CHAPTER 4

TESTING

4.1   Aim of the test

The aim of the model testing is to compare the ELC and ULC treatments of the model to the industrial practice. The model is mainly compared desulfurization, denitrogenization, decarburization, treatment time and temperature during the treatment. The test is carried out in the steel plant at Dillinger Huette GTS in Dillingen Germany.

4.2   Description of the vacuum tank degassing unit (TD) at Dillinger Huette GTS

Desulfurization, denitrogenization and decarburization are mainly carried out in the tank degassing unit, therefore the main consideration of the test is emphasized on this unit.

The vacuum tank degassing unit is located in a 185 t BOF steel shop. The steel shop is equipped with a bottom stirred LD converter and two continuous slab casting machines. The tank degassing unit is composed of several auxiliary installations, such as an oxygen lance with a blowing rate of 25 m^3/min, temperature and sampling devices, alloy addition under vacuum and normal atmosphere, and three wire feeders for aluminium and cored wires. Bunkers for trimming alloys and cooling scrap are situated with the pillar line of the hall. The vacuum treatment is carried out in a basic carbon-bonded dolomite ladle. In the slag zone of the wall, refractory bricks with 10% carbon-magnesite are used. The freeboard area is lined with fired dolomite. A high rate of metal/slag reaction as well as degassing is achieved by an intensive stirring of the melt via 3 porous plugs in the bottom of the ladle. The maximum stirring rate of argon is 1.8 m^3/min. The schematic Figure of TD is shown in Figure 4.1.
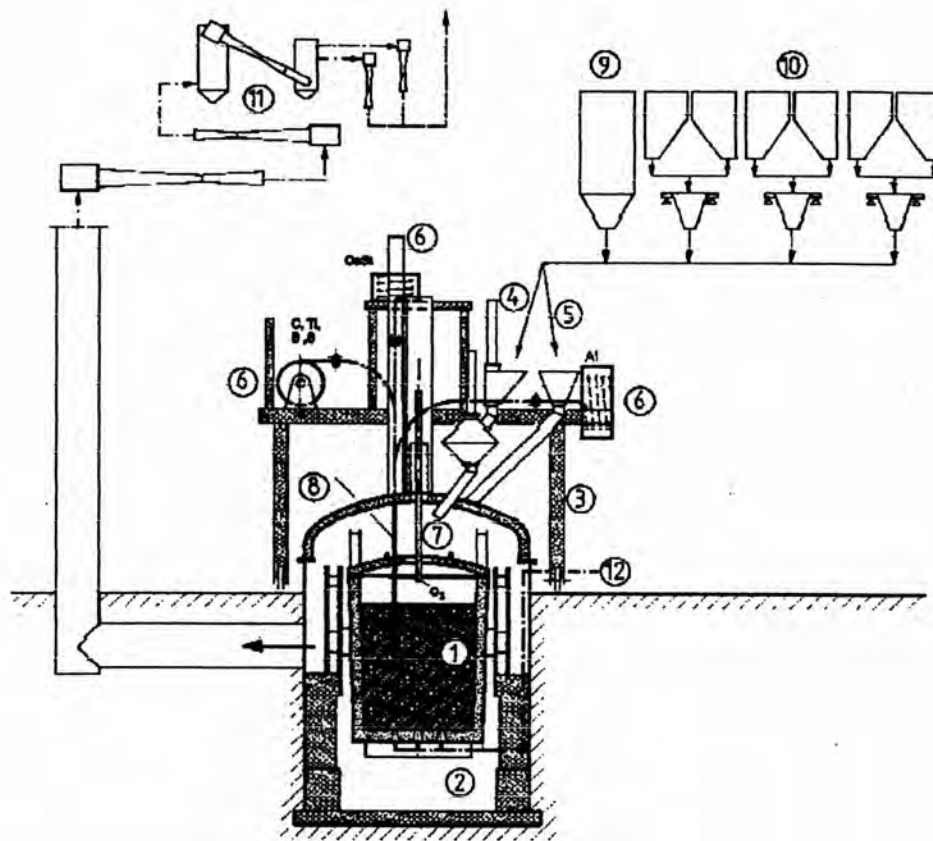
① Covered steel ladle
② Vacuum vessel
③ Cover car
④ Alloy feed vacuum locks
⑤ Alloy and cooling agent additions
⑥ Wire feeding machines

⑦ O_2 Blowing lance
⑧ Sampling and temperature lance
⑨ Cooling agent bunkers
⑩ Alloying agent bunkers
⑪ Steam jet pump
⑫ Ladle bottom stirring

Figure 4.1   Schematic arrangement installation of TD at Dillinger Huette

GTS [58]

4.3 Testing performance

In comparison, two steel grades are selected to test the model's foundation.

1) Steel grade F56NBV is selected to consider desulfurization, denitrogenization as well as temperature drop during treatment.

2) Steel grades T41Ti is selected to consider decarburization and temperature drop during treatment.

The compositions of F56NBV and T41Ti as well as the composition of ELC and ULC are shown in Table 4.1.

Table 4.1   Compositions of considered steel grades

steel grades		C	Si	Mn	P	S	Al	N	V	Nb	Ti
ELC - model		0.050	0.150	0.300	0.008	0.0100	0.040	0.0040	-	-	-
F56NBV	min	0.072	0.300	1.520	0.000	0.0000	0.020	0.0000	0.040	0.032	-
	max	0.085	0.350	1.600	0.015	0.0015	0.050	0.0090	0.050	0.038	-
ULC - model		0.005	0.030	0.150	0.009	0.0050	0.045	0.0035	-	-	-
T41Ti	min	0.000	0.000	0.090	0.000	0.0000	0.020	0.0000	-	-	0.060
	max	0.004	0.030	0.180	0.012	0.0120	0.050	0.0050	-	-	0.080

Industrial practical data of F56NBV and T41Ti are recorded as follows:

1)   Amount of flux and alloy additions

2)   Steel temperature measurement at the time of:

2.1)   before tapping (BOF)

2.2)   before vacuum treatment (TD)

2.3)   after vacuum treatment (TD)

2.4)   during casting (tundish)

3)   Steel analysis at the time of:

3.1)   before tapping (BOF)

3.2)   before vacuum treatment (TD)

3.3)   after vacuum treatment (TD)

3.4)   during casting (mold)

4)   Slag analysis at the time of:

4.1)   before tapping (BOF)

4.2)   before vacuum treatment (TD)

4.4   Recorded data

The complete data of T41Ti and F56NBV from the time at ready tapping to casting, are listed in the appendix (Table A1-A11, B1-B12).

The considered data will be compared with the model's foundation as follows:

4.4.1   Desulfurization of F56NBV

Sample S1-S12 represent sulfur contents, the amount of CaO addition and percent CaO in the slag before vacuum treatment as well as degree of desulfurization of F56NBV as shown in Table 4.2 and Figure 4.2.

Table 4.2   Sulfur contents, CaO addition, percent CaO in the slag before

vacuum treatment and degree of desulfurization of F56NBV

| sample	%S tapping	%S before vacuum	%S after vacuum	%S during casting	CaO addition (kg)	%CaO in slag before vacuum	%deS before vacuum	%deS during vacuum	%deS overall
S1	0.0156	0.0113	0.0010	0.0011	1340	58.59	27.6	91.2	93.6
S2	0.0207	0.0147	0.0019	0.0016	1290	58.93	29.0	87.1	90.8
S3	0.0211	0.0081	0.0020	0.0015	1390	57.54	61.6	75.3	90.5
S4	0.0213	0.0089	0.0009	0.0012	1389	58.50	58.2	89.9	95.8
S5	0.0235	0.0157	0.0009	0.0011	1310	60.60	33.2	94.3	96.2
S6	0.0224	0.0099	0.0012	0.0013	1501	59.04	55.8	87.9	94.6
S7	0.0242	0.0081	0.0013	0.0014	1446	57.30	66.5	84.0	94.6
S8	0.0239	0.0130	0.0010	0.0010	1400	60.27	45.6	92.3	95.8
S9	0.0199	0.0115	0.0008	0.0008	1302	58.56	42.2	93.0	96.0
S10	0.0223	0.0159	0.0009	0.0009	1290	60.54	28.7	94.3	96.0
S11	0.0259	0.0102	0.0010	0.0008	1709	58.53	60.6	90.2	96.1
S12	0.0257	0.0078	0.0010	0.0008	1439	59.13	69.6	87.2	96.1
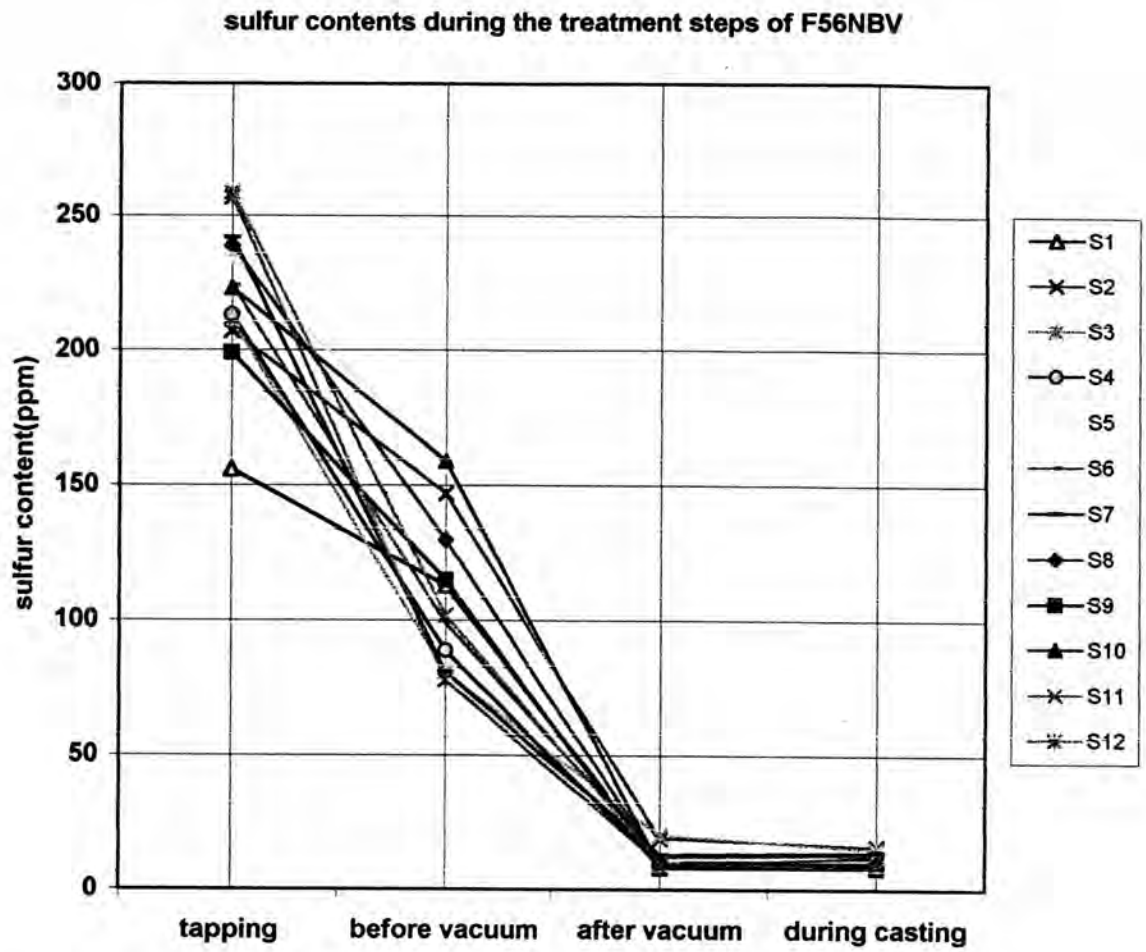
Figure 4.2   Sulfur content during the treatment steps of F56NBV

4.4.2   Denitrogenization of F56NBV

Samples N1-N12 represent nitrogen contents as well as degree of denitrogenization of F56NBV as shown in Table.4.3 and Figure 4.3.

Table 4.3   Nitrogen contents and degree of denitrogenization of

F56NBV

sample	%N tapping	%N before vacuum	%N after vacuum	during casting	%deN at TD
N1	0.0019	0.0045	0.0033	0.0047	26.7
N2	0.0027	0.0046	0.0037	0.0043	19.6
N3	0.0024	0.0060	0.0038	0.0048	36.7
N4	0.0025	0.0045	0.0034	0.0037	24.4
N5	0.0029	0.0052	0.0027	0.0039	48.1
N6	0.0032	0.0061	0.0041	0.0043	32.8
N7	0.0039	0.0067	0.0043	0.0045	35.8
N8	0.0033	0.0063	0.0043	0.0048	31.7
N9	0.0028	0.0049	0.0037	0.0039	24.5
N10	0.0025	0.0044	0.0033	0.0035	25.0
N11	0.0027	0.0067	0.0041	0.0042	38.8
N12	0.0025	0.0052	0.0034	0.0037	34.6

nitrogen contents during the treatment steps of F56NBV

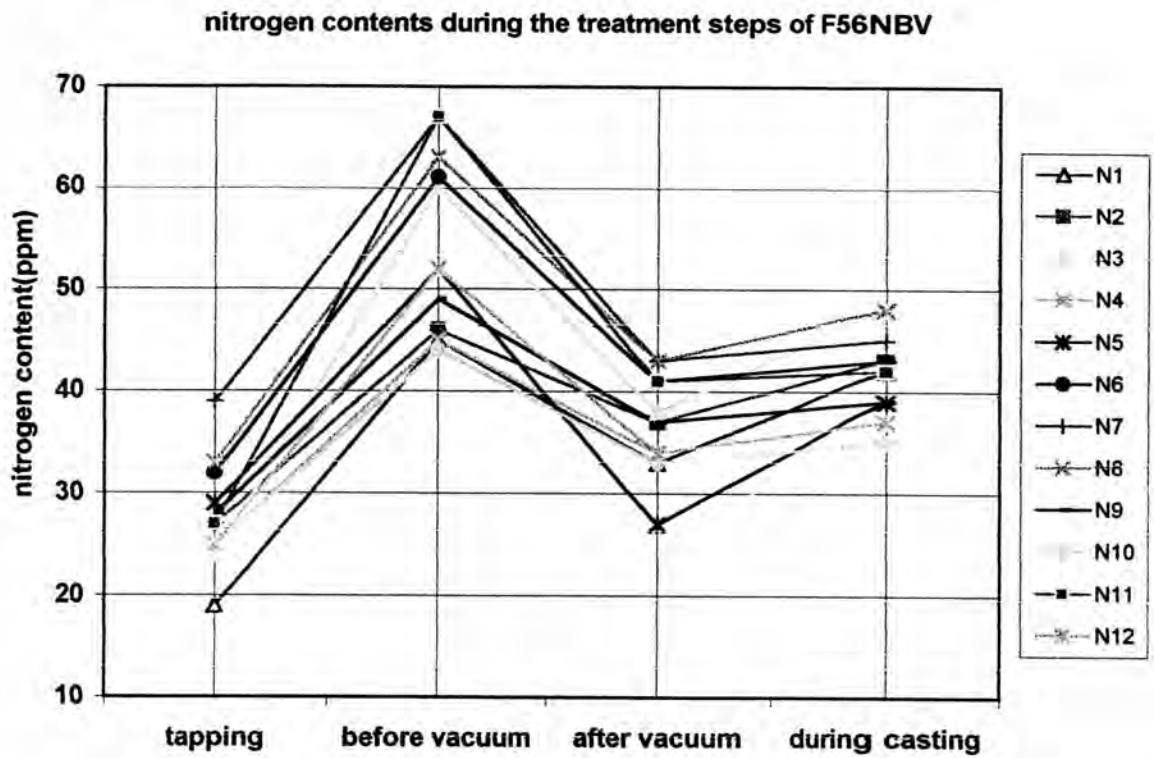Figure 4.3   Nitrogen contents during the treatment steps of F56NBV

4.4.3   Decarburization of T41Ti

Samples C1-C11 represent carbon and oxygen contents as well as the

amount of carbon addition of T41Ti as shown in Table 4.4 and Figure 4.4.

Table 4.4   Carbon and oxygen contents and the amount of carbon

addition of   T41Ti

Sample	%C before tapping	ppmO before tapping	C addition (kg)	%C before vacuum	ppmO before vacuum	%C after vacuum	%C during casting
C1	0.020	759	15	0.014	519	0.003	0.004
C2	0.019	816	20	0.018	533	0.003	0.003
C3	0.021	901	30	0.019	522	0.002	0.003
C4	0.027	738	15	0.026	485	0.003	0.003
C5	0.025	703	10	0.020	541	0.003	0.004
C6	0.030	660	0	0.020	591	0.003	0.004
C7	0.028	574	0	0.017	429	0.004	0.004
C8	0.021	700	0	0.010	565	0.002	0.004
C9	0.022	853	0	#	531	0.003	0.004
C10	0.032	700	20	0.032	433	0.002	0.004
C11	0.021	#	20	#	627	0.003	0.004

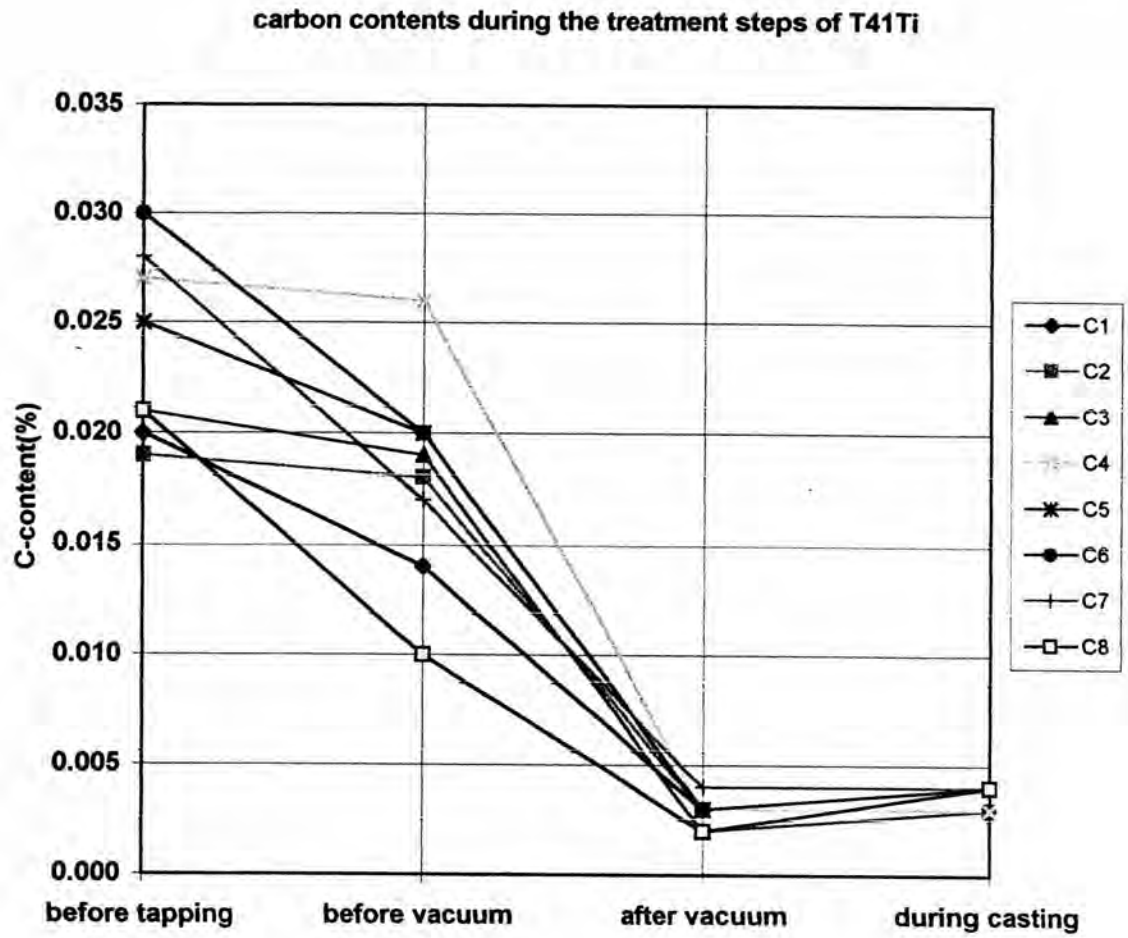**carbon contents during the treatment steps of T41Ti**

Figure 4.4   Carbon contents during the treatment steps of T41Ti.

4.4.4 Temperature drop during the time period from tapping to before vacuum treatment of F56NBV

Samples S1-S12 represent temperature, amount of additions as well as aluminium content before vacuum treatment of F56NBV during the considered time period as shown in Table 4.5.

Table 4.5 Temperature drop, amount of additions and aluminum content of F56NBV during the period from tapping to before vacuum treatment

| sample | time from T-tapping to T-vacuum(min) | T-tapping (°C) | T-before vacuum (°C) | delta T | Addition | | | | | | | | [%Al] before vacuum |
					CaO (kg)	Al-dp. (kg)	MnAf (kg)	MgO (kg)	FeMn (kg)	SiMn (kg)	FeV (kg)	FeNb (kg)	
S1	29	1716	1635	81	1340	279	296	75	786	2268	79	82	0.048
S2	27	1678	1607	71	1290	297	318	75	862	2276	82	87	0.053
S3	21	1731	1654	77	1390	299	328	75	858	2254	82	82	0.029
S4	37	1701	1612	89	1300	284	264	75	878	2258	84	86	0.040
S5	37	1698	1612	86	1310	289	248	75	884	2278	78	88	0.057
S6	33	1696	1603	93	1300	286	222	76	856	2232	81	81	0.045
S7	26	1698	1616	82	1290	291	462	75	786	2254	80	85	0.038
S8	23	1703	1633	70	1400	294	376	75	808	2252	83	81	0.044
S9	32	1695	1614	81	1250	295	312	75	880	2292	81	84	0.048
S10	31	1686	1606	80	1290	295	408	75	802	2282	78	87	0.062
S11	29	1731	1639	92	1550	298	510	75	746	2552	82	83	0.021
S12	33	1694	1612	82	1380	292	602	75	606	2268	77	85	0.038

4.4.5 Temperature drop at tank degassing unit of F56NBV

Samples S1-S12 represent temperature and amount of additions of F56NBV during the considered time period as shown in Table 4.6.

Table 4.6   Temperature drop and amount of additions of F56NBV at tank degassing unit

sample	time from T-before vacuum to T-after vacuum(min)	T-before vacuum (°C)	T-after vacuum (°C)	delta T	CaO (kg)	Al-dp (kg)	C (kg)	scrap (kg)	sand (kg)	FeMn (kg)	FeSi (kg)
S1	21	1635	1602	33	0	99	18	1510	58	157	141
S2	19	1607	1586	21	0	89	0	0	46	250	211
S3	19	1654	1625	29	0	204	0	0	0	180	224
S4	20	1612	1578	34	89	139	0	1590	0	181	206
S5	20	1612	1581	31	0	101	0	1060	110	246	204
S6	18	1603	1582	21	201	134	0	0	0	199	194
S7	18	1616	#	#	156	130	0	0	48	65	194
S8	21	1633	1592	41	0	111	0	2190	32	175	199
S9	22	1614	1585	29	52	157	0	1040	0	140	127
S10	20	1606	1585	21	0	145	0	0	113	115	133
S11	22	1639	1592	47	159	259	0	2000	0	111	147
S12	21	1612	1585	27	59	203	0	810	0	0	123

4.4.6   Temperature drop during the time period from tapping to before

vacuum treatment of T41Ti

Samples C1-C11 represent temperature and amount of additions of

T41Ti during the considered time period as shown in Table 4.7.

Table 4.7   Temperature drop and amount of additions of T41Ti during

the time period from tapping to before vacuum treatment

					Addition		
sample	time from T-tapping to T-before vacuum(min)	T tapping (°C)	T before vacuum (°C)	deltaT	C (kg)	MgO (kg)	ElMn (kg)
C1	32	1694	1627	67	15	150	60
C2	19	1681	1630	51	20	150	70
C3	11	1711	1675	36	30	160	0
C4	42	1698	1629	69	15	160	0
C5	17	1694	1643	51	10	145	0
C6	22	1698	1649	49	0	150	0
C7	27	1686	1620	66	0	150	0
C8	16	1695	1651	44	0	150	0
C9	37	1715	1641	74	25	150	0
C10	24	1693	1637	56	20	150	50
C11	18	1702	1648	54	20	150	0

4.4.7   Temperature drop at tank degassing unit of T41Ti

Samples C1-C11 represent temperature and amount of additions of T41Ti during the considered time period as shown in Table 4.8.

Table 4.8   Temperature drop and amount of additions of T41Ti at vacuum tank degassing unit

sample	time from T-before vacuum to T-after vacuum	T before vacuum (°C)	T after vacuum (°C)	delta T	Addition		
					Al (kg)	CaO (kg)	scrap (kg)
C1	32	1627	1611	16	150	400	
C2	34	1630	1613	17	166	399	
C3	32	1633	1617	16	158	400	
C4	33	1622	1605	17	151	401	
C5	33	1643	1619	24	163	401	
C6	30	1649	1628	21	180	401	
C7	34	1620	1595	25	145	403	
C8	31	1651	1613	38	192	749	
C9	33	1642	1625	17	209	748	
C10	37	1637	1593	44	171	748	570
C11	32	1648	1614	34	241	749	