

**Application of Neural Networks in optimizing critical temperature control loop in
steam production of a Gas-to-liquid plant**

*A Master Thesis
Presented by*

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ABSTRACT**

Steam production and availability remains a critical part of Gas-to-liquid (GTL) production plant as it serves as both an important raw materials in synthetic gas (syngas) making as well as many other GTL critical sub-processes in power generation, steam-driven gas compressor and hydrogen production. At the heart of steam production is the package boiler unit which produces steam at required temperature to the steam header for various plant users. This package boiler operation is dependent on the efficient control of its critical control loops - main steam pressure, main steam temperature, drum water level, furnace pressure etc.

Package boiler temperature control ranges from simple on/off to a more advanced PID control. Although, conventional Proportional Integral Derivative (PID) controllers produces a fairly acceptable control operation on many control loops using simplified tuning process however, it is difficult to achieve same result in temperature control loops due to temperature loop peculiarity; high dead time, time lag/time delay, nonlinearity, load dependent time constant [3]. This is evident in the current operation and reliability issues associated with package boiler PID-controlled temperature loop at Escravos GTL plant. It is against this backdrop that many modern steam boilers have adopted advanced process control or model predictive control (MPC) for steam temperature control.

This research paper seeks to explore the use of backpropagation neural network (NEURAL NETWORK) in optimizing critical temperature control loop in steam production of a package boiler in a Gas-to-liquid plant. This NEURAL NETWORK model consider the unique fuel mixture (natural and tail gas) that are available to the package boiler in this GTL plant among other related variables that form the input vectors. Unlike most MPC solutions that requires step change on live process, NEURAL NETWORK has an advantage of leveraging on historical process data to model the plant thereby avoiding the complex first principle method of developing model.

This study also further seeks to demonstrate the capability of the model to give instant prediction to operator of the required process parameters that could help to achieve a set temperature thereby helping to improve operator's response in critical process upset scenario.

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I would like to give thanks to Almighty God the creators of heaven and earth and all its fulness for without His enabling strength, this would not have been possible.

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Finally, I want to express my profound gratitude to my loving wife Alade Temitayo for her support and commitment to see this thesis work succeed.

Declaration

I declare that this thesis was prepared by myself and that the analysis contained therein is my exclusive work except where stated otherwise in the text, and that this work is submitted to EIT as part of requirement for the Master of Engineering degree in Industrial Automation

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Abbreviations

HPSH: High pressure steam header,

GTL: Gas to liquid,

PID: Proportional Integral and Derivative,

LPO: Loss production opportunity

ASU: Air separation unit

ANN: Artificial neural network

CHAPTER 1

Introduction

1.1 Motivation

Steam systems are a part of almost every major industrial process today [4] and about thirty-seven percent of all fossil fuel burned in US industry are used to produce steam. All major early and modern industrial processes utilize steam as a major raw material (utility) to aid their processes. In most cases, the steam plant is the critical utility plant that will first come online before any other and must constantly be online throughout operation of the plant. Common industrial processes with steam application are food, paper & mill, beverages, building, chemicals, and textiles [2]. This is not different from a GTL plant, as steam is critical to its core process of synthetic gas production through steam reforming, partial oxidation, or combinations [5]. At the heart of steam production is boiler which is an enclosed or sealed vessel with a singular purpose of producing steam at high pressure for domestic or industrial use [1]. To generate high pressure steam up to a range of 300bar, two major design are commonly used; the water tube and the flame tube/smoke tube boiler. Water tube design is commonly used in Package Boiler because they are very rugged and can withstand high pressure.

Boiler control system ranges from simple on/off control (with use of thermostat) to a more complex control system with PID or complex algorithm. In a complex industrial process, there is need to balance the operational constraints of package boilers (temperature, pressure) with the demand of steam by the processes from the steam header.

Despite the wide advantages of single loop Proportional Integral Derivative (PID) control in process industries, there is difficulty in achieving efficient temperature control using convectional PID controllers due to temperature loop peculiarity; high dead time, time lag/time delay, nonlinearity, load dependent time constant[2 pp]

This project proposal seeks to evaluate application of Neural Networks in optimizing critical temperature control loop in steam production of a GTL plant. The steam (utility) plant takes processes water from water treatment plant which is then used to generate steam on the package boiler that are fired with fuel gas. The fuel source is a combination of Natural gas (NG) and Tail gas (TG) which is the by-product of the plant's processes in an approximate 30 to 70% contribution in a normal plant stable process. The steam produced by package boilers are channelled to High Pressure Steam Header (HPSH) from where all plant steam demand is supplied. It was observed that during plant upset (loss of processes that produce TG), the Natural gas flow increases

to makeup the total fuel causing more heating and eventually high temperature on the package boiler. The simple PID temperature controller of the package boiler was unable to maintain the temperature of the package boiler in a scenario of increased NG flow even when Cooling system is activated. There is an opportunity for efficiency in this process by developing Model that can clearly evaluate correlation of parameters related to temperature with the expectation to be able to predict/manage the temperature control more efficiently.

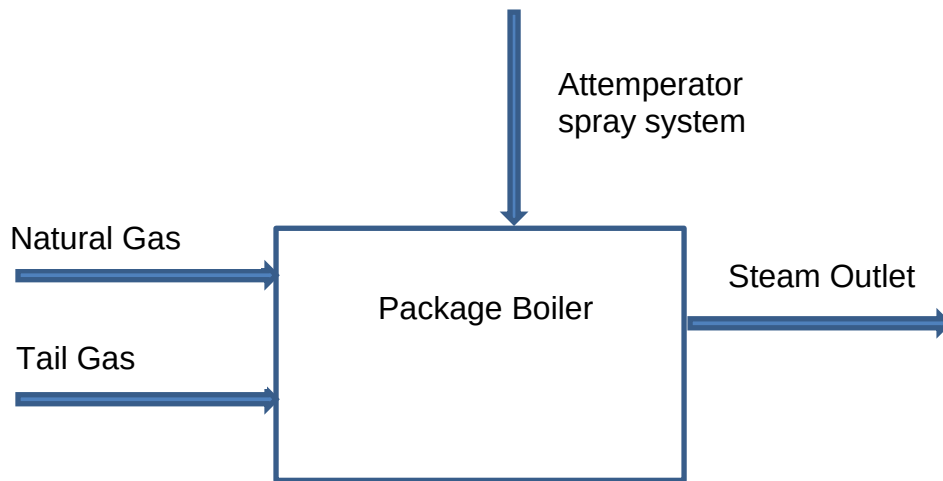


Fig. 1.0 Simplified schematic diagram of Package Boiler

1.2 Aims & objectives of the research

The aim of this research is to evaluate efficiency of neural network in optimizing critical temperature control loop in steam production of a Gas-to-liquid plant. The NEURAL NETWORK model is particularly considered because of the advantage of leveraging historical process data to develop plant model where life process data are not available. Another alternative is to generate the plant model from the first principle but this extremely cumbersome and overly complex. The research will leverage on plant historical data available through plant's historian application to develop NEURAL NETWORK model for the temperature control loop. Generally the project will;

- Demonstrate optimization of temperature control on the package boiler with the help of neural network predictive model
- Reduction of plant instability and spurious plant trip due to loss of tail gas during plant upset
- Improvement in plant reliability & profitability by minimizing LPO and preventing asset damage

- Demonstrate inadequacies of simple PID Temperature control for the Package Boiler in a major process upset scenario compare to neural network predictive model

1.3 Dissertation outlines

This work starts with brief introduction under Chapter 1 where the aims and objectives of the research are also stated. Chapter 2 lays the theoretical background and principle of operation for the proposed neural network solution and also provide overview of GTL plant steam production. The GTL plant used as case study is located in Delta state, Nigeria.

Chapter 3 describes the method applied in this work including data extraction, analysis, and deployment into NEURAL NETWORK fitting tool in Matlab to generate the model.

Chapter 4 entails actual NEURAL NETWORK model design using historical process data in Matlab and evaluation of result in comparison to traditional PID control loop. This chapter also seeks to validate model performance in line with research aims and objectives.

Chapter 5 summarizes the result of simulation in previous chapter, provides recommendation and possible future work based on the drawback or limitation discovered from the research findings.

CHAPTER 2

Background and Description

2.1 What is Neural network

Neural network simply means network of neurons that are highly interconnected through a large number of processing elements in an architecture inspired by the brain. Artificial neural network (ANNEURAL NETWORK) or artificial equivalent of neural network is indeed a computational data model that replicates functionality of biological neural network (as found in human brain) and are very efficient in recognizing patterns [6]. A neural network or simply Artificial neural networks are used interchangeably in many research to mean same thing - imitation of computational capability of human brains.

2.1.1 History and composition of Neural Network

Study in the field of neural network gained prominence in the early 1940s, thanks to scholarly work by McCulloch and Pitts published in 1943 as the first systematic studies of the artificial neural networks [7]. This work leads to some impressive result which encouraged future research and developments of powerful and phenomenon Artificial Neural Networks. Since then, there have been notable works by other researchers - like Rosenblatt et al (1957) on The learning algorithm for neuron model and a very notable work by Rumelhart et al 1986 which advanced backpropagation solution to the problem of efficient training of neural network among others.

Every study in this field is inspired primarily with the capability of natural brain to learn new things, adapt to new and changing environment [8]. The human brain is a very sophisticated and complex organ that controls the whole body through some interconnected cells called neurons. There are about 100 billion computing unit neuron in human brains and work to exchange and process information through their connectors - by summing up information received, benchmark it against a potential and acts to send a pulse or not. A typical human neuron consists of a cell body, axon and dendrite. Fig 2.1 below shows brain neuron with associated components

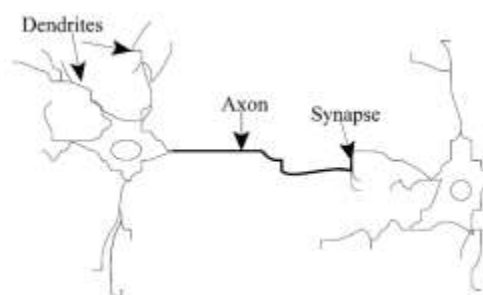


Fig 2.1 A typical human neuron [8]

Although there are many variation of human neurons, yet a basic neuron has components shown above which functions as follows; **dendrites** resemble human hair and are extension of neuron nucleus called Soma and provides a path by which a neuron receive signal from another neuron, if the strength of the received signal exceed certain thresholds, it activates the neuron which then send its own signal to next neurons through **Axon and Synapses** [11]. In the same manner, neural networks use clustering of simple artificial neurons interconnected via weight connectors and then compute outputs after summing up the weight of incoming inputs [9].

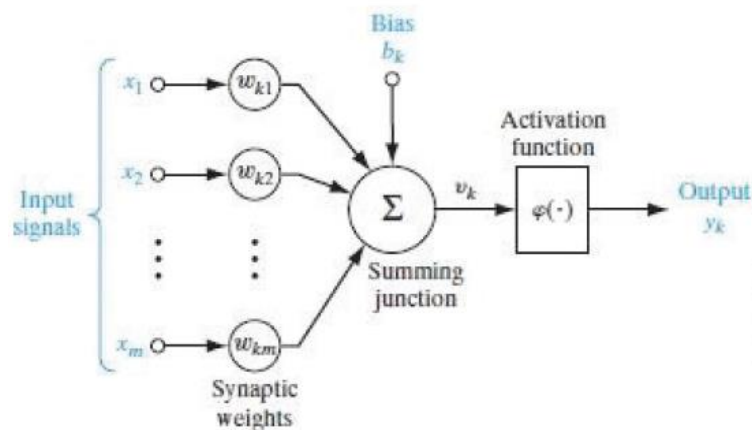


Fig. 2.2 A mathematical diagram of artificial neuron [9]

Given that,

Input signals are - $x_1, x_2, \dots, x_m$

Neuron are represented by: $k_1, k_2, \dots, k_m$

Weights of each neuron: $w_{k1}, w_{k2}, \dots, w_{km}$ (weight * neuron)

Bias: b_k (mostly initialized to 1)

Activation function: φ

Output: y_k

Then,

Mathematically, the output can be expressed as:

$$y_k = \varphi \left(\sum_{i=1}^m x_i \cdot w_{ki} + b_k \right) \dots\dots\dots 1$$

Neural network uses activation function to help the network comprehend complex patterns in the data thereby normalizing output of each neurons to 1 and 0 or -1 and 1. This can easily be

considered to be like similar functionality that determines what is to be fired to the next neuron in human brain. A simple neural network without an activation function may be considered as a linear regression model and it takes activation function to perform non-linear transformation so the neural network can handle complex analysis.

Activation function in Fig.2.2 above can be expressed as,

$$\Phi(x) = \frac{1}{1 + e^{-x/20}}$$

Where , $\text{sum} = \sum_{i=1}^m \mathbf{x}_i \cdot \mathbf{w}_i$

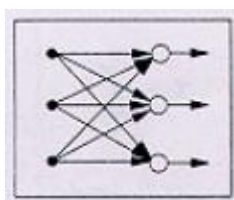
There are generally 3-types of activation functions;

1. Binary or on/off function
2. Linear function
3. Non-linear activation function: common activation function in this group are; Sigmoid, TanH, ReLU, Softmax and Swish.

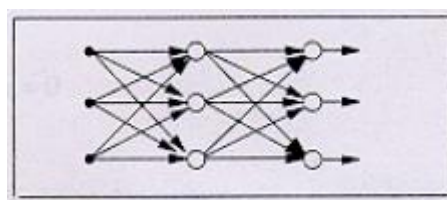
Composition of Neural network

There are different composition or architecture of neural network leading to different topology to serve required purpose. The general categories are supervised and unsupervised (or simple) computational network. Common architecture are;

1. Single layer perceptron: This is the basic or simplest form of feed-forward network that simply sum up inputs, apply activation function and pass outcome to output layer [10].
2. Feedforward neural network: this network contained multiple neurons arranged in layers; input, hidden and output layers
3. Multilayer perceptron: Another feed-forward network that contained one or more hidden layers.



Single-layer perceptron



Multilayer perceptron

Fig 2.3 diagram showing neurons' architecture

2.1.2 Steps to develop NEURAL NETWORK model

The primary motivation in NEURAL NETWORK model is its capability to identify patterns among other things by analysing and training with existing data. The basic steps involve in building a NEURAL NETWORK models are;

- I. Quality data set - Data will be fed into NEURAL NETWORK as input data and should preferably be of particular pattern or contain information to be classified.
- II. Training and Validation - Data are classified as training or validation data, serving different purposes. Training data forms the dataset used by the model for learning.
- III. Hidden layers selection - selection of hidden layers and number of neurons. Some NEURAL NETWORK tools makes some default selections but can be adjusted accordingly by the programmer. Care must be taken to ensure proper selection to avoid over-fitting of the model.
- IV. Parameters selection and training - NEURAL NETWORK model requires training which is the process of calibrating biases and weight so that final outcome is within expected threshold
- V. Evaluation and validation - This process help to determine the degree of learning by the model by comparing result at interval till acceptable outcome is achieved.

2.1.3 Application and limitation of NEURAL NETWORK

Artificial neural network has shown tremendous success when applied in different field of life due to their ability to reproduce and model linear and nonlinear system. Some of the notable areas of ANEURAL NETWORK footprints are;

- I. Digital Signal processing: This is the bedrock for the technology used in categorization, transformation, segregation, and interpretation of signals [9]. This required some high level computational, statistical and transformational analysis which are available through system modelling in ANEURAL NETWORK.
- II. Parallel operation: ANEURAL NETWORK unlike computer work in parallel operation thereby able capable of speed when processing data
- III. Because of their ability to self-learn and store data in themselves, ANEURAL NETWORK are use in image processing, language processing and speech recognition

- IV. Medical: ANEURAL NETWORK is having a strong impact in medical field with ongoing research in the areas of body part modelling, early disease prediction and patient recovery pattern by analysing various medical data [11].
- V. Other areas of interest are in computer science, aviation industry, weather forecast and business modelling.

2.1.4 NEURAL NETWORK model tool in Matlab

Matlab is a sophisticated computer software that have various module for specialized applications. The application used for NEURAL NETWORK is under deep learning toolbox and grouped into machine learning.

The most useful tool in this category to develop NEURAL NETWORK model is Neural Net Fitting tool which is a two-layer feedforward neural network. The tool is self-explanatory and guide into step by step action required to develop the model.

The steps involve are: Data selection, validation and testing, network architecture hidden layers selection, training of network, network evaluation, performance test and solution deployment.

2.2 GTL Plant Steam Production

2.2.1 Process Description and Plant overview

Gas to Liquid technologies primarily converts natural gas to hydrocarbon liquid fuel. This technology alongside similar process of generating synthetic liquid hydrocarbon (coal to liquid and Biogas to liquid) has been reviewed and considered alternative to crude oil synthesis from the early 19th century. The most common technology in GTL industrial process is Fischer-Tropsche (FT) synthesis and it involves five basic steps [12];

1. Synthesis (syn) gas production
2. Gas purification and cleaning which involve removal of water, and other impurities
3. Hydrocarbons synthesis
4. Condensation of liquid products and recovery of gasoline from product gas
5. Product workup and purification

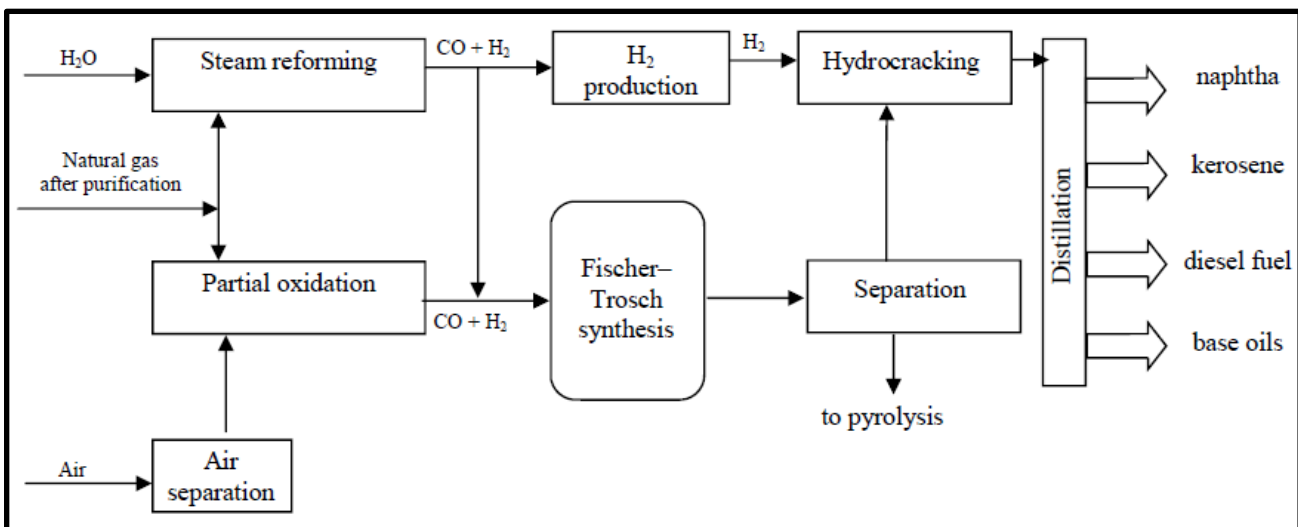
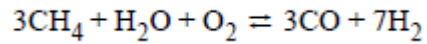


Fig. 2.4 Simplified GTL block diagram [13]

2.2.2 Steam production and operation

Steam production is at the heart of the plant operation in GTL plant as it supplied required steam for the whole plant operation. The very key application of steam is in autothermal reforming process which involves a combination of partial oxidation and steam reforming to produce what is called synthetic (syn) gas. The combining ratio of CO and H₂ is very critical as it affect other processes in the production line particularly FT process.



Package boiler are the major producer of steam for the plant operation. At plant start-up, only natural gas is used as fuel source for the package boilers but are compensated with Tail gas when the plant is fully on load and tail gas are available. Tail gas are natural gas of low calorific value and essentially a There are total of three package boilers (A, B & C) in this Escravos GTL plant and they all work together to supply steam to the High Pressure Steam Header (HPSH). Each package boiler can be fired up to 144megawat and produce up to 165tons of steam at 64.5bar to the steam header.

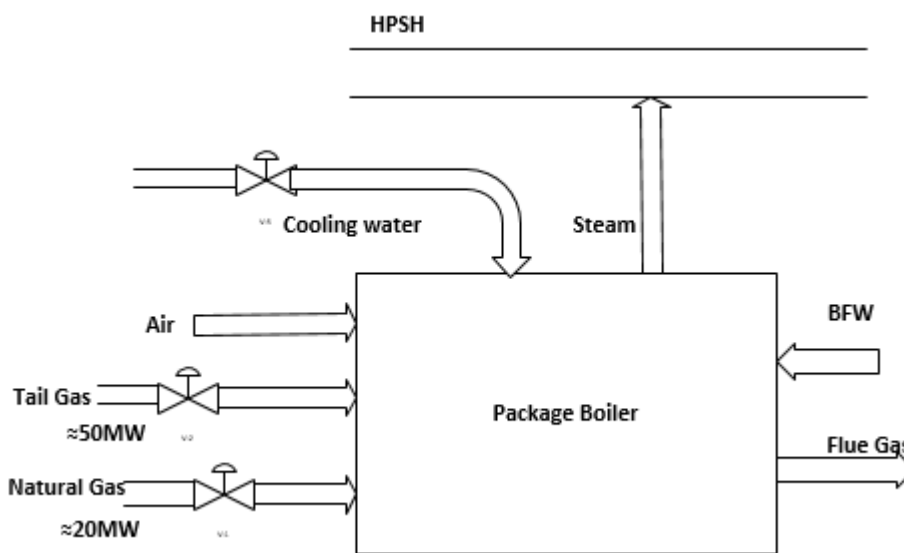


Fig. 2.5 Simple schematic diagram of a package boiler

The flow of natural and tail gas in nm³/hr was converted and rated in Megawatt to ensure easy correlation with package boiler rating also in megawatt.

2.2.3 Package boiler temperature control's limitation

Temperature loop remains the critical control loop of the package boiler and It is control with PID controller. This temperature control loop helps to provides some kind of protection helps to prevent uNeural networkecessary material and thermal stress and also reduce fuel cost.

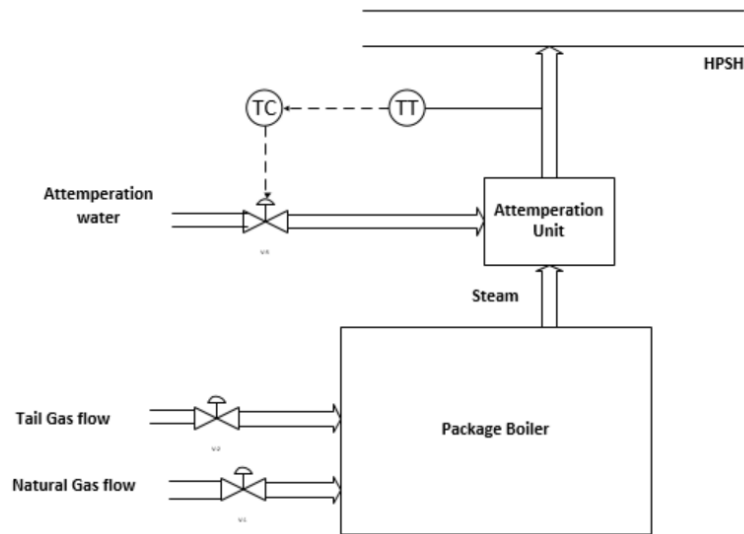


Fig. 2.6 A package boiler with Temperature control loop

The temperature transmitter TT senses the temperature of the steam going to the HPSH and send the signal to a PID temperature controller which then generate output to operate control valve on attemperation water.

The PID controller is able to maintain the boiler operation when the plant is stable but unable to provide quality response in plant upset scenario. In a situation of sudden drop in the amount of tail gas available from plant processes, there will be drop in the steam produced by the package boiler. The HPSH header controller increases the flow of natural gas to make up for the loss of tail gas and thereby increasing the duty (burning) and subsequent increase in the steam temperature. With the steam temperature approaching trip value (@410°C) during such situation, the PID struggle to activate enough attemperation water required to keep the temperature under control.

2.2.4 Alternative proposal with better performance

Generally, there is difficulty in achieving efficient temperature control using convectional PID controllers on boilers due to temperature loop peculiarity; high dead time, time lag/time delay, nonlinearity, load dependent time constant. The PID temperature controller was unable to accurately predict temperature increase associated with sudden increase in natural gas, could not provide sufficient attemperation water and thereby causing spurious trip from high temperature condition.

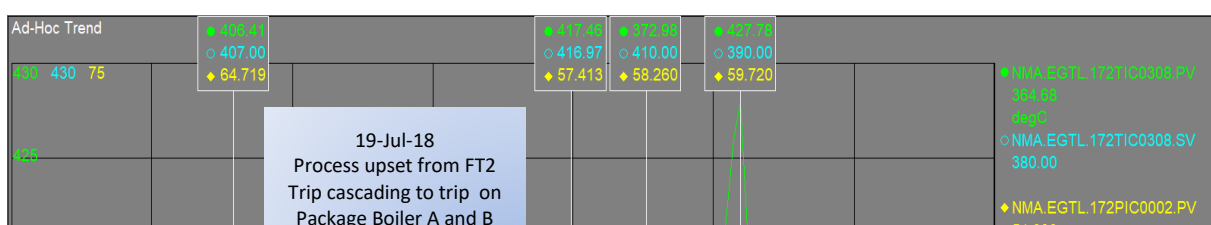


Table 2.1 A PI application graph of package boiler trip because of attemperation temperature

To ensure better temperature control, an artificial neural network solution is recommended on the package boiler temperature loop. A NEURAL NETWORK tool is used to develop the plant model based on the plant historical data and subsequently use the model to predict future temperature thereby helping the PID controllers to respond early enough to anticipated temperature change by initiating sufficient attemperation water as at when due.

Methodology

3.1 Overview of the process data

One of the unique advantage of NEURAL NETWORK is that the model can be obtained from historical process data thereby removing the possibility of direct interaction with live process data which could be risky in process plant. The process data for this thesis is obtained from the PI application which is the primary historian software for the GTL plant. This data was uploaded to excel workbook through PI datalink addon tool on the workbook. The data is formatted properly so it can be read to Matlab application.

3.2 Selection criteria of inputs and output vectors

To achieve desired NEURAL NETWORK model for this work, careful review and classification of the associated parameters of the package boiler temperature loop was done. The inputs vectors of the models (MVs) were selected from the temperature loops as those parameters that have direct correlation to the Attenuation temperature of the boiler;

1. Tail Gas Flow (TG) - This is the 'waste' natural gas that comes from plant process and is of much lower calorific value compare to natural gas. It is normally routed to flare but could be added as fuel sources to reduce required natural gas as cost reduction initiative.
2. Natural Gas Flow (NG) - This is the main fuel source to the package boiler
3. Attenuator temperature (BT) - This is the upstream steam temperature of the package boiler as it delivers steam to the HPSH. The operating temperature of the package boiler is considered to set the temperature trip point to avoid material damage to the boiler. It is important to select this parameter as one of the input so that NEURAL NETWORK can use it to make prediction of future temperature.
4. Attenuator water valve % opening (CW) - This is also called 'quench' water as it is used to manage the steam temperature of the boiler.

The output vector (CV) is the Attenuator temperature of the boiler which is the parameter that we try to control to ensure efficient operation of the package boiler such that we operate below the trip point even in process upset scenario.

1. Attenuator temperature (BT)

All identified input parameters were obtained and formatted as shown in the sample below;

Sample	TG (MV1)	NG (MV2)	CW (MV3)	BT (MV4)
--------	----------	----------	----------	----------

Time				
30	47.43905258	21.05890656	23.83969307	406.9502512
60	47.60954285	21.09671402	23.90129662	406.9504574
90	46.55300903	21.09859657	23.96128082	406.8170877
120	46.50693512	21.07294083	24.01597977	406.799095
150	46.50465775	19.96000671	24.07229614	406.8146582
180	46.61660004	19.97196579	24.13638687	406.7825459
210	47.04130554	20.97885323	24.1892128	406.7120221
240	46.69343948	21.00439262	24.18764114	406.636217
270	46.81987	21.02524567	24.18606758	406.6027032
300	46.81612778	21.02288246	24.14736176	406.552621
330	46.78412628	21.07621193	24.06262398	406.4572173
360	46.59970856	21.07235718	23.97130203	406.3964904
390	46.04282379	21.07270241	23.85626984	406.3892149
420	46.27132034	21.03628731	23.73211479	406.4515484
450	45.68882751	21.03041077	23.58196831	406.3975269
480	46.06724167	21.07563972	23.43196487	406.3684223
510	46.0229454	21.09994125	23.28625679	406.3604821
540	45.87637329	21.10294914	23.14055061	406.3399048
570	46.3022728	21.07340431	23.00111771	406.4305231

Table 3.0 Sample data of input vectors

3.3 Data Analysis and parameter selection

The dataset of the 4 input vectors (NG, TG, BT and CW) were obtained for 18 July 2018 between 00:00hrs and 02:49hrs with more than 95% (3219 of 3224) of the dataset covering normal plant operation. This is particularly important such that the model have a good resemblance of the real process. The other less than 5% of the data contained behaviour during process upset scenario was deliberately captured to compare model's behaviour in such situation.

A dataset of 3224 samples was used for the analysis with 70% for training, 15% for validation and last 15% for testing.

There is no theoretical basis as of yet to determine number of hidden layers and number of neurons per each layer in neural network. Generally, a shallow network uses 1 hidden layers while deep network starts from at least 2 hidden layers. Most neural network will do just fine with 2

hidden layers especially with fewer dataset. For the purpose of this analysis, we tried different hidden layer and neurons but got the best result with 3-hidden layer with 20, 30 and 20neurons for each layer respectively.

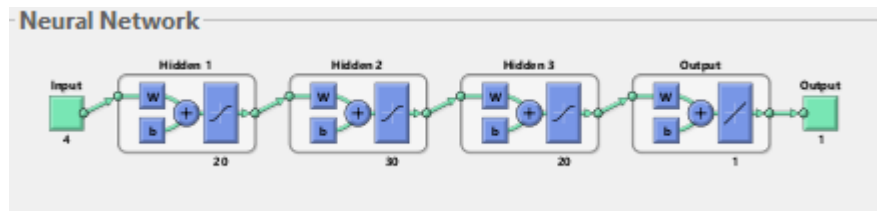


Fig. 3.0 The neural network showing hidden layers and neurons

Chapter 4

Neural network design and evaluation

4.1 NEURAL NETWORK model formulation in Matlab

The formatted process data is saved as 'main_process_data.xls' and read into Matlab application using Matlab code below;

```
%% Read Dataset
T = readtable('main_process_data.xls');
data = T.Variables;
xin = data(:,2:end-1)/4;
y = data(:,end);
```

To develop a neural network, one can either call 'nftool' from Matlab application or using Matlab code. This thesis applied Matlab code to generate the model. The code below included selection of inputs to the model and the prediction which is delayed by 150secs;

```
%% ANEURAL NETWORK Model
% 2min:30-seconds delay {4-input}
del = floor(30*5/delay);
xin2 = [xin(1:end-del,:) y(1:end-del,:)];
y2 = y((del+1):end,:);

net = fitnet([10 10]);
net.divideParam.trainRatio = 70/100;
net.divideParam.valRatio = 15/100;
net.divideParam.testRatio = 15/100;
net = train(net,xin2',y2');
%yp2 = net(xin2');

% -----4 inputs-----
X = NaN(size(xin,1)+del,size(xin,2)+2);
X(1:end-del,1:end-1) = [xin y(:)];
X(del+1:end,end) = net(X(1:end-del,1:end-1)')';
```

The NEURAL NETWORK was designed to be able to make future prediction of attemperator temperature such that the model is able to predict what the value of boiler temperature will be in 2.5mins (150secs) time. This prediction will help the PID loop to respond early to possible future temperature rise, thereby preventing the temperature from reaching the trip setpoint.

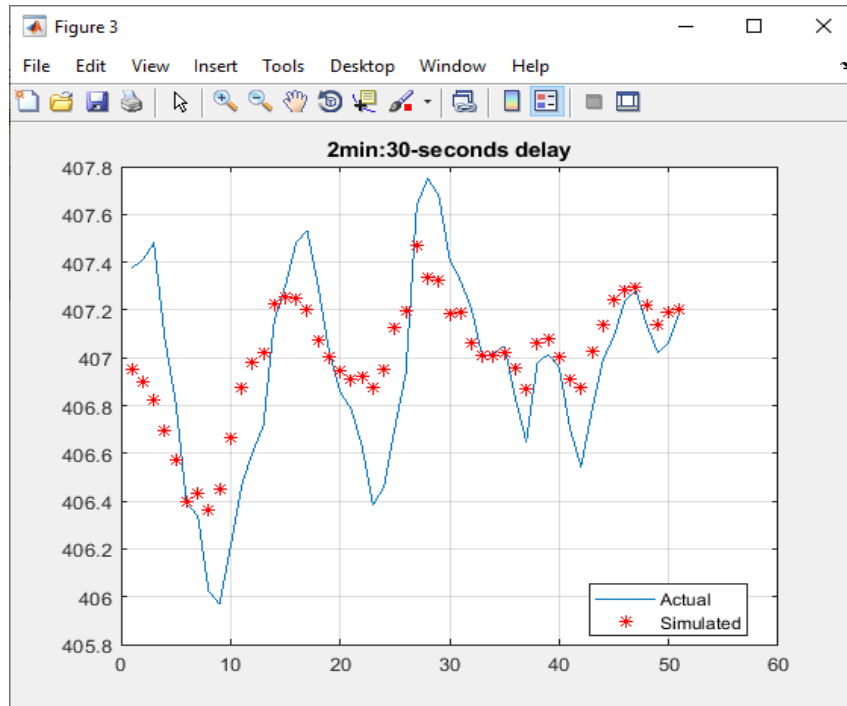


Fig. 4.0 Target vs neural network output with 150secs delay

4.2 NEURAL NETWORK Analysis and Evaluation

The NEURAL NETWORK model was evaluated using regression and performance plot on the Matlab and the result was good.

4.2.1 Performance plot

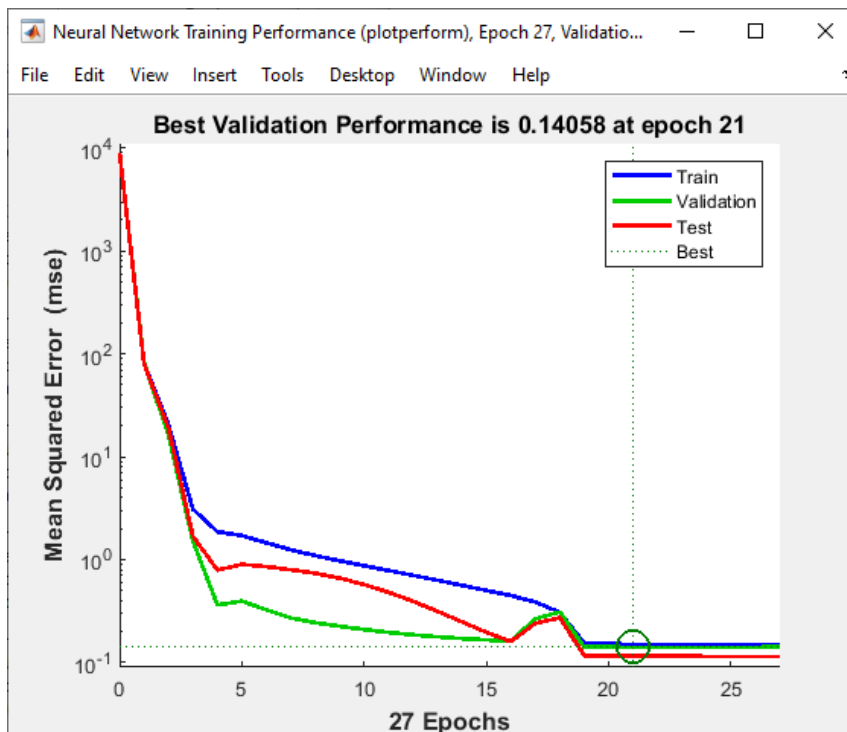


Fig. 4.1 NEURAL NETWORK performance plot

The low MSE value 0.14058 on performance plot indicate a well trained ANEURAL NETWORK as the desired output and ANEURAL NETWORK output appeared converge at Epoch 21.

4.2.2 Regression plot

This plot compares the target values to the NEURAL NETWORK output for all sample data used for training, validation, and testing. The test result shows some outliers, but the overall regression value below is 0.96071 which indicate that the neural network output is close to the target output. A perfect regression is given as unity value.

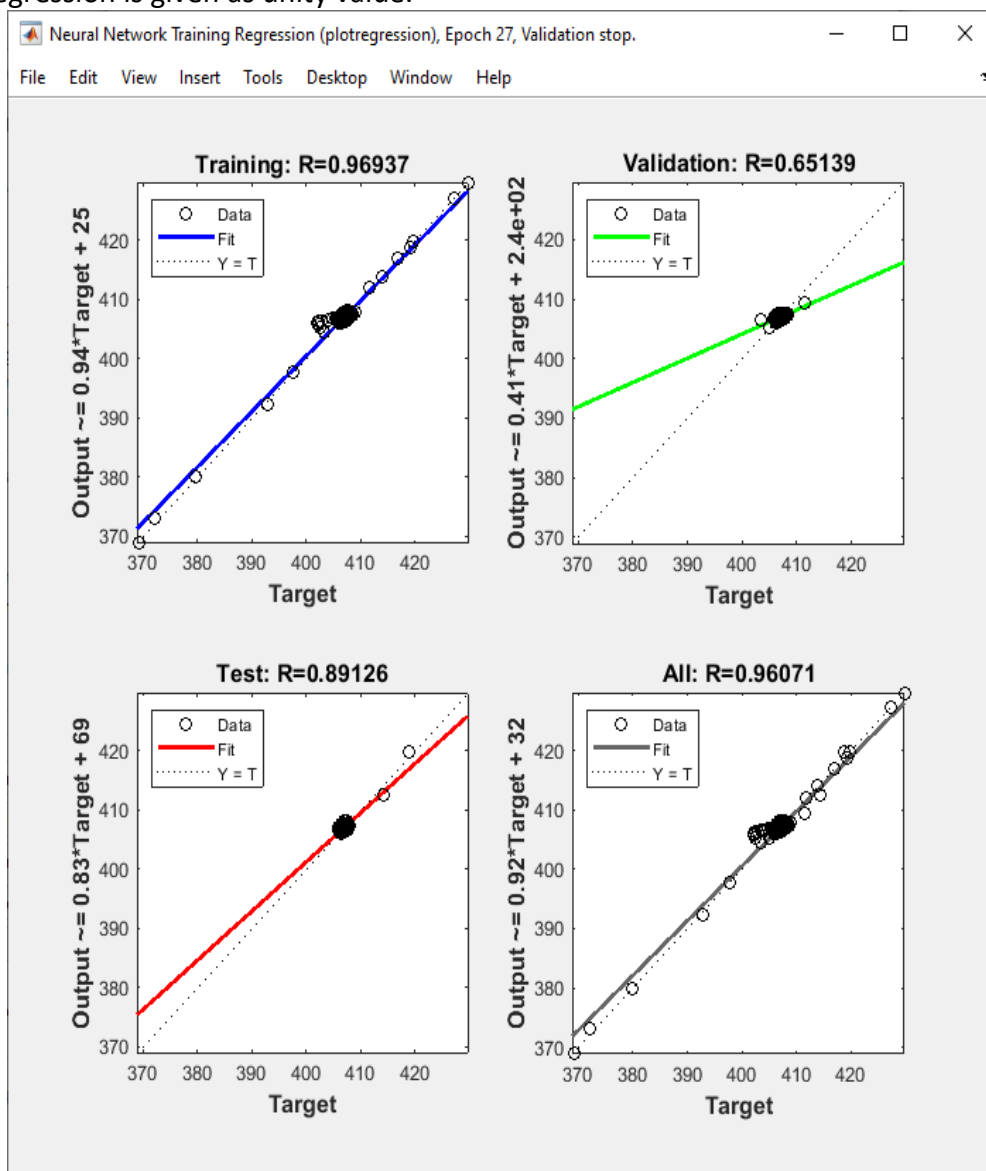


Fig. 4.2 NEURAL NETWORK Regression plot

4.2.3 Neural network Training

The parameters for the training of the network was selected as shown below;

Data division: Random

Training: Levenberg-Marquardt

Performance: Mean Squared Error



Fig. 4.3 NEURAL NETWORK neural network training box

4.3 Performance result and comparison

The neural network generated was used to make prediction and the result was read to an excel workbook where it can be compared to target output from process data.

4.3.1 Neural network result with time-delay

Different time delay (150, 210sec) was used with the neural network output predictions and compared with process data for accuracy and consistency. This was done with a Matlab code as seen below;

```
% 2min:30-seconds delay
del = floor(30*5/delay);
xin2 = [xin(1:end-del,:) y(1:end-del,:)];
y2 = y((del+1):end,:);

net2 = fitnet([20 30 20]);
net2 = train(net2,xin2',y2');
yp2 = net2(xin2');

perf2 = perform(net2,yp2,y2);

% 3min:30-seconds delay
del = floor(30*7/delay);
xin3 = [xin(1:end-del,:) y(1:end-del,:)];
y3 = y((del+1):end,:);

net3 = fitnet([20 30 20]);
net3 = train(net3,xin3',y3');
yp3 = net3(xin3');

perf3 = perform(net3,yp3,y3);
```

A plot of simulated output vs actual (from process data) was plotted for comparison below;

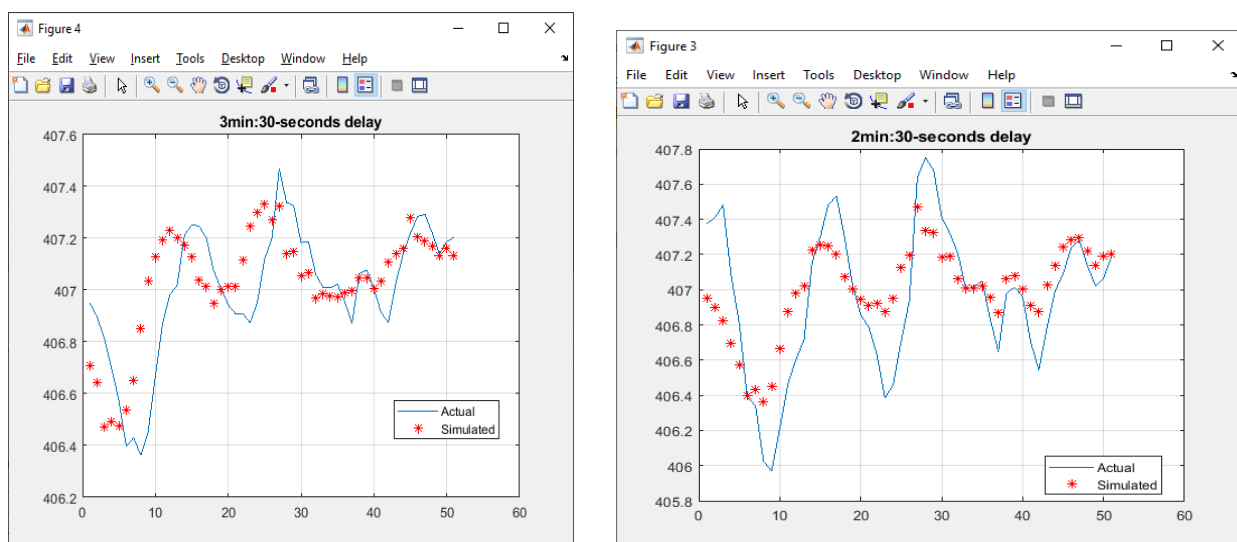


Fig. 4.4 Sample of actual vs simulated output with time delay

The neural network with **150secs** delay was better fitted with process output and was used for this thesis. The table below shows the result of the neural network for each samples of input data

TG	NG	CW	BT	BT150	BT210
52.91599655	21.13598442	21.64222717	404.1571045	405.9701149	406.3746016
50.46305847	21.22984695	21.01987076	403.4698181	405.6495968	406.2485684
48.5283699	21.4625473	20.29797173	402.868927	405.3092977	406.0883853
47.07256699	21.61700821	19.54314613	402.3070984	404.6018313	405.7640644
45.58293915	21.81506538	18.75549316	402.125885	403.4167948	405.2598832
43.43444061	22.1194191	18.01378822	402.1626587	401.5550496	404.4521122
41.5790062	23.39726448	17.35024834	402.5056763	401.8650614	405.2036948
40.16127777	24.70713806	16.84715271	403.4124146	403.7988425	406.5136964
38.63951492	26.19826698	16.83458138	404.9107056	405.0910658	407.744367
37.06654358	28.05225945	17.09552956	406.5789185	406.4455841	409.508243
35.22003555	29.67977333	17.92767525	408.9872437	408.6258185	412.5915993
34.08583069	32.11710358	18.75982094	411.4378357	411.3632154	416.9368475
32.45208359	34.24435806	21.17500496	414.2382507	414.0765425	419.7707304
31.06673622	37.04927063	24.0180397	416.7663574	416.823422	418.8143193
29.16128731	37.04927063	32.79286575	418.8262024	419.0152272	412.0730604
27.51273537	44.89438629	42.96875763	419.1394348	418.9367818	392.1830698
26.48667908	48.20598221	53.14464951	411.6639404	411.7400123	373.0844247
25.97590637	52.37466812	61.7578125	392.8957825	392.8793968	368.87249
25.97590637	55.47776413	31.48335838	372.213501	368.1674572	379.9567848

Table 4.0 sample result of neural network model with 150 and 210sec delay

4.3.2 Neural network prediction's analysis

The neural network result is the prediction of package boiler temperature 150secs ahead of time such that when integrated properly, the existing temperature loop PID controllers can see the future temperature earlier and begin to move the CV accordingly thereby having a better control and preventing high temperature trip.

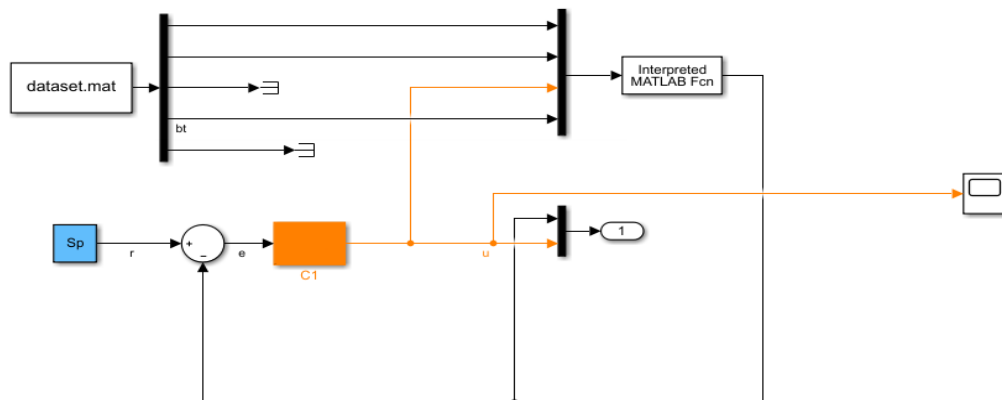


Fig 4.5 neural network model integration to existing PID controller

The full integration scope was not covered in this thesis but intended for future work but a Simulink model of the neural network was customized to provide platform to operator for instant simulation of required attemperation water (CW) that is required to achieve a particular temperature (BT).

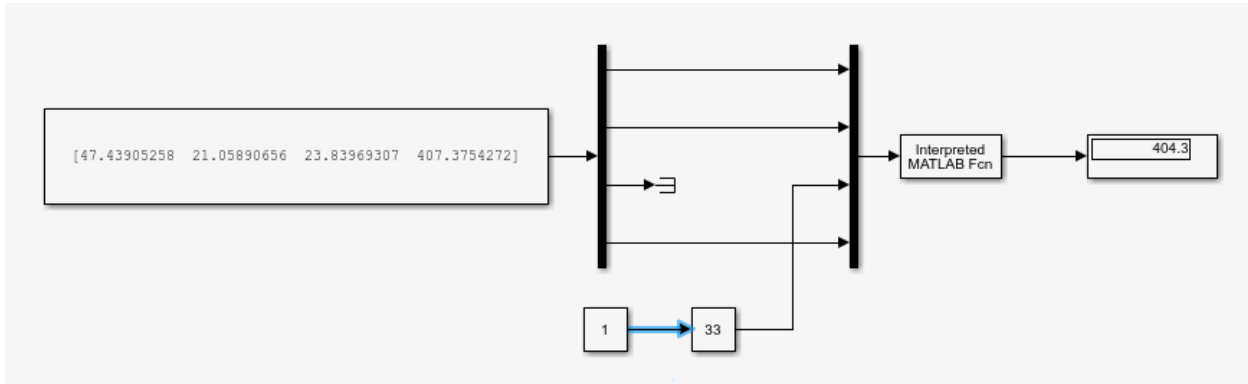


Fig. 4.5A Simulink model for instant temperature prediction

This is particularly important for smooth operation such that the exact attemperation water (cooling water) required to keep desired temperature can be achieved on the spot, thereby helping to run the boiler unit safely and efficiently.

4.3.3 Input data weight evaluation

One of the factors that affect the accuracy of neural network is the careful selection of the right input vectors. These input contributed to the overall output at different amount. To evaluate the contribution of each inputs, we statistically analyse random 100 samples of the output of the neural network and compare with output when one input is missing and found as follows;

TG	NG	CW	BT	BT150_4 _inputs	BT150_ no_TG	BT150_no _NG	BT150_no _CW	BT150_no_ BT_input
51.17	21.07	24.37	406.83	406.71	352.64	393.05	407.93	372.45
50.98	21.07	24.35	406.76	406.76	352.65	392.89	407.98	372.42
51.22	21.09	24.33	406.81	406.73	352.65	393.15	407.94	372.46
51.27	21.07	24.30	406.79	406.73	352.65	393.31	407.93	372.48
51.07	21.10	24.27	406.84	406.79	352.63	393.11	407.98	372.43
50.80	21.10	24.27	406.92	406.80	352.62	393.23	407.98	372.44
50.69	21.11	24.27	407.08	406.81	352.63	393.07	408.00	372.42
50.97	21.08	24.26	406.98	406.80	352.63	393.30	407.97	372.45
51.32	21.19	24.26	406.85	406.80	352.63	393.35	407.96	372.46
50.97	21.15	24.23	406.78	406.83	352.63	393.28	407.99	372.44
50.93	21.14	24.20	406.77	406.86	352.62	393.15	408.02	372.42
51.07	21.16	24.16	406.75	406.90	352.60	393.17	408.04	372.41
50.81	21.16	24.12	406.78	406.86	352.61	393.31	408.00	372.43
50.84	21.17	24.10	406.90	406.82	352.65	393.47	407.96	372.48
50.75	21.19	24.08	407.02	406.84	352.65	393.23	408.00	372.44
50.88	21.19	24.08	407.08	406.84	352.65	393.23	408.00	372.44

50.58	21.22	24.08	407.11	406.83	352.66	393.36	407.99	372.46
51.00	21.18	24.08	407.05	406.86	352.66	393.26	408.02	372.44
50.84	21.22	24.08	406.98	406.88	352.64	393.37	408.02	372.45
50.78	21.21	24.08	407.03	406.91	352.63	393.40	408.03	372.44
50.71	21.20	24.08	407.08	406.91	352.62	393.52	408.02	372.45
50.27	21.24	24.08	407.05	406.94	352.63	393.33	408.05	372.43
50.70	21.22	24.08	407.11	406.90	352.63	393.59	408.01	372.47
50.88	21.19	24.09	407.05	406.90	352.64	393.44	408.02	372.45
50.58	21.19	24.09	406.94	406.91	352.64	393.43	408.03	372.45
50.58	21.14	24.09	406.97	406.92	352.63	393.40	408.04	372.44
50.76	21.16	24.09	406.96	406.94	352.64	393.06	408.08	372.40
50.86	21.19	24.08	407.01	406.93	352.62	393.41	408.04	372.44
50.91	21.19	24.06	407.01	406.91	352.63	393.50	408.02	372.45
50.78	21.12	24.04	406.78	406.91	352.64	393.22	408.05	372.42
50.38	21.10	23.99	406.75	406.91	352.63	393.24	408.04	372.42
50.86	21.01	23.92	406.75	406.90	352.63	393.37	408.03	372.44
50.91	21.10	23.86	406.50	406.90	352.63	393.47	408.02	372.45
50.78	21.09	23.77	406.53	406.90	352.63	393.53	408.01	372.46
50.78	21.07	23.69	406.52	406.87	352.66	393.33	408.02	372.44
50.47	21.06	23.60	406.55	406.89	352.66	393.09	408.06	372.40
51.15	21.07	23.54	406.46	406.87	352.64	393.50	408.01	372.44
51.00	21.08	23.48	406.63	406.83	352.70	393.46	408.00	372.47
51.13	21.02	23.45	406.70	406.86	352.70	393.50	408.01	372.46
51.00	21.03	23.42	406.85	406.87	352.70	393.60	408.01	372.46
50.82	20.97	23.42	407.00	406.90	352.70	393.50	408.04	372.44
50.99	20.97	23.42	407.06	406.84	352.72	393.97	407.97	372.52
51.69	21.00	23.42	407.10	406.89	352.70	394.04	407.99	372.51
51.58	20.94	23.42	407.25	406.89	352.68	394.21	407.98	372.52
51.12	20.93	23.42	407.36	406.93	352.66	394.23	407.99	372.51
51.18	20.92	23.42	407.38	406.96	352.63	394.19	408.02	372.48
51.06	20.92	23.42	407.41	406.96	352.62	394.34	408.00	372.50
51.53	20.91	23.42	407.35	406.90	352.62	394.82	407.93	372.59
50.79	20.94	23.42	407.40	406.94	352.59	394.84	407.95	372.56
50.88	20.93	23.42	407.38	406.99	352.57	394.60	407.99	372.51
50.56	20.92	23.42	407.40	406.99	352.57	394.65	407.99	372.51
50.96	20.91	23.88	407.35	407.00	352.56	394.58	408.00	372.50
50.87	20.90	23.91	407.21	406.96	352.57	394.87	407.95	372.55
50.64	20.87	23.95	407.24	407.02	352.57	394.38	408.03	372.47
50.47	20.90	23.98	407.25	407.01	352.57	394.44	408.02	372.48
50.36	20.89	24.02	407.22	407.03	352.56	394.22	408.05	372.45
50.51	20.90	24.05	407.15	406.95	352.55	393.96	408.01	372.44
50.76	20.90	24.05	407.08	406.93	352.56	393.78	408.01	372.43
50.41	20.86	24.05	407.13	406.94	352.55	393.59	408.04	372.40
50.44	20.85	24.05	407.01	406.95	352.55	393.44	408.05	372.38
50.28	20.85	24.05	407.07	406.94	352.55	393.29	408.06	372.37
50.28	20.89	24.05	406.99	406.92	352.56	393.34	408.05	372.38

50.58	20.91	24.06	406.90	406.90	352.57	393.48	408.02	372.41
50.52	20.86	24.06	406.90	406.92	352.56	393.25	408.06	372.37
50.67	20.90	24.05	406.90	406.90	352.57	393.20	408.05	372.37
50.23	20.90	24.05	406.92	406.91	352.56	393.11	408.07	372.35
49.50	20.90	24.04	406.82	406.91	352.58	393.07	408.07	372.36
48.12	20.93	23.98	406.69	406.88	352.60	393.24	408.04	372.39
50.03	20.99	23.87	406.36	406.88	352.59	393.20	408.04	372.38
50.18	20.97	23.71	406.01	406.88	352.60	393.30	408.03	372.40
50.45	20.97	23.49	405.79	406.90	352.59	393.00	408.07	372.36
50.95	20.96	23.23	405.62	406.90	352.61	392.40	408.15	372.29
51.55	21.03	22.70	405.29	406.88	352.63	391.25	408.35	372.19
52.24	21.01	22.17	404.83	406.86	352.70	392.76	408.09	372.36
52.92	21.14	21.64	404.16	406.81	352.75	392.85	408.06	372.39
50.46	21.23	21.02	403.47	406.78	352.79	393.18	408.02	372.43
48.53	21.46	20.30	402.87	406.73	352.83	393.69	407.95	372.51
47.07	21.62	19.54	402.31	406.64	352.92	394.43	407.85	372.66
45.58	21.82	18.76	402.13	406.42	353.01	395.02	407.69	372.83
43.43	22.12	18.01	402.16	406.00	353.17	395.25	407.44	373.06
41.58	23.40	17.35	402.51	406.64	353.34	394.63	407.92	372.76
40.16	24.71	16.85	403.41	406.88	353.55	393.90	408.33	372.62
38.64	26.20	16.83	404.91	407.03	353.74	393.34	408.84	372.55
37.07	28.05	17.10	406.58	407.30	353.90	392.84	409.68	372.49
35.22	29.68	17.93	408.99	407.95	354.07	391.60	411.86	372.37
34.09	32.12	18.76	411.44	409.54	354.58	390.45	415.82	372.41
32.45	34.24	21.18	414.24	411.87	355.11	389.44	419.56	372.49
31.07	37.05	24.02	416.77	415.32	355.65	387.14	419.92	372.54
29.16	37.05	32.79	418.83	419.83	356.44	382.42	404.94	372.61
27.51	44.89	42.97	419.14	420.13	356.86	369.91	374.98	372.55
26.49	48.21	53.14	411.66	410.87	357.93	355.14	365.58	372.71
25.98	52.37	61.76	392.90	388.56	358.13	336.17	361.77	372.57
25.98	55.48	31.48	372.21	373.75	358.79	325.81	360.91	372.54
21.97	59.02	1.58	369.31	369.55	355.24	321.82	359.13	371.91
20.83	63.36	1.58	379.75	379.25	359.93	324.23	361.06	371.89
20.27	65.56	3.02	397.64	397.94	365.92	356.53	366.92	371.78
19.58	65.92	39.89	413.90	412.65	355.16	405.12	389.92	371.76
18.52	68.94	76.76	427.18	428.28	382.15	405.38	441.01	376.22
18.50	13.48	101.47	429.71	443.58	381.05	410.44	443.50	434.52
18.50	10.88	101.48	419.72	419.18	379.01	361.82	415.90	440.80
			Mean	406.900	352.637	393.339	408.017	372.446
			Standard dev	7.865	5.076	14.758	12.784	9.191
			% output reduction		0.133	0.033	-0.003	0.085
			Absolute reduction		0.133	0.033	0.003	0.085

Table 4.0 Output comparison with varying input with 100 samples

It was observed as follows;

- I. With no TG, 13% deviation was observed on the outputs
- II. With no NG, 3% deviation was observed on the output
- III. With no CW, 0.3% deviation was observed on the output
- IV. With no BT, 8.5% deviation was observed on the output

With these findings, it is therefore safe to conclude that Tail gas (TG) contributed the highest impact to the input vectors follows by Boiler temperature (BT) with cooling water contributing the least.

Chapter 5

Conclusion and Recommendation

5.1 Remarks and conclusion

This research work has been able to successfully demonstrate how to apply neural network to optimize critical temperature control loop in steam production of a Gas-to-liquid plant. Although, neural network has been applied to boiler temperature loop control in other research work, but the GTL plant offers a different perspective in terms of fuel sources; natural gas and tail gas unlike many boilers with single fuel sources. The neural network was developed with historical process data and this is an advantage over other MPC solution that could have required using live process data.

The neural network was tested and demonstrated better performance as the future temperature rise could be determine in advance and the right response can be initiated to prevent high temperature trip.

The work also provided a Simulink tool that support instant operation action of bringing the temperature under control by simulating the right amount of cooling water for temperature attemperation.

5.2 Recommendation and future work

It is recommended that all related variables (MVs) are identified and used as input vectors for the model and that a sizeable volume of process data is used to develop the model. Another opportunity is to integrate the output of the model to an existing temperature loop PID controller in a closed loop.

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Appendix A

Process data used for NEURAL NETWORK model (sample data)

Sample Time (secs)	(TG)	(TG)	(CW)	(BT)
30	47.439	21.059	23.840	407.375
60	47.610	21.097	23.901	407.368
90	46.553	21.099	23.961	407.474
120	46.507	21.073	24.016	407.483
150	46.505	19.960	24.072	407.480
180	46.617	19.972	24.136	407.386
210	47.041	20.979	24.189	407.095
240	46.693	21.004	24.188	407.013
270	46.820	21.025	24.186	406.895
300	46.816	21.023	24.147	406.754
330	46.784	21.076	24.063	406.526
360	46.600	21.072	23.971	406.384
390	46.043	21.073	23.856	406.383
420	46.271	21.036	23.732	406.383
450	45.689	21.030	23.582	406.279
480	46.067	21.076	23.432	406.091
510	46.023	21.100	23.286	406.007
540	45.876	21.103	23.141	405.910
570	46.302	21.073	23.001	405.945
600	46.264	21.075	22.873	406.061
630	46.151	21.082	22.750	406.146
660	46.059	21.116	22.634	406.255

690	46.334	21.092	22.519	406.335
720	46.195	21.143	22.433	406.463
750	46.275	21.119	22.346	406.519
780	45.906	21.103	22.278	406.604
810	46.321	21.126	22.220	406.604
840	45.726	21.106	22.179	406.604
870	45.589	21.121	22.166	406.744
900	45.312	21.160	22.164	406.999
930	45.820	21.130	22.178	407.139
960	45.886	19.857	22.191	407.238
990	45.873	20.647	22.205	407.300
1020	45.703	21.064	22.255	407.300
1050	45.581	21.037	22.313	407.414
1080	45.677	21.063	22.407	407.485
1110	46.122	21.077	22.508	407.523
1140	46.220	21.102	22.615	407.544
1170	45.905	21.164	22.723	407.511
1200	45.510	21.141	22.757	407.474
1230	45.812	21.167	22.763	407.256
1260	46.477	21.143	22.771	407.128
1290	46.168	21.151	22.780	407.040
1320	46.089	21.142	22.789	406.954
1350	46.410	21.133	22.787	406.899
1380	46.042	21.178	22.784	406.828
1410	46.399	21.138	22.780	406.798
1440	45.977	21.140	22.757	406.787
1470	46.212	21.125	22.731	406.818
1500	46.259	19.921	22.688	406.684
1530	46.816	20.743	22.637	406.552
1560	46.919	21.085	22.522	406.384
1590	46.692	21.056	22.406	406.384
1620	46.538	21.123	22.323	406.384
1650	46.488	21.153	22.248	406.444
1680	47.080	21.076	22.184	406.520
1710	46.987	21.134	22.123	406.533
1740	46.847	21.122	22.108	406.823
1770	46.667	21.084	22.105	406.934
1800	46.545	21.130	22.106	406.934
1830	47.563	21.115	22.110	407.413
1860	47.864	21.127	22.226	407.573
1890	47.521	21.120	22.366	407.737
1920	47.211	21.126	22.479	407.795
1950	46.793	21.102	22.589	407.739
1980	47.140	21.050	22.625	407.739
2010	47.155	21.069	22.659	407.739
2040	47.349	21.056	22.729	407.442

2070	46.994	21.050	22.801	407.419
2100	46.846	21.066	22.883	407.410
2130	47.514	21.022	22.965	407.381
2160	47.685	21.044	23.013	407.321
2190	47.391	21.068	23.059	407.280
2220	47.069	21.055	23.089	407.239
2250	47.048	21.054	23.116	407.156
2280	47.308	21.012	23.120	407.053
2310	47.385	21.027	23.122	406.990
2340	47.112	21.014	23.124	407.029
2370	47.267	21.033	23.126	407.012
2400	47.375	21.015	23.144	407.049
2430	47.378	21.052	23.161	407.066
2460	47.482	21.054	23.165	407.038
2490	47.553	19.542	23.169	406.966
2520	47.567	20.748	23.168	406.831
2550	47.395	21.076	23.167	406.643
2580	48.144	21.109	23.115	406.661
2610	48.257	21.111	23.060	406.629
2640	48.288	21.158	23.056	406.863
2670	48.212	21.165	23.054	407.007
2700	47.997	21.218	23.053	407.007
2730	48.167	21.152	23.053	407.017
2760	48.076	21.208	23.053	407.007
2790	47.648	21.238	23.053	407.028
2820	47.589	21.243	23.052	406.915
2850	47.634	21.268	23.043	406.773
2880	47.913	21.268	22.957	406.702
2910	47.805	21.120	22.870	406.521
2940	47.787	21.156	22.815	406.494
2970	47.830	21.169	22.768	406.618
3000	47.718	21.241	22.745	406.758
3030	48.241	21.254	22.727	406.787
3060	48.292	21.272	22.708	406.787
3090	48.066	21.280	22.690	406.980
3120	47.959	21.268	22.687	407.041
3150	48.064	19.718	22.687	407.080
3180	48.939	20.744	22.687	407.094
3210	48.675	21.175	22.695	407.117
3240	48.463	21.239	22.703	407.240
3270	48.238	21.227	22.720	407.300
3300	48.464	21.209	22.768	407.318
3330	48.719	21.259	22.804	407.230
3360	48.963	21.119	22.814	407.124
3390	48.382	21.128	22.830	407.140
3420	48.211	21.092	22.851	407.080

3450	48.163	21.096	22.865	407.035
3480	48.334	21.105	22.865	406.970
3510	48.701	21.085	22.865	406.971
3540	48.511	21.005	22.865	407.127
3570	48.130	21.029	22.873	407.190
3600	48.067	21.018	22.910	407.190
3630	48.607	21.075	22.942	407.220
3660	48.658	21.033	22.964	407.130
3690	48.762	20.978	22.985	407.040
3720	48.062	20.997	22.988	407.069
3750	48.211	21.053	22.930	406.638
3780	48.782	21.004	22.873	406.457
3810	48.800	21.052	22.797	406.425
3840	48.804	20.978	22.698	406.410
3870	48.342	21.027	22.599	406.373
3900	48.885	21.056	22.501	406.311
3930	49.743	21.077	22.415	406.288
3960	49.511	21.035	22.383	406.523
3990	49.154	21.078	22.350	406.683
4020	49.048	21.018	22.315	406.750
4050	49.218	21.061	22.278	406.750
4080	49.194	21.058	22.227	406.728
4110	49.272	21.051	22.178	406.835
4140	49.463	21.026	22.178	407.006
4170	49.599	21.021	22.177	407.057
4200	49.460	21.076	22.179	407.136
4230	50.011	21.079	22.183	407.387
4260	49.560	21.043	22.299	407.529
4290	49.515	21.046	22.455	407.743
4320	49.272	21.058	22.586	407.744
4350	50.187	21.014	22.656	407.689
4380	50.210	21.087	22.756	407.650
4410	50.163	21.039	22.888	407.744
4440	49.663	21.083	23.015	407.834
4470	49.988	21.117	23.136	407.757
4500	49.935	21.078	23.249	407.657
4530	50.108	21.113	23.293	407.496
4560	50.284	21.053	23.336	407.446
4590	50.160	21.053	23.380	407.446
4620	49.516	21.053	23.423	407.362
4650	50.041	21.072	23.452	407.300
4680	50.124	21.172	23.463	407.120
4710	50.200	21.144	23.481	407.164
4740	49.837	21.117	23.509	407.206
4770	49.529	21.094	23.538	407.153
4800	50.048	21.102	23.567	407.223

4830	50.025	21.099	23.592	407.193
4860	49.578	21.123	23.615	407.227
4890	49.314	21.122	23.637	407.135
4920	49.356	21.123	23.645	407.004
4950	49.685	21.080	23.649	406.897
4980	49.933	21.092	23.651	406.860
5010	49.060	21.126	23.652	406.930
5040	48.638	21.111	23.652	406.925
5070	49.262	21.107	23.648	406.921
5100	49.699	21.107	23.641	406.873
5130	49.300	21.159	23.631	406.843
5160	49.331	21.169	23.605	406.848
5190	48.891	21.109	23.579	406.721
5220	48.877	21.133	23.522	406.660
5250	49.277	21.179	23.453	406.534
5280	48.764	21.163	23.397	406.674
5310	48.296	21.133	23.352	406.742
5340	48.501	21.138	23.317	406.734
5370	48.792	21.137	23.286	406.746
5400	48.574	21.130	23.255	406.782
5430	48.630	21.120	23.224	406.867
5460	48.729	21.152	23.216	406.934
5490	48.539	21.169	23.209	406.934
5520	48.839	21.169	23.190	406.888
5550	49.181	21.157	23.158	406.934
5580	48.460	21.132	23.141	406.976
5610	48.411	21.132	23.138	406.961
5640	48.320	21.162	23.135	407.032
5670	48.996	21.174	23.133	407.080
5700	48.702	21.174	23.135	407.080
5730	48.296	21.141	23.136	407.153
5760	48.731	21.095	23.146	407.153
5790	48.398	21.070	23.162	407.153
5820	49.054	21.113	23.174	407.151
5850	48.735	21.098	23.184	407.132
5880	48.592	21.131	23.194	407.076
5910	48.358	21.139	23.200	407.080
5940	49.055	21.134	23.204	407.112
5970	49.133	21.142	23.208	407.024
6000	49.095	21.136	23.239	407.067
6030	48.671	21.118	23.274	407.109
6060	48.691	21.111	23.304	407.227
6090	48.455	21.118	23.331	407.227
6120	49.263	21.179	23.360	407.227
6150	49.210	21.121	23.401	407.211
6180	48.833	21.142	23.440	407.177

6210	48.713	21.092	23.471	407.179
6240	49.022	21.093	23.501	407.137
6270	49.014	21.103	23.507	407.077
6300	49.065	21.123	23.511	407.016
6330	49.386	21.101	23.515	406.947
6360	49.386	21.143	23.518	406.897
6390	48.584	21.154	23.516	406.896
6420	49.190	21.165	23.514	406.929
6450	49.190	21.136	23.514	407.000
6480	49.235	21.119	23.513	407.059
6510	49.155	21.178	23.513	407.007
6540	49.155	21.168	23.513	407.071
6570	49.556	21.168	23.512	407.077
6600	49.412	21.171	23.527	407.117
6630	49.420	21.130	23.560	407.117
6660	48.916	21.138	23.592	407.300
6690	49.814	21.139	23.671	407.300
6720	49.633	21.164	23.769	407.435
6750	49.601	21.154	23.806	407.373
6780	49.238	21.139	23.808	407.373
6810	48.964	21.127	23.823	407.263
6840	49.571	21.136	23.849	407.180
6870	49.618	21.153	23.874	407.153
6900	49.389	21.115	23.899	407.043
6930	49.330	21.161	23.903	407.043
6960	48.852	21.129	23.906	406.854
6990	49.222	21.092	23.897	406.741
7020	49.922	21.144	23.886	406.612
7050	49.401	21.135	23.841	406.641
7080	49.119	21.101	23.780	406.634
7110	49.126	21.122	23.718	406.604
7140	49.778	21.153	23.658	406.617
7170	49.154	21.126	23.621	406.640
7200	49.278	21.146	23.585	406.820
7230	49.073	21.149	23.562	406.846
7260	48.862	21.134	23.538	406.819
7290	49.152	21.136	23.519	406.897
7320	48.711	21.113	23.514	406.897
7350	48.538	21.138	23.509	406.897
7380	48.341	21.146	23.509	407.122
7410	48.445	21.048	23.509	407.076
7440	48.853	21.080	23.513	407.007
7470	48.965	21.077	23.518	407.007
7500	48.773	21.070	23.524	407.007
7530	48.413	21.134	23.537	407.184
7560	48.813	21.078	23.551	407.017

7590	49.124	21.118	23.555	406.970
7620	48.978	21.140	23.557	406.905
7650	48.929	21.113	23.558	406.970
7680	48.529	21.119	23.558	406.985
7710	48.847	21.107	23.558	406.999
7740	48.504	21.131	23.558	407.044
7770	48.805	21.133	23.558	407.057
7800	48.877	21.134	23.558	407.070
7830	48.308	21.137	23.558	407.067
7860	49.045	21.163	23.559	407.076
7890	49.048	21.170	23.573	407.184
7920	48.668	21.187	23.636	407.293
7950	48.483	21.179	23.703	407.452
7980	48.796	21.194	23.787	407.555
8010	48.593	21.208	23.870	407.534
8040	48.369	21.228	23.946	407.466
8070	48.511	21.160	23.976	407.300
8100	48.305	21.192	24.004	407.300
8130	48.354	21.208	24.004	407.041
8160	48.267	21.210	24.002	406.642
8190	47.994	21.196	23.898	406.493
8220	47.888	21.191	23.797	406.355
8250	47.943	21.176	23.667	406.510
8280	47.918	21.202	23.538	406.372
8310	48.115	21.187	23.464	406.387
8340	47.712	21.182	23.390	406.485
8370	47.788	21.186	23.318	406.604
8400	47.531	21.170	23.315	406.677
8430	47.873	21.154	23.312	406.760
8460	48.308	21.111	23.303	406.911
8490	48.498	21.115	23.280	406.973
8520	47.849	21.119	23.267	407.032
8550	47.895	21.132	23.267	407.080
8580	47.603	21.112	23.267	407.124
8610	48.154	21.133	23.273	407.184
8640	48.368	21.116	23.280	407.182
8670	47.680	21.097	23.295	407.266
8700	47.739	21.080	23.312	407.114
8730	47.883	21.146	23.329	406.982
8760	47.637	21.147	23.347	406.888
8790	48.068	21.137	23.338	406.846
8820	47.579	21.134	23.328	406.906
8850	47.824	21.093	23.323	406.964
8880	47.579	21.125	23.319	406.926
8910	47.525	21.099	23.318	406.960
8940	47.393	21.122	23.317	407.031

8970	47.135	21.130	23.315	407.101
9000	47.313	21.116	23.314	407.096
9030	47.839	21.111	23.320	407.176
9060	47.543	21.079	23.327	407.264
9090	47.492	21.112	23.404	407.313
9120	47.033	21.073	23.482	407.228
9150	47.141	21.113	23.489	407.079
9180	47.711	21.116	23.488	406.934
9210	47.576	21.141	23.475	406.934
9240	47.654	21.133	23.461	406.809
9270	46.850	21.135	23.436	406.762
9300	47.294	21.175	23.410	406.696
9330	47.358	21.157	23.368	406.797
9360	47.601	21.145	23.328	406.901
9390	47.276	21.183	23.328	407.035
9420	47.389	21.150	23.327	407.018
9450	47.695	21.178	23.308	406.927
9480	47.973	21.169	23.289	406.838
9510	47.989	21.159	23.270	406.782
9540	47.758	21.185	23.249	406.802
9570	47.507	21.158	23.225	406.860
9600	47.695	21.183	23.203	406.860
9630	47.837	21.163	23.203	406.970
9660	48.013	21.189	23.202	407.107
9690	47.864	21.167	23.208	407.277
9720	47.884	21.144	23.230	407.355
9750	47.690	21.124	23.252	407.283
9780	47.917	21.123	23.273	407.180
9810	47.840	21.144	23.281	407.043
9840	47.750	21.162	23.283	406.931
9870	47.942	21.148	23.284	406.894
9900	48.715	21.172	23.284	406.820
9930	48.759	21.185	23.284	406.842
9960	49.237	21.131	23.277	406.799
9990	49.237	21.162	23.269	406.824
10020	48.255	21.123	23.267	406.934
10050	48.061	21.126	23.267	406.894
10080	49.009	21.114	23.267	406.859
10110	48.703	21.088	23.267	406.824
10140	48.360	21.127	23.267	406.891
10170	48.690	21.146	23.170	406.897
10200	49.049	21.126	23.167	407.009
10230	49.597	21.138	23.164	407.214
10260	49.495	21.066	23.207	407.428
10290	49.314	21.066	23.289	407.644
10320	48.989	21.103	23.370	407.776

10350	49.075	21.139	23.508	407.776
10380	49.452	21.184	23.650	407.747
10410	49.710	21.112	23.774	407.761
10440	48.883	21.137	23.866	407.756
10470	48.857	21.143	23.956	407.728
10500	49.435	21.143	24.044	407.572
10530	49.507	21.121	24.131	407.474
10560	49.322	21.148	24.190	407.410
10590	48.956	21.117	24.235	407.333
10620	48.665	21.160	24.271	407.219
10650	49.602	21.142	24.305	407.043
10680	49.244	21.126	24.313	406.946
10710	48.383	21.144	24.313	406.866
10740	48.601	21.168	24.303	406.808
10770	48.381	21.155	24.290	406.780
10800	48.747	21.177	24.270	406.753
10830	48.186	21.133	24.248	406.845
10860	48.113	21.146	24.241	407.024
10890	47.738	21.138	24.237	407.079
10920	48.327	21.141	24.236	407.117
10950	48.376	21.142	24.236	407.167
10980	47.769	21.122	24.243	407.227
11010	47.590	21.153	24.251	407.322
11040	47.643	21.112	24.293	407.399
11070	47.631	21.118	24.346	407.254
11100	47.631	21.133	24.374	407.256
11130	47.252	21.077	24.393	407.118
11160	47.526	21.130	24.401	407.060
11190	46.788	21.136	24.405	407.058
11220	46.785	21.146	24.408	406.951
11250	46.739	21.122	24.409	406.841
11280	46.693	21.117	24.399	406.723
11310	46.603	21.127	24.377	406.772
11340	46.530	21.131	24.354	406.669
11370	46.522	21.114	24.253	406.494
11400	46.169	21.096	24.130	406.335
11430	45.964	21.126	24.013	406.300
11460	45.836	21.069	23.920	406.310
11490	45.661	21.058	23.827	406.421
11520	45.992	21.046	23.723	406.393
11550	46.116	21.066	23.623	406.431
11580	46.046	21.007	23.566	406.531
11610	45.528	21.008	23.508	406.579
11640	45.254	21.015	23.451	406.639
11670	45.635	20.982	23.394	406.604
11700	45.707	20.938	23.338	406.590

11730	45.575	20.951	23.277	406.634
11760	45.571	20.880	23.214	406.648
11790	45.442	20.813	23.163	406.649
11820	45.132	20.758	23.118	406.714
11850	44.840	20.801	23.069	406.772
11880	44.772	20.778	23.014	406.710
11910	44.745	20.742	22.967	406.677
11940	45.134	20.745	22.928	406.677
11970	45.009	20.721	22.907	406.712
12000	45.356	20.721	22.902	406.816
12030	45.235	20.777	22.895	406.864
12060	44.786	20.777	22.877	406.890
12090	44.805	20.692	22.859	406.801
12120	45.178	20.666	22.842	406.856
12150	45.255	20.658	22.824	406.963
12180	45.121	20.612	22.806	406.913
12210	45.048	20.647	22.804	407.098
12240	45.187	20.604	22.805	407.084
12270	45.343	20.604	22.807	407.060
12300	45.175	20.597	22.808	407.007
12330	45.143	20.623	22.809	407.070
12360	45.055	20.555	22.808	407.037
12390	45.292	20.555	22.805	407.007
12420	45.132	20.555	22.816	407.007
12450	45.462	20.642	22.819	406.966
12480	45.195	20.638	22.818	406.905
12510	45.700	20.641	22.813	406.806
12540	45.768	20.641	22.779	406.770
12570	45.790	20.706	22.746	406.769
12600	45.879	20.688	22.716	406.750
12630	45.805	20.746	22.687	406.750
12660	45.760	20.773	22.658	406.824
12690	45.886	20.750	22.631	406.794
12720	46.516	20.766	22.615	406.945
12750	45.971	20.726	22.611	407.256
12780	46.055	20.776	22.609	407.335
12810	45.773	20.788	22.658	407.373
12840	46.572	20.811	22.708	407.331
12870	46.429	20.373	22.736	407.234
12900	47.019	19.096	22.762	407.091
12930	46.694	20.774	22.769	406.934
12960	46.078	20.832	22.769	406.821
12990	47.426	20.905	22.767	406.880
13020	47.360	20.925	22.764	406.934
13050	47.354	20.987	22.770	406.934
13080	47.072	20.966	22.849	407.307

13110	46.815	21.002	22.934	407.617
13140	47.108	21.064	23.045	407.669
13170	47.108	21.092	23.152	407.668
13200	47.108	21.086	23.234	407.642
13230	47.348	21.131	23.310	407.536
13260	47.065	21.146	23.361	407.407
13290	47.312	21.146	23.412	407.313
13320	47.308	21.201	23.437	407.176
13350	47.643	21.168	23.439	407.210
13380	47.221	21.187	23.462	407.208
13410	46.814	21.183	23.508	407.035
13440	47.928	21.197	23.532	407.001
13470	47.908	21.231	23.532	407.036
13500	47.717	21.211	23.532	407.190
13530	47.548	21.211	23.534	407.148
13560	47.780	21.257	23.536	407.050
13590	47.959	21.235	23.536	406.885
13620	47.775	21.231	23.536	406.795
13650	47.956	21.238	23.533	406.822
13680	47.916	21.233	23.519	406.823
13710	48.448	21.267	23.505	406.926
13740	49.091	21.257	23.505	407.007
13770	48.441	21.342	23.505	407.082
13800	48.258	21.342	23.505	407.058
13830	48.082	21.308	23.505	406.990
13860	48.435	21.346	23.494	406.741
13890	48.581	21.320	23.400	406.585
13920	48.537	21.259	23.310	406.531
13950	48.108	21.300	23.261	406.563
13980	47.482	21.317	23.214	406.719
14010	48.785	21.322	23.213	406.835
14040	48.607	21.295	23.211	406.901
14070	48.631	21.309	23.211	407.064
14100	48.364	21.309	23.210	407.245
14130	48.622	21.305	23.217	407.281
14160	48.681	21.337	23.241	407.256
14190	48.748	21.255	23.272	407.293
14220	48.697	21.255	23.317	407.288
14250	48.297	21.255	23.363	407.277
14280	48.598	21.338	23.408	407.252
14310	49.132	21.348	23.453	407.227
14340	48.885	21.310	23.498	407.304
14370	48.703	21.259	23.575	407.405
14400	48.414	21.331	23.662	407.446
14430	49.136	21.316	23.694	407.349
14460	48.905	21.352	23.717	407.097

14490	48.887	21.309	23.712	406.922
14520	48.684	21.309	23.706	406.822
14550	48.521	21.282	23.699	406.669
14580	49.553	21.379	23.597	406.422
14610	49.538	21.311	23.491	406.361
14640	49.529	21.304	23.381	406.274
14670	49.221	21.306	23.272	406.334
14700	49.024	21.291	23.158	406.381
14730	49.477	21.286	23.031	406.400
14760	49.477	21.298	22.903	406.384
14790	49.442	21.298	22.868	406.384
14820	49.454	21.306	22.838	406.588
14850	49.784	21.322	22.808	406.634
14880	50.231	21.329	22.777	406.701
14910	50.141	21.329	22.745	406.768
14940	49.988	21.277	22.714	406.978
14970	49.584	21.295	22.706	407.042
15000	50.439	21.337	22.706	406.934
15030	50.780	21.271	22.704	406.903
15060	50.546	21.308	22.684	406.853
15090	50.342	21.277	22.665	406.920
15120	50.192	21.343	22.665	406.970
15150	51.046	21.320	22.665	406.947
15180	51.419	21.296	22.665	407.007
15210	51.134	21.283	22.665	407.098
15240	50.506	21.264	22.676	407.330
15270	49.993	21.308	22.702	407.346
15300	50.269	21.252	22.728	407.341
15330	50.954	21.308	22.804	407.422
15360	50.947	21.246	22.900	407.572
15390	51.159	21.275	23.047	407.769
15420	51.328	21.288	23.246	408.067
15450	51.718	21.325	23.486	408.324
15480	51.657	21.290	23.779	408.503
15510	51.347	21.245	23.999	408.470
15540	51.062	21.240	24.137	408.429
15570	51.994	21.281	24.308	408.468
15600	52.065	21.233	24.552	408.254
15630	52.227	21.297	24.767	408.118
15660	52.225	21.285	24.911	407.843
15690	51.199	21.267	25.033	407.552
15720	51.616	21.235	25.033	407.527
15750	51.830	21.285	25.033	407.663
15780	51.961	21.232	25.033	406.890
15810	51.370	21.236	25.018	406.874
15840	51.370	21.236	24.956	406.755

15870	51.247	21.265	24.895	406.616
15900	51.321	21.221	24.841	406.580
15930	50.970	21.294	24.790	406.633
15960	50.683	21.274	24.754	406.719
15990	50.504	21.259	24.730	406.770
16020	51.166	21.277	24.707	406.762
16050	51.506	21.242	24.672	406.766
16080	50.780	21.250	24.634	406.846
16110	51.113	21.256	24.609	406.934
16140	50.408	21.304	24.609	406.929
16170	50.846	21.353	24.605	406.859
16200	50.083	21.349	24.599	406.930
16230	49.769	21.339	24.596	407.002
16260	49.693	21.347	24.596	406.906
16290	50.019	21.309	24.596	406.967
16320	50.010	21.319	24.596	407.046
16350	50.444	21.354	24.595	407.154
16380	49.921	21.352	24.595	407.239
16410	49.071	21.329	24.601	407.190
16440	49.355	21.329	24.614	407.190
16470	49.416	21.329	24.620	406.843
16500	49.464	21.357	24.620	406.857
16530	48.771	21.404	24.610	406.799
16560	49.137	21.416	24.593	406.805
16590	48.312	21.381	24.557	406.750
16620	48.660	21.361	24.510	406.760
16650	48.788	21.329	24.470	406.751
16680	48.300	21.310	24.440	406.728
16710	48.056	21.313	24.403	406.686
16740	48.160	21.337	24.360	406.772
16770	48.016	21.395	24.324	406.808
16800	47.693	21.401	24.306	406.894
16830	47.531	21.323	24.288	406.933
16860	47.416	21.365	24.271	406.817
16890	47.240	21.364	24.223	406.787
16920	47.470	21.364	24.162	406.677
16950	46.857	21.269	24.087	406.620
16980	46.807	21.285	23.931	406.479
17010	46.683	21.298	23.774	406.235
17040	47.115	21.301	23.618	406.102
17070	47.078	21.290	23.462	405.933
17100	47.207	21.226	23.305	405.882
17130	47.021	21.140	23.148	405.798
17160	47.101	20.217	22.991	405.786
17190	47.061	19.903	22.791	405.652
17220	46.830	21.062	22.581	405.614

17250	46.837	19.248	22.365	405.579
17280	47.029	20.858	22.147	405.615
17310	47.188	21.053	21.901	405.688
17340	47.244	20.128	21.643	405.688
17370	47.294	19.599	21.572	405.688
17400	47.098	21.002	21.575	406.421
17430	46.905	21.024	21.579	406.421
17460	47.089	19.334	21.579	406.904
17490	47.298	20.771	21.579	407.007
17520	47.070	20.895	21.579	407.077
17550	47.025	20.819	21.579	407.042
17580	46.523	19.274	21.579	407.097
17610	46.893	20.978	21.579	406.963
17640	46.883	21.063	21.579	406.907
17670	46.494	21.077	21.579	406.984
17700	46.693	21.122	21.579	407.063
17730	46.445	21.128	21.580	407.190
17760	47.197	21.170	21.580	407.325
17790	47.016	21.184	21.624	407.308
17820	47.457	21.189	21.698	407.314
17850	47.065	21.201	21.765	407.309
17880	46.755	21.191	21.813	407.263
17910	47.160	21.189	21.847	407.227
17940	47.306	20.887	21.852	407.195
17970	47.423	20.325	21.866	407.163
18000	47.389	21.067	21.904	407.118
18030	46.702	21.147	21.942	407.179
18060	47.478	21.131	21.981	407.280
18090	47.904	21.137	22.036	407.435
18120	47.708	21.161	22.098	407.479
18150	47.344	21.119	22.163	407.549
18180	47.235	21.188	22.231	407.472
18210	47.682	21.178	22.292	407.394
18240	47.582	21.190	22.343	407.261
18270	47.613	19.287	22.394	407.235
18300	47.486	20.141	22.416	407.066
18330	47.209	20.141	22.414	406.970
18360	47.280	21.072	22.412	406.937
18390	47.603	21.118	22.410	406.997
18420	47.687	21.116	22.409	407.136
18450	47.260	21.138	22.420	407.251
18480	47.362	21.160	22.432	407.174
18510	47.514	21.180	22.441	407.113
18540	47.885	21.147	22.447	407.043
18570	47.468	21.145	22.462	407.043
18600	47.122	21.145	22.483	407.043

18630	47.102	19.444	22.504	407.177
18660	47.839	19.075	22.523	407.177
18690	47.666	21.078	22.542	407.163
18720	47.494	21.109	22.568	407.225
18750	47.311	21.109	22.610	407.294
18780	47.352	21.115	22.652	407.273
18810	47.435	21.168	22.692	407.227
18840	47.693	21.175	22.731	407.263
18870	47.417	21.128	22.795	407.346
18900	47.380	21.101	22.892	407.462
18930	47.703	21.157	22.957	407.379
18960	48.044	21.082	22.980	407.278
18990	47.836	19.690	23.012	407.231
19020	47.752	20.615	23.061	407.139
19050	47.595	21.018	23.084	406.935
19080	47.893	21.044	23.051	406.701
19110	48.337	21.058	23.024	406.715
19140	47.936	21.082	23.010	406.893
19170	47.657	21.083	22.998	406.956
19200	47.429	21.096	22.996	406.907
19230	47.652	21.127	22.986	406.860
19260	47.658	21.118	22.961	406.845
19290	47.576	21.128	22.936	406.897
19320	47.616	21.101	22.909	406.865
19350	47.070	21.162	22.875	406.824
19380	47.605	21.076	22.843	406.798
19410	47.392	19.201	22.832	406.930
19440	47.301	20.930	22.822	406.827
19470	47.252	21.063	22.803	406.848
19500	46.875	21.059	22.783	406.954
19530	47.538	21.063	22.782	407.007
19560	47.270	21.124	22.781	407.091
19590	47.281	21.066	22.782	407.190
19620	46.985	21.122	22.784	407.223
19650	46.859	21.086	22.818	407.273
19680	46.676	21.124	22.852	407.198
19710	47.198	21.133	22.861	407.162
19740	46.981	21.110	22.870	407.210
19770	46.757	21.139	22.910	407.211
19800	46.460	21.165	22.949	407.205
19830	47.004	19.500	22.975	407.226
19860	46.736	20.633	23.002	407.126
19890	46.925	21.036	23.007	407.044
19920	46.845	21.081	23.011	407.007
19950	46.706	21.129	23.011	406.970
19980	46.857	21.159	23.011	406.934

20010	46.668	21.115	23.009	406.858
20040	46.654	21.123	23.008	406.824
20070	46.437	21.163	22.992	406.768
20100	46.340	21.166	22.972	406.720
20130	46.568	21.174	22.930	406.654
20160	46.627	21.116	22.884	406.663
20190	46.506	19.762	22.838	406.819
20220	46.090	20.576	22.764	406.692
20250	46.427	21.057	22.682	406.496
20280	46.134	21.083	22.576	406.370
20310	46.564	21.134	22.470	406.390
20340	46.501	21.093	22.418	406.520
20370	46.271	21.116	22.375	406.668
20400	46.067	21.143	22.334	406.777
20430	46.568	21.183	22.299	406.820
20460	46.597	21.146	22.272	406.779
20490	46.976	21.196	22.264	406.801
20520	46.400	19.501	22.257	406.897
20550	46.978	21.004	22.239	406.854
20580	47.255	21.115	22.197	406.794
20610	46.898	21.086	22.156	406.860
20640	47.252	21.145	22.149	406.860
20670	46.856	21.082	22.142	406.860
20700	47.352	21.188	22.143	407.153
20730	47.842	21.162	22.143	407.260
20760	47.626	21.162	22.150	407.296
20790	47.595	20.639	22.179	407.213
20820	47.240	21.074	22.208	407.201
20850	47.882	21.017	22.226	407.153
20880	48.019	21.144	22.244	407.153
20910	47.961	21.135	22.263	407.153
20940	47.989	21.102	22.284	407.221
20970	47.379	21.136	22.349	407.315
21000	48.813	21.136	22.414	407.393
21030	48.692	21.152	22.514	407.464
21060	48.852	21.174	22.618	407.596
21090	48.446	21.199	22.748	407.717
21120	48.014	21.205	22.880	407.742
21150	48.810	21.209	22.949	407.776
21180	48.569	21.172	23.017	407.609
21210	48.412	21.165	23.078	407.432
21240	48.235	21.160	23.138	407.313
21270	48.248	21.180	23.193	407.138
21300	48.706	21.167	23.193	407.106
21330	49.047	21.190	23.199	407.049
21360	48.937	21.127	23.245	407.212

21390	48.583	21.154	23.307	407.457
21420	48.437	21.114	23.421	407.520
21450	49.165	21.195	23.529	407.610
21480	48.998	21.151	23.617	407.666
21510	48.798	21.158	23.722	407.770
21540	48.556	21.159	23.853	407.813
21570	48.221	21.147	23.994	407.813
21600	48.802	21.193	24.147	407.811
21630	48.306	21.154	24.276	407.703
21660	48.059	21.187	24.384	407.572
21690	48.343	21.205	24.430	407.367
21720	47.806	21.132	24.435	407.227
21750	47.565	21.172	24.437	406.976
21780	47.789	21.159	24.437	406.860
21810	47.439	21.171	24.436	406.860
21840	47.201	21.194	24.435	406.994
21870	46.978	21.130	24.430	406.935
21900	47.256	21.168	24.422	406.917
21930	46.443	21.197	24.414	406.885
21960	46.874	21.180	24.390	406.831
21990	46.409	21.175	24.364	406.734
22020	46.470	21.155	24.330	406.604
22050	46.772	21.200	24.221	406.537
22080	46.581	21.135	24.122	406.567
22110	46.589	21.210	24.073	406.596
22140	46.136	21.148	24.023	406.604
22170	46.282	21.205	23.948	406.526
22200	46.210	21.179	23.871	406.487
22230	45.963	21.186	23.724	406.317
22260	45.919	21.170	23.578	406.155
22290	45.754	21.216	23.446	406.062
22320	46.028	21.210	23.314	406.051
22350	45.342	21.210	23.170	406.048
22380	45.536	21.162	23.027	406.091
22410	45.339	21.195	22.884	406.240
22440	45.057	21.205	22.802	406.324
22470	45.247	21.183	22.767	406.495
22500	45.290	21.235	22.718	406.594
22530	45.348	21.201	22.665	406.820
22560	45.417	21.213	22.657	407.071
22590	45.007	21.223	22.661	407.227
22620	45.626	21.221	22.661	407.190
22650	45.426	21.254	22.661	407.270
22680	45.581	21.242	22.661	407.351
22710	45.213	21.261	22.661	407.246
22740	45.192	21.240	22.661	407.360

