	0.7390	0.2610	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6(1)	7.00E-02	20	1.01	1.99E-03	-5.93E+02	0.8500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1500	0.0000
7	1.04E+02	21.8	1.01	3.36E+00	-2.76E+05	0.0261	0.0000	0.1930	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7810	0.0000	0.0000	0.0000
8	1.04E+02	29.7	1.1	3.36E+00	-2.75E+05	0.0261	0.0000	0.1930	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7810	0.0000	0.0000	0.0000
9	8.61E+02	26	1.05	4.24E+01	-1.24E+07	0.8780	0.0065	0.0001	0.0605	0.0000	0.0000	0.0061	0.0180	0.0305	0.0000	0.0000	0.0000	0.0000
10	1.55E+02	9	1.4	7.63E+00	-2.24E+06	0.8760	0.0043	0.0002	0.0652	0.0000	0.0000	0.0109	0.0155	0.0280	0.0000	0.0000	0.0000	0.0000
11	0.00E+00	na	na	0.00E+00	na	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	0.00E+00	na	na	0.00E+00	na	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	7.06E+02	26.8	25.4	3.48E+01	-1.01E+07	0.8780	0.0067	0.0001	0.0604	0.0000	0.0000	0.0059	0.0181	0.0305	0.0000	0.0000	0.0000	0.0000
14	6.81E+02	138	25.4	3.39E+01	-9.45E+06	0.8630	0.0404	0.0111	0.0431	0.0000	0.0000	0.0002	0.0296	0.0130	0.0000	0.0000	0.0000	0.0000
15	2.47E+01	26.8	25.4	1.22E+00	-3.55E+05	0.8780	0.0067	0.0001	0.0604	0.0000	0.0000	0.0059	0.0181	0.0305	0.0000	0.0000	0.0000	0.0000
16	6.80E+02	147	25	3.49E+01	-9.52E+06	0.8750	0.0523	0.0029	0.0349	0.0000	0.0000	0.0002	0.0244	0.0101	0.0000	0.0000	0.0000	0.0000
17	6.79E+02	30.5	25	3.47E+01	-9.82E+06	0.8920	0.0278	0.0000	0.0428	0.0000	0.0000	0.0051	0.0057	0.0269	0.0000	0.0000	0.0000	0.0000
18	6.79E+02	21.2	1.05	3.47E+01	-9.85E+06	0.8910	0.0269	0.0000	0.0445	0.0000	0.0000	0.0068	0.0048	0.0262	0.0000	0.0000	0.0000	0.0000
19(1)	3.04E-02	20	1.01	1.71E-03	-3.99E+02	0.7390	0.2610	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	2.58E+01	54.3	24.5	5.88E-01	-2.31E+05	0.0068	0.0002	0.9930	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	9.35E+00	52.9	24.5	4.57E-01	-1.36E+05	0.8870	0.0003	0.0090	0.0518	0.0000	0.0000	0.0002	0.0494	0.0021	0.0000	0.0000	0.0000	0.0000
22	1.45E-02	20	1.01	8.05E-04	-2.30E+02	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	9.37E+00	50	24.5	4.58E-01	-1.36E+05	0.8870	0.0003	0.0089	0.0518	0.0000	0.0000	0.0002	0.0494	0.0021	0.0000	0.0000	0.0000	0.0000
24	2.57E+01	35	24.5	5.85E-01	-2.30E+05	0.0030	0.0000	0.9970	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

#	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
25	2.57E+01	28.2	110	5.83E-01	-2.36E+05	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
26	3.70E-02	35	24.5	1.95E-03	-5.66E+02	0.9590	0.0000	0.0128	0.0141	0.0000	0.0000	0.0000	0.0141	0.0000	0.0000	0.0000	0.0000	0.0000
27	2.53E-02	52.9	24.5	1.23E-03	-3.67E+02	0.8870	0.0003	0.0090	0.0518	0.0000	0.0000	0.0002	0.0494	0.0021	0.0000	0.0000	0.0000	0.0000
28	1.85E+00	30.5	25	9.43E-02	-2.67E+04	0.8920	0.0278	0.0000	0.0428	0.0000	0.0000	0.0051	0.0057	0.0269	0.0000	0.0000	0.0000	0.0000
29	1.91E+00	75.4	24.5	9.74E-02	-2.73E+04	0.8900	0.0327	0.0000	0.0394	0.0000	0.0000	0.0016	0.0130	0.0233	0.0000	0.0000	0.0000	0.0000
30	8.12E-01	92.9	1.15	4.02E-02	-8.38E+03	0.6780	0.2310	0.0916	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	1.10E+00	105	1.25	6.09E-02	-1.70E+04	1.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
32	1.10E+00	34.3	1.25	6.09E-02	-1.74E+04	1.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
33	7.74E+01	10.5	1.01	2.74E+00	-3.74E+04	0.0115	0.0035	0.0261	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9590	0.0000	0.0000	0.0000
34	7.72E+01	15.1	1.01	2.73E+00	-3.72E+04	0.0171	0.0002	0.0232	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9590	0.0000	0.0000	0.0000
35	8.07E+01	42.4	1.01	2.93E+00	-8.29E+04	0.0833	0.0000	0.0219	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.8950	0.0000	0.0000	0.0000
36[(1)]	2.64E-02	20	1.1	2.93E-04	na	0.1000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9000
37[(1)]	3.53E-02	20	1.01	2.93E-04	na	0.1000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9000	0.0000
38	1.57E+01	10.8	1.04	8.54E-01	-2.46E+05	0.9800	0.0006	0.0000	0.0097	0.0000	0.0000	0.0006	0.0073	0.0013	0.0000	0.0000	0.0000	0.0000
39	1.57E-04	1.5	1.2	8.54E-06	-2.47E+00	0.9800	0.0005	0.0000	0.0099	0.0000	0.0000	0.0007	0.0072	0.0013	0.0000	0.0000	0.0000	0.0000
40	1.57E+01	89.6	1.4	8.56E-01	-2.41E+05	0.9800	0.0049	0.0035	0.0058	0.0000	0.0000	0.0001	0.0047	0.0009	0.0000	0.0000	0.0000	0.0000
41	1.51E+01	98.8	1.01	8.40E-01	-2.35E+05	0.9990	0.0009	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
42	1.55E+01	13.9	1.01	8.60E-01	-2.46E+05	0.9990	0.0009	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
43	5.81E-01	68	1.01	2.14E-02	-4.55E+03	0.2080	0.4260	0.3660	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0006	0.0000	0.0000	0.0000
44	3.54E-01	20	1.01	1.96E-02	-5.62E+03	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45	3.16E-02	32.5	24.5	1.75E-03	-5.01E+02	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

(1) Apparent composition

Table 4.4. 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 4.5. Main energy consumers of the CAP applied to the "Base" case defined in CEMCAP. Design at medium air leak, run at low air leak. First ½ of the year.

Variable	Value
$\dot{Q}_{\mathrm{heat,tot}}$ [MW_{th}]	58.22
$\dot{Q}_{\mathrm{heat,Reb-1}}$ [MW_{th}]	53.68
$T_{\mathrm{Reb-1}}$ [°C]	145
$\dot{Q}_{\mathrm{heat,Reb-2}}$ [MW_{th}]	3.21
$T_{\mathrm{Reb-2}}$ [°C]	99
$\dot{Q}_{\mathrm{heat,Reb-3}}$ [MW_{th}]	1.33
$T_{\mathrm{Reb-3}}$ [°C]	105
$\dot{Q}_{\mathrm{cool,tot}}$ [MW_{th}]	76.74
$\dot{Q}_{\mathrm{cool,Cond-1}}$ [MW_{th}]	0
$T_{\mathrm{out,Cond-1}}$ [°C]	-
$\dot{Q}_{\mathrm{cool,Cond-2}}$ [MW_{th}]	2.42
$T_{\mathrm{out,Cond-2}}$ [°C]	68.0
$\dot{Q}_{\mathrm{cool,Cool-1}}$ [MW_{th}]	9.71
$T_{\mathrm{out,Cool-1}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-2}}$ [MW_{th}]	1.54
$T_{\mathrm{out,Cool-2}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-3}}$ [MW_{th}]	24.08
$T_{\mathrm{out,Cool-3}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-4}}$ [MW_{th}]	0.25
$T_{\mathrm{out,Cool-4}}$ [°C]	50.0
$\dot{Q}_{\mathrm{cool,Cool-5}}$ [MW_{th}]	0.53
$T_{\mathrm{out,Cool-5}}$ [°C]	35.0
$\dot{Q}_{\mathrm{cool,Cool-6}}$ [MW_{th}]	7.80
$T_{\mathrm{out,Cool-6}}$ [°C]	28.2
$\dot{Q}_{\mathrm{cool,Cool-7}}$ [MW_{th}]	30.41
$T_{\mathrm{out,Cool-7}}$ [°C]	21.2

Variable	Value
$\dot{Q}_{\mathrm{chill,tot}}$ [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
$\dot{W}_{\mathrm{CO_2comp,Comp-1}}$ [MW$_{\mathrm{el}}$]	2.04

Table 4.6. Main energy consumers of the CAP applied to the "Base" case defined in CEMCAP. Design at medium air leak, run 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$_{\mathrm{th}}$]	7.91

Variable	Value
$T_{\text{out,Cool}-6}$ [°C]	28.2
$\dot{Q}_{\text{cool,Cool}-7}$ [MW_{th}]	29.02
$T_{\text{out,Cool}-7}$ [°C]	21.2
$\dot{Q}_{\text{chill,tot}}$ [MW_{th}]	7.98
$\dot{Q}_{\text{chill,Chill}-1}$ [MW_{th}]	7.98
$T_{\text{out,Chill}-1}$ [°C]	9.0
$\dot{Q}_{\text{chill,Chill}-2}$ [MW_{th}]	0
$T_{\text{out,Chill}-2}$ [°C]	-
$\dot{Q}_{\text{chill,Chill}-3}$ [MW_{th}]	0
$T_{\text{out,Chill}-3}$ [°C]	-
$\dot{W}_{\text{aux,tot}}$ [MW_{el}]	3.15
$\dot{W}_{\text{aux,Fan}-1}$ [MW_{el}]	0.85
$\dot{W}_{\text{aux,Pump}-1}$ [MW_{el}]	2.30
$\dot{W}_{\text{CO}_2\text{comp,Comp}-1}$ [MW_{el}]	2.07

4.2.2 Constant low air leak in mill

Stream data for the MEA process in the case with constant low air leak in the mill is given in Table 4.7. Stream data for the CO_2 conditioning process is given in Table 4.8. The main energy consumers in the CAP are listed in Table 4.9.

Table 4.7. Specifications of the streams of the CAP applied to the "Constant low air leak" case defined in CEMCAP.

#	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	0.1100	0.0000	0.2200	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.6700	200 mg/Nm^3	0.0000	0.0000
2	1.86E+02	48.2	1.01	1.03E+01	-2.93E+06	1.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	7.37E-01	34.2	1.01	4.09E-02	-1.17E+04	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	1.81E+02	21.2	1.01	1.01E+01	-2.88E+06	1.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5(1)	3.46E-02	20	1.1	1.95E-03	-4.54E+02	0.7390	0.2610	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6(1)	5.95E-02	20	1.01	1.70E-03	-4.54E+02	0.8500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1500	0.0000
7	8.39E+01	22.2	1.01	2.66E+00	-2.69E+05	0.0266	0.0000	0.2410	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7330	0.0000	0.0000	0.0000
8	8.39E+01	29.9	1.1	2.66E+00	-2.68E+05	0.0266	0.0000	0.2410	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7330	0.0000	0.0000	0.0000
9	7.24E+02	24.4	1.05	3.66E+01	-1.07E+07	0.9100	0.0037	0.0001	0.0451	0.0000	0.0000	0.0038	0.0189	0.0185	0.0000	0.0000	0.0000	0.0000
10	1.09E+02	12	1.4	5.49E+00	-1.61E+06	0.9090	0.0027	0.0002	0.0467	0.0000	0.0000	0.0056	0.0178	0.0178	0.0000	0.0000	0.0000	0.0000
11	0.00E+00	na	na	0.00E+00	na	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	0.00E+00	na	na	0.00E+00	na	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	6.15E+02	25	20.4	3.11E+01	-9.08E+06	0.9100	0.0037	0.0001	0.0450	0.0000	0.0000	0.0038	0.0190	0.0185	0.0000	0.0000	0.0000	0.0000
14	5.91E+02	137	20.4	3.03E+01	-8.42E+06	0.9000	0.0312	0.0129	0.0281	0.0000	0.0000	0.0002	0.0207	0.0071	0.0000	0.0000	0.0000	0.0000
15	2.46E+01	25	20.4	1.25E+00	-3.63E+05	0.9100	0.0037	0.0001	0.0450	0.0000	0.0000	0.0038	0.0190	0.0185	0.0000	0.0000	0.0000	0.0000
16	5.90E+02	149	20	3.12E+01	-8.50E+06	0.9150	0.0417	0.0024	0.0206	0.0000	0.0000	0.0001	0.0156	0.0048	0.0000	0.0000	0.0000	0.0000
17	5.89E+02	29.6	20	3.11E+01	-8.78E+06	0.9260	0.0253	0.0000	0.0260	0.0000	0.0000	0.0031	0.0039	0.0159	0.0000	0.0000	0.0000	0.0000
18	5.89E+02	21.2	1.05	3.11E+01	-8.80E+06	0.9260	0.0248	0.0000	0.0269	0.0000	0.0000	0.0040	0.0033	0.0156	0.0000	0.0000	0.0000	0.0000
19(1)	1.14E-02	20	1.01	6.44E-04	-1.50E+02	0.7390	0.2610	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	2.54E+01	47.5	19.5	5.79E-01	-2.27E+05	0.0062	0.0001	0.9940	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
21	7.85E+00	46.7	19.5	4.24E-01	-1.22E+05	0.9780	0.0000	0.0068	0.0076	0.0000	0.0000	0.0000	0.0075	0.0000	0.0000	0.0000	0.0000	0.0000
22	8.41E-02	20	1.01	4.67E-03	-1.34E+03	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

#	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
23	7.94E+00	45	19.5	4.29E-01	-1.23E+05	0.9780	0.0000	0.0067	0.0075	0.0000	0.0000	0.0000	0.0075	0.0000	0.0000	0.0000	0.0000	0.0000
24	2.54E+01	35	19.5	5.77E-01	-2.27E+05	0.0036	0.0000	0.9960	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
25	2.53E+01	28.2	110	5.75E-01	-2.32E+05	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
26	2.67E-02	35	19.5	1.46E-03	-4.19E+02	0.9900	0.0000	0.0083	0.0007	0.0000	0.0000	0.0000	0.0007	0.0000	0.0000	0.0000	0.0000	0.0000
27	8.83E-02	46.7	19.5	4.77E-03	-1.37E+03	0.9780	0.0000	0.0068	0.0076	0.0000	0.0000	0.0000	0.0075	0.0000	0.0000	0.0000	0.0000	0.0000
28	1.23E+00	29.6	20	6.50E-02	-1.84E+04	0.9260	0.0253	0.0000	0.0260	0.0000	0.0000	0.0031	0.0039	0.0159	0.0000	0.0000	0.0000	0.0000
29	1.35E+00	74.2	19.5	7.11E-02	-1.99E+04	0.9290	0.0262	0.0000	0.0230	0.0000	0.0000	0.0010	0.0083	0.0127	0.0000	0.0000	0.0000	0.0000
30	4.90E-01	95.8	1.15	2.52E-02	-5.41E+03	0.7630	0.1740	0.0622	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	8.56E-01	105	1.25	4.75E-02	-1.33E+04	1.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
32	8.56E-01	41.5	1.25	4.75E-02	-1.35E+04	1.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
33	5.81E+01	12.8	1.01	2.05E+00	-3.44E+04	0.0138	0.0019	0.0330	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9510	0.0000	0.0000	0.0000
34	5.80E+01	15.4	1.01	2.05E+00	-3.43E+04	0.0174	0.0001	0.0312	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9510	0.0000	0.0000	0.0000
35	6.17E+01	47.3	1.01	2.25E+00	-8.26E+04	0.1080	0.0000	0.0286	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.8640	0.0000	0.0000	0.0000
36(1)	1.05E-02	20	1.1	1.16E-04	na	0.1000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9000
37(1)	1.41E-02	20	1.01	1.16E-04	na	0.1000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9000	0.0000
38	1.17E+01	12.9	1.04	6.41E-01	-1.85E+05	0.9880	0.0003	0.0000	0.0060	0.0000	0.0000	0.0002	0.0052	0.0004	0.0000	0.0000	0.0000	0.0000
39	1.17E-04	1.5	1.2	6.41E-06	-1.85E+00	0.9880	0.0002	0.0000	0.0061	0.0000	0.0000	0.0003	0.0051	0.0004	0.0000	0.0000	0.0000	0.0000
40	1.17E+01	91.7	1.4	6.43E-01	-1.81E+05	0.9880	0.0029	0.0024	0.0035	0.0000	0.0000	0.0000	0.0031	0.0003	0.0000	0.0000	0.0000	0.0000
41	1.15E+01	98.8	1.01	6.36E-01	-1.78E+05	0.9990	0.0009	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
42	1.16E+01	15	1.01	6.45E-01	-1.85E+05	0.9990	0.0009	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
43	2.64E-01	68	1.01	9.45E-03	-2.11E+03	0.2110	0.3920	0.3960	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0011	0.0000	0.0000	0.0000
44	1.66E-01	20	1.01	9.22E-03	-2.64E+03	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45	3.80E-02	32.3	19.5	2.11E-03	-6.02E+02	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

(1) *Apparent composition*

Table 4.8. 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	19.50	2078.19	0.0036	0.9964	0.0000	0.0000
2	1.00	28.20	19.11	2078.19	0.0036	0.9964	0.0000	0.0000
3	1.00	28.20	19.11	2076.20	0.0027	0.9973	0.0000	0.0000
4	1.00	29.63	18.15	2070.97	0.0001	0.9999	0.0000	0.0000
5	1.00	166.85	80.00	2070.97	0.0001	0.9999	0.0000	0.0000
6	0.00	28.20	78.40	2070.97	0.0001	0.9999	0.0000	0.0000
7	0.00	36.26	110.40	2070.97	0.0001	0.9999	0.0000	0.0000
8	0.00	28.20	110.00	2070.97	0.0001	0.9999	0.0000	0.0000

Table 4.9. Main energy consumers of the CAP applied to the "Constant low air leak" case defined in CEMCAP.

Variable	Value
$\dot{Q}_{\mathrm{heat,tot}}$ [MW_{th}]	57.91
$\dot{Q}_{\mathrm{heat,Reb-1}}$ [MW_{th}]	53.85
$T_{\mathrm{Reb-1}}$ [°C]	149.0
$\dot{Q}_{\mathrm{heat,Reb-2}}$ [MW_{th}]	2.85
$T_{\mathrm{Reb-2}}$ [°C]	99.0
$\dot{Q}_{\mathrm{heat,Reb-3}}$ [MW_{th}]	1.21
$T_{\mathrm{Reb-3}}$ [°C]	105.0
$\dot{Q}_{\mathrm{cool,tot}}$ [MW_{th}]	84.17
$\dot{Q}_{\mathrm{cool,Cond-1}}$ [MW_{th}]	0
$T_{\mathrm{out,Cond-1}}$ [°C]	-
$\dot{Q}_{\mathrm{cool,Cond-2}}$ [MW_{th}]	2.23
$T_{\mathrm{out,Cond-2}}$ [°C]	68.0
$\dot{Q}_{\mathrm{cool,Cool-1}}$ [MW_{th}]	9.65
$T_{\mathrm{out,Cool-1}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-2}}$ [MW_{th}]	1.39
$T_{\mathrm{out,Cool-2}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-3}}$ [MW_{th}]	19.68
$T_{\mathrm{out,Cool-3}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-4}}$ [MW_{th}]	0.05
$T_{\mathrm{out,Cool-4}}$ [°C]	45.0
$\dot{Q}_{\mathrm{cool,Cool-5}}$ [MW_{th}]	0.32
$T_{\mathrm{out,Cool-5}}$ [°C]	35.0
$\dot{Q}_{\mathrm{cool,Cool-6}}$ [MW_{th}]	8.33
$T_{\mathrm{out,Cool-6}}$ [°C]	28.2
$\dot{Q}_{\mathrm{cool,Cool-7}}$ [MW_{th}]	34.21

Variable	Value
$T_{\text{out,Cool}-7}$ [°C]	21.2
$\dot{Q}_{\text{chill,tot}}$ [MW_{th}]	4.12
$\dot{Q}_{\text{chill,Chill}-1}$ [MW_{th}]	4.07
$T_{\text{out,Chill}-1}$ [°C]	12.0
$\dot{Q}_{\text{chill,Chill}-2}$ [MW_{th}]	0
$T_{\text{out,Chill}-2}$ [°C]	-
$\dot{Q}_{\text{chill,Chill}-3}$ [MW_{th}]	0.05
$T_{\text{out,Chill}-3}$ [°C]	15.0
$\dot{W}_{\text{aux,tot}}$ [MW_{el}]	2.24
$\dot{W}_{\text{aux,Fan}-1}$ [MW_{el}]	0.67
$\dot{W}_{\text{aux,Pump}-1}$ [MW_{el}]	1.56
$\dot{W}_{\text{CO}_2\text{comp,Comp}-1}$ [MW_{el}]	2.48

4.2.3 Optional extent of capture

In this case 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 4.10 and stream data for the second half of the year is given in Table 4.11. Stream data for the CO_2 conditioning process is given in Table 4.12. The main energy consumers in the CAP for the first half of the year are listed in Table 4.13 and for the second half of the year in Table 4.14.

Table 4.10. Specifications of the streams of the CAP applied to the "Optional extent of capture" case defined in CEMCAP. Design at medium air leak, run 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	0.1100	0.0000	0.2200	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.6700	200 mg/Nm^3	0.0000	0.0000
2	1.86E+02	48.2	1.01	1.03E+01	-2.93E+06	1.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	7.47E-01	34.3	1.01	4.15E-02	-1.18E+04	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	1.81E+02	21.2	1.01	1.01E+01	-2.88E+06	1.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5(1)	3.46E-02	20	1.1	1.95E-03	-4.53E+02	0.7390	0.2610	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6(1)	5.95E-02	20	1.01	1.69E-03	-4.53E+02	0.8500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1500	0.0000
7	8.39E+01	22.2	1.01	2.66E+00	-2.69E+05	0.0266	0.0000	0.2410	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7330	0.0000	0.0000	0.0000
8	8.39E+01	29.9	1.1	2.66E+00	-2.68E+05	0.0266	0.0000	0.2410	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7330	0.0000	0.0000	0.0000
9	7.00E+02	24.5	1.05	3.54E+01	-1.03E+07	0.9090	0.0034	0.0001	0.0455	0.0000	0.0000	0.0037	0.0198	0.0182	0.0000	0.0000	0.0000	0.0000
10	8.40E+01	13	1.4	4.25E+00	-1.24E+06	0.9090	0.0026	0.0002	0.0470	0.0000	0.0000	0.0053	0.0188	0.0177	0.0000	0.0000	0.0000	0.0000
11	0.00E+00	na	na	0.00E+00	na	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	0.00E+00	na	na	0.00E+00	na	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	6.16E+02	25.1	20.4	3.11E+01	-9.08E+06	0.9090	0.0035	0.0001	0.0454	0.0000	0.0000	0.0037	0.0198	0.0183	0.0000	0.0000	0.0000	0.0000
14	5.95E+02	136	20.4	3.04E+01	-8.48E+06	0.9000	0.0297	0.0123	0.0292	0.0000	0.0000	0.0002	0.0215	0.0074	0.0000	0.0000	0.0000	0.0000
15	2.16E+01	25.1	20.4	1.09E+00	-3.18E+05	0.9090	0.0035	0.0001	0.0454	0.0000	0.0000	0.0037	0.0198	0.0182	0.0000	0.0000	0.0000	0.0000
16	5.92E+02	147	20	3.12E+01	-8.53E+06	0.9140	0.0397	0.0024	0.0221	0.0000	0.0000	0.0001	0.0166	0.0053	0.0000	0.0000	0.0000	0.0000
17	5.91E+02	29.5	20	3.11E+01	-8.80E+06	0.9250	0.0226	0.0000	0.0278	0.0000	0.0000	0.0033	0.0044	0.0168	0.0000	0.0000	0.0000	0.0000
18	5.91E+02	21.2	1.05	3.11E+01	-8.82E+06	0.9250	0.0220	0.0000	0.0287	0.0000	0.0000	0.0043	0.0037	0.0165	0.0000	0.0000	0.0000	0.0000
19(1)	1.36E-02	20	1.01	7.67E-04	-1.78E+02	0.7390	0.2610	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

#	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
20	2.39E+01	50.1	19.5	5.46E-01	-2.14E+05	0.0070	0.0001	0.9930	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
21	8.43E+00	48.5	19.5	4.20E-01	-1.24E+05	0.9070	0.0002	0.0083	0.0424	0.0000	0.0000	0.0001	0.0409	0.0013	0.0000	0.0000	0.0000	0.0000
22	1.67E-03	20	1.01	9.29E-05	-2.66E+01	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	8.43E+00	45	19.5	4.21E-01	-1.24E+05	0.9070	0.0002	0.0082	0.0424	0.0000	0.0000	0.0001	0.0409	0.0013	0.0000	0.0000	0.0000	0.0000
24	2.39E+01	35	19.5	5.44E-01	-2.14E+05	0.0035	0.0000	0.9960	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
25	2.39E+01	28.2	110	5.42E-01	-2.19E+05	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
26	2.53E-02	35	19.5	1.35E-03	-3.90E+02	0.9670	0.0000	0.0100	0.0115	0.0000	0.0000	0.0000	0.0115	0.0000	0.0000	0.0000	0.0000	0.0000
27	1.43E-02	48.5	19.5	7.11E-04	-2.10E+02	0.9070	0.0002	0.0083	0.0424	0.0000	0.0000	0.0001	0.0409	0.0013	0.0000	0.0000	0.0000	0.0000
28	1.11E+00	29.5	20	5.84E-02	-1.66E+04	0.9250	0.0226	0.0000	0.0278	0.0000	0.0000	0.0033	0.0044	0.0168	0.0000	0.0000	0.0000	0.0000
29	1.15E+00	73.4	19.5	6.05E-02	-1.70E+04	0.9240	0.0256	0.0000	0.0258	0.0000	0.0000	0.0011	0.0093	0.0143	0.0000	0.0000	0.0000	0.0000
30	4.29E-01	95.4	1.15	2.19E-02	-4.69E+03	0.7500	0.1810	0.0683	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	7.22E-01	105	1.25	4.01E-02	-1.12E+04	1.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
32	7.22E-01	40.3	1.25	4.01E-02	-1.14E+04	1.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
33	5.96E+01	14.4	1.01	2.08E+00	-4.84E+04	0.0153	0.0023	0.0486	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9340	0.0000	0.0000	0.0000
34	5.95E+01	16.7	1.01	2.08E+00	-4.81E+04	0.0189	0.0001	0.0464	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9350	0.0000	0.0000	0.0000
35	6.32E+01	47.3	1.01	2.29E+00	-9.62E+04	0.1070	0.0000	0.0425	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.8500	0.0000	0.0000	0.0000
36(1)	1.24E-02	20	1.1	1.38E-04	na	0.1000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9000
37(1)	1.66E-02	20	1.01	1.38E-04	na	0.1000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9000	0.0000
38	1.21E+01	14.5	1.04	6.59E-01	-1.90E+05	0.9860	0.0003	0.0001	0.0071	0.0000	0.0000	0.0002	0.0061	0.0005	0.0000	0.0000	0.0000	0.0000
39	1.21E-04	1.5	1.2	6.59E-06	-1.91E+00	0.9860	0.0002	0.0001	0.0072	0.0000	0.0000	0.0003	0.0061	0.0005	0.0000	0.0000	0.0000	0.0000
40	1.21E+01	91	1.4	6.61E-01	-1.86E+05	0.9860	0.0033	0.0029	0.0041	0.0000	0.0000	0.0000	0.0035	0.0005	0.0000	0.0000	0.0000	0.0000
41	1.18E+01	98.8	1.01	6.52E-01	-1.83E+05	0.9990	0.0009	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
42	1.19E+01	15	1.01	6.62E-01	-1.90E+05	0.9990	0.0009	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
43	3.21E-01	68	1.01	1.15E-02	-2.57E+03	0.2110	0.3950	0.3940	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0009	0.0000	0.0000	0.0000
44	1.80E-01	20	1.01	9.97E-03	-2.85E+03	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45	3.52E-02	32.2	19.5	1.96E-03	-5.58E+02	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

(1) *Apparent composition*

Table 4.11. Specifications of the streams of the CAP applied to the "Optional extent of capture" case defined in CEMCAP. Design at medium air leak, run 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	0.0900	0.0000	0.1800	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7300	200 mg/Nm³	0.0000	0.0000
2	2.24E+02	42.9	1.01	1.24E+01	-3.54E+06	1.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	7.01E-01	31.5	1.01	3.89E-02	-1.11E+04	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	2.20E+02	21.2	1.01	1.22E+01	-3.49E+06	1.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5(1)	4.07E-02	20	1.1	2.29E-03	-5.33E+02	0.7390	0.2610	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6(1)	7.00E-02	20	1.01	1.99E-03	-5.93E+02	0.8500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1500	0.0000
7	1.04E+02	21.8	1.01	3.36E+00	-2.76E+05	0.0261	0.0000	0.1930	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7810	0.0000	0.0000	0.0000
8	1.04E+02	29.7	1.1	3.36E+00	-2.75E+05	0.0261	0.0000	0.1930	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7810	0.0000	0.0000	0.0000
9	6.91E+02	24.1	1.05	3.44E+01	-1.00E+07	0.8920	0.0044	0.0001	0.0540	0.0000	0.0000	0.0050	0.0199	0.0241	0.0000	0.0000	0.0000	0.0000
10	1.45E+02	12	1.4	7.22E+00	-2.12E+06	0.8910	0.0032	0.0002	0.0563	0.0000	0.0000	0.0074	0.0185	0.0231	0.0000	0.0000	0.0000	0.0000
11	0.00E+00	na	na	0.00E+00	na	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	0.00E+00	na	na	0.00E+00	na	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	5.46E+02	24.7	20.4	2.71E+01	-7.93E+06	0.8920	0.0045	0.0001	0.0540	0.0000	0.0000	0.0049	0.0200	0.0242	0.0000	0.0000	0.0000	0.0000
14	5.24E+02	135	20.4	2.64E+01	-7.36E+06	0.8800	0.0354	0.0130	0.0358	0.0000	0.0000	0.0002	0.0250	0.0104	0.0000	0.0000	0.0000	0.0000
15	2.18E+01	24.7	20.4	1.09E+00	-3.17E+05	0.8920	0.0045	0.0001	0.0540	0.0000	0.0000	0.0049	0.0200	0.0242	0.0000	0.0000	0.0000	0.0000
16	5.21E+02	147	20	2.72E+01	-7.41E+06	0.8960	0.0488	0.0022	0.0265	0.0000	0.0000	0.0002	0.0189	0.0072	0.0000	0.0000	0.0000	0.0000
17	5.19E+02	28.7	20	2.71E+01	-7.64E+06	0.9090	0.0297	0.0000	0.0326	0.0000	0.0000	0.0040	0.0042	0.0203	0.0000	0.0000	0.0000	0.0000
18	5.19E+02	21.2	1.05	2.71E+01	-7.65E+06	0.9090	0.0291	0.0000	0.0336	0.0000	0.0000	0.0050	0.0037	0.0199	0.0000	0.0000	0.0000	0.0000
19(1)	3.23E-02	20	1.01	1.82E-03	-4.24E+02	0.7390	0.2610	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	2.47E+01	64.6	19.5	5.66E-01	-2.21E+05	0.0133	0.0005	0.9860	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	8.53E+00	61.9	19.5	4.29E-01	-1.26E+05	0.9140	0.0006	0.0052	0.0403	0.0000	0.0000	0.0001	0.0379	0.0021	0.0000	0.0000	0.0000	0.0000
22	5.54E-02	20	1.01	3.07E-03	-8.79E+02	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	8.59E+00	50	19.5	4.32E-01	-1.27E+05	0.9140	0.0004	0.0048	0.0403	0.0000	0.0000	0.0002	0.0381	0.0019	0.0000	0.0000	0.0000	0.0000
24	2.46E+01	35	19.5	5.60E-01	-2.20E+05	0.0035	0.0000	0.9960	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	2.46E+01	28.2	110	5.58E-01	-2.26E+05	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
26	5.53E-02	35	19.5	2.94E-03	-8.51E+02	0.9640	0.0000	0.0102	0.0126	0.0000	0.0000	0.0000	0.0126	0.0000	0.0000	0.0000	0.0000	0.0000

#	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
27	1.21E-01	61.9	19.5	6.06E-03	-1.78E+03	0.9140	0.0006	0.0052	0.0403	0.0000	0.0000	0.0001	0.0379	0.0021	0.0000	0.0000	0.0000	0.0000
28	1.51E+00	28.7	20	7.88E-02	-2.22E+04	0.9090	0.0297	0.0000	0.0326	0.0000	0.0000	0.0040	0.0042	0.0203	0.0000	0.0000	0.0000	0.0000
29	1.69E+00	77.4	19.5	8.78E-02	-2.46E+04	0.9100	0.0296	0.0000	0.0307	0.0000	0.0000	0.0012	0.0110	0.0173	0.0000	0.0000	0.0000	0.0000
30	6.69E-01	94.4	1.15	3.38E-02	-7.15E+03	0.7220	0.2010	0.0768	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	1.02E+00	105	1.25	5.66E-02	-1.58E+04	1.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
32	1.02E+00	35.5	1.25	5.66E-02	-1.61E+04	1.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
33	7.85E+01	12.6	1.01	2.76E+00	-4.79E+04	0.0134	0.0028	0.0345	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9490	0.0000	0.0000	0.0000
34	7.83E+01	16	1.01	2.76E+00	-4.78E+04	0.0181	0.0001	0.0321	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9500	0.0000	0.0000	0.0000
35	8.19E+01	42.4	1.01	2.96E+00	-9.33E+04	0.0833	0.0000	0.0302	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.8870	0.0000	0.0000	0.0000
36(1)	2.04E-02	20	1.1	2.27E-04	na	0.1000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9000
37(1)	1.66E-02	20	1.01	1.38E-04	na	0.1000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9000	0.0000
38	1.59E+01	12.7	1.04	8.67E-01	-2.50E+05	0.9840	0.0004	0.0000	0.0081	0.0000	0.0000	0.0003	0.0066	0.0008	0.0000	0.0000	0.0000	0.0000
39	1.59E-04	1.5	1.2	8.67E-06	-2.51E+00	0.9840	0.0003	0.0001	0.0082	0.0000	0.0000	0.0005	0.0065	0.0008	0.0000	0.0000	0.0000	0.0000
40	1.59E+01	90.5	1.4	8.69E-01	-2.45E+05	0.9840	0.0040	0.0031	0.0047	0.0000	0.0000	0.0001	0.0040	0.0006	0.0000	0.0000	0.0000	0.0000
41	1.54E+01	98.8	1.01	8.56E-01	-2.40E+05	0.9990	0.0009	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
42	1.57E+01	15	1.01	8.72E-01	-2.50E+05	0.9990	0.0009	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
43	4.87E-01	68	1.01	1.77E-02	-3.85E+03	0.2090	0.4100	0.3800	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0008	0.0000	0.0000	0.0000
44	2.97E-01	20	1.01	1.65E-02	-4.72E+03	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45	3.59E-02	32.2	19.5	1.99E-03	-5.69E+02	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

(1) *Apparent composition*

Table 4.12. 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	19.50	2016.61	0.0035	0.9965	0.0000	0.0000
2	1.00	28.20	19.11	2016.61	0.0035	0.9965	0.0000	0.0000
3	1.00	28.20	19.11	2014.89	0.0027	0.9973	0.0000	0.0000
4	1.00	29.63	18.15	2009.81	0.0001	0.9999	0.0000	0.0000
5	1.00	166.85	80.00	2009.81	0.0001	0.9999	0.0000	0.0000
6	0.00	28.20	78.40	2009.81	0.0001	0.9999	0.0000	0.0000
7	0.00	36.26	110.40	2009.81	0.0001	0.9999	0.0000	0.0000
8	0.00	28.20	110.00	2009.81	0.0001	0.9999	0.0000	0.0000

Table 4.13. Main energy consumers of the CAP applied to the "Optional extent of capture" case defined in CEMCAP. Design at medium air leak, run at low air leak. First ½ of the year.

Variable	Value
$\dot{Q}_{\mathrm{heat,tot}}$ [MW_{th}]	54.31
$\dot{Q}_{\mathrm{heat,Reb-1}}$ [MW_{th}]	50.13
$T_{\mathrm{Reb-1}}$ [°C]	147
$\dot{Q}_{\mathrm{heat,Reb-2}}$ [MW_{th}]	3.13
$T_{\mathrm{Reb-2}}$ [°C]	99
$\dot{Q}_{\mathrm{heat,Reb-3}}$ [MW_{th}]	1.06
$T_{\mathrm{Reb-3}}$ [°C]	105
$\dot{Q}_{\mathrm{cool,tot}}$ [MW_{th}]	72.80
$\dot{Q}_{\mathrm{cool,Cond-1}}$ [MW_{th}]	0
$T_{\mathrm{out,Cond-1}}$ [°C]	-
$\dot{Q}_{\mathrm{cool,Cond-2}}$ [MW_{th}]	2.39
$T_{\mathrm{out,Cond-2}}$ [°C]	68.0
$\dot{Q}_{\mathrm{cool,Cool-1}}$ [MW_{th}]	9.71
$T_{\mathrm{out,Cool-1}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-2}}$ [MW_{th}]	1.11
$T_{\mathrm{out,Cool-2}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-3}}$ [MW_{th}]	19.55
$T_{\mathrm{out,Cool-3}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-4}}$ [MW_{th}]	0.12
$T_{\mathrm{out,Cool-4}}$ [°C]	45.0
$\dot{Q}_{\mathrm{cool,Cool-5}}$ [MW_{th}]	0.31
$T_{\mathrm{out,Cool-5}}$ [°C]	35.0
$\dot{Q}_{\mathrm{cool,Cool-6}}$ [MW_{th}]	7.86
$T_{\mathrm{out,Cool-6}}$ [°C]	28.2
$\dot{Q}_{\mathrm{cool,Cool-7}}$ [MW_{th}]	31.74

Variable	Value
$T_{\mathrm{out,Cool-7}}$ [°C]	21.2
$\dot{Q}_{\mathrm{chill,tot}}$ [MW$_{\mathrm{th}}$]	2.93
$\dot{Q}_{\mathrm{chill,Chill-1}}$ [MW$_{\mathrm{th}}$]	2.80
$T_{\mathrm{out,Chill-1}}$ [°C]	13.0
$\dot{Q}_{\mathrm{chill,Chill-2}}$ [MW$_{\mathrm{th}}$]	0
$T_{\mathrm{out,Chill-2}}$ [°C]	-
$\dot{Q}_{\mathrm{chill,Chill-3}}$ [MW$_{\mathrm{th}}$]	0.13
$T_{\mathrm{out,Chill-3}}$ [°C]	15.0
$\dot{W}_{\mathrm{aux,tot}}$ [MW$_{\mathrm{el}}$]	2.23
$\dot{W}_{\mathrm{aux,Fan-1}}$ [MW$_{\mathrm{el}}$]	0.67
$\dot{W}_{\mathrm{aux,Pump-1}}$ [MW$_{\mathrm{el}}$]	1.56
$\dot{W}_{\mathrm{CO_2comp,Comp-1}}$ [MW$_{\mathrm{el}}$]	2.34

Table 4.14. Main energy consumers of the CAP applied to the "Optional extent of capture" case defined in CEMCAP. Design at medium air leak, run at medium air leak. Second ½ of the year.

Variable	Value
$\dot{Q}_{\mathrm{heat,tot}}$ [MW$_{\mathrm{th}}$]	58.29
$\dot{Q}_{\mathrm{heat,Reb-1}}$ [MW$_{\mathrm{th}}$]	52.31
$T_{\mathrm{Reb-1}}$ [°C]	147
$\dot{Q}_{\mathrm{heat,Reb-2}}$ [MW$_{\mathrm{th}}$]	4.38
$T_{\mathrm{Reb-2}}$ [°C]	99
$\dot{Q}_{\mathrm{heat,Reb-3}}$ [MW$_{\mathrm{th}}$]	1.60
$T_{\mathrm{Reb-3}}$ [°C]	105
$\dot{Q}_{\mathrm{cool,tot}}$ [MW$_{\mathrm{th}}$]	74.39
$\dot{Q}_{\mathrm{cool,Cond-1}}$ [MW$_{\mathrm{th}}$]	0
$T_{\mathrm{out,Cond-1}}$ [°C]	-
$\dot{Q}_{\mathrm{cool,Cond-2}}$ [MW$_{\mathrm{th}}$]	3.29
$T_{\mathrm{out,Cond-2}}$ [°C]	68.0
$\dot{Q}_{\mathrm{cool,Cool-1}}$ [MW$_{\mathrm{th}}$]	9.32
$T_{\mathrm{out,Cool-1}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-2}}$ [MW$_{\mathrm{th}}$]	1.69
$T_{\mathrm{out,Cool-2}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-3}}$ [MW$_{\mathrm{th}}$]	15.31
$T_{\mathrm{out,Cool-3}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-4}}$ [MW$_{\mathrm{th}}$]	0.39
$T_{\mathrm{out,Cool-4}}$ [°C]	50.0
$\dot{Q}_{\mathrm{cool,Cool-5}}$ [MW$_{\mathrm{th}}$]	0.57
$T_{\mathrm{out,Cool-5}}$ [°C]	35.0

Variable	Value
$\dot{Q}_{\mathrm{cool,Cool-6}}$ [MW$_{th}$]	8.09
$T_{\mathrm{out,Cool-6}}$ [°C]	28.2
$\dot{Q}_{\mathrm{cool,Cool-7}}$ [MW$_{th}$]	35.72
$T_{\mathrm{out,Cool-7}}$ [°C]	21.2
$\dot{Q}_{\mathrm{chill,tot}}$ [MW$_{th}$]	5.55
$\dot{Q}_{\mathrm{chill,Chill-1}}$ [MW$_{th}$]	5.50
$T_{\mathrm{out,Chill-1}}$ [°C]	12.0
$\dot{Q}_{\mathrm{chill,Chill-2}}$ [MW$_{th}$]	0
$T_{\mathrm{out,Chill-2}}$ [°C]	-
$\dot{Q}_{\mathrm{chill,Chill-3}}$ [MW$_{th}$]	0.05
$T_{\mathrm{out,Chill-3}}$ [°C]	15.0
$\dot{W}_{\mathrm{aux,tot}}$ [MW$_{el}$]	2.25
$\dot{W}_{\mathrm{aux,Fan-1}}$ [MW$_{el}$]	0.85
$\dot{W}_{\mathrm{aux,Pump-1}}$ [MW$_{el}$]	1.39
$\dot{W}_{\mathrm{CO_2comp,Comp-1}}$ [MW$_{el}$]	2.41

4.2.4 Ship transport

In the ship transport case, the capture process is identical to the base case. Stream data for the CO_2 conditioning process is given in Table 4.15.

Table 4.15. Stream data for the CO_2 conditioning process for ship 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	2081.41	0.0030	0.9970	0.0000	0.0000
2	1.00	28.00	24.01	2081.41	0.0030	0.9970	0.0000	0.0000
3	1.00	4.00	23.53	2081.41	0.0030	0.9970	0.0000	0.0000
4	1.00	4.00	23.53	2076.23	0.0006	0.9994	0.0000	0.0000
5	1.00	12.51	23.53	2723.95	0.0004	0.9996	0.0000	0.0000
6	1.00	25.07	27.50	2723.95	0.0004	0.9996	0.0000	0.0000
7	1.00	28.00	26.95	2723.95	0.0004	0.9996	0.0000	0.0000
8	1.00	4.00	26.41	2723.95	0.0004	0.9996	0.0000	0.0000
9	1.00	4.00	26.41	2723.95	0.0004	0.9996	0.0000	0.0000
10	1.00	4.00	25.91	2722.78	0.0000	1.0000	0.0000	0.0000
11	0.00	-10.71	25.51	2722.78	0.0000	1.0000	0.0000	0.0000
12	0.24	-48.86	6.90	2722.78	0.0000	1.0000	0.0000	0.0000
13	0.00	-48.86	6.90	2074.96	0.0000	1.0000	0.0000	0.0000
14	0.00	-51.86	6.50	2074.96	0.0000	1.0000	0.0000	0.0000
15	1.00	-48.86	6.90	647.82	0.0000	1.0000	0.0000	0.0000
16	1.00	40.75	23.53	647.72	0.0000	1.0000	0.0000	0.0000

4.2.5 Steam import

In this case 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 4.18 and stream data for the second half of the year is given in Table 4.19. Stream data for the CO_2 conditioning process is given in Table 4.20. The main energy consumers in the CAP for the first half of the year are listed in Table 4.21 and for the second half of the year in Table 4.22.

Table 4.16. Specifications of the streams of the CAP applied to the "Steam import" case defined in CEMCAP. Design at medium air leak, run 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	0.1100	0.0000	0.2200	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.6700	200 mg/Nm3	0.0000	0.0000
2	1.86E+02	48.2	1.01	1.03E+01	-2.93E+06	1.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	7.55E-01	34.3	1.01	4.19E-02	-1.19E+04	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	1.81E+02	21.2	1.01	1.01E+01	-2.88E+06	1.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5(1)	3.46E-02	20	1.1	1.95E-03	-4.54E+02	0.7390	0.2610	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6(1)	5.95E-02	20	1.01	1.70E-03	-4.54E+02	0.8500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1500	0.0000
7	8.39E+01	22.2	1.01	2.66E+00	-2.69E+05	0.0266	0.0000	0.2410	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7330	0.0000	0.0000	0.0000
8	8.39E+01	29.9	1.1	2.66E+00	-2.68E+05	0.0266	0.0000	0.2410	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7330	0.0000	0.0000	0.0000
9	8.89E+02	24.8	1.05	4.42E+01	-1.29E+07	0.8930	0.0045	0.0001	0.0539	0.0000	0.0000	0.0049	0.0199	0.0242	0.0000	0.0000	0.0000	0.0000
10	1.07E+02	12	1.4	5.31E+00	-1.56E+06	0.8910	0.0032	0.0002	0.0563	0.0000	0.0000	0.0074	0.0184	0.0231	0.0000	0.0000	0.0000	0.0000
11	0.00E+00	na	na	0.00E+00	na	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	0.00E+00	na	na	0.00E+00	na	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	7.82E+02	25.1	10.4	3.89E+01	-1.14E+07	0.8930	0.0046	0.0001	0.0538	0.0000	0.0000	0.0049	0.0199	0.0242	0.0000	0.0000	0.0000	0.0000
14	7.53E+02	116	10.4	3.77E+01	-1.07E+07	0.8840	0.0264	0.0078	0.0413	0.0000	0.0000	0.0004	0.0263	0.0143	0.0000	0.0000	0.0000	0.0000
15	2.93E+01	25.1	10.4	1.46E+00	-4.26E+05	0.8930	0.0046	0.0001	0.0538	0.0000	0.0000	0.0049	0.0199	0.0242	0.0000	0.0000	0.0000	0.0000
16	7.56E+02	125	10	3.89E+01	-1.08E+07	0.8950	0.0369	0.0009	0.0337	0.0000	0.0000	0.0004	0.0211	0.0119	0.0000	0.0000	0.0000	0.0000
17	7.55E+02	29.9	10	3.88E+01	-1.11E+07	0.9070	0.0204	0.0000	0.0388	0.0000	0.0000	0.0046	0.0063	0.0234	0.0000	0.0000	0.0000	0.0000
18	7.55E+02	21.2	1.05	3.88E+01	-1.11E+07	0.9060	0.0194	0.0000	0.0403	0.0000	0.0000	0.0060	0.0054	0.0230	0.0000	0.0000	0.0000	0.0000
19(1)	1.05E-02	20	1.01	5.90E-04	-1.37E+02	0.7390	0.2610	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	2.55E+01	53.5	9.5	5.85E-01	-2.28E+05	0.0150	0.0006	0.9840	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	8.68E+00	53	9.5	4.40E-01	-1.29E+05	0.9190	0.0005	0.0034	0.0384	0.0000	0.0000	0.0002	0.0356	0.0024	0.0000	0.0000	0.0000	0.0000
22	8.57E-02	20	1.01	4.76E-03	-1.36E+03	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	8.77E+00	50	9.5	4.44E-01	-1.30E+05	0.9200	0.0005	0.0033	0.0381	0.0000	0.0000	0.0002	0.0353	0.0023	0.0000	0.0000	0.0000	0.0000
24	2.54E+01	35	9.5	5.79E-01	-2.27E+05	0.0064	0.0000	0.9940	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	2.53E+01	28.2	110	5.76E-01	-2.33E+05	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
26	8.97E-02	35	9.5	4.72E-03	-1.37E+03	0.9550	0.0000	0.0060	0.0196	0.0000	0.0000	0.0000	0.0193	0.0002	0.0000	0.0000	0.0000	0.0000

#	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
27	1.09E-01	53	9.5	5.52E-03	-1.62E+03	0.9190	0.0005	0.0034	0.0384	0.0000	0.0000	0.0002	0.0356	0.0024	0.0000	0.0000	0.0000	0.0000
28	1.23E+00	29.9	10	6.34E-02	-1.81E+04	0.9070	0.0204	0.0000	0.0388	0.0000	0.0000	0.0046	0.0063	0.0234	0.0000	0.0000	0.0000	0.0000
29	1.43E+00	73.1	9.5	7.36E-02	-2.08E+04	0.9090	0.0211	0.0000	0.0356	0.0000	0.0000	0.0013	0.0141	0.0188	0.0000	0.0000	0.0000	0.0000
30	5.68E-01	94.1	1.15	2.82E-02	-6.04E+03	0.7130	0.1970	0.0896	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	8.63E-01	105	1.25	4.79E-02	-1.34E+04	1.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
32	8.63E-01	43	1.25	4.79E-02	-1.36E+04	1.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
33	5.81E+01	12.4	1.01	2.05E+00	-3.45E+04	0.0132	0.0027	0.0334	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9510	0.0000	0.0000	0.0000
34	5.80E+01	15.8	1.01	2.05E+00	-3.44E+04	0.0178	0.0001	0.0311	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9510	0.0000	0.0000	0.0000
35	6.17E+01	47.3	1.01	2.25E+00	-8.25E+04	0.1080	0.0000	0.0285	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.8640	0.0000	0.0000	0.0000
36(1)	1.47E-02	20	1.1	1.63E-04	na	0.1000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9000
37(1)	1.97E-02	20	1.01	1.63E-04	na	0.1000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9000	0.0000
38	1.18E+01	12.5	1.04	6.41E-01	-1.85E+05	0.9840	0.0004	0.0000	0.0079	0.0000	0.0000	0.0003	0.0065	0.0008	0.0000	0.0000	0.0000	0.0000
39	1.18E-04	1.5	1.2	6.41E-06	-1.85E+00	0.9840	0.0003	0.0000	0.0080	0.0000	0.0000	0.0004	0.0064	0.0008	0.0000	0.0000	0.0000	0.0000
40	1.18E+01	90.6	1.4	6.43E-01	-1.81E+05	0.9840	0.0039	0.0030	0.0046	0.0000	0.0000	0.0001	0.0039	0.0006	0.0000	0.0000	0.0000	0.0000
41	1.14E+01	98.8	1.01	6.33E-01	-1.77E+05	0.9990	0.0009	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
42	1.16E+01	15	1.01	6.45E-01	-1.85E+05	0.9990	0.0009	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
43	3.52E-01	68	1.01	1.28E-02	-2.78E+03	0.2090	0.4090	0.3810	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0008	0.0000	0.0000	0.0000
44	2.18E-01	20	1.01	1.21E-02	-3.46E+03	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45	6.69E-02	31.2	9.5	3.71E-03	-1.06E+03	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

(1) Apparent composition

Table 4.17. Specifications of the streams of the CAP applied to the "Steam import" case defined in CEMCAP. Design at medium air leak, run 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	0.0900	0.0000	0.1800	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7300	200 mg/Nm³	0.0000	0.0000
2	2.24E+02	42.9	1.01	1.24E+01	-3.54E+06	1.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	6.28E-01	31.2	1.01	3.49E-02	-9.95E+03	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	2.20E+02	21.2	1.01	1.22E+01	-3.49E+06	1.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5(1)	4.07E-02	20	1.1	2.29E-03	-5.33E+02	0.7390	0.2610	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6(1)	7.00E-02	20	1.01	1.99E-03	-5.93E+02	0.8500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1500	0.0000
7	1.04E+02	21.8	1.01	3.36E+00	-2.76E+05	0.0261	0.0000	0.1930	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7810	0.0000	0.0000	0.0000
8	1.04E+02	29.7	1.1	3.36E+00	-2.75E+05	0.0261	0.0000	0.1930	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7810	0.0000	0.0000	0.0000
9	8.61E+02	26	1.05	4.24E+01	-1.24E+07	0.8780	0.0065	0.0001	0.0605	0.0000	0.0000	0.0061	0.0180	0.0305	0.0000	0.0000	0.0000	0.0000
10	1.55E+02	9	1.4	7.63E+00	-2.24E+06	0.8760	0.0043	0.0002	0.0652	0.0000	0.0000	0.0109	0.0155	0.0280	0.0000	0.0000	0.0000	0.0000
11	0.00E+00	na	na	0.00E+00	na	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	0.00E+00	na	na	0.00E+00	na	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	7.06E+02	26.3	10.4	3.48E+01	-1.01E+07	0.8780	0.0066	0.0001	0.0605	0.0000	0.0000	0.0060	0.0180	0.0305	0.0000	0.0000	0.0000	0.0000
14	6.71E+02	117	10.4	3.33E+01	-9.37E+06	0.8670	0.0324	0.0078	0.0468	0.0000	0.0000	0.0005	0.0283	0.0176	0.0000	0.0000	0.0000	0.0000
15	3.53E+01	26.3	10.4	1.74E+00	-5.07E+05	0.8780	0.0066	0.0001	0.0605	0.0000	0.0000	0.0060	0.0180	0.0305	0.0000	0.0000	0.0000	0.0000
16	6.80E+02	126	10	3.48E+01	-9.59E+06	0.8790	0.0458	0.0008	0.0374	0.0000	0.0000	0.0004	0.0223	0.0143	0.0000	0.0000	0.0000	0.0000
17	6.78E+02	31.4	10	3.46E+01	-9.82E+06	0.8920	0.0279	0.0000	0.0427	0.0000	0.0000	0.0049	0.0059	0.0270	0.0000	0.0000	0.0000	0.0000
18	6.79E+02	21.2	1.05	3.46E+01	-9.84E+06	0.8910	0.0268	0.0000	0.0445	0.0000	0.0000	0.0068	0.0048	0.0262	0.0000	0.0000	0.0000	0.0000
19(1)	3.09E-02	20	1.01	1.74E-03	-4.05E+02	0.7390	0.2610	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	2.58E+01	52	9.5	5.91E-01	-2.31E+05	0.0136	0.0006	0.9860	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	8.76E+00	51.6	9.5	4.43E-01	-1.30E+05	0.9190	0.0005	0.0036	0.0384	0.0000	0.0000	0.0002	0.0358	0.0022	0.0000	0.0000	0.0000	0.0000
22	1.09E-01	20	1.01	6.03E-03	-1.73E+03	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	8.87E+00	50	9.5	4.49E-01	-1.32E+05	0.9200	0.0005	0.0035	0.0380	0.0000	0.0000	0.0002	0.0354	0.0022	0.0000	0.0000	0.0000	0.0000
24	2.57E+01	35	9.5	5.86E-01	-2.30E+05	0.0064	0.0000	0.9940	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	2.56E+01	28.2	110	5.82E-01	-2.35E+05	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
26	8.64E-02	35	9.5	4.55E-03	-1.32E+03	0.9560	0.0000	0.0060	0.0191	0.0000	0.0000	0.0000	0.0189	0.0002	0.0000	0.0000	0.0000	0.0000

#	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
27	1.22E-01	51.6	9.5	6.20E-03	-1.82E+03	0.9190	0.0005	0.0036	0.0384	0.0000	0.0000	0.0002	0.0358	0.0022	0.0000	0.0000	0.0000	0.0000
28	1.86E+00	31.4	10	9.48E-02	-2.69E+04	0.8920	0.0279	0.0000	0.0427	0.0000	0.0000	0.0049	0.0059	0.0270	0.0000	0.0000	0.0000	0.0000
29	2.07E+00	76.5	9.5	1.06E-01	-2.97E+04	0.8940	0.0297	0.0000	0.0389	0.0000	0.0000	0.0015	0.0137	0.0223	0.0000	0.0000	0.0000	0.0000
30	8.68E-01	93.2	1.15	4.30E-02	-9.03E+03	0.6850	0.2230	0.0920	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	1.20E+00	105	1.25	6.65E-02	-1.86E+04	1.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
32	1.20E+00	36.7	1.25	6.65E-02	-1.89E+04	1.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
33	7.74E+01	9.3	1.01	2.73E+00	-3.73E+04	0.0107	0.0035	0.0265	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9590	0.0000	0.0000	0.0000
34	7.71E+01	14.1	1.01	2.73E+00	-3.69E+04	0.0160	0.0002	0.0236	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9600	0.0000	0.0000	0.0000
35	8.08E+01	42.4	1.01	2.93E+00	-8.33E+04	0.0833	0.0000	0.0223	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.8940	0.0000	0.0000	0.0000
36[1]	2.49E-02	20	1.1	2.77E-04	na	0.1000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9000
37[1]	3.34E-02	20	1.01	2.77E-04	na	0.1000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9000	0.0000
38	1.57E+01	9.6	1.04	8.54E-01	-2.47E+05	0.9810	0.0005	0.0000	0.0097	0.0000	0.0000	0.0005	0.0074	0.0012	0.0000	0.0000	0.0000	0.0000
39	1.57E-04	1.5	1.2	8.54E-06	-2.47E+00	0.9810	0.0004	0.0001	0.0098	0.0000	0.0000	0.0007	0.0073	0.0012	0.0000	0.0000	0.0000	0.0000
40	1.57E+01	89.6	1.4	8.57E-01	-2.41E+05	0.9800	0.0048	0.0035	0.0057	0.0000	0.0000	0.0001	0.0046	0.0009	0.0000	0.0000	0.0000	0.0000
41	1.51E+01	98.8	1.01	8.41E-01	-2.35E+05	0.9990	0.0009	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
42	1.55E+01	12.8	1.01	8.60E-01	-2.46E+05	0.9990	0.0009	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
43	5.77E-01	68	1.01	2.12E-02	-4.52E+03	0.2080	0.4220	0.3690	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0006	0.0000	0.0000	0.0000
44	3.43E-01	20	1.01	1.91E-02	-5.45E+03	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45	6.75E-02	31.1	9.5	3.75E-03	-1.07E+03	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

(1) Apparent composition

Table 4.18. 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	9.50	2085.29	0.0064	0.9936	0.0000	0.0000
2	1.00	28.20	9.31	2085.29	0.0064	0.9936	0.0000	0.0000
3	1.00	28.20	9.31	2081.57	0.0046	0.9954	0.0000	0.0000
4	1.00	32.44	8.84	2072.41	0.0002	0.9998	0.0000	0.0000
5	1.00	243.32	80.00	2072.41	0.0002	0.9998	0.0000	0.0000
6	0.00	28.20	78.40	2072.41	0.0002	0.9998	0.0000	0.0000
7	0.00	36.25	110.40	2072.41	0.0002	0.9998	0.0000	0.0000
8	0.00	28.20	110.00	2072.41	0.0002	0.9998	0.0000	0.0000

Table 4.19. Main energy consumers of the CAP applied to the "Steam import" case defined in CEMCAP. Design at medium air leak, run at low air leak. First ½ of the year.

Variable	Value
$\dot{Q}_{\mathrm{heat,tot}}$ [MW_{th}]	61.88
$\dot{Q}_{\mathrm{heat,Reb-1}}$ [MW_{th}]	57.30
$T_{\mathrm{Reb-1}}$ [°C]	124
$\dot{Q}_{\mathrm{heat,Reb-2}}$ [MW_{th}]	3.21
$T_{\mathrm{Reb-2}}$ [°C]	99
$\dot{Q}_{\mathrm{heat,Reb-3}}$ [MW_{th}]	1.37
$T_{\mathrm{Reb-3}}$ [°C]	105
$\dot{Q}_{\mathrm{cool,tot}}$ [MW_{th}]	80.67
$\dot{Q}_{\mathrm{cool,Cond-1}}$ [MW_{th}]	0
$T_{\mathrm{out,Cond-1}}$ [°C]	-
$\dot{Q}_{\mathrm{cool,Cond-2}}$ [MW_{th}]	2.42
$T_{\mathrm{out,Cond-2}}$ [°C]	68.0
$\dot{Q}_{\mathrm{cool,Cool-1}}$ [MW_{th}]	9.71
$T_{\mathrm{out,Cool-1}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-2}}$ [MW_{th}]	1.54
$T_{\mathrm{out,Cool-2}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-3}}$ [MW_{th}]	25.85
$T_{\mathrm{out,Cool-3}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-4}}$ [MW_{th}]	0.09
$T_{\mathrm{out,Cool-4}}$ [°C]	50.0
$\dot{Q}_{\mathrm{cool,Cool-5}}$ [MW_{th}]	0.58
$T_{\mathrm{out,Cool-5}}$ [°C]	35.0
$\dot{Q}_{\mathrm{cool,Cool-6}}$ [MW_{th}]	10.02
$T_{\mathrm{out,Cool-6}}$ [°C]	28.2
$\dot{Q}_{\mathrm{cool,Cool-7}}$ [MW_{th}]	30.45
$T_{\mathrm{out,Cool-7}}$ [°C]	21.2

Variable	Value
$\dot{Q}_{\mathrm{chill,tot}}$ [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$_{\mathrm{el}}$]	1.64
$\dot{W}_{\mathrm{aux,Fan-1}}$ [MW$_{\mathrm{el}}$]	0.67
$\dot{W}_{\mathrm{aux,Pump-1}}$ [MW$_{\mathrm{el}}$]	0.96
$\dot{W}_{\mathrm{CO_2comp,Comp-1}}$ [MW$_{\mathrm{el}}$]	3.97

Table 4.20. Main energy consumers of the CAP applied to the "Steam import" case defined in CEMCAP. Design at medium air leak, run at medium air leak. Second ½ of the year.

Variable	Value
$\dot{Q}_{\mathrm{heat,tot}}$ [MW$_{\mathrm{th}}$]	67.22
$\dot{Q}_{\mathrm{heat,Reb-1}}$ [MW$_{\mathrm{th}}$]	60.50
$T_{\mathrm{Reb-1}}$ [°C]	126
$\dot{Q}_{\mathrm{heat,Reb-2}}$ [MW$_{\mathrm{th}}$]	4.67
$T_{\mathrm{Reb-2}}$ [°C]	99
$\dot{Q}_{\mathrm{heat,Reb-3}}$ [MW$_{\mathrm{th}}$]	2.05
$T_{\mathrm{Reb-3}}$ [°C]	105
$\dot{Q}_{\mathrm{cool,tot}}$ [MW$_{\mathrm{th}}$]	82.25
$\dot{Q}_{\mathrm{cool,Cond-1}}$ [MW$_{\mathrm{th}}$]	0
$T_{\mathrm{out,Cond-1}}$ [°C]	-
$\dot{Q}_{\mathrm{cool,Cond-2}}$ [MW$_{\mathrm{th}}$]	3.41
$T_{\mathrm{out,Cond-2}}$ [°C]	68.0
$\dot{Q}_{\mathrm{cool,Cool-1}}$ [MW$_{\mathrm{th}}$]	9.02
$T_{\mathrm{out,Cool-1}}$ [°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$_{\mathrm{th}}$]	26.82
$T_{\mathrm{out,Cool-3}}$ [°C]	21.2
$\dot{Q}_{\mathrm{cool,Cool-4}}$ [MW$_{\mathrm{th}}$]	0.04
$T_{\mathrm{out,Cool-4}}$ [°C]	50.0
$\dot{Q}_{\mathrm{cool,Cool-5}}$ [MW$_{\mathrm{th}}$]	0.57
$T_{\mathrm{out,Cool-5}}$ [°C]	35.0
$\dot{Q}_{\mathrm{cool,Cool-6}}$ [MW$_{\mathrm{th}}$]	10.14

Variable	Value
$T_{\text{out,Cool}-6}$ [°C]	28.2
$\dot{Q}_{\text{cool,Cool}-7}$ [MW_{th}]	29.25
$T_{\text{out,Cool}-7}$ [°C]	21.2
$\dot{Q}_{\text{chill,tot}}$ [MW_{th}]	7.98
$\dot{Q}_{\text{chill,Chill}-1}$ [MW_{th}]	7.98
$T_{\text{out,Chill}-1}$ [°C]	9.0
$\dot{Q}_{\text{chill,Chill}-2}$ [MW_{th}]	0
$T_{\text{out,Chill}-2}$ [°C]	-
$\dot{Q}_{\text{chill,Chill}-3}$ [MW_{th}]	0
$T_{\text{out,Chill}-3}$ [°C]	-
$\dot{W}_{\text{aux,tot}}$ [MW_{el}]	1.74
$\dot{W}_{\text{aux,Fan}-1}$ [MW_{el}]	0.85
$\dot{W}_{\text{aux,Pump}-1}$ [MW_{el}]	0.88
$\dot{W}_{\text{CO}_2\text{comp,Comp}-1}$ [MW_{el}]	4.02

4.3 Equipment list

A list of all process equipment included in the cost estimate prepared by GE is provided in Table 4.21.

Table 4.21. Equipment list for the chilled ammonia process. Equipment marked "option pipepline transport" is only included in pipeline transport cases, and equipment marked with "option ship transport" is only included in the ship transport case.

Equipment type	Name	Qty.	Remarks
Pressure vessels	Stripper Condensate Receiver	1	
	CO_2 Dryer Receiver	1	
	DCC/NH_3 Wash/DCH/Absorber Area Drain Sump	1	
	Regenerator Area Drain Sump	1	
	LT Suction Drum	1	
	HT Refrigerant Receiver	1	
	Chiller Surge Drum No. 4	1	
	Chiller Surge Drum No. 5	1	
	Chiller Surge Drum No. 6	1	
	Vent Gas-Solution Knock-Out Drum	1	
	Regenerator Steam Condensate Receiver	1	
	Stripper Steam Condensate Receiver	1	
	Appendix Stripper Steam Condensate Receiver	1	
	CO_2 Surge Drum No. 2	1	Option Pipeline Transport
	CO_2 Surge Drum No. 3	1	Option Pipeline Transport
	Liquid CO_2 Receiver	1	Option Pipeline Transport
	CO_2 Surge Drum No. 1	1	Option Ship Transport

Equipment type	Name	Qty.	Remarks
	CO_2 Surge Drum No. 2	1	Option Ship Transport
	CO_2 Surge Drum No. 3	1	Option Ship Transport
	Liquid CO_2 Receiver	1	Option Ship Transport
	CO_2 Storage Tank	2	Option Ship Transport
Atmospheric tanks	Auxiliary Tank	1	
	Ammonium Sulfate Storage Tank	1	
	Sulfuric Acid Storage Tank	1	
	Reagent Storage Tank	1	
Columns	Direct Contact Cooler Column (DCC)	1	
	Absorber Column	1	
	Direct Contact Heater Column (DCH)	1	
	Regenerator Column	1	
	CO_2 Wash Column	1	
	Stripper Column	1	
	Appendix Stripper Column	1	
	NH_3 Wash Column	1	
Heat exchangers	DCC Circulation Chiller	1	
	Absorber Circulation Cooler	1	
	Absorber LT Chiller	1	
	Lean Solution Cooler	1	
	DCH Circulation Water Cooler	1	
	Flue Gas Reheater	1	
	Rich Solution-Steam Condensate Heat Exchanger	1	
	Rich-Lean Heat Exchanger B	1	
	Condensate Cooler	1	
	Rich-Lean Heat Exchanger C	1	
	CO_2 Wash Cooler	1	
	Regenerator Reboiler	1	
	Stripper Overhead Condenser	1	
	NH_3 Rich-Lean Heat Exchanger	1	
	Appendix Stripper Bottoms Cooler	1	
	Stripper Reboiler	1	
	Appendix Stripper Reboiler	1	
	NH_3 Wash A1 Chiller	1	
	NH_3 Wash A2 Chiller	1	
	Stripper Feed Heat Exchanger	1	
	Refrigerant Condenser	1	
	CO_2 IS Cooler 1	1	Option Pipeline Transport
	CO_2 Condenser	1	Option Pipeline Transport
	CO_2 Chiller 1	1	Option Pipeline Transport
	Regeneration Gas Recuperator	1	Option Pipeline Transport
	Regeneration Gas Heater	1	Option Pipeline Transport
	Regeneration Gas Cooler	1	Option Pipeline Transport
	CO_2 IS Cooler 1	1	Option Ship Transport

Equipment type	Name	Qty.	Remarks
	CO_2 Condenser	1	Option Ship Transport
	CO_2 Chiller 1	1	Option Ship Transport
	CO_2 Chiller 2	1	Option Ship Transport
	CO_2 IS Cooler	1	Option Ship Transport
	Regeneration Gas Recuperator	1	Option Ship Transport
	Regeneration Gas Heater	1	Option Ship Transport
	Regeneration Gas Cooler	1	Option Ship Transport
Pumps	DCH Circulation Pump	1	
	DCH Feed Pump	1	
	Regenerator Feed Pump	1	
	Absorber A3 Circulation Pump	1	
	Circulation Water Pump	1	
	DCH A1 Circulation Pump	1	
	CO_2 Wash Circulation Pump	1	
	Stripper Reflux Pump	1	
	CO_2 Wash Feed Pump	1	
	Stripper Bottoms Pump	1	
	Appendix Stripper Bottoms Pump	1	
	NH_3 Wash A1 Circulation Pump	1	
	Stripper Feed Pump	1	
	Auxiliary Tank Return Pump	1	
	Ammonium Sulfate Pump	1	
	DCC/NH_3 Wash/DCH/Absorber Area Drain Sump Pump	1	
	Regenerator Area Drain Sump Pump	1	
	Sulphuric Acid Feed Pump	1	
	Reagent Feed Pump	1	
	Solution Knock-out Pump	1	
	CO_2 Pump	1	Option Pipeline Transport
Compressors	Booster Fan	1	
	Back Pressure Turbine with Generator	1	Option Pipeline Transport
	LT Refrigerant Compressor	1	Option Pipeline Transport
	CO_2 Compressor	1	Option Pipeline Transport
	Back Pressure Turbine with Generator	1	Option Ship Transport
	LT Refrigerant Compressor	1	Option Ship Transport
	CO_2 Compressor	1	Option Ship Transport
Package units	CO_2 Dehydration Unit (dessicant in fixed bed)	1	
Other	Inlet Isolation Damper	3	
	Absorber Solution Mixer	1	
	Outlet Isolation Damper	3	
	LT Inline Mixer	1	

5 MEMBRANE-ASSISTED LIQUEFACTION

The project partners responsible for the process simulations and for compiling equipment lists for the membrane-assisted liquefaction technology are listed in Table 5.1.

Table 5.1. Responsible project partners for process simulations and compilation of equipment lists for the membrane-assisted liquefaction technology.

	Responsible partner
Process simulations	SINTEF ER
Equipment lists	SINTEF ER

5.1 Process flow diagram

The process flowsheets for the membrane-assisted CO_2 liquefaction process, with liquefaction for pipeline and ship transport respectively, are shown in Figure 5.1 and Figure 5.2.

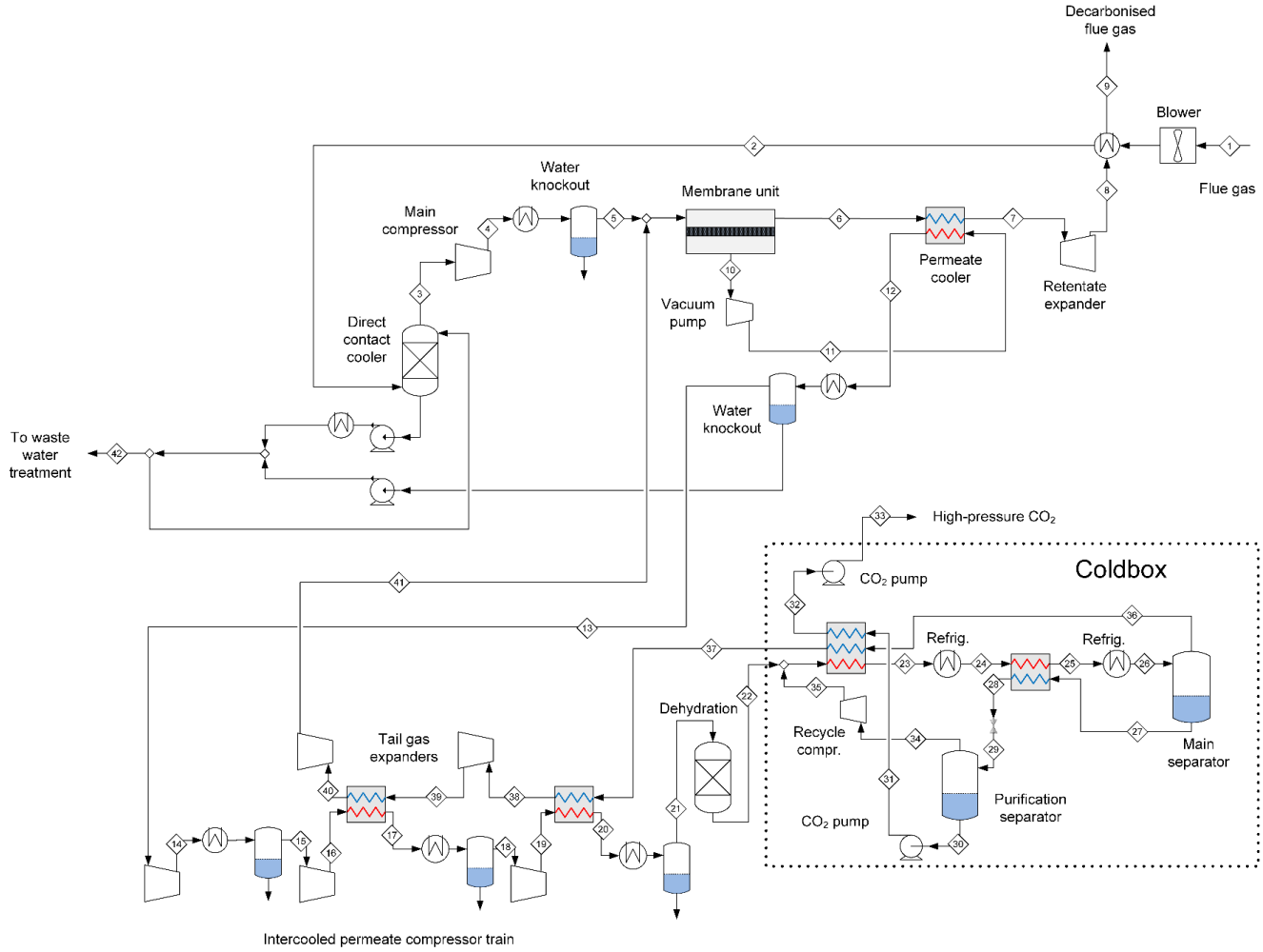

Figure 5.1. Process flowsheet of the membrane-assisted CO_2 liquefaction process, with liquefaction for pipeline transportation.

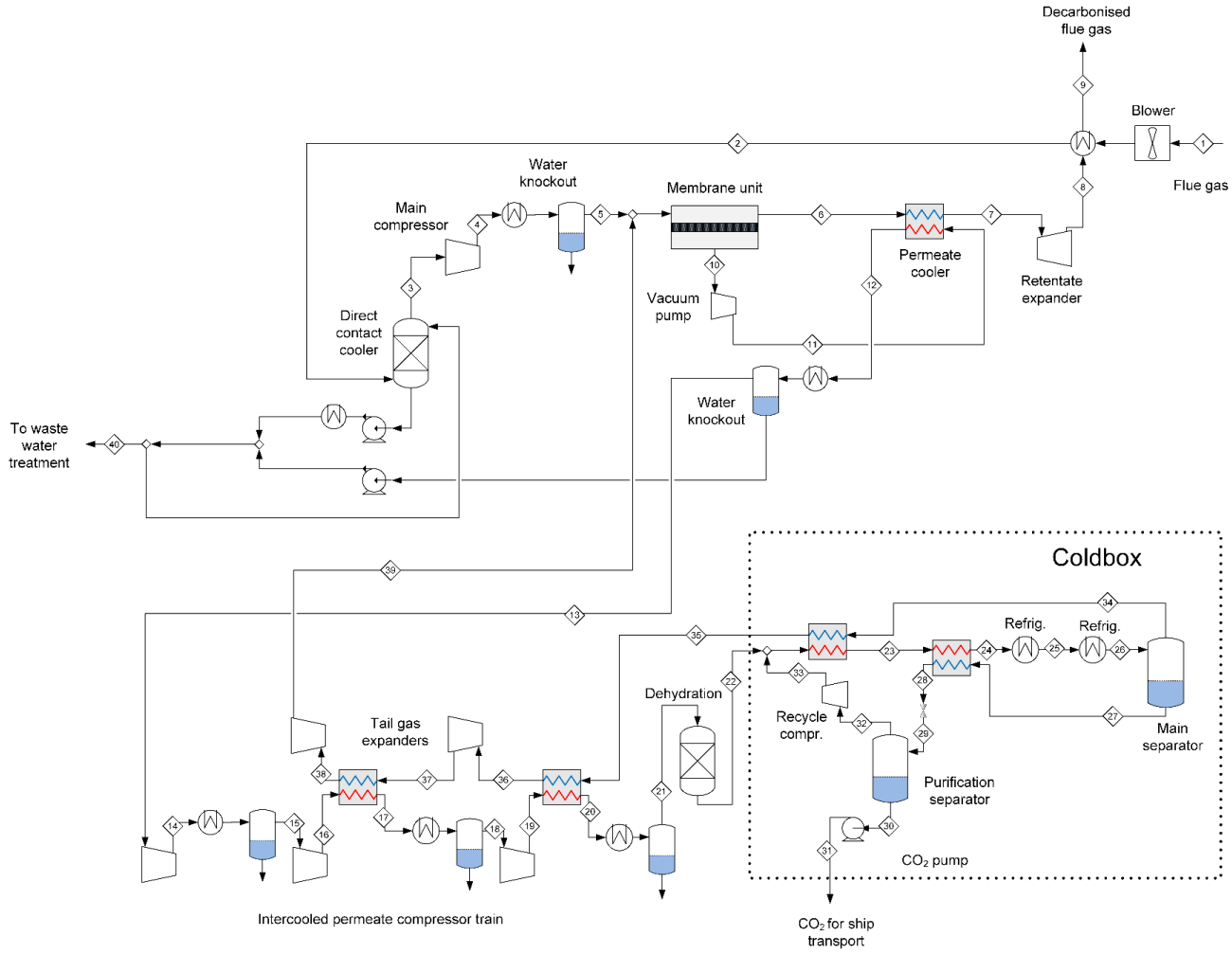

Figure 5.2. Process flowsheet of the membrane-assisted CO_2 liquefaction process, with liquefaction for ship transport.

5.2 Stream data

5.2.1 Base case

In the base case 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 at 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 5.2. 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

#	Vapor fraction	Temperature [°C]	Pressure [bar]	Molar flow [kmol/h]	Mole fraction			
					H_2O	CO_2	O_2	N_2
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 5.3. 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

#	Vapor fraction	Temperature [°C]	Pressure [bar]	Molar flow [kmol/h]	Mole fraction			
					H_2O	CO_2	O_2	N_2
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

5.2.2 Constant low air leak

In this case the stream data is identical to the stream data presented in the base case for low air leak conditions, *cf*. Table 5.2.

5.2.3 Optional extent of capture

In this case the air leak conditions are identical to the base case. However, the membrane-assisted CO_2 liquefaction process is designed to avoid 60% CO_2 from the flue gases, instead of 90%, with the whole flue gas stream passing the CO_2 capture process. Stream data for the first half of the year is given in Table 5.4 and for the second half of the year in Table 5.5.

Table 5.4. 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	137.45	1.18	10362	0.1100	0.2200	0.0700	0.6000
3	1.00	41.98	1.02	10027	0.0804	0.2272	0.0723	0.6200
4	1.00	28.91	30.75	2248	0.0000	0.7388	0.0825	0.1787
5	1.00	28.00	1.42	9474	0.0267	0.2405	0.0766	0.6563
6	1.00	26.61	1.42	7889	0.0071	0.1148	0.0912	0.7869
7	1.00	65.64	1.29	7889	0.0071	0.1148	0.0912	0.7869
8	1.00	53.18	1.10	7889	0.0071	0.1148	0.0912	0.7869
9	1.00	72.00	1.08	7889	0.0071	0.1148	0.0912	0.7869
10	1.00	26.61	0.23	2266	0.0871	0.6806	0.0716	0.1607
11	1.00	185.03	1.03	2266	0.0871	0.6806	0.0716	0.1607
12	1.00	76.57	1.01	2266	0.0871	0.6806	0.0716	0.1607
13	1.00	28.00	1.01	2149	0.0372	0.7177	0.0755	0.1695
14	1.00	133.75	3.24	2149	0.0372	0.7177	0.0755	0.1695
15	1.00	28.00	3.18	2094	0.0123	0.7363	0.0775	0.1739
16	1.00	134.17	10.17	2094	0.0123	0.7363	0.0775	0.1739
17	1.00	106.53	9.97	2094	0.0123	0.7363	0.0775	0.1739
18	1.00	28.00	9.97	2077	0.0043	0.7422	0.0781	0.1753
19	1.00	136.01	31.89	2077	0.0043	0.7422	0.0781	0.1753
20	1.00	107.49	31.25	2077	0.0043	0.7422	0.0781	0.1753
21	1.00	28.00	31.25	2072	0.0020	0.7440	0.0783	0.1757
22	1.00	28.00	31.25	2068	0.0000	0.7455	0.0785	0.1761
23	0.84	-20.58	30.35	2248	0.0000	0.7388	0.0825	0.1787
24	0.40	-39.15	29.95	2248	0.0000	0.7388	0.0825	0.1787
25	0.37	-43.43	29.55	2248	0.0000	0.7388	0.0825	0.1787
26	0.31	-54.00	29.15	2248	0.0000	0.7388	0.0825	0.1787
27	0.00	-54.00	29.15	1559	0.0000	0.9555	0.0175	0.0271
28	0.01	-42.15	28.75	1559	0.0000	0.9555	0.0175	0.0271
29	0.12	-55.00	8.39	1559	0.0000	0.9555	0.0175	0.0271
30	0.00	-55.00	8.39	1377	0.0000	0.9941	0.0028	0.0031
31	0.00	-51.73	80.00	1377	0.0000	0.9941	0.0028	0.0031
32	0.00	7.28	79.60	1377	0.0000	0.9941	0.0028	0.0031
33	0.00	10.71	110.00	1377	0.0000	0.9941	0.0028	0.0031
34	1.00	-55.00	8.39	182	0.0000	0.6625	0.1284	0.2092
35	1.00	45.27	31.25	182	0.0000	0.6625	0.1284	0.2092
36	1.00	-54.00	29.15	689	0.0000	0.2489	0.2295	0.5216

#	Vapor fraction	Temperature [°C]	Pressure [bar]	Molar flow [kmol/h]	Mole fraction			
					H_2O	CO_2	O_2	N_2
37	1.00	7.28	28.57	689	0.0000	0.2489	0.2295	0.5216
38	1.00	111.01	28.00	689	0.0000	0.2489	0.2295	0.5216
39	1.00	7.80	6.81	689	0.0000	0.2489	0.2295	0.5216
40	1.00	109.17	6.67	689	0.0000	0.2489	0.2295	0.5216
41	1.00	0.37	1.42	689	0.0000	0.2489	0.2295	0.5216
42	0.00	28.00	4.45	451	0.9999	0.0001	0.0000	0.0000

Table 5.5. 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

#	Vapor fraction	Temperature [°C]	Pressure [bar]	Molar flow [kmol/h]	Mole fraction			
					H_2O	CO_2	O_2	N_2
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

5.2.4 Ship transport

In the ship transport case 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 at medium air leak. Stream data for the first half of the year is given in Table 5.6 and stream data for the second half of the year is given in Table 5.7.

Table 5.6. 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	10362.24	0.1100	0.2200	0.0700	0.6000
2	1.00	148.25	1.18	10362.24	0.1100	0.2200	0.0700	0.6000
3	1.00	43.04	1.02	10077.65	0.0850	0.2261	0.0720	0.6169
4	1.00	14.65	2.07	1731.23	0.0000	0.2499	0.2493	0.5009
5	1.00	28.00	2.07	9394.49	0.0185	0.2425	0.0772	0.6618
6	1.00	25.93	2.07	7161.26	0.0003	0.0308	0.1009	0.8680
7	1.00	116.05	1.93	7161.26	0.0003	0.0308	0.1009	0.8680
8	1.00	68.04	1.10	7161.26	0.0003	0.0308	0.1009	0.8680
9	1.00	72.00	1.08	7161.26	0.0003	0.0308	0.1009	0.8680
10	1.00	25.93	0.20	3964.46	0.0432	0.6281	0.1096	0.2191
11	1.00	204.96	1.03	3964.46	0.0432	0.6281	0.1096	0.2191
12	1.00	75.90	1.01	3964.46	0.0432	0.6281	0.1096	0.2191
13	1.00	28.00	1.01	3939.67	0.0372	0.6320	0.1103	0.2205
14	1.00	136.56	3.24	3939.67	0.0372	0.6320	0.1103	0.2205
15	1.00	28.00	3.18	3840.02	0.0122	0.6484	0.1131	0.2262
16	1.00	136.96	10.17	3840.02	0.0122	0.6484	0.1131	0.2262
17	1.00	101.86	9.97	3840.02	0.0122	0.6484	0.1131	0.2262
18	1.00	28.00	9.97	3809.36	0.0043	0.6536	0.1141	0.2280
19	1.00	138.56	31.89	3809.36	0.0043	0.6536	0.1141	0.2280
20	1.00	107.50	31.25	3809.36	0.0043	0.6536	0.1141	0.2280
21	1.00	28.00	31.25	3800.16	0.0019	0.6552	0.1143	0.2286
22	1.00	28.00	31.25	3792.82	0.0000	0.6564	0.1146	0.2290

#	Vapor fraction	Temperature [°C]	Pressure [bar]	Molar flow [kmol/h]	Mole fraction			
					H_2O	CO_2	O_2	N_2
23	1.00	11.56	30.14	5113.90	0.0000	0.7164	0.0971	0.1865
24	0.83	-22.94	29.74	5113.90	0.0000	0.7164	0.0971	0.1865
25	0.45	-39.15	29.34	5113.90	0.0000	0.7164	0.0971	0.1865
26	0.34	-54.00	28.94	5113.90	0.0000	0.7164	0.0971	0.1865
27	0.00	-54.00	28.94	3381.85	0.0000	0.9553	0.0189	0.0258
28	0.20	-15.15	28.54	3381.85	0.0000	0.9553	0.0189	0.0258
29	0.39	-52.00	6.90	3381.85	0.0000	0.9553	0.0189	0.0258
30	0.00	-52.00	6.90	2054.65	0.0000	0.9984	0.0009	0.0008
31	0.00	-55.00	6.50	2054.65	0.0000	0.9984	0.0009	0.0008
32	1.00	-52.00	6.90	1327.20	0.0000	0.8888	0.0468	0.0645
33	1.00	61.03	31.25	1327.20	0.0000	0.8888	0.0468	0.0645
34	1.00	-54.00	28.94	1732.05	0.0000	0.2499	0.2497	0.5004
35	1.00	33.62	28.36	1732.05	0.0000	0.2499	0.2497	0.5004
36	1.00	113.56	27.79	1732.05	0.0000	0.2499	0.2497	0.5004
37	1.00	21.09	8.08	1732.05	0.0000	0.2499	0.2497	0.5004
38	1.00	111.96	7.92	1732.05	0.0000	0.2499	0.2497	0.5004
39	1.00	14.64	2.07	1732.05	0.0000	0.2499	0.2497	0.5004
40	0.00	28.00	5.11	308.05	0.9999	0.0001	0.0000	0.0000

Table 5.7. 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	12770.04	0.0900	0.1800	0.1000	0.6300
2	1.00	110.66	1.18	12770.04	0.0900	0.1800	0.1000	0.6300
3	1.00	40.12	1.02	12531.80	0.0728	0.1833	0.1019	0.6420
4	1.00	21.67	2.51	2271.87	0.0000	0.2318	0.3120	0.4562
5	1.00	28.00	2.51	11800.15	0.0153	0.1947	0.1082	0.6818
6	1.00	26.97	2.51	9535.66	0.0002	0.0229	0.1335	0.8435
7	1.00	105.71	2.36	9535.66	0.0002	0.0229	0.1335	0.8435
8	1.00	43.55	1.10	9535.66	0.0002	0.0229	0.1335	0.8435
9	1.00	72.00	1.08	9535.66	0.0002	0.0229	0.1335	0.8435
10	1.00	26.97	0.20	4536.36	0.0395	0.5745	0.1571	0.2289
11	1.00	209.86	1.03	4536.36	0.0395	0.5745	0.1571	0.2289
12	1.00	76.94	1.01	4536.36	0.0395	0.5745	0.1571	0.2289
13	1.00	28.00	1.01	4525.61	0.0372	0.5758	0.1575	0.2294
14	1.00	142.04	3.35	4525.61	0.0372	0.5758	0.1575	0.2294
15	1.00	28.00	3.29	4409.41	0.0118	0.5910	0.1617	0.2355
16	1.00	142.47	10.88	4409.41	0.0118	0.5910	0.1617	0.2355
17	1.00	102.09	10.66	4409.41	0.0118	0.5910	0.1617	0.2355
18	1.00	28.00	10.66	4374.86	0.0041	0.5956	0.1630	0.2373
19	1.00	144.11	35.29	4374.86	0.0041	0.5956	0.1630	0.2373

#	Vapor fraction	Temperature [°C]	Pressure [bar]	Molar flow [kmol/h]	Mole fraction			
					H_2O	CO_2	O_2	N_2
20	1.00	106.45	34.59	4374.86	0.0041	0.5956	0.1630	0.2373
21	1.00	28.00	34.59	4364.90	0.0018	0.5970	0.1633	0.2379
22	1.00	28.00	34.59	4356.99	0.0000	0.5981	0.1636	0.2383
23	1.00	8.31	33.40	5741.75	0.0000	0.6642	0.1395	0.1964
24	0.84	-23.40	33.00	5741.75	0.0000	0.6642	0.1395	0.1964
25	0.51	-39.15	32.60	5741.75	0.0000	0.6642	0.1395	0.1964
26	0.40	-54.00	32.20	5741.75	0.0000	0.6642	0.1395	0.1964
27	0.00	-54.00	32.20	3469.43	0.0000	0.9474	0.0263	0.0263
28	0.20	-13.20	31.80	3469.43	0.0000	0.9474	0.0263	0.0263
29	0.40	-52.49	6.90	3469.43	0.0000	0.9474	0.0263	0.0263
30	0.00	-52.49	6.90	2072.10	0.0000	0.9981	0.0012	0.0008
31	0.00	-55.49	6.50	2072.10	0.0000	0.9981	0.0012	0.0008
32	1.00	-52.49	6.90	1397.32	0.0000	0.8722	0.0636	0.0642
33	1.00	69.58	34.59	1397.32	0.0000	0.8722	0.0636	0.0642
34	1.00	-54.00	32.20	2272.33	0.0000	0.2318	0.3122	0.4560
35	1.00	35.31	31.56	2272.33	0.0000	0.2318	0.3122	0.4560
36	1.00	119.11	30.93	2272.33	0.0000	0.2318	0.3122	0.4560
37	1.00	27.21	9.31	2272.33	0.0000	0.2318	0.3122	0.4560
38	1.00	117.47	9.12	2272.33	0.0000	0.2318	0.3122	0.4560
39	1.00	21.67	2.51	2272.33	0.0000	0.2318	0.3122	0.4560
40	0.00	28.00	5.56	247.76	0.9999	0.0001	0.0000	0.0000

5.3 Equipment list

5.3.1 Base case

Equipment lists for the various sections of the membrane-assisted liquefaction process in the base case are presented in Table 5.8 - Table 5.10.

Table 5.8. Equipment list for heat exchangers, columns, fans, compressors and expanders in both CO_2 capture and compression section.

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Frame		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Flue gas/CO2 lean gas HX	P&F	2 250	63	1130	2.0	158	SS304L	220	743	APEA
Direct contact cooler	P&F	10 942	17	463	6.5	82	SS304L	93	383	APEA
Waste heater 1 (gas/gas)	P&F	2 315	50	171	37.4	172	SS304L	36	241	APEA
Waste heater 2 (gas/gas)	P&F	1 818	46	146	11.6	170	SS304L	31	232	APEA
Waste heater 3 (gas/gas)	P&F	6 141	74	303	3.2	237	SS304L	62	350	APEA
Cooler 1 (gas/water)	P&F	21 392	44	1352	1.8	168	SS304L	262	824	APEA
Cooler 2 (gas/water)	P&F	2 314	25	250	1.8	105	SS304L	52	319	APEA
Cooler 3 (gas/water)	P&F	6 551	43	338	4.1	170	SS304L	69	357	APEA
Cooler 4 (gas/water)	P&F	3 730	32	256	11.4	130	SS304L	53	321	APEA
Cooler 5 (gas/water)	P&F	3 330	30	245	36.6	123	SS304L	51	318	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		ID	H Packing	H Column	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Columns		(m)	(m)	(m)	barg	°C		k€2014	k€2014	
Direct Contact Cooler	Vertical	5.5	5	10	2.0	139	SS304L	1051	2122	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Q/LMTD	C-value	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Fin		(kW)	(K)	(W/K)	(€2014/(W/K))	barg	°C		k€2014	k€2014	
LT heat exchanger 1 (3 streams)	P&Fin	4 696	9			86.9	-59	SS304L	521	1 041	D4.4
LT heat exchanger 2 (2 streams)	P&Fin	685	6	106 364	0.3	35.2	-59	SS304L	165	331	D4.4
Refrigerated cooler 1	P&Fin	4 922	7	730 434	0.1	35.6	-44	SS304L	465	929	D4.4
Refrigerated cooler 2	P&Fin	2 516	7	385 777	0.2	34.8	-59	SS304L	330	660	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	INLET TEMPERATURE		COST	COST	SOURCE
Fans, Compressors and Expanders		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Flue gas blower 1		441393	2531	1.8	2.0	138	SS304L	667	933	D4.4
Flue gas compressor	Centrifugal, horizontal	351368	12143	1.8	3.4	68	SS304L	32515	37434	APEA
Centrifugal gas expander 1	Turboexpander	2567	1920	33.1	10.1	147	SS304L	1077	1494	APEA
Centrifugal gas expander 2	Turboexpander	8731	2056	9.9	3.3	145	SS304L	1140	1715	APEA
Centrifugal gas expander 3	Turboexpander	139982	5320	3.0	2.0	133	SS304L	2836	5720	APEA
Permeate compressor 1	Centrifugal, horizontal	121980	5571	1.8	4.1	56	SS304L	10226	12244	APEA
Permeate compressor 2	Centrifugal, horizontal	36503	5394	4.1	11.6	56	SS304L	5631	6479	APEA
Permeate compressor 3	Centrifugal, horizontal	10952	5248	11.4	37.4	56	SS304L	2375	2887	APEA
Vacuum pump	Water-sealed	619184	9156	1.8	0.0	55	CS	8577	10297	APEA
Small recycle compressor	Centrifugal, horizontal	603	281	9.7	36.6	-60	SS304L	1024	1254	APEA

Table 5.9. Equipment list for membrane package, vessels, pumps, generators and dehydration equipment in both CO_2 capture and compression section.

DESCRIPTION	SIZE	DESIGN	DESIGN	EQUIPMENT	DIRECT	COST
	Area (Design)	PRESSURE	TEMPERATURE	COST	COST	SOURCE
Membrane Package	(m2)	barg	°C	k€2014	k€2014	
Membrane	250800	3.3	55	N/A	11 506	D4.4

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
Water separator 1	Vertical	14.41	129577	5.2	20.7	3.3	56	SS304L	690	1184	APEA
Water separator 2	Vertical	2.28	36503	3.4	13.5	4.1	56	SS304L	262	600	APEA
Water separator 3	Vertical	0.68	10952	2.3	9.1	11.4	56	SS304L	244	560	APEA
Water separator 4	Vertical	0.20	3134	1.5	6.0	36.6	56	SS304L	132	251	APEA
Water separator 5	Vertical	0.24	121980	5.1	20.2	1.8	56	SS304L	559	1044	APEA
Main Liquid CO2 separator	Vertical	100.18	1208	1.6	6.3	34.4	-59	SS304L	143	374	APEA
CO2 purification separator	Vertical	86.46	603	1.4	5.7	9.7	-60	SS304L	59	290	APEA

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Pumps		(l/s)	(kW)	barg	°C		k€2014	k€2014	
DCC pump	Centrifugal	109.9	65.6	6.5	82	SS304L	79	218	APEA
Water KO1 pump	Centrifugal	0.1	0.04	6.4	56	SS304L	42	71	APEA
Liquid CO2 pump 1	Centrifugal	24	213	86.9	-60	SS304L	375	623	D4.4
Liquid CO2 pump 2	Centrifugal	31	118	13.1	40	SS304L	226	375	D4.4

DESCRIPTION	SIZE		MATERIAL	EQUIPMENT	DIRECT	COST
	Power (DESIGN)	Output (DESIGN)		COST	COST	SOURCE
Generators	(kW)	(kVa)		k€2014	k€2014	
Electric generator 1 (Gas expander 3)	5054	6317	CS	5266	5627	APEA
Electric generator 2 (Gas expanders 1&2)	3777	4721	CS	4415	4737	APEA

DESCRIPTION	TYPE	SIZE				ABSORBENT MASS	DESIGN	DESIGN	MATERIAL	MATERIAL	EQUIPMENT	TOTAL DIRECT	COST
		Flow (DESIGN)	Water flow (DESIGN	ID	Length	TOTAL	PRESSURE	TEMPERATURE		COST	COST	COST	SOURCE
Other Equipment	No. Of trains	(m3/s)	(kg/h)	(m)	(m)	(t)	barg	°C		k€2014	k€2014	k€2014	
Molecular sieve, single vessel dimensions	2	0.87	156.8	1.4	2.59	0.933	33.5	56	SS304L	3	132	357	APEA + D4.4

Table 5.10. Equipment list for external refrigeration system.

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Frame		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Cooler/condenser	P&F	11 205	12	351.3	11.8	68.4	SS304L	71	347	APEA

DESCRIPTION	TYPE	SIZE	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Fin		(kW)	barg	°C		k€2014	k€2014	
LT Heat Exchanger	P&Fin	2 825	9.3	-47	SS304L	360	720	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	INLET TEMPERATURE		COST	COST	SOURCE
Fans, Compressors and Expanders		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Cooling media compressor 1	Centrifugal, horizontal	3215	340	5.1	9.3	-59	SS304L	894	1244	APEA
Cooling media compressor 2	Centrifugal, horizontal	36083	1498	1.8	4.1	-44	SS304L	3244	4208	APEA
Cooling media compressor 3	Centrifugal, horizontal	17244	2306	4.1	11.8	-16	SS304L	2080	2714	APEA

DESCRIPTION	SIZE		EQUIPMENT	DIRECT	COST
	Flow (OP)	Flow (DESIGN)	COST	COST	SOURCE
Cooling tower	(m3/h)	(l/s)	k€2014	k€2014	
Complete cooling tower, field assembly	3341	1020.8	508	871	APEA

5.3.2 Constant low air leak

Equipment lists for the various sections of the membrane-assisted liquefaction process in the constant low air leak case are presented in Table 5.11 - Table 5.13.

Table 5.11. Equipment list for heat exchangers, columns, fans, compressors and expanders in both CO_2 capture and compression section.

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Frame		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Flue gas/CO2 lean gas HX	P&F	1 085	82	415	2.0	178.7	SS304L	84	382	APEA
Direct contact cooler	P&F	13 161	19	502	6.2	86.8	SS304L	100	395	APEA
Waste heater 1 (gas/gas)	P&F	1 841	50	134	34.1	167.0	SS304L	29	227	APEA
Waste heater 2 (gas/gas)	P&F	1 474	47	116	11.0	165.4	SS304L	25	221	APEA
Waste heater 3 (gas/gas)	P&F	4 752	65	267	2.9	216.9	SS304L	55	336	APEA
Cooler 1 (gas/water)	P&F	16 985	40	1162	3.1	155.5	SS304L	226	752	APEA
Cooler 2 (gas/water)	P&F	2 040	25	223	1.8	104.2	SS304L	46	309	APEA
Cooler 3 (gas/water)	P&F	5 748	41	305	4.0	165.0	SS304L	62	346	APEA
Cooler 4 (gas/water)	P&F	3 395	32	234	10.8	129.9	SS304L	49	314	APEA
Cooler 5 (gas/water)	P&F	3 092	30	224	33.5	124.3	SS304L	47	311	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		ID	H Packing	H Column	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Columns		(m)	(m)	(m)	barg	°C		k€2014	k€2014	
Direct Contact Cooler	Vertical	5.5	5	10	2.0	138.5	SS304L	1051	2122	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Q/LMTD	C-value	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Fin		(kW)	(K)	(W/K)	(€2014/(W/K))	barg	°C		k€2014	k€2014	
LT heat exchanger 1 (3 streams)	P&Fin	4 287	9			86.9	-26.0	SS304L	521	1 041	D4.4
LT heat exchanger 2 (2 streams)	P&Fin	677	6	106 053	0.3	32.2	-26.0	SS304L	165	330	D4.4
Refrigerated cooler 1	P&Fin	5 162	7	749 111	0.1	32.6	2.1	SS304L	471	942	D4.4
Refrigerated cooler 2	P&Fin	2 316	6	357 692	0.2	31.8	-14.1	SS304L	317	634	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	INLET TEMPERATURE		COST	COST	SOURCE
Fans, Compressors and Expanders		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Flue gas blower 1		376870	2160	1.8	2.0	138	SS304L	610	855	D4.4
Flue gas compressor	Centrifugal, horizontal	283197	8420	1.8	3.1	70	SS304L	25299	29203	APEA
Centrifugal gas expander 1	Turboexpander	2295	1559	30.2	9.2	142	SS304L	912	1324	APEA
Centrifugal gas expander 2	Turboexpander	7822	1682	9.0	3.1	140	SS304L	968	1538	APEA
Centrifugal gas expander 3	Turboexpander	118889	3436	2.9	1.9	135	SS304L	2496	5850	APEA
Permeate compressor 1	Centrifugal, horizontal	109960	4866	1.8	4.0	56	SS304L	8539	10254	APEA
Permeate compressor 2	Centrifugal, horizontal	33939	4711	4.0	11.0	56	SS304L	4411	5247	APEA
Permeate compressor 3	Centrifugal, horizontal	10500	4581	10.8	34.1	56	SS304L	2288	2741	APEA
Vacuum pump	Water-sealed	483884	7414	1.8	0.0	54	CS	6943	8336	APEA
Small recycle compressor	Centrifugal, horizontal	598	254	9.2	33.5	-60	SS304L	1005	1228	APEA

Table 5.12. Equipment list for membrane package, vessels, pumps, generators and dehydration equipment in both CO_2 capture and compression section.

DESCRIPTION	No. of units	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Area (OP)	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Membrane Package		(m2)	(m2)	barg	°C		k€2014	k€2014	
Membrane		228 000	250800	3.0	54			11 400	D4.4

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
Water separator 1	Vertical	12.90	115481	5.0	19.9	3.0	56	SS304L	613	1098	APEA
Water separator 2	Vertical	2.03	33939	3.3	13.2	4.0	56	SS304L	243	579	APEA
Water separator 3	Vertical	0.62	10500	2.2	8.9	10.8	56	SS304L	198	509	APEA
Water separator 4	Vertical	0.19	3103	1.5	6.0	33.5	56	SS304L	124	243	APEA
Water separator 5	Vertical	0.15	109960	4.9	19.5	1.8	56	SS304L	524	1002	APEA
Main Liquid CO2 separator	Vertical	98.47	1104	1.6	6.2	31.4	-59	SS304L	142	372	APEA
CO2 purification separator	Vertical	85.70	598	1.4	5.7	9.2	-60	SS304L	57	288	APEA

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Pumps		(l/s)	(kW)	barg	°C		k€2014	k€2014	
DCC pump	Centrifugal	110.8	62.0	6.2	87	SS304L	79	219	APEA
Water KO1 pump	Centrifugal	0.0	0.02	6.1	56	SS304L	42	71	APEA
Liquid CO2 pump 1	Centrifugal	24	213	86.9	-57	SS304L	375	622	D4.4
Liquid CO2 pump 2	Centrifugal	30	115	119.9	39	SS304L	222	369	D4.4

DESCRIPTION	SIZE		MATERIAL	EQUIPMENT	DIRECT	COST
	Power (DESIGN)	Output (DESIGN)		COST	COST	SOURCE
Generators	(kW)	(kVa)		k€2014	k€2014	
Electric generator 1 (Gas expander 3)	3265	4081	CS	4043	4356	APEA
Electric generator 2 (Gas expanders 1&2)	3079	3848	CS	3902	4211	APEA

DESCRIPTION	TYPE	SIZE				ABSORBENT MASS	DESIGN	DESIGN	MATERIAL	MATERIAL	EQUIPMENT	TOTAL DIRECT	COST
		Flow (DESIGN)	Water flow (DESIGN)	ID	Length	TOTAL	PRESSURE	TEMPERATURE		COST	COST	COST	SOURCE
Other Equipment	No. Of trains	(m3/s)	(kg/h)	(m)	(m)	(t)	barg	°C		k€2014	k€2014	k€2014	
Molecular sieve, single vessel dimensions	2	0.86	149.5	1.4	2.57	0.890	33.5	56	SS304L	2	131	357	APEA + D4.4

Table 5.13. Equipment list for external refrigeration system.

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Frame		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Cooler/condenser	P&F	11 228	12	352.0	11.8	68	SS304L	71	347	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Q/LMTD	C-value	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Fin		(kW)	(K)	(W/K)	(€2014/(W/K))	barg	°C		k€2014	k€2014	
LT Heat Exchanger	P&Fin	2 601	5	499 823	0.1	9.3	-47	SS304L	344	689	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	INLET TEMPERATURE		COST	COST	SOURCE
Fans, Compressors and Expanders		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Cooling media compressor 1	Centrifugal, horizontal	2960	313	5.1	9.3	-59	SS304L	883	1232	APEA
Cooling media compressor 2	Centrifugal, horizontal	36156	1501	1.8	4.1	-44	SS304L	3244	4209	APEA
Cooling media compressor 3	Centrifugal, horizontal	17279	2310	4.1	11.8	-16	SS304L	2080	2714	APEA

DESCRIPTION	SIZE		EQUIPMENT	DIRECT	COST
	Flow (OP)	Flow (DESIGN)	COST	COST	SOURCE
Cooling tower	(m3/h)	(l/s)	k€2014	k€2014	
Complete cooling tower, field assembly	3380	1032.9	511	875	APEA

5.3.3 Optional extent of capture

Equipment lists for the various sections of the membrane-assisted liquefaction process in the optional extent of capture case are presented in Table 5.14 - Table 5.16.

Table 5.14. Equipment list for heat exchangers, columns, fans, compressors and expanders in both CO_2 capture and compression section.

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Frame		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Flue gas/CO2 lean gas HX	P&F	2 426	62	1240	2.0	158	SS304L	241	774	APEA
Direct contact cooler	P&F	10 860	17	461	5.5	82	SS304L	92	383	APEA
Waste heater 1 (gas/gas)	P&F	859	54	59	37.4	169	SS304L	14	165	APEA
Waste heater 2 (gas/gas)	P&F	787	52	55	11.6	167	SS304L	13	133	APEA
Waste heater 3 (gas/gas)	P&F	3 319	88	139	2.3	232	SS304L	30	229	APEA
Cooler 1 (gas/water)	P&F	14 088	29	1353	2.4	115	SS304L	262	800	APEA
Cooler 2 (gas/water)	P&F	2 975	25	323	1.8	105	SS304L	66	342	APEA
Cooler 3 (gas/water)	P&F	3 372	42	178	4.1	166	SS304L	38	243	APEA
Cooler 4 (gas/water)	P&F	2 077	33	138	11.4	134	SS304L	30	225	APEA
Cooler 5 (gas/water)	P&F	2 098	33	139	36.6	135	SS304L	30	225	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		ID	H Packing	H Column	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Columns		(m)	(m)	(m)	barg	°C		k€2014	k€2014	
Direct Contact Cooler	Vertical	5.5	5	10	2.0	137	SS304L	1051	2122	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Q/LMTD	C-value	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Fin		(kW)	(K)	(W/K)	(€2014/(W/K))	barg	°C		k€2014	k€2014	
LT heat exchanger 1 (3 streams)	P&Fin	2 726	10			86.9	-59	SS304L	246	492	D4.4
LT heat exchanger 2 (2 streams)	P&Fin	455	6	75 553	0.4	35.2	-59	SS304L	138	275	D4.4
Refrigerated cooler 1	P&Fin	3 816	9	448 177	0.2	35.6	-44	SS304L	358	715	D4.4
Refrigerated cooler 2	P&Fin	1 010	6	165 957	0.3	35.2	-59	SS304L	210	420	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	INLET TEMPERATURE		COST	COST	SOURCE
Fans, Compressors and Expanders		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Flue gas blower 1		441393	2531	1.8	2.0	138	SS304L	667	933	D4.4
Flue gas compressor	Centrifugal, horizontal	350976	5690	1.8	2.4	68	SS304L	26075	30863	APEA
Centrifugal gas expander 1	Turboexpander	971	833	33.1	8.3	144	SS304L	480	660	APEA
Centrifugal gas expander 2	Turboexpander	4099	897	8.1	2.4	142	SS304L	510	795	APEA
Centrifugal gas expander 3	Turboexpander	219138	1998	2.3	1.9	93	SS304L	1114	4421	APEA
Permeate compressor 1	Centrifugal, horizontal	62869	2860	1.8	4.1	56	SS304L	4625	5977	APEA
Permeate compressor 2	Centrifugal, horizontal	18789	2764	4.1	11.6	56	SS304L	2478	3090	APEA
Permeate compressor 3	Centrifugal, horizontal	5612	2676	11.4	37.4	56	SS304L	1613	1983	APEA
Vacuum pump	Water-sealed	337872	4991	1.8	0.0	55	CS	4901	5884	APEA
Small recycle compressor	Centrifugal, horizontal	401	187	9.7	36.6	-60	SS304L	961	1176	APEA

Table 5.15. Equipment list for membrane package, vessels, pumps, generators and dehydration equipment in both CO_2 capture and compression section.

DESCRIPTION	SIZE		DESIGN	DESIGN	DIRECT	COST
	Area (OP)	Area (Design)	PRESSURE	TEMPERATURE	COST	SOURCE
Membrane Package	(m2)	(m2)	barg	°C	k€2014	
Membrane	152 000	167200	3.3	55	7 657	D4.4

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
Water separator 1	Vertical	12.19	207065	6.0	24.1	2.4	56	SS304L	886	1414	APEA
Water separator 2	Vertical	1.18	18789	2.7	10.9	4.1	56	SS304L	166	467	APEA
Water separator 3	Vertical	0.35	5612	1.8	7.3	11.4	56	SS304L	131	408	APEA
Water separator 4	Vertical	0.10	1577	1.2	4.8	36.6	56	SS304L	92	194	APEA
Water separator 5	Vertical	0.16	1616	1.2	4.8	1.8	56	SS304L	47	192	APEA
Main Liquid CO2 separator	Vertical	66.65	461	1.3	5.2	34.4	-59	SS304L	97	299	APEA
CO2 purification separator	Vertical	57.54	401	1.2	5.0	9.7	-60	SS304L	51	261	APEA

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Pumps		(l/s)	(kW)	barg	°C		k€2014	k€2014	
DCC pump	Centrifugal	109.9	51.6	5.5	82	SS304L	76	215	APEA
Water KO1 pump	Centrifugal	0.8	0.38	5.4	56	SS304L	42	77	APEA
Liquid CO2 pump 1	Centrifugal	16	142	86.9	-60	SS304L	266	441	D4.4
Liquid CO2 pump 2	Centrifugal	21	78	119.9	40	SS304L	160	265	D4.4

DESCRIPTION	SIZE		MATERIAL	EQUIPMENT	DIRECT	COST
	Power (DESIGN)	Output (DESIGN)		COST	COST	SOURCE
Generators	(kW)	(kVa)		k€2014	k€2014	
Electric generator 1 (Gas expander 3)	1898	2373	CS	2915	3204	APEA
Electric generator 2 (Gas expanders 1&2)	1644	2054	CS	2669	2935	APEA

DESCRIPTION	TYPE	SIZE				ABSORBENT MASS	DESIGN	DESIGN	MATERIAL	MATERIAL	EQUIPMENT	TOTAL DIRECT	COST
		Flow (DESIGN)	Water flow (DESIGN	ID	Length	TOTAL	PRESSURE	TEMPERATURE		COST	COST	COST	SOURCE
Other Equipment	No. Of trains	(m3/s)	(kg/h)	(m)	(m)	(t)	barg	°C		k€2014	k€2014	k€2014	
Molecular sieve, single vessel dimensions	2	0.44	82.7	1.0	2.62	0.492	33.5	56	SS304L	1	94	315	APEA + D4.4

Table 5.16. Equipment list for external refrigeration system.

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Frame		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Cooler/condenser	P&F	7 162	12	224.5	11.8	68.4	SS304L	47	306	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Q/LMTD	C-value	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Fin		(kW)	(K)	(W/K)	(€2014/(W/K))	barg	°C		k€2014	k€2014	
LT Heat Exchanger	P&Fin	1 134	5	217 999	0.2	9.3	-14.2	SS304L	243	486	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	INLET TEMPERATURE		COST	COST	SOURCE
Fans, Compressors and Expanders		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Cooling media compressor 1	Centrifugal, horizontal	1291	136	5.1	9.3	-59	SS304L	794	1072	APEA
Cooling media compressor 2	Centrifugal, horizontal	23173	962	1.8	4.1	-44	SS304L	1979	2670	APEA
Cooling media compressor 3	Centrifugal, horizontal	11023	1474	4.1	11.8	-16	SS304L	1396	1867	APEA

DESCRIPTION	SIZE		EQUIPMENT	DIRECT	COST
	Flow (OP)	Flow (DESIGN)	COST	COST	SOURCE
Cooling tower	(m3/h)	(l/s)	k€2014	k€2014	
Complete cooling tower, field assembly	2542	776.6	396	689	APEA

5.3.4 Ship transport

Equipment lists for the various sections of the membrane-assisted liquefaction process in the ship transport case are presented in Table 5.17 - Table 5.19.

Table 5.17. Equipment list for heat exchangers, columns, fans, compressors and expanders in both CO_2 capture and compression section.

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Frame		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Flue gas/CO2 lean gas HX	P&F	2 232	63	627	2.0	158	SS304L	124	497	APEA
Direct contact cooler	P&F	10 950	17	463	6.5	82	SS304L	93	383	APEA
Waste heater 1 (gas/gas)	P&F	1 791	44	149	37.7	172	SS304L	32	234	APEA
Waste heater 2 (gas/gas)	P&F	1 849	45	149	11.7	171	SS304L	32	234	APEA
Waste heater 3 (gas/gas)	P&F	6 203	74	306	3.2	238	SS304L	63	351	APEA
Cooler 1 (gas/water)	P&F	21 459	44	1353	3.4	168	SS304L	262	824	APEA
Cooler 2 (gas/water)	P&F	2 307	25	250	1.8	105	SS304L	52	319	APEA
Cooler 3 (gas/water)	P&F	6 601	43	340	4.2	170	SS304L	69	357	APEA
Cooler 4 (gas/water)	P&F	3 742	32	257	11.5	130	SS304L	53	322	APEA
Cooler 5 (gas/water)	P&F	3 903	33	259	36.9	134	SS304L	53	323	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		ID	H Packing	H Column	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Columns		(m)	(m)	(m)	barg	°C		k€2014	k€2014	
Direct Contact Cooler	Vertical	5.5	5	10	2.0	138.5	SS304L	1051	2122	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Q/LMTD	C-value	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Fin		(kW)	(K)	(W/K)	(€2014/(W/K))	barg	°C		k€2014	k€2014	
LT heat exchanger 1 (2 streams)	P&Fin	1 982	20	99 207	0.3	36.4	-26.0	SS304L	159	319	D4.4
LT heat exchanger 2 (2 streams)	P&Fin	5 230	9	603 718	0.1	35.6	-26.0	SS304L	420	839	D4.4
Refrigerated cooler 1	P&Fin	7 581	8	985 963	0.1	35.6	-11.2	SS304L	546	1 092	D4.4
Refrigerated cooler 2	P&Fin	3 706	7	568 240	0.1	34.8	-26.0	SS304L	406	812	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	INLET TEMPERATURE		COST	COST	SOURCE
Fans, Compressors and Expanders		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Flue gas blower 1		441393	2531	1.8	2.0	138	SS304L	667	933	D4.4
Flue gas compressor	Centrifugal, horizontal	351368	12143	1.8	3.4	68	SS304L	32515	37434	APEA
Centrifugal gas expander 1	Turboexpander	2611	1954	33.1	10.1	147	SS304L	1093	1510	APEA
Centrifugal gas expander 2	Turboexpander	8868	2090	9.9	3.3	146	SS304L	1068	1641	APEA
Centrifugal gas expander 3	Turboexpander	139893	5365	3.2	1.9	134	SS304L	2856	5741	APEA
Permeate compressor 1	Centrifugal, horizontal	122588	5615	1.8	4.2	56	SS304L	10270	12290	APEA
Permeate compressor 2	Centrifugal, horizontal	36572	5436	4.1	11.7	56	SS304L	5626	6474	APEA
Permeate compressor 3	Centrifugal, horizontal	10938	5289	11.5	37.7	56	SS304L	2378	2890	APEA
Vacuum pump	Water-sealed	622151	9235	1.8	0.0	55	CS	8577	10297	APEA
Small recycle compressor	Centrifugal, horizontal	3753	1642	7.7	36.9	-57	SS304L	1406	1741	APEA

Table 5.18. Equipment list for membrane package, vessels, pumps, generators and dehydration equipment in both CO_2 capture and compression section.

DESCRIPTION	SIZE		DESIGN	DESIGN	EQUIPMENT	DIRECT	COST
	Area (OP)	Area (Design)	PRESSURE	TEMPERATURE	COST	COST	SOURCE
Membrane Package	(m2)	(m2)	barg	°C	k€2014	k€2014	
Membrane	228 000	250800	3.3	55		11 506	D4.4

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
Water separator 1	Vertical	14.43	129052	5.2	20.6	3.3	56	SS304L	688	1183	APEA
Water separator 2	Vertical	2.29	36572	3.4	13.5	4.1	56	SS304L	262	600	APEA
Water separator 3	Vertical	0.68	10938	2.3	9.1	11.5	56	SS304L	244	560	APEA
Water separator 4	Vertical	0.20	3119	1.5	6.0	36.9	56	SS304L	132	251	APEA
Water separator 5	Vertical	0.21	122588	5.1	20.3	1.8	56	SS304L	560	1045	APEA
Main Liquid CO2 separator	Vertical	146.29	1227	1.7	6.9	34.4	-59	SS304L	164	403	APEA
CO2 purification separator	Vertical	86.54	3753	1.8	7.4	7.7	-60	SS304L	84	354	APEA

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Pumps		(l/s)	(kW)	barg	°C		k€2014	k€2014	
DCC pump	Centrifugal	109.9	65.8	6.5	82	SS304L	79	218	APEA
Water KO1 pump	Centrifugal	0.1	0.04	6.4	56	SS304L	42	71	APEA

DESCRIPTION	TYPE	SIZE		MATERIAL	EQUIPMENT	DIRECT	COST
		Power (DESIGN)	Output (DESIGN)		COST	COST	SOURCE
Generators		(kW)	(kVa)		k€2014	k€2014	
Electric generator 1 (Gas expander 3)		5096	6370	CS	5292	5655	APEA
Electric generator 2 (Gas expanders 1&2)		3841	4802	CS	4461	4784	APEA

DESCRIPTION	TYPE	SIZE				ABSORBENT MASS	DESIGN	DESIGN	MATERIAL	MATERIAL	EQUIPMENT	TOTAL DIRECT	COST
		Flow (DESIGN)	Water flow (DESIGN)	ID	Length	TOTAL	PRESSURE	TEMPERATURE		COST	COST	COST	SOURCE
Other Equipment	No. Of trains	(m3/s)	(kg/h)	(m)	(m)	(t)	barg	°C		k€2014	k€2014	k€2014	
Molecular sieve, single vessel dimensions	2	0.87	156.9	1.4	2.60	0.934	33.5	56	SS304L	3	132	358	APEA + D4.4

Table 5.19. Equipment list for external refrigeration system.

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Frame		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Cooler/condenser	P&F	17 268	12	541.4	11.8	68.4	SS304L	108	460	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Q/LMTD	C-value	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Fin		(kW)	(K)	(W/K)	(€2014/(W/K))	barg	°C		k€2014	k€2014	
LT Heat Exchanger	P&Fin	4 363	5	834 527	0.1	9.3	-14.2	SS304L	454	907	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	INLET TEMPERATURE		COST	COST	SOURCE
Fans, Compressors and Expanders		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Cooling media compressor 1	Centrifugal, horizontal	5214	566	4.8	9.3	-60	SS304L	955	1369	APEA
Cooling media compressor 2	Centrifugal, horizontal	55333	2298	1.8	4.1	-44	SS304L	4368	5709	APEA
Cooling media compressor 3	Centrifugal, horizontal	26576	3554	4.1	11.8	-16	SS304L	2788	3628	APEA

DESCRIPTION	SIZE		EQUIPMENT	DIRECT	COST
	Flow (OP)	Flow (DESIGN)	COST	COST	SOURCE
Cooling tower	(m3/h)	(l/s)	k€2014	k€2014	
Complete cooling tower, field assembly	3906	1193.5	570	1027	APEA

6 CALCIUM LOOPING – TAIL-END CONFIGURATION

The project partners responsible for the process simulations and for compiling equipment lists for the calcium looping tail-end technology are listed in Table 6.1.

Table 6.1. Responsible project partners for process simulations and compilation of equipment lists for the calcium looping tail-end technology.

	Responsible partner
Process simulations	PoliMi (core process and steam cycle) SINTEF ER (CPU)
Equipment lists	PoliMi (core process and steam cycle) SINTEF ER (CPU)

6.1 Process flow diagram

The process flowsheet for calcium looping tail-end process is shown in Figure 6.1. Process flow diagrams of the CPU are given in Figure 6.2 for pipeline transport and in Figure 6.3 for ship transport.

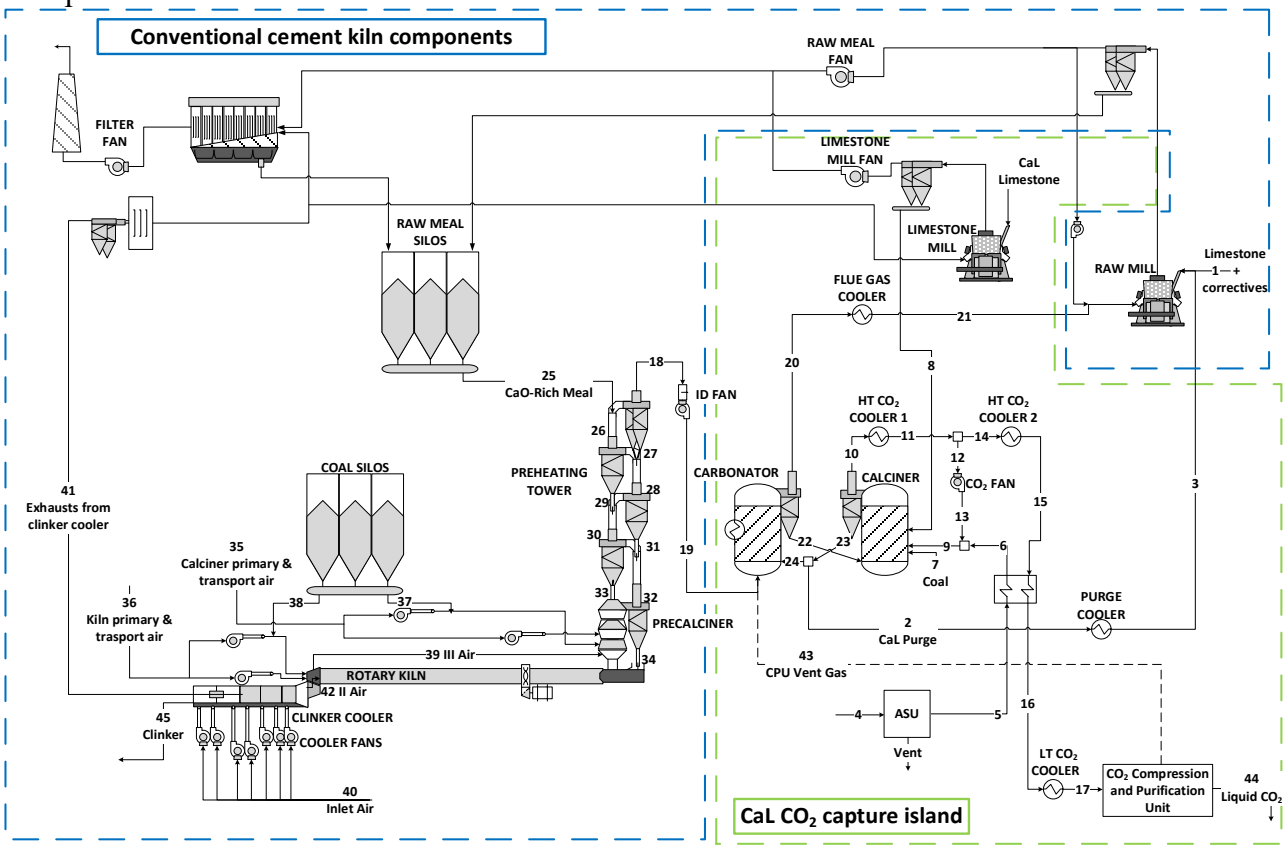

Figure 6.1. Process flowsheet of the tail-end CaL process integration for CO_2 capture in a cement kiln.

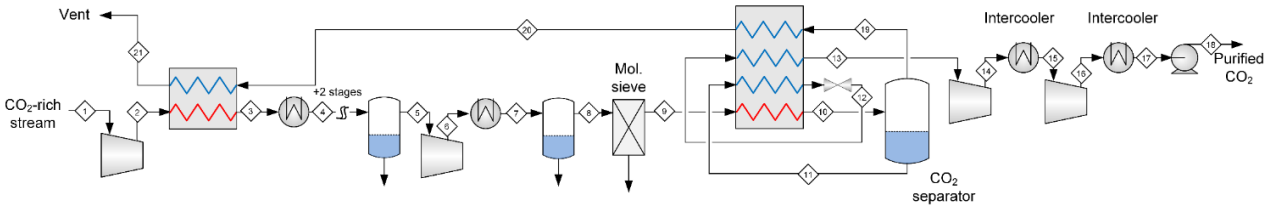

Figure 6.2. Process flowsheet of the CPU for pipeline transport.

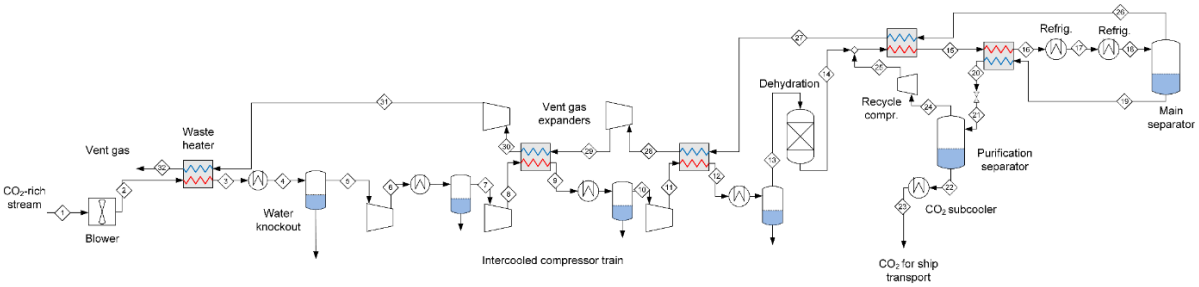

Figure 6.3. Process flowsheet of the CPU for ship transport.

6.2 Stream data

6.2.1 Base case

Stream data for the core process in the base case is given in Table 6.2. Stream data for the CPU is given in Table 6.3.

Table 6.2. Streams properties of base case 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					

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
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					
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

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
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 6.3																				
44	G	See stream #18 in Table 6.3																				
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 6.3: Main stream data for the CPU with pipeline transport in the calcium looping tail-end process in the base case.

#	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

6.2.2 IL20%

Stream data for the core process in the IL20% case is given in Table 6.4. Stream data for the CPU is given in Table 6.5.

Table 6.4: Streams properties of base case CaL cement kiln with IL=20% (s: solid stream, g: gas stream)

Stream (IL20%)		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	44.80	1.37	15.0	3.18	76.73	0.00	2.33	0.33	1.76	0.00	15.67	0.00	0.00	0.00	0.00	0.00					
2	s	5.94	0.18	920.0	6.48	0.00	81.10	0.80	0.00	0.00	0.34	8.72	0.00	0.00	0.00	2.55	0.00					
3	s	5.94	0.18	120.0	6.48	0.00	81.10	0.80	0.00	0.00	0.34	8.72	0.00	0.00	0.00	2.55	0.00					
4	g	73.18	2.23	15.0														0.92	0.03	1.03	20.73	77.28
5	g	17.80	0.54	15.0														3.00	0.00	0.00	95.00	2.00
6	g	17.80	0.54	150.0														3.00	0.00	0.00	95.00	2.00
7	s	7.19	0.22	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	8.32	0.25	60.0	-	100	-	-	-	-	-	-	-	-	-	-	-					
9	g	39.97	1.22	315.4														2.19	40.26	6.04	50.00	1.51
10	g	70.19	2.14	920.1														1.39	80.52	12.07	5.00	1.03
11	g	70.19	2.14	400.0														1.39	80.52	12.07	5.00	1.03
12	g	22.17	0.68	400.0														1.39	80.52	12.07	5.00	1.03
13	g	22.17	0.68	427.0														1.39	80.52	12.07	5.00	1.03
14	g	48.02	1.46	400.0														1.39	80.52	12.07	5.00	1.03
15	g	48.02	1.46	320.0														1.39	80.52	12.07	5.00	1.03
16	g	48.02	1.46	278.3														1.39	80.52	12.07	5.00	1.03
17	g	48.02	1.46	35.0														1.39	80.52	12.07	5.00	1.03
18	g	61.72	1.88	328.6														0.73	27.61	4.77	5.22	61.67
	s	2.43	0.07	328.6	3.58	67.94	9.53	2.16	0.00	1.52	0.06	14.90	0.00	0.01	0.00	0.30	0.00					
19	g	61.72	1.88	328.5														0.73	27.61	4.77	5.22	61.67
	s	2.43	0.07	328.6	3.58	67.94	9.53	2.16	0.00	1.52	0.06	14.90	0.00	0.01	0.00	0.30	0.00					
20	g	41.07	1.25	650.0														0.97	4.10	6.32	6.92	81.70
21	g	41.07	1.25	430.5														0.97	4.10	6.32	6.92	81.70
22	s	203.30	6.20	650.0	5.82	23.10	59.93	0.72	0.00	0.00	0.30	7.84	0.00	0.00	0.00	2.29	0.00					
23	s	188.59	5.75	920.1	6.48	0.00	81.11	0.80	0.00	0.00	0.34	8.72	0.00	0.00	0.00	2.55	0.00					

Stream (IL20%)		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
24	s	182.66	5.57	920.1	6.48	0.00	81.10	0.80	0.00	0.00	0.34	8.72	0.00	0.00	0.00	2.55	0.00					
25	s	50.74	1.55	60.0	3.57	67.75	9.49	2.15	0.29	1.55	0.04	14.86	0.00	0.00	0.00	0.30	0.00					
26	g	60.78	1.85	508.0														0.74	28.13	4.41	5.02	61.71
	s	9.38	0.29	508.0	3.58	67.89	9.59	2.16	0.00	1.30	0.16	14.91	0.02	0.07	0.00	0.30	0.01					
27	s	57.54	1.76	328.6	3.58	67.94	9.53	2.16	0.00	1.52	0.06	14.90	0.00	0.01	0.00	0.30	0.00					
28	g	60.38	1.84	651.1														0.74	28.13	4.41	5.02	61.71
	s	9.50	0.29	651.1	3.62	67.56	9.98	2.18	0.00	0.00	0.80	14.93	0.13	0.44	0.03	0.31	0.02					
29	s	57.67	1.76	508.0	3.58	67.89	9.59	2.16	0.00	1.30	0.16	14.91	0.02	0.07	0.00	0.30	0.01					
30	g	59.99	1.83	761.0														0.73	28.55	4.46	4.78	61.48
	s	10.07	0.31	761.0	3.82	56.83	16.77	2.28	0.00	0.00	0.85	14.90	0.89	2.97	0.19	0.35	0.15					
31	s	58.24	1.78	651.1	3.62	67.56	9.98	2.18	0.00	0.00	0.80	14.93	0.13	0.44	0.03	0.31	0.02					
32	g	59.59	1.82	860.2														0.73	28.76	4.48	4.66	61.36
	s	12.41	0.38	860.2	4.76	6.46	48.65	2.78	0.00	0.00	1.10	14.75	4.44	14.82	0.93	0.54	0.76					
33	s	60.57	1.85	761.0	3.82	56.83	16.77	2.28	0.00	0.00	0.85	14.90	0.89	2.97	0.19	0.35	0.15					
34	s	38.42	1.17	860.2	4.76	6.46	48.65	2.78	0.00	0.00	1.10	14.75	4.44	14.82	0.93	0.54	0.76					
35	g	0.57	0.02	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	1.87	0.06	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																	
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	1137														0.92	0.03	1.03	20.73	77.28
	s	0.69	0.02	1137	0.00	0.00	0.77	0.00	0.00	0.00	1.14	0.00	64.39	14.02	9.55	0.63	9.50					
40	g	78.47	2.39	15.0														0.92	0.03	1.03	20.73	77.28
41	g	41.31	1.26	284.9														0.92	0.03	1.03	20.73	77.28
	s	1.19	0.04	284.9	0.00	0.00	0.77	0.00	0.00	0.00	1.14	0.00	64.39	14.02	9.55	0.63	9.50					
42	g	10.97	0.33	1137														0.92	0.03	1.03	20.73	77.28
	s	0.27	0.01	1137	0.00	0.00	0.77	0.00	0.00	0.00	1.14	0.00	64.39	14.02	9.55	0.63	9.50					

Stream (IL20%)		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
43*	g	See stream #21 in Table 6.5																				
44	g	See stream #18 in Table 6.5																				
45	s	32.79	1.00	114.9	0.00	0.00	0.77	0.00	0.00	0.00	1.14	0.00	64.39	14.02	9.55	0.63	9.50					

*CPU vent gas to atmosphere

Table 6.5: Main stream data for the CPU with pipeline transport in the calcium looping tail-end process in the IL20% case.

#	Vapor fraction	Temperature [°C]	Pressure [bar]	Molar flow [kmol/h]	Mole fraction			
					H_2O	CO_2	O_2	N_2
1	0.93	35.00	1.01	4316.22	0.0139	0.8051	0.1207	0.0500
9	1.00	30.30	21.80	3794.98	0.0158	0.9156	0.0000	0.0569
17	0.00	28.00	82.32	3499.93	0.0084	0.9629	0.0000	0.0249
18	1.00	37.19	110.00	3499.93	0.0084	0.9629	0.0000	0.0249
19	1.00	-50.00	21.80	295.05	0.1040	0.3548	0.0000	0.4363
20	1.00	20.30	21.80	295.05	0.1040	0.3548	0.0000	0.4363
21	1.00	70.34	1.10	295.05	0.1040	0.3548	0.0000	0.4363

6.2.3 Ship transport

The stream data for the core process is identical to the base case (*cf*. Table 6.2). The stream data for the CPU for ship transport is given in Table 6.6.

Table 6.6: Main stream data for the CPU with ship transport in the calcium looping tail-end process in the ship transport case.

#	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
14	1.00	28.00	25.23	3457.53	0.0147	0.9181	0.0000	0.0564
19	0.00	-54.00	23.13	10829.43	0.0117	0.9544	0.0000	0.0297
23	0.00	-55.04	6.10	3072.47	0.0004	0.9988	0.0000	0.0007
25	1.00	47.11	25.23	7765.96	0.0164	0.9369	0.0000	0.0408
26	1.00	100.17	22.21	394.06	0.1288	0.2891	0.0000	0.4827
32	1.00	70.00	1.05	394.06	0.1288	0.2891	0.0000	0.4827

6.3 Equipment list

The main components of the calcium looping tail-end process, including the heat recovery steam cycle, are shown in Figure 6.4. The equipment list for the core process in both the base case and the ship transport case is presented in Table 6.7.

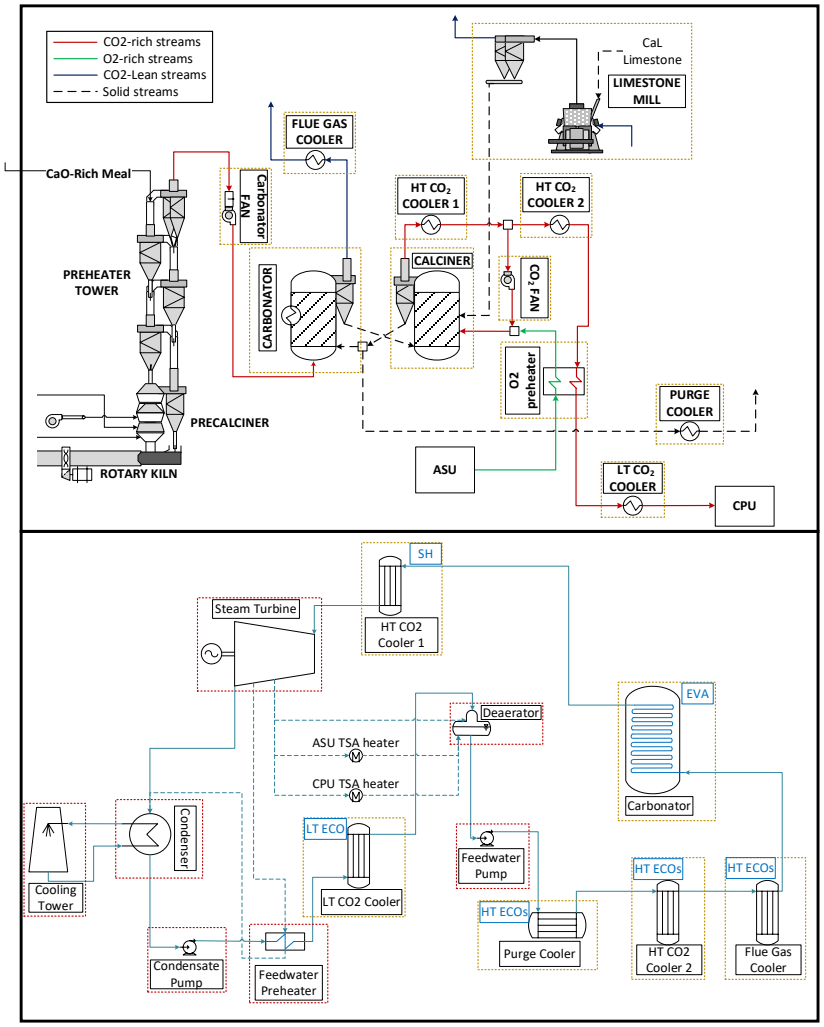

Figure 6.4: Main components of the Tail End CaL process with CFB reactors (top) and of the heat recovery steam cycle (bottom).

Table 6.7: Equipment list of units shown in Figure 6.4.

Limestone grinding plant				
	Limestone Mill			
IL	20%		50%	
Mass flow rate, t/h	30.0		76.5	
Average particle diameter of milled limestone, μm	~200		~200	
TEC+IC, k€	1,326.8		2,484.2	
Fans				
	CO_2 fan		**Carbonator fan**	
Type	Sealed		Standard	
IL	20%	50%	20%	50%
Volumetric low rate (Design), m^3/h	121,185	102,976	364,185	336,873
Head, kPa	20	20	20	20
Temperature, °C	400	400	312.5	312.5
Power (Design), kW	812.9	690.8	2,458.5	2276.7
MC, k€	134.7	124.2	166.8	160.4
EMC, k€	81.8	73.6	219.2	208.5
EIC, k€	64.9	59.3	115.8	110.7
OC, k€	42.2	38.6	75.3	72.0
TEC, k€	323.6	295.7	577.1	551.6
IC, k€	129.5	118.3	230.9	220.7
Reactors				
	Carbonator		**Calciner**	
Type	CFB, Cooled		CFB, Refractory lined	
IL	20%	50%	20%	50%
Volumetric flow, m^3/h – Nm^3/h	393,863 – 116,565	395,117 – 116,937	429,576 – 98,362	365,016 – 83,579
Operating temperature, °C	650	650	920	920
Superficial gas velocity, m/s	5	5	5	5
Outlet temperature, °C	650	650	920	920
Width x Depth, m	4.7 x 4.7	4.7 x 4.7	4.9 x 4.9	4.5 x 4.5
Height, m	20	20	20	20
Thickness of steel, mm	7.0	7.0	25	25
Thickness of refractory, mm	-	-	200	200
TEC, k€	11,776	7,522	5,945	5,273
IC, k€	13,845	8,232	7,056	5,679
Pumps				
	Condensate pump		**Feedwater pump**	
Type	Vertical canned		Multistage centrifugal	
IL	20%	50%	20%	50%
Flow rate, kg/s	111.2	77.37	65.14	41.94
Head, m H_2O	114.3	99.06	1,645.9	1645.9
Electricity absorption, kW	125.5	75.51	1,413.1	920.4
TEC, k€	28.5	19.5	353.8	307.2
IC, k€	3.5	2.5	20.6	13.8
Deaerator				
Type	Tank Car			
IL	20%		50%	
Feedwater mass flow, kg/s	61.88		39.84	
Pressure, bar	3.614		3.614	
Temperature, °C	140		140	
Total storage volume, l	28,070		18072	

Overall height, m	5.727	5.186
Overall length, m	6.24	5.53
Storage tank		
-Thickness, mm	15.88	12.7
-Outer diameter, m	2.691	2.286
-Total length, m	6.24	5.53
Heater		
-Thickness, mm	15.88	12.7
-Outer diameter, m	2.691	2.286
-Total length, m	2.731	2.595
TEC, k€	269.5	194.1
IC, k€	24.0	17.0
Regenerative Feedwater Preheater		
Type	Includes condensing section, drain cooler	
IL	20%	50%
Shell pressure, bar	0.36	0.36
Saturation temperature, °C	73.37	73.37
Feedwater mass flow rate, kg/s	55.60	38.68
Heat transfer rate, MW	7.11	4.96
Feedwater Heater Tube		
-Type	Bare Tube	Bare Tube
-Material,	Stainless Steel	Stainless Steel
-Layout in crossflow	Rotated Square 45°	Rotated Square 45°
-Design point water pressure, bar	5.664	4.926
-Number of tubes in heater,	524	430
-Length, m	10.58	9.43
-Outer diameter, mm	15.88	15.88
-Thickness, mm	1.25	1.25
Feedwater Heater Shell		
-Material,	Carbon Steel	Carbon Steel
-Steam pressure, bar	0.36	0.36
-Overall length, m	11.8	10.5
-Overall outer diameter, mm	923	812
-Shell wall thickness, mm	4.762	4.762
TEC, k€	167.4	144.2
IC, k€	13.1	10.9

Condenser		
Type	Shell & tube	
IL	20%	50%
Heat rejection, MW	109.4	76.7
Pressure, bar	0.07	0.07
Temperature, °C	39.03	39.03
Non-condensable removal system,	Vacuum Pump	Vacuum Pump
Water depth in hotwell, m	0.71	0.59
Volume water stored in hotwell, l	16,800	11,690
Condenser Tube		
-Material,	Stainless steel	Stainless steel
-Length, m	7.4	7.0
-Outer diameter, m	25.4	25.4
-Thickness, mm	0.71	0.71
Condenser Shell		
-Material,	Carbon steel	Carbon steel
-Thickness, mm	12.7	12.7
-Length x Width x Height, m	10 x 3.2 x 5.5	9.1 x 2.8 x 4.8
TEC, k€	824.3	671.8
IC, k€	269.3	207.1
Cooling Tower for steam cycle condenser heat rejection		
Type	Crossflow, Film Fill	
IL	20%	50%
Heat rejection, MW	109.8	77.0
Total number of cells in tower	4	4
Number of rows	1	1
Length per row, m	47.83	40.05
Length per cell, m	11.96	10.01
Width at top of cell, m	12.35	10.78
Width at bottom of cell, m	9.40	8.31
Height, m	11.72	9.81
Basin area, m^2	536.9	405.9
Fan diameter, m	7.97	6.68
TEC, k€	992.1	817.5
IC, k€	545.5	408.6
Steam Turbine and electric generator		
Type	Condensing, Non-Reheat	
IL	20%	50%
Capacity, MVA	81.2	52.5
Throttle Pressure, bar	110.5	110.5
Throttle Temperature, °C	532.0	532.0
Throttle Mass flow, kg/s	61.88	39.84
Exhaust End Type	Down Draft	Down Draft
Number of stages,	19	20
Generator Power, MW	69.60	44.97
Generator Efficiency, %	98.38	98.08
Overall Steam Turbine and Generator Length, m	16.75	14.96
Overall Steam Turbine and Generator Width, m	4.50	4.03
Overall Steam Turbine and Generator Weight, kg	222,150	162,150
Foundation Length, m	18.80	16.78

Foundation Width, m	5.4	4.8
TEC, k€	10,486.2	8,550.9
IC, k€	1127.1	872.9
CO2 Compression and Purification Unit		
IL	20%	50%
TEC, k€	29,739	31,873
IC, k€	6,679	6,009
ASU		
IL	20%	50%
Oxygen producted, tpd	1,599.3	1,359.9
TEC+IC, k€	48,249	43,775

Heat exchangers												
	Flue gases Cooler		**HT CO_2 Cooler 1**		**HT CO_2 Cooler 2**		**LT CO_2 Cooler**		**Purge Cooler**		**O_2 preheater**	
Type	Bare Tube		Bare Tube		Bare Tube		Bare Tube		Bare Tube		Bare Tube	
IL	20%	50%	20%	50%	20%	50%	20%	50%	20%	50%	20%	50%
Design point hot stream temperature, °C	650	650	920	920	400	400	276.9	276.9	920	920	316.5	316.5
Design point operating pressure, bar	114.9	115.7	114.42	114.42	130.34	124.42	5.209	4.62	134.42	134.4	1.03	1.03
Area, m^2	266.3	289.6	2,001.8	748.2	274.2	122.5	250.7	437.8	48.0	24	309.1	112.8
Duty, MW	9.8	9.7	46.3	29.9	4.5	3.9	3.0	9.0	3.2	1.6	2.2	1.9
Material	T22	T22	T91	T91	Carbon Steel	Carbon Steel	Carbon Steel	Carbon Steel	Carbon Steel	Carbon Steel	Stainless Steel	Stainless Steel
Weight, kg	3,740	4,070	38,870	14,530	4,790	2,140	3,510	6,160	2,162	1,060	1,790	654
Surface cost, k€	22.4	24.4	408.1	152.6	14.4	6.4	10.5	18.5	6.5	3.2	12.5	4.6
Auxiliary equipment cost, k€	22.4	24.4	408.1	152.6	14.4	6.4	10.5	18.5	6.5	3.2	12.5	4.6
TEC, k€	44.9	48.8	816.3	305.1	28.7	12.8	21.1	37.0	13.0	6.4	25.1	9.2
IC, k€	11.2	12.2	204.1	76.3	7.2	3.2	5.3	9.2	3.2	1.6	6.3	2.3

6.3.1 Base case

The equipment list of the CPU in the base case is presented in Table 6.8.

Table 6.8: Equipment list for the CO_2 purification unit

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	TEMPERATURE (IN)		COST	COST	SOURCE
Fans, Compressors and Expanders		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Compressor 1-4	Centrifugal, horizontal	99242	10955	1,8	25,3	56	SS304L	26074	27241	APEA
Compressor 5-6	Centrifugal, horizontal	6717	5594	12,2	91,3	48	SS304L	2715	3179	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
Water separator 1	Vertical	6,00	99256	4,7	18,9	1,8	56	SS304L	483	958	APEA
Water separator 2	Vertical	1,44	44982	3,6	14,5	2,9	56	SS304L	249	612	APEA
Water separator 3	Vertical	0,66	20068	2,8	11,1	5,5	56	SS304L	169	476	APEA
Water separator 4	Vertical	0,30	8868	2,1	8,4	11,1	56	SS304L	127	342	APEA
Water separator 5	Vertical	0,13	3789	1,6	6,4	24,8	56	SS304L	125	269	APEA
Liquid CO2 separator	Vertical	136,4	195	1,6	6,3	24,8	-55	SS304L	119	365	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Frame		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Gas/gas heat exchanger 1	P&F	116	44	10	2,9	124	SS304L	4	94	APEA
Flue gas cooler before CPU	P&F	1 122	9	349	1,8	63	SS304L	71	351	APEA
Intercooler 1	P&F	3 388	35	210	2,9	121	SS304L	44	305	APEA
Intercooler 2	P&F	3 019	37	179	5,6	124	SS304L	38	239	APEA
Intercooler 3	P&F	2 852	37	168	11,3	125	SS304L	36	236	APEA
Intercooler 4	P&F	2 953	38	171	25,3	126	SS304L	40	259	APEA
Intercooler 5	P&F	3 134	41	167	34,3	133	SS304L	40	266	APEA
Intercooler 6	P&F	8 746	48	403	91,3	146	SS304L	102	463	APEA

DESCRIPTION	TYPE	SIZE	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Fin		(kW)	barg	°C		k€2014	k€2014	
LT heat exchanger 1 (4 streams)	P&Fin	15 530	24,8	-55	SS304L	824	1 030	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Pumps		(m3/h)	(kW)	barg	°C		k€2014	k€2014	
Liquid CO2 pump	Centrifugal	303	291	119,9	65	SS304L	489	812	D4.4

DESCRIPTION	TYPE	SIZE				ABSORBENT MASS	DESIGN	DESIGN	MATERIAL	MATERIAL	EQUIPMENT	TOTAL DIRECT	COST
		Flow (DESIGN)	Water flow (DESIGN)	ID	Length	TOTAL	PRESSURE	TEMPERATURE		COST	COST	COST	SOURCE
Other Equipment	No. Of trains	(m3/s)	(kg/h)	(m)	(m)	(t)	barg	°C		k€2014	k€2014	k€2014	
Molecular sieve, single vessel dimensions	2	1,06	159,6	1,5	2,50	0,950	24,8	58	3A, SS304L	4	125	384	APEA + D4.4

6.3.2 IL20%

The equipment list of the CPU in the IL20% case is presented in Table 6.9.

Table 6.9: Equipment list for the CO_2 purification unit.

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	TEMPERATURE (IN)		COST	COST	SOURCE
Fans, Compressors and Expanders		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Compressor 1-4	Centrifugal, horizontal	108922	11886	1,8	25,3	56	SS304L	23644	25342	APEA
Compressor 5-6	Centrifugal, horizontal	7529	6192	12,2	91,3	48	SS304L	2791	3309	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
Water separator 1	Vertical	7,34	108922	4,9	19,5	1,8	56	SS304L	524	1002	APEA
Water separator 2	Vertical	1,57	49815	3,8	15,0	2,9	56	SS304L	266	633	APEA
Water separator 3	Vertical	0,73	22432	2,9	11,5	5,5	56	SS304L	185	494	APEA
Water separator 4	Vertical	0,33	10015	2,2	8,8	11,1	56	SS304L	146	377	APEA
Water separator 5	Vertical	0,15	4330	1,7	6,7	24,8	56	SS304L	139	284	APEA
Liquid CO2 separator	Vertical	148,3	248	1,6	6,5	24,8	-55	SS304L	123	373	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Frame		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Gas/gas heat exchanger 1	P&F	160	47	12	2,9	123	SS304L	4	95	APEA
Flue gas cooler before CPU	P&F	1 238	9	385	1,8	63	SS304L	78	363	APEA
Intercooler 1	P&F	3 662	35	232	2,9	119	SS304L	48	314	APEA
Intercooler 2	P&F	3 279	37	197	5,6	123	SS304L	41	245	APEA
Intercooler 3	P&F	3 093	37	184	11,3	124	SS304L	39	241	APEA
Intercooler 4	P&F	3 189	37	188	25,3	125	SS304L	43	265	APEA
Intercooler 5	P&F	3 487	42	182	34,3	134	SS304L	43	271	APEA
Intercooler 6	P&F	9 672	48	440	91,3	147	SS304L	111	477	APEA

DESCRIPTION	TYPE	SIZE	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Fin		(kW)	barg	°C		k€2014	k€2014	
LT heat exchanger 1 (4 streams)	P&Fin	16 992	24,8	-55	SS304L	862	1 078	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Pumps		(m3/h)	(kW)	barg	°C		k€2014	k€2014	
Liquid CO2 pump	Centrifugal	325	313	119,9	65	SS304L	519	862	D4.4

DESCRIPTION	TYPE	SIZE				ABSORBENT MASS	DESIGN	DESIGN	MATERIAL	MATERIAL	EQUIPMENT	TOTAL DIRECT	COST
		Flow (DESIGN)	Water flow (DESIGN)	ID	Length	TOTAL	PRESSURE	TEMPERATURE		COST	COST	COST	SOURCE
Other Equipment	No. Of trains	(m3/s)	(kg/h)	(m)	(m)	(t)	barg	°C		k€2014	k€2014	k€2014	
Molecular sieve, single vessel dimensions	2	1,20	179,1	1,6	2,49	1,066	24,8	58	3A, SS304L	5	133	394	APEA + D4.4

6.3.3 Ship transport

The equipment list of the CPU in the ship transport case is presented in Table 6.10.

Table 6.10: Equipment list for the CO_2 purification unit.

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	TEMPERATURE		COST	COST	SOURCE
Fans, Compressors and Expanders		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Centrifugal gas expander 1	CENT HORIZONTAL	597	368,0	24,4	6,2	128	SS304L	267	423	APEA
Centrifugal gas expander 2	CENT HORIZONTAL	2531	408,2	6,1	1,9	126	SS304L	285	432	APEA
Compressor 1-3	CENT HORIZONTAL	99209	11566,5	1,9	27,9	56	SS304L	23644	25343	APEA
Small recycle compressor	CENT HORIZONTAL	22124	7423,9	7,3	28,4	-57	SS304L	3316	4210	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014
Water separator 1	Vertical	5,98	99209	4,7	18,9	1,9	56	SS304L	483	958
Water separator 2	Vertical	1,78	32591	3,3	13,0	3,7	56	SS304L	231	566
Water separator 3	Vertical	0,58	10681	2,2	9,0	9,4	56	SS304L	137	368
Water separator 4	Vertical	0,19	3296	1,5	6,1	27,4	56	SS304L	112	251
Main CO2 separator	Vertical	453,88	303	2,3	9,2	25,3	-59	SS304L	281	634
CO2 purification separator	Vertical	128,47	22124	3,0	12,0	7,3	-57	SS304L	241	703

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Frame		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Vent gas heater	P&F	278	85	102,9	3,8	151	SS304L	23	213	APEA
Flue gas cooler	P&F	1 121	9	348,3	1,8	63	SS304L	78	337	APEA
Gas/gas heat exchanger 1	P&F	225	48	17,3	27,9	153	SS304L	5	119	APEA
Gas/gas heat exchanger 2	P&F	347	59	21,5	9,6	151	SS304L	6	121	APEA
Intercooler 1	P&F	4 530	37	269,1	3,8	144	SS304L	55	326	APEA
Intercooler 2	P&F	3 731	37	224,2	9,4	143	SS304L	47	311	APEA
Intercooler 3	P&F	3 942	38	228,2	27,4	148	SS304L	47	314	APEA

DESCRIPTION	TYPE	SIZE	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Fin		(kW)	barg	°C		k€2014	k€2014	
LT heat exchanger 1 (2 streams)	P&Fin	337	26,9	-59	SS304L	19	38	D4.4
LT heat exchanger 2 (2 streams)	P&Fin	31 315	26,5	-59	SS304L	1039	2 078	D4.4
CO2 subcooler	P&Fin	212	7,3	-60	SS304L	119	239	D4.4
Refrigerated cooler 1	P&Fin	16 844	26,1	-44	SS304L	1012	2 024	D4.4
Refrigerated cooler 2	P&Fin	4 869	25,7	-59	SS304L	399	798	D4.4

DESCRIPTION	TYPE	SIZE				ABSORBENT MASS	DESIGN	DESIGN	MATERIAL	MATERIAL	EQUIPMENT	TOTAL DIRECT	COST
		Flow (DESIGN)	Water flow (DESIGN)	ID	Length	TOTAL	PRESSURE	TEMPERATURE		COST	COST	COST	SOURCE
Other Equipment	No. Of trains	(m3/s)	(kg/h)	(m)	(m)	(t)	barg	°C		k€2014	k€2014	k€2014	
Molecular sieve, single vessel dimensions	2	0,92	151,9	1,4	2,55	0,904	27,4	56	SS304L	5	120	348	APEA + D4.4

DESCRIPTION	TYPE	SIZE		MATERIAL	EQUIPMENT	DIRECT	COST
		Power (DESIGN)	Output (DESIGN)		COST	COST	SOURCE
Generators		(kW)	(kVa)		k€2014	k€2014	
Electric generator (Gas expanders 1&2)		737	922	CS	1644	1849	APEA

7 CALCIUM LOOPING – INTEGRATED ENTRAINED FLOW CONFIGURATION

The project partners responsible for the process simulations and for compiling equipment lists for the calcium looping integrated entrained flow technology are listed in Table 7.1.

Table 7.1. Responsible project partners for process simulations and compilation of equipment lists for the calcium looping integrated entrained flow technology.

	Responsible partner
Process simulations	PoliMi (core process and steam cycle) SINTEF ER (CPU)
Equipment lists	PoliMi (core process and steam cycle) SINTEF ER (CPU)

7.1 Process flow diagram

The process flowsheet for calcium looping integrated entrained flow process is shown in Figure 7.1. Process flow diagrams of the CPU are identical to the calcium looping tail-end process and are given in Figure 6.2 for pipeline transport and in Figure 6.3 for ship transport.

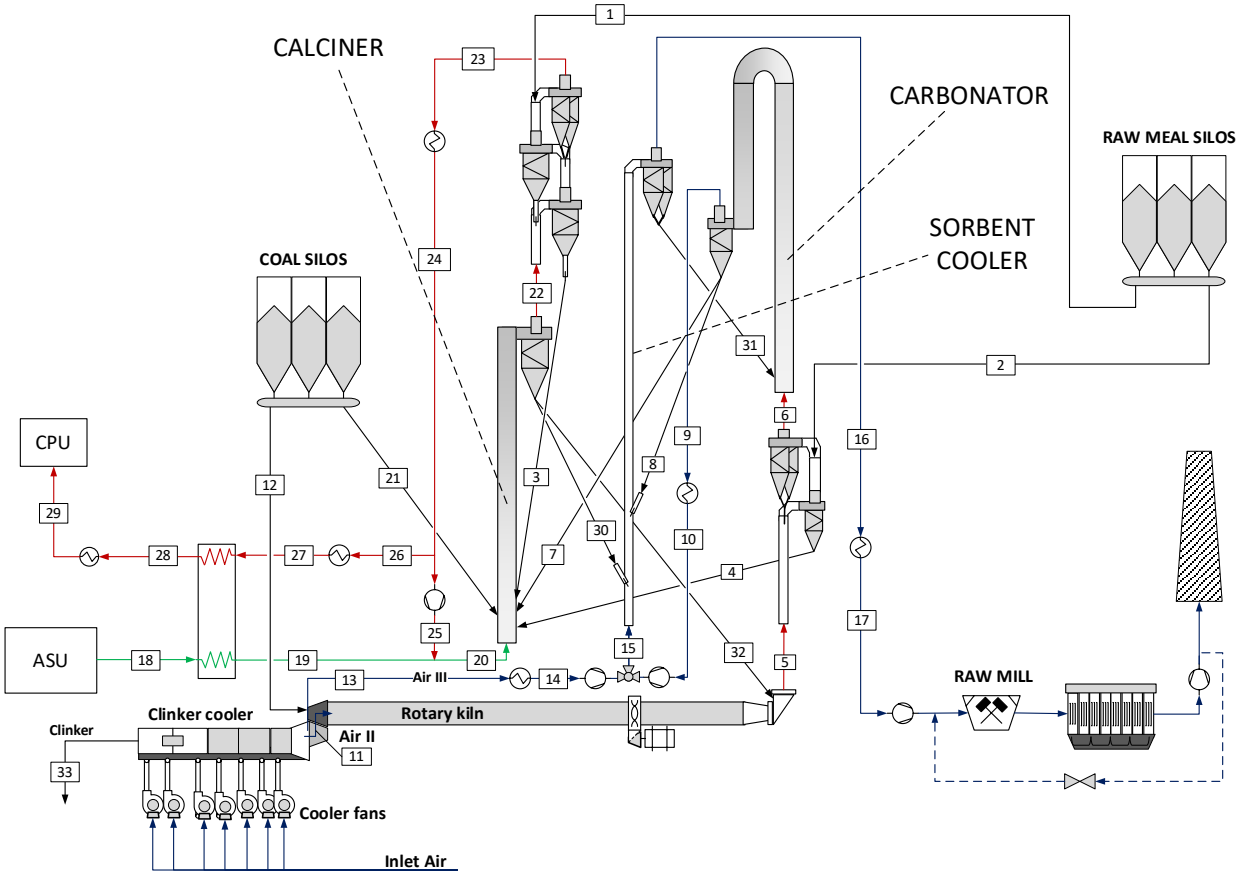

Figure 7.1. Process flowsheet of the integrated EF CaL process with entrained flow reactors.

7.2 Stream data

7.2.1 Base case

Stream data for the core process in the base case is given in Table 7.2. Stream data for the CPU is given in Table 7.3.

Table 7.2: Streams properties of base case 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													

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 (g)	52.33	112,273	361.4	1.11	1.67	62.18	8.74	1.18	26.22													
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 7.3. Main stream data for the CPU with pipeline transport in the calcium looping integrated entrained flow process in the base case.

#	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

7.2.2 Ship transport

The stream data for the core process is identical to the base case (*cf*. Table 7.2). The stream data for the CPU for ship transport is given in Table 7.4.

Table 7.4. Main stream data for the CPU with ship transport in the calcium looping integrated entrained flow process in the ship transport case.

#	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
14	1.00	28.00	25.23	3027.36	0.0142	0.9167	0.0000	0.0583
19	0.00	-54.00	23.13	10331.15	0.0110	0.9545	0.0000	0.0306
23	0.00	-54.98	6.10	2685.87	0.0004	0.9988	0.0000	0.0007
25	1.00	47.12	25.23	7654.13	0.0148	0.9390	0.0000	0.0411
26	1.00	100.18	22.21	350.34	0.1212	0.2890	0.0000	0.4982
32	1.00	70.00	1.05	350.34	0.1212	0.2890	0.0000	0.4982

7.3 Equipment list

The main components of the calcium looping integrated entrained flow process, including the heat recovery steam cycle, are shown in Figure 7.2. The equipment list for the core process in both the base case and the ship transport case is presented in Table 7.5.

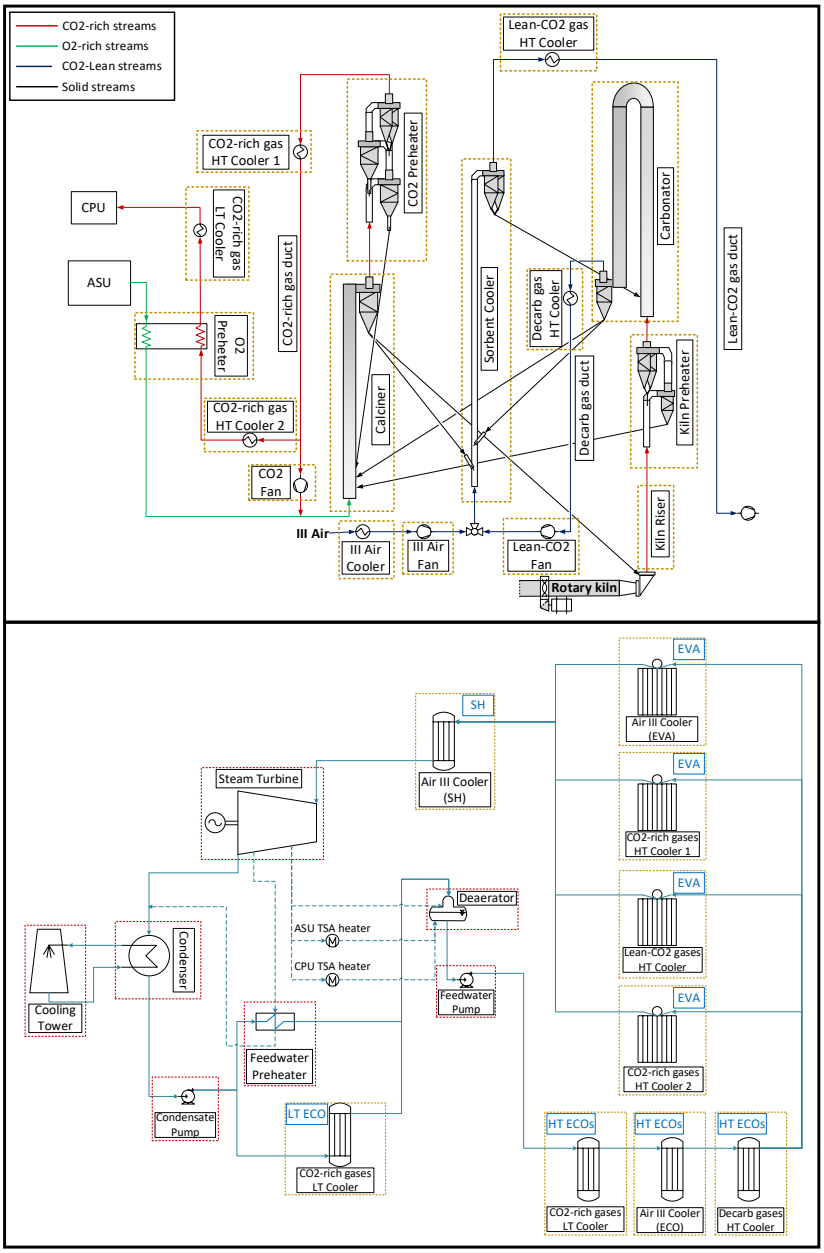

Figure 7.2: Main components of the Integrated EF CaL process with EF reactors (top) and of the heat recovery steam cycle (bottom).

Table 7.5: Equipment list of units shown in Figure 7.2.

Kiln risers	
Design volumetric flow, Nm^3/h	45,156
Design temperature, °C	1080
Diameter, m	2
Length, m	12
Thickness of steel, mm	12
Thickness of refractory, mm	200
TEC, k€	67.6
IC, k€	139.4

Ducts			
	Lean-CO_2 duct	**Decarb gas duct**	**CO_2-rich gas duct**
Type	Insulated	Refractory	Insulated
Design volumetric flow, Nm^3/h	121,076	39,446	75,058
Design temperature, °C	280	670	400
Design gas velocity, m/s	15	15	15
Diameter, m	2.3	1.8	2.1
Length, m	70	40	120
Steel, kg/m^2	90	90	90
Refractory/Insulation, kg/m^2	14	318	14
TEC, k€	190.3	160.4	261.9
IC, k€	265,9	285.7	444.9

Fans			
	CO_2 fan	**III Air fan**	**Lean-CO_2 fan**
Type	Sealed	Standard	Standard
Design flow rate, m^3/h	222,255	160,887	90,720
Head, kPa	11	4	8
Temperature, °C	400	265.2	265.2
Power, kW	847	229	278
MC, k€	182.4	52.8	39.6
EMC, k€	84.0	26.4	30.0
EIC, k€	79.9	23.8	20.9
OC, k€	52.0	15.4	13.6
TEC, k€	398.4	118.4	104.1
IC, k€	159.4	47.4	41.6

Reactors		
	Carbonator	**Calciner**
Type	Gooseneck - Refractory	Oxyfuel – Refractory
Volumetric flow, m^3/h – Nm^3/h	137,763 – 39,446	524,337 – 120,059
Outlet temperature, °C	668.3	920
Solid-gas ratio, kg/m^3 – kg/Nm^3	4.69 – 12.32	0.51 – 2.21
Diameter, m	1.8	3.5
Length, m	120	45
Thickness of steel, mm	12	25
Thickness of refractory, mm	150	200
TEC, k€	3,454.8	4,118.4
IC, k€	included in “Tower structure”	
Tower Structure, k€	**40,314.5**	

Suspension Preheater/Cooler			
	CO_2 Preheater	**Kiln Preheater**	**Sorbent cooler**
# Stages	3	2	1
1st stage	High efficiency	High efficiency	High efficiency
Gas mass flow rate, kg/s	77.24	17.06	40.06
Solid mass flow rate, kg/s	38.89	22.44	154.22
Design gas velocity, m/s	15	15	15
Inlet gas temperature, °C	804.7	749.8	273.7

Suspension Preheater/Cooler			
Inlet solid temperature, °C	60.0	60.0	742.9
Outlet temperature, °C	614.0	434.6	621.5
Solid-gas ratio, kg/m^3 – kg/Nm^3	0.23 – 0.90	0.47 – 1.93	1.48 – 4.93
Riser duct			
Diameter, mm	3470	1676	2970
Length, m	5	5	5
Thickness of refractory, mm	100	130	150
Steel, kg/m^2	80	80	80
Feed pipe			
Diameter, mm	1047	397	734
Length, m	10	10	10
Thickness of refractory, mm	100	130	150
Steel, kg/m^2	80	80	80
Cyclone			
# cyclones	2	2	2
Diameter, mm	5235	2833	3668
Height, m	6	4	4
Thickness of refractory, mm	100	130	150
Steel, kg/m^2	80	80	80
2nd stage	Standard efficiency	Standard efficiency	
Gas mass flow, kg/s	77.24	17.06	
Solid mass flow, kg/s	42.58	24.19	
Design gas velocity, m/s	15	15	
Inlet temperature of gas, °C	885.0	1078.5	
Inlet temperature of solid, °C	614.0	434.6	
Outlet temperature, °C	804.7	749.8	
Solid-gas ratio, kg/m^3 – kg/Nm^3	0.23 – 0.99	0.38 – 1.93	
Riser duct			
Diameter, mm	3819	2010	
Length, m	5	5	
Thickness of refractory, mm	180	200	
Steel, kg/m^2	80	80	
Feed pipe			
Diameter, mm	916	639	
Length, m	10	10	
Thickness of refractory, mm	180	200	
Steel, kg/m^2	80	80	
Cyclone			
# cyclones	1	1	
Diameter, m	6540	4566	
Height, m	8	6	
Thickness of refractory, mm	180	200	
Steel, kg/m^2	80	80	
3rd stage	Standard efficiency		
Gas mass flow, kg/s	77.24		
Solid mass flow, kg/s	40.91		
Design gas velocity, m/s	15		
Inlet temperature of gas, °C	920.0		
Inlet temperature of solid, °C	804.7		
Outlet temperature, °C	885.0		
Solid-gas ratio, kg/m^3 – kg/Nm^3	0.22 – 0.95		
Riser duct			
Diameter, mm	4018		
Length, m	5		
Thickness of refractory, mm	200		
Steel, kg/m^2	80		
Feed pipe			
Diameter, mm	934		

Suspension Preheater/Cooler			
Length, m	10		
Thickness of refractory, mm	200		
Steel, kg/m^2	80		
Cyclone			
# cyclones	1		
Diameter, mm	6673		
Height, m	8		
Thickness of refractory, mm	200		
Steel, kg/m^2	80		
TEC, k€	500.4	150.3	402.4
IC, k€	846.2	255.7	included in "Tower structure"

Pumps		
	Condensate pump	**Feedwater pump**
Type	Multistage centrifugal	Multistage centrifugal
Design flow rate, kg/s	31.24	25.28
Head, m H_2O	198.1	975.4
Electricity absorption, kW	75.75	327.7
TEC, k€	95.9	177.1
IC, k€	2.5	5.9

Deaerator	
Type	Tank Car
Design feedwater mass flow, kg/s	24.02
Design pressure, bar	3.89
Design temperature, °C	142.6
Total storage volume, l	10922
Overall height, m	4.665
Overall length, m	4.841
Storage tank	
-Thickness, mm	11.11
-Outer diameter, m	1.896
-Total length, m	4.841
Heater	
-Thickness, mm	11.11
-Outer diameter, m	1.896
-Total length, m	2.464
TEC, k€	143.0
IC, k€	10.7

Condenser	
Type	Shell & tube
Design heat rejection, MW	49.3
Design pressure, bar	0.07
Design temperature, °C	39.03
Non-condensable removal system,	Vacuum Pump
Water depth in hotwell, m	0.45
Volume water stored in hotwell, l	7,080
Condenser Tube	
-Material,	Stainless steel
-Length, m	6.7
-Outside diameter, m	25.4

-Thickness, mm	0.71
Condenser Shell	
-Material,	Carbon steel
-Thickness, mm	9.5
-Length x Width x Height, m	8.4 x 2.3 x 4.0
TEC, k€	486.2
IC, k€	139.6
Cooling Tower	
Type	Crossflow, Film Fill
Design heat rejection, MW	49.4
Total number of cells in tower	4
Number of rows	1
Length per row, m	32.09
Length per cell, m	8.02
Width at top of cell, m	9.03
Width at bottom of cell, m	7.05
Height, m	7.86
Basin area, m^2	285.1
Fan diameter, m	5.35
TEC, k€	641.9
IC, k€	283.0
Steam Turbine and electric generator	
Type	Condensing, Non-Reheat
Design capacity, MVA	27.9
Throttle Pressure, bar	63.0
Throttle Temperature, °C	460.0
Throttle Mass flow, kg/s	24.02
Exhaust End Type	Down Draft
Number of stages,	18
Generator Power, MW	23.88
Generator Efficiency, %	97.65
Overall Steam Turbine and Generator Length, m	11.94
Overall Steam Turbine and Generator Width, m	3.51
Overall Steam Turbine and Generator Weight, kg	102,100
Foundation Length, m	13.58
Foundation Width, m	4.2
TEC, k€	5,460.5
IC, k€	584.0
CO2 Compression and Purification Unit	
TEC, k€	28,911
IC, k€	6,712
ASU	
Oxygen producted, tpd	1,163.4
TEC+IC, k€	39,863

Heat exchangers									
	III Air Cooler SH	**III Air Cooler EVA**	**III Air Cooler ECO**	**Decarb gas HT Cooler**	**Lean-CO_2 gas HT Cooler**	**CO_2-rich gases HT cooler 1**	**CO_2-rich gases HT cooler 2**	**CO_2-rich gases LT cooler**	**O_2 preheater**
Type	Bare Tube	Bare Tube	Bare Tube	Bare Tube	Bare Tube	Bare Tube	Bare Tube	Bare Tube	Bare Tube
Design point gas temperature, °C	1,049.8	630.2	347.4	668.3	621.5	614.0	400.0	283.3	320.4
Design point operating pressure, bar	65.2	65.2	76.6	81.6	65.2	65.2	66.8	13.6	1.036
Area, m^2	273.6	499.6	452.1	332.8	343.4	897.6	385.5	2328.9	201.7
Duty, MW	13.2	8.3	2.3	9.4	8.3	20.3	3.4	8.9	1.5
Material	T91	Carbon Steel	Carbon Steel	T22	Carbon Steel	Carbon Steel	Carbon Steel	Carbon Steel	Stainless Steel
Weight, kg	4,270	7,800	6,380	4,030	5,360	14,020	5,410	50,300	1,170
Surface cost, k€	44.8	23.4	19.1	24.2	16.1	42.1	16.2	150.9	8.2
Auxiliary equipment cost, k€	44.8	23.4	19.1	24.2	16.1	42.1	16.2	150.9	8.2
TEC, k€	89.7	46.8	38.3	48.4	32.2	84.1	32.5	301.8	16.4
IC, k€	22.4	11.7	9.6	12.1	8.0	21.0	8.1	75.5	4.1

7.3.1 Base case

The equipment list of the CPU in the base case is presented in Table 7.6.

Table 7.6: Equipment list for the CO_2 purification unit.

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	TEMPERATURE (IN)		COST	COST	SOURCE
Fans, Compressors and Expanders		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Compressor 1-4	Centrifugal, horizontal	86893	9453	1,8	24,2	56	SS304L	23451	25016	APEA
Compressor 5-6	Centrifugal, horizontal	6203	5037	12,2	91,3	49	SS304L	2681	3144	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
Water separator 1	Vertical	5,40	86879	4,5	18,1	1,8	56	SS304L	398	815	APEA
Water separator 2	Vertical	1,25	39826	3,5	13,9	2,9	56	SS304L	253	592	APEA
Water separator 3	Vertical	0,58	17975	2,7	10,7	5,4	56	SS304L	179	481	APEA
Water separator 4	Vertical	0,26	8044	2,0	8,2	10,8	56	SS304L	117	330	APEA
Water separator 5	Vertical	0,12	3488	1,5	6,2	23,7	56	SS304L	102	241	APEA
Liquid CO2 separator	Vertical	118,4	198	1,5	6,0	23,7	-55	SS304L	97	340	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Frame		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Gas/gas heat exchanger 1	P&F	126	47	10	3,0	123	SS304L	4	94	APEA
Flue gas cooler before CPU	P&F	984	9	306	1,8	63	SS304L	63	316	APEA
Intercooler 1	P&F	2 914	30	214	3,0	119	SS304L	45	307	APEA
Intercooler 2	P&F	2 609	31	185	5,5	123	SS304L	39	241	APEA
Intercooler 3	P&F	2 460	31	174	11,0	124	SS304L	37	238	APEA
Intercooler 4	P&F	2 534	32	177	24,2	125	SS304L	37	239	APEA
Intercooler 5	P&F	2 816	35	179	33,5	136	SS304L	43	271	APEA
Intercooler 6	P&F	7 802	38	449	91,3	148	SS304L	113	482	APEA

DESCRIPTION	TYPE	SIZE	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Fin		(kW)	barg	°C		k€2014	k€2014	
LT heat exchanger 1 (4 streams)	P&Fin	13 575	23,7	-55	SS304L	714	1 429	D4.4

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Pumps		(m3/h)	(kW)	barg	°C		k€2014	k€2014	
Liquid CO2 pump	Centrifugal	259	249	119,9	65	SS304L	428	710	D4.4

DESCRIPTION	TYPE	SIZE				ABSORBENT MASS	DESIGN	DESIGN	MATERIAL	EQUIPMENT	TOTAL DIRECT	COST
		Flow (DESIGN)	Water flow (DESIGN)	ID	Length	TOTAL	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Other Equipment	No. Of trains	(m3/s)	(kg/h)	(m)	(m)	(t)	barg	°C		k€2014	k€2014	
Molecular sieve, single vessel dimensions	2	0,97	143,8	1,4	2,49	0,856	23,7	58	3A, SS304L	112	338	APEA + D4.4

7.3.2 Ship transport

The equipment list of the CPU in the ship transport case is presented in Table 7.7.

Table 7.7: Equipment list for the CO_2 purification unit.

DESCRIPTION	TYPE	SIZE		DESIGN	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Flow (DESIGN)	Power (DESIGN)	INLET PRESSURE	OUTLET PRESSURE	TEMPERATURE		COST	COST	SOURCE
Fans, Compressors and Expanders		(m3/h)	(kW)	barg	barg	°C		k€2014	k€2014	
Centrifugal gas expander 1	CENT HORIZONTAL	530	327	24,4	6,2	128	SS304L	248	404	APEA
Centrifugal gas expander 2	CENT HORIZONTAL	2250	363	6,1	1,9	126	SS304L	255	465	APEA
Compressor 1-3	CENT HORIZONTAL	86867	10128	1,8	27,9	56	SS304L	23543	25104	APEA
Recycle compressor	CENT HORIZONTAL	21808	7316	7,3	27,4	-57	SS304L	3311	4205	APEA

DESCRIPTION	TYPE	SIZE				DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Liq Flow (DESIGN)	Gas Flow (DESIGN)	ID	H	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Tanks & Vessels		(m3/h)	(m3/h)	(mm)	(mm)	barg	°C		k€2014	k€2014	
Water separator 1	Vertical	5,38	86867	4,5	18,1	1,8	56	SS304L	398	815	APEA
Water separator 2	Vertical	1,56	28537	3,1	12,5	3,7	56	SS304L	213	545	APEA
Water separator 3	Vertical	0,51	9353	2,1	8,6	9,4	56	SS304L	118	333	APEA
Water separator 4	Vertical	0,17	2887	1,5	5,8	27,4	57	SS304L	109	247	APEA
Main CO2 separator	Vertical	432,94	269	2,3	9,1	25,3	-59	SS304L	290	642	APEA
CO2 purification separator	Vertical	112,32	21808	3,0	11,9	7,3	-57	SS304L	240	702	APEA

DESCRIPTION	TYPE	SIZE			DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	LMTD	Area (Design)	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Frame		(kW)	(K)	(m2)	barg	°C		k€2014	k€2014	
Vent gas heater	P&F	247	85	91,5	3,8	151	SS304L	20	209	APEA
Flue gas cooler	P&F	983	9	305,4	1,8	63	SS304L	62	316	APEA
Gas/gas heat exchanger 1	P&F	199	48	15,3	27,9	153	SS304L	5	133	APEA
Gas/gas heat exchanger 2	P&F	309	59	19,1	9,6	151	SS304L	6	119	APEA
Intercooler 1	P&F	3 963	37	235,5	3,8	144	SS304L	49	315	APEA
Intercooler 2	P&F	3 262	37	196,2	9,4	142	SS304L	41	245	APEA
Intercooler 3	P&F	3 449	38	199,8	27,4	147	SS304L	47	278	APEA

DESCRIPTION	TYPE	SIZE	DESIGN	DESIGN	MATERIAL	EQUIPMENT	DIRECT	COST
		Duty	PRESSURE	TEMPERATURE		COST	COST	SOURCE
Heat Exchangers - Plate & Fin		(kW)	barg	°C		k€2014	k€2014	
LT heat exchanger 1 (2 streams)	P&Fin	301	26,9	-59	SS304L	15	30	D4.4
LT heat exchanger 2 (2 streams)	P&Fin	30 924	26,5	-59	SS304L	1064	2 129	D4.4
CO2 subcooler	P&Fin	186	7,3	-60	SS304L	111	222	D4.4
Refrigerated cooler 1	P&Fin	15 125	26,1	-44	SS304L	658	1 316	D4.4
Refrigerated cooler 2	P&Fin	4 603	25,7	-59	SS304L	387	774	D4.4

DESCRIPTION	TYPE	SIZE				ABSORBENT MASS	DESIGN	DESIGN	MATERIAL	MATERIAL	EQUIPMENT	TOTAL DIRECT	COST
		Flow (DESIGN)	Water flow (DESIGN)	ID	Length	TOTAL	PRESSURE	TEMPERATURE		COST	COST	COST	SOURCE
Other Equipment	No. Of trains	(m3/s)	(kg/h)	(m)	(m)	(t)	barg	°C		k€2014	k€2014	k€2014	
Molecular sieve, single vessel dimensions	2	0,80	133,0	1,3	2,55	0,792	30,0	56	SS304L	5	114	341	APEA + D4.4

DESCRIPTION	SIZE		MATERIAL	EQUIPMENT	DIRECT	COST
	Power (DESIGN)	Output (DESIGN)		COST	COST	SOURCE
Generators	(kW)	(kVa)		k€2014	k€2014	
Electric generator (Gas expanders 1&2)	656	820	CS	1532	1734	APEA