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DESIGN AND DEVELOPMENT OF VAPOR LOCK DETECTION TO PREVENT BRAKE SYSTEM FAILURE

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ABSTRACT
Traffic accidents in Indonesia often occur due to failure on the braking system. The results of the KNKT investigation show that there are three phenomena that most often cause brake system failure, namely brake fading, a decrease in the volume of compressed air and vapor lock. The aim of this research is to conduct experimental studies and develop designs for vapor lock detection devices to prevent failure in the braking system. Experimental studies on vapor lock characteristics were carried out through observations and measurements of boiling points and bubbles (the beginning of vapor lock) in the brake fluid heating process with various variations in water content. Experiments on vapor lock characteristics show that increasing the percentage of water content in the brake fluid has an effect on reducing the boiling point of the brake fluid and an empirical equation is produced to predict the boiling point of the brake fluid based on the percentage of water content in it. Apart from that, we have successfully developed a design for a vapor lock detection device to prevent failure in the braking system which is equipped with a water cooler brake system to prevent the temperature from reaching the boiling point of the brake fluid.

Keywords: brake system; hydraulic brake vapor lock; pneumatic brake failure; prototype

INTRODUCTION
Transportation is a vital element in supporting the success of development, particularly in supporting economic activities (Siti Sahara & Saputra Yogi, 2023). According to data compiled by the Central Statistics Agency (BPS), there was an increase in the number of motor vehicles in Indonesia from 141,992,573 units in 2021 to 148,261,817 units in 2022, with significant increases in the categories of passenger cars, buses, trucks, and motorcycles (Perkembangan Jumlah Kendaraan Bermotor Menurut Jenis (Unit), 2021-2022.).However, this increase in the number of motor vehicles is also accompanied by an increase in traffic accidents.

According to the Indonesian National Police Traffic Corps (Korlantas Polri) related to the recapitulation of data throughout 2023, there were 148,307 accidents across Indonesia. This figure increased by about 0.06 percent compared to 2022, which had 140,248 accidents (Sepanjang 2023 Ada 148.307 Kasus Kecelakaan Di Seluruh Indonesia, Jawa Timur Mendominasi)Traffic accidents in Indonesia often occur due to brake system failures. Brakes are a supporting component on motor vehicles that function to dissipate the vehicle's kinetic energy, causing the vehicle to decelerate (Dzikrullah dkk, 2017). According to the investigation data of the National Transportation Safety Committee (KNKT), there were 15 buses and 30 trucks that had accidents due to brake failure between 2019 and 2022. The Senior Investigator of KNKT found that there are three types of brake failures that often occur in Indonesia: brake fading, pressure drop, and vapor lock (Ahmad Wildan, 2022).

Vapor lock is a condition where the brake temperature becomes too hot due to prolonged braking, causing the brake fluid to boil, generating vapor or vapor lock, and triggering brake failure (Alghifary, 2024). This phenomenon can occur in hydraulic brake systems. During braking, the brake pads press against the drum, creating friction and generating heat. If the braking process is prolonged, the heat will spread to the wheel cylinder and brake fluid. If the temperature of the brake fluid reaches its boiling point, air bubbles will form in the brake fluid. These air bubbles then create an empty space in the hydraulic line, preventing hydraulic pressure from the master cylinder from being properly transmitted to the wheel cylinder, thus failing to push the brake pads to press the drum effectively (Ahmad Wildan, 2022). Brake fluid is hydrophilic, making it easy to mix with water while driving (Š. Čorňák & Skolil2, 2008). Additionally, the brake fluid commonly used today is Glycolether series, which absorbs atmospheric water. As a result, the water content in the brake fluid increases over time, and its boiling point gradually decreases (Kawakami et al., 2000). This is consistent with previous studies' findings that the higher the water content in brake fluid, the lower its boiling point (Hunter et al., 1998);(Wijayanta et al., 2019). Based on the above discussion, an in-depth experimental study on the vapor lock phenomenon in braking systems is necessary. Subsequently, the experimental study results can be used as input data for developing a vapor lock detection device to prevent brake system failure. To date, there have been several previous studies related to the research conducted by the author, summarized in Table 1.

Table 1.
Relevant Research

No	Title, Author, and Year	Excess	Lack
1.	Sistem Pengendalian Panas Rem Tromol dengan *Water Cooler* sebagai solusi Losse Brake pada Truk (Jusnita et al., 2022)	Using a *water cooler brake drum* can reduce the temperature compared to a standard drum by up to 30%. The temperature difference between the standard drum and the *water cooler brake drum* will be even greater when the brake working temperature is above 100 ℃	There is a lack of more detailed information regarding the process of making *water cooler brake drums* , making it difficult for readers to understand understand the implementation of this technology .
2.	Sistem Pendingin Paksa Anti Panas Lebih *(Over Heating)* pada Rem Cakram *(Disk Brake)* (Dewanto & Andreas Wijaya, 2011)	This research compares cooling systems using air and water, providing a better understanding of the effectiveness of both in overcoming brake *overheating problems.*	Using water when the temperature reaches the maximum point that water can handle can cause the brake components to bounce, this shows that this approach has not been completely successful in solving *the overheating problem.*
3 .	Rancang Bangun Sistem Peringatan Suhu Pengereman Berbasis Mikrokontroller ATmega 16 (M.Fariz Anjasmara dkk, 2015)	The use of tool calibration methods with variations in distance and temperature provides a comprehensive approach in testing braking temperature warning systems. This variation allows the system to recognize significant temperature changes.	have been no direct automatic preventive system steps implemented to overcome the problem of increasing temperatures in the braking system.
4.	Rancang Bangun Alat Pendeteksi Suhu Kampas Rem Tromol Berbasis *Internet Of Things (IOT)* (Jatmicho, 2022)	The use of the *(I O T)* concept in the drum brake lining temperature detection tool is its ability to store data directly and display it via a link created by the researcher . The server web page also provides the location of the vehicle when it experienced *brake fading* .	Even though it provides information to the driver in an emergency, this tool does not have a direct prevention feature to handle overheating situations *in* the braking system.
5.	*The cooling device of drum brake system by using thermoelestic cooling module* (Hsueh, 2012)	The application of TEC (Peltier) chips as part of the drum brake cooling system shows an innovative approach and is able to reduce brake shoe temperatures significantly.	There is no automatic mechanism controlled by a microcontroller to be able to regulate and activate cooling according to needs.

METHOD

This research employs the Research and Development method to produce and test the effectiveness of a product (Jusnita et al., 2022). related to a vapor lock detection device to prevent brake system failure. The stages of product development include Analysis, Design, Development or Production, Implementation or Delivery, and Evaluation (Maydiantoro, 2020). However, this study only covers up to the Development or Production stage. The components required for the design and construction of the device include the following:

1. Arduino Nano

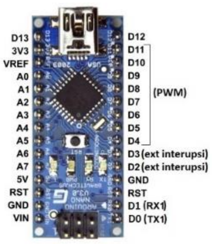


Figure 1. Arduino Nano

   Arduino is a type of small board that can easily utilize a microcontroller by giving it a logic or programming command. The microcontroller functions as a brain to control the input and output processes in electronic circuits (Yoga Widiana et al., 2019)

2. Type K Thermocouple

Figure 2. Type K Thermocouple

   Thermocouple is a type of temperature sensor that is often used in various circuits or electrical and electronic equipment related to temperature. Some of the advantages of thermocouples are their fast response to temperature changes and also their wide operational temperature range, which is between - 200˚C to 2000˚C. Apart from fast response and a wide temperature range, thermocouples are also resistant to shock/vibration and easy to use (Gianita, 2017).

3. Thermoelectric Cooler (TEC)

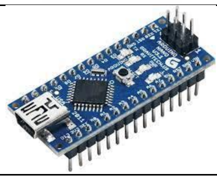
Figure 3. Thermoelectric Cooler

   Thermoelectric coolers, or Peltier coolers, work based on the Peltier effect, where heat is transferred when an electric current flows through two different conducting materials. The electric current flowing through this module makes electrons move from the N type to the P type semiconductor material, taking heat from the cold side of the module and releasing it on the hot side. The cold side absorbs heat from the object it wants to cool, while the hot side dissipates it into the environment. To be effective, Peltier coolers need a good cooling system because they produce both heat and cold. The cooling system for the Peltier uses additional components, namely a radiator, water block, cooling water and pump. By using a water cooling system, the Peltier element can be cooled optimally.

Figure 4. One Theromoelectric Cooler Kit

In the process of designing the tool design, there are tools and other additional materials that are used to support the design of the vapor lock preventer prototype *(water cooler brake system)* as can be seen in table 2.

Table 1.
Tools and Materials for Design and Construction of Tools

No	Name	Picture	Specification
1.	*Power Supply* 12 V		*Input* : AC 85~240 V *Output* : DC 12V 30A Max power: 360Watts Dimensions: L 21cm x W 11cm x H 5cm
2.	Peltier TEC-12706 DC 12V 6A		Model: TEC1-12706 Size: 40 x 40 x 4mm Working voltage: 12VDC and 6A Working temperature: -30 to 70
3.	*Water blocks*		Material: Aluminum Size: 40x80x12 mm
4.	*Water cooling radiators*		Material: aluminum. Size: 100 x 80 x 35mm. Nipple outer diameter: 8mm.
5.	12V DC Water Pump		*Outlet* diamater: 8mm *Inlet* diameter: 8mm Maximum discharge: 4L/min Voltage: DC 12V Size: 18cm x 10cm
6.	Slang Tube Tubing Pipe Silicone		Transparent silicon material. Inner diameter 8 mm. Outer diameter 12 mm.
7.	Arduino Nano V3 ATMEGA 328		Working voltage: 5 V Input Voltage: 6-20 V Speed :16 MHz Length: 45mm

8.	Buzzer 5 V		Voltage: 3v-12v DC Size: 12mm, 8.5mm thick (12085) Sound: 80-85 dB
9.	Relay 1 Chanel		Voltage: 5V Working current: 65mA Product size: 43x17x17mm
10.	I2C 16x 2 LCD		*Interface* : I2C *I2C Address* : 0x27 *Supply voltage* : 5V Size: 27.7mm42.6mm
11.	*Type K Thermocouple*		Probe material: *stainless steel* Probe length: 10 mm Working temperature: - 200˚C to 2000˚C
13.	*DC Dimmers*		Operating voltage: DC4.5V-35V Output current: 0-5AOutput power: 90W PWM duty cycle: 1%-100%Size: 30mm x 26mm x 14mm
14.	Potentio Meter		Width: 9 mm Diameter of adjustment rod: 6mm Resistance: 50K

The working principle of this device uses a water content sensor and a thermocouple sensor connected to an Arduino to detect vapor lock in the braking system. The data obtained from these two sensors is processed and displayed on an LCD. When the brake fluid temperature approaches its boiling point, specifically if it reaches 5% below the brake fluid's boiling point, the Arduino will activate a buzzer and relay. This will channel current from the power supply (battery) to activate the brake shoe and pad cooling system (water cooler brake system). The flowchart and schematic diagram of the vapor lock detection device to prevent brake system failure can be seen in Figures 5 & 6.

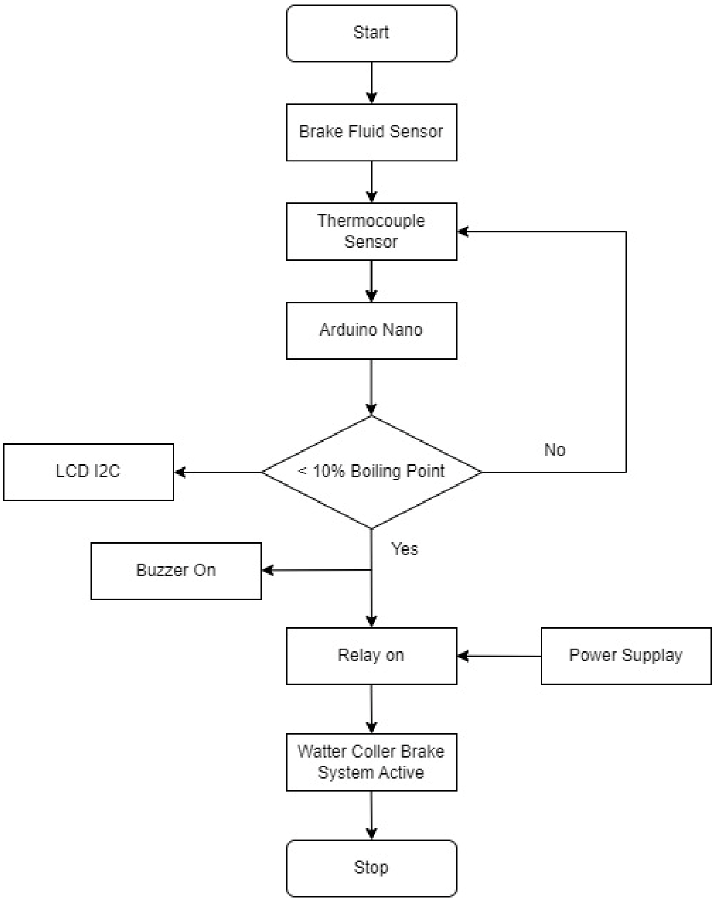


Figure 5Flow diagram of the working principle of the *vapor lock detection device*

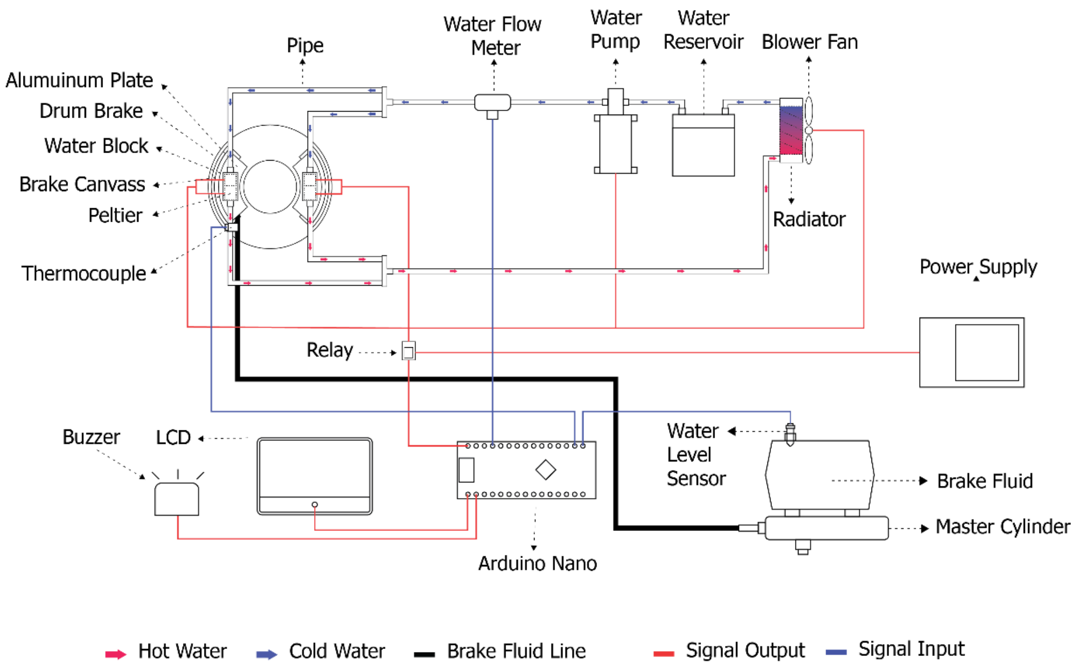


Figure 6. *Vapor lock* detection device design scheme

This research involves the analysis of boiling points and bubble formation characteristics during the heating process of DOT 3 brake fluid with varying water content percentages (0%, 1%, 3%, and 4%). The results of this study show that the boiling points of brake fluid with water mixtures of 0%, 1%, 3%, and 4% are 210°C, 178°C, 157°C, and 130°C, respectively. The effect of varying water content percentages in brake fluid on the boiling point of brake fluid from the experimental data by Wijayanta et al., (2023), Kao et al., (2006) and Hunter et al., (1998) can be seen in Figure 7.

The graph shows that the experimental data from Wijayanta et al., (2023), Kao et al., (2006), and Hunter et al.,(1998) indicate the same trend. An increase in the percentage of water content in brake fluid leads to a decrease in the boiling point of the brake fluid. From this experimental data, an empirical equation can be derived to predict the boiling point (°C) of brake fluid based on the water content (%) in the brake fluid, as follows: **Boiling point = 1.9046 (Water content)^2 – 27.683 (Water content) + 214.72.**

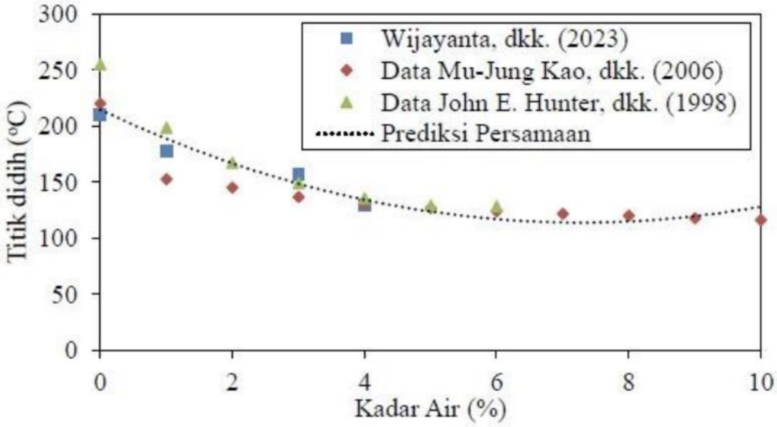


Figure 7**.** Boiling point *of brake fluid* with varying percentage of water content

RESULTS AND DISCUSSION

The steps that must be carried out in designing a *vapor lock detection device* to prevent failure of the braking system include the following:

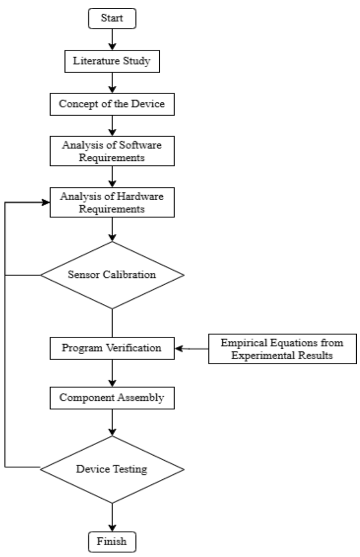


Figure 8. Flow diagram for the design of a *vapor lock detection device*

a. Literature Study
Conduct literature studies by looking for book, journal and internet media references regarding braking systems, water content sensors, *thermocouples* , microcontrollers and components related to the brake cooling system.
b. Concept of the Device
Designing a *vapor lock detection device concept* to prevent failure in the braking system based on a literature review. The tool schematic is in Figure 6, while the flow diagram is in Figure 5.
c. Analysis of Software Requirements
Before assembling the Arduino, sensors and other components in the box, carry out the wiring diagram design and simulation stage using Arduino Thinkercad software. This aims to minimize short circuits during assembly and testing. Next, to enter the program code into the Arduino, use the Arduino IDE software.
d. Analysis of Hardware Requirements
Hardware requirements include the components needed to make a *vapor lock detection device* for a heating system including: Power Supply, Peltier TEC, Water Block, Watter Cooling Radiator, Water Pump, Hose/pipe, Arduino Nano, Buzzer, Relay, *Type K Thermocouple*, *Capacitive Sensor Soil Moisture.*
e. Sensor Calibration
Calibration testing of this tool was carried out to determine the level of accuracy of the sensor with conventional measuring tools (WIBOWO & Prasetya, 2021). *The thermocouple sensor* is equipped with a module, so it can be connected to an Arduino and calibrated by comparing the results of the Arduino LCD readings with the measurement results of a digital thermometer which is equipped with a calibration certificate. The output signal from the water content sensor is in the form of voltage, so calibration needs to be done to change the voltage to percent (%). Calibration is carried out by inserting the sensor into *brake fluid* with 5 (five) variations in the percentage of water mixture (% volume). The voltage values of the 5 (five) variations in the percentage of the water mixture were recorded and then created a linear regression equation for the relationship between voltage (volts) and the percentage of water content (%)
f. Verification Program
In this research stage, programming design is required using Arduino IDE software. This software is useful as a text editor for creating, editing and validating program code. The following program code is entered into the Ardiuino:

```
#include <SPI.h>
#include "max6675.h"

const int thermoDO = 2 ;
const int thermoCS = 3 ;
const int thermoCLK = 4 ;
const int buzzerPin = 7 ;
const int relayPin = 10 ;
const int temperatureThreshold = 50 ; // Define temperature threshold here (in degrees
Celsius)
const int SoilsensorPin = A2; // Connect the sensor to analog pin A2

int MinSensorValue = 40 ;
int MaxSensorValue = 1010 ;
```

```
MAX6675 thermocouple ( thermCLK, thermoCS, thermoDO ) ;
#include <Wire.h> // I2C communication library
#include <LiquidCrystal_I2C.h> // I2C LCD module library

// default address 0x27
// LCD type 16x2 (16.2)
LiquidCrystal_I2C lcd = LiquidCrystal_I2C ( 0x 27 , 16 , 2 ) ;
void setup () {
    Serial . begin ( 9600 ) ;
    pinMode ( SoilsensorPin, INPUT ) ;
    pinMode ( buzzerPin , OUTPUT ) ;
    pinMode ( relayPin, OUTPUT ) ;
    lcd . init () ;
    lcd . backlight () ;
}
void loop () {
    int Soilsensor = analogRead ( SoilsensorPin ) ;
    int percentage = map ( Soilsensor, MinSensorvalue, MaxSensorvalue, 0 , 5 ) ;
    float Boiling point = 1.9046 * pow ( percentage, 2 ) - 27.683 * ( percentage ) + 214.72
;
    Serial . print ( "Percentage: " ) ;
    Serial . print ( percentage ) ;
    Serial . print ( "%, Boiling Point: " ) ;
    Serial . print ( boilingpoint ) ;
    Serial . println ( "°C" ) ;
    double temperature = thermocouple . readCelsius () ;
    //boiling point float = -18*temperature +
    // Display temperature in Serial Monitor
    Serial . print ( "Temperature: " ) ;
    Serial . print ( temperature ) ; // serial print = displays on PC
    Serial . println ( "C" ) ;

    // Display temperature in Serial Plotter
    Serial . print ( temperature ) ; // Send temperature in CSV format to Serial Plotter
    Serial . println () ; // Move to the next line in the Serial Plotter
    lcd . clear () ;
    lcd . setCursor ( 0 , 0 ) ;
    lcd . print ( "A" ) ;
    lcd . print ( percentage ) ;
    lcd . print ( "%" ) ;
    lcd . setCursor ( 4 , 0 ) ;
    lcd . print ( "T" ) ;
    lcd . print ( temperature, 0 ) ;
    lcd . print ( "c" ) ;
    lcd . setCursor ( 10 , 0 ) ;
    lcd . print ( "TD" ) ;
    lcd . print ( boiling point, 0 ) ;
    lcd . print ( "c" ) ;
    if ( temperature >= 0.9 * Boiling point ) {
        digitalWrite ( buzzerPin , HIGH ) ;
```

```
        digitalWrite ( relayPin, LOW ) ;
        lcd . setCursor ( 3 , 1 ) ;
        lcd . print ( " Vapor lock " ) ; }
        else {
        digitalWrite ( buzzerPin , LOW ) ;
        digitalWrite ( relayPin, HIGH ) ; }
    // Wait a moment before reading the temperature again
        delay ( 250 ) ;
      }
```

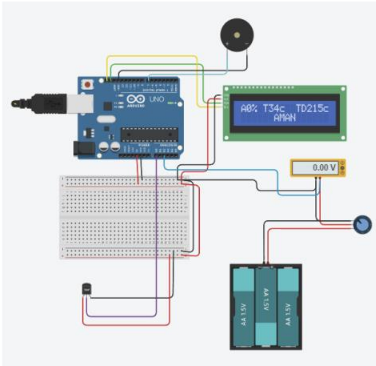
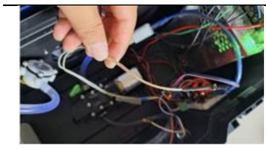
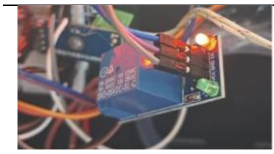


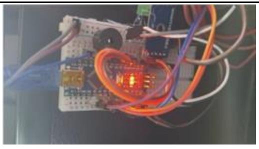
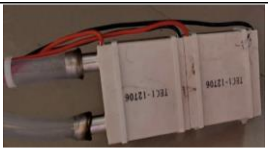
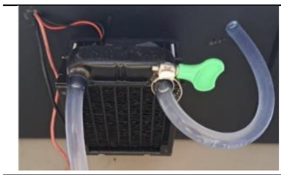
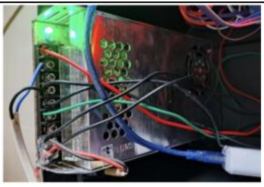
Figure 9. *Vapor lock* detection tool program simulation

g. Component Assembly

There are several stages in assembling tool design components, including the following:

Table 2.
Assembling tool components

Picture	Information
	Connecting *thermocouple* and the module to Arduino.
	Prepare a reservoir tube as a place to store fluid and attach the hose and clamp.
	Connect the positive and negative cables of the electric pump to the power supply. After that, attach the hose to the in valve for input and the out valve for output from the pump
	Attach the I2C LCD to the box that has been prepared, then connect the jumper cable to the Arduino Nano
	Connect the cable from the relay to the Arduino and power supply

	Installation buzzer , Arduino nano, *thermocouple module* , relay and jumper cables on the Breadboard kit according to the wiring diagram
	assembly . Attach the hose to the water block and connect the positive and negative peltier cables to the power supply.
	Connect the cable from the radiator fan to the power supply, then attach the hose to the in and out valve of the radiator
	Install the power supply in the box and connect the power supply to the relay, pump, radiator fan and peltier.
	Tidy up the cables and hoses in the box and check the functionality of the components by connecting the power supply to an AC current source.

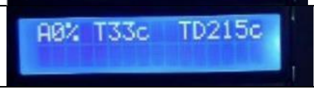
h. Device Testing

Trials are conducted to test the performance of the tool to ensure it works according to the concept or design. The trials include the following:

1) Testing LCD display and *Thermocouple performance*

The testing of the LCD display and thermocouple performance is carried out to test the temperature measurement results with the thermocouple and the boiling point calculation results of the brake fluid using empirical equations. To simulate varying water content in the brake fluid, a potentiometer is used, and the results are displayed on the LCD with code A. The temperature measurement results at the tip of the thermocouple are displayed on the LCD with code T and verified with a digital thermometer. The boiling point calculation results of the brake fluid using the empirical equation are displayed on the LCD with code TD. The test results show that the LCD can clearly display the values of A, T, and TD. The temperature measurement results with the thermocouple are consistent with the measurement results from the digital thermometer, and the TD value is also consistent with the calculation results from the empirical equation. Examples of the LCD display of the values A, T, and TD are shown in Table 4.

Table 3.
LCD display test results on various variations in water content

Water Content *Brake fluid*	Appearance LCD
4%	
3%	
2%	
1%	
0%	

2) Testing the Vapor Lock Detection and Brake Shoe Cooling System Performance *(Water Cooler Brake System)*

From the experimental results, the vapor lock condition occurs when bubbles form in the brake fluid as the brake fluid reaches its boiling point. However, as a preventive function, the vapor lock detection device and brake shoe cooling system are designed to activate when the brake shoe temperature reaches 10% below the brake fluid's boiling point. The brake shoe temperature is measured with a thermocouple and simulated by touching a heater (soldering iron) to the tip of the thermocouple.

(a)

(b)

(a)

Figure 10. LCD display of *vapor lock detection device performance*
(a) no *vapor lock has occurred* (b) *vapor lock begins to occur* (c) peltier reaches 0°C

The test results show that when the temperature at the tip of the thermocouple reaches 10% below the brake fluid's boiling point (with various water content percentages), the buzzer activates, and the LCD displays "vapor lock" as shown in Figure 6 (b). Simultaneously, the relay activates, and electrical current is passed through the relay to the Peltier and water pump. The hot side of the Peltier is cooled by the water block and cooling water, which is then circulated to the radiator and released into the atmosphere with the help of a cooling fan. Meanwhile, the cold side of the Peltier gradually decreases in temperature until it reaches 0°C, as shown in Figure 10 (c). The graph of temperature decrease over time from when the cooling system activates until the temperature reaches 0°C is shown in Figure 11. The decrease in temperature from room temperature (35℃) to 0℃ takes 36 seconds, resulting in an average cooling rate of 0.972℃/second or approximately 1℃/second.

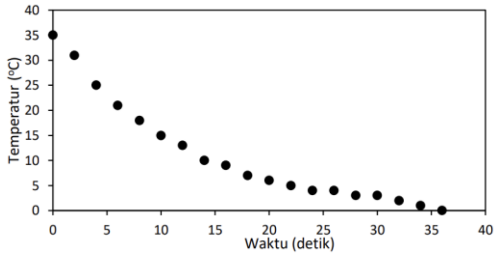


Figure 11. Graph of temperature decrease on the cold side of the Peltier

CONCLUSION

The vapor lock detection device is designed using key components such as a thermocouple, water content sensor, Arduino, LCD, and buzzer. Additionally, it is equipped with a brake shoe cooling system that operates automatically if the brake shoe temperature is 10% below the brake fluid's boiling point. The test results show that the vapor lock detection device works effectively. When the temperature reaches 10% below the brake fluid's boiling point (with various water content percentages), the buzzer activates, and the LCD displays "vapor lock." Simultaneously, the relay activates, and electrical current is passed through the relay to the Peltier and water pump. The hot side of the Peltier is cooled by the water block and cooling water, which is then circulated to the radiator and released into the atmosphere with the help of a cooling fan. Meanwhile, the cold side of the Peltier gradually decreases in temperature until it reaches 0℃, with an average cooling rate of 0.972℃ per second.

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