IMPLEMENTATION OF TEMPERATURE CONTROL SYSTEM IN NGV CAR STORAGE

By

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FINAL YEAR PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

Disember 2005

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

23/12/05

Mohd. Aminullah B Mohd. Khalid

ABSTRACT

During dispensing natural gas from natural gas dispenser to NGV car storage tank, mass, pressure and temperature of the natural gas inside the tank are increase. Based on Ideal Gas Law, as mass is inversely proportional to temperature, the value of temperature should be as low as possible to get the maximum value of mass of natural gas dispensed to the tank. Thus, a temperature control system is invented using instrumentation equipments available in Natural Gas Test Rig and Industrial Automation Instrumentation Laboratory and simulated using LabView Data Acquisition software. A cooling mechanism represented by a fan and a heating mechanism represented by a light bulb are assembled in order to provide a specific range of temperature of the tank; if the temperature exceeded the highest limit a cooling system will starts and if the temperature goes below the lowest limit, a heating system will starts. While the temperature is within the range, a PID controller will control the temperature of the tank to a certain value that will maximize the mass dispenses into the tank.

ACKNOWLEDGEMENTS

First of all I would like to thank Allah the Almighty, for blessing me in my journey to complete my Final Year Project (FYP) as a partial fulfillment of the requirements for the Degree Bachelor of Engineering (Hons) in Electrical & Electronics Engineering Programme.

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LIST OF ABBREVIATIONS

Words	Abbreviation
Natural Gas Vehicle	(NGV)
University Technology of PETRONAS	(UTP)
Compressed Natural Gas	(CNG)
Virtual Instrument	(VI)
Research Officer	(RO)
Input-Output	(I/O)

CHAPTER 1
INTRODUCTION

1.1 Background

Automotive industry is one of the fastest growing industries in the world. This results to the production of million of highway vehicles that operate every single day which in turn imposes severe environmental problems to the world. Emissions from millions of cars and light-duty trucks, almost exclusively operating on gasoline and diesel fuel, are major contributors to this problem. In addition, heavy-duty trucks and buses using diesel fuel are major sources of particulates (small unburned particles of hydrocarbons and sulfur) and nitrogen oxide emissions in urban areas. Particulates are a special concern because the public is frequently exposed to them and current research suggests significant respiratory problems and cancer-causing potential from particulates (Bechtold, 1997).

Alternative vehicle fuels such as natural gas, methanol, ethanol, propane, and electricity have long been proposed as a way to provide significant air quality benefits over petroleum fuels. However, great interest is given to natural gas vehicle technology. Significant advances have been made in the past few years that have highlighted the efficiency and emissions potential of natural gas vehicles. In transportation sector, natural gas is becoming more important. Compressed Natural Gas Vehicle (CNGV) has many overwhelming advantages against traditional means of transportation using gasoline and diesel. Firstly, it brings environmental benefits because natural gas is completely burnt in comparison to gasoline, alcohol or diesel. This is why NGVs emit less pollutant, i.e. nitrous oxides (NOx), carbon dioxide (CO_2) and especially carbon monoxide (CO). Secondly, the natural gas resource is more abundant, which makes the fuel cost lower than gasoline. Besides, it is a safer fuel. As natural gas is lighter than air, in the case of leakage, it dissipates into the atmosphere, thereby reducing the risk of explosions and fires.

It has long been known that gasoline engines of the type used in automotive vehicles can, with relatively minor modifications, be made to run efficiently on compressed natural gas (CNG). Most CNG fuel systems currently in service were designed to be installed on a gasoline vehicle while retaining the gasoline fuel system. This bifuel approach allows the driver to change from one fuel to the other by flipping a switch (the vehicle can only use one fuel at a time), or the vehicle can be set up to switch automatically to gasoline when the CNG is depleted. The oldest-style natural gas fuel systems used the idea of reducing the pressure of the gas coming from the CNG tanks and employ simple mechanical mechanisms to mix the natural gas with the air entering the engine. In a normal car, the CNG tank is installed inside the back car boot and natural gas dispensed at the front car boot from dispenser to the storage tank (refer to figure 1.1 below) :

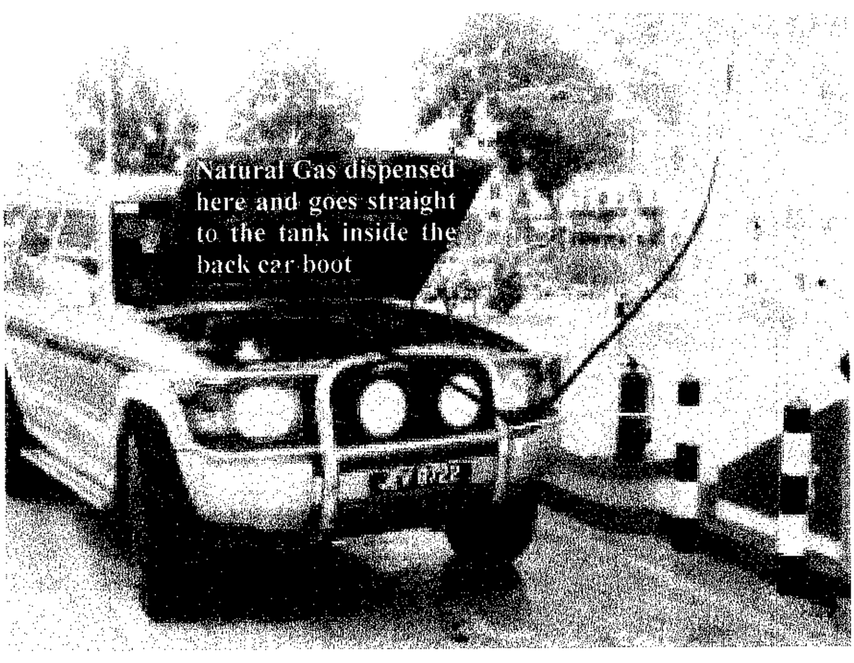


Figure 1.1: Dispensing natural gas from dispenser at the station to the car storage

1.2 Problem Statement

To dispensed compressed natural gas (CNG) to a natural gas vehicle (NGV), a hose from the storage vessels is connected to the tank on the vehicle to be refueled, allowing CNG to flow from storage vessel to the tank. During the dispensing operation, pressure and temperature of the car storage tank will increase. According to Ideal Gas Law (refer to Literature Review on Ideal Gas Law for detail explanation) formula:

$$PV = nRT \qquad (1-1)$$

Where:

V = volume in liters

n = moles of gas = mass / molecular mass = m / Mw

P = pressure in atm

T = temperature in Kelvin

R = the *molar gas constant*, where R=0.082058 L x atm x mol^{-1} x K^{-1}.

mass is inversely proportional to temperature, T if we rearrange the equation 1-1 to:

$$\frac{PV}{RT} = n \qquad (1-2)$$

$$\frac{PV}{RT} = \frac{m}{Mw} \qquad (1-3)$$

As both pressure and temperature increase during the dispensing operation, we won't get maximum amount of mass. Thus to maximize the mass dispensed to the tank, we need to control the value of temperature as low as possible while the pressure increases.

1.3 Objectives and Scope of Study

1.3.1 Objectives

1. To study and familiarize with the NVG test rig operation and process flow
2. To assemble necessary instrumentation equipments available at Natural Gas test Rig and Industrial Automation Instrumentation laboratory to be used for designing natural gas car storage temperature control system
3. To provide PID controller that will control the temperature of the tank to a certain value that will maximize the mass dispenses into the tank.

1.3.2 Scope of Study

The scope of this study will focus on designing natural gas car storage temperature control system using necessary instrumentation equipments available at Natural Gas test Rig and Industrial Automation Instrumentation laboratory. The temperature control system will be simulated using LabView software.

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.1 Natural Gas Vehicle

Natural Gas Vehicle (NGV) is one of the alternative fuels for vehicles that have been considered as a way to provide significant air quality benefits over petroleum fuels such as gasoline and diesel. Natural gas has unique physicochemical properties, and there are vast reserves of the material, with a highly developed network for supplying it from deposits to many regions over major gas pipelines, which combine with a low price and considerable ecological advantages by comparison with traditional fuels, all of which make NG a universal vehicle fuel for the 21st century (Kirillov, 2001).

2.1.1 CNG Vehicle Fuel Systems

Just as tanks have evolved, natural gas fuel systems have evolved tremendously over the past few years as the popularity of natural gas vehicles grown. The oldest-style natural gas fuel systems reduce the pressure of the gas coming from the CNG tanks and employ simple mechanical mechanisms to mix the natural gas with the air entering the engine. Bechtold (1997) indicates that the most advanced CNG fuel system technology, as found in dedicated CNG vehicles built by vehicle manufacturers, is essentially the same as the prevalent multipoint fuel injection systems found in almost all new gasoline vehicles. The primary difference is that the injectors are optimized to use natural gas instead of gasoline. Most CNG fuel systems currently in service were designed to be installed on a gasoline vehicle while retaining the gasoline fuel system. This bifuel approach allows the driver to change from one fuel to the other by flipping a switch (the vehicle can only use one fuel at a time), or the vehicle can be set up to switch automatically to gasoline when the CNG is depleted. Bifuel configurations were adopted for two reasons:

- the difficulty of incorporating enough CNG fuel storage to equal the operating range on gasoline; and
- the scarcity of places to refuel with CNG, other than the home base of the vehicle.

Auto manufacturers recognize that bifuel CNG vehicles can play an important role in creating demand for CNG refueling infrastructure, and have decided to assist by offering vehicles especially configured to become bifuel vehicles. The only difference in these vehicles is that a few engine modifications have been made in the interests of engine durability when using natural gas, and a smaller gasoline fuel tank is usually installed, creating more room for CNG cylinders.

2.2 Natural Gas Dispensing System

Compressed natural gas is being used increasingly as a substitute for gasoline for use in motor vehicles. The vehicles are fitted with compressed natural gas connected to the engine and the cylinder filled at filling stations. These stations are generally combined with the gasoline filling facilities and are thus typically located in residential areas. Two types of compressed natural gas filling stations are represented in use – one utilizing a "slow fill" system and the other a "fast fill" system (Knowlton, 1989).

Slow fill type filling stations are commonly used by fleet car operators when the vehicles are available for refilling for an extended period, e.g. overnight. In this system, gas is fed from the utility gas supply at pressure of typically 20-60 psig, compressed and delivered at up to 3600 psig to stations having multiple filling delivery connections. The delivery connections are connected with high pressure hoses to the storage cylinder of the vehicle, which when full contains gas at pressure of approximately 3000psig.

Fast fill type filling stations are typically provided for retail use and provide compressed natural gas on demand so that so that a refilling period pf typically 34 minutes is normal. Gas from the utility gas supply is compressed and fed to the diverter which allows the gas to be directed to either storage or a filling station. The diverter also allows stored gas to flow from storage to the filling station. The storage pressure is maintained typically between 3200 psig and 3600 psig by the compressor, with compressor start initiated at the lower pressure and the compressor stop the higher pressure. If during filling the pressure in the line from the diverter to the filling station drops below approximately 3200 psig the diverter will direct gas directly via the lines from the compressor through the diverter to the filling station. If the pressure in this line is above approximately 3200 psig, lines are interconnected via the diverter so that the filling station is connected to both storage and compressor.

The filling stations are connected to the storage cylinder of the vehicles by high pressure hoses. Thus, it can be seen the primary advantage of the fast fill system over the slow fill system is the short time period of 3-4 minutes required to fill a vehicle. This short period is obtained by storing pressurized gas above the cylinder filling pressure. Typical vehicle storage will contain, when full, approximately 2 cubic feet of compressed gas at 3000 psig. The storage cylinders provided at the filling stations typically provide 80 cubic feet of compressed gas at 3600psig. During vehicle filling, with the compressor not in operation, the pressure in the storage cylinder may fall to 3000 psig and still fill the vehicle. However, if the storage cylinder pressure falls below this pressure it is not possible to completely fill the vehicle cylinder. Thus the inventory in the storage is represented by the gas volume available from lowering the storage pressure from its operating value to approximately 3000 psig.

2.3 UTP Natural Gas Test Rig

In this project, all the experiments were done at the Natural Gas Test Rig. Although the scope of this project is concentrated to the natural gas car storage, it is still important to understand the operation and process flow of the test rig as the test rig is designed in such that it shall be able to replicate the actual filling condition in actual filling station.

NGV Dispenser Test Rig consists of storage cylinders horizontally stacked in metal frame, panel mounted dispenser, slow-filled compressor, gas piping, electrical control and data acquisition system. The test rig also has been equipped with necessary and adequate instrumentation system for purpose of studying and analyzing flow measurement of natural gas. The process and instrumentation diagram of the test rig can be referred in ***figure 2.1*** at the next page and at Appendix F and G.

2.3.1 Process Flow Description of Natural Gas Test Rig

The high-pressure natural gas is stored inside storage cylinders at 3600 psig. After the dispenser start button is switched on, the gas flows from the storage cylinders to the dispenser and finally to a tank which is considered as a vehicle tank. The sequencing is done automatically via dispenser control and the total amount of gas flow to the vehicle tank is registered on a display panel. There are four types of flow meters installed in the dispensing system, which are Coriolis, vortex, differential pressure and turbine with Coriolis flow meter used as the master reference. While dispensing gas to the vehicle tank, all process parameters such as pressures, temperatures and flow rates are being transmitted to a data acquisition system (DAQ). DAQ will then process the data and produce tables and charts.

Recycling system is used to empty the vehicle tank by transferring the gas to the storage cylinders. This is done via slow-filled compressor that has the inlet and discharge pressure of 1.25 psig and 3600 psig respectively. Once empty, the compressor will stop and the next sampling process could take place.

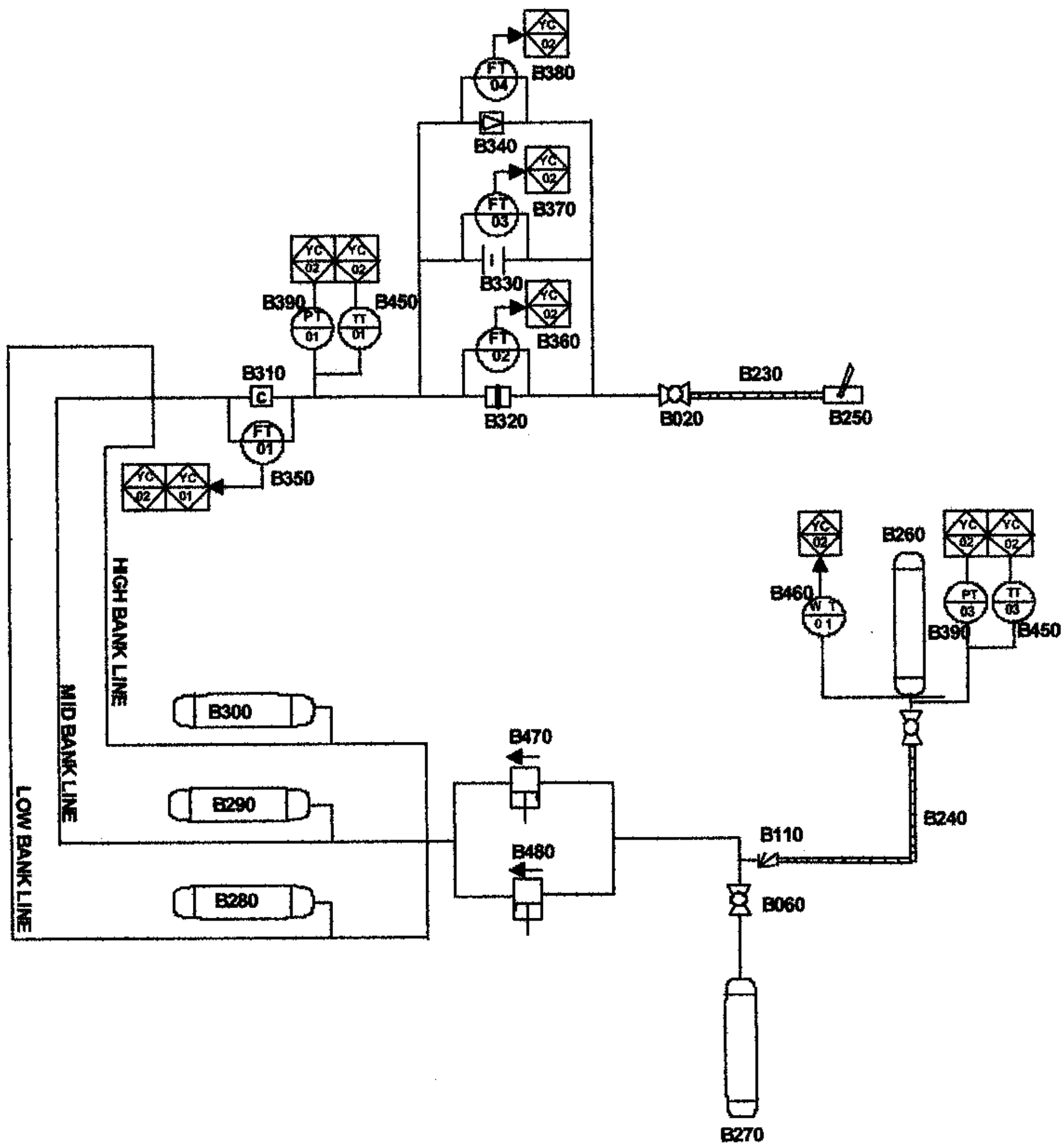


Figure 2.1: Simplified flow diagram of NGV Dispenser Test Rig

2.3.2 Sections of Natural Gas Test Rig

The test rig system has four main sections:

1. Supply storage system

   The supply storage system consists of **nine (9)** 55 liters cylindrical tanks altogether with maximum pressure at 3600 psig (at 70 °C) and they are all placed in one rack. These tanks are sub-divided into three different bank systems, low bank (LB), medium bank (MB) and high bank (HB). LB, MB and HB systems have 4, 3 and 2 cylindrical tanks respectively. The filling process will start with LB system followed by MB and HB systems as necessary. This is achieved by sequence control of solenoid value based on flow measurement.

2. Car storage system

   The car storage system is a replicate of an actual car storage tank plus additional instrumentation systems including the load cell system to measure the actual filling weight and imbedded thermocouples.

3. Flow metering system

   There are four types of flow meters installed in the dispensing system:

   1. Coriolis (MicroMotion CNG050)
   2. Vortex (Endress + Hauser)
   3. Differential Pressure (Endress + Hauser)
   4. Turbine (Hoffer Flow)

   with Coriolis flow meter becomes the master reference. At any time, only Coriolis and any one of the three flow meters could be used. Data from all flow meters is electronically retrieved and stored in a data acquisition system. The flow metering system is based on mass flow principle intended for comparison of various flow measurement systems with Coriolis mass flow meter.

4. Recycle and make-up system

This section is to recover and recycle the natural gas from car storage into the supply storage system. The system consists of a recycle piping and booster compressors. It is expected a small amount of natural gas from car storage will be lost during each experiment trial. Thus, the system is equipped with make-up cylinders to compensate for the losses.

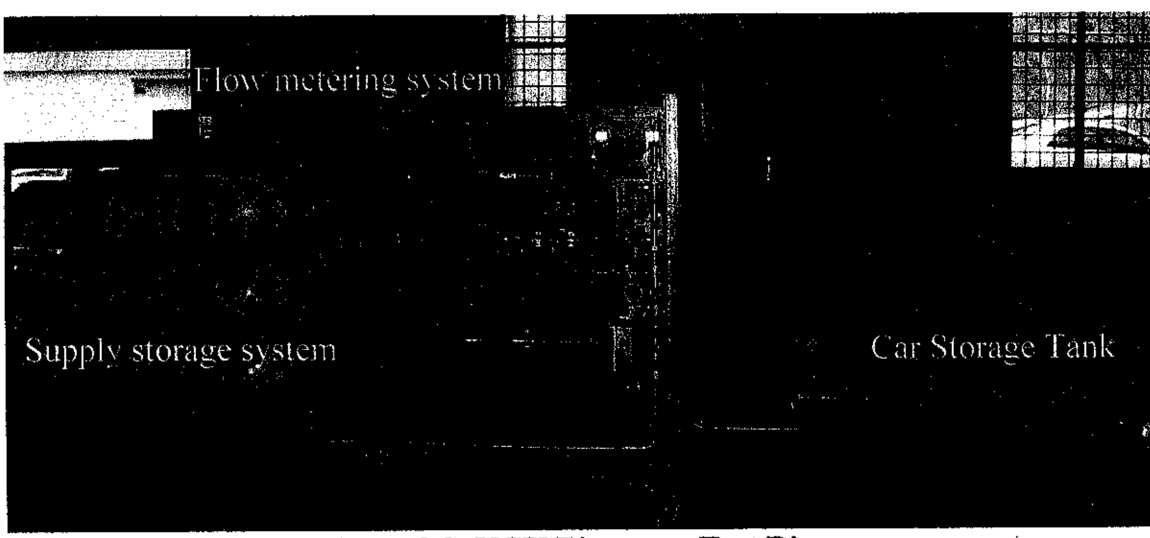


Figure 2.2: NGV Dispenser Test Rig

In this project, scope of the study is concentrated at section 2: Car storage system.

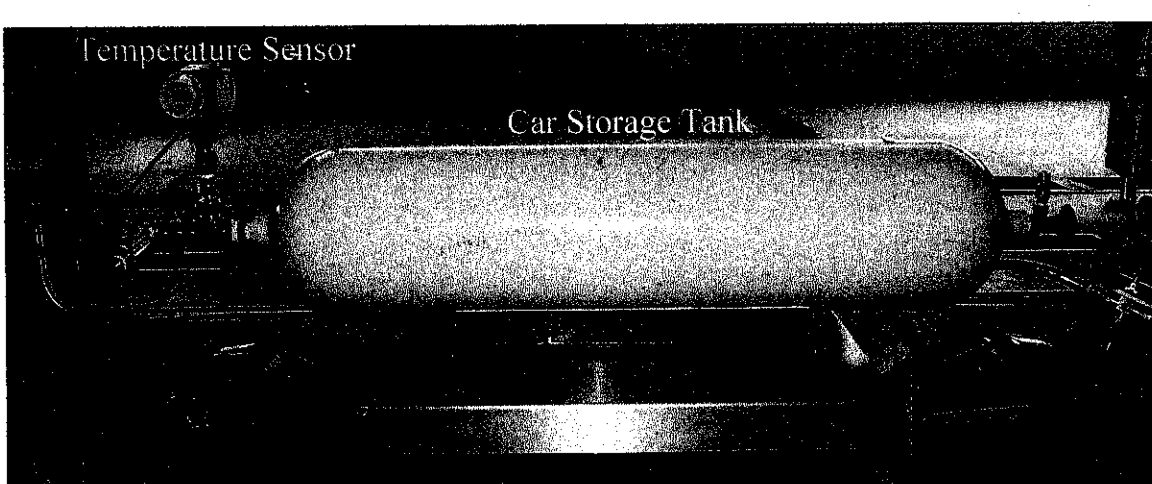


Figure 2.3: Car Storage System

2.4 Temperature Increasing Phenomena during dispensing operation

It has long been recognized that when a gas is introduced into a tank from a source of higher pressure, the gas in the tank will increase in temperature. This phenomena is disadvantageous in situations a pressure tank is desired to be filled to capacity at a relatively high fill rate. In such a case, the length of filling time, is short, typically a few minutes, compared to the time it takes for the tank and its contents to stabilize in terms of temperature through heat transfer to surroundings at ambient temperature requiring typically a few hours. The increased temperature associated with fast filling processes, in turn, results in a corresponding increase in pressure. Thus, if a tank is simply fast-charged to its rated pressure from a source at or near ambient temperature, it will not contain a full pressure charge when the contained gas is allowed to cool to ambient temperature (Tison, 1996).

This phenomena is particularly important in the fast filling of CNG fuel tanks utilized as on board fuel tanks for natural gas vehicles. In this situation, it is especially beneficial to charge a fuel tank to its full mass capacity since the tank volume capacity is often limited owing to practical limitation on the available space on the vehicle. Where a vehicle tank is fast filled simply by charging it its nominal rated pressure, the tank will, in practice be under-filled in mass by a factor of 10 to 15% and often as much as 20%. It is known in certain applications to over-pressurize a fuel tank during refueling by some amount so that when the fuel cools to ambient temperature and the pressure drops correspondingly, it approaches a full mass charge. The general problem is exacerbated when tanks of different size and different residual pressures are presented to the filling station for refueling. There exists a need for a convenient and automatic way of determining how much over-pressurizing or other adjustment is to be made to compensate for the heating of the gas that occurs during fast filling (Tison, 1996).

2.5 Ideal Gas Law

The simplest equation that relates mass and volume for gas is the ideal gas equation. All substances behave according to this simple equation at sufficiently high specific volume (low density). This is because, at vanishingly low density, the individual molecules are essentially "point particles", occupying zero volume and never colliding with one another (Winnick, 1997).

The Ideal Gas Law was first written in 1834 by Emil Clapeyron. The Ideal Gas Law formula is pretty accurate for all gases as we assume that the gas molecules are point masses and the collisions of the molecules are totally elastic. (A completely elastic collision means that the energy of the molecules before a collision equals the energy of the molecules after a collision, or, to put it another way, there is no attraction among the molecules). A gas may be completely described by its makeup, pressure, temperature, and volume. Where P is the pressure, V is the volume, n is the number of mols of gas, T is the absolute temperature, and R is the Universal Gas Constant,

Ideal gas equation:

$$PV = nRT \qquad (2-1)$$

Where:

V=volume in liters

n=moles of gas

P = pressure in atm

T = temperature in kelvins

R = the *molar gas constant*, where R=0.082058 $L*atm*mol^{-1}*K^{-1}$.

The Ideal Gas Law assumes several factors about the molecules of gas. The volume of the molecules is considered negligible compared to the volume of the container in which they are held. The gas molecules are also assumed to move randomly, and collide in completely elastic collisions. Attractive and repulsive forces between the molecules are therefore considered negligible.

2.6 Proportional-Integral-Derivative (PID) controller (Ziegler-Nichols Tuning Method)

The ability of Proportional-integral-derivative (PID) controllers to compensate most practical industries has led to their wide acceptance in industrial application. It also is being used due to their relatively simple structure, which can be easily understood and implemented. The PID then usually integrates into complex control structure in order to attain a better control performance. From the various complex control structures, the cascade control system is commonly used because of easy implementation and also for the purpose of reducing the integral error of disturbance responses.

The Ziegler-Nichols is one of the well-known tuning methods used all over the world. The advantages of Ziegler-Nichols is it could be applied to process that are not well modeled by first order with dead time models and also it provides considerable insight into the effects of all loops elements (process, instrumentation and control algorithm) on stability and proper tuning constant values. Below is the opened-loop tuning correlations of Ziegler-Nichols method shown in Table 2.1 [4].

Table 2.1: The Ziegler-Nichols opened-loop tuning correlations

Controller	K_c	τ_i	τ_d
P	$(1/K_p)/(\tau/\theta)$	-	-
PI	$(0.9/K_p)/(\tau/\theta)$	3.3θ	-
PID	$(1.2/K_p)/(\tau/\theta)$	2.0θ	0.5θ

*where K_p is the process gain, τ is the time constant and θ is the dead / delay time

Table 2.2: The Ziegler-Nichols closed-loop tuning correlations

Controller	K_c	τ_i	τ_d
P	$K_u / 2$	-	-
PI	$K_u / 2.2$	$P_u / 1.2$	-
PID	$K_u / 1.7$	$P_u / 2$	$P_u / 8$

*Where K_u is the ultimate gain and P_u is ultimate period

2.7 Examples of Temperature Control System available

2.7.1 CSC32 Compact CN9500 Controller in Rugged Benchtop Case

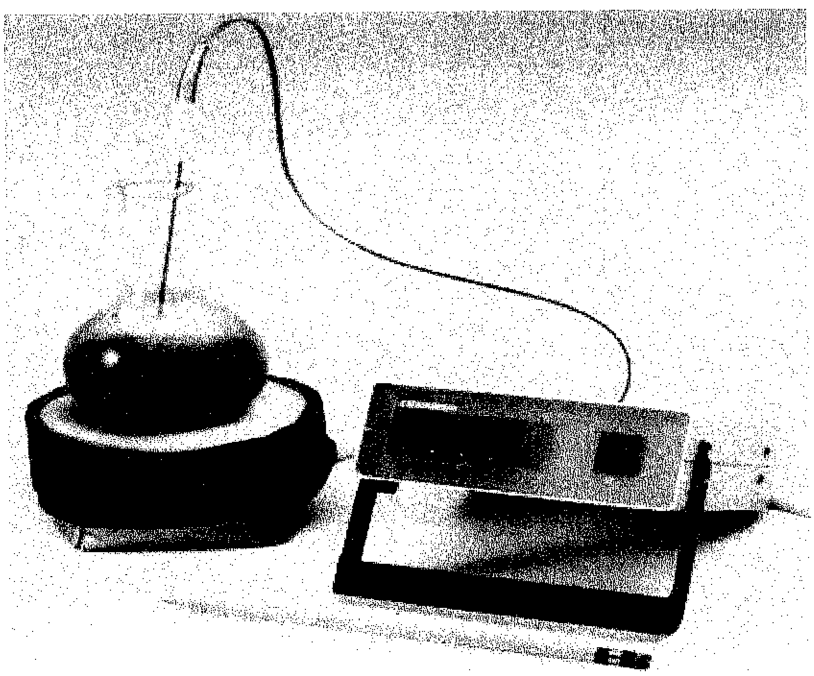


Figure 2.4: Compact CN9500 Controller in Rugged Benchtop Case

The CSC32 series compact benchtop controllers are ideal for laboratory use and applications requiring portable temperature and process control. Pre-wired input and output receptacles in the rear of the case enable quick and easy connections to power, input, power output and digital communications. These benchtop controllers are factory configured and calibrated for a dedicated input type by model number.

The 1/32 DIN CN9500 controller used in this benchtop controller series can be programmed for either On/Off, or PID Autotune Control (with autotune Feature) via the front panel or through the use of a PC and CN9-SW communications software.

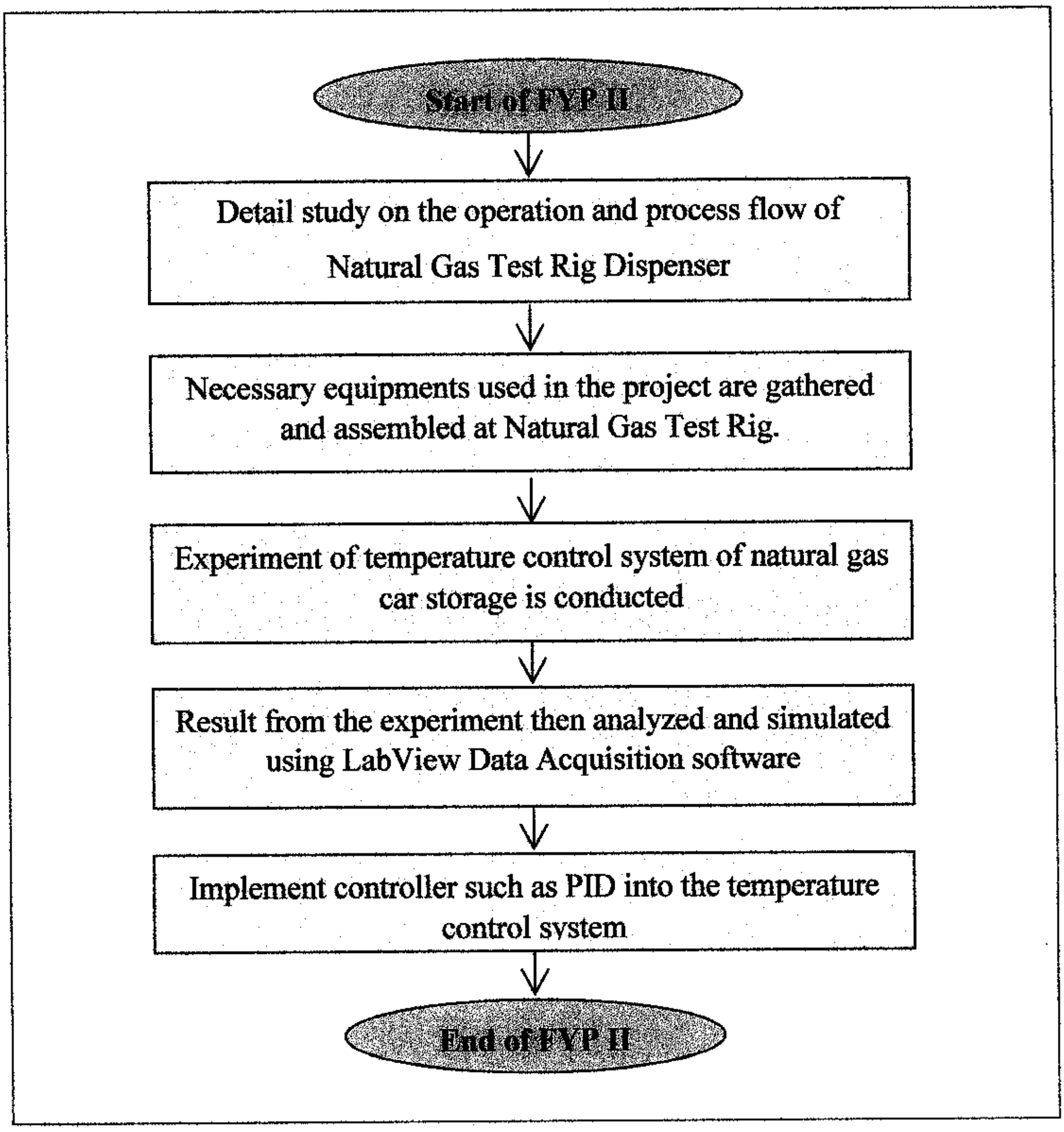
CN9-SW software is designed to interface with the CN9300, CN9400, CN9500 and CSC32 Series benchtop controllers with optional communication hardware. Benefits:

1. Time saving benefit and convenience of remotely configuring and adjusting units.
   Saving and retrieving settings to and from files.
2. Highly flexible logging and "real time" charting capability for providing hard copy QA records for ISO-9000 and other management purposes.
3. Software is capable of logging readings from up to 128 instruments which it stores in data files.
4. The data can be exported into text files in Comma Separated Variable format. In addition, up to 12 controllers can be displayed on a single chart, or individual charts can be set up for each instrument.
5. A Virtual full color chart recorder can log process variables such as: °C, °F, Bar, PSI, pH, rH, or user defined engineering units

CHAPTER 3
METHODOLOGY

3.1 Procedures

3.1.1 Flow Chart



3.1.2 Procedures

In order to complete this project, there are four critical stages involved. The first stage is to understand the operation and process flow of Natural Gas Test Rig Dispenser. The equipments at the Test Rig are built specifically for the purpose of developing and conducting research for the natural gas dispensing system. Having understood the operation and process flow, necessary equipments used in the project such as National Instrument PCI Card NI 6036E, temperature field transmitter and SDBS Distributor were gathered. All these equipments are available in the Test Rig and Industrial Automation Instrumentation Laboratory. Experiment of temperature control system is then conducted. At this stage, the scope of the project has been narrowed down to the operation involving NGV car storage tank of the Test Rig. Result from the experiment then analyzed and simulated using LabView Data Acquisition software. After that, another stage is to implement controller such as PID into the temperature control system. In this stage, the best range of temperature inside NGV car storage compartment to get optimum mass of natural gas injected into the storage tank during a filling process is determined. Next and last stage, the best cooling system inside the NGV car storage compartment to control the temperature is recommended.

3.2 Tools and Equipments used

3.2.1 LabVIEW software

LabVIEW is the main software used in this project. With LabVIEW, signals from plug-in boards, USB devices, and Ethernet-based systems can be quickly acquired and generated. These Input-Output (I/O) capabilities, combined with special data types and measurement analysis Virtual Instruments (VI)s, are specifically designed to get the measurements you need from your physical sensors as quickly and easily as possible.

3.2.2 National Instrument PCI Card NI 6036E

The PCI-6036E offers 16-bit synchronized input and output, which makes it an ideal low cost option for stimulus response. The data acquisition device has 16 single-ended (or 8 differential), 16-bit 1 analog inputs that sample at a maximum of 200 kS/s, two 16-bit analog outputs, eight digital I/O lines, and two 24-bit counter/timers. With its pretrigger and postrigger modes, the device can acquire data before and after a digital trigger occurs. Like all E Series devices, the device features the Real-Time System Integration Bus (RTSI) for multiple device synchronization and ships with a calibration certificate that guarantees the device performs at the specified accuracy.

The NI 6036E, is a National Instrument low-cost 16-bit DAQ device that uses E Series technology to deliver reliable, 16-bit acquisition in a wide range of applications. The card is an accurate and powerful measurement instrument that plugs into any PCI slot in personal computer. Combined with powerful software, it turns the personal computer into a measurement system that may be used to automate experiments, construct product test stands, monitor and control production equipment. It can produces measurements of up to 16 channels at a resolution of 16 bits, one part in 65,536 on one of 4 ranges may be taken at rates up to 200,000 samples per second. Discrete digital bi-directional I/O lines (8) can control relays and solenoids, and monitor switch and contact closures. Simple and complex triggering of measurements is handled by the several types of trigger signal inputs and the powerful programmable trigger logic of the board. Digital events may be used to initiate measurement (input) process. Powerful software translates a complex capability into simple-to-understand and configure parameters.

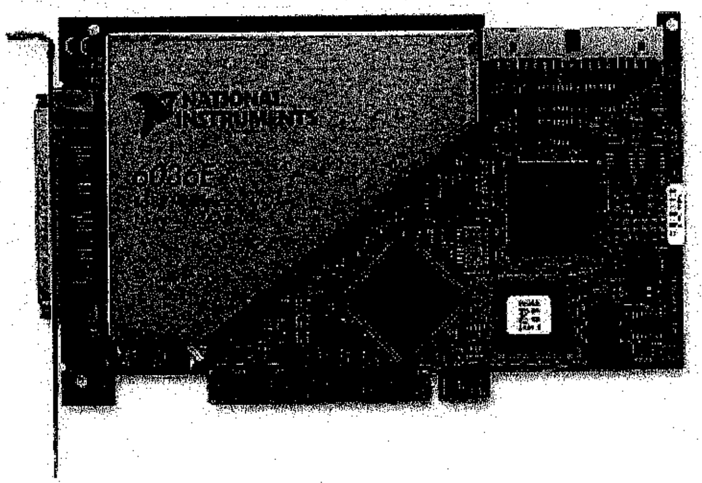


Figure 3.1: NI (PCI-6036E)

*Full specifications of NI (PCI-6036E) can be referred at appendix B

3.2.3 iTemp TMT 162 HART Temperature Field Transmitter

The iTEMP® HART® temperature field transmitter TMT 162 is a two-wire transmitter with analogue output, two (optional) measuring inputs for resistance thermometers and resistance transmitters in 2-wire, 3-wire or 4-wire connection, thermocouples and voltage transmitters. The Liquid Crystal display shows the current measured value digitally and as a bar graph with an indicator for limit value violation. The TMT 162 can be operated via the HART® protocol using a handheld terminal (DXR 275) or PC (COMMUWIN II, FieldCare or ReadWin® 2000 operating software).

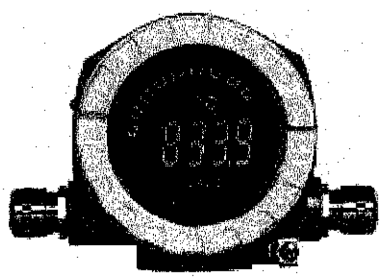


Figure 3.2: iTEMP® HART® temperature field transmitter TMT 162

*Full specifications iTEMP® HART® temperature field transmitter TMT 162 can be referred at appendix C

3.2.4 Compact Thermocouple Thermometer Omnigrad S TMT 162C

The temperature assembly TMT 162C from the family Omnigrad S is a compact thermocouple (TC) thermometer specifically designed to fulfill the requirements of different process industries such as the chemical, petrochemical, oil & gas and energy but even suitable to other general purpose applications. The thermometer assembly TMT 162C consists of a temperature thermocouple sensor insert (TC type J or K) and an electronic two-wire Temperature transmitter providing a 4 to 20 mA output, configurable via HART® protocol. Thanks to the versatility of its product structure, the TMT 162C is easily adaptable to various applications in many different industrial processes.

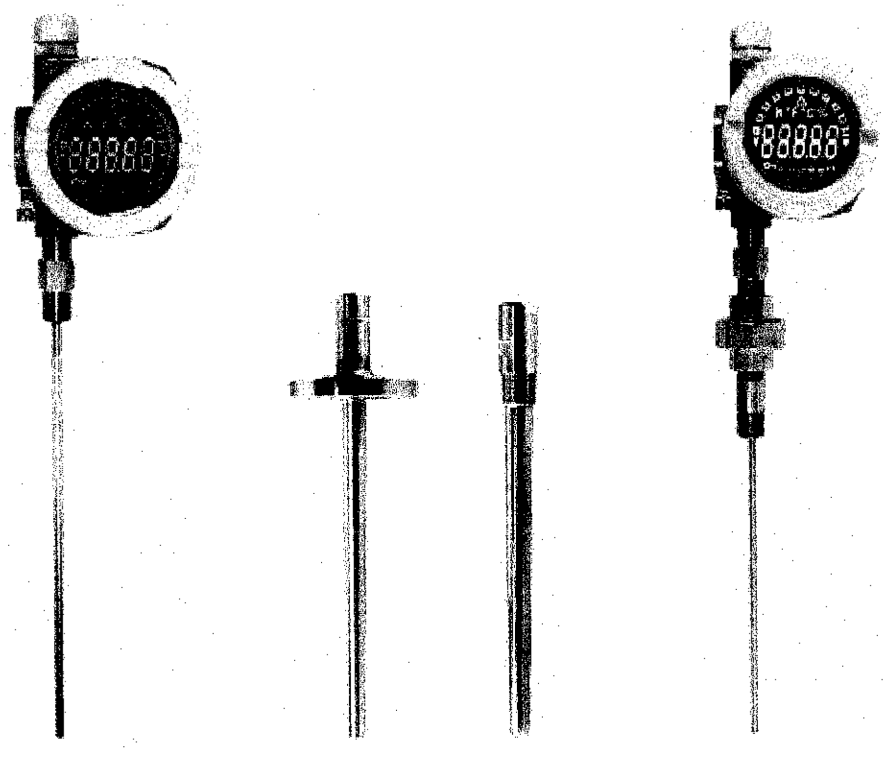


Figure 3.3: Compact Thermocouple Thermometer Omnigrad S TMT 162C

*Full specifications of SDBS Distributor can be referred at appendix D

3.2.5 SDBS Distributor

The Model SDBS Distributor supplies power to a two-wire transmitter and converts the 4 to 20 mA DC transmitter signal current to two 1 to 5 V DC output signals. Isolation between input/output and distributor power supply is provided. Current limiting (to protect against transmitter wiring short circuits) is also provided.

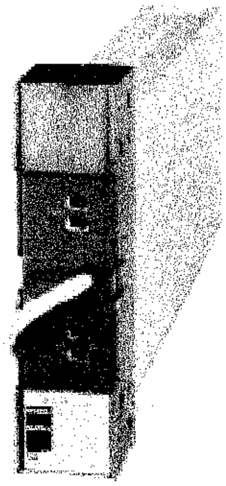


Figure 3.4: SDBS Distributor

*Full specifications of SDBS Distributor can be referred at appendix E

3.2.6 National Instruments I/O connector blocks CB-68LP

National Instruments I/O connector block is a 68 screw terminals for easy connection of field I/O signals to any devices. The connector blocks include standoffs for use on a desktop or mounting in a custom panel. The CB-68LP has a vertically mounted 68-pin connector.

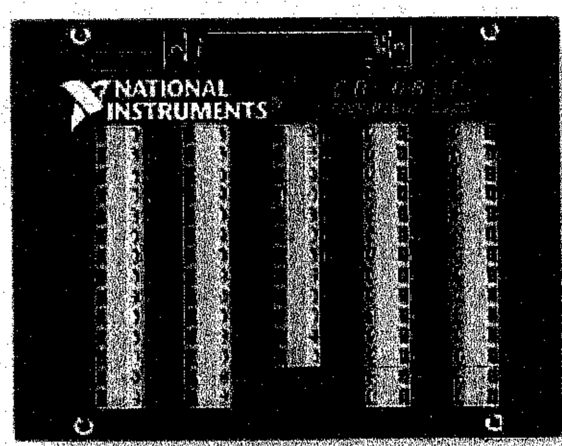


Figure 3.5: National Instruments I/O connector blocks CB-68LP

3.2.7 +5 Vdc Fan

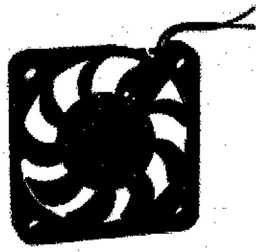


Figure 3.6: +5 Vdc Fan

Specifications:

- +5 Vdc
- 0.09 Amp miniature cooling fan
- 1.58" square x 0.27" thick. 9 blade impeller
- 5" wire leads
- Hypro bearing
- 5500 RPM
- 22.2 dB

CHAPTER 4
RESULT AND DISCUSSION

4.1 Experiments Results

A few experiments had been conducted at the test rig throughout this project. Data of these experiments are used in order to proof the Ideal Gas Law. Experiments that have been done were experiment on collecting data of temperature, mass and pressure value of the storage tank during dispensing operation. Below are the results of the experiment:

4.1.1 Temperature of the Tank

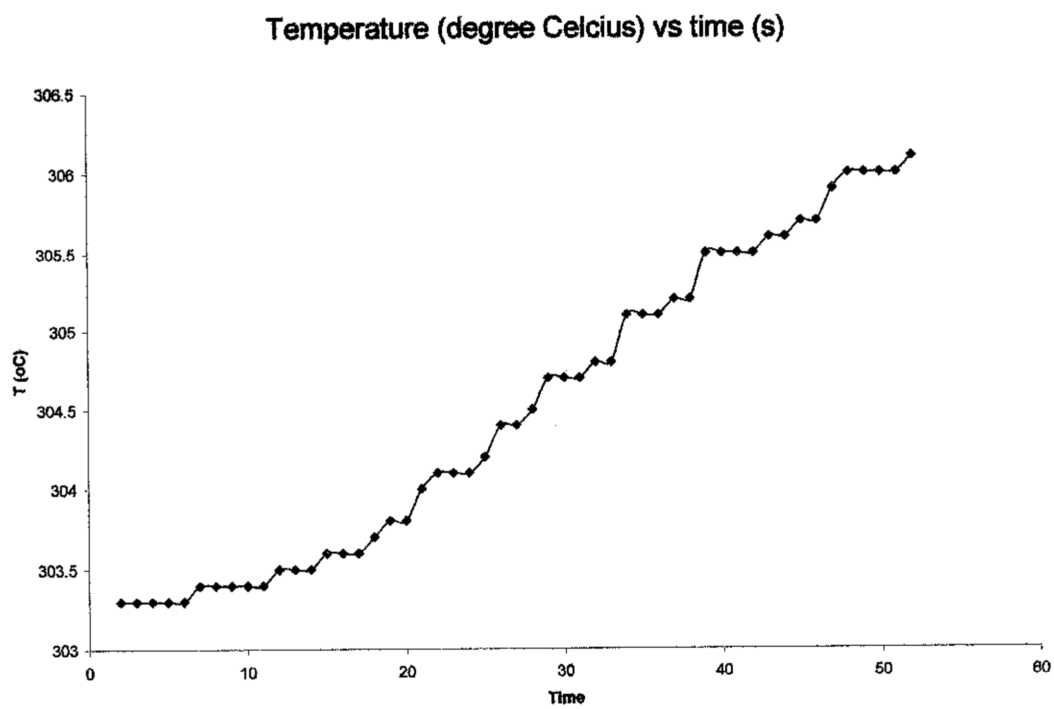


Figure 4.1: Graph of Temperature of storage tank during dispensing operation vs Time

*Table of details of the Temperature values can be referred at Appendix A

From the graph above, we can see that the temperature of the storage tank increased steadily during the dispensing operation. The temperature increases as the gas expands – high energy produced during the dispensing operation and there is no mean to take the energy out of the tank. The temperature keeps increasing inside the tank due to the collisions that occur inside the tank between molecules, as well as between molecules and the tank's wall.

4.1.2 Mass of the Tank

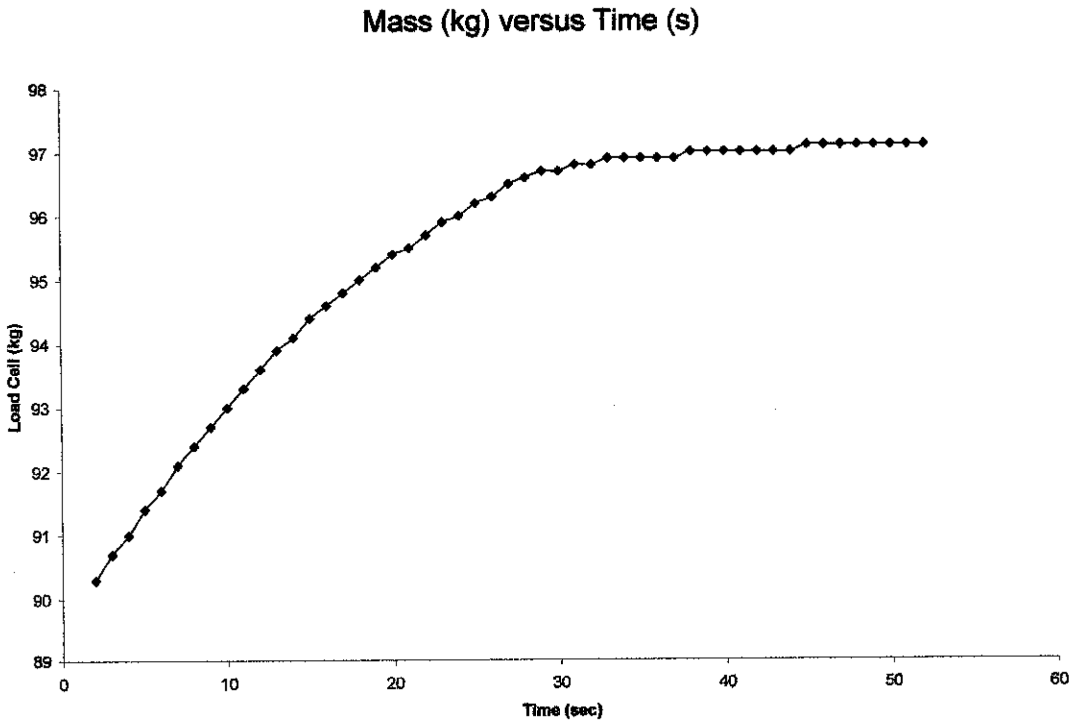


Figure 4.2: Graph of Mass of storage tank during dispensing operation vs Time

*Table of details of the Mass values can be referred at Appendix A

4.1.3 Pressure of the Tank

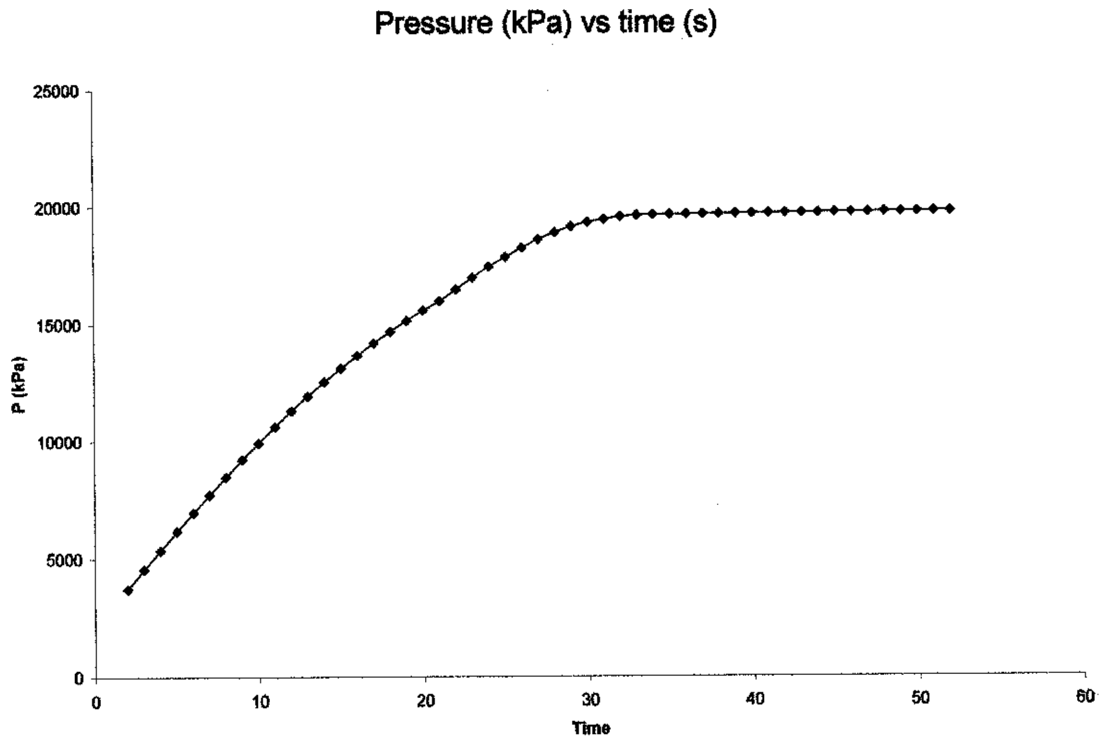


Figure 4.3: Graph of Pressure of storage tank during dispensing operation vs Time

*Table of details of the Pressure values can be referred at Appendix A

From the graph 4.2 and 4.3 above, we can see that the pressure and mass of natural gas inside the tank increased in a relatively constant manner as the tank receives an even amount of gas per unit of time. It is due to the fact that the amount of gas flowing into the tank is a function of the mass velocity of the gas flow. The pressure and mass of the natural gas inside the tank become constant after about 25 seconds. At this period, the natural gas inside the tank had reached its maximum capacity at pressure of 20 MPa. The flow became lesser which make the incremental of the mass become small.

All three graphs show that all three temperature, mass and pressure of the gas inside the storage tank were increased when natural gas is dispensed from NGV dispenser to the storage tank and Ideal Gas Law is proven. In the mean time, the temperature inside the storage tank needs to be controlled to get the maximum amount of mass of natural gas dispensed to the tank during dispensing operation.

4.2 Simulation of the Temperature Control System

4.2.1 Simple Controller

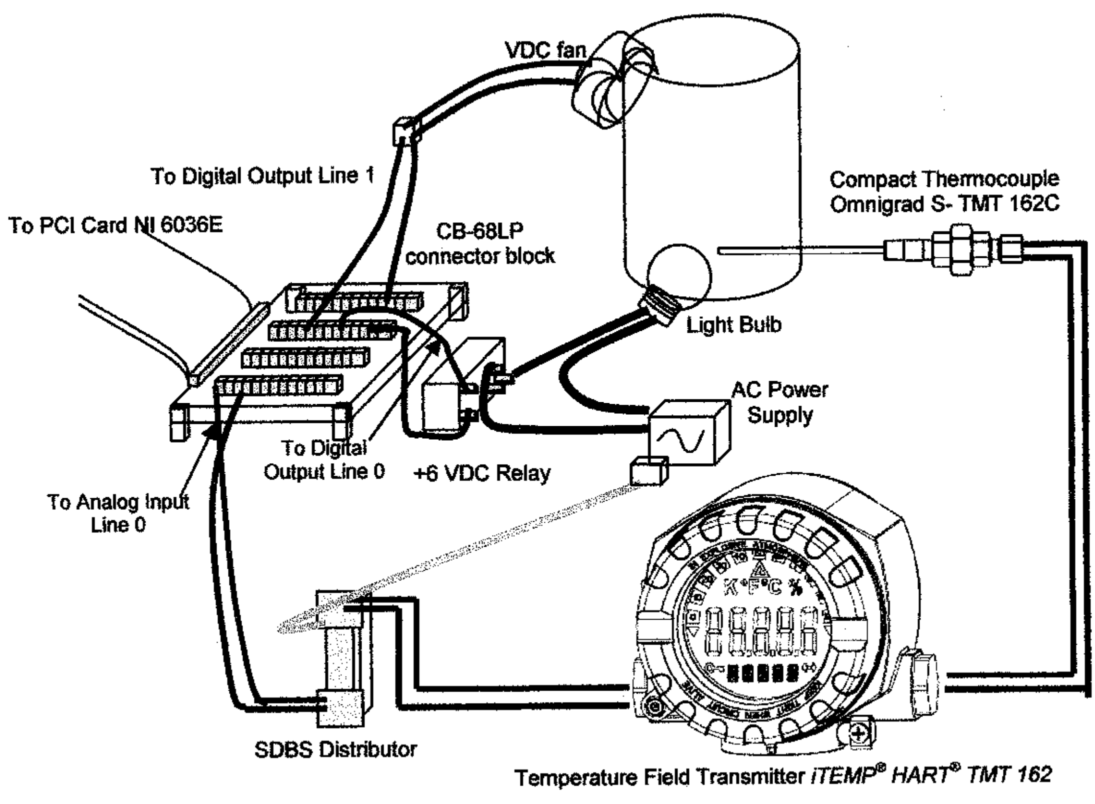


Figure 4.4: Equipments assembly for simple controller

There are two simulations done for this project; one is a simple controller (without PID controller and analog output from the PCI Card) and the other one is with PID controller. Simulation of simple controller of the temperature control system was done based on the equipments assembled in the test rig as shown in ***figure 4.4*** above. The digital output ports used are port 0 and 1. Port 0 is used to turn on the +6 VDC Relay which will turn on the light bulb. The other port is used to turn on the fan. In order to provide a specific range of temperature of the tank, the light bulb is set to be acting as a heating mechanism and the fan is set to be acting as cooling mechanism. There is a Compact Thermocouple Omnigrad S-TMT 162C attached to the temperature transmitter. The thermocouple is put inside a compartment represented the NGV car storage tank and will senses the changes of temperature inside the compartment.

The simulation started with the light bulb turned ON first as the temperature of the tank is almost the same as the ambient temperature at the beginning of the experiment. If the temperature exceeded the highest limit a cooling system will starts and if the temperature goes below the lowest limit, a heating system will starts. The changes of the temperature during the experiment are simulated using LabView Data Acquisition software as shown in ***figure 4.5*** and ***figure 4.6*** below.

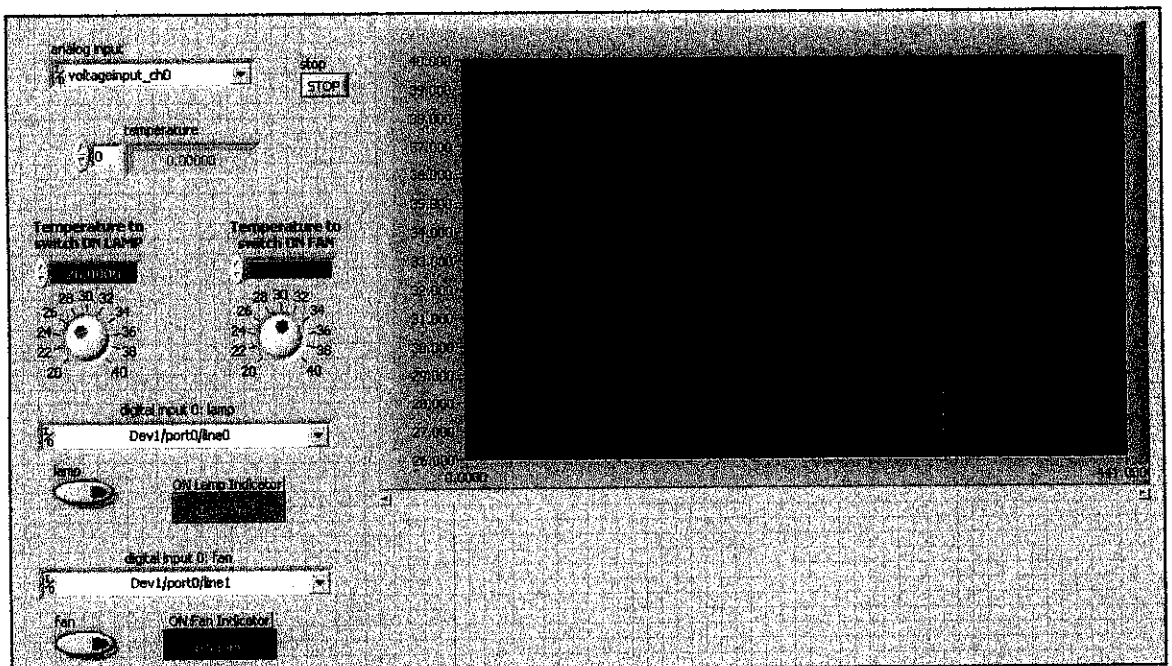


Figure 4.5: Front panel of LabView programming of the Temperature Control System

From the figure of the front panel, we can see that there are a waveform graph, 2 value setters, one analog input chooser and 2 digital output choosers. Before the virtual instrument (VI) set to RUN, all the analog input and digital outputs must be set according to their channels. When the VI is running, the value of the temperature sensed by the temperature transmitter will be plotted in the waveform graph. Two set of graphs produced from the experiment can be referred at ***figure 4.7*** and ***figure 4.8***. If the temperature value is at below the lowest limit ON lamp indicator will be triggered and if the temperature value exceeds the highest limit, ON fan indicator will be triggered.

The block diagram programming of the temperature control system can be referred at ***Figure 4.6***. The programming is divided to four main parts. The first part is analog input part, second part is the temperature limit setting part and the last parts are the digital output parts.

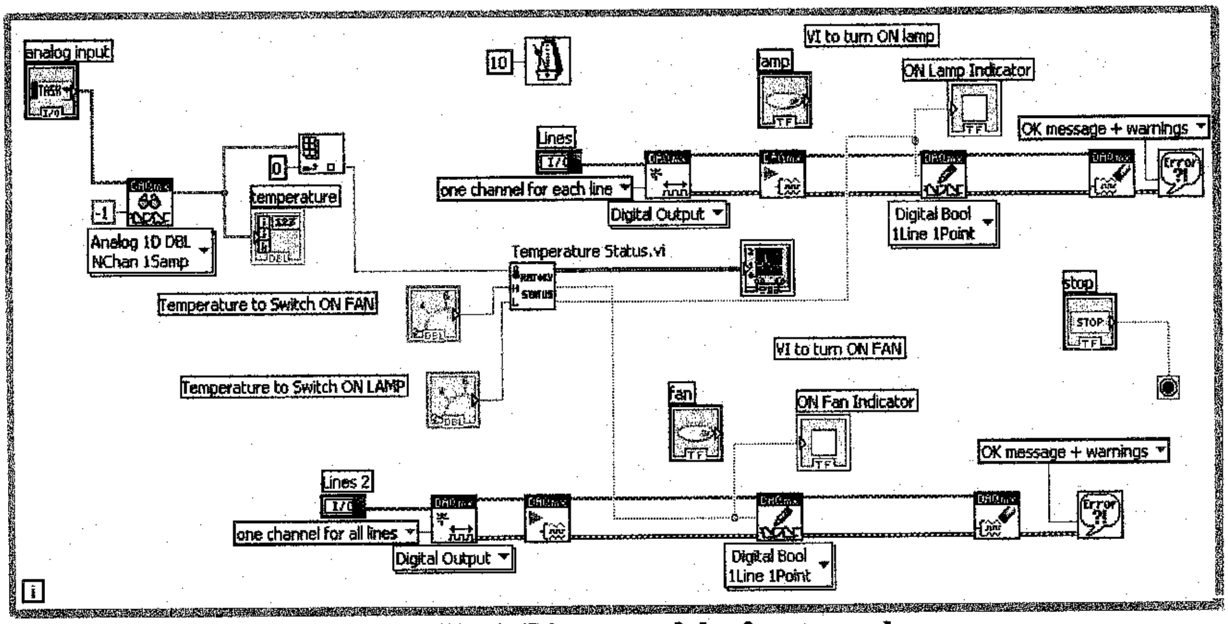


Figure 4.6: Block Diagram of the front panel

From both figures ***figure 4.7*** and ***figure 4.8***, we can see that the temperature value does not exceed the highest limit and go below the lowest limit set during the experiment. During both experiments, the temperature started below the lowest limit as the room where the experiment was conducted is air-conditioned. When the temperature is at below the lowest limit, the heating mechanism will start until it reached the highest limit. When it has reached the highest limit, the heating mechanism will stop and the cooling mechanism will start. The VI can also be programmed to the heating mechanism will only start if the temperature goes below the lowest limit and stop if the temperature is above the lowest limit.

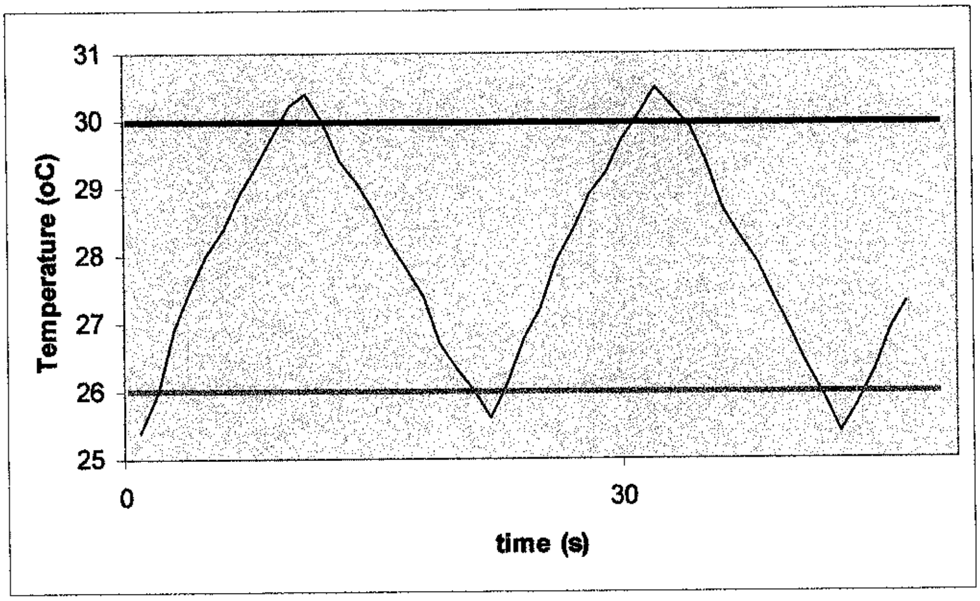


Figure 4.7: Graph of temperature at the range of 26°C to 30°C

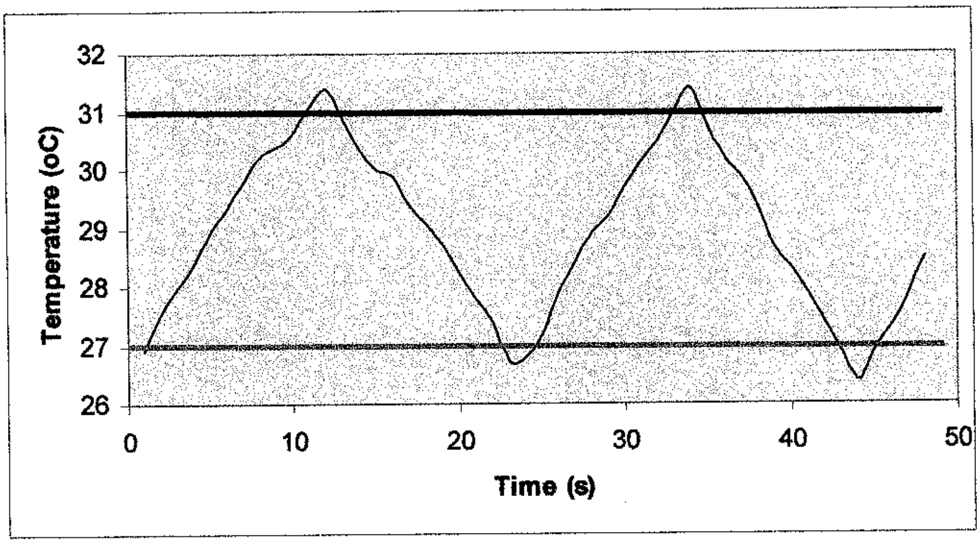


Figure 4.8: Graph of temperature at the range of 27°C to 31°C

4.2.2 PID controller

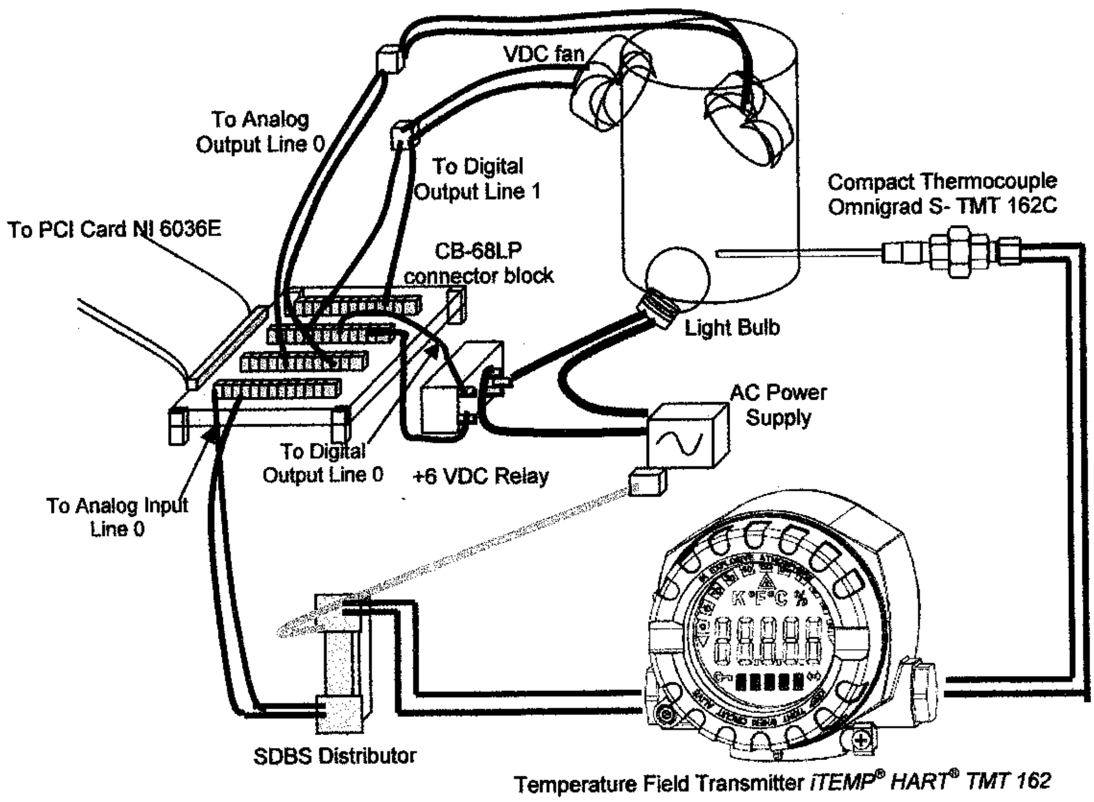


Figure 4.9: Equipments assembly for PID controller

Equipments were assembled at the Test Rig. In this experiment, inputs are in form of analog input and outputs are in form of digital and analog outputs based on the capability of the Natural Instrument PCI Card NI 6036E. The PCI Card is connected to a connector block, National Instruments I/O connector block CB-68LP which has 68 screw terminals for easy connection of field I/O signals to input and output devices used in this experiment.

There are one analog input, one analog output and two digital outputs used in this experiment. The analog input is in form of 1 – 5 Volts coming from the SDBS Distributor. The Distributor converts the signal of 4 to 20mA comes from the Temperature Field Transmitter iTEMP® HART® TMT 162 and sends signal of 1 – 5 volts to the analog input port. The distributor uses AC power supply and it provides the power supply for the temperature transmitter.

The digital output ports used are port 0 and 1. Port 0 is used to turn on the +6 VDC Relay which will turn on the light bulb. The other port is used to turn on the fan. The light bulb is acting as a heating mechanism and the fan is acting as cooling mechanism. Analog output port used is port 0. The analog output is controlled by PID output and it will vary the speed of the other fan. There is a Compact Thermocouple Omnigrad S-TMT 162C attached to the temperature transmitter. The thermocouple is put inside a compartment represented the NGV car storage tank and will senses the changes of temperature inside the compartment.

Simulation of the temperature control system was done based on the equipments assembled in the test rig as shown in ***figure 4.9*** above. In order to provide a specific range of temperature of the tank, the light bulb is set to be acting as a heating mechanism and the fan is set to be acting as cooling mechanism. The other fan will control the temperature inside the compartment to the set point value set by PID controller.

The simulation started with the light bulb turned ON first to indicate the dispensing operation is started. Temperature will increase when the light bulb turned ON as the light bulb provides heat inside the compartment. While increasing, if the temperature exceeded the highest limit a cooling system will starts and if the temperature goes below the lowest limit, a heating system will starts. Both heating and cooling mechanism will provide a range of allowed temperature inside the compartment and while the temperature is within the range, PID controller will control the temperature value to achieve a steady state value as set in the set point.

4.3 Simulation Results

4.3.1 Parameter estimation for PID controller

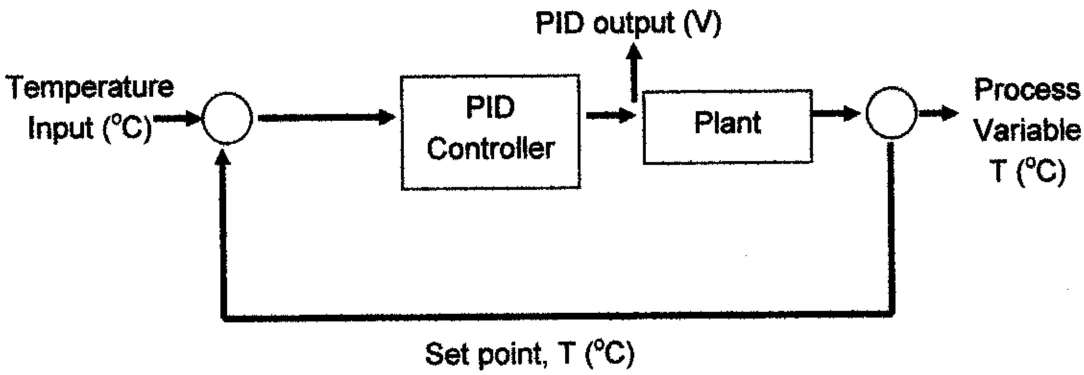


Figure 4.10: Process Model Block Diagram for Temperature Control System

For this project, there is one process model that needs to be identified and obtained in order to design the process loop in temperature control system. The temperature will be the only loop as the PID system has only one loop. To start the PID experiment, the temperature process model needs to obtain from the plant experiment. From the experiment, the temperature will be controlled through the on and off bulb and fans. Therefore, the manipulated variable will be the speed of the second fan and the controlled variable is the temperature inside the compartment.

The desired result from plant experiment is a process reaction curve of a first-order-with-dead-time model, shown in ***Figure 4.11*** below: -

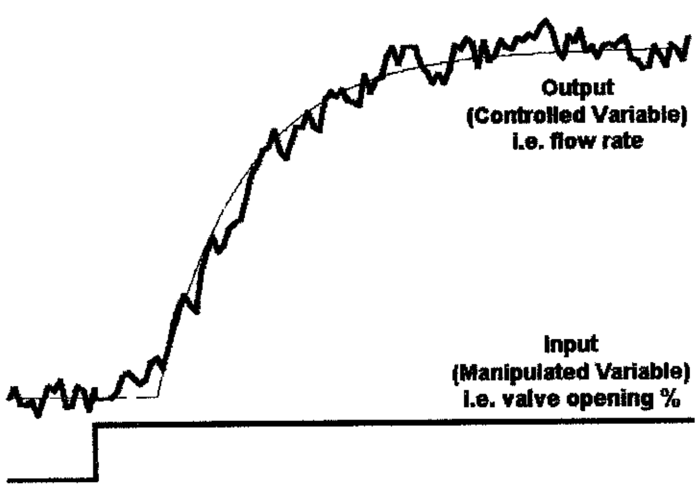


Figure 4.11: Process Reaction Curve.

Among the acceptance criteria for the process reaction curve obtained is that there should be no disturbance occurrence, which can be verified by returning the manipulated variable's value back to the initial value and ensuring that the controlled variable also returns to its initial value.

The next step is to determine the model parameters using Method I or Method II (the latter is preferred since it gives more accurate result). The model parameters are:

TABLE 4.1: Model Parameters Calculation

Parameter	Description	Calculation (Method II)
K_p	Process Gain	$K_p = \Delta / \delta$, where Δ = magnitude of change in MV
τ	Time Constant	$\tau = 1.5(t_{63\%} - t_{28\%})$
θ	Dead Time	$\theta = t_{63\%} - \tau$

In designing the PID controller for temperature control system, the correct mode of controller needs to use. In this case, the temperature loop must have the proportional mode to get enough response and rapid action. Thus, the mode that should be use is P+I. The integral mode is very important in order to reduce the offset to zero. If no integral mode, the process variable is impossible to keep to the set point.

4.3.2 Temperature curve with PID controller

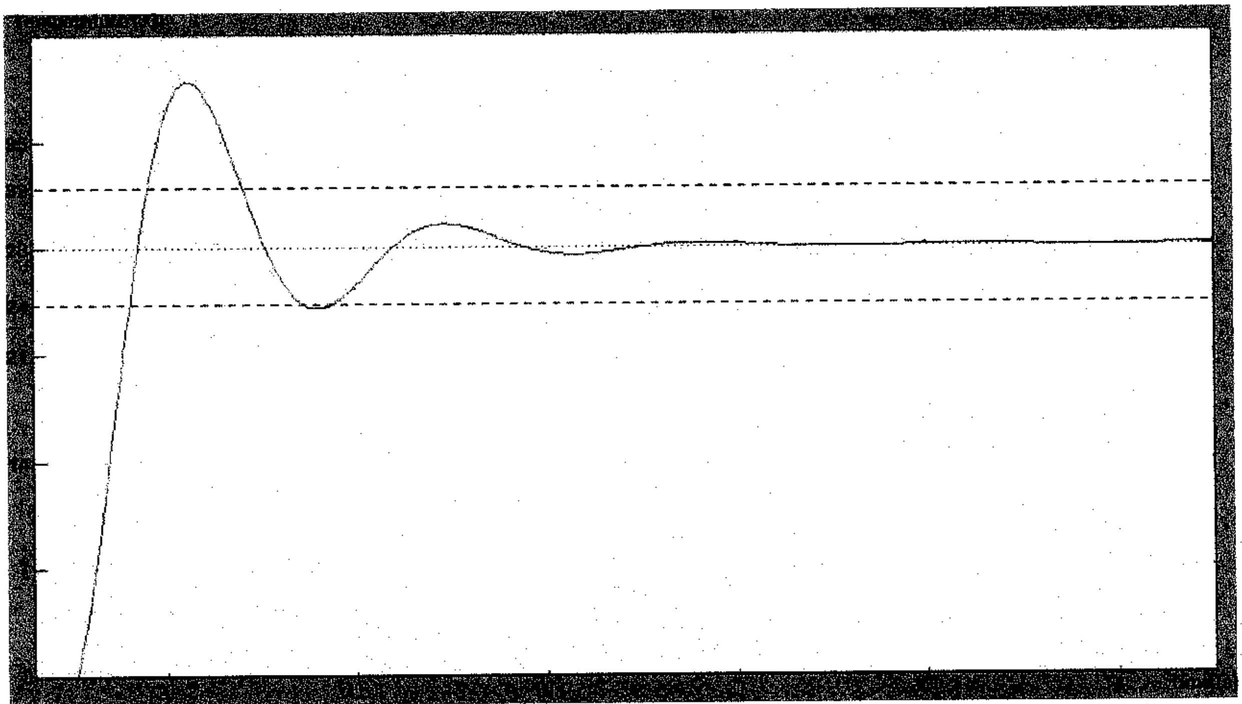


Figure 4.12: The result of simulation for temperature curve with PID controller

From the result of the simulation, the graph shows that the temperature, which is the controlled variable, CV is successfully controlled and returned back to its set point, SP (which is set at 28°C). PID controller controls the temperature by adjusting the speed of the fan so that any deviation of temperature will be brought back to its set point. It took the temperature more than 1 minute to reach steady state value.

The red line represents the highest limit of the temperature and the blue line represents the lowest limit. From the graph we can also see that the percentage of overshoot, %OS is about 40% and it is acceptable. The response reach the peak time at 22.3s and at this time the process have the highest amont of %OS.

4.3.3 Temperature results' comparison

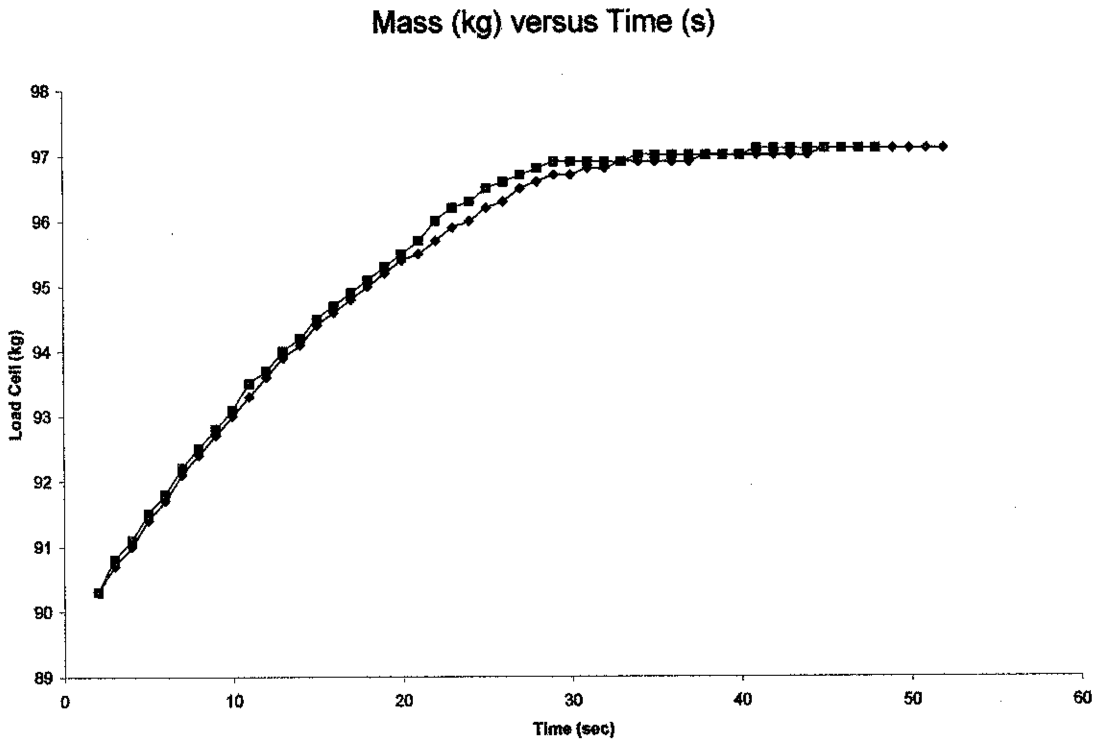


Figure 4.13: The result of comparison for mass curves before and after applying the temperature controller system

From graph of results' comparison of mass dispensed into the tank during dispensing operation above, we can see that the curve of mass dispensed into the tank with temperature controller system (the pink dotted line) is a little bit steeper than curve of mass dispensed into the tank without temperature controller system (the black dotted line). The mass dispensed into the tank achieved its maximum value inside the tank a little faster when the temperature controller system is applied to the tank.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

The temperature control system is able to control the temperature of the NGV storage tank inside the car compartment to get the maximum mass during the dispensing operation. Temperature of the tank during the operation is maintained for a specific range as if the temperature exceeded the highest limit, a cooling system will start and if the temperature goes below the lowest limit, a heating system will starts. While the temperature is within the range, a PID controller will control the temperature of the tank to a certain value that will maximize the mass dispenses into the tank.

During the dispensing operation, temperature will increase rapidly and because of this, there is no need of a heating system inside the car compartment. The important thing to be put inside the car compartment is a cooling system. In the experiment at the Test Rig, a +5V DC fan used to cool the temperature inside the case represented NGV car storage tank. However, a fan is not suitable to be installed inside a car compartment. Thus, a better cooling system is recommended to be installed inside the car compartment to cool the NGV storage tank.

5.1 Recommendation: cooling system inside the car compartment

In the new cooling system, the storage tank inside the back car boot will has a case covering the tank. There is a piping inside the case which is connected to the coolant tank at the car engine compartment. The coolant will circulate inside the case the cool down the tank during dispensing operation.

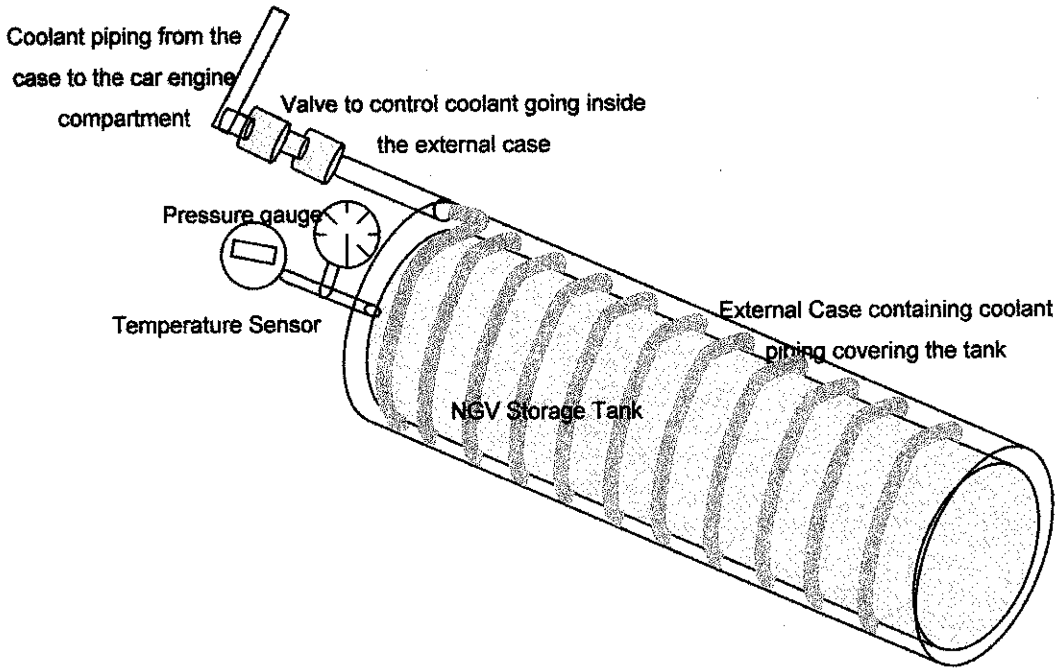


Figure 5.1: Recommended Cooling System of the car storage tank inside the back car compartment

REFERENCES

1. R.L.Bechtold, (1997, March), Alternative Fuels for Vehicle Fleet Demonstration Program (Volume 1).

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3. Robert E. Knowlton (1989, February), natural Gas Storage and Retrieval System, C-I-L Inc., North York, Canada.

4. Aidan O'Dwyer, *"Handbook of PI and PID Controller Tuning Rules"*, Imperial College Press, 2003.

5. http://ni.com/labview/io_options - LabView official website.

6. Engineering, Procurement, Construction and Comissioning of Natural Gas Dispenser Test Rig Operation Manual prepared by Gas Emas Corporation Sdn. Bhd.

7. Operating instructions manual of iTEMP® HART® TMT 162 Temperature field transmitter.

8. http://members.aol.com/profchm/gas_laws.html - Ideal Gas Law website

APPENDICES

APPENDIX A

TABLE OF RESULTS

Table A.1: Temperature of storage tank during dispensing operation

Time of the Experiment	Temperature of the Tank (°C)
3:47:03 PM	29.7403086
3:47:05 PM	29.75032032
3:47:07 PM	29.80707278
3:47:09 PM	29.87716645
3:47:11 PM	29.96895993
3:47:13 PM	30.02904188
3:47:15 PM	30.30441068
3:47:18 PM	30.35115143
3:47:20 PM	30.43960379
3:47:21 PM	30.72499596
3:47:24 PM	30.77338981
3:47:25 PM	31.03708215
3:47:28 PM	31.2941039
3:47:30 PM	31.38423264
3:47:32 PM	31.60620173
3:47:34 PM	31.69799522
3:47:36 PM	31.95834644
3:47:38 PM	31.99339909
3:47:40 PM	32.26877954
3:47:41 PM	32.30882641
3:47:43 PM	32.57585987
3:47:45 PM	32.60590667
3:47:47 PM	32.63928294
3:47:48 PM	32.74442926
3:47:50 PM	32.99143929
3:47:54 PM	33.08323277
3:47:55 PM	33.18670271

Table A.2: Mass of storage tank during dispensing operation

Time of the experiment	Mass of the Tank (kg)
3:46:55 PM	91.21151848
3:46:57 PM	91.71971502
3:46:59 PM	92.49577448
3:47:01 PM	93.50465876
3:47:03 PM	93.87016213
3:47:05 PM	94.46097279
3:47:07 PM	94.91910492
3:47:09 PM	95.46735124
3:47:11 PM	95.88292774
3:47:13 PM	96.29098673
3:47:15 PM	96.69403404
3:47:18 PM	96.98193495
3:47:20 PM	97.27483008
3:47:21 PM	97.53018126
3:47:24 PM	97.80556171
3:47:25 PM	97.99331634
3:47:28 PM	98.49650993
3:47:30 PM	98.75186111
3:47:32 PM	98.89955723
3:47:34 PM	99.04225913
3:47:36 PM	99.137385
3:47:38 PM	99.22501082
3:47:40 PM	99.35768936
3:47:41 PM	99.58800834
3:47:43 PM	99.68313421
3:47:45 PM	99.77076002
3:47:47 PM	99.81831859
3:47:48 PM	99.86839173
3:47:50 PM	99.81582148
3:47:52 PM	99.81831859
3:47:54 PM	99.81831859
3:47:55 PM	99.81582148

Table A.3: Pressure of storage tank during dispensing operation

Time of the Experiment	Pressure of the Tank (psi)
3:47:07 PM	35.59651785
3:47:09 PM	323.9085211
3:47:11 PM	600.2875173
3:47:13 PM	859.810157
3:47:15 PM	889.8512763
3:47:18 PM	1070.015046
3:47:20 PM	1252.515272
3:47:21 PM	1422.164701
3:47:24 PM	1574.373369
3:47:25 PM	1713.313891
3:47:28 PM	1897.065872
3:47:30 PM	2007.050121
3:47:32 PM	2102.764761
3:47:34 PM	2147.409164
3:47:36 PM	2227.018327
3:47:38 PM	2383.483138
3:47:40 PM	2506.818769
3:47:41 PM	2603.534872
3:47:43 PM	2672.963224
3:47:45 PM	2719.193494
3:47:47 PM	2758.914693
3:47:48 PM	2768.344043
3:47:50 PM	2894.76759
3:47:52 PM	2941.915505
3:47:54 PM	3006.003303
3:47:55 PM	3035.710747

APPENDIX B

SPECIFICATIONS OF NATIONAL INSTRUMENT PCI CARD

PCI-6036E

Analog Input Section

A/D converter	Successive Approximation type, min 200kS/s Conversion rate.
Resolution	16 bits, 1-in-65536
Number of channels	16 single ended /8 differential, Software selectable
Input ranges	±10V, ±5V, ±500mV, ±50mV, Software selectable
A/D pacing	Internal counter — ASIC. Software selectable time base: • Internal 40MHz, 50ppm stability • External Source via AUXIN<5:0>, Software selectable.
	External convert strobe: A/D CONVERT
	Software paced
Burst mode	Software selectable option, burst rate = 5μS.
A/D Gate Sources	External digital: A/D GATE
A/D gating modes	External digital: Programmable, active high or active low, level or edge
A/D trigger sources	External digital: A/D START TRIGGER A/D STOP TRIGGER
A/D triggering modes	External digital: Software-configurable for rising or falling edge.
	Pre-/Post-trigger: Unlimited number of pre-trigger samples, 16 Meg post-trigger samples.

ADC Pacer Out	Available at user connector: A/D PACER OUT
RAM buffer size	8K samples
Data transfer	DMA
	Programmed I/O
DMA Modes	Demand or Non-Demand using scatter gather.
Configuration Memory	Up to 8K elements. Programmable channel, gain, and offset
Streaming-to-disk rate	200kS/s, system dependent

Accuracy

200 kS/s sampling rate, single channel operation and a 15-minute warm-up. Accuracies listed are for measurements made following an internal calibration. They are valid for operational temperatures within ±1°C of internal calibration temperature and ±10°C of factory calibration temperature. Calibrator test source high side tied to Channel 0 High and low side tied to Channel 0 Low. Low-level ground is tied to Channel 0 Low at the user connector.

Settling Time

Settling time is defined as the time required for a channel to settle to within a specified accuracy in response to a full-scale (FS) step. Two channels are scanned at the specified rate. A —FS DC signal is presented to Channel 1; a +FS DC signal is presented to Channel 0.

Condition	*Range*	*Accuracy*	
		±0.0031% (±2.0 LSB)	±0.0062% (±4.0 LSB)
Same range to same range	±10V	5µS max	*
	±5V	5µS max	*
	±500mV	5µS typ	*
	±50mV	*	5µS typ

Parametrics

Max working voltage (signal + common-mode)	±11V
CMRR @ 60Hz	±10V Range: 85dB
	±5V Range : 85dB
	±500mV Range: 93dB
	±50mV Range: 93dB
Small signal bandwidth, all ranges	413 kHz
Input coupling	DC
Input impedance	100 GOhm in normal operation.
	2 kOhm typ in powered off or overload condition.
Input bias current	±200pA
Input offset current	±100pA

Absolute maximum input voltage	±25V powered on, ±15V powered off. Protected Inputs: • CH<15:0> IN • AISENSE
Crosstalk	Adjacent Channels: -75dB
	All other Channels: -90dB

Noise Performance

Table A1 below summarizes the noise performance. Noise distribution is determined by gathering 50K samples with inputs tied to ground at the user connector. Samples are gathered at the maximum specified single-channel-sampling rate. Specification applies to both single-ended and differential modes of operation.

Table A1 — *Analog Input Noise Performance*

Range	***Counts***	***LSBrms***
±10V	7	0.7
±5V	7	0.7
±500mV	11	1.1
±50mV	45	5.6

Analog Input Calibration

Recommended warm-up time	15 minutes
Calibration	Auto-calibration, calibration factors for each range stored on board in non-volatile RAM.

Onboard calibration reference	DC Level: 10.000V± 5mv. Actual measured values stored in EEPROM.
	Tempco: 5ppm/°C max, 2ppm/°C typical
	Long-term stability: 15ppm, T = 1000 hrs, non-cumulative
Calibration interval	1 year

Digital Input / Output

Digital Type	Discrete, 5V/TTL compatible
Number of I/O	8
Configuration	8 bits, independently programmable for input or output. All pins pulled up to +5V via 47K resistors (default). Positions available for pull down to ground. Hardware selectable via solder gap.
Input high voltage	2.0V min, 7.0V absolute max
Input low voltage	0.8V max, —0.5V absolute min
Output high voltage (IOH = -32mA)	3.80V min, 4.20V typ
Output low voltage (IOL = 32mA)	0.55V max, 0.22V typ
Data Transfer	Programmed I/O
Power-up / reset state	Input mode (high impedance)

Counter Section

User counter type	82C54

Number of Channels	2
Resolution	16-bits
Compatibility	5V/TTL
CTRn base clock source (Software selectable)	Internal 10MHz, Internal 100KHz or External connector (CTRn CLK)
Internal 10MHz clock source stability	50ppm
Counter n Gate	Available at connector (CTRn GATE).
Counter n Output	Available at connector (CTRn OUT).
Clock input frequency	10 MHz max
High pulse width (clock input)	15ns min
Low pulse width (clock input)	25ns min
Gate width high	25ns min
Gate width low	25ns min
Input low voltage	0.8V max
Input high voltage	2.0V min
Output low voltage	0.4V max
Output high voltage	3.0V min

Power Consumption

+5V	0.9A typical, 1.1A max. . Does not include power consumed through the I/O connector.
+5V available at I/O connector	1A max, protected with a resettable fuse

Environmental

Operating Temperature Range	0 to 55°C
Storage Temperature Range	-20 to 70°C
Humidity	0 to 90% non-condensing

Mechanical

Card dimensions	PCI half card: 174.4mm(L) x 100.6mm(W) x11.65mm(H)

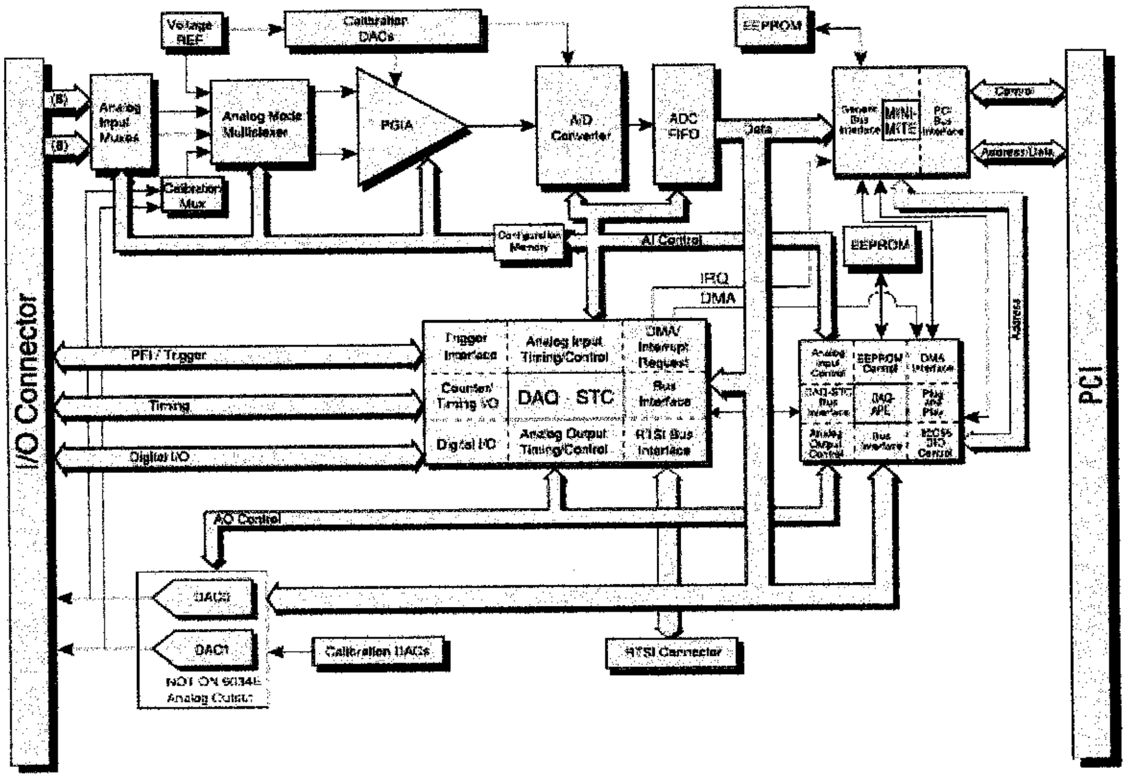


Figure A2: NI 6036E Block Diagram

APPENDIX C

SPECIFICATIONS OF ITEMP® HART® TEMPERATURE FIELD TRANSMITTER TMT 162

The iTEMP® HART® temperature field transmitter TMT 162 is a two-wire transmitter with analogue output, two (optional) measuring inputs for resistance thermometers and resistance transmitters in 2-wire, 3-wire or 4-wire connection, thermocouples and voltage transmitters. The LC display shows the current measured value digitally and as a bar graph with an indicator for limit value violation. The TMT 162 can be operated via the HART® protocol using a handheld terminal (DXR 275) or PC (COMMUWIN II, FieldCare or ReadWin® 2000 operating software).

The iTemp TMT 162 HART temperature field transmitter has now been cleverly combined with a compact thermocouple (TMT 162C) and a compact RTD assembly (TMT 162R) for maximum versatility. These compact devices are easily adaptable to a wide range of applications throughout the process industries, from power and pulp and paper to more arduous environments encountered in petrochemical and oil and gas applications. The backbone of these compact devices is the TMT 162 HART field transmitter.

Reliable and robust, the TMT 162 offers the maximum in functional safety with EMC immunity to NAMUR NE 21 (insensitive to motors and generators), signal on alarm functions to NAMUR NE 43 and basic requirements to NAMUR NE 89 (providing information on sensor input corrosion and excess ambient temperature).

In addition, the TMT 162 is ATEX certified (Ex ia, Ex d, Ex nA) for hazardous area use and stainless steel housing is available as an option, offering excellent protection in harsh environments. The TMT 162 features a brilliant rear-illuminated display: measured values can be easily read from a distance or in difficult conditions - day or night. Set-up is quick and easy and can be done online, so there is no need to disconnect the measuring point when re-programming.

The loop-powered TMT 162 has 2000v galvanic isolation and a dual compartment for simple sensor connection. The large gold-plated terminals are suitable for cables up to 2.5 mm2, for use in a wide range of applications. In addition, redundant temperature measurement is possible via the dual sensor input, enabling automatic switching in the event of sensor failure to minimize downtime.

Application

1. Temperature field transmitter with HART® -protocol for converting various input signals to an analogue, scalable 4 to 20 mA output signal
2. Input:
   Resistance thermometer (RTD)
   Thermocouples (TC)
   Resistance transmitter (Ohm)
   Voltage transmitter (mV)
3. HART® -protocol for operating the device on site using handheld terminal (DXR275/DXR375) or remotely via the PC

Input

1. Measured variable: Temperature (temperature linear transmission behavior), resistance and voltage
2. Measuring range: The transmitter records different measuring ranges depending on the sensor connection and input signals.
3. Type of input :

Table B1 : Type of inputs of iTEMP HART temperature field transmitter TMT 162

Input	Designation	Measuring range limits	Min. span
Resistance thermometer (RTD)	Pt100 Pt500 Pt1000 to IEC 751 (a = 0.00385)	-200 to 850 °C (-328 to 1562 °F) -200 to 250 °C (-328 to 482 °F) -200 to 250 °C (-328 to 482 °F)	10 K 10 K 10 K
	Pt100 to JIS C1604-81 (a = 0.003916)	-200 to 649 °C (-328 to 1200 °F)	10 K
	Ni100 Ni1000 to DIN 43760 (a = 0.006180)	-60 to 250 °C (-76 to 482 °F) -60 to 150 °C (-76 to 302 °F)	10 K 10 K

Input	Designation	Measuring range limits	Min. span
	• Type of connection: 2-wire, 3-wire or 4-wire connection • With 2-wire circuit, compensation of wire resistance possible (0 to 50 Ω) • With 3-wire and 4-wire connection, sensor wire resistance to max. 50 Ω per wire • Sensor current: ≤ 0.3 mA		
Resistance transmitter	Resistance Ω	10 to 400 Ω 10 to 2000 Ω	10 Ω 100 Ω
Thermocouples (TC)	B (PtRh30-PtRh6) C (W5Re-W26Re)[1] D (W3Re-W25Re)[1] E (NiCr-CuNi) J (Fe-CuNi) K (NiCr-Ni) L (Fe-CuNi)[2] N (NiCrSi-NiSi) R (PtRh13-Pt) S (PtRh10-Pt) T (Cu-CuNi) U (Cu-CuNi)[2] to IEC 584 part 1	0 to +1820 °C (32 to 3308 °F) 0 to +2320 °C (32 to 4208 °F) 0 to +2495 °C (32 to 4523 °F) -270 to +1000 °C (-454 to 1832 °F) -210 to +1200 °C (-346 to 2192 °F) -270 to +1372 °C (-454 to 2501 °F) -200 to +900 °C (-328 to 1652 °F) -270 to +1300 °C (-454 to 2372 °F) -50 to +1768 °C (-58 to 3214 °F) -50 to +1768 °C (-58 to 3214 °F) -270 to +400 °C (-454 to 752 °F) -200 to +600 °C (-328 to 1112 °F)	50 K 50 K 50 K 50 K 50 K 50 K 50 K 50 K 50 K 50 K 50 K 50 K
	• Internal cold junction (Pt100) • Accuracy of cold junction: ± 1 K • Max. sensor resistance 10 kΩ (if sensor resistance is greater than 10 kΩ, error message as per NAMUR NE 89)		
Voltage transmitter (mV)	Millivolt transmitter (mV)	-20 to 100 mV	5 mV

Output

1. Output signal : Analogue 4 to 20 mA, 20 to 4 mA
2. Signal on alarm
   i. Underranging: Linear drop to 3.8 mA
   ii. Overranging: Linear rise to 20.5 mA
   iii. Sensor break; sensor short-circuit (not for thermocouples TC): ≲3.6 mA or ≳21.0 mA
3. Load: Max. (Vpower supply- 10.5 V) / 0.022 A (current output)
4. Linearization/transmission behavior: Temperature linear, resistance linear, voltage linear
5. Filter 1st order digital filter: 0 to 60 s
6. Galvanic isolation: U = 2 kV AC (input/output)
7. Input current required: ≲3.5 mA
8. Current limit: ≲23 mA
9. Switch-on delay: 4 s (during switch-on operation Ia ≲4 mA)

Electrical Connection

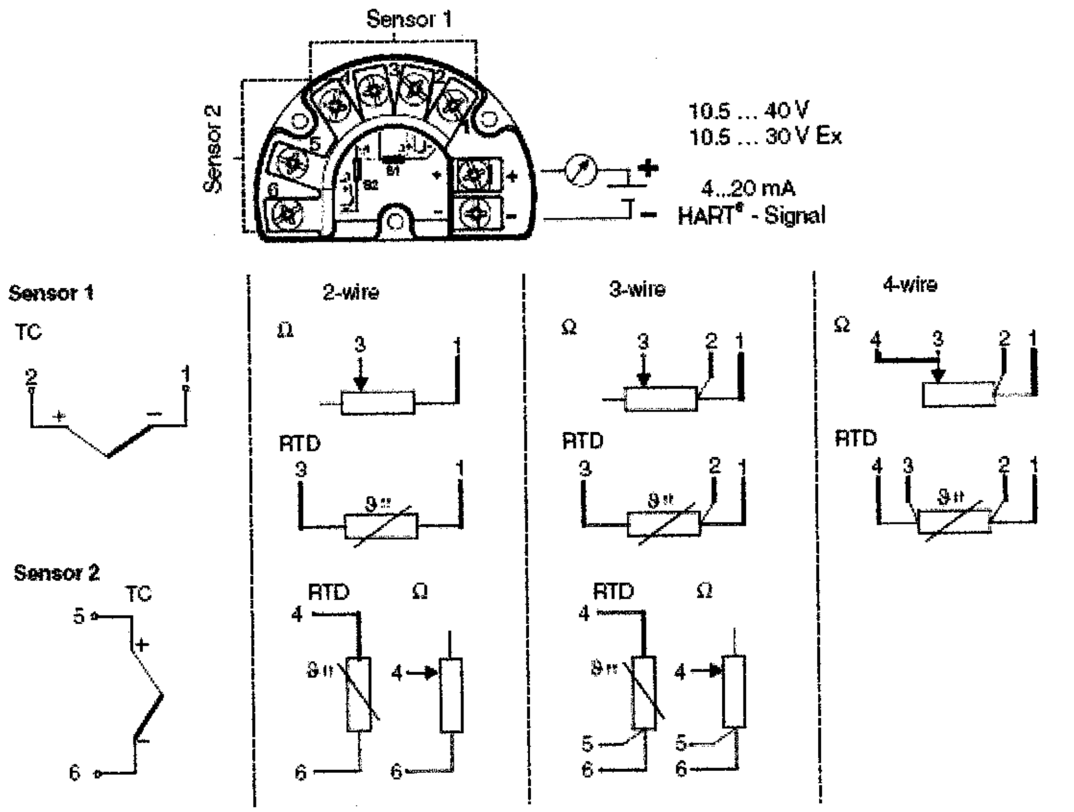
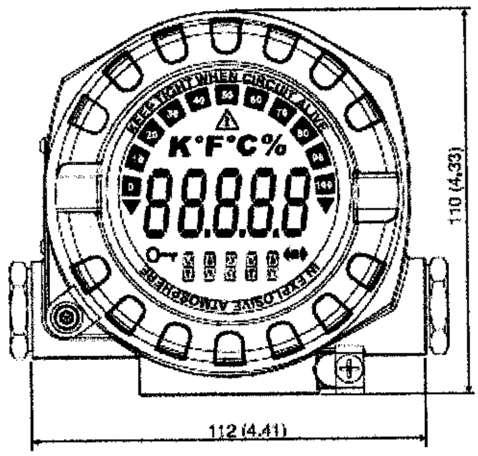


Figure B1: Electrical connection of iTEMP HART temperature field transmitter TMT 162

Mechanical Construction



Data in mm (inch)

Figure B2: Design and Dimension of iTEMP HART temperature field transmitter TMT 162 (front view)

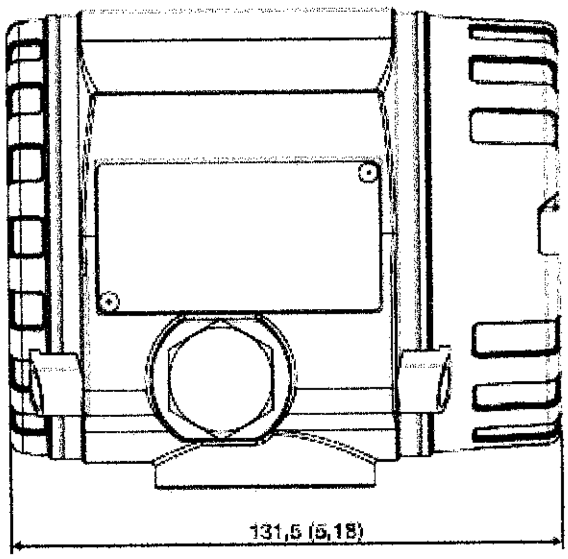


Figure B3: Design and Dimension of iTEMP HART temperature field transmitter TMT 162 (side view)

Display Element

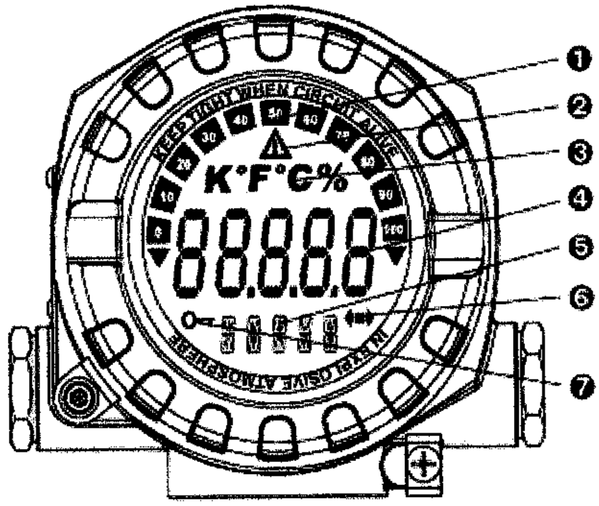


Figure B4: LC display of the field transmitter (illuminated, rotable in 90° stages)

Item 1: Bar graph display in 10 % stages with indicators for overranging / underranging

Item 2: 'Caution' display

Item 3: Unit display K, °F, °C or %

Item 4: Measured value display - height of digits 20.5 mm (0.807 in)

Item 5: Status and information display

Item 6: 'Communication' display

Item 7: 'Programming disabled' display

14. Aluminium or Stainless steel (optional) housing with ingress protection degree IP67 or NEMA 4x
15. Explosion certifications according to ATEX (EEx d and EEx ia), FM and CSA (Ex d and Ex i)
16. Calibration certificate can be ordered together with the assembly

Areas of application

1. Chemical and pharma/chemical industries
2. Petrochemical industry
3. Oil & Gas industry
4. Energy industry
5. Waste burning treatment

Function and system design

1. **Measuring principle**

In the thermocouple thermometer the sensing element is created by the physical junction of two homogeneous but different alloys (wires) isolated for the entire length, except in the junction point. The two wires are welded on one side, named 'measuring or hot junction', while the other free wires side, named 'reference or cold junction' is connected to an electrical circuit measuring the electromotive force (mVolts) generated by the different thermoelectric characteristics of the two thermocouple wires when a temperature difference between the hot junction (T1) and the cold junction (T0) occurs. This thermoelectric effect is named Seebeck effect and the T0 temperature must be referred to the 0°C as reference point. The function linking the electromotive force to the temperatures T1 and T0 depends on the materials utilized in the alloys (Ni, Cr, Fe, Cu,). These functions are standardized curves, for different alloys couples, by the following international norms DIN EN 60584 (Europe) and ANSI MC96.1 (North America).

2. **Equipment architecture**

The compact temperature assembly TMT 162C consists of a thermocouple sensor (TC type J or K) mounted on a fully programmable HART® protocol transmitter which belongs to the iTEMP® family. The sensor construction is based on the DIN EN 60584 standard, giving high reliability and performance in all the typical industrial environment conditions.

The TC sensing elements are created by two types of alloy couples: the type J (Iron-Constantan or Fe-CuNi) or the type K (Chromel®-Alumel® or NiCr-NiAl). The measuring ranges of this temperature sensing elements have different values depending on the couple types. The sensing element (hot junction) is located on the tip of the sensor. The measuring probe (TC replaceable insert) must be installed in a suitable thermowell. Thanks to the spring load construction method, the thermometer insert stays always in contact with the inner tip of the thermowell in order to guarantee the best heating transfer from the process to the sensing element.

The transmitter housing is available either in aluminium (double color painted) or in Stainless steel (optional), with or without LC display. The way in which it fits to the thermowell and the cable gland ensures a minimum IP65 (Ingress Protection) grade. The thermowell (to be ordered separately) can be either bar-stock or welded tube fabricated, depending on the specific application. The thermowells are available in different forms and with many process connections threads, flanges or weld-in types (see the paragraph "Thermowell"). Endress+Hauser has a full range of thermowells for the TMT 162C assembly, according to the various specific application.

3. Material

Transmitter housing is in painted aluminium or stainless steel.

Sensor stem: SS 316L/1.4404.

4. Weight

From 1.5 to 5 kg for standard options (aluminium housing).

5. Electronics

The TMT 162C output signal is a 4 to 20 mA (or 20 to 4 mA), in 2-wires technology. In case of sensor breakage, the transmitter can set the output signal value above the maximum (21 mA) or below the minimum (3.6 mA). A dual input functionality is also available: two input signals coming from two different TC elements can be managed as difference, average or redundancy. The TMT 162C transmitter can be configured through the HART® protocol by means of the operative "hand-held" DXR 275 (Universal HART® Communicator). For the two wire powering of the TMT 162C in the hazardous areas, Endress+Hauser produces suitable electronic supply modules, galvanically isolated and specifically designed for the intrinsic safety interfacing. For any further details or information on the iTEMP transmitter please refer to the relevant documentation (see TI codes at the end of this document). The electronic module compact thermometers such as the TMT 162C, should not be exposed at very high ambient temperature exceeding the maximum working temperature specified (see fig. 4).

Performance

1. **Operating conditions**

   i. Ambient temperature

• transmitter without display -40÷85°C (-40÷185°F)

• transmitter with display -30÷70°C (-22÷158°F)

   ii. Storage temperature

• transmitter without display -40÷100°C (-40÷212°F)

• transmitter with display -40÷85°C (-40÷185°F)

   iii. Process temperature

Could be limited by the thermowell.

2. **Maximum process pressure**

Maximum pressure values at various temperatures are indicated in the Technical Information of the different thermowells (see TI documentation codes at the end of this document).

3. **Maximum flow velocity**

The maximum flow velocity to which the TMT 162C can be exposed reduces with the increasing of the immersion length of the sensor inside the flow. The maximum flow velocity depends on the mechanical and construction characteristics of the thermowell itself, on the fluid characteristics and on the working conditions (pressure, temperature). For the choice of the proper thermowell according to the process conditions, flow velocity, etc. you are kindly requested to contact the Sales office of Endress+Hauser in your country.

4. Accuracy

The accuracy values of thermocouples type J and K are defined by the DIN EN 60584 standard, as follow.

Type	Standard tolerance (DIN EN 60584)		Reduced tolerance (DIN EN 60584)	
	Class	Deviation	Class	Deviation
J (Fe-CuNi)	2	+/-2.5°C (-40...333°C) +/-0.0075| t| (333...750°C)	1	+/-1.5°C (-40...375°C) +/-0.004| t| (375...750°C)
K (NiCr-Ni)	2	+/-2.5°C (-40...333°C) +/-0.0075| t| (333...1200°C)	1	+/-1.5°C (-40...375°C) +/-0.004| t| (375...1000°C)

(ItI=absolute temperature value in °C)

5. Measurement range

- Thermocouple sensor type J -40...750°C
- Thermocouple sensor type K -40...1100°C

6. Response time

Tests in water at 0.4 m/s (according to DIN EN 60584; 23 to 33°C step changes), only on the TC insert:

- T50 2.5 s
- T90: 7 s

7. Insulation

Insulation resistance between terminals and probe sheath above 1 GΩa 25°C

(according to DIN EN 60584, test voltage 500 Vdc) above 5MΩa 500°C

8. Self heating

Negligible

9. Installation

The Omnigrad S thermocouple thermometer model TMT 162C can be mounted on the wall of pipes or vessels or other plant parts that may be necessary. In the case of ATEX/FM/CSA certified components (transmitter + insert), please refer to the relevant documentation (TI code at the end of this document).

The immersion depth may have an effect on the accuracy of the measurement. If the immersion is too low, an error may be generated in the temperature detected due to the lower temperature of the process fluid near to the walls and the heat transfer, which takes place through the sensor stem. The incidence of such an error can be not negligible if there is a big difference between the process temperature and the ambient temperature. In order to avoid this source of inaccuracy, the thermowell should have a small diameter and the immersion length (L) should be, if possible, at least 100÷150 mm. In pipes of a small section the axis line of the duct must be reached and if possible slightly exceeded by the tip of the probe (refer to figure C1 A - C). Insulation of the outer part of the sensor reduces the effect produced by a low immersion. Another solution may be a tilted installation (see figure C1 B - D).

In the case of two-phase flows, please pay special attention to the choice of the measurement point, as there may be fluctuations in the value of the detected temperature. With regard to corrosion, it's important to choose the right base material of the thermowells. In case that the sensor components are disassembled and than re-mounted the proper assembling torque must be applied in order to guarantee the original tightness and ingress protection in the coupling sensor-housing.

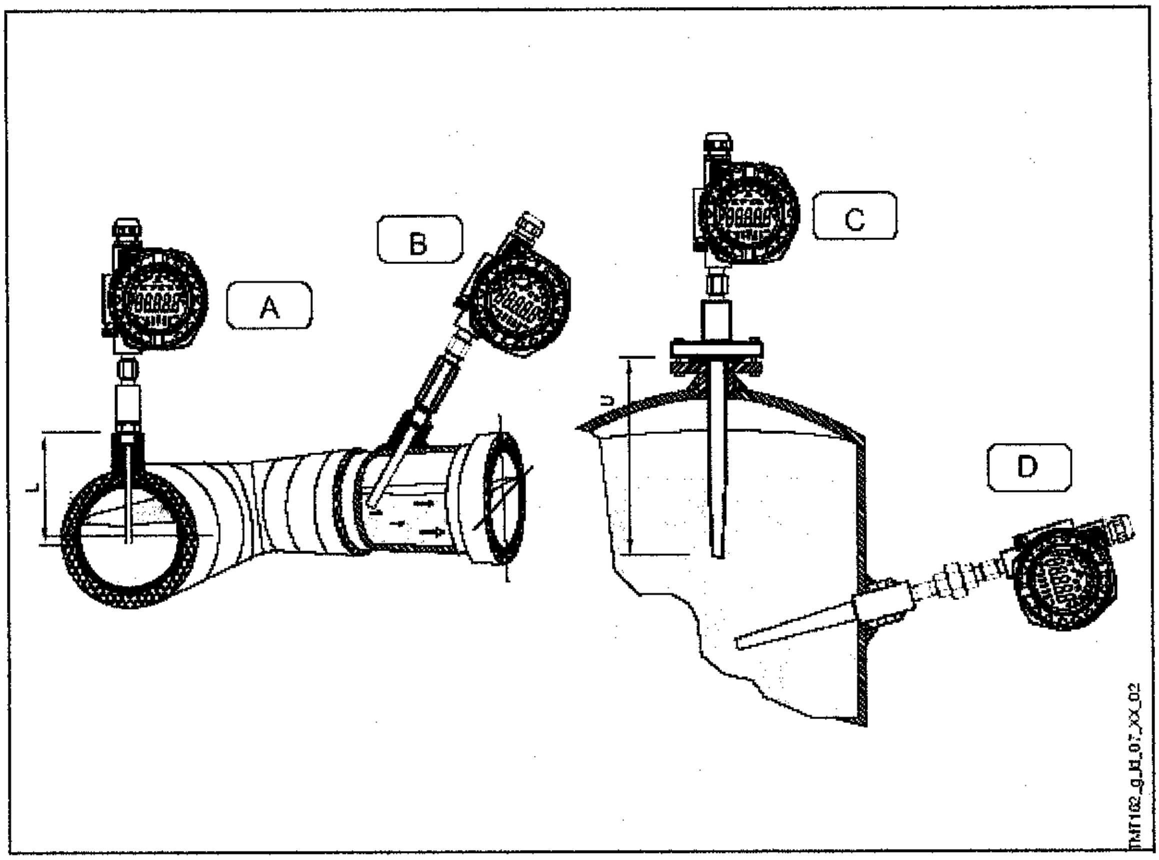


Figure C1: Examples of installation

System components

1. **Housing**

The housing of the TMT 162C is a dual compartment container. One compartment includes the electronics of the transmitter and the LC digital display (optional) while the second compartment, mechanically separated but electrically cabled to the first, contains the terminals for the electrical interface (for the TC sensor and output current 4...20 mA with HART® protocol) and the cable entries. When necessary, the display can easily be rotated with 90 degrees angle rotation thus adapting the display to the different local visualization needs. The housing is available either in painted aluminium (blue-grey E+H corporate colors) and, optionally, in stainless steel.

The ingress protection of the TMT 162C housing is IP67-Nema 4x; the electrical cable connection for the signal output 4 to 20 mA is available in different versions (1/2"NPT, M20x1.5,). The standard coupling sensor-housing is realized through 1/2"NPT thread, thus granting an IP65 ingress protection.

2. Extension neck

The extension neck is the mechanical interface between the process connections of the sensor and the housing. The function of the extension neck is to separate the electronics from the high temperature of the process. It is normally made of a tube assembled to various fittings (nipples, union) suitable to adapt the temperature sensor to the different thermowells existing in the plant or available from the E+H catalog. The neck material is usually SS 316L/1.4404.

The standard lengths (N) and the extension neck versions are selectable amongst the following options:

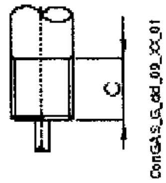
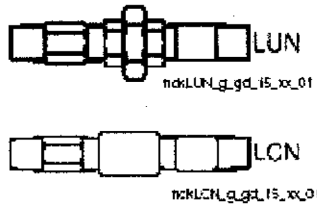
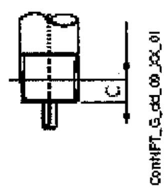
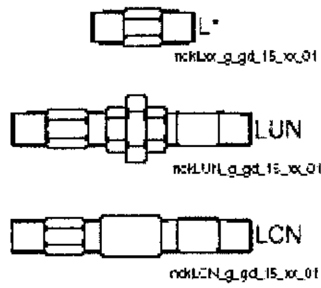
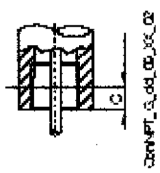
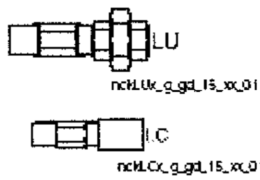
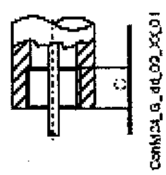
– 52 mm (only 1/2" NPT, type L)

– 102 mm (nipple+union, type LU)

– 96 mm (nipple+coupling, type LC)

– 144 mm (nipple+union+nipple, type LUN)

– 138 mm (nipple+coupling+nipple, type LCN)

Process connection to thermowell: threads					
Type	**Threads**	**Option**	**C (mm)**	**Details**	**Neck type**
Male	G 1/2"	D	15		
Male	1/2" NPT	N	8		
Male	3/4" NPT	P	8.5		
Female	1/2" NPT	U	8		
Female	M24x1.5	5	16		

3. Thermowell

The compact thermometer TMT 162C can be assembled to a thermowell separately ordered or already existing in the plant. To this scope the extension neck is available with different forms and executions. In order to easily select the right mechanical fitting for the thermowell you are kindly requested to use the table list and the ML values described at the chapter "Probe".

4. Probe

In the TMT 162C compact thermometer the probe is made by a mineral oxide insert (MgO) which shall be assembled to a temperature thermowell (thermowell to be ordered separately). The length of the sensor is freely selectable inside the predefined lengths range (50 to 990 mm). Sensors exceeding the 990 mm length can be ordered separately after technical analysis of the application. The immersion length (ML) must be defined as a function of the type and length of the relevant Thermowell. In case of spare inserts to be ordered please read carefully the following table (table valid for standard thickness tip):

Thermowell type	ML	Thermowell type	ML	Thermowell type	ML
TW 10*	ML = A - 8	TA 535	ML = A - 8	TA 560	ML = A - 11
TW 11*	ML = A - 8			TA 562	ML = A - 11
TW 12*	ML = A - 8	TA 540	ML = A - 10	TA 565	ML = A - 11
TW 13*	ML = A - 8	TA 541*	ML = A - 10	TA 566	ML = A - 11
TW 10**	ML = A - 15			TA 570	ML = A - 11
TW 11**	ML = A - 15	TA 550	ML = A - 11	TA 571	ML = A - 11
TW 12**	ML = A - 15	TA 555	ML = A - 10	TA 572	ML = A - 11
TW 13**	ML = A - 15	TA 556	ML = A - 10	TA 575	ML = A - 11
TW 15**	ML = A - 12	TA 557	ML = A - 10	TA 576	ML = A - 10

APPENDIX E

SPECIFICATIONS OF SDBS DISTRIBUTOR

The Model SDBS Distributor supplies power to a two-wire transmitter and converts the 4 to 20 mA DC transmitter signal current to two 1 to 5 V DC output signals. Isolation between input/output and distributor power supply is provided. Current limiting (to protect against transmitter wiring short circuits) is also provided.

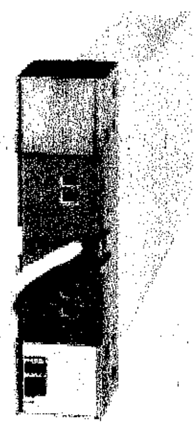


Figure B1: SDBS Distributor

<u>Input Signals</u>

- Input: Used with 24 V DC, 4 to 20 mA, 2-wire transmitters (four points)
- Leadwire Resistance (between transmitter and distributor):

$$\text{Maximum}(\Omega) = \frac{(20 - E_T)^{*}\, V_S}{0.02\ \text{A}}$$

E_T : Transmitter maximum on-load voltage drop

Note*: Distributor minimum(no-load) output voltage – Maximum no-load voltage drop.

<u>Output Signals</u>

- Output: 1 to 5V DC (one output per input)

- Load Resistance: At least 2k Ω

Isolation

- Loop Isolation Type: Input signal is not isolated from output signal. Input signal and output signal are isolated from distributor power source - i.e. inter-loop isolation.

Mounting and Appearance

- Mounting: Rack mounting.
- Wiring

1. Signal Wiring: ISO M4 size (4mm) screws on terminal block.
2. Power and Ground Wiring

    i. 100 V version: JIS C 8303 two-pin plug with earthing contact (IEC A5-15, UL458)

    ii. 220 V version: CEE 7 VII (CENELEC standard) plug (/A2ER).

- Cable Length: 300 mm.
- External Dimensions: 180 (H) x 48 (W) x 300 (D)
- Depth behind panel (mm)
- Weight: 1.7 kg (including case)

Standard Performance

- Accuracy: ±0.2 % of span
- Transmitter Supply Voltage (from distributor): 25.0 V DC to 28.0 V DC.
- Transmitter Power Supply ON/OFF Switch: Separate switch for each transmitter.
- Maximum Power Consumption:
    1. 210 mA with 24 V DC supply,
    2. 11.6 VA with 100 V AC supply,
    3. 14.6 VA with 220 V AC supply.
- Insulation Resistance
    1. Between I/O terminals and Ground: 100 M_/ 500 V DC

2. Between Power and Ground: 100 M__500 V DC
3. Between Loops: 100 M__500 V DC

- Dielectric Strength
  1. Between I/O terminals and Ground: 500 V AC for 1 minute.
  2. Between Power and ground: 1000 V AC for 1 minute (100 V version)
     1500 V AC for 1 minute (220 V version)
  3. Between Loops: 500 V AC for 1 minute

Normal Operating Conditions

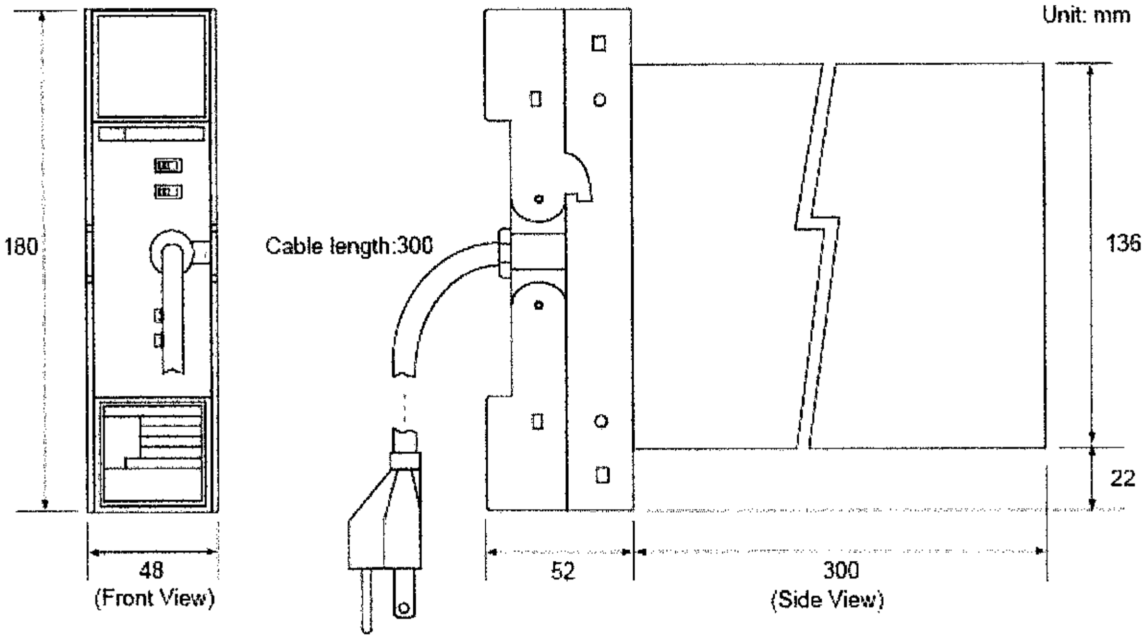
- Ambient Temperature: 0 to 50 °C
- Ambient Humidity: 5 to 90 % relative humidity (noncondensing)
- Power Supply: Two versions, for "100 V" (standard) or "220 V" (option
- Both versions may use AC or DC, without change to the instrument:

Version	100 V	220 V
DC(no polarity)	20 to 130 V	120 to 340 V
AC(47 to 63 Hz)	80 to 138 V	138 to 264 V

Accessories

- 1A fuse, quantity one.

External Dimensions



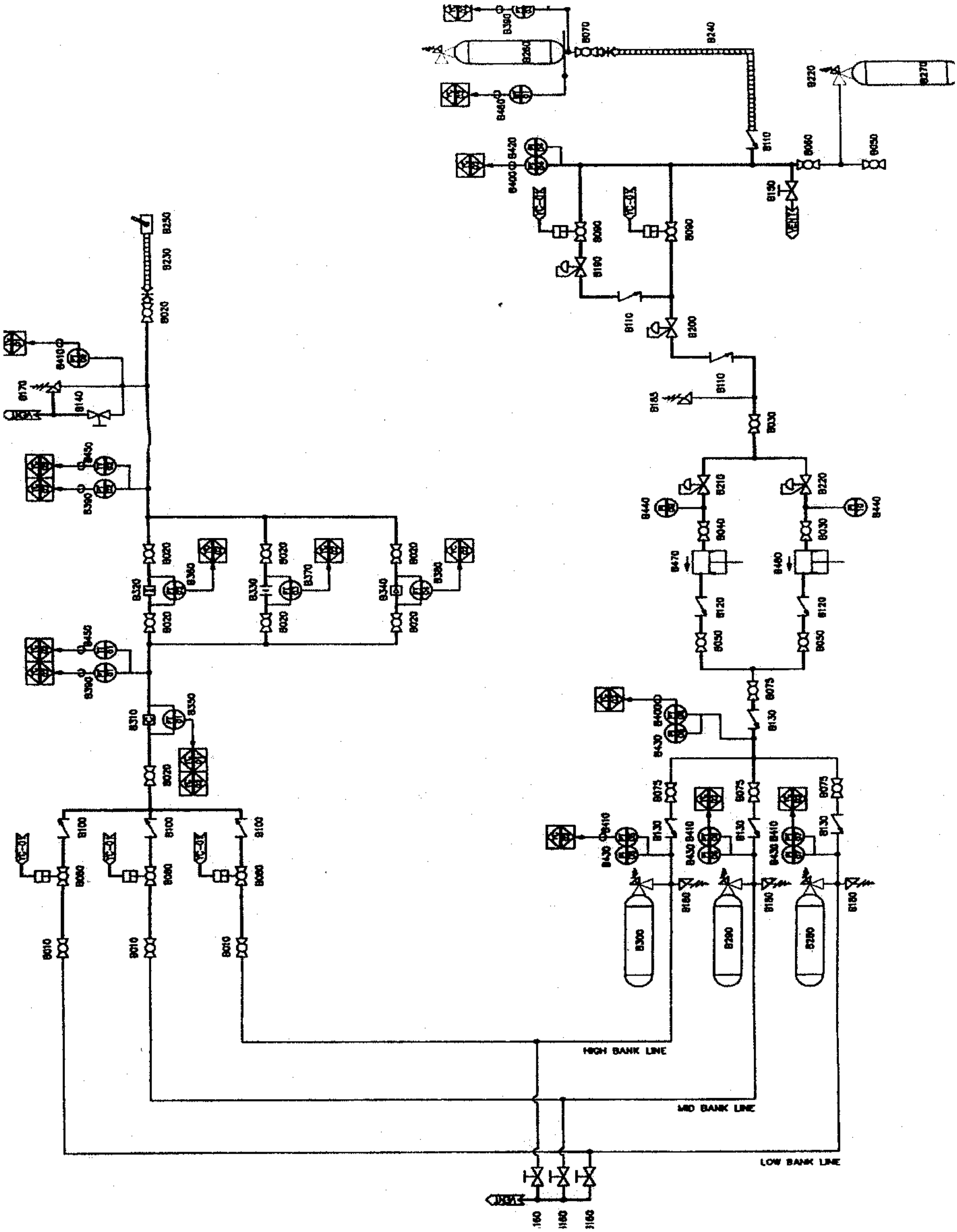
Terminal Connections

Terminal Designation	Description
1	+ Transmitter 1 (Input 1)
2	–
3	+ Transmitter 3 (Input 3)
4	–
5	+ Transmitter 2 (Input 2)
6	–
7	+ Transmitter 4 (Input 4)
8	–

Terminal Designation	Description
A	+ Output 1 (Transmitter 1)
B	–
C	+ Output 3 (Transmitter 3)
D	–
F	+ Output 2 (Transmitter 2)
H	–
J	+ Output 4 (Transmitter 4)
K	–

APPENDIX F

PROCESS AND INSTRUMENTATION DIAGRAM OF NGV TEST RIG



APPENDIX G

BILL OF MATERIAL FOR NGV TEST RIG

INSTRUMENTATION WITH TAG REPRESENTATION

ITEM	DESCRIPTION	QTY.	MATERIAL/SPECIFICATION
B010	VALVE, BALL	3	PARKER P/N: HPB6S8A
B020	VALVE, BALL	8	PARKER P/N: HPB6S8FF
B030	VALVE, BALL	2	KITZ BRASS 150PSIG MAWP
B040	VALVE, BALL	1	SWAGELOK P/N: SS-63TS8
B050	VALVE, BALL	3	SWAGELOK P/N: SS-33VF4
B060	VALVE, BALL	1	SWAGELOK P/N: SS-83KS8
B070	VALVE, BALL	1	OASIS P/N: BV506-NT
B075	VALVE, BALL	4	PARKER P/N: 4A-B2LJ2-SSP
B080	VALVE, BALL PNUEMATIC	3	PARKER P/N: 8A-B8LJ2-SSP-62AC-3
B090	VALVE, BALL PNUEMATIC	2	PARKER P/N: 8F-B8LJ2-SSP-62AC-3
B100	VALVE, CHECK	3	PARKER P/N: 8A-C8L-1-SS
B110	VALVE, CHECK	3	SWAGELOK P/N: SS-CHS16-1
B120	VALVE, CHECK	2	SWAGELOK P/N: SS-CHS4-1
B130	VALVE, CHECK	4	PARKER P/N: 4A-C4L-1-SS
B140	VALVE, NEEDLE	1	AGCO P/N: H5RIC-22
B150	VALVE, NEEDLE	1	SWAGELOK P/N: SS-1RS4
B160	VALVE, NEEDLE	3	PARKER P/N: 4A-V4LN-SS
B170	VALVE, RELIEF	1	SWAGELOK P/N: SS-4R3A1 SET @ 3750PSIG
B180	VALVE, RELIEF	3	SWAGELOK P/N: SS-4R3A SET @ 3950PSIG
B185	VALVE, RELIEF	1	SWAGELOK P/N: SS-RL4M8F8 SET @ 100PSIG
B190	VALVE, REGULATOR	1	JORDAN P/N: JHR Cv=0.6 SET @ 150PSIG
B200	VALVE, REGULATOR	1	JORDAN P/N: JHR Cv=0.6 SET @ 30PSIG
B210	VALVE, REGULATOR	1	JORDAN P/N: MARK608 5/16" OR SET @ 7" H2O
B220	VALVE, REGULATOR	1	JORDAN P/N: MARK608 5/16" OR SET @ 35" H2O
B230	HOSE, FLEXIBLE	1	SWAGELOK P/N: SS-NGS6-NN-120X
B240	HOSE, FLEXIBLE	1	PARKER P/N: 5CNG0101-16-16-16-120
B250	NOZZLE	1	SWAGELOK P/N: SS-83XKF4
B260	CYLINDER, NGV	1	EKC 1X55LWC 3600PSIG
B270	CYLINDER, NGV	1	EKC 3X55LWC 3600PSIG
B280	CYLINDER, NGV	1	EKC 4X55LWC 3600PSIG LOW BANK
B290	CYLINDER, NGV	1	EKC 3X55LWC 3600PSIG MEDIUM BANK
B300	CYLINDER, NGV	1	EKC 2X55LWC 3600PSIG HIGH BANK
B310	FLOW, SENSOR CORIOUS	1	MICROMOTION P/N: CNG050S239NCAZEZZZ
B320	FLOW, SENSOR TURBINE	1	HOFFER P/N: 3/4X3/4-25-CB-1RPR-MS-CE
B330	FLOW, SENSOR ORIFICE	1	ENDRESS + HAUSER P/N: DN25 PN250
B340	FLOW, SENSOR VORTEX	1	ENDRESS + HAUSER P/N: 70HS25-D0D20B1B100
B350	FLOW, TRANSMITTER CORIOUS	1	MICROMOTION P/N: 2700I11BBFEZZZ
B360	FLOW, TRANSMITTER TURBINE	1	HOOFER P/N: HIT2A-3-B-C-X-FX
B370	FLOW, TRANSMITTER ORIFICE	1	ENDRESS + HAUSER P/N: PMD235-MB588EM3C
B380	FLOW, TRANSMITTER VORTEX	1	ENDRESS + HAUSER P/N: 70HS25-D0D20B1B100
B390	PRESSURE, TRANSMITTER	3	ENDRESS + HAUSER P/N: PMP731-I33Z1M21X1
B400	PRESSURE, TRANSMITTER	2	MURPHY P/N: PXMS-6000
B410	PRESSURE, TRANSMITTER	5	MURPHY P/N: PXMS-5000
B420	PRESSURE, GAUGE	1	SWAGELOK P/N:
B430	PRESSURE, GAUGE	4	SWAGELOK P/N:
B440	PRESSURE, GAUGE	2	ASHCROFT 2-1/2" DIAL 0-60" H2O
B450	TEMPERATURE, TRANSMITTER	3	ENDRESS + HAUSER P/N: TMT162-E21231AAA
B460	LOAD CELL	1	METTLER TOLEDO EX APPROVED, 0-150KG
B470	COMPRESSOR, TIME FILLED	1	FUEL MAKER P/N: FMQ-2-36
B480	COMPRESSOR, TIME FILLED	1	FUEL MAKER P/N: FMQ-8-36
YC-01	DISPENSER REGISTER	1	KRAUS P/N: 09 N28AGUCGMS-D
YC-02	DATA ACQUISITION SYSTEM	1	ENDRESS + HAUSER P/N: RSG10-B162C21BB