CHAPTER 5

DISCUSSIONS

5.1   Metallurgical treatment comparison

The comparison of metallurgical treatment is separated into 2 parts, one for ELC and the other for ULC.

1)   ELC comparison:

    1.1)   Vacuum desulfurization of the model is compared to F56NBV.

    1.2)   Vacuum denitrogenization of the model is compared to F56NBV.

2)   ULC comparison:

    2.1)   Vacuum decarburization of the model is compared to T41Ti.

    2.2)   Vacuum desulfurization of the model is compared to F56NBV.

    2.3)   Vacuum denitrogenization of the model is compared to F56NBV.

5.1.1 Desulfurization comparison

For desulfurization, a comparison of the model and the industrial tests concerning the amount and composition of slag are the topic. All samples which are taken from the steel grade F56NBV have reached the slag compositions near lime saturated index =1. The slag amounts of F56NBV can not be determined directly, but they can be estimated with the amount of slag carry over from the converter, remained slag in the ladle from the former heat and flux addition. The total amount of slag carry over from the converter and the remained slag in the ladle from the former heat is assumed to be 600 kg which contains approximately 55% CaO. From these approximation, the amount of ladle slag can be assumed as:

$$S_L.(\%CaO)_{bv} \quad = \quad (\%CaO)_{o,r} \times S_{o,r} + 100.x. \; kg \; CaO \; addition \quad (5.1)$$

where S_L = Slag weight in the ladle (kg)

$S_{o,r}$ = slag carry over + remained slag (about 600 kg.)

$(\%CaO)_{bv}$ = CaO in the slag before vacuum treatment (%)

$(\%CaO)_{o,r}$ = CaO in the slag from slag carry over and

remained slag (about 55%)

Substituting $S_{o,r}$, $(\%CaO)_{o,r}$ into Eq.(5.1), the amount of ladle slag (S_L) can be approximated by:

$$S_L = \frac{100.(330 + kg\ CaO\ addition)}{(\%CaO)_{bv}} \qquad (5.2)$$

Slag amounts of F56NBV (S1-S12), which are approximated by Eq.(5.2), are listed in the Table 5.1.

From desulfurization practice of the model foundation (Chapter 3.2.1), the desulfurization degree is determined by using Figure 3.3. With an assumed sulfur partition ratio of 1000 and the lime saturated slag with an saturation index of 1, the desulfurization degree can be determined as shown in the Table 5.1. The slag amount of the ELC and ULC 's model is also shown in Table 5.1.

Table 5.1   Slag amount and desulfurization degree of F56NBV, ELC and

                   ULC

	Industrial data of F56NBV						Calculation from model foundation		
Sample	initial sulfur(%)	final sulfur(%)	deS(%)	steel wt.(t)	CaO-addition (kg)	(%CaO) before vacuum	slag wt. (kg)	kg.slag/t.steel	deS(%) from model foundation
S1	0.0156	0.0010	93.6	187.2	1340	58.59	2850.3	15.2	94
S2	0.0207	0.0019	90.8	191.9	1290	58.93	2749.0	14.3	93
S3	0.0211	0.0020	90.5	183.5	1390	57.54	2989.2	16.3	94
S4	0.0213	0.0009	95.8	185.9	1389	58.5	2938.5	15.8	94
S5	0.0235	0.0009	96.2	187.6	1310	60.6	2706.3	14.4	94
S6	0.0224	0.0012	94.6	186.3	1501	59.04	3101.3	16.6	94
S7	0.0242	0.0013	94.6	182.7	1446	57.3	3099.5	17.0	94
S8	0.0239	0.0010	95.8	191	1400	60.27	2870.4	15.0	94
S9	0.0199	0.0008	96.0	188.9	1302	58.86	2772.7	14.7	94
S10	0.0223	0.0009	96.0	186.9	1290	60.54	2675.9	14.3	93
S11	0.0102	0.0010	90.2	187.2	1709	58.53	3483.7	18.6	95
S12	0.0257	0.0010	96.1	181.2	1439	59.13	2991.7	16.5	94
ELC model	0.1070	0.0100	90.7	180	1188	60	1980	11.0	90.7
ULC model	0.1070	0.0050	95.5	180	2376	60	3960	22.0	95.5

From Table 5.1, the slag amounts (which are approximated from CaO addition, slag carry over from BOF and remained slag in the ladle) varies between 14.3 - 18.6 kg/t.steel. These amounts of slag obtain desulfurization degree between 93% and 95%. The desulfurization degrees are nearly equal to industrial data occurring during the production of steel grade F56NBV. This means that, the assumption of desulfurization which used the desulfurization practice of the model foundation, are reliable.

The model calculated that 11 kg/t.steel of slag needs to be formed during the production of ELC and 22 kg/t.steel for the production of ULC. These amounts are not included the slag carry over from EAF and remaining slag in the ladle of the former heat, because the slag carry over and the remaining slag should be ideally minimized due to the phosphorus content in the slag carry over is very high and the sulfur content in the remaining slag is also very high. Eventually, the slag carry over from EAF and the remaining slag in the ladle are ignored to be included into the refining slag of the model foundation. Finally, it could be possible to performed 90.7% desulfurization by using the slag amount of 11 kg/t.steel and a desulfurization of 95.5% by using the slag amount 22 kg/t.steel.

5.1.2 Denitrogenization comparison

For denitrogenization a comparison between the F56NBV and denitrogenization practice of the model foundation is considered for only 5 samples which consist of the nitrogen contents before vacuum treatment not less than 60 ppm. Since the limitation of denitrogenization of the model foundation is inapplicable for less than 60 ppm of the nitrogen content before vacuum treatment. The nitrogen contents after vacuum denitrogenization of these 5 samples determined by using Figure 3.9 for 10 minutes of the vacuum period and a sulfur content of about 10 ppm is shown in the Table 5.2.

From Table 5.2, nitrogen contents after vacuum treatment which estimated from Figure 2.9 are very close to the industrial data. This means that denitrogenization of the model foundation is reliable and can be used to determine the vacuum denitrogenization time. Although the model is only applicable when the nitrogen content before vacuum treatment is in the range of 60 to 80 ppm, but there is no problem for the production route of EAF-LHF-VOD because the nitrogen content of the crude steel produced from EAF (electric arc furnace) is in the range of 70 to 80 ppm, which is normally 30 - 40 ppm higher than that from BOF (Basic Oxygen Furnace).

Table 5.2   Comparison of nitrogen content after vacuum treatment

between model foundation and the ndustrial data of F56NBV

| sample | Industrial data of | F56NBV | Model | difference |
	[%N] before vacuum	[%N] after vacuum	[%N] after vacuum (using Figure 3.9)	
N3	0.0060	0.0038	0.0038	0.0000
N6	0.0061	0.0041	0.0038	+0.0003
N7	0.0067	0.0043	0.0042	+0.0001
N8	0.0063	0.0043	0.0040	+0.0003
N11	0.0067	0.0041	0.0042	-0.0001

5.1.3   Decarburization comparison

Decarburization of ULC of model foundation is compared to decarburization of T41Ti in Figure 5.1.

Carbon content of T41Ti:

Carbon contents after tapping and adding carbon for deoxidation are about 200-450 ppm. Before the beginning of vacuum decarburization, carbon contents are about 120-320 ppm and after finish of vacuum decarburization, carbon contents

are in the range between 20 and 40 ppm. During casting, carbon contents of T41T1 increase slightly 2 to 10 ppm.

Carbon content of ULC:

During tapping of the crude steel, carbon and oxygen content of ULC was assumed to be 400 ppm and 600 ppm respectively. From the tapping time to the start of vacuum oxygen blowing, carbon decreases to approximately 350 ppm due to C-O evolution. Then, carbon is decreased to about 200 ppm at the end of vacuum oxygen blowing. Afterwards, only vacuum operation and argon purging are performed and carbon is finally decreased to about 30 ppm at the end of the vacuum deep decarburization period.

During tapping, carbon content of the model is 150-200ppm higher than T41Ti and still higher until oxygen blowing is finished. After oxygen blowing, the carbon content calculated by the model is in the range of carbon contents of T41Ti. Then the evolution of the carbon content of the model is comparable to the measured carbon amount in the T41Ti steel grade.
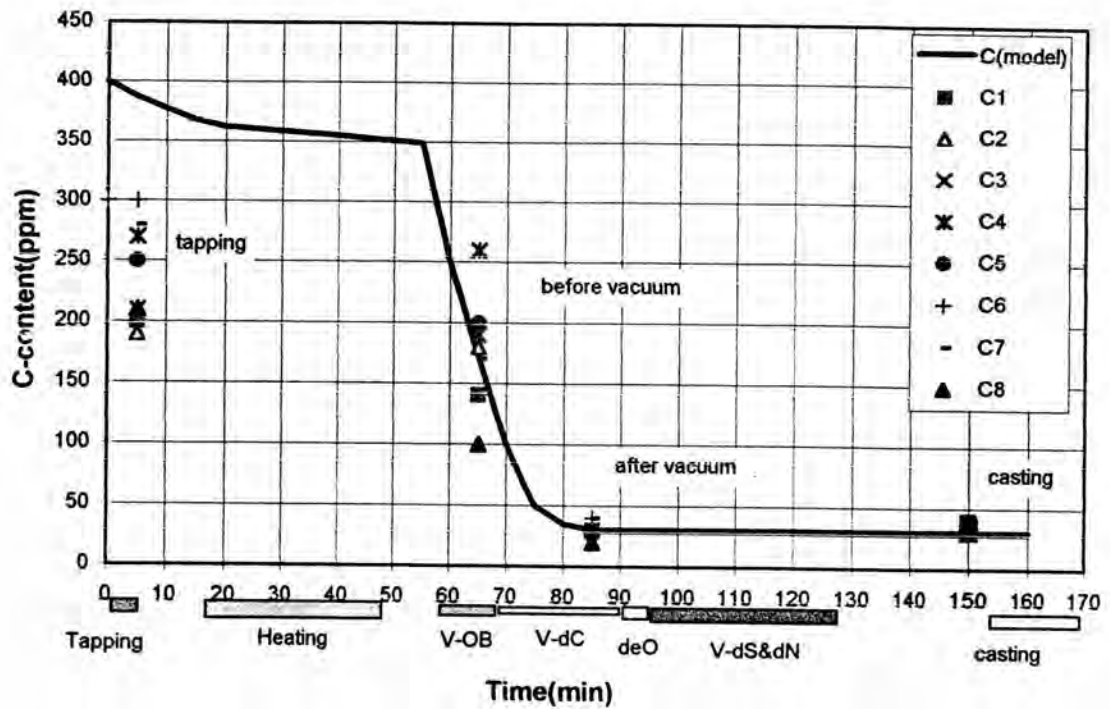
Figure 5.1　　　Carbon profile of ULC-model and T41Ti

5.2　　Temperature drop comparison

For temperature evolution during the treatment, the cooling factors

used to calculate the temperature drop due to flux and alloy additions as well as

radiation and heat extraction to the ladle refractory are as follows:

-Temperature drop with radiation and refractory of the ladle　= 20 °C

-Temperature drop with time from tapping to the start of vacuum treatment

$$= 1 \ ^{\circ}C/min$$

-Temperature drop with time during vacuum treatment $= 0.8$ C/min

-Temperature drop with flux and alloy additions $= \dfrac{Kg.addition}{100} \times cooling\ factor$

cooling factor:

C	=	3.1
Sand	=	2.5
CaO	=	1.45
MgO	=	1.40
ElMn	=	1.2
$MnAf(FeMn_{af})$	=	1.2
V(FeV)	=	1.0
SiMn	=	0.95
Scrap	=	1.0
Ti(FeTi)	=	0.7
Nb(FeNb)	=	0.6
FeSi	=	-0.25 (increase temperature)

Temperature increase with Al addition $= \left[Kg.\,Al - \dfrac{[\%\,Al]}{100} \cdot steel.\,wt.\,(kg) \right] \cdot \dfrac{8.5}{100}$

In the following section the cooling factors are taken to calculate the temperature drop of the treatment to compare to the measured temperature during the treatment of T41Ti and F56NBV steel grades.

5.2.1   Temperature drop from tapping to before vacuum treatment of

T41Ti

The comparison of the temperature drop from tapping to before vacuum treatment between the calculated data of the model and the measured temperature drop during the treatment of T41Ti is shown in Table 5.3 and Figure 5.2.

Table 5.3   Temperature drop from tapping to before vacuum of model and T41Ti

| sample	time from tapping to before vacuum (min)	T Tapping (°C)	T before TD (°C)	T drop (°C)	Addition			Calculation (°C)					
					C (kg)	MgO (kg)	ElMn (kg)	Tdrop with C	Tdrop MgO	Tdrop ElMn	Tdrop radiation	Tdrop time	total T drop
C1	32	1694	1627	67	15	150	60	0.47	2.1	7.2	20	32	61.8
C2	19	1681	1630	51	20	150	70	0.62	2.1	8.4	20	19	50.1
C3	11	1711	1675	36	30	160	0	0.93	2.24	0	20	11	34.2
C4	42	1698	1629	69	15	160	0	0.47	2.24	0	20	42	64.7
C5	17	1694	1643	51	10	145	0	0.31	2.03	0	20	17	39.3
C6	22	1698	1649	49	0	150	0	0.00	2.1	0	20	22	44.1
C7	27	1686	1620	66	0	150	0	0.00	2.1	0	20	27	49.1
C8	16	1695	1651	44	0	150	0	0.00	2.1	0	20	16	38.1
C9	37	1715	1641	74	25	150	0	0.78	2.1	0	20	37	59.9
C10	24	1693	1637	56	20	150	50	0.62	2.1	6	20	24	52.7
C11	18	1702	1648	54	20	150	0	0.62	2.1	0	20	18	40.7
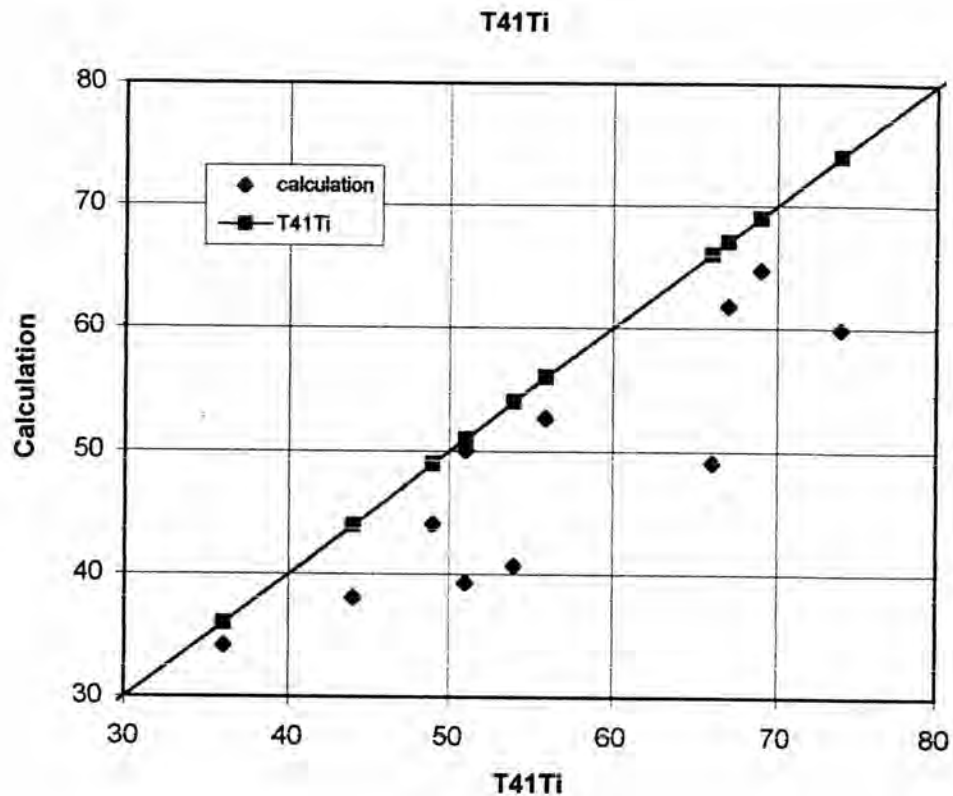
Figure 5.2   Comparison of temperature drop (°C) from tapping to the start

of vacuum between calculation and T41Ti

It can be seen that the calculated data are slightly lower than the real

measured data. One parameter which influences on the difference is the

duration between the temperature measurement in the BOF to the start of

tapping. The rate of the temperature drop during this time is not constant

throughout the duration and decreases with longer time [54]. Therefore the rate of

the temperature drop of 1 °C/min used in calculation are not precise all samples

of the steel grade T41Ti. Nevertheless, the difference between the calculation and the real values are relatively small (average difference = 7.5 °C). Furthermore, the feature of the calculated temperature drops of the model trends to be in the same direction as the real temperature drops.

5.2.2 Temperature drop at vacuum tank degasser of T41Ti

The calculated temperature drops during the vacuum treatment are compared to the real measured temperature drops of T41Ti is shown in Table 5.4 and Figure 5.3.

At the temperature drops lower than 30 °C, the difference of temperature drop from calculation and the real data of T41Ti is very close. Above 30 °C the difference is large. Only three from eleven samples of T41Ti differ from the calculated values more 10 °C. If these three samples are not taken into account, the temperature drop difference between the calculation and the real data of T41Ti averages to be only 3.5 °C. The three samples which differ strongly from the calculation (C8, C10, C11), have the temperature drops of 38, 44 and 34 respectively (greater than 30 °C). It can be noticed that, the temperature before the vacuum treatment of this three samples are relatively higher than the others. This leads to greater temperature drop.[54].

Table 5.4   Temperature drop at TD of calculation and T41Ti

Sample	time (min)	T before vacuum (°C)	T after vacuum (°C)	T-drop (°C)	Addition(kg)			T-drop from calculation (°C)			
					Al	CaO	steel(t)	time	CaO	Al	total T-drop (model)
C1	32	1627	1611	16	150	400	177.9	25.6	5.8	-12.7	18.6
C2	34	1630	1613	17	166	399	180.1	27.2	5.8	-14.1	18.9
C3	32	1633	1617	16	158	400	180.3	25.6	5.8	-13.4	18.0
C4	33	1622	1605	17	151	401	188.1	26.4	5.8	-12.8	19.4
C5	33	1643	1619	24	163	401	186.2	26.4	5.8	-13.8	18.4
C6	30	1649	1628	21	180	401	184.0	24.0	5.8	-15.3	14.5
C7	34	1620	1595	25	145	403	188.1	27.2	5.8	-12.3	20.7
C8	31	1651	1613	38	192	749	179.3	24.8	10.9	-16.3	19.3
C9	33	1642	1625	17	209	748	183.8	26.4	10.8	-17.7	19.5
C10*	37	1637	1593	44	171	748	173.0	29.6	10.8	-14.5	31.6*
C11	32	1648	1614	34	241	749	182.5	25.6	10.9	-20.5	16.0

(The total temperature drop of C10* is 31.6 °C. It includes temperature drop of
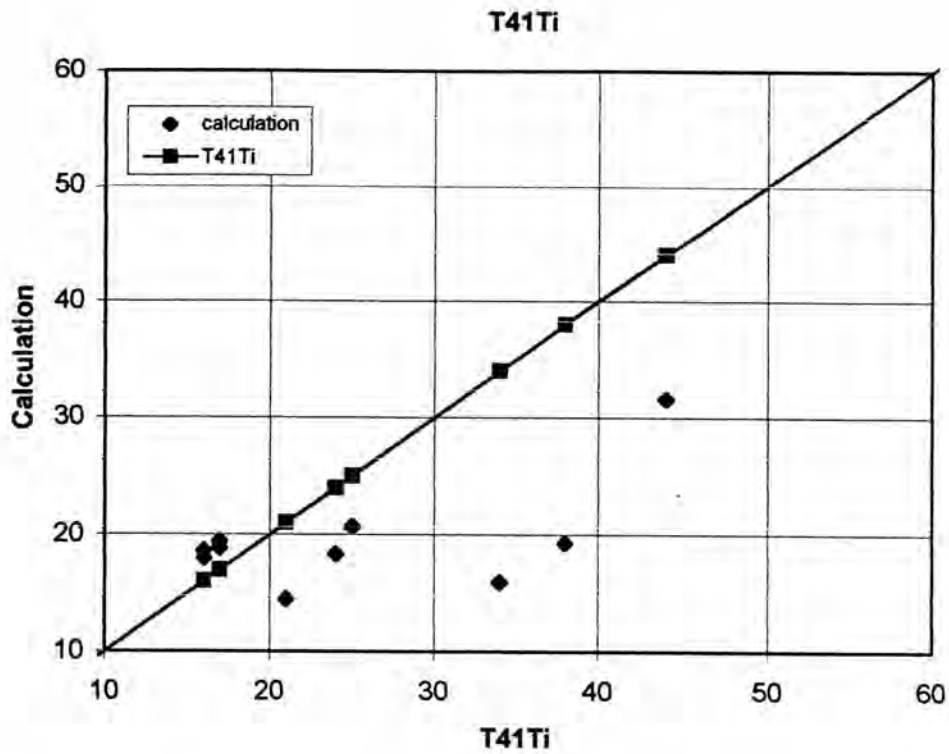
about 5.7 °C from 570 kg of scrap addition)

T41Ti

Figure 5.3   Comparison of temperature drop (°C) at TD between

culation and T41Ti

5.2.3   Temperature drop from tapping to before vacuum treatment of

F56NBV

The temperature drop from tapping to before vacuum treatment is

compared between calculated data and the measured data of F56NBV and is

shown in Table 5.5 and Figure 5.4.

Table 5.5   Temperature drop from tapping to before vacuum of the

model and F56NBV

sample	time from tapping to before-vacuum(min)	T-tapping (°C)	T-before vacuum (°C)	T drop (°C)	Addition									T-drop (calculation) (°C)
					CaO (kg)	Al- (kg)	MnAf (kg)	MgO (kg)	FeMn (kg)	SiMn (kg)	FeV (kg)	FeNb (kg)	[%Al] before vacuum	
S1	29	1716	1635	81	1340	279	296	75	786	2268	79	82	0.048	81.4
S2	27	1678	1607	71	1290	297	318	75	862	2276	82	87	0.053	78.4
S3	21	1731	1654	77	1390	299	328	75	858	2254	82	82	0.029	73.5
S4	37	1701	1612	89	1300	284	264	75	878	2258	84	86	0.040	89.0
S5	37	1698	1612	86	1310	289	248	75	884	2278	78	88	0.057	88.8
S6	33	1696	1603	93	1300	286	222	76	856	2232	81	81	0.045	83.8
S7	26	1698	1616	82	1290	291	462	75	786	2254	80	85	0.038	78.5
S8	23	1703	1633	70	1400	294	376	75	808	2252	83	81	0.044	76.0
S9	32	1695	1614	81	1250	295	312	75	880	2292	81	84	0.048	83.3
S10	31	1686	1606	80	1290	295	408	75	802	2282	78	87	0.062	83.0
S11	29	1731	1639	92	1550	298	510	75	746	2552	82	83	0.021	87.6
S12	33	1694	1612	82	1380	292	602	75	606	2268	77	85	0.038	86.3

Comparing to the results of T41Ti, the temperature drop of the model

and the measured values of F56NBV show better results. The difference

between the calculation and the real data of F56NBV is relatively small
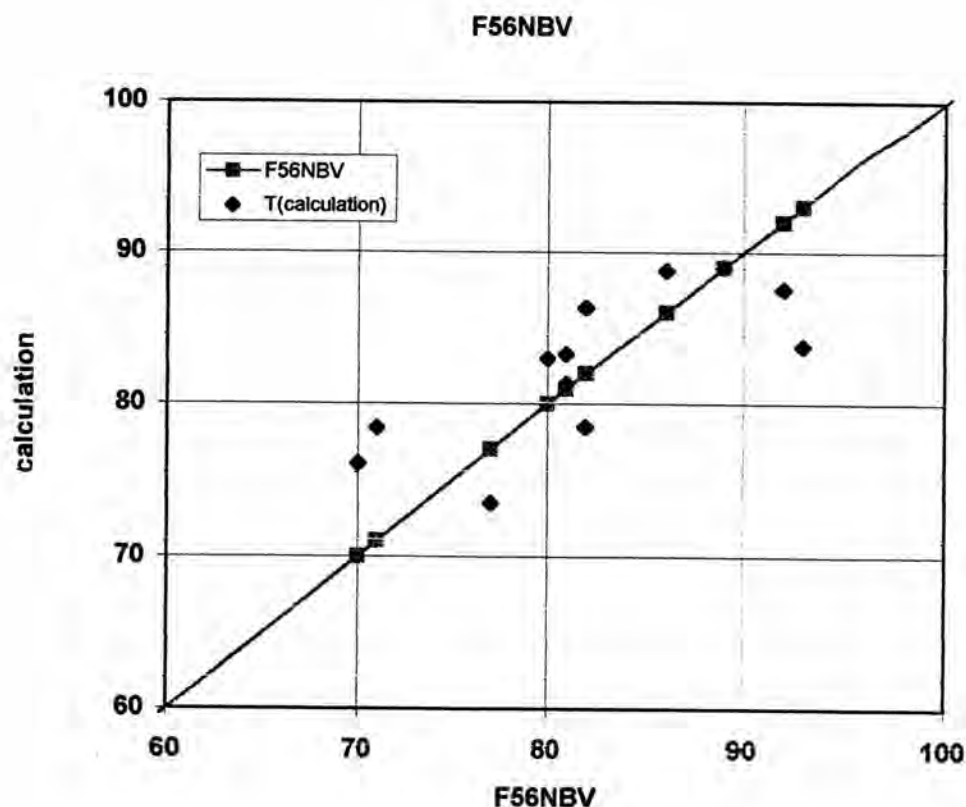
averaging of to be about 3.9 °C.

F56NBV

Figure 5.4   Comparison of temperature drop (°C) tapping to start of

vacuum between calculation and F56NBV

In comparison of the temperature drops between the real data (T41Ti, F56NBV) and the calculated values using cooling factors of the flux and alloy additions, it can be seen that the model foundation is reliable and applicable for approximating the temperature drop of the production of ELC and ULC steel grades. Moreover, the temperature control during the production can be achieved by advanced temperature drop estimation and using the heating device such as LHF to adjust the desired temperature.