Faculty of Engineering
Ain Shams University
Senior Mechatronics Program
Fall 2022

MEP212: Heat Transfer

Project 1

TEAM 8

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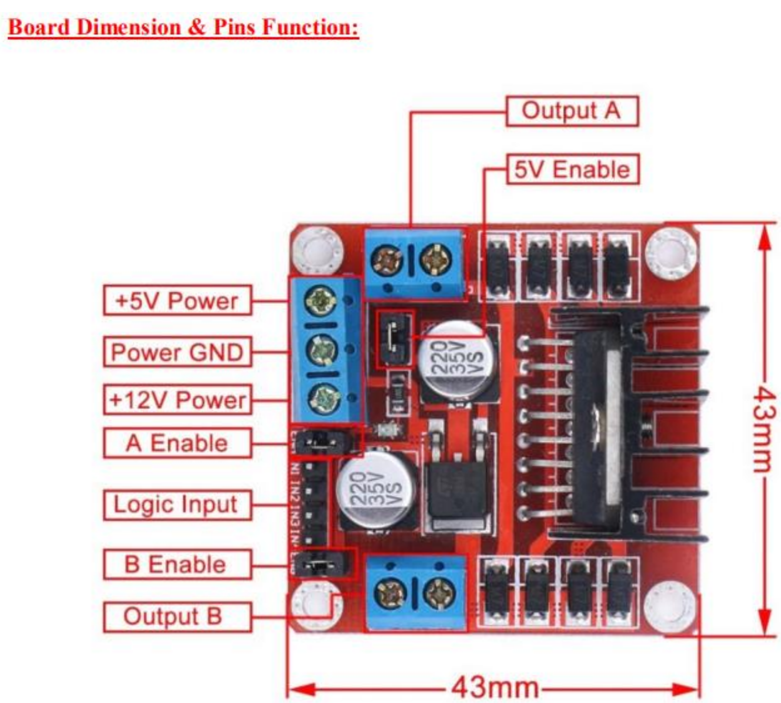
Introduction

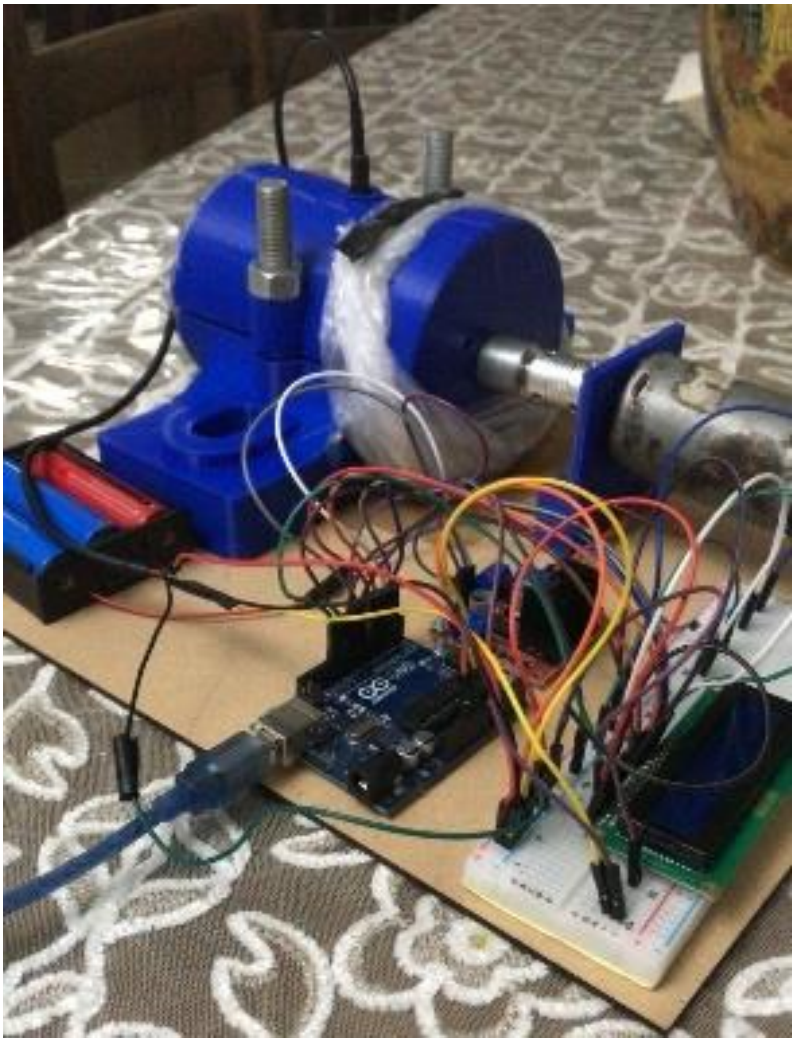
Journal Bearings are widely used for lubrication, and are of great importance in many machines. During working conditions, the lubricant may reach unwanted temperatures due to friction and therefore lose its function and may lead to failure. In this project, we are required to design a journal bearing model and apply required control to prevent the lubricant used (oil) from reaching such temperatures.

Project Parts

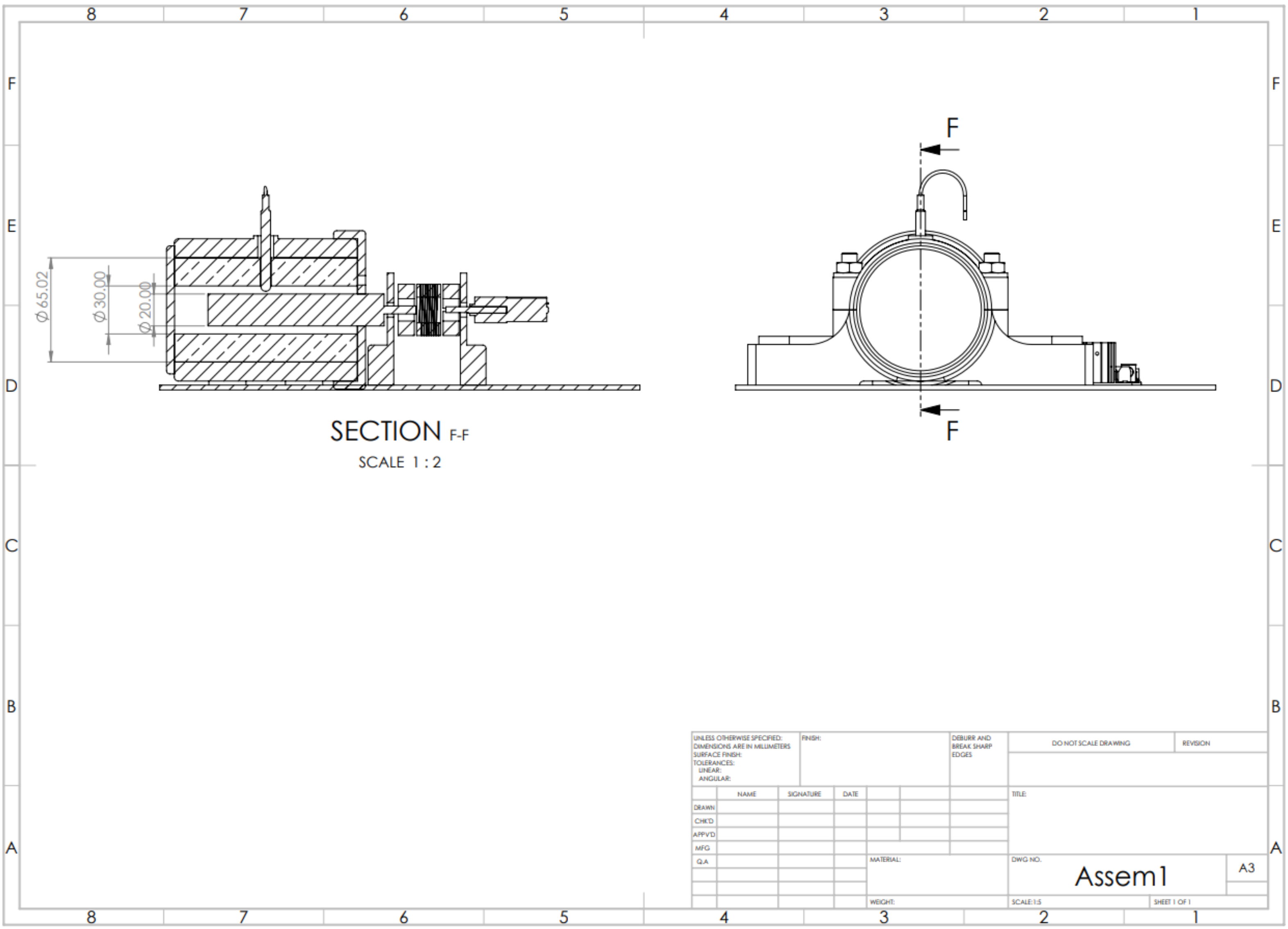
1. 3D Printed Journal Bearing
2. Arduino Uno
3. DC Motor (12V 13000 RPM)
4. Motor Shaft + Coupler
5. L298N Motor Driver IC



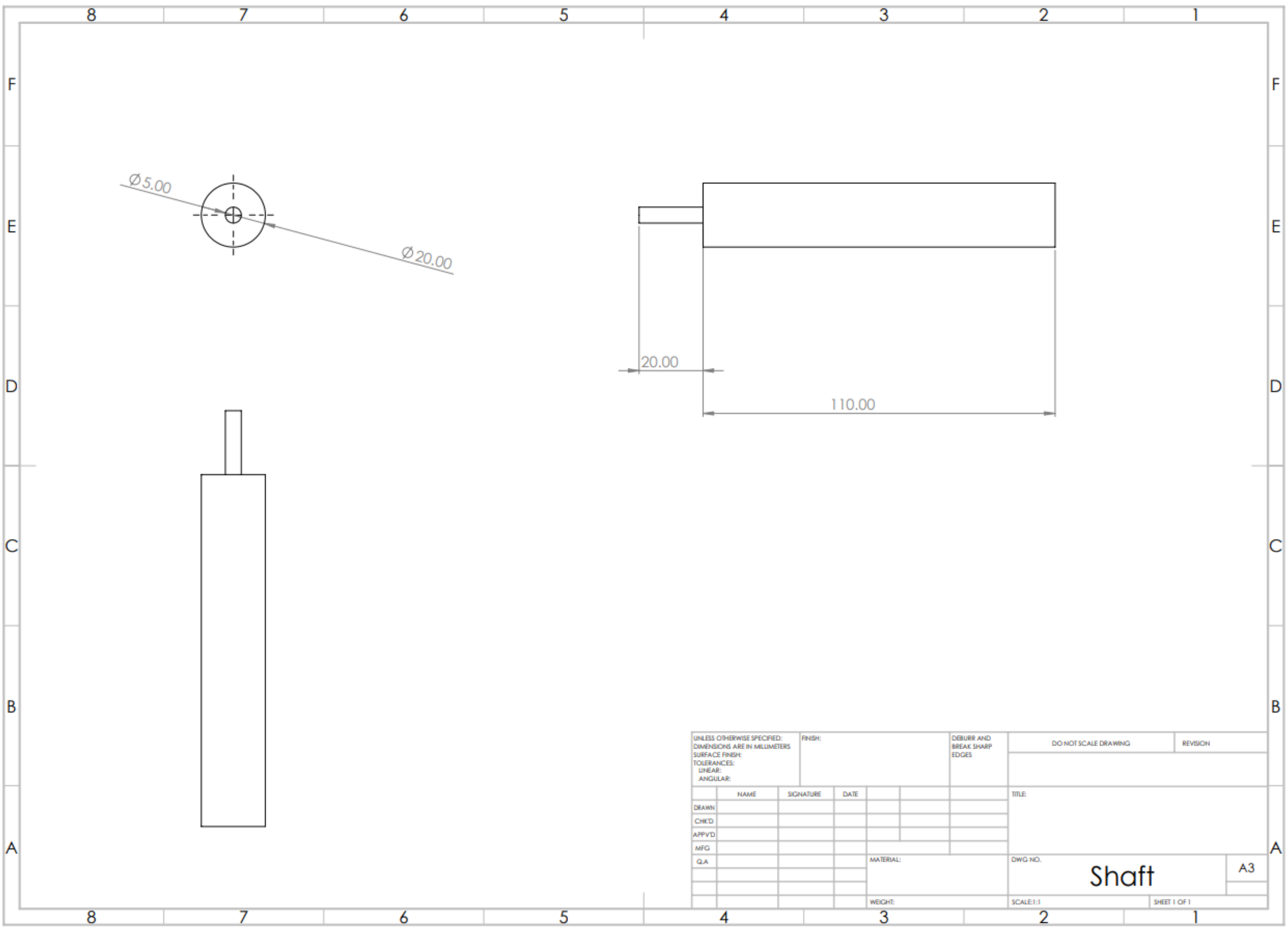
6. Temperature Sensor
7. LCD Screen
8. Breadboard + Wiring
9. Batteries
10. Oil (SAE 50 Dot 4 Brake Fluid)

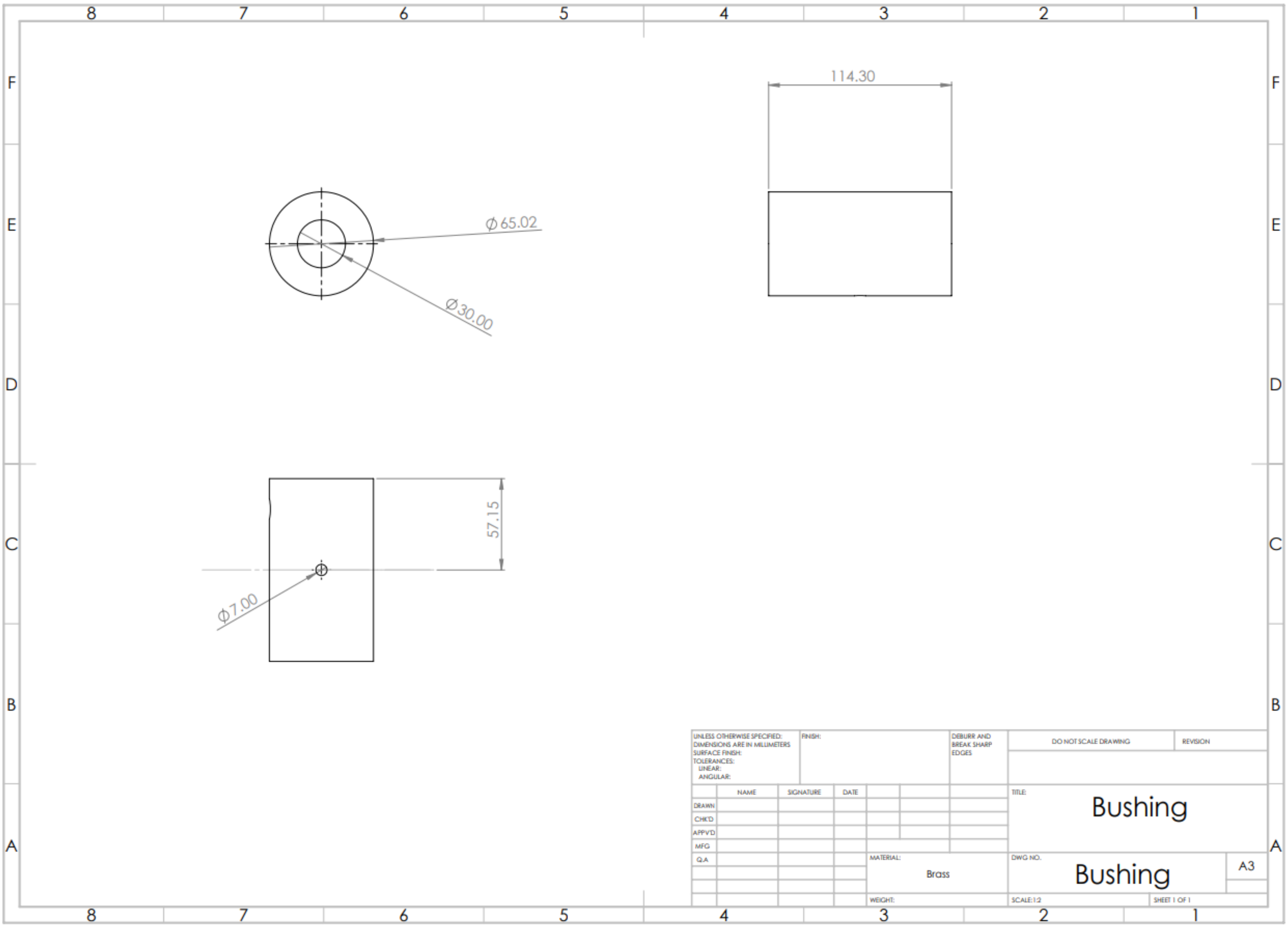


Assembly Drawing



Working Drawings




114.30
Ø 65.02
Ø 30.00
57.15
Ø 7.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
Bushing
MATERIAL:
Brass
DWG NO.
Bushing
A3
WEIGHT:
SCALE:1:2
SHEET 1 OF 1

Calculations

The flow of oil in a journal bearing can be approximated as parallel flow between two large plates with one plate moving and the other stationary. Such flows are known as Coutte flows. Consider two large isothermal plates separated by 5mm thick oil film.

- Assumptions

1- Steady operating conditions exist.

2- Oil is an incompressible substance with constant properties.

3- Body forces such as gravity are negligible.

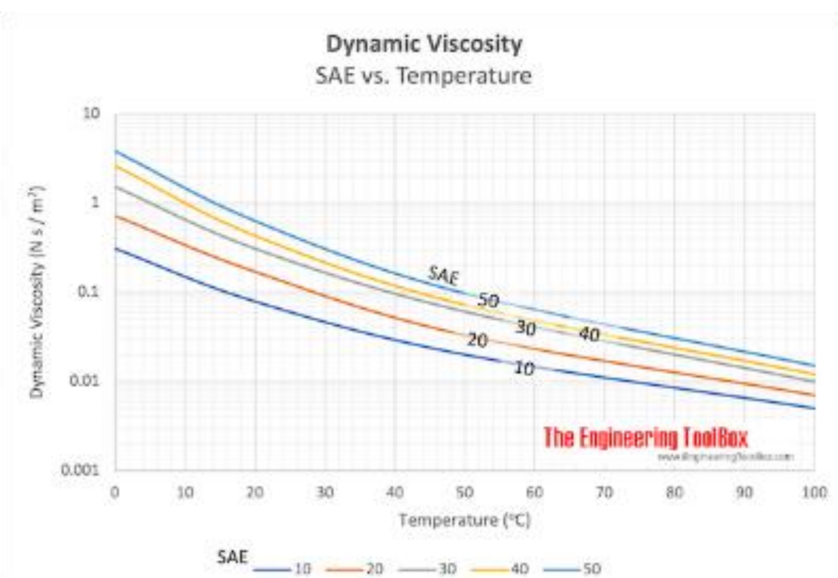
4- The plates are large so that there is no variation in the z-direction.

-Givens

Shaft Diameter: $d = 2cm = 1 \times 10^{-2}m$

Properties of Dot 4 Brake Fluid SAE 50 at $T_0 = 25°C$: $k = 0.15\ W/m.K$

We can get the viscosity of the Oil at $T_0 = 25°C$ from the following graph and given values:



Material/Substance	Thermal Conductivity - k - W/(m K) (Btu/(ft h F)) 25 °C (77 °F)
Nitrous oxide (gas)	0.0151
Nylon 6, Nylon 6/6	0.25
Oil, machine lubricating SAE 50	0.15
Olive oil	0.17
Oxygen (gas)	0.024

Dynamic Viscosity (*N s/m²*)				
SAE	Temperature (°C)			
	0	20	50	100
10	0.31	0.079	0.020	0.005
20	0.72	0.170	0.033	0.007
30	1.53	0.310	0.061	0.010
40	2.61	0.430	0.072	0.012
50	3.82	0.630	0.097	0.015

$$\mu \cong 0.6\ Pa.s$$

-Proof

We take the x-axis to be the flow direction and y to be the normal direction. This is a parallel flow between two plates and thus v = 0. Then the continuity equation reduces to:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \rightarrow \frac{\partial u}{\partial y} = 0$$

$$\therefore u = u(y)$$

Therefore, the x-component of velocity does not change in the flow direction (i.e. the velocity profile remains unchanged). Noting that u = u(y), v = 0 and $\frac{\partial p}{\partial x}$= 0 (flow is maintained by the motion of upper plate rather than the x — momentum equation reduces to:

$$\rho\left(u\ \frac{\partial u}{\partial x} + \ v\frac{\partial v}{\partial y}\right) = \mu\frac{\partial^2 u}{\partial y^2} - \frac{\partial P}{\partial x}$$

$$\therefore\ \frac{\partial^2 u}{\partial y^2} = 0$$

This is a second order ordinary differential equation, by integrating twice gives:

$$u(y)\ =\ C1y +\ C2$$

the fluid velocities at the plate surfaces must be equal to velocities of the plates because of the no slip condition. Therefore, the boundary conditions are $u(O) = 0$ and $u(L) = V$ and when applied gives the velocity distribution to be:

$$u(y) = \frac{y}{L}V$$

Frictional heating due to viscous dissipation in this case is significant because of the high viscosity of oil and the large plate velocity. The plates are isothermal and there is no charge in the flow direction and thus the temperature depends on y only $T = T(y)$. Also $u\ u(y)$ and $v = O$. Then the energy equation with dissipation reduce to:

$$\rho C_p\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right) = K\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) + \mu\varphi$$

$$\varphi = 2\left[\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2\right] + \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2$$

$$\therefore 0 = k\frac{\partial^2 T}{\partial y^2} + \mu\left(\frac{\partial u}{\partial y}\right)^2$$

$$\therefore\ k\frac{\partial^2 T}{\partial y^2} = \mu\left(\frac{V}{L}\right)^2$$

$$\frac{\partial u}{\partial y} = \frac{V}{L}$$

Dividing both sides by k and integrating twice give:

$$T(y) = \frac{\mu}{2k}\left(\frac{y}{L}V\right)^2 + C_3 y + C_4$$

Applying the boundary conditions:

$T(O) = TO\ and\ T(L) = TO$ to give the temperature distribution:

$$T(y) = T_o + \frac{\mu V^2}{2k}\left(\frac{y}{L} - \frac{y^2}{L^2}\right)$$

The temperature gradient determined by differentiating T(y) with respect to y;

$$\frac{dT}{dy} = \frac{\mu V^2}{2kL}\left(1 - 2\frac{y}{L}\right)$$

The location of maximum temperature is determined by setting dT/dy = 0 and solving for y:

$$\frac{dT}{dy} = \frac{\mu V^2}{2kL}\left(1 - 2\frac{y}{L}\right) = 0$$

$$\therefore y = \frac{L}{2}$$

Therefore, maximum temperature at mid plane which is not surprising since both plates are maintained at the same temperatures the maximum temperature is given by:

$$T_{max} = T\left(\frac{L}{2}\right) = T_O + \mu V^2\left(\frac{\frac{L}{2}}{L} - \frac{\left(\frac{L}{2}\right)^2}{L^2}\right)$$

$$T_{max} = T_O + \frac{\mu V^2}{8K}\ (Equation\ 1)$$

Heat flux at the plates is determined from the definition of heat flux:

$$\dot{q}_0 = -k\frac{dT}{dy}|_{y=\infty} = -k\frac{\mu V^2}{2kL}(1-0) = -\frac{\mu V^2}{2L}\ (Equation\ 2)$$

-Experimental Values

From the Viscosity-Temperature graph of the oil, we can see that the viscosity reaches 0.1 $Pa.s$ at almost $50°C$,so we can consider this to be T_{max}.

From Equation 1:

$$V = \frac{2\pi N}{60} \times r$$

$$50 = 25 + \frac{0.6 \times (\frac{2\pi N}{60} \times 1 \times 10^{-2})^{\,2}}{8 \times 0.15}$$

$$N = 6752.372\, rpm$$

From Equation 2:

$$\dot{q}_0 = -\frac{0.6 \times \left(\frac{2\pi \times 6752.372}{60} \times 10^{-2}\right)^2}{2(5 \times 10^{-3})} = 3000\, W/m^2$$

To decrease T_{max} by 20%, we can decrease the rpm to:

$$50(0.8) = 25 + \frac{0.6 \times (\frac{2\pi N}{60} \times 1 \times 10^{-2})^{\,2}}{8 \times 0.15}$$

$$N_{-20\%} = 5230.365\, rpm$$

To increase T_{max} by 10% and 20%, we repeat the previous step at $T_{max} = 50(1.1)$ and $T_{max} = 50(1.2)$ to get:

$$N_{+10\%} = 7396.85\, rpm, N_{+20\%} = 7989.515\, rpm$$

Control Code

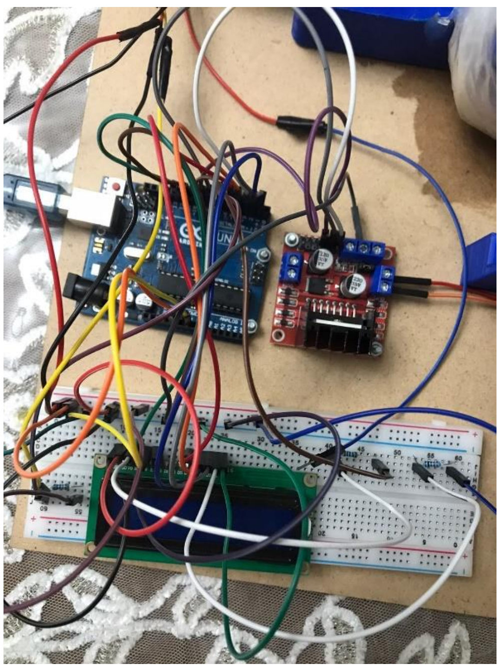
```
#include <LiquidCrystal.h>
#include <OneWire.h>
#include <DallasTemperature.h>

#define ONE_WIRE_BUS 7

/*ThermoCouple Pins*/
/**********************************/
OneWire oneWire(ONE_WIRE_BUS);

DallasTemperature sensors(&oneWire);

float Celcius = 0;

/*********************************/

/*LCD Pins*/
const int rs = 12, en = 11, d4 = 5, d5 = 4, d6 = 1, d7 = 2;
LiquidCrystal lcd(12, 11, 5, 4, 1, 2);
/*************************************/

/*Bridge Pins*/
```

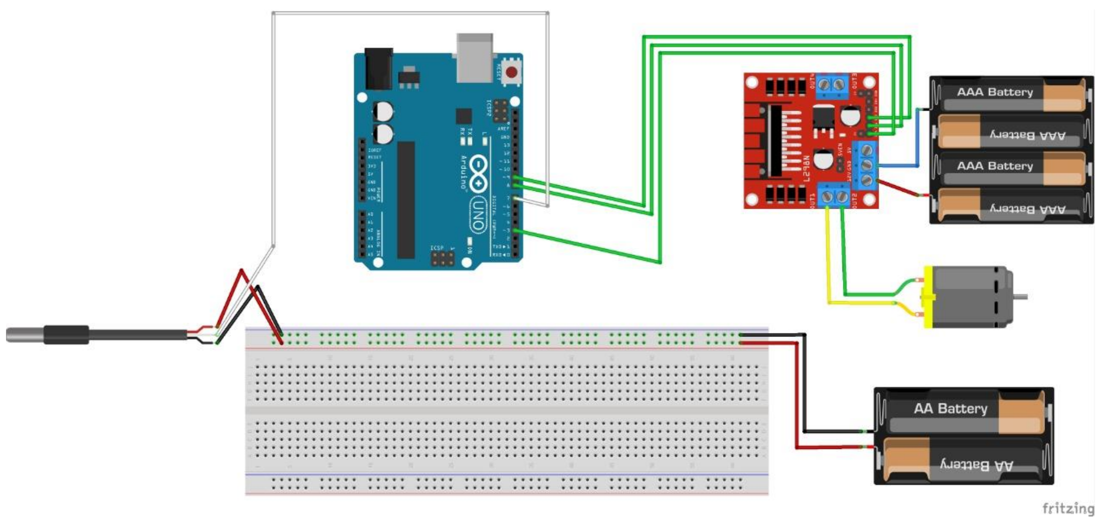
```
const int pwm = 3 ;  //initializing pin 3 as pwm
const int in_1 = 8 ;
const int in_2 = 9 ;
/********************/

void setup()
{
sensors.begin();
lcd.begin(16, 2);
lcd.clear();
pinMode(10, OUTPUT);
analogWrite(10, 0);
pinMode(in_1, OUTPUT);
pinMode(in_2, OUTPUT);
Serial.begin(9600);
}
void loop()
{
sensors.requestTemperatures();
Celcius=sensors.getTempCByIndex(0);
lcd.setCursor(0, 0);
lcd.print("Temp = ");
lcd.setCursor(10, 0);
lcd.print(Celcius);
```

```
delay(1000);
/*digitalWrite(in_1,HIGH) ;
digitalWrite(in_2,LOW) ;
analogWrite(pwm,255) ;*/
Serial.print(Celcius);
Serial.print("\n");
lcd.setCursor(0, 0);
lcd.print("Temp = ");
lcd.print(Celcius);

 if(Celcius >= 45 )
  {
   digitalWrite(in_1,LOW) ;
   digitalWrite(in_2,LOW) ;

  }
  else  if(Celcius < 45  || Celcius >= 25 )
  {
    digitalWrite(in_1,HIGH) ;
    digitalWrite(in_2,LOW) ;
    analogWrite(pwm,125) ;
  }
  else if( Celcius < 25)
  {
```

```
  digitalWrite(in_1,HIGH) ;
  digitalWrite(in_2,LOW) ;
  analogWrite(pwm,255) ;
 }
}
```

Circuit Connection





Conclusion

Using this method, we were able to control the system to prevent any potential failure.

References

1) https://www.engineeringtoolbox.com/dynamic-viscosity-motor-oils-d_1759.html
2) https://www.engineeringtoolbox.com/thermal-conductivity-d_429.html
3) http://www.handsontec.com/dataspecs/L298N%20Motor%20Driver.pdf