CHAPTER 3

EXPERIMENTAL PROCEDURE

3.1 Description of Data

Melt-shop data from a steel plant in Germany were used in this work. One data set consists of the variables of one heat process. Each data set consists of 28 variables. These variables are listed as below:

1.) X_1: Converter temperature: temperature of liquid steel in the converter
2.) X_2: Tapping time: time duration tapping liquid steel from converter into a ladle
3.) X_3: time from finished tapping to the first temperature measurement in the ladle
4.) X_4: Empty ladle time: time a ladle has not been used in the process
5) X_5: Time from converter temperature measurement to beginning of tapping.
6.) X_6: Steel weight in ladle
7.) X_7: Charge number
8.) X_8: Number of ladle
9.) X_9: Stirring stands number
10.) X_{10}: [%Al]: % Aluminum in steel
11.) X_{11}: %Fe in converter slag
12.) X_{12}: Calcium Oxide (CaO): flux
13.) X_{13}: Magnesium Oxide (MgO): flux
14.) X_{14}: Carbon (C): additive
15.) X_{15}: Aluminum (Aldrops): additive
16.) X_{16}: Manganese (Mncar): additive
17.) X_{17}: Manganese (Mnaff): additive
18.) X_{18}: Ferrosilicon ($FeSi$): additive
19.) X_{19}: Flurospar (CaF_2): flux
20.) X_{20}: Ferrochromium ($FeCr$): additive

21.) X_{21}: Nickel (Ni): additive
22.) X_{22}: Copper (Cu): additive
23.) X_{23}: Molybdenum (Mo): additive
24.) X_{24}: Niobium (Nb): additive
25.) X_{25}: Mn el (Manganese electrolyte): additive
26.) X_{26}: Silicomanganese (SiMn): additive
27.) X_{27}: Vanadium (V): additive
28.) X_{28}: Final temperature: the first measured temperature in the ladle

The variables from X_1 to X_{27} were used as input data set. X_{28} was used as the output data. There were total of 8380 sets from this steel plant.

3.2 Data Pre-processing

3.2.1 Scaling

All data were scaled in range of minimum and maximum. The minimum and maximum data were compared to 0 and 1 respectively, as described by (3.1)

$$X' = \frac{X - X_{\min}}{X_{\max} - X_{\min}} \qquad \text{Equation (3.1)}$$

The data must lie between 0 and 1 because the output of network is calculated from a sigmoidal activation function which ranges between 0 and 1. Therefore, data in each group of variables were scaled according to the corresponding data range.

3.2.2 Data for training and testing model

The total input data 8380 sets were randomly divided into two groups. The first group was used for learning phase and second group was used for testing phase of network

3.2.3 Data for testing of input-output dependencies

After receiving the optimize model from modeling step, it is possible to determine the functional dependence of temperature change on the various factors. The optimize model was used for testing the effect of such factors. One input data set had been selected as given condition. The given condition is shown in Table 3.1.

Variable	Amount
Converter temperature (C)	1736
Tapping time (sec)	350
T_Abend time (sec)	474
Steel weight (ton)	196
[%Al] in steel	0.063
Kg carbon addition	133
Kg. Aluminium addition	443
Kg. Mn addition	802
Kg. FeCr addition	956
Kg. CaO flux addition	1680
Kg. SiMn addition	2334

Table 3.1 Given condition for the testing input-output dependencies

For testing one variable, that variable was varied between minimum and maximum in range of the total data while other variables were fixed in the given condition. This new data set will be used as the input data of the optimize model. The result of this new data set represented the effect of only one variable that was varied to temperature change.

3.3. Modeling

First, all input data were used. Pruning was applied to reduce the input data that has less influence to the output. The input data with less relative relevance to output data were cut out from the model during repeating iteration of learning phase. The pruning was done by limiting the value of relevance. If the relevance is less than 0.01, the input data will be cut out. After training this model, a new model with the main influencing factors on the temperature change is built. These input data are listed below:

1. Converter temperature
2. Tapping time
3. Abend time
4. Steel weight
5. [%Al] in steel
6. Al droplet addition
7. Carbon addition
8. Mn addition
9. FeCr addition
10. SiMn addition
11. CaO flux

The new model with these 11 input data will be used for further study. Many architectures are trained to find out the optimized model (minimum error). Various architectures studied the influence of the layer and the neuron numbers in each layer is shown in Table 3.2. To compare the learning behavior of network, different values of learning rate and momentum were set to the optimized architecture of network.

Four values of learning rate were varied to consider the effect of learning rate. Three values of momentum were changed to consider its effect. Table 3.3 includes various of learning rate and momentum, which was used for studying the learning behavior of network. Figure 3.1 shows the flowchart of training cycle in the neural network. This cycle will be continued until the minimum error is obtained.

Model Number	Number of neurons in				Learning rate	Momentum
	Input layer	Hidden layer		Output layer		
		1	2			
1	11	3	-	1	0.01	0.5
2	11	4	-	1	0.01	0.50
3	11	5	-	1	0.01	0.5
4	11	9	-	1	0.01	0.5
5	11	11	-	1	0.01	0.5
6	11	2	2	1	0.01	0.5
7	11	3	1	1	0.01	0.5

Table 3.2 Various architecture of network for finding the optimized model

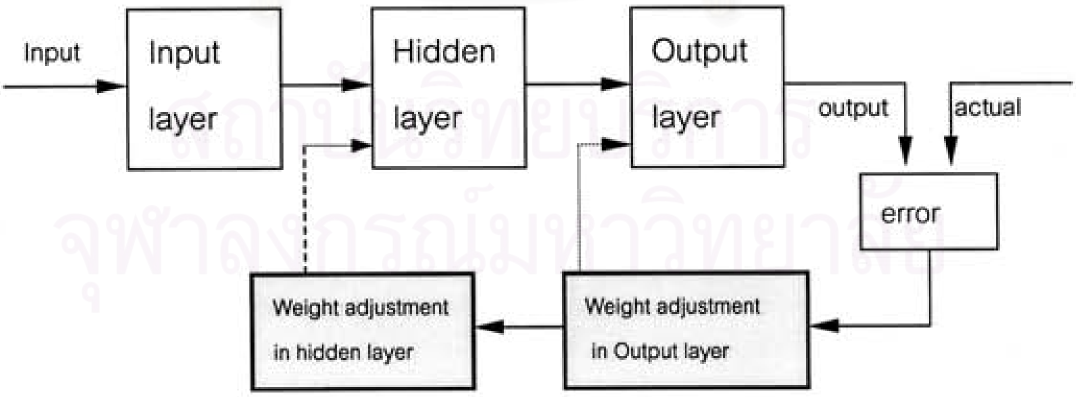

Figure 3.1 Flowchart of training cycle in neural network

Model	Number of neurons in			Learning	
Number	Input layer	Hidden layer	Output layer	rate	Momentum
2	11	4	1	0.01	0.5
8	11	4	1	0.1	0.5
9	11	4	1	0.5	0.5
10	11	4	1	0.9	0.5
11	11	4	1	0.01	0.1
12	11	4	1	0.01	0.9

Table 3.3 The various of learning rate and momentum

3.4. Testing

3.4.1 Testing of Model

The second part of input data set, which had not been used in the learning phase, was used for testing the model. Four types of error measurements were used for testing the model.

MAE	= mean absolute error	RMSE	= root mean square error
MSE	= mean square error	MAPE	= mean absolute percent error

$$MAE=\frac{1}{n}\sum_{i=1}^{n}|e_i|$$

$$MSE=\frac{1}{n}\sum_{i=1}^{n}e_i^2$$

$$RMSE=\sqrt{\frac{1}{n}\sum_{i=1}^{n}e_i^2}$$

$$MAPE=\frac{1}{n}\sum_{i=1}^{n}\left|\frac{e_i}{x_i}\right|\times 100$$

e_i= actual temperature change – predicted temperature change

3.4.2 Testing of input-output dependencies

The optimized model, which has minimum error, was used for this testing. Data from 3.2.3 were fed into the optimized model then the output is calculated. The results from these testing were the results from varying only one variable. These results are then compared with the result from calculation of the thermodynamic.

3.5 Calculation of Cooling Coefficient for Different Additions

This calculation is base on the given condition in **3.2.3**, converter temperature 1736°C and steel weight 196 ton.

$$\Delta H_{T(Fe)} = \Delta H_{T(additive)}$$

$C_p(Fe)$ $= 10$ cal/deg/mol (temp. range m.p.-1873 C)

$C_p(CaO)$ $= 11.86+1.08*10^{-3}T-1.66*10^{5}T^{-2}$ cal/deg/mol

$C_p(C)$ $= 4.1+1.02*10^{-3}T-2.1*10^{5}T^{-2}$ cal/deg/mol

$C_p(Mn)$ $= 5.16+3.81*10^{-3}T$ cal/deg/mol(temp. range 298-1000K)

$= 8.33+0.66*10^{-3}T$cal/deg/mol(temp. range 1000-1374K)

$= 10.7$ cal/deg/mol(temp. range 1374-1410K)

$= 11.3$ cal/deg/mol(temp. range 1410-1517K)

$= 11$ cal/deg/mol(temp. range 1517-2009K)

$L_t(Mn)$ $= 0.48$, kcal/mole (at 720°C)

$L_t(Mn)$ $= 0.55$ kcal/mole (at 1100°C)

$= 0.43$ kcal/mole (at 1136°C)

$L_f(Mn)$ $= 3.2$ kcal/mole (at 1244°C)

$\underline{Mn} + \underline{O} = MnO \qquad \Delta H^{\circ}_{298} = -32.95$ kcal/mole

$C_p(MnO) = 11.11+1.94*10^{-3}T-0.88*10^{5}T^{-2}$

$C_p(Cr) = 5.84+2.36*10^{-3}T-0.88*10^{5}T^{-2}$

$C_p(Al_2O_3) = 25.48+4.25*10^{-3}T-6.82*10^{5}T^{-2}$

$2\underline{Al} + 3\underline{O} = Al_2O_3 \qquad \Delta H^{\circ}_{298} = -67.55$ kcal/mole

$$\Delta H_{(Fe)} = \int_{2009}^{T} 10\,dT = 10*(\Delta T) \quad \text{cal/mol}$$

Fe 196 ton = 196*1000*1000/55.8 = 3512544.8 mol

$\therefore$ net $\Delta H^{T}_{(Fe)} = 35125448*\Delta T$ cal

$\therefore$ $\Delta T = \Delta H^{T}_{(addition)}/35125448$

3.5.1 Cooling Coefficient of CaO

$$\Delta H_{(CaO)} = \int_{298}^{2009} (11.86+1.08*10^{-3}T-1.66*10^{5}T^{-2})dT$$

$= 21873.32$ cal/mol

$= 389898.75$ cal/kg

$\therefore \Delta T$ from 1 kg. CaO = 389898.75/35125448 = 0.011°C

3.5.2 Cooling Coefficient of Carbon

$$\Delta H_{(C)} = \int_{298}^{2009} (4.1+1.02*10^{-3}T-2.1*10^{5}T^{-2})dT$$

$= 8630.87$ cal/mol

$= 719239.25$ cal/kg.

$\therefore \Delta T$ from 1 kg. C = 719239.25/35125448 = 0.021°C

Yield of carbon = 90%

$\therefore$ ΔT from 1 kg of carbon = 0.021*.9 = 0.0189°C

3.5.3 Cooling Coefficient of Manganese

$$\Delta H_{(Mn)} = \int_{298}^{1000} (5.16+3.81*10^{-3}T)dT + \int_{1000}^{1374} (8.33+0.66*10^{-3}T)dT +$$

$$\int_{1374}^{1400} 10.7dT + \int_{1410}^{1517} 11.3dT + \int_{1517}^{2009} 11dT + 4660$$

$= 29543.04$ cal/mol

$= 538126.47$ cal/kg.

$\therefore \Delta T$ from 1 kg. Mn = 538126.47/35125448 = 0.015 °C

Yield of Ferromanganese = 95% and Ferromanganese 80% Mn

$\therefore \Delta T$ from 1 kg. FeMn = 0.015*.8*.95 = 0.0114°C

$$\Delta H^{T}_{(MnO)} = \int_{298}^{2009} (11.11+1.94*10^{-3}T-0.88*10^{5}T^{-1})$$

$= 22852.52$ cal/mole

$\Delta H^{\circ}_{298\,(MnO)} = -32950$ cal/mole

$\Delta H^{T}_{(MnO)} + \Delta H^{\circ}_{298\,(MnO)} = -10097.48$ cal/mole

$= -183924.95$ cal/kg

$\therefore \Delta T$ from 1 kg. MnO = -183924.95/35125448 = -0.005236°C

$\therefore$net ΔT from 1 kg. MnO = -0.005236*.2*.05 = -0.00005236 °C

3.5.4 Cooling Coefficient of Chromium

$$\Delta H_{(Cr)} = \int_{298}^{2173} (5.84+2.36*10^{-3}T-0.88*10^{5}T^{-2})dT + 5000$$

$$= 20145.37 \quad \text{cal/mol}$$

$$= 387410.96 \quad \text{cal/kg.}$$

$\therefore \Delta T$ from 1 kg. Cr = 387410.96/35125448 = 0.011°C

Yield of Ferrochromium = 90% and Ferrochromium 75%Cr

$\therefore \Delta T$ from 1 kg. FeCr = 0.011*.9*.75 = 0.0075°C

3.5.5 Cooling Coefficient of Aluminium

Aliminium is deoxidation agent which increases the temperature of liquid steel. The first part of aluminium is dissolved in liquid steel until the system approach to equilibrium. After that the retained aluminium reacts with oxygen to form Al_2O_3 and gives energy to system.

$$\Delta H^{\circ}_{298(Al2O3)} = -67550 \text{ cal/mole}$$

$$\Delta H_{(Al2O3)} = \int_{298}^{2009} (25.48+4.25*10^{-3}T+6.82*10^{-5}T^{2})dT$$

$$= 50035.12 \quad \text{cal/mol}$$

$$\Delta H^{\circ}_{298(Al2O3)} + \Delta H_{2009(Al2O3)} = -67550+50035.12 = -17514.88 \text{ cal/mole}$$

$$= -648576 \text{ cal/kg}$$

$\therefore \Delta T$ from 1 kg. Al = -648576/35125448

= -0.01846°C