Steam Table Property Estimation with the Help of an Artificial Neural Network

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Introduction

Steam is a part of almost all thermal and chemical engineering operations. The estimation of thermodynamic properties of water are commonly done using steam table in printed form. Because of arbitrariness in using these tables, computerised forms of these tables are used. In the present article, artificial neural network models have been successfully developed for estimation of thermodynamic properties, namely steam temperature and specific enthalpy as a function of steam pressure and steam pressure and specific enthalpy as a function of steam temperature. The models have been validated with test data and observed to be of high accuracy levels and excellent speed. These models can be used for industrial applications or any other estimation of steam properties with ease and speed.

Methodology

- In this report, the prepared model of the neural network has 2 inputs which represents Temperature and Pressure and two outputs, Specific Enthalpy of saturated liquid and Specific Enthalpy of saturated vapor (at those conditions) as output1 and output2 respectively.
- There are 20 patterns used in which 15 are for train the neural network and the rest is for testing.
- The number of hidden neurons is varied to check the optimality along with the learning rate of the network. 3 cases of learning rate are considered in the code i.e., 0.2, 0.5 and 0.8.
- Number of hidden neurons are considered as 2, 3, 4 and 5.
- The code is written in C++ language.

Input Data

Temp(℃)	Pressure(MPa)
120	0.19867
121	0.20505
122	0.21159
123	0.21830
124	0.22518
125	0.23224
126	0.23947
127	0.24689
128	0.25450
129	0.26229
130	0.27028
131	0.27846
132	0.28685
133	0.29543
134	0.30423
135	0.31323
136	0.32245
137	0.33188
138	0.34154
139	0.35143
140	0.36154

Target Data

$h_f\ (kj/kg)$	$h_g(kj/kg)$
503.81	2705.9
508.06	2707.4
512.31	2708.8
516.56	2710.3
520.82	2711.7
525.07	2713.1
529.33	2714.5
533.59	2715.9
537.85	2717.3
542.12	2718.7
546.38	2720.1
550.65	2721.5
554.92	2722.8
559.19	2724.2
563.47	2725.5
567.74	2726.9
572.02	2728.2
576.30	2729.5
580.59	2730.8
584.87	2732.1
589.16	2733.4

Results

For η ***= 0.2 and M=2***

```
                                        TESTING  DATA

Pattrern            Input 1     Input 2         Target 1        Output 1        Target 2        Output 2
15                  134         0.30423         563.47          565.269         2725.5          2684.89
16                  135         0.31323         567.74          569.703         2726.9          2684.73
17                  136         0.32245         572.02          574.023         2728.2          2684.56
18                  137         0.33188         576.3           578.201         2729.5          2684.38
19                  138         0.34154         580.59          582.224         2730.8          2684.18
20                  139         0.35143         584.87          586.071         2732.1          2683.97
```

- Error in prediction for learning rate=0.2 and number of hidden neuron=2 is 0.000256673
- 3808 iterations needed to get an accuracy of 0.0001 in mean square error.

For η *= 0.2 and M=3*

TESTING DATA

Pattrern	Input 1	Input 2	Target 1	Output 1	Target 2	Output 2
15	134	0.30423	563.47	561.016	2725.5	2693.99
16	135	0.31323	567.74	565.564	2726.9	2695.01
17	136	0.32245	572.02	570.244	2728.2	2696.03
18	137	0.33188	576.3	575.056	2729.5	2697.06
19	138	0.34154	580.59	580	2730.8	2698.1
20	139	0.35143	584.87	585.073	2732.1	2699.14

- Error in prediction for learning rate=0.2and number of hidden neurons=3 is 0.000137763
- 1321 iterations needed to get an accuracy of 0.0001 in mean square error.

For η *= 0.2 and M=4*

TESTING DATA

Pattrern	Input 1	Input 2	Target 1	Output 1	Target 2	Output 2
15	134	0.30423	563.47	564.851	2725.5	2680.4
16	135	0.31323	567.74	570.487	2726.9	2678.46
17	136	0.32245	572.02	576.298	2728.2	2676.33
18	137	0.33188	576.3	582.256	2729.5	2674
19	138	0.34154	580.59	588.343	2730.8	2671.47
20	139	0.35143	584.87	594.526	2732.1	2668.72

- Error in prediction for learning rate=0.2and number of hidden neurons=4 is 0.000459416
- 1656 iterations needed to get an accuracy of 0.0001 in mean square error.

For η = 0.2 and M=5

TESTING DATA

Pattrern	Input 1	Input 2	Target 1	Output 1	Target 2	Output 2
15	134	0.30423	563.47	566.887	2725.5	2695.77
16	135	0.31323	567.74	572.071	2726.9	2697.05
17	136	0.32245	572.02	577.318	2728.2	2698.3
18	137	0.33188	576.3	582.614	2729.5	2699.51
19	138	0.34154	580.59	587.961	2730.8	2700.69
20	139	0.35143	584.87	593.348	2732.1	2701.83

- Error in prediction for learning rate=0.2and number of hidden neurons=5 is 0.000204438
- 1048 iterations needed to get an accuracy of 0.0001 in mean square error.

Hence the optimal number of hidden neurons is coming out to be 3.

Now,

For M=3 and η = 0.5

TESTING DATA

Pattrern	Input 1	Input 2	Target 1	Output 1	Target 2	Output 2
15	134	0.30423	563.47	558.922	2725.5	2686.57
16	135	0.31323	567.74	562.887	2726.9	2685.92
17	136	0.32245	572.02	566.898	2728.2	2685.25
18	137	0.33188	576.3	570.95	2729.5	2684.57
19	138	0.34154	580.59	575.031	2730.8	2683.87
20	139	0.35143	584.87	579.133	2732.1	2683.17

- Error in prediction for learning rate=0.5and number of hidden neuron=3 is 0.000310933
- 592 iterations needed to get an accuracy of 0.0001 in mean square error.

For M=3 and η = 0.8

TESTING DATA

Pattrern	Input 1	Input 2	Target 1	Output 1	Target 2	Output 2
15	134	0.30423	563.47	566.893	2725.5	2689.99
16	135	0.31323	567.74	573.644	2726.9	2690.33
17	136	0.32245	572.02	580.841	2728.2	2690.65
18	137	0.33188	576.3	588.483	2729.5	2690.97
19	138	0.34154	580.59	596.574	2730.8	2691.27
20	139	0.35143	584.87	605.103	2732.1	2691.55

- Error in prediction for learning rate=0.8and number of hidden neuron=3 is 0.00056356
- 297 iterations needed to get an accuracy of 0.0001 in mean square error.

Discussion:

It is observed that with increase in learning rate iterations needed to get a desired accuracy becomes lesser. But on the other hand, Mean Square Error value is increasing. So to design a perfect artificial neural network we need to optimize the results.

Conclusion:

Hence optimal condition to build the network is Number of Hidden Neuron=3 and Learning rate= 0.2.

For this combination:

Wjk updated values are

W[0][1]= -0.339224 W[0][2]= 1.69445

W[1][1]= 0.495452 W[1][2]= -0.122217

W[2][1]= 0.08748 W[2][2]= 0.545939

W[3][1]= 0.760238 W[3][2]= 0.990954

Vij updated values are

V[0][1]= -0.666623 V[0][2]= 0.909854 V[0][3]= 1.00117

V[1][1]= -0.992897 V[1][2]= 1.10629 V[1][3]= 0.484789

V[2][1]= -0.999779 V[2][2]= -0.86558 V[2][3]= -0.802992

Training Data

Pattrern	Input 1	Input 2	Target 1	Output 1	Target 2	Output 2
1	120	0.19867	503.81	509.344	2705.9	2681.17
2	121	0.20505	508.06	512.435	2707.4	2682
3	122	0.21159	512.31	515.597	2708.8	2682.83
4	123	0.2183	516.56	518.838	2710.3	2683.68
5	124	0.22518	520.82	522.16	2711.7	2684.54
6	125	0.23224	525.07	525.569	2713.1	2685.42
7	126	0.23947	529.33	529.07	2714.5	2686.31
8	127	0.24689	533.59	532.67	2715.9	2687.22
9	128	0.2545	537.85	536.373	2717.3	2688.14
10	129	0.26229	542.12	540.182	2718.7	2689.08
11	130	0.27028	546.38	544.106	2720.1	2690.03
12	131	0.27846	550.65	548.146	2721.5	2691
13	132	0.28685	554.92	552.31	2722.8	2691.98
14	133	0.29543	559.19	556.597	2724.2	2692.97
15	134	0.30423	563.47	561.015	2725.5	2693.98

TESTING DATA

Pattrern	Input 1	Input 2	Target 1	Output 1	Target 2	Output 2
15	134	0.30423	563.47	561.016	2725.5	2693.99
16	135	0.31323	567.74	565.564	2726.9	2695.01
17	136	0.32245	572.02	570.244	2728.2	2696.03
18	137	0.33188	576.3	575.056	2729.5	2697.06
19	138	0.34154	580.59	580	2730.8	2698.1
20	139	0.35143	584.87	585.073	2732.1	2699.14