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Design and Implementation of a Waste Vegetable Oil (WVO) Fuel System with Temperature Controlled Heating for a 1985 Mercedes

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DESIGN AND IMPLEMENTATION OF A WASTE VEGETABLE OIL (WVO) FUEL SYSTEM WITH TEMPERATURE CONTROLLED HEATING FOR A 1985 MERCEDES

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April 29, 2013

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Waste vegetable oil (WVO) has been recognized as a clean and cheap fuel for diesel engines. However, WVO can only be used if it is heated to approximately 160 to 180 degree F, due to its high viscosity at lower temperatures. In this project, a fuel system was designed and built for a 1985 Mercedes 300SD diesel car to use either WVO or diesel. It uses both engine coolant and electric heating wires for heating WVO. A temperature-controlled switch is used to control the temperature of WVO entering the engine. The heating components were designed and simulated using Matlab, and tested both in the laboratory and on the car. Temperatures of various spots in this system can be monitored through temperature gauges. This new and unique design eliminates the need to run on diesel during warm-up. The whole system has been tested on the car and functioned as desired.

Introduction

With the rising fuel price, people are becoming more and more concerned with new sources of energy and alternative fuels on a car. Purchasing an electric or plug-in hybrid vehicle at the moment still costs significantly higher than buying a conventional internal combustion engine vehicle. Even after the tax credit, the prices of electric or plug-in cars are still not competitive.[1] Therefore, electric or plug-in vehicles are not yet able to solve the problem of increasing fuel cost.

A cheaper way to switch away from the conventional fuel is needed to truly solve the problem, before the cost of electric cars could be significantly reduced. Thus, people's attention had turned to the Waste Vegetable Oil (WVO). Back when inventor Rudolph Diesel was running his first engine, he used vegetable oil. And modern diesel engines of almost every brand and type today could still run on WVO without significant modification to the engine. In addition, nowadays restaurants are paying rendering companies in order to have their WVO properly disposed.[2] If the WVO from the restaurants is used to power diesel engine cars, then it saves money for both restaurants and car owners. Besides, running on WVO is comparatively cleaner than running on diesel.[3]

The thought of converting diesel cars to run on WVO is not new. There are commercially available kits to perform such conversion. They provide reliable WVO usage in many situations. However, there are still some drawbacks with a typical conversion kit. The engine cold start process could only use diesel. It not only uses lots of diesel fuel, but also is not very clean, since the cold start is when air pollution is most severe. In addition, the

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1 Andrew Holland. [High Cost Prevents Electric Cars from Penetrating the Market]
2 Erick Panger. [Can a Diesel Engine Really Run on Vegetable Oil?]
3 Larry Redilia. [Our Vegetable Oil Car]

heating elements included may not be sufficient to cope with the cold winter in Connecticut.[4] The detailed reason for heating elements is explained in the Methodology section.

Therefore, the best way to switch away from using conventional fuel in the Connecticut area at the moment is to design and build a customized WVO conversion system. The system needs to be at a reasonable cost and be able to work properly in a typical cold weather in Connecticut.

Goals

The goal of this project is to design, build and install a system that enables a 1985 Mercedes 300SD to run on the waste vegetable oil from Mather in most weather conditions in Connecticut.

More specifically, the designed system should include a fuel system that is able to deliver WVO to the engine. The system also needs to be able to heat the WVO to 82±11°C (180±20°F) before injecting the oil into the engine, when the engine is operating normally and during cold start in environment temperatures as cold as 0°C (32°F). Heating is needed due to a characteristic of WVO compared to diesel, which will be elaborated in Methodology section.

In addition, the factory diesel fuel system will be retained. This is because when the environment temperature gets lower than 0°C (32°F), the WVO system may not be able to safely start the engine and diesel will be used. Before the engine stops, diesel will also be used to run the engine so that only diesel is left in the engine, since any leftover WVO in the engine could not be heated by the system. Besides, if the car is used to run long distances and WVO is not available, the factory diesel fuel system can keep the car running on diesel fuel. Therefore, another design goal is to have a mechanism that can switch between WVO and diesel to feed into the engine.

Methodology

In order to design a system that could let the engine run on WVO reliably, it is very important to understand the difference between diesel fuel and WVO fuel. When using as fuel in a diesel engine, the biggest difference between these two fuels is the kinematic viscosity. In normal environment temperatures, WVO has a much bigger kinematic viscosity then diesel does. It means it is significantly more difficult for WVO to flow inside the fuel system and atomize properly to allow complete combustion in the combustion chamber inside an engine. Incomplete combustion not only lowers engine

[4] Greasecar Vegetable Fuel Systems [Mercedes Sedan 1979-1994]

power output but also damages the engine.[5] Only when the WVO is heated to above 71°C (160°F) is its kinematic viscosity lowered to close to that of diesel.[6] Figure 1 below provides a quantitative view of the difference in kinematic viscosity between diesel and nearly every kind of vegetable oil commercially available at different temperatures.[7] Therefore, the system designed in this project has to be able to heat up the WVO to higher than 71°C (160°F) before injecting WVO into the engine.

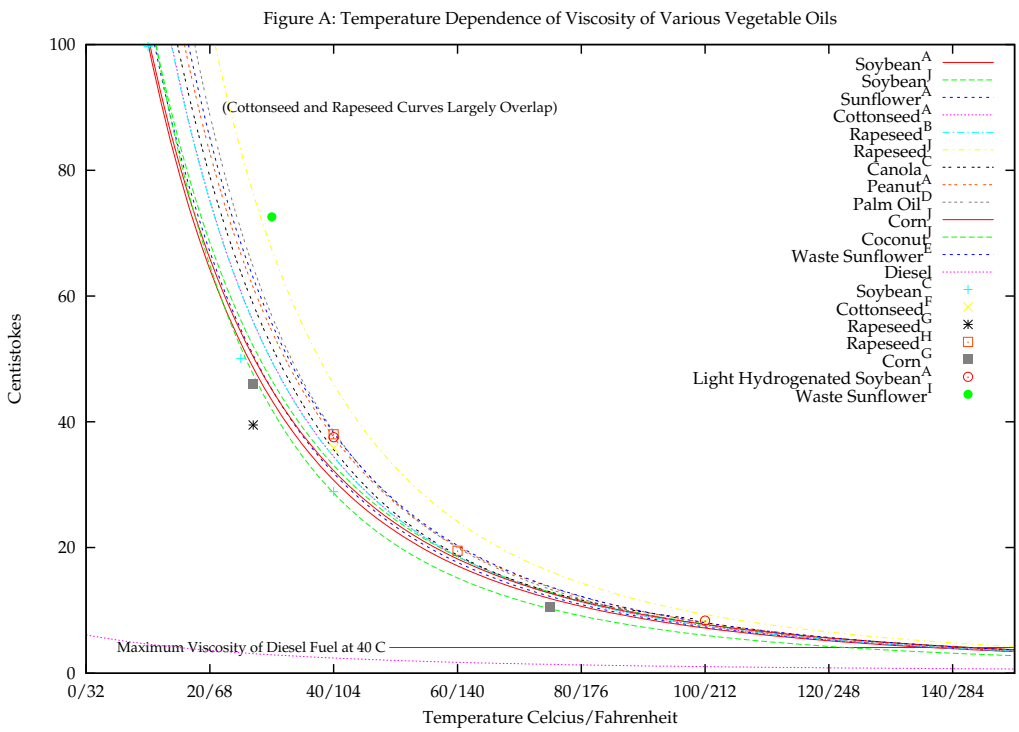

Figure 1: **Kinematic Viscosity of Vegetable Oils vs. Temperature**

As mentioned in the Introduction section, the design of a heating mechanism that could handle the winter weather in Connecticut is not established in a typical commercially available system. Thus, to determine the specifications of the heating mechanism, heat transfer analysis has to be performed first. This means a simulation model would be created in computer, after a thorough study of the factory fuel system, research of several commercially available conversion systems and experiments with the WVO from Mather to determine its characteristics. Then, a draft design would be proposed according to the heat transfer analysis results. The design would be tested in the laboratory to verify its

[5] Wikipedia. [Vegetable Oil Fuel]
[6] WVO Designs. [Modifying a Diesel Fuel System]
[7] Forest Gregg [Kinematic Viscosity of Vegetable Oils at Different Temperatures]

effectiveness. The draft design would be modified and retested according to the testing results until the desired function is realized. After the experimental verification, the final design of heating elements would be established.

The other parts of the WVO car conversion system are also of great importance. They include the fuel pipes, a fuel pump, a fuel filter, cooling water hoses, valves and a control system, etc. Because some commercially available systems have already created successful examples of WVO car conversion systems, they could be great sources of reference. Similarly, a draft design would be proposed first, and it would then be tested in the laboratory. Changes would be made to the draft design if necessary, until a properly working system is made and tested, and this design would be the final design.

After the design of the whole system is finalized, the system would be installed on the car and tested. During the process, the system might need further adjustments. If the effect of any change were unknown, the system would be retested in the laboratory until it functions properly. If the system worked as desired on the car, test drives would be performed to detect and solve any other problems that could occur. The goal of the project would be successfully realized if the car could reliably run on WVO in various conditions and the car could be switch back to run on diesel fuel without problem when desired.

Selection of Design

To reach the goal of heating the WVO to 82±11°C (180±20°F) before injecting it into the engine, several options for the heating elements were available. The first option was to use engine coolant to heat, including coolant heating in the fuel tank, and on the fuel line through several heat exchangers. The second option was to use electric heating wires. This meant to put powerful heating wires inside the fuel tank and along the fuel line. The third option was a combination of engine coolant and electric heating wire heating.

The first option, as mentioned in the Introduction section, is already applied by commercially available systems. Therefore, it is easy to purchase and install. However, this option requires the engine to run on diesel fuel before getting warmed up, which does not meet the design goal of this project. The heating power of the engine coolant may not be sufficient to bring the temperature of WVO to the desired temperature during winter. As a result, the first option had to be discarded. The second option addresses all the drawbacks of the first option, which means it meets the design goal. But all electric heating means the system will draw a significant amount of electric power. A preliminary calculation shows, to bring 5 gallons of WVO from 0°C (32°F), to 82°C (180°F) every hour, more than 800 watt of heating power is needed continuously even without any loss. For a 12 Volt car battery, this means an extra current draw of 67 Amp. The Mercedes,

which this project is based on, uses an alternator that generates 55 Amp of current. For this reason, using option 2 means installing a more powerful alternator and battery for the car. A more powerful alternator will also worsen the fuel economy of the car. The third option, if designed properly, eliminates the drawbacks of both the first and the second options. If the third option is used, during the cold start period, the engine can run on WVO with powerful electric heating from a secondary battery. After the engine has been warmed up, the WVO can be heating by engine coolant and less powerful electric heating from factory alternator or battery.

After careful evaluation, the third option for the heating elements was chosen. It not only meets the design goal, but also is more energy efficient, since it uses less electric heating power. With this draft design in mind, the design of other parts besides the heating elements can be decided accordingly.

Implementation

During the analysis stage, Matlab was used to create a simulation model for the heating elements of the system. In this model, a system represented below in Figure 2 was created. In the system, there were a 45-Liter WVO tank, a 0.5-Liter tank-in-tank, a 3-meter long feed line, a 3-meter long return line and 5 0.2-meter long high pressure fuel lines. The flow rate in each fuel line when the engine is running is also indicated in the figure. A 100-watt heating element was added in the tank-in-tank, a 200-watt heating element was added in the return line, a 400-watt heating element was added onto the feed line and a 40-watt heating element was added onto each of the 5 high pressure lines. The heating elements drew a power of 900 watts combined.

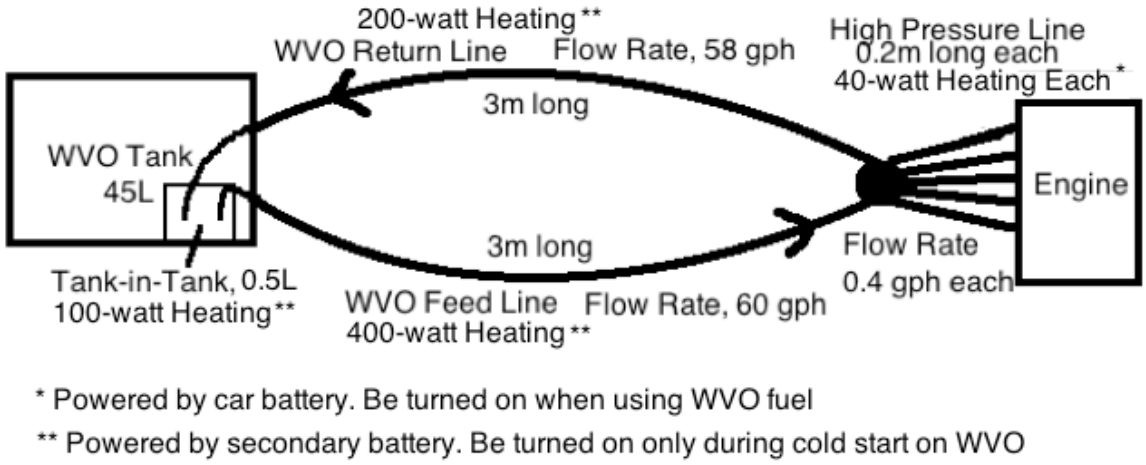

Figure 2: **Representation of the Matlab model created**

To carry out the calculation, the whole system was divided into many finite elements and time was also divided into many time instants that had very small intervals in between. Here the system was divided into 0.01m long elements, and time step during the simulation was 0.1 second. Much finer system division and time step had also been tried and compared. Since the results did not differ more than 1%, the current division should provide results that are accurate to 1%. The temperature of each element at each time instant was calculated using the equations below.

$$\dot{E}_{stored} = \dot{E}_{in} - \dot{E}_{out} + \dot{E}_{generated} \qquad (1)$$

Here, $\dot{E}_{generated} = 0$. If the fuel pipe was being analyzed and that part of pipe had heating element that had been turned on, then $\dot{E}_{in}$ should include the electrical heating power calculated as below.

$$\dot{E}_{electrical} = P*dx/d_{heated} \qquad (2)$$

P donated to the total power of that heating element, and d_{heated} meant the total length of the pipe that had heating element. dx was the length of one element of the system. If there was conduction of heat, then either $\dot{E}_{in}$ or $\dot{E}_{out}$ (depending on the relative temperature difference between two elements) should include the term below for every conduction surface.

$$\dot{E}_{conduction} = -k*A_c*dT/dx \qquad (3)$$

In this equation, k was the thermal conductivity for the material, A_c was the conduction surface area, dT was the temperature difference between two elements, and dx was distance between two elements. In addition, if there is convection of heat, then either $\dot{E}_{in}$ or $\dot{E}_{out}$ (depending on the relative temperature difference between two elements) should also include the term below for every convection surface.

$$\dot{E}_{convection} = h*A_s(T_1 - T_2) \qquad (4)$$

Here h was the convection coefficient, A_s was the convection surface area, T_1 was the temperature of the neighboring element, and T_2 was the temperature of the element being analyzed. After taking into account all the $\dot{E}_{in}$ and $\dot{E}_{out}$ terms, the $\dot{E}_{stored}$ could be calculated. It will then be used to calculate the temperature change of the element dT, as shown in Equation 5 below.

$$dT = \dot{E}_{stored}*dt/(\varrho*v*c) \qquad (5)$$

dt was the time step of this simulation, ϱ was the density of the material, v was the

volume of the element being analyzed, and c was the specific heat capacity of the material.

The calculation had been performed to simulate 5 minutes before and after the car engine started in a cold start condition, with an environment temperature of 0°C (32°F). The heating elements in the tank-in-tank, the fuel feed line and the return line were turned on throughout the whole process, and the heating elements in the 5 high pressure lines were only turned on after the engine started. There was no need to heat the high pressure lines before the engine started because the engine would first run on some diesel that was left in the high pressure lines before the engine stopped. Calculation has also been performed to simulate the condition after the car engine had been warmed up, with an environment temperature of 0°C (32°F). In this case, only the high pressure line heating was turned on. The temperature of WVO entering the feed line from the fuel tank was assumed to be 50°C (122°F), because of engine coolant heating. The minimum power needed to keep the WVO entering the engine at 82°C (180°F) was found.

In addition, several assumptions were made when carrying out the calculations. The temperatures of the WVO fuel tank and the tank-in-tank were assumed to be uniform. The temperature of all fuel lines after the engine started was also assumed to be uniform. These two assumptions were made since the temperature was already very close to uniform. It was also assumed that there was no conduction of heat within WVO. This was because the thermal conductivity of WVO is 0.2 watt/m-K, whereas that of the aluminum pipe was more than 200 watt/m-K in temperature ranges that concerned this simulation.[8,9] The Matlab code written is attached in Appendix B.

All the parameters mentioned could also be easily modified by changing the values of the corresponding variables in Matlab. Updated results could be obtained by running the code once more. Modifications would be made in the next step, according to the testing result of the WVO sample gathered from Mather Hall in Trinity College.

After the analysis stage, important parameters of the design, such as the power for each electrical heating element, were calculated. Then, tests were performed to verify the validity of the design. A preliminary test of WVO had been carried out. During the test, 1 gallon of WVO had been refrigerated to -14.7°C (5.5°F), and then slowly heated up to 55°C (131°F). Throughout the process, the time it took at different temperatures to transfer 200mL of oil using the same pump and pipe setup had been recorded. The results were then used to calculate the flow rate.

Then, based on the results of the analysis, an inspection of the Mercedes, a Haynes

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[8] Burr Zimmerman. [Heat Transfer and Cooking]
[9] The Engineering ToolBox. [Thermal Conductivity of Some Common Materials and Gases]

Automotive Repair Manual and discussion on several online forums, a more detailed design was made. The design is presented in the figures below. It includes the power for each heating element, the major components of the system and the routing of all hoses and fuel lines.

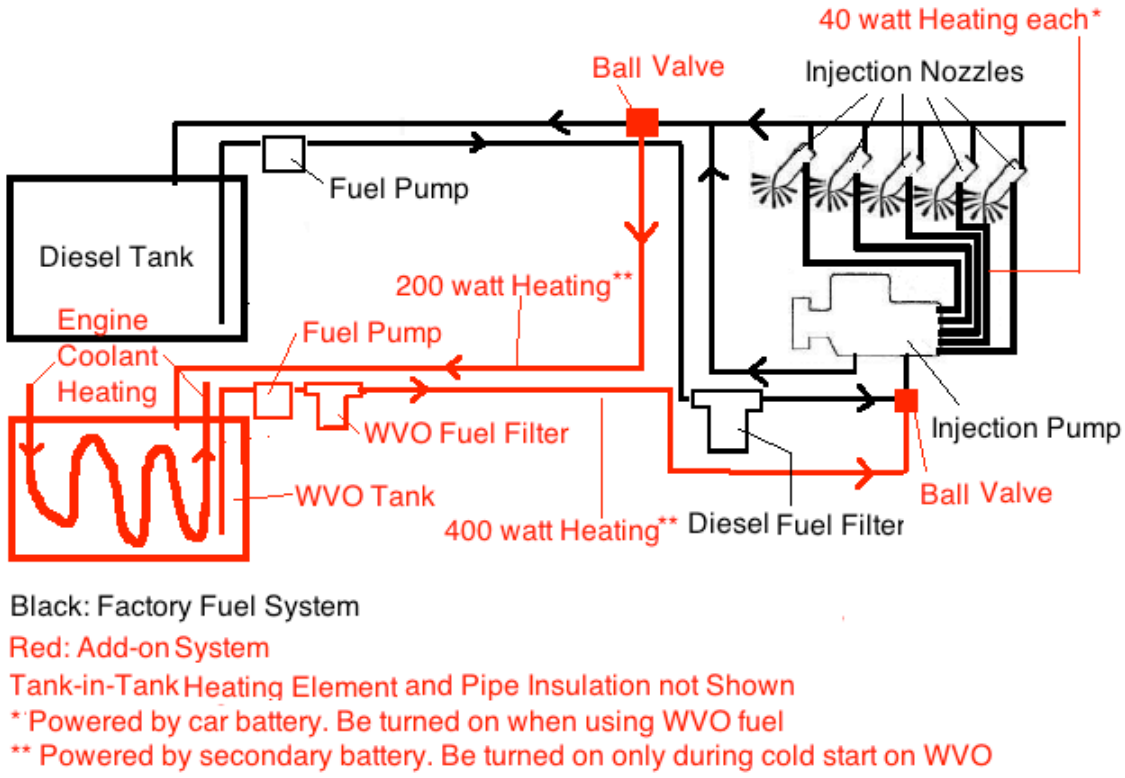

Figure 3: **Design of the overall system without the tank-in-tank electric heating element**

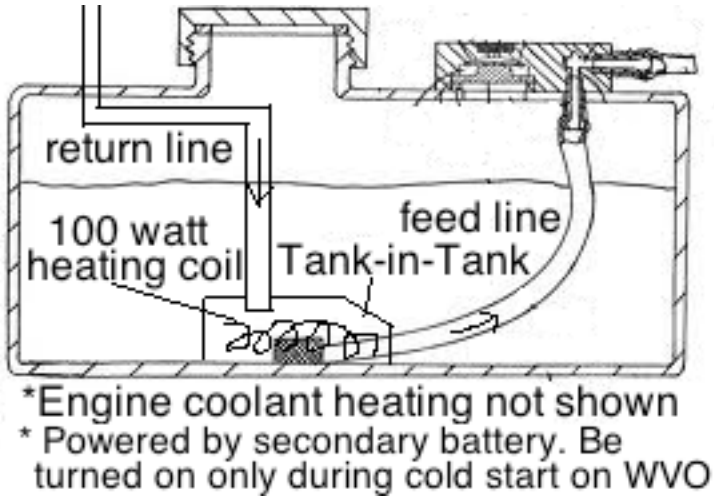

Figure 4: **Design of the tank-in-tank electric heating system**

In this design, aluminum pipes were chosen, instead of copper pipes, which are also widely used in car's fuel systems. This was because free fatty acids in WVO may affect and react with copper, but not with aluminum.[10] Moreover, an additional fuel filter, electric fuel pump, feed line and return line were added onto the factory system, in order to have minimum amount of WVO go into the diesel tank during a fuel switch from WVO to diesel, and vise versa. Additionally, in the cooling system, part of the coolant going through the heater core would be routed to go through the coolant line inside the WVO tank instead. This additional heating for WVO could let part of the electric heating elements shut off and thus save energy. It also meant a control system to maintain the fuel temperature was needed. The temperature control could enable the car to be driven at hot weather as well. To achieve this, a temperature-controlled switch was used. The switch is closed under a set temperature, which could be between 30°C (86°F) and 110°C (230°F), and automatically opens above that temperature. Lastly, two mechanical ball valves were also included in the design to enable the switch of the fuel that feed into the engine. The more convenient solenoid valve was not chosen, due to its high cost and possible leaking. The system design was subject to change depending on the experimental testing results.

After that, parts were purchased, and the system was built and tested. The tests included the functioning for each individual component, the heating effect for each electric heating element and the functioning of the secondary battery under high current and high power output. Because 0°C (32°F) environmental temperature could not be achieved in the laboratory or outdoors during the time of testing, the actual environmental temperature during the testing was around 20°C (68°F). Since the specific heat capacity of WVO does not vary significantly, the temperature increase caused by the heating element provided verification of the heating power. The results of the testing could be found in the Results

[10] Wikipedia. [Vegetable Oil Fuel]

and Discussion section.

Following the testing, some parameters for the heating elements were changed. These parameters at different design stages could be found in the Results and Discussion section below. Since the change in design was not significant enough to reconsider the original design, the system was then installed on the car. The exact specifications of each component installed, and the wiring diagram can be found in the Communication for Manufacture document.

Results and Discussion

The results of the Matlab modeling are presented in the following figures below. In these figures, time instants from 0 to 300 seconds donate to the 5 minutes of simulation before the engine started, and time instants from 300 to 600 seconds represent the 5 minutes of simulation after the engine started from cold. The distance of the feed line goes from 0 meter, which represents the end that connects the fuel tank, to 3 meters, which represents the end that connects the injection pump. The distance of the return line goes from 0 meter, which represents that connects the injection pump, to 3 meters, which represents the end that connects the fuel tank. The distance of the high pressure line goes from 0 meter, which represents the end that connects the injection pump, to 0.2 meter, which represents the end that connects the injection nozzle in the cylinder head of the engine.

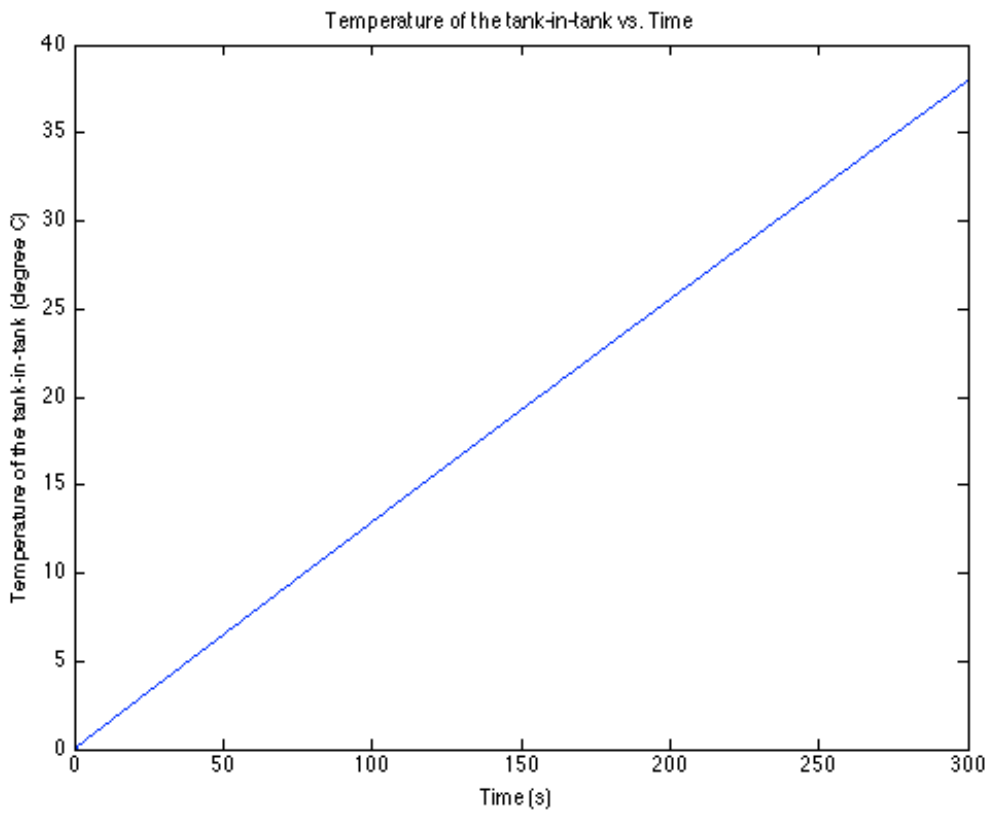

Figure 5: **Temperature of the tank-in-tank before the engine started**

The tank-in-tank with a 1-liter volume before the engine started was heated by a 200 watt heating element. Thus, there was a temperature increase as time passed. The temperature of WVO in the tank-in-tank was assumed to be uniform, so the temperature is only a function of time.

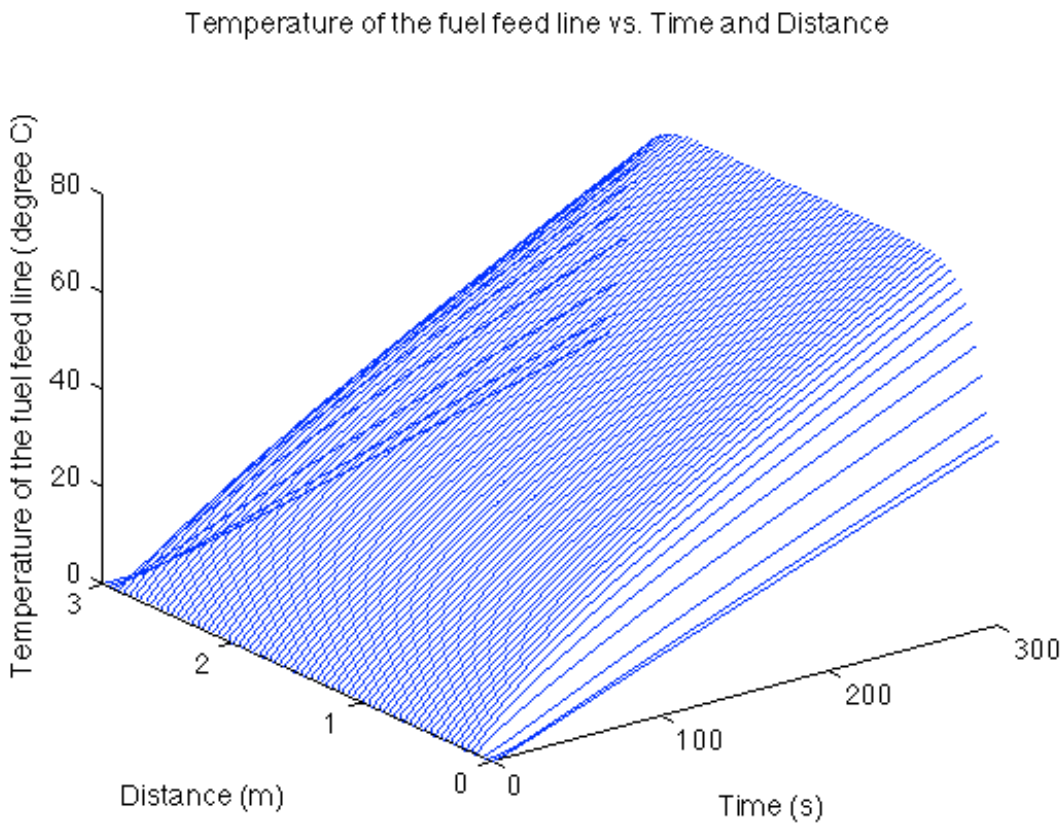

Figure 6: **Temperature of the feed line pipe before the engine started**

The feed line before the engine started was heated from 0.1 m to 2.9 m, by a 400 watt heating element. Thus, there was a temperature increase as time passed.

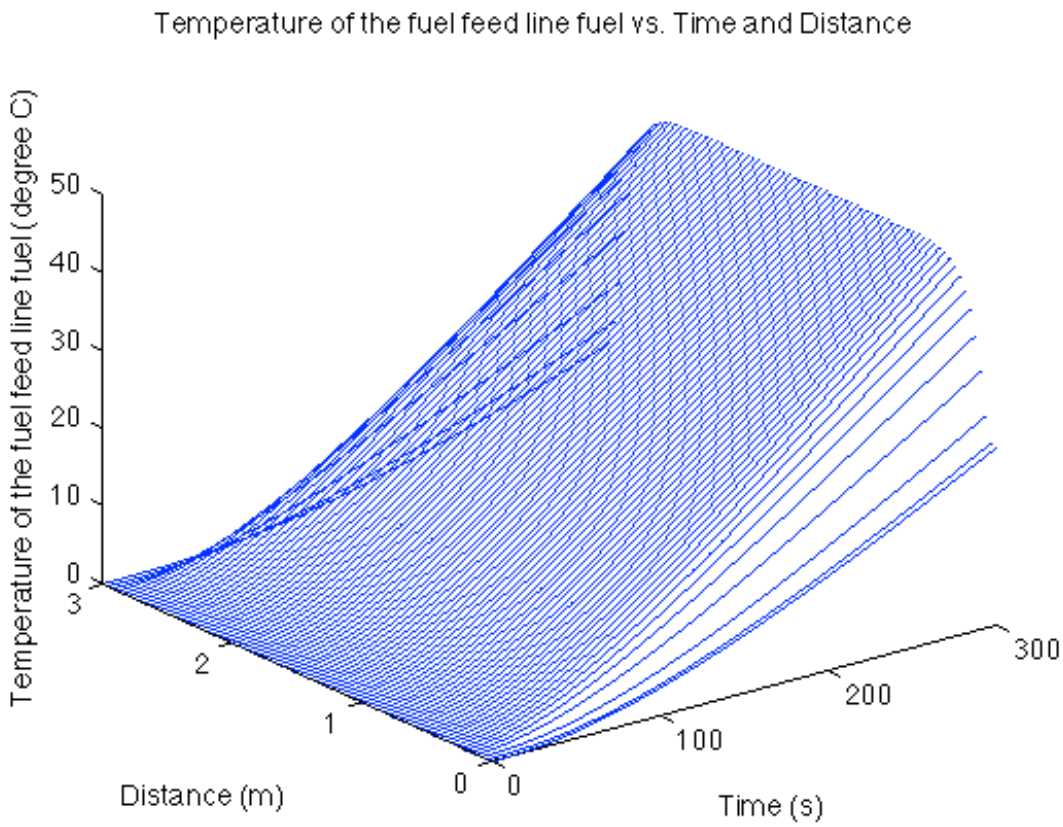

Figure 7: **Temperature of the fuel in the feed line before the engine started**

The fuel in the feed line also had a temperature increase before the engine started. That was because the heat was transferred from the pipe to the fuel. Not all heat from the heating element could be passed by the pipe to the fuel, and the fuel did not reach a temperature as high as the pipe did.

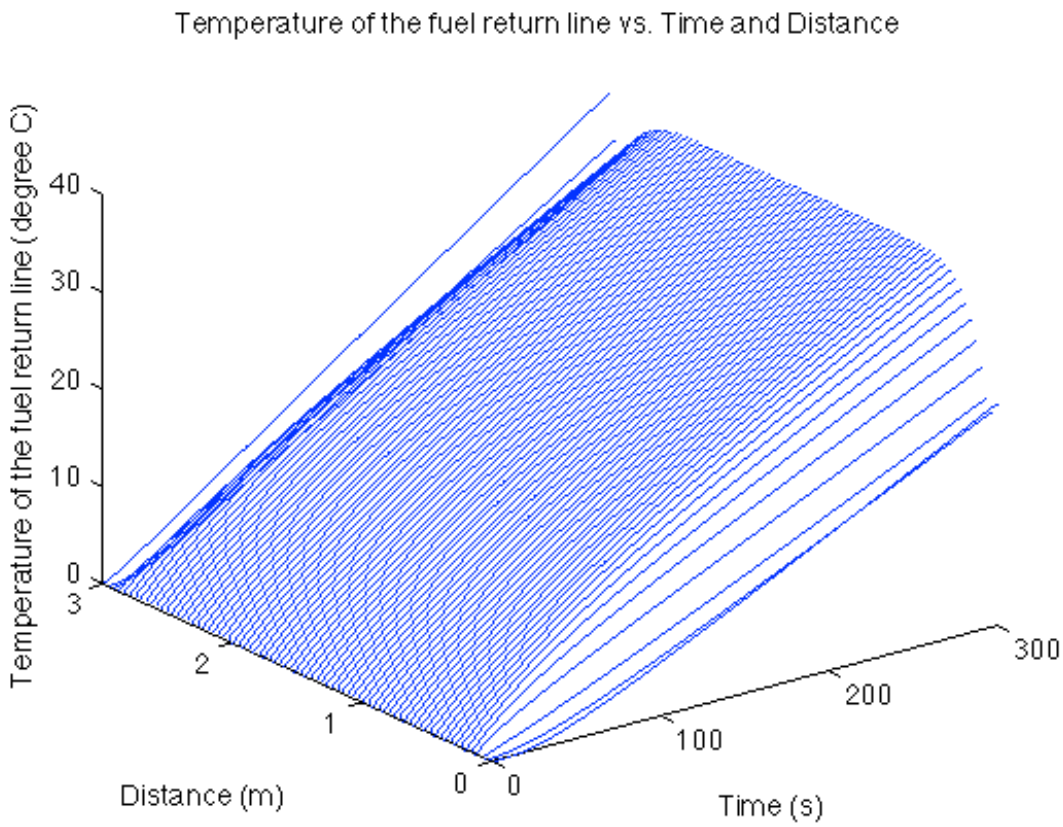

Figure 8: **Temperature of the return line pipe before the engine started**

The return line before the engine started was heated from 0.1 m to 2.9 m, by a 200 watt heating element. Thus, there was a temperature increase as time passed.

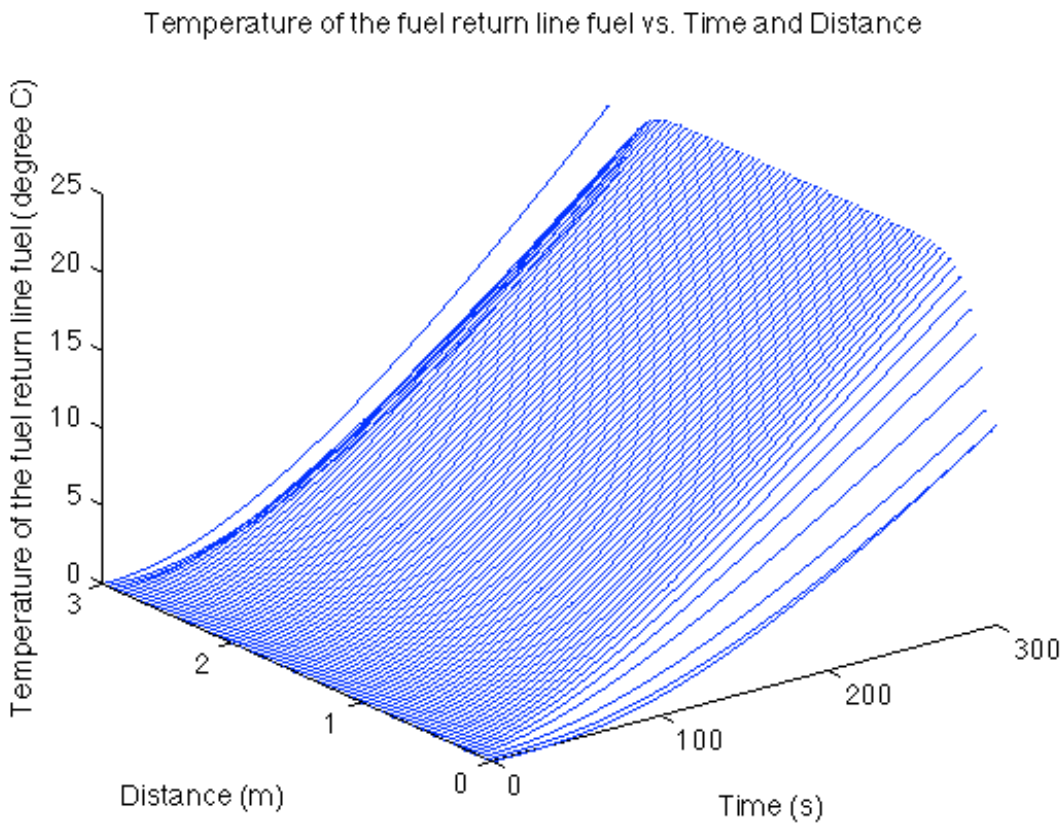

Figure 9: **Temperature of the fuel in the return line before the engine started**

The fuel in the return line also had a temperature increase before the engine started. That was because the heat was transferred from the pipe to the fuel. Not all heat from the heating element could be passed by the pipe to the fuel, and the fuel did not reach a temperature as high as the pipe did.

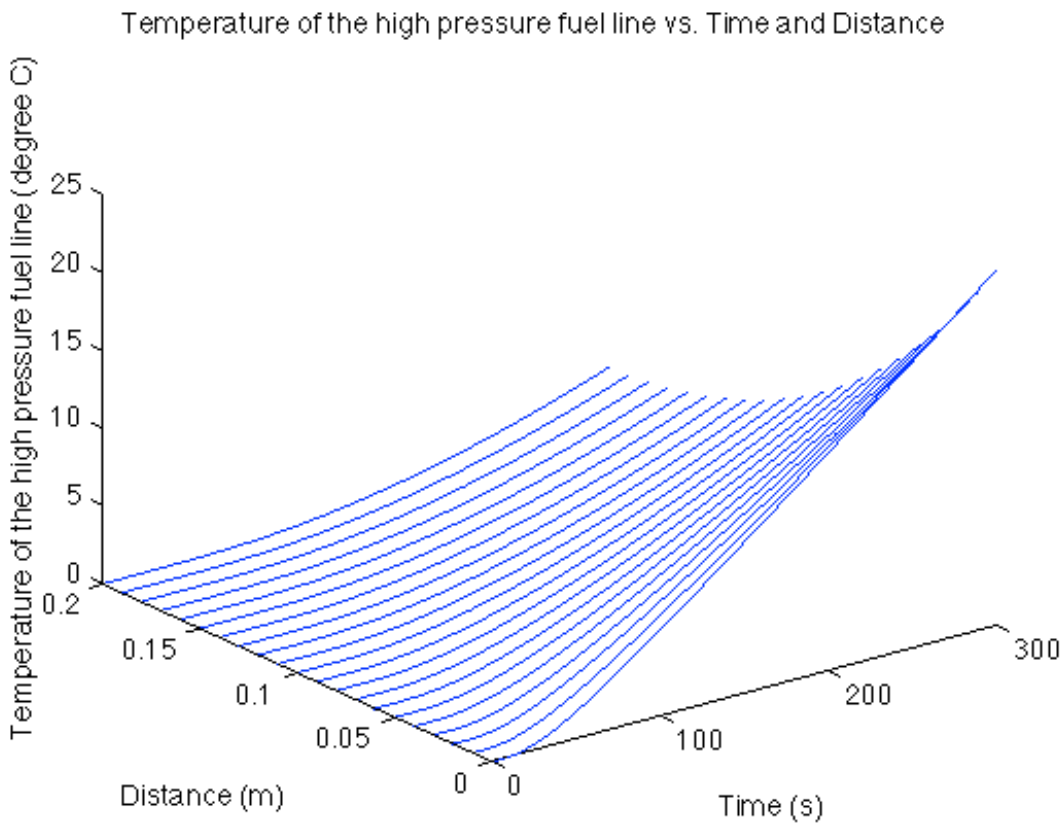

Figure 10: **Temperature of the high pressure line pipe before the engine started**

The heating element in the high pressure line was turned off before the engine started, because at that time diesel was still left in the high pressure line and was not needed to be heated. Similar to the return line pipe, the temperature had a small increase due to the conduction of heat from the feed line pipe.

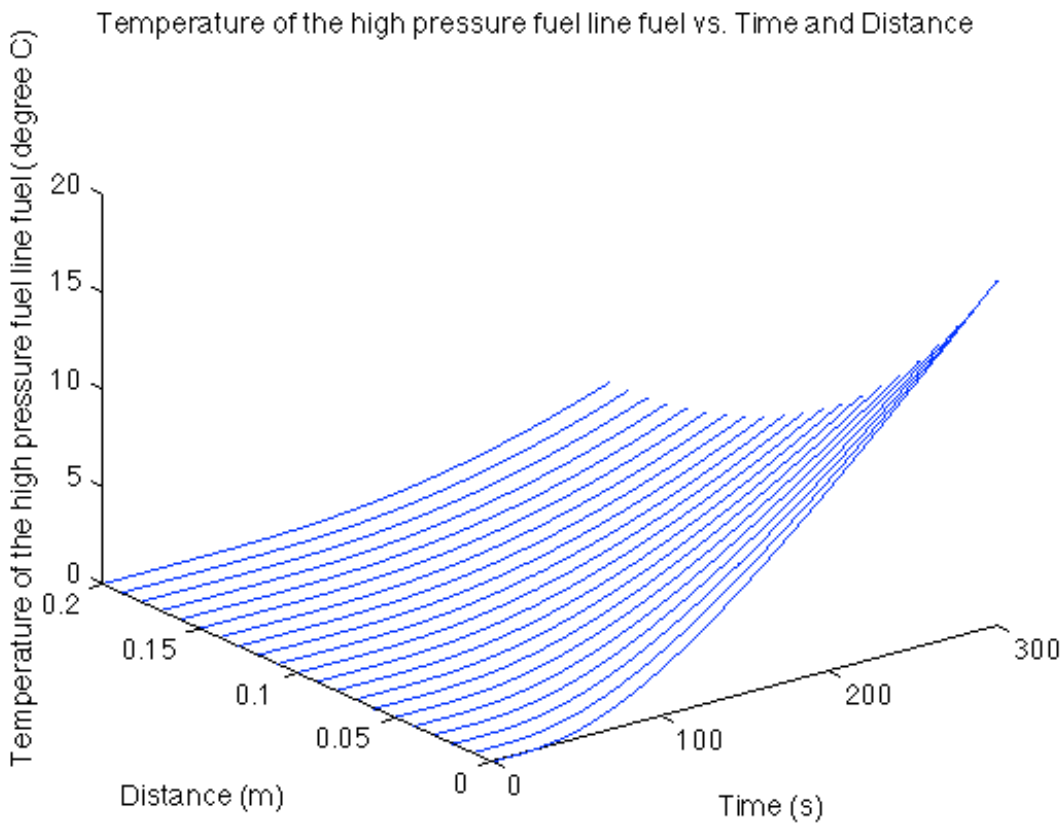

Figure 11: **Temperature of the fuel in the high pressure line before the engine started**

Similar to the pipe, the temperature of the fuel in the high pressure line was mostly unchanged. At the end close to the feed line, there was a small temperature increase because of the heat transferred from the pipe.

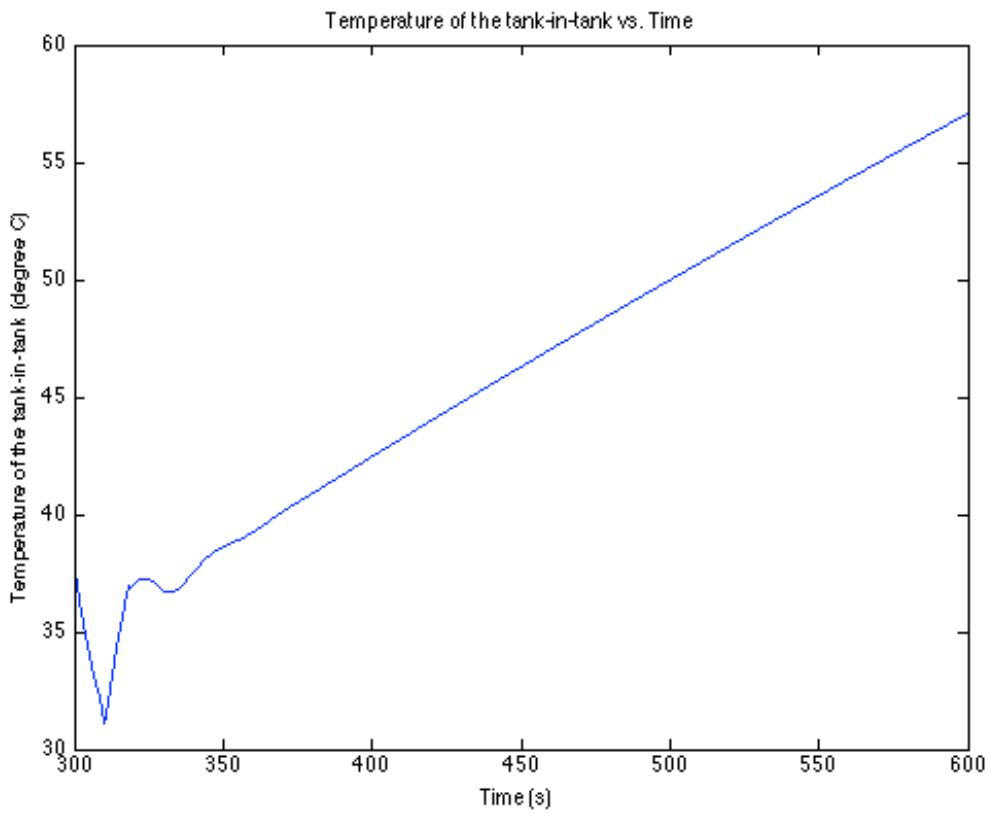

Figure 12: **Temperature of the tank-in-tank after the engine started**

After the engine started, the oil began to flow in and out of the tank-in-tank, and that resulted in some undulations in the temperature. Overall, the temperature still kept increasing steadily.

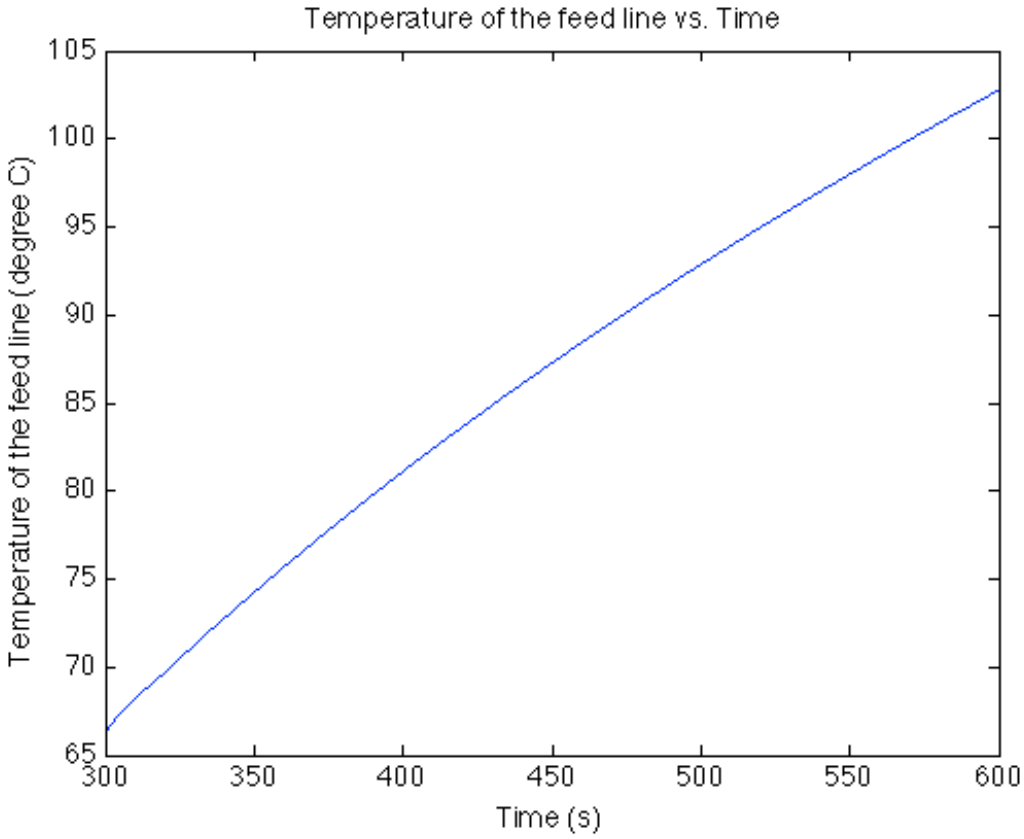

Figure 13: **Temperature of the feed line pipe after the engine started**

After the engine started, the temperatures of the pipes were assumed to be uniform, and therefore temperature only varied with time. The 400-watt heating element kept the temperature rising.

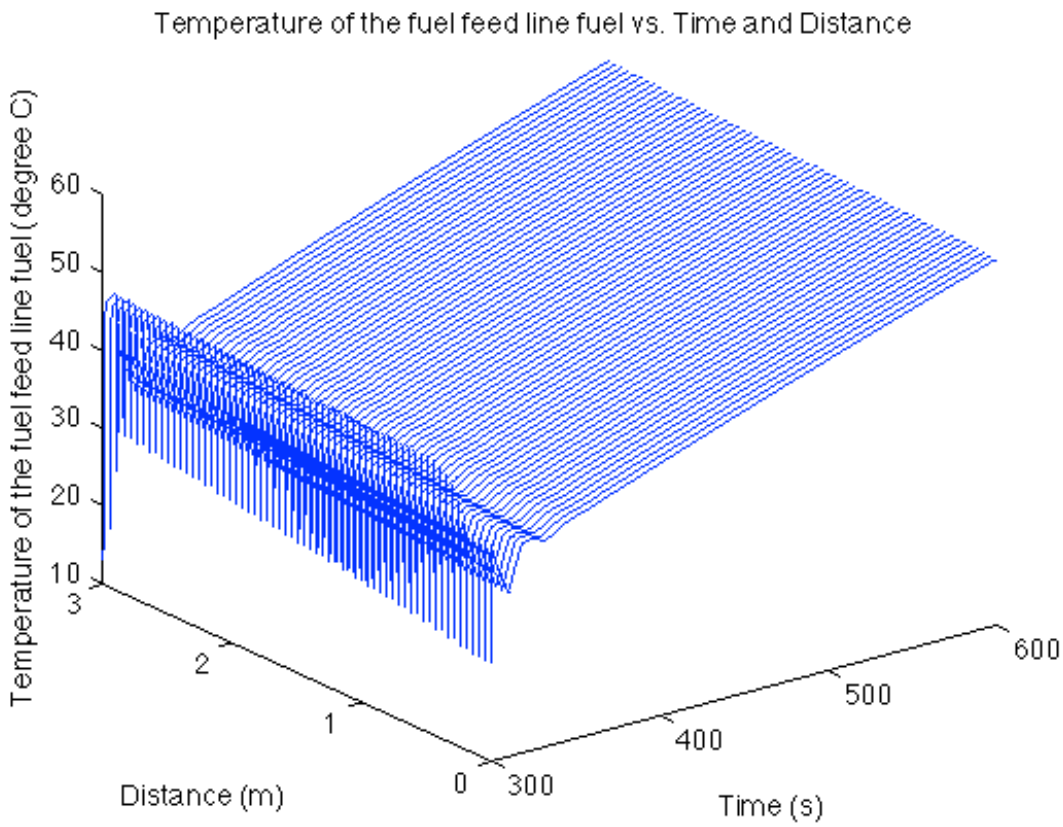

Figure 14: **Temperature of the fuel in the feed line after the engine started**

The inflow of unheated feed line oil and oil from the tank-in-tank caused some undulations in the temperature. Overall, the temperature still kept increasing steadily.

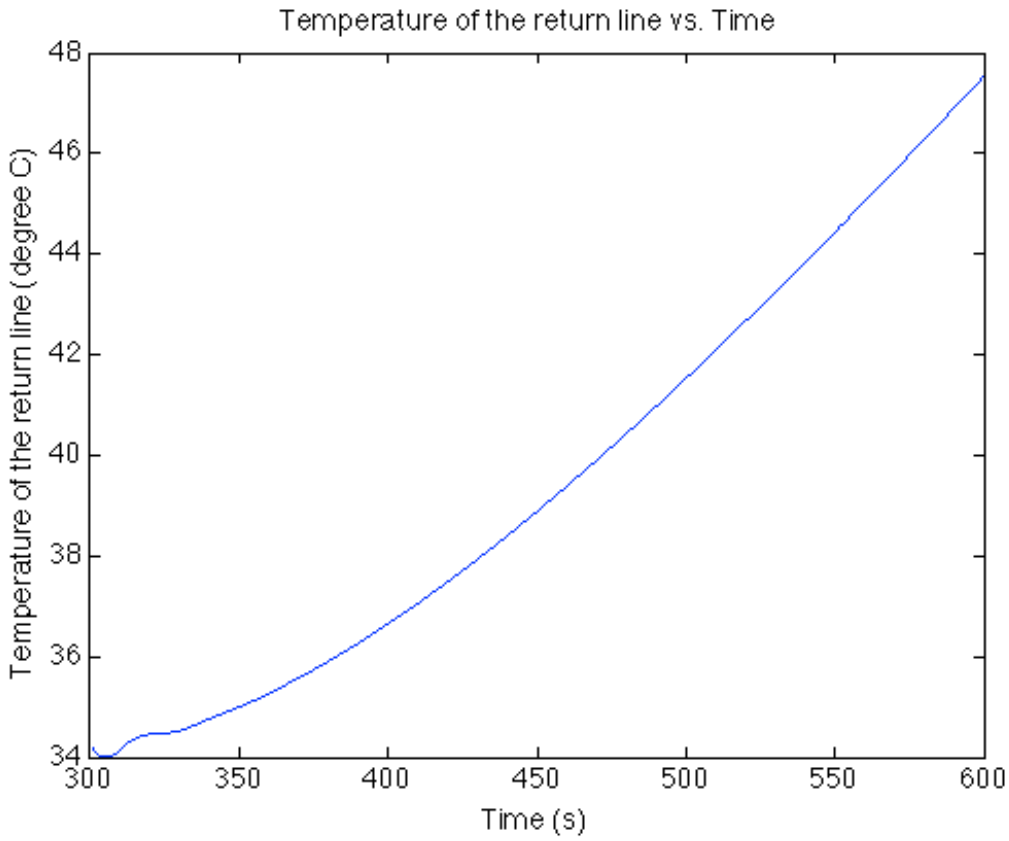

Figure 15: **Temperature of the return line pipe after the engine started**

After the engine started, the temperatures of the pipes were assumed to be uniform, and therefore temperature only varied with time. The 200-watt heating element kept the temperature rising.

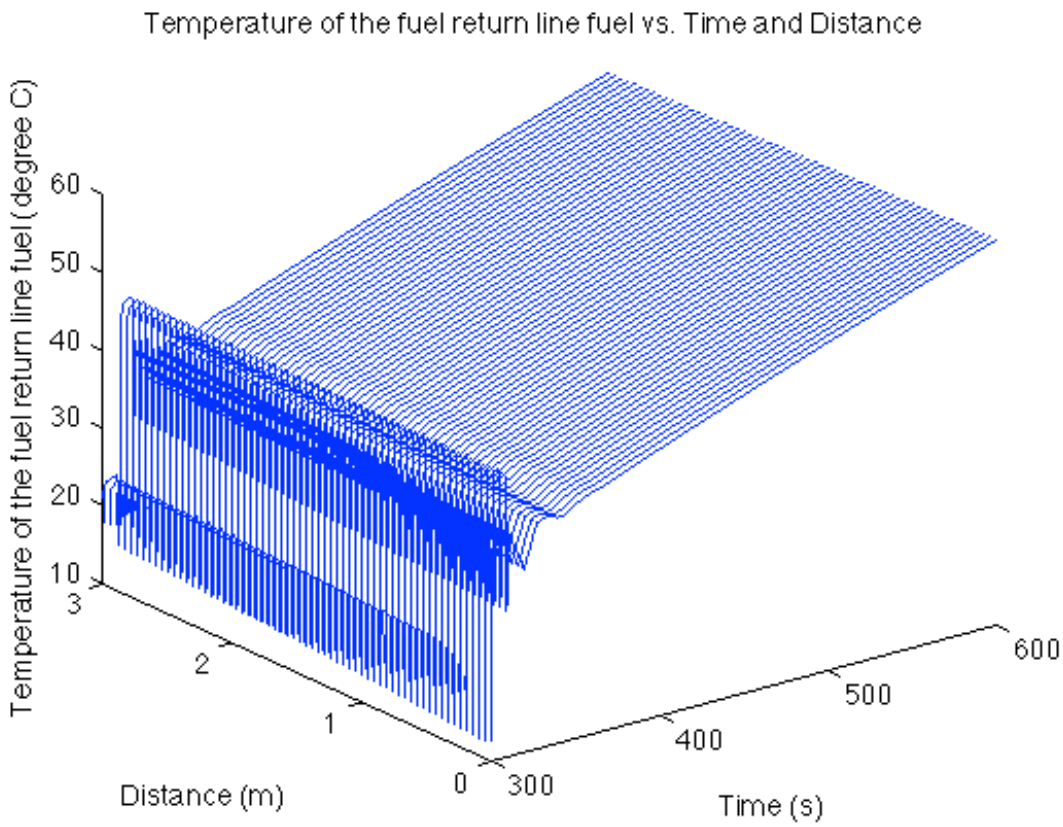

Figure 16: **Temperature of the fuel in the return line after the engine started**

The inflow of unheated return line oil caused some undulations in the temperature. Overall, the temperature still kept increasing steadily.

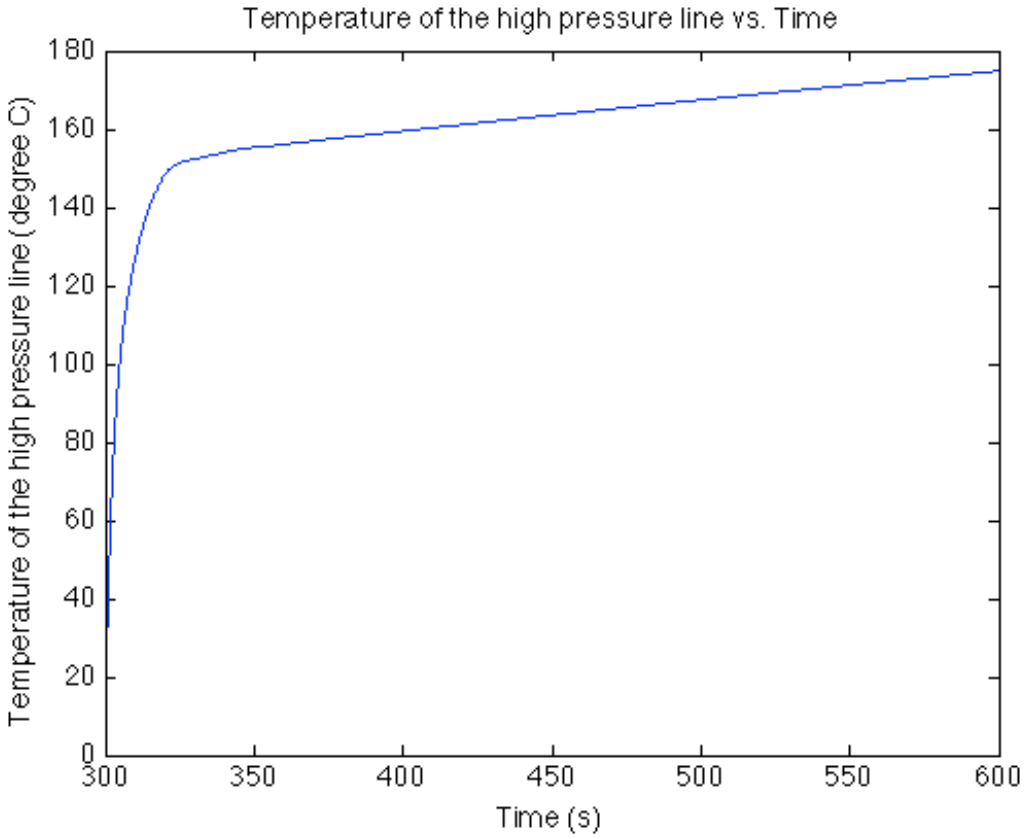

Figure 17: **Temperature of the high pressure line pipe after the engine started**

On the 5 high pressure lines, a total of 200-watt heating elements were turned on at time equal to 300 second. Although the heating power here is less than that in the feed line, the power is more concentrated because the high pressure lines were very short. The heating power was able to quickly heat the pipes and keep the temperature above 140°C (284°F).

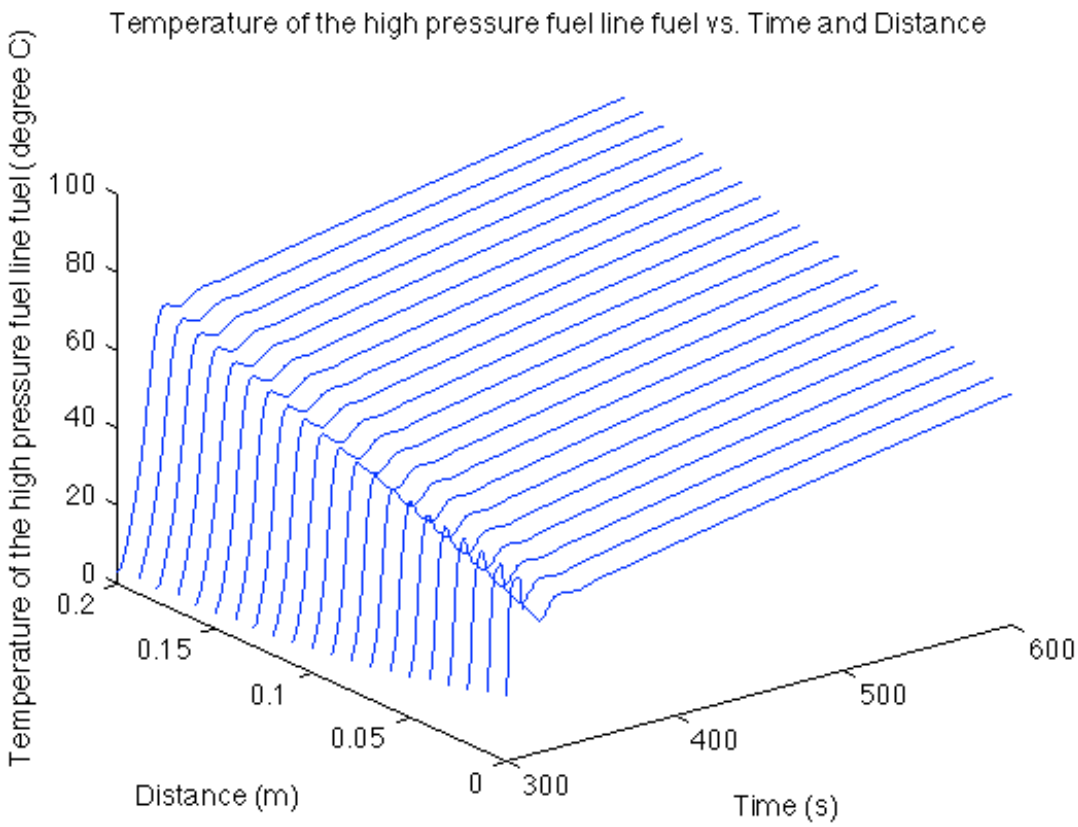

Figure 18: **Temperature of the fuel in the high pressure line after the engine started**

At distance equal to 0 m, the fuel just entered the high pressure line from the feed line. As the fuel proceeded in the high pressure line, it was heated up significantly. Before the fuel went into the injection nozzle, the target temperature 82±11°C (180±20°F) was achieved.

Another Matlab analysis was also performed for the case when the engine has been warmed up. The temperature of WVO entering the feed line was assumed to be 50°C (122°F), because of engine coolant heating. The high pressure line heating was turned on and the tank-in-tank heating, the feed line heating and return line heating element were turned off.

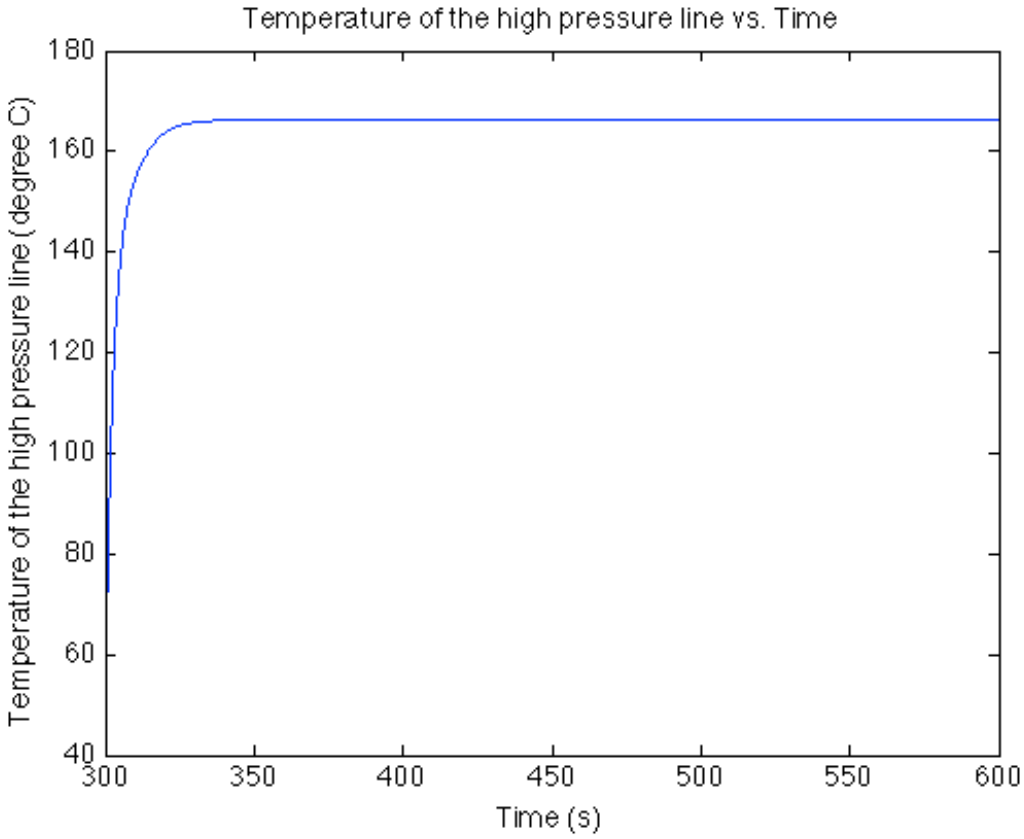

Figure 19: **Temperature of the high pressure line after the engine has been warmed up**

The temperature of the fuel line stabilized at around 165°C (329°F), with a 20-watt heating element on each of the 5 high pressure lines.

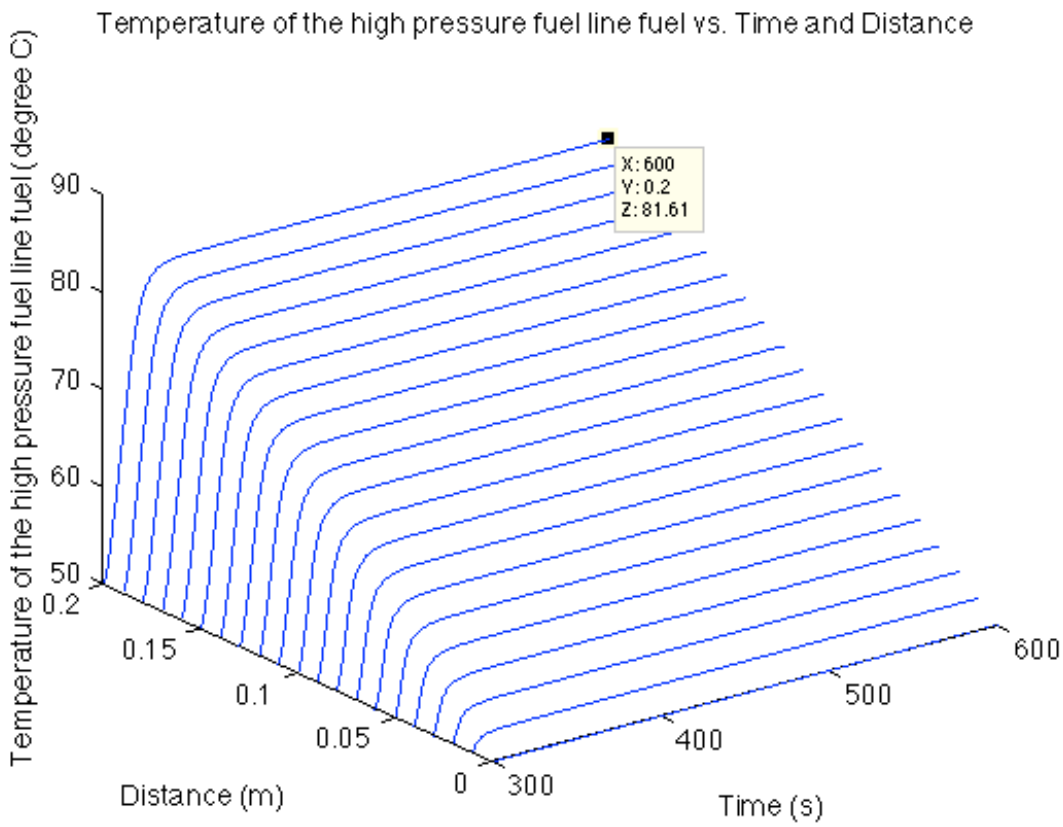

Figure 20: **Temperature of the fuel in the high pressure line after the engine has been warmed up**

In this analysis, the WVO temperature exiting the high pressure line and going into the engine became a constant as time passed. Its value depends on the power of the high pressure line heating. The minimum power required to maintain a temperature of 82°C (180°F) was found to be 100 watt. Therefore, a 200-watt heating element on the high pressure line would be sufficient, but a temperature control mechanism was needed.

This simulation results proved that the setup was able to meet the temperature requirement. However, it needs to be tested in the lab to prove its feasibility. Modifications may be made according to the experimental results.

The testing results of the WVO sample from Mather are listed in the table below.

Table 1: **Testing results of the Mather WVO sample**

Temperature (°C)	Temperature (°F)	Time took to pump 200 ml (s)	Flow Rate (lph)	Flow Rate (Gph)
-14.7	5.5	148.9	4.84	1.28
-10.5	13.1	92.3	7.80	2.06
-6.5	20.3	71.2	10.11	2.67
0.0	32.0	56.2	12.81	3.38
8.0	46.4	37.0	19.46	5.14
11.5	52.7	29.5	24.41	6.45
14.5	58.1	24.0	30.00	7.93
18.0	64.4	19.4	37.11	9.80
20	68.0	16.2	44.44	11.74
27	80.6	12.6	57.14	15.10
39	102.2	11.5	62.61	16.54
55	131.0	9.6	75.00	19.81

A flow rate vs. Temperature graph has also been plotted as shown below.

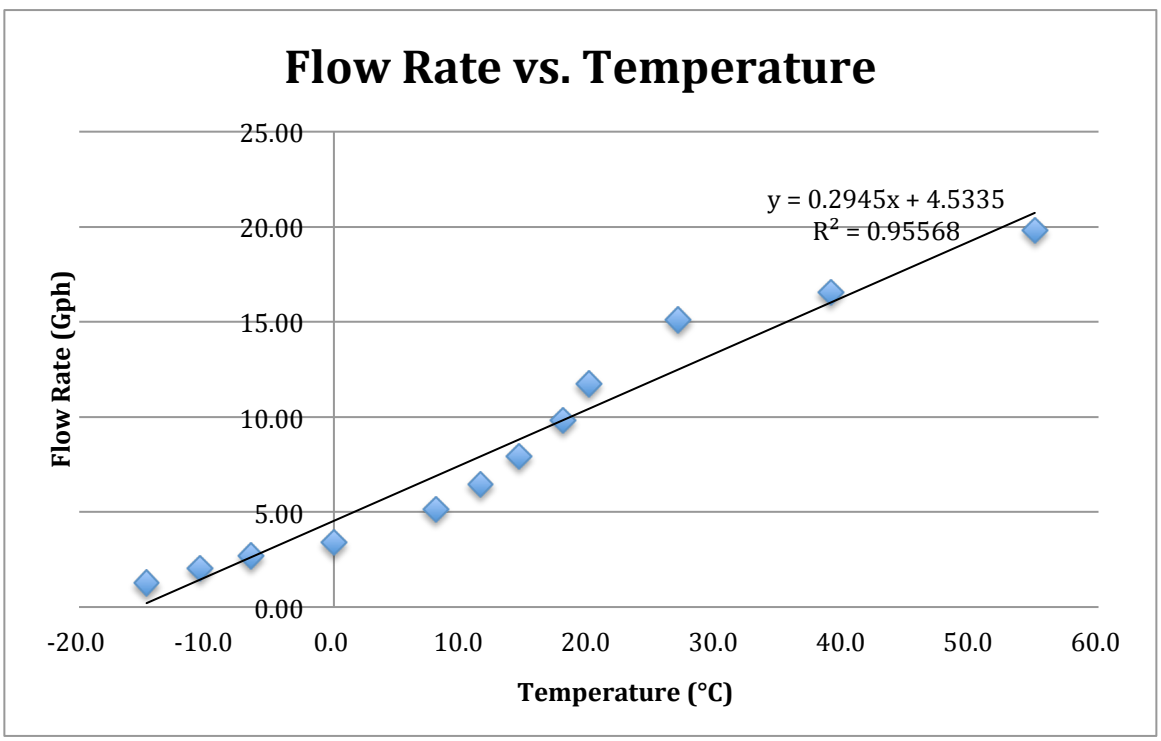

Figure 21: **Flow rate vs. Temperature plot of the Mather WVO sample**

As can be seen from the graph, the flow rate increased by a significant amount as the temperature increased from -14.7°C (5.5°F) to 55°C (131°F). Thus, the viscosity of the oil also decreased significantly as the temperature increased. This result corresponded

well with expected results and the researched results shown in Figure 1. As a result, the last version (whose results are shown above) of the Matlab model simulating the heating elements contained heating element in the tank-in-tank and on the return line. Although the heating elements may look redundant at first, they facilitate the flow of WVO at low temperatures during the engine cold start.

After the analysis, the testing of the system was carried out. Because the tank-in-tank that fits well into the fuel tank had a volume of 0.5 Liter, half of the volume used in the analysis, the heating element used was 100 watt instead of 200 watt. The power of other heating elements remained unchanged. The feed line had 400-watt heating element, the return line had 200-watt heating element, and each high pressure line had 40-watt heating element. The results are displayed below.

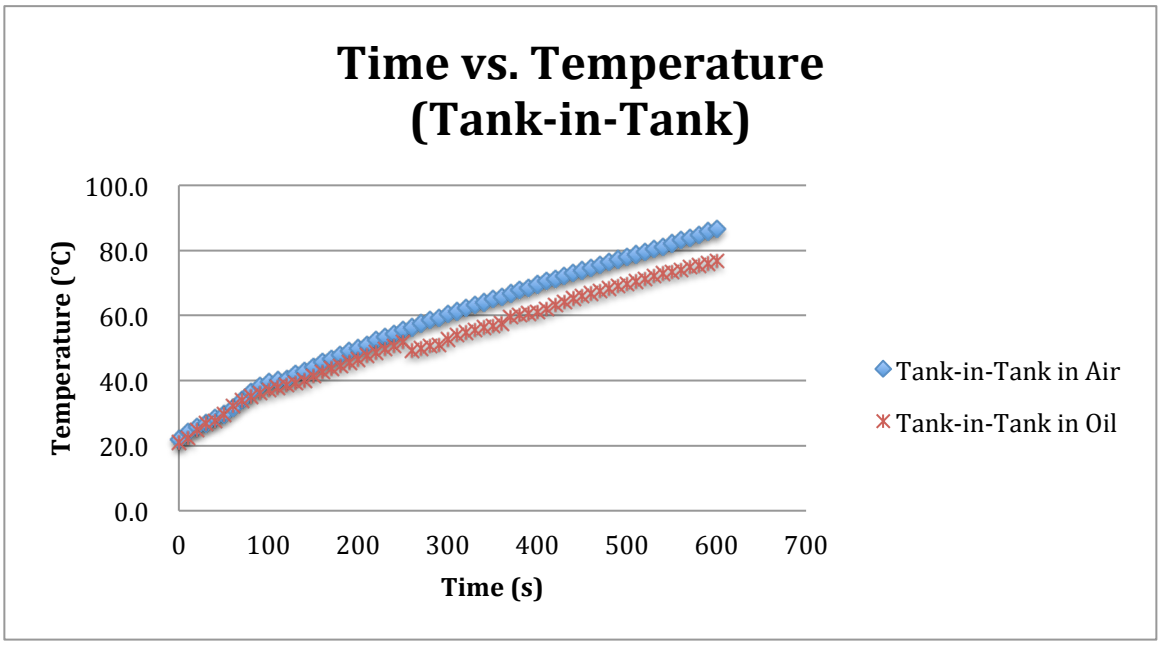

Figure 22: **Time vs. Temperature plot of the oil in tank-in-tank with a 100-watt heating element.**

Tests were done with the oil filled tank-in-tank placed in air and in oil. Tank-in-tank placed in oil is a closer simulation to the real condition. In both cases, the heating element was very effective and was able to bring around 60°C (108°F) temperature rise to the oil in 10 minutes.

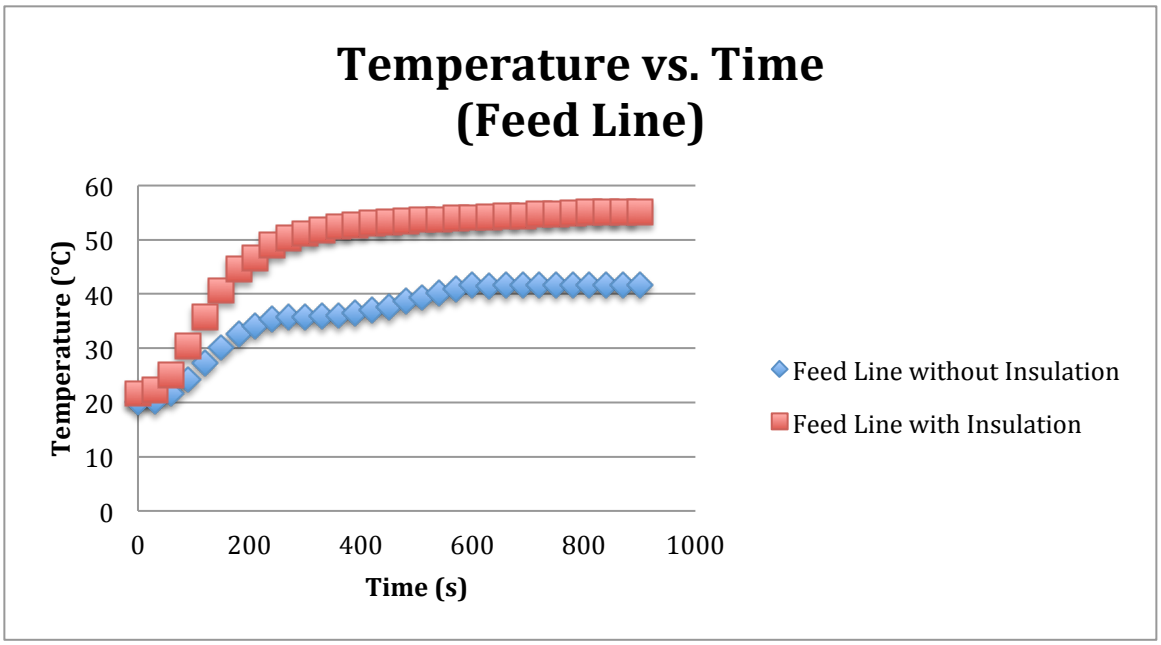

Figure 23: **Time vs. Temperature plot of the oil exiting the feed line with a 400-watt heating element and with the WVO flowing**

The feed line heating element was tested with and without insulation. The temperature was measured at the exit of the feed line. As can be seen in the figure above, the insulation affected the temperature significantly. With the insulation, a temperature increase of more than 30°C (54°F) could be achieved.

Table 2: **Testing results of the 200-watt return line heating element.**

Return Line Heating Element Test with Oil Inlet Temperature at 21.9 ° C		
	Feed Line	Return Line
Heat Element Power (w)	400	200
Temperature of Oil Exiting the Line In Steady State (°C)	41.7	51.4
Temperature Change Caused by the Heating Element (°C)	19.8	9.7

The only purpose of the return line heating element was to prevent temperature drop of WVO and facilitate the flowing of WVO back to the fuel tank. The table above shows the return line heating element was not only able to prevent a temperature drop, but also able to further increase the WVO temperature. It proves the return line heating element was able to fulfill its purpose.

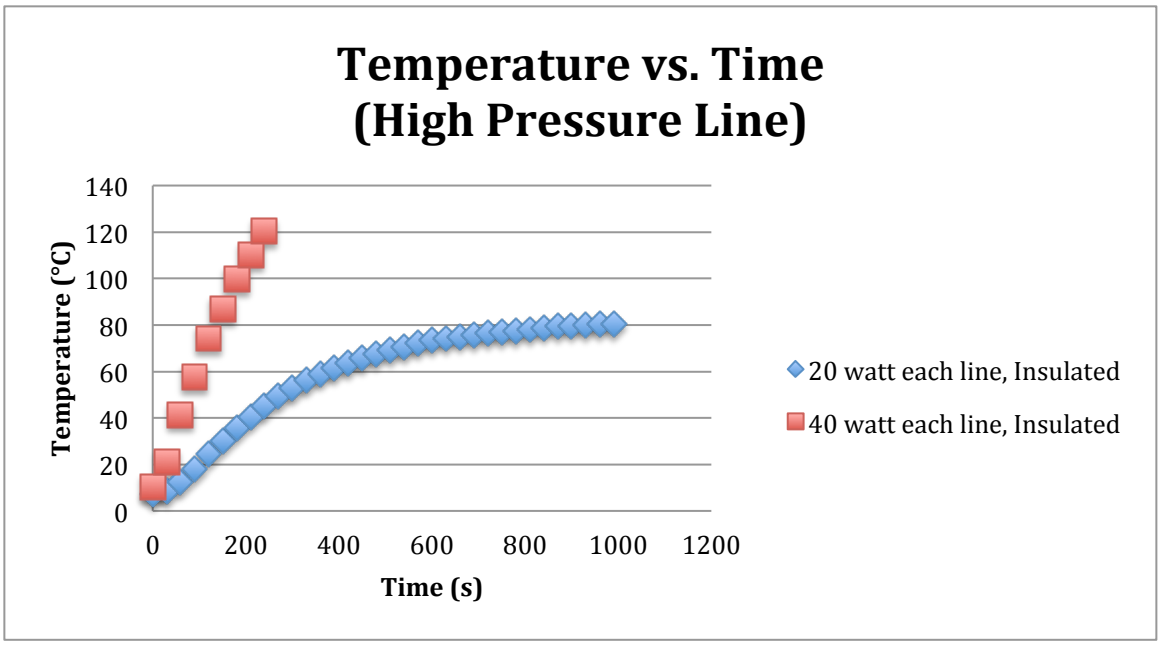

Figure 24: **Time vs. Temperature plot of one of the high pressure lines**

Heating elements with two different heating powers (20 watt and 40 watt) were tested on a high pressure line. This fuel line carries the fuel from the injection pump directly to the engine, so the fuel has to get to 82±11°C (180±20°F). From the figure above, the 20-watt heating element was deemed in sufficient, and 40-watt heating element was selected to be installed on the car, with a temperature control mechanism to prevent the fuel line from getting too hot.

According to the test results, the arrangement of the heating elements are summarized in the table below.

Table 3: **Arrangement of the heating elements**

Heating Element	Power (watt)	Power Source	Status during Cold Start before Starting the Engine	Status during Cold Start Starting the Engine	Status during Normal Operation with Warmed-up Engine
Tank-in-Tank	100	Secondary Battery	on	on	off
Feed Line	400	Secondary Battery	on	on (off with 20+°C environment temperature)	off
Return Line	200	Secondary Battery	on	on (off with 20+°C environment temperature)	off
High Pressure Line	200	Car Battery	off	on (with temperature control)	on (with temperature control)

After the test, the system was installed on the car. With this system installed, the driver is able to switch between the diesel and WVO fuel, control the high pressure line heating element, and the WVO pump from the engine compartment. The control of the tank-in-tank, the feed line and the return line heating element is at the dashboard. Temperatures of the high pressure line, the oil in the tank-in-tank, and the return line, and the fuel level of the WVO tank can be monitored at the dashboard.

The system has been tested on the car. It is able to successfully deliver WVO, switch between WVO and diesel fuel, and heat WVO to proper temperature. Because the fuel delivery and the heating function as desired, the engine is able to use WVO without noticeable change in power output and engine noise. However, the placement of the temperature sensors may need further adjustment for the temperature gauges to more accurately display the temperature of the desired spots.

The installation followed the design in Figure 3, Figure 4, and Table 3 above. The specifications of the system and the wiring diagram can be found in the Communication for Manufacture document. The operating procedure of this system can be found in the Operator's Checklist document. A budget of this project is in Appendix A.

Conclusion

The project aimed to convert a 1985 diesel Mercedes 300SD to run on Waste Vegetable Oil (WVO), both during the cold start period and in normal operation conditions. The conversion system should be able to heat the WVO to 82±11°C (180±20°F) before injecting the oil into the engine. It should also have a mechanism to choose the fuel (diesel or WVO) that feed into the engine. During the design and analysis stage, a heating elements simulation model was carried out in Matlab. This model helped decide the specifications of the heating elements. WVO was obtained from Mather Hall in Trinity College. After a feasible design was made, the system was built and tests to the WVO and the system were performed. The tests proved the effectiveness of the system design. The system was then installed on the car and tested. The test showed the system was able to successfully deliver the WVO to the engine, while heating it to the target temperature. As a result, the engine is able to successfully run on WVO.

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Appendix A: Budget

DESIGN AND IMPLEMENTATION OF A WASTE VEGETABLE OIL (WVO) FUEL SYSTEM WITH TEMPERATURE CONTROLLED HEATING FOR A 1985 MERCEDES: BUDGET

Order	Item	Usage	Amount	Unit Price ($)	Shipping ($)	Tax ($)	Total Price ($)	Source
1	Haynes Automotive Repair Manual	Understanding the car and learn how to work on the car	1	26.95	0.00	0.00	26.95	Haynes website
	2 Diverting 3-Port Bronze Ball Valves	Valves for choosing fuel type	2	25.27		0.00		
2	Type 303 Ss Multi-barbed Tube Fitting	Connect the valves with fuel lines	8	4.47	5.11	0.00	91.41	McMaster-Carr website
3	Greasecar Aluminum Tubing 25ft roll	WVO feed and return line	2*25ft	35.00	23.34	0.00	94.34	Greasecar website
	Greasecar Goodyear Heater Hose	Coolant flow to and from the engine to the WVO tank	1*35 ft	40.00		0.00		
	Fibreglass Reinforced Nylon Tee Fitting	Connects added coolant hose to the car coolant hose	1 pair	10.00		0.00		
4	Greasecar 5/8 Brass Tee Fitting	Connects added coolant hose to the car coolant hose	1 pair	8.00	15.53	0.00	73.53	Greasecar website
5	Kinetik KHC1800 1800-Watt 12-Vault Power Cell	Battery for electric heating	1	191.99	0.00	0.00	191.99	Sonic Electronix website
	Frost King 1/2 in. x 3 ft. Fiberglass Pipe Insulation	WVO line insulation	6*3ft	4.97	0.00			
6	Ideal 3/8 - 7/8 in. Hose Repair Clamp 10 pack	Hose clamp	2*10pack	7.27	0.00	2.82	47.18	HomeDepot shop
7	Rubberized Undercoat	Anti-corrosion for drilled holes in the car	1	8.49	0.00	0.54	9.03	NAPA shop
8	Nichrome Wire	WVO line heating	1*1lb spool	38.50	11.50	0.00	50.00	Jacobs Online website
9	Zeus PTFE Heat Shrink Tubing	Insulation wrap for heating wires	2*4ft	10.51	5.13	0.00	26.15	Amazon website
10	AGT30/40 Amp Relay	Relays used to control	5	4.99	5.99	0.00	10.98	Amazon website
11	6 AWG THHN Copper Building Wire	Wiring for heating wires	2*25ft	15.25	22.64	0.00	53.14	Wires and Cables website
12	Kapton Tape 0.001" Thick, 1/2" Wide	Electric insulation for heating heating wires	3*36yard roll	9.22	0.00	0.00	27.66	Amazon website
13	Stainless Steel Barbed Tube Fitting, Reducing	Tube fitting for fuel filter	2	3.16	4.49	0.00	10.81	McMaster-Carr website
14	NAPA Engine Coolant	Engine coolant	4*1 gallon	12.33	0.00	0.00	49.32	NAPA shop
	Kapton Tape 0.001" Thick, 1/2" Wide	Electric insulation for heating heating wires	3*36yard roll	8.02				
15	Lock&Lock 19-Fluid Ounce Rectangular Case	Tank-in-Tank main body	1	6.28	0.00	0.00	30.34	Amazon website
	Bussmann BP/CBC-30HB Type I 30 Amp Circuit Breaker	Circuit breaker for heating circuit	2	3.78	0.00	0.00		
	Bussmann BP/CBC-20HB Type I 20 Amp Circuit Breaker	Circuit breaker for heating circuit	3	3.78				
16	Pilot PLSW26 Safety Cover Racing Toggle Switch	Master switch for high pressure line heating circuit	1	7.00	0.00	0.00	25.90	Amazon website
17	New Battery Kill Safety Shut Off Disconnect Switch	Master switch for extra battery powered heating circuit	1	28.95	8.85	0.00	37.80	Amazon website
18	Rocker Toggle LED Switch Red Light On-Off Control	Switches for control circuit	1*10pcs	9.99	0.00	0.00	9.99	Amazon website
	Bussmann BP/CBC-40HB Type I 40 Amp Circuit Breaker	Circuit breaker for heating circuit	1	3.77				
	Sunpro CP7583 Fuel Level Sender	Fuel lever sigal sender for WVO tank	1	14.90				
19	Sunpro CP8219 StyleLine Electrical Fuel Level Gauge	Fuel lever gauge for WVO tank	1	16.55	0.00	0.00	35.22	Amazon website
20	OIL Temp Temperature Gauge Meter Blue Digital LED	Temperature gauges and sensors	3	27.95	0.00	0.00	83.35	Amazon website
21	JB Weld - Water Weld	Seal for WVO tank cover	1	7.49	0.00	0.48	7.97	NAPA shop
22	JB Weld - Water Weld	Seal for WVO tank cover	3	5.77	0.00	1.10	18.41	HomeDepot shop
	14" Natural Cable Tie	Mounting ties for fixation	1*100pk	10.78	0.00			
	Teks 1/2" Pan/Drill Screws	Screws for fixation on metal	1*300pcs	5.48	0.00			
23	Ideal 3/8 - 7/8 in. Hose Repair Clamp 10 pack	Hose clamp	1*10pack	7.27	0.00	1.49	25.02	HomeDepot shop
Total($)							1036.49	

Appendix B: Matlab code created for simulating the heating element

```
clear all
close all
clc

% Waste Vegetable Oil (WVO) fuel system heating modeling

%% Define variables
% To avoid confusion, all variable names contain letters only, no numbers.
% All variables of size 1-by-1 are in lower case letters.
% All variables of larger size include higher case letters.

% simulation parameters
frf = 6.3090E-5; %m^3/s, 60gph, fuel flow rate in feed line
frr = 6.0987E-5; %m^3/s, 58gph, fuel flow rate in return line
frh = (frf - frr)/5; %m^3/s, 2/5 = 0.4 gph, fuel flow rate in high pressure line
ta = 300; %s, heating time before the engine turns on
tb = 600; %s, total simulation time
ti = 0.1; %s, time step for the stage before the engine starts
di = 0.01; %m, length step for the stage before the engine starts
% dif = 0.01; %m, length step of feed line for the stage before the engine starts
% dir = 0.01; %m, length step of return line for the stage before the engine starts
% dih = 0.01; %m, length step of high pressure line for the stage before the engine starts
tj = 0.1; %s, time step for the stage after the engine starts
djf = 0.01;%calc length step of feed line for the stage after the engine starts
djr = 0.01;%calc length step of return line for the stage after the engine starts
djh = 0.01;%calc length step of high pressure line for the stage after the engine starts
tmpi = 0; %degree C, the initial fuel temperature

h = 46.33; %W/m^2-K, heat transfer coefficient between pipe and fuel
itvfa = 4; % plot interval for distanc in feed line before the engine starts
itvra = 4; % plot interval for distanc in return line before the engine starts
itvha = 1; % plot interval for distanc in high pressure line before the engine starts
itvfb = 5; % plot interval for distanc in feed line after the engine starts
itvrb = 5; % plot interval for distanc in return line after the engine starts
itvhb = 1; % plot interval for distanc in high pressure line after the engine starts

% fuel system info
lf = 3; %m, length of fuel feed line, from fuel tank to injection pump
dfo = 0.021336; %m, outer diameter of the fuel feed line
```

```
dfi = 0.0157988; %m, inner diameter of the fuel feed line

lr = 3; %m, length of fuel return line, from injection pump to fuel tank
dro = 0.021336; %m, outer diameter of the fuel return line
dri = 0.0157988; %m, inner diameter of the fuel return line

lh = 0.2; %m, length of high pressure fuel line, from injection pump to injectors
dho = 0.0095; %m, outer diameter of the high pressure fuel line
dhi = 0.0071; %m, inner diameter of the high pressure fuel line

v = 0.001; %m^3, volume of the tank-in-tank
rhop = 2700; %kg/m^3, density of aluminum
cp = 896; %J/kg-K, specific heat capacity of aluminum
kp = 250;%J/sec-m-K, thermal conductivity of aluminum

% fuel info
rhof = 922; %kg/m^3, density of WVO
cf = 1670; %J/kg-K, specific heat capacity of WVO
kf = 0.2; %J/sec-m-K, thermo conductivity of WVO

% insulation info
rcontact = 0.0002; %R_contact between pipe and insulation
ho = 5; %W/m^2-K, heat transfer coefficient between insulation and air
kin = 0.04; %J/sec-m-K, thermo conductivity of insulation

dinfi = dfo; %m, inner diameter of the feed line insulation
dinfo = dinfi + 2*0.015; %m, outer diameter of the feed line insulation

dinri = dro; %m, inner diameter of the return line insulation
dinro = dinri + 2*0.015; %m, outer diameter of the return line insulation

dinhi = dho; %m, inner diameter of the high pressure line insulation
dinho = dinhi + 2*0.005; %m, outer diameter of the high pressure line insulation

% heating system info
pfa = 400; %Watt, power of the first heating element on the fuel feed line
dfas = 0.1; %m, distance from the start point of heating element to fuel tank
dfae = 2.9; %m, distance from the end point of heating element to fuel tank

pra = 200; %Watt, power of the first heating element on the fuel return line
dras = 0.1; %m, distance from the start point of heating element to injection pump
```

```
drae = 2.9; %m, distance from the end point of heating element to injection pump

pha = 100; %Watt, power of the first heating element on the high pressure fuel line
dhas = 0.05; %m, distance from the start point of heating element to injection pump
dhae = 0.15; %m, distance from the end point of heating element to injection pump

ptank = 200; %Watt, power of the heating element in tank-in-tank
parea = 0.01*0.01*6; %m^2, surface area of the tank-in-tank cover

%% Calculation, preparation
% frequently used
pfi = pi*dfi; %m, inner cross section perimeter of the fuel feed line
afi = pi*(dfi/2)^2; %m^2, inner cross section area of the fuel feed line
afp = pi*(dfo/2)^2 - pi*(dfi/2)^2; %m^2, feed line pipe cross sectional area
vpfa = di*afp; %m^3, element volume of feed line, before the engine starts
vpfb = djf*afp; %m^3, element volume of feed line, after the engine starts
vffa = di*afi; %m^3, element volume of fuel in feed line, before the engine starts
vffb = djf*afi; %m^3, element volume of fuel in feed line, after the engine starts

dkf = frf*tj/afi; % flow step length of feed line, after the engine starts
vffc = dkf*afi; %m^3, flow element volume of fuel in feed line, after the engine starts
nf = dkf/djf;

% heat transfer coefficient considering from pipe through insulation to
% outside for feed line
uf = 1/(rcontact + (pi*dfo*log(dinfo/dinfi))/(2*pi*kin) + 1/ho);

pri = pi*dri; %m, inner cross section perimeter of the fuel return line
ari = pi*(dri/2)^2; %m^2, inner cross section area of the fuel return line
arp = pi*(dro/2)^2 - pi*(dri/2)^2; %m^2, return line pipe cross sectional area
vpra = di*arp; %m^3, element volume of return line, before the engine starts
vprb = djr*arp; %m^3, element volume of return line, after the engine starts
vfra = di*ari; %m^3, element volume of fuel in return line, before the engine starts
vfrb = djr*ari; %m^3, element volume of fuel in return line, after the engine starts

dkr = frr*tj/ari; % flow step length of return line, after the engine starts
vfrc = dkr*ari; %m^3, flow element volume of fuel in return line, after the engine starts
nr = dkr/djr;

% heat transfer coefficient considering from pipe through insulation to
% outside for return line
```

```
ur = 1/(rcontact + (pi*dro*log(dinro/dinri))/(2*pi*kin) + 1/ho);

phi = pi*dhi; %m, inner cross section perimeter of the high pressure fuel line
ahi = pi*(dhi/2)^2; %m^2, inner cross section area of the highre pressre fuel line
ahp = pi*(dho/2)^2 - pi*(dhi/2)^2; %m^2, high pressure line pipe cross sectional area
vpha = di*ahp; %m^3, element volume of high pressure line, before the engine starts
vphb = djh*ahp; %m^3, element volume of high pressure line, after the engine starts
vfha = di*ahi; %m^3, element volume of fuel in high pressure line, before the engine
starts
vfhb = djh*ahi; %m^3, element volume of fuel in high pressure line, after the engine
starts

dkh = frh*tj/ahi; % flow step length of high pressure line, after the engine starts
vfhc = dkh*ahi; %m^3, flow element volume of fuel in high pressure line, after the
engine starts
nh = dkh/djh;

% heat transfer coefficient considering from pipe through insulation to
% outside for high pressure line
uh = 1/(rcontact + (pi*dho*log(dinho/dinhi))/(2*pi*kin) + 1/ho);

% for plotting graphs
Tpa = 0:ti:ta; %s, all the time before engine turns on, for plotting
Tpb = ta:tj:tb; %s, all the time after engine turns on, for plotting

Distfa = 0:di:lf; %m, all the distances for the feed line, before the engine starts, for
plotting
lengthfa = length(Distfa); % number of elements in "Distfa"

Distra = 0:di:lr; %m, all the distances for the return line, before the engine starts, for
plotting
lengthra = length(Distra); % number of elements in "Distra"

Distha = 0:di:lh; %m, all the distances for the high pressure line, before the engine starts,
for plotting
lengthha = length(Distha); % number of elements in "Distha"

Distfb = 0:djf:lf; %m, all the distances for the feed line, after the engine starts, for
plotting
lengthfb = length(Distfb); % number of elements in "Distfb"
```

```
Distrb = 0:djr:lr; %m, all the distances for the return line, after the engine starts, for
plotting
lengthrb = length(Distrb); % number of elements in "Distrb"

Disthb = 0:djh:lh; %m, all the distances for the high pressure line, after the engine starts,
for plotting
lengthhb = length(Disthb); % number of elements in "Disthb"

%% Calculation, before the engine starts
% assume no conduction in the fuel

% time = 0, initial condition
Tmpta(1) = tmpi; % initial temperature in the fuel tank
Tmppfa(1,1:lengthfa) = tmpi; % initial temperature in feed line, before the engine starts
Tmppra(1,1:lengthra) = tmpi; % initial temperature in return line, before the engine starts
Tmppha(1,1:lengthha) = tmpi; % initial temperature in high pressure line, before the
engine starts
Tmpffa(1,1:lengthfa) = tmpi; % initial temperature of fuel in feed line, before the engine
starts
Tmpfra(1,1:lengthra) = tmpi; % initial temperature of fuel in return line, before the
engine starts
Tmpfha(1,1:lengthha) = tmpi; % initial temperature of fuel in high pressure line, before
the engine starts

% 0 < time <= 300
for i = 2:length(Tpa) % analyze through each time instant
	Tpa(i)

	%%%%%%% First, analyze the tank-in-tank temperature

	% assume the temperature is the same everywhere in the tank-in-tank
	% no mass flow, no conduction, convection with the aluminum cover
%	 pwrcond = -kf*afi*((Tmpt(i-1) - Tmpffa((i-1),1))/di) - kf*afi*((Tmpt(i-1) -
Tmpfra((i-1),lengthra))/di); %rate of energy change
%	 Tmpt(i) = Tmpt(i-1) + pwrcond*ti/(cf*rhof*v);
	 pwrconv = h*parea*(Tmpta(i-1) - tmpi); % convection with the tank-in-tank
cover
	 Tmpta(i) = Tmpta(i-1) + (ptank*ti - pwrconv)/(v*rhof*cf);

	%%%%%%% Second, analyze the feed line
```

```
% analyze the first element of the feed line right after the fuel tank
% for pipe, no mass flow, have conduction and convection
pwrcond = -kp*afp*((Tmppfa((i-1),1) - Tmpta(i-1))/di) - kp*afp*((Tmppfa((i-1),1) -
Tmppfa((i-1),2))/di);
% for convection, assume no electric heating for this element
pwrconv = h*di*pfi*(Tmpffa((i-1),1) - Tmppfa((i-1),1));
pwrconv2 = uf*di*pfi*(tmpi - Tmppfa((i-1),1)); % heat loss to environment
Tmppfa(i,1) = Tmppfa((i-1),1) + (pwrcond + pwrconv +
pwrconv2)*ti/(cp*rhop*vpfa);
% for fuel, no mass flow, no conduction, only convection
Tmpffa(i,1) = Tmpffa((i-1),1) - pwrconv*ti/(cf*rhof*vffa);

% analyze the feed line, except the first and the last elements
for j = 2:(lengthfa - 1)
    % for pipe, no mass flow, have conduction and convection
    pwrcond = -kp*afp*((Tmppfa((i-1),j) - Tmppfa((i-1),(j-1)))/di) -
kp*afp*((Tmppfa((i-1),j) - Tmppfa((i-1),(j+1)))/di);
    pwrconv = h*di*pfi*(Tmpffa((i-1),j) - Tmppfa((i-1),j));
    pwrconv2 = uf*di*pfi*(tmpi - Tmppfa((i-1),j)); % heat loss to environment
    % for fuel, no mass flow, no conduction, only convection
    Tmpffa(i,j) = Tmpffa((i-1),j) - pwrconv*ti/(cf*rhof*vffa);
    % if it is in the heating region, convection from the heating wires
    if Distfa(j)>=dfas && Distfa(j)<=dfae
        pwrconv = pwrconv + pfa*di/(dfae - dfas);
    end
    Tmppfa(i,j) = Tmppfa((i-1),j) + (pwrcond + pwrconv +
pwrconv2)*ti/(cp*rhop*vpfa);
end

% analyze the last element of the feed line
% for pipe, no mass flow, have conduction and convection
% no electric heating for this element
% for fuel, no mass flow, no conduction, only convection
j = j + 1;
pwrcond = -kp*afp*((Tmppfa((i-1),j) - Tmppfa((i-1),(j-1)))/di) -
kp*arp*((Tmppfa((i-1),j) - Tmppra((i-1),1))/di) - kp*ahp*((Tmppfa((i-1),j) -
Tmppha((i-1),1))/di);
pwrconv = h*di*pfi*(Tmpffa((i-1),j) - Tmppfa((i-1),j));
pwrconv2 = uf*di*pfi*(tmpi - Tmppfa((i-1),j)); % heat loss to environment
Tmppfa(i,j) = Tmppfa((i-1),j) + (pwrcond + pwrconv +
pwrconv2)*ti/(cp*rhop*vpfa);
```

```
	Tmpffa(i,j) = Tmpffa((i-1),j) - pwrconv*ti/(cf*rhof*vffa);

	%%%%%%% Third, analyze the return line

	% analyze the first element of the return line
	% for pipe, no mass flow, have conduction and convection
	pwrcond = -kp*afp*((Tmppra((i-1),1) - Tmppfa((i-1),j))/di) -
kp*ahp*((Tmppra((i-1),1) - Tmppha((i-1),1))/di) - kp*arp*((Tmppra((i-1),1) -
Tmppra((i-1),2))/di);
	% for convection, assume no electric heating for this element
	pwrconv = h*di*pri*(Tmpfra((i-1),1) - Tmppra((i-1),1));
	pwrconv2 = ur*di*pri*(tmpi - Tmppra((i-1),1)); % heat loss to environment
	Tmppra(i,1) = Tmppra((i-1),1) + (pwrcond + pwrconv +
pwrconv2)*ti/(cp*rhop*vpra);
	% for fuel, no mass flow, no conduction, only convection
	Tmpfra(i,1) = Tmpfra((i-1),1) - pwrconv*ti/(cf*rhof*vfra);

	% analyze the return line, except the first and the last elements
	for j = 2:(lengthra - 1)
		% for pipe, no mass flow, have conduction and convection
		pwrcond = -kp*arp*((Tmppra((i-1),j) - Tmppra((i-1),(j-1)))/di) -
kp*arp*((Tmppra((i-1),j) - Tmppra((i-1),(j+1)))/di);
		pwrconv = h*di*pri*(Tmpfra((i-1),j) - Tmppra((i-1),j));
		pwrconv2 = ur*di*pri*(tmpi - Tmppra((i-1),j)); % heat loss to environment
		% for fuel, no mass flow, no conduction, only convection
		Tmpfra(i,j) = Tmpfra((i-1),j) - pwrconv*ti/(cf*rhof*vfra);
		% if it is in the heating region, convection from the heating wires
		if Distra(j)>=dras && Distra(j)<=drae
			pwrconv = pwrconv + pra*di/(drae - dras);
		end
		Tmppra(i,j) = Tmppra((i-1),j) + (pwrcond + pwrconv
+pwrconv2)*ti/(cp*rhop*vpra);
	end

	% analyze the last element of the return line
	% for pipe, no mass flow, have conduction and convection
	% no electric heating for this element
	% for fuel, no mass flow, no conduction, only convection
	j = j + 1;
	pwrcond = -kp*arp*((Tmppra((i-1),j) - Tmppra((i-1),(j-1)))/di) -
kp*arp*((Tmppra((i-1),j) - Tmpta(i-1))/di);
```

```
	pwrconv = h*di*pri*(Tmpfra((i-1),j) - Tmppra((i-1),j));
	pwrconv2 = ur*di*pri*(tmpi - Tmppra((i-1),j)); % heat loss to environment
	Tmppra(i,j) = Tmppra((i-1),j) + (pwrcond + pwrconv +
pwrconv2)*ti/(cp*rhop*vpra);
	Tmpfra(i,j) = Tmpfra((i-1),j) - pwrconv*ti/(cf*rhof*vfra);

	%%%%%% Fourth, analyze the high pressure line

	% analyze the first element of the high pressure line
	pwrcond = -kp*afp*((Tmppha((i-1),1) - Tmppfa((i-1),lengthfa))/di) -
kp*ahp*((Tmppha((i-1),1) - Tmppha((i-1),2))/di) - kp*arp*((Tmppha((i-1),1) -
Tmppra((i-1),1))/di);
	% for convection, assume no electric heating for this element
	pwrconv = h*di*phi*(Tmpfha((i-1),1) - Tmppha((i-1),1));
	pwrconv2 = uh*di*phi*(tmpi - Tmppha((i-1),1)); % heat loss to environment
	Tmppha(i,1) = Tmppha((i-1),1) + (pwrcond + pwrconv +
pwrconv2)*ti/(cp*rhop*vpha);
	% for fuel, no mass flow, no conduction, only convection
	Tmpfha(i,1) = Tmpfha((i-1),1) - pwrconv*ti/(cf*rhof*vfha);

	% analyze the high pressure line, except the first and the last elements
	for j = 2:(lengthha - 1)
		% for pipe, no mass flow, have conduction and convection
		pwrcond = -kp*ahp*((Tmppha((i-1),j) - Tmppha((i-1),(j-1)))/di) -
kp*ahp*((Tmppha((i-1),j) - Tmppha((i-1),(j+1)))/di);
		pwrconv = h*di*phi*(Tmpfha((i-1),j) - Tmppha((i-1),j));
		pwrconv2 = uh*di*phi*(tmpi - Tmppha((i-1),j)); % heat loss to environment
		% for fuel, no mass flow, no conduction, only convection
		Tmpfha(i,j) = Tmpfha((i-1),j) - pwrconv*ti/(cf*rhof*vfha);
		% if it is in the heating region, convection from the heating wires
		if Distha(j)>=dhas && Distha(j)<=dhae
			pwrconv = pwrconv + 0*di/(5*(dhae - dhas));
		end
		Tmppha(i,j) = Tmppha((i-1),j) + (pwrcond + pwrconv +
pwrconv2)*ti/(cp*rhop*vpha);
	end

	% analyze the last element of the high pressure line
	% for pipe, no mass flow, have conduction and convection
	% no electric heating for this element
	% for fuel, no mass flow, no conduction, only convection
```

```
	j = j + 1;
	pwrcond = -kp*ahp*((Tmppha((i-1),j) - Tmppha((i-1),(j-1)))/di);
	pwrconv = h*di*phi*(Tmpfha((i-1),j) - Tmppha((i-1),j));
	pwrconv2 = uh*di*phi*(tmpi - Tmppha((i-1),j)); % heat loss to environment
	Tmppha(i,j) = Tmppha((i-1),j) + (pwrcond + pwrconv +
pwrconv2)*ti/(cp*rhop*vpha);
	Tmpfha(i,j) = Tmpfha((i-1),j) - pwrconv*ti/(cf*rhof*vfha);
end

%% Calculation, after the engine starts
% assume univorm temperature for fuel in the tank-in-tank
% assume uniform temperature for the pipes
% Since the engine is cold in 300-600s, so assume no engine coolant heating
% in the fuel tank in this period

% time = 300s, initial condition
Tmptb(1) = Tmpta(length(Tpa)); % temperature in the fuel tank is still unchanged

% for the temperature of the fuel
% match the initial condition after the engine starts with the final
% condition before the engine starts
for n = 1:lengthfb
	index = find(abs(Distfb(n) - Distfa) == min(abs(Distfb(n) - Distfa)));
	%Tmppfb(1,n) = Tmppfa(length(Tpa), index);
	Tmpffb(1,n) = Tmpffa(length(Tpa), index);
end
for n = 1:lengthrb
	index = find(abs(Distrb(n) - Distra) == min(abs(Distrb(n) - Distra)));
	%Tmpprb(1,n) = Tmppra(length(Tpa), index);
	Tmpfrb(1,n) = Tmpfra(length(Tpa), index);
end
for n = 1:lengthhb
	index = find(abs(Disthb(n) - Distha) == min(abs(Disthb(n) - Distha)));
	%Tmpphb(1,n) = Tmppha(length(Tpa), index);
	Tmpfhb(1,n) = Tmpfha(length(Tpa), index);
end

% assign the uniform initial pipe temperature
Tmppfb(1,1:lengthfb) = mean(Tmppfa(length(Tpa),:));
Tmpprb(1,1:lengthrb) = mean(Tmppra(length(Tpa),:));
Tmpphb(1,1:lengthhb) = mean(Tmppha(length(Tpa),:));
```

```
% 300 < time <= 600
for i = 2:length(Tpb) % analyze through each time instant
	Tpb(i)

	%%%%%%% First, analyze the fuel tank temperature

	% temperature change is caused by mass flow
	eng = 0;
	% add in the energy from return line
	if nr >=1;
		for jj = 1:floor(nr)
			eng = eng + vfrb*rhof*cf*(Tmpfrb((i-1),(lengthrb-jj+1)) - Tmptb(i-1));
		end
		eng = eng + ((vfrc-vfrb*jj)/vfrb)*vfrb*rhof*cf*(Tmpfrb((i-1),(lengthrb-jj)) -
Tmptb(i-1));
	else
		jj = 0;
		eng = eng + ((vfrc-vfrb*jj)/vfrb)*vfrb*rhof*cf*(Tmpfrb((i-1),(lengthrb-jj)) -
Tmptb(i-1));
	end
	% add in the energy from electric heating
	eng = eng + ptank*tj;
	% minus the energy to heat the new cold oil
	eng = eng - (vffc - vfrc)*rhof*cf*(Tmptb(i-1) - tmpi);
	% calculate the temperature
	Tmptb(i) = Tmptb(i-1) + eng/(rhof*v*cf);

	%%%%%%% Second, analyze the feed line

	% analyze the whole pipe
	pwrconv = 0;
	for j = 1:lengthfb
		pwrconv = pwrconv + (h-uf)*pfi*djf*(Tmpffb((i-1),j) - Tmppfb((i-1),j));
	end
	Tmppfb(i,1:lengthfb) = Tmppfb((i-1),1) + (pwrconv + pfa)*tj/(rhop*lf*afp*cp);

	% analyze the fuel

	% analyze the first a few elements of fuel in the feed line right after the fuel tank
	% the fuel comes all or partly from the fuel tank
```

```
    if nf >=1
        for jj = 1:floor(nf)
            Tmpffb(i,jj) = Tmptb(i-1);
        end
        Tmpffb(i,(jj+1)) = ((vffc-vffb*jj)/vffb)*Tmptb(i-1) +
(1-(vffc-vffb*jj)/vffb)*Tmpffb((i-1),1);
    else
        jj = 0;
        Tmpffb(i,(jj+1)) = ((vffc-vffb*jj)/vffb)*Tmptb(i-1) +
(1-(vffc-vffb*jj)/vffb)*Tmpffb((i-1),1);
    end

    % analyze the fuel, except the first a few elements
    for j = (jj+2):lengthfb
        pwrconv = ((vffc-vffb*floor(nf))/vffb)*(-
h*pfi*djf*(Tmpffb((i-1),(j-floor(nf)-1)) - Tmppfb((i-1),(j-floor(nf)-1)))) +
(1-(vffc-vffb*floor(nf))/vffb)*(- h*pfi*djf*(Tmpffb((i-1),(j-floor(nf))) -
Tmppfb((i-1),(j-floor(nf)))));
        Tmpffb(i,j) = ((vffc-vffb*floor(nf))/vffb)*Tmpffb((i-1),(j-floor(nf)-1)) +
(1-(vffc-vffb*floor(nf))/vffb)*Tmpffb((i-1),(j-floor(nf))) + pwrconv*tj/(rhof*vffb*cf);
    end


    %%%%%%% Third, analyze the return line

    % analyze the whole pipe
    pwrconv = 0;
    for j = 1:lengthrb
        pwrconv = pwrconv + (h-ur)*pri*djr*(Tmpfrb((i-1),j) - Tmpprb((i-1),j));
    end
    %Tmpprb(i,1:lengthrb) = Tmpprb((i-1),1) + (pwrconv + pra)*tj/(rhop*lr*arp*cp);
    Tmpprb(i,1:lengthrb) = Tmpprb((i-1),1) + (pwrconv + 0)*tj/(rhop*lr*arp*cp);

    % analyze the fuel

    % analyze the first a few elements of fuel in the return line
    % these elements come all or partly from the feed line

    if nr >= 1
        for jj = 1:floor(nr)
```

```
                Tmpfrb(i,jj) =
((vfrc-vfrb*floor(nr))/vfrb)*Tmpffb((i-1),(lengthfb-floor(nr)-1+jj)) +
(1-(vfrc-vfrb*floor(nr))/vfrb)*Tmpffb((i-1),(lengthfb-floor(nr)+jj));
            end
            Tmpfrb(i,(jj+1)) =
((vfrc-vfrb*floor(nr))/vfrb)*Tmpffb((i-1),(lengthfb-floor(nr)+jj)) +
(1-(vfrc-vfrb*floor(nr))/vfrb)*Tmpfrb((i-1),1);
        else
            jj = 0;
            Tmpfrb(i,(jj+1)) =
((vfrc-vfrb*floor(nr))/vfrb)*Tmpffb((i-1),(lengthfb-floor(nr)+jj)) +
(1-(vfrc-vfrb*floor(nr))/vfrb)*Tmpfrb((i-1),1);
        end

        % analyze the fuel, except the first a few elements
        for j = (jj+2):lengthrb
            pwrconv = ((vfrc-vfrb*floor(nr))/vfrb)*(-
h*pri*djr*(Tmpfrb((i-1),(j-floor(nr)-1)) - Tmpprb((i-1),(j-floor(nr)-1)))) +
(1-(vfrc-vfrb*floor(nr))/vfrb)*(- h*pri*djr*(Tmpfrb((i-1),(j-floor(nr))) -
Tmpprb((i-1),(j-floor(nr)))));
            Tmpfrb(i,j) = ((vfrc-vfrb*floor(nr))/vfrb)*Tmpfrb((i-1),(j-floor(nr)-1)) +
(1-(vfrc-vfrb*floor(nr))/vfrb)*Tmpfrb((i-1),(j-floor(nr))) + pwrconv*tj/(rhof*vfrb*cf);
        end

        %%%%%%% Fourth, analyze the high pressure line

        % analyze the whole pipe
        pwrconv = 0;
        for j = 1:lengthhb
            pwrconv = pwrconv + (h-uh)*phi*djh*(Tmpfhb((i-1),j) - Tmpphb((i-1),j));
        end
        Tmpphb(i,1:lengthhb) = Tmpphb((i-1),1) + (pwrconv + pha/5)/(rhof*lh*ahp*cp);

        % analyze the fuel

        % analyze the first a few elements of fuel in the high pressure line
        % these elements come all or partly from the feed line
        if nh >= 1
            for jj = 1:floor(nh)
```

```
                Tmpfhb(i,jj) =
((vfhc-vfhb*floor(nh))/vfhb)*Tmpffb((i-1),(lengthfb-floor(nh)-1+jj)) +
(1-(vfhc-vfhb*floor(nh))/vfhb)*Tmpffb((i-1),(lengthfb-floor(nh)+jj));
            end
            Tmpfhb(i,(jj+1)) =
((vfhc-vfhb*floor(nh))/vfhb)*Tmpffb((i-1),(lengthfb-floor(nh)+jj)) +
(1-(vfhc-vfhb*floor(nh))/vfhb)*Tmpfhb((i-1),1);
        else
            jj = 0;
            Tmpfhb(i,(jj+1)) =
((vfhc-vfhb*floor(nh))/vfhb)*Tmpffb((i-1),(lengthfb-floor(nh)+jj)) +
(1-(vfhc-vfhb*floor(nh))/vfhb)*Tmpfhb((i-1),1);
        end

        % analyze the fuel, except the first a few elements
        for j = (jj+2):lengthhb
            pwrconv = ((vfhc-vfhb*floor(nh))/vfhb)*(-
h*phi*djh*(Tmpfhb((i-1),(j-floor(nh)-1)) - Tmpphb((i-1),(j-floor(nh)-1)))) +
(1-(vfhc-vfhb*floor(nh))/vfhb)*(- h*phi*djh*(Tmpfhb((i-1),(j-floor(nh))) -
Tmpphb((i-1),(j-floor(nh)))));
            Tmpfhb(i,j) = ((vfhc-vfhb*floor(nh))/vfhb)*Tmpfhb((i-1),(j-floor(nh)-1)) +
(1-(vfhc-vfhb*floor(nh))/vfhb)*Tmpfhb((i-1),(j-floor(nh))) + pwrconv*tj/(rhof*vfhb*cf);
        end

end

%% Plot, before the engine starts
figure (1) % Temperature of the tank-in-tank vs. time
plot(Tpa, Tmpta)
hold on
title('Temperature of the tank-in-tank vs. Time')
xlabel('Time (s)')
ylabel('Temperature of the tank-in-tank (degree C)')
hold off

figure (2) % Temperature of the feed line vs. time and distance
numoftime = length(Tpa);
for m = 1:itvfa:lengthfa
        distance(1:numoftime) = Distfa(m);
        plot3(Tpa, distance, Tmppfa(:,m))
        hold on
```

```
end
title('Temperature of the fuel feed line vs. Time and Distance')
xlabel('Time (s)')
ylabel('Distance (m)')
zlabel('Temperature of the fuel feed line (degree C)')
set([gca; findall(gca, 'Type','text')], 'FontSize', 14);
hold off

figure (3) % Temperature of the feed line fuel vs. time and distance
numoftime = length(Tpa);
for m = 1:itvfa:lengthfa
	distance(1:numoftime) = Distfa(m);
	plot3(Tpa, distance, Tmpffa(:,m))
	hold on
end
title('Temperature of the fuel feed line fuel vs. Time and Distance')
xlabel('Time (s)')
ylabel('Distance (m)')
zlabel('Temperature of the fuel feed line fuel (degree C)')
set([gca; findall(gca, 'Type','text')], 'FontSize', 14);
hold off

figure (4) % Temperature of the return line vs. time and distance
numoftime = length(Tpa);
for m = 1:itvra:lengthra
	distance(1:numoftime) = Distra(m);
	plot3(Tpa, distance, Tmppra(:,m))
	hold on
end
title('Temperature of the fuel return line vs. Time and Distance')
xlabel('Time (s)')
ylabel('Distance (m)')
zlabel('Temperature of the fuel return line (degree C)')
set([gca; findall(gca, 'Type','text')], 'FontSize', 14);
hold off

figure (5) % Temperature of the return line fuel vs. time and distance
numoftime = length(Tpa);
for m = 1:itvra:lengthra
	distance(1:numoftime) = Distra(m);
	plot3(Tpa, distance, Tmpfra(:,m))
```

```
    hold on
end
title('Temperature of the fuel return line fuel vs. Time and Distance')
xlabel('Time (s)')
ylabel('Distance (m)')
zlabel('Temperature of the fuel return line fuel (degree C)')
set([gca; findall(gca, 'Type','text')], 'FontSize', 14);
hold off

figure (6) % Temperature of the high pressure line vs. time and distance
numoftime = length(Tpa);
for m = 1:itvha:lengthha
    distance(1:numoftime) = Distha(m);
    plot3(Tpa, distance, Tmppha(:,m))
    hold on
end
title('Temperature of the high pressure fuel line vs. Time and Distance')
xlabel('Time (s)')
ylabel('Distance (m)')
zlabel('Temperature of the high pressure fuel line (degree C)')
set([gca; findall(gca, 'Type','text')], 'FontSize', 14);
hold off

figure (7) % Temperature of the high pressure line fuel vs. time and distance
numoftime = length(Tpa);
for m = 1:itvha:lengthha
    distance(1:numoftime) = Distha(m);
    plot3(Tpa, distance, Tmpfha(:,m))
    hold on
end
title('Temperature of the high pressure fuel line fuel vs. Time and Distance')
xlabel('Time (s)')
ylabel('Distance (m)')
zlabel('Temperature of the high pressure fuel line fuel (degree C)')
set([gca; findall(gca, 'Type','text')], 'FontSize', 14);
hold off

%% Plot, after the engine starts
figure (8) % Temperature of the tank-in-tank vs. time
plot(Tpb, Tmptb)
hold on
```

```
title('Temperature of the tank-in-tank vs. Time')
xlabel('Time (s)')
ylabel('Temperature of the tank-in-tank (degree C)')
hold off

figure (9) % Temperature of the feed line vs. Time
plot(Tpb,Tmppfb(:,1))
title('Temperature of the feed line vs. Time')
xlabel('Time (s)')
ylabel('Temperature of the feed line (degree C)')
set([gca; findall(gca, 'Type','text')], 'FontSize', 14);

figure (10) % Temperature of the feed line fuel vs. time and distance
numoftime = length(Tpb);
for m = 1:itvfb:lengthfb
	distance(1:numoftime) = Distfb(m);
	plot3(Tpb, distance, Tmpffb(:,m))
	hold on
end
title('Temperature of the fuel feed line fuel vs. Time and Distance')
xlabel('Time (s)')
ylabel('Distance (m)')
zlabel('Temperature of the fuel feed line fuel (degree C)')
set([gca; findall(gca, 'Type','text')], 'FontSize', 14);
hold off

figure (11) % Temperature of the return line vs. Time
plot(Tpb,Tmpprb(:,1))
title('Temperature of the return line vs. Time')
xlabel('Time (s)')
ylabel('Temperature of the return line (degree C)')
set([gca; findall(gca, 'Type','text')], 'FontSize', 14);

figure (12) % Temperature of the return line fuel vs. time and distance
numoftime = length(Tpb);
for m = 1:itvrb:lengthrb
	distance(1:numoftime) = Distrb(m);
	plot3(Tpb, distance, Tmpfrb(:,m))
	hold on
end
title('Temperature of the fuel return line fuel vs. Time and Distance')
```

```
xlabel('Time (s)')
ylabel('Distance (m)')
zlabel('Temperature of the fuel return line fuel (degree C)')
set([gca; findall(gca, 'Type','text')], 'FontSize', 14);
hold off

figure (13) % Temperature of the high pressure line vs. Time
plot(Tpb,Tmpphb(:,1))
title('Temperature of the high pressure line vs. Time')
xlabel('Time (s)')
ylabel('Temperature of the high pressure line (degree C)')
set([gca; findall(gca, 'Type','text')], 'FontSize', 14);

figure (14) % Temperature of the high pressure line fuel vs. time and distance
numoftime = length(Tpb);
for m = 1:itvhb:lengthhb
	distance(1:numoftime) = Disthb(m);
	plot3(Tpb, distance, Tmpfhb(:,m))
	hold on
end
title('Temperature of the high pressure fuel line fuel vs. Time and Distance')
xlabel('Time (s)')
ylabel('Distance (m)')
zlabel('Temperature of the high pressure fuel line fuel (degree C)')
set([gca; findall(gca, 'Type','text')], 'FontSize', 14);
hold off
```

WASTE VEGETABLE OIL (WVO) FUEL SYSTEM WITH TEMPERATURE CONTROLLED HEATING FOR A 1985 MERCEDES

COMMUNICATION FOR MANUFACTURE

Han Wu

Advisors: Dr. John D. Mertens,

Dr. Lin Cheng

April 29, 2013

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Summary

The Waste Vegetable Oil (WVO) fuel system installed on this 1985 Mercedes 300SD Turbodiesel consists of 4 sub systems. They are coolant circulation system, fuel delivery system, car battery powered electric system and secondary battery powered electric system.

The coolant circulation system taps into the coolant lines linking to and from the heater core and circulates the coolant to the heating coils inside the WVO tank.

The fuel delivery system taps into the factory fuel system, and delivers WVO fuel to the engine through a separate fuel feed line, return line, fuel pump and fuel filter.

The car battery powered electric system includes high pressure line heating element, WVO fuel pump and temperature and fuel level gauges. As the name indicates, they are electric components that get their power from the car battery.

The secondary battery powered electric system includes tank-in-tank, feed line and return line heating elements. Also as the name suggests, they are electric components that get their power from the extra secondary battery located in the trunk.

Some components do not belong to any of the sub systems above. They are listed in the miscellaneous section.

The detailed specifications of components in each system are shown below.

Coolant Circulation System

The diagram below shows the layout of the coolant circulation system. The specifications of each component can be found in the table below. The budget of the project contains more information about purchased items.

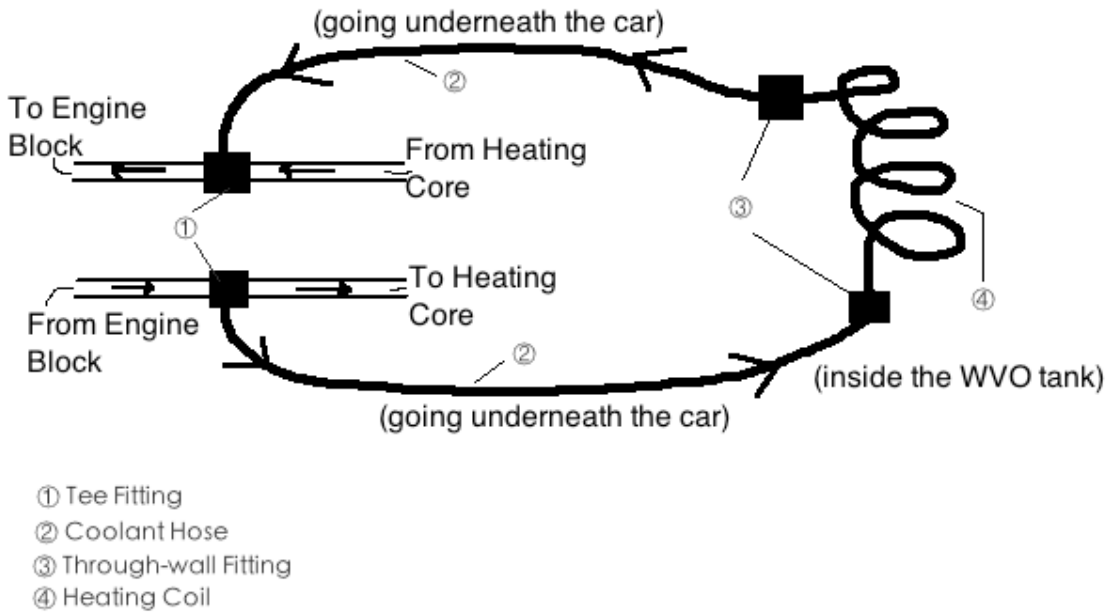

Figure 1: **Diagram showing the layout of the coolant circulation system**

Table 1: **Specifications of the components in the coolant circulation system**

Component	Name of the Component	Temperature Requirement	Pressure Requirement	Specifications	Quantity needed	Name of the Item Purchased (for reference in the budget)
①	Tee Fitting	0 - 220 °F	15 psi	Barbed tee fitting, 5/8in Diameter	2	Greasecar 5/8 Brass Tee Fitting
②	Coolant Hose	0 - 220 °F	15 psi	5/8in ID	35 ft	Greasecar Goodyear Heater Hose
③	Through-wall Fitting	0 - 220 °F	15 psi	Barbed fitting on one side and push connection on the other. 5/8in Diameter	2	From last year's project
④	Heating Coil	0 - 220 °F	15 psi	Copper, 5/8in OD	20 ft	From last year's project

Fuel Delivery System

The diagram below shows the layout of the fuel delivery system. The specifications of each component can be found in the table below. The budget of the project contains more information about purchased items.

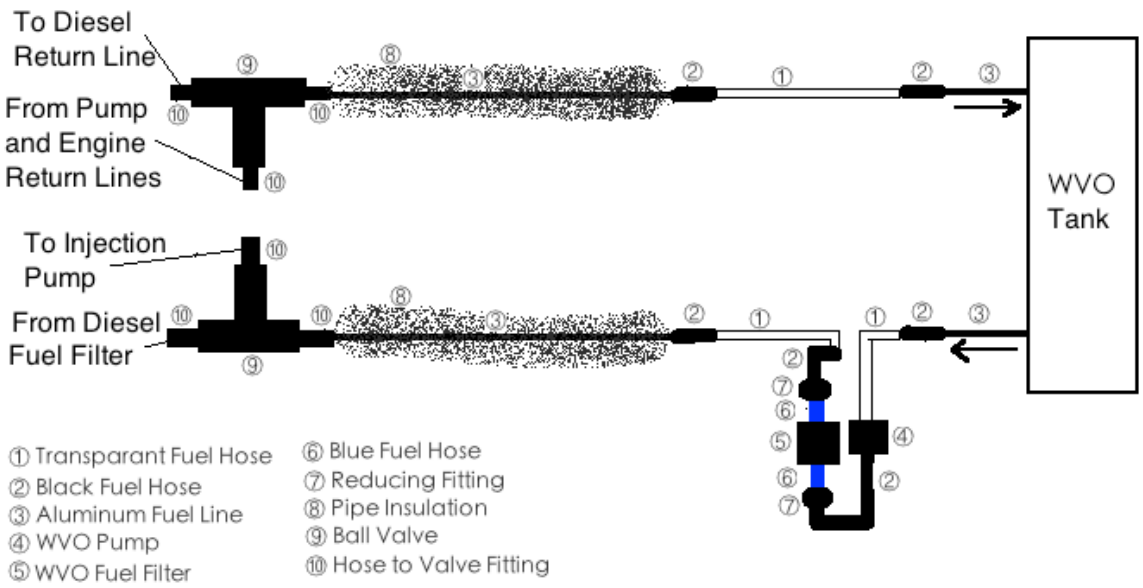

Figure 2: **Diagram showing the layout of the fuel delivery system**

Table 2: **Specifications of the components in the fuel delivery system**

Component	Name of the Component	Temperature Requirement	Pressure Requirement	Specifications	Quantity needed	Name of the Item Purchased (for reference in the budget)
①	Transparant Fuel Hose	0 - 180 °F	10 psi	Soft, 3/8in OD	20ft	From last year's project
②	Black Fuel Hose	0 - 180 °F	10 psi	Soft, 3/8in ID	15ft	From last year's project
③	Aluminum Fuel Line	0 - 500 °F	10 psi	Bendable by hand, 3/8in OD	25ft	Greasecar Aluminum Tubing 25ft roll
④	WVO Pump	0 - 180 °F	10 psi	Automotive fuel pump, 5-9psi	1	From last year's project
⑤	WVO Fuel Filter	0 - 180 °F	10 psi	Automotive fuel filter	1	From last year's project
⑥	Blue Fuel Hose	0 - 180 °F	10 psi	Soft, 1/2in ID	1ft	From last year's project
⑦	Reducing Fittings	0 - 180 °F	10 psi	Barbed Fitting, 1/2in Diameter to 3/8in Diameter, stainless steel	2	Stainless Steel Barbed Tube Fitting, Reducing
⑧	Pipe Insulation	0 - 500 °F	N/A	Fit 1/2in OD pipe	15ft	Frost King 1/2 in. x 3 ft. Fiberglass Pipe Insulation
⑨	Ball Valve	0 - 180 °F	10 psi	3-way, 3/8in Diameter, NPT female threaded fitting, bronze	2	2 Diverting 3-Port Bronze Ball Valves
⑩	Hose to Valve Fittings	0 - 180 °F	10 psi	3/8in Diameter, barbed fitting on one side and NPT male threaded fitting on the other, stainless steel	6	Type 303 Ss Multi-barbed Tube Fitting

Car Battery Powered Electric System

The circuit schematic below shows the layout of the car battery powered electric system. The specifications of each component can be found in the table below. The budget of the project contains more information about purchased items.

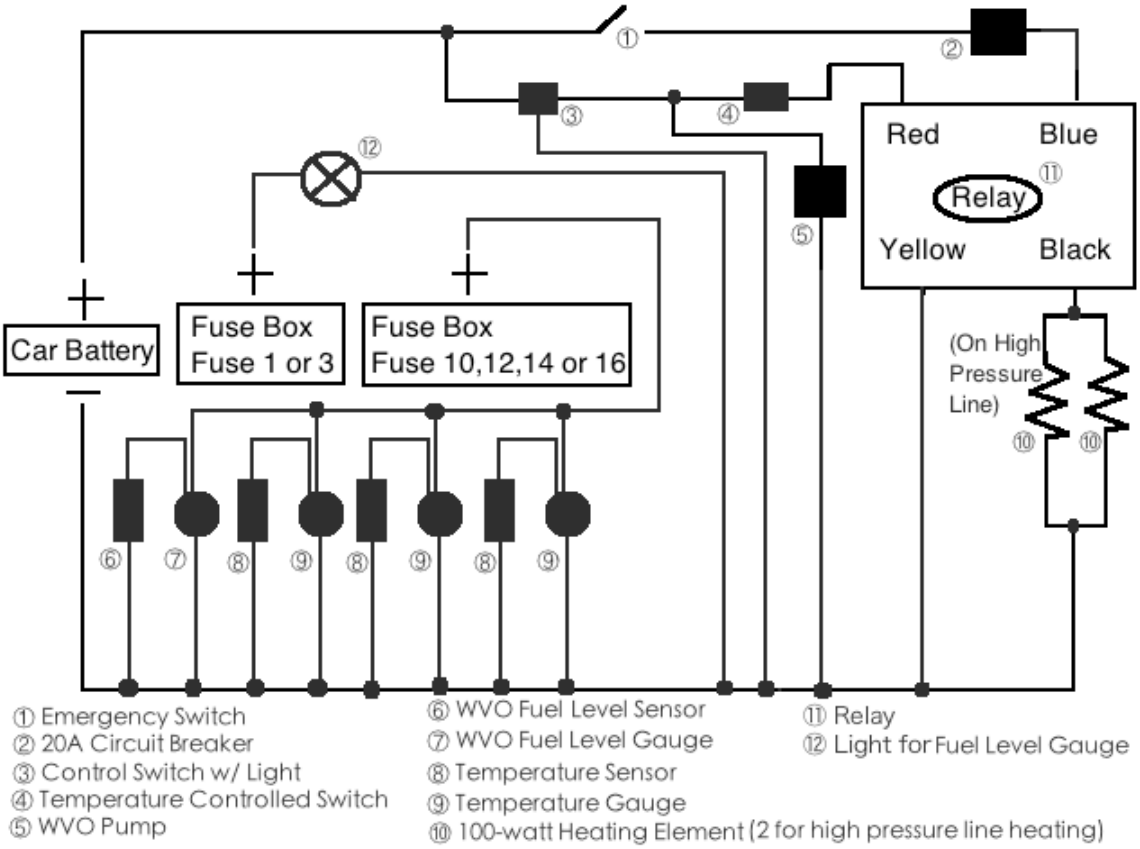

Figure 3: **Circuit diagram of the car battery powered electric system**

Table 3: **Specifications of the components in the car battery powered electric system**

Component	Name of the Component	Specifications	Name of the Item Purchased (for reference in the budget)
①	Emergency Switch	Max current 20A	Pilot PLSW26 Safety Cover Racing Toggle Switch
②	20A Circuit Breaker	N/A	Bussmann BP/CBC-20HB Type I 20 Amp Circuit Breaker
③	Control Switch w/ Light	N/A	Rocker Toggle LED Switch Red Light On-Off Control
④	Temperature Controlled Switch	Control temperature range covers 30-110°C	N/A
⑤	WVO Pump	Automotive fuel pump, 5-9psi	From last year's project
⑥	WVO Fuel Level Sensor	Should work with fuel gauge	Sunpro CP7583 Fuel Level Sender
⑦	WVO Fuel Level Gauge	Should work with fuel level sensor	Sunpro CP8219 StyleLine Electrical Fuel Level Gauge
⑧	Temperature Sensor	Temperature range covers 40-150°C	OIL Temp Temperature Gauge Meter Blue Digital LED
⑨	Temperature Gauge	Temperature range covers 40-150°C	
⑩	100-watt Heating Element	8.25ft 14-gauge nichrome wire wrapped by kapton tape	Nichrome Wire
			Kapton Tape 0.001" Thick, 1/2" Wide
⑪	Relay	12V, 30A automotive relay	AGT30/40 Amp Relay
⑫	Light for Fuel Level Gauge	Should work with fuel gauge	Sunpro CP8219 StyleLine Electrical Fuel Level Gauge

Secondary Battery Powered Electric System

The circuit schematic below shows the layout of the secondary battery powered electric system. The specifications of each component can be found in the table below. The budget of the project contains more information about purchased items.

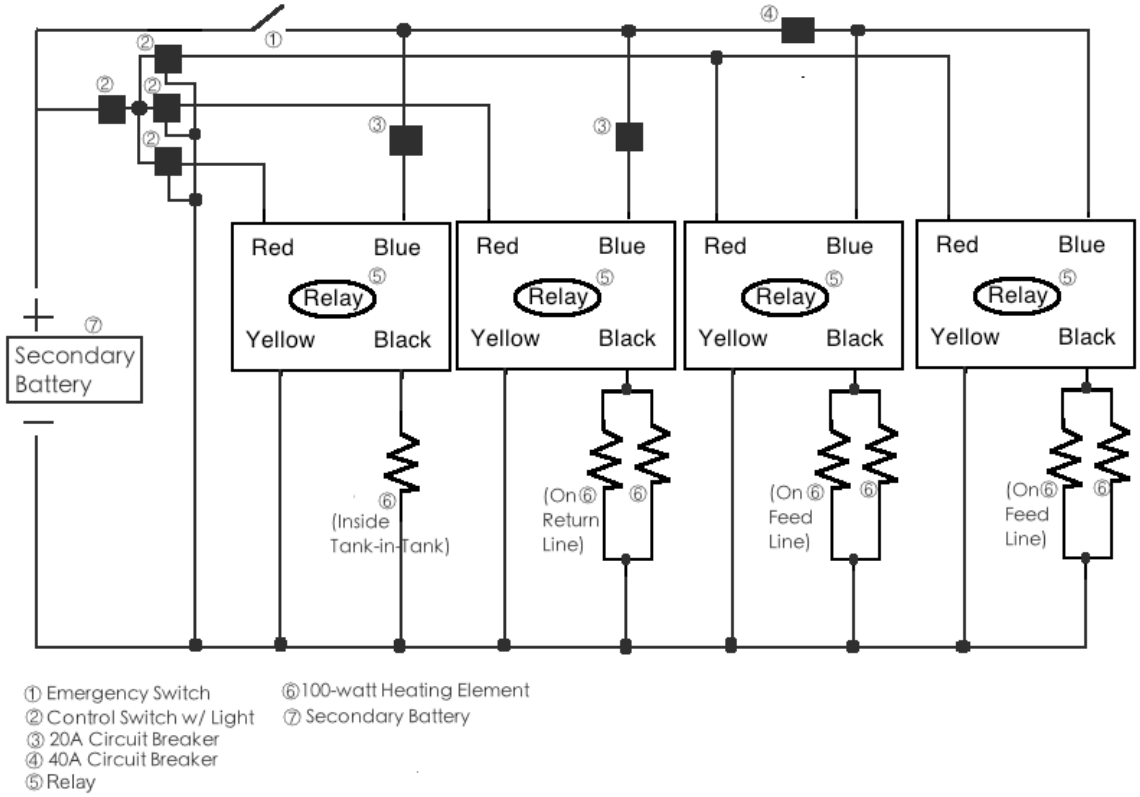

Figure 4: **Circuit diagram of the secondary battery powered electric system**

Table 4: **Specifications of the components in the secondary battery powered electric system**

Component	Name of the Component	Specifications	Name of the Item Purchased (for reference in the budget)
①	Emergency Switch	Max current 175A	New Battery Kill Safety Shut Off Disconnect Switch
②	Control Switch w/ Light	N/A	Rocker Toggle LED Switch Red Light On-Off Control
③	20A Circuit Breaker	N/A	Bussmann BP/CBC-20HB Type I 20 Amp Circuit Breaker
④	40A Circuit Breaker	N/A	Bussmann BP/CBC-40HB Type I 40 Amp Circuit Breaker
⑤	Relay	12V, 30A automotive relay	AGT30/40 Amp Relay
⑥	100-watt Heating Element	8.25ft 14-gauge nichrome wire wrapped by kapton tape	Nichrome Wire
			Kapton Tape 0.001" Thick, 1/2" Wide
⑦	Secondary Battery	1800-watt Car Battery	Kinetik KHC1800 1800-Watt 12-Vault Power Cell

Miscellaneous

For the components that are not listed in any of the systems above, their information can be found in the table below. The budget of the project contains more information about purchased items.

Table 5: **Specifications of the components not included in the systems above**

Item	**Usage**	**Quantity Needed**	**Specifications**	**Name of the Item Purchased (for reference in the budget)**
Hose Clamp	Hose Connection	30	Fit 3/8-7/8in OD hose	Ideal 3/8 - 7/8 in. Hose Repair Clamp 10 pack
Anti-corrosion spray	Anti-corrosion for drilled holes in the car	1	N/A	Rubberized Undercoat
Engine Coolant	Engine coolant	3 gallons	Water/ethylene glycol based, 50:50mix	NAPA Engine Coolant
Plastic Case	Tank-in-Tank main body	1	5.7x4.3x2.6in	Lock&Lock 19-Fluid Ounce Rectangular Case
Epoxy Putty	Seal WVO tank cover	4	Work with plactic fuel tank	JB Weld - Water Weld
Mounting tie	Fixating components	14" 100pcs, 8" 100pcs	N/A	14" Natural Cable Tie
				From last year's project
Electric wire	Connecting electric components	5ft of 6 gauge, 100ft of 12 gauge, 200ft of 18 gauge	N/A	6 AWG THHN Copper Building Wire
				From last year's project
				From Andrew
Screws, washers, nuts, electric tapes etc. are also needed				

WASTE VEGETABLE OIL (WVO) FUEL SYSTEM WITH TEMPERATURE CONTROLLED HEATING FOR 1985 MERCEDES 300SD TURBODIESEL

Operator's Checklist

To run on diesel:

Use the car the same way as an unmodified car. No extra operation needed.

To run on Waste Vegetable Oil (WVO) including cold start:

1. Turn on switch ① on the dashboard for 2-5 minutes depending on the environmental temperature
2. Start the engine (on diesel fuel) when Tank-in-Tank temperature reaches 50°C
3. Open the hood; turn on the switch (for WVO pump and high pressure line heating) by pushing the button. The light will come on. Turn both ball valves ccw for 90° to change the fuel to WVO
4. Close the hood and drive
5. Turn off switch ① 2-5 minutes (depending on the environmental temperature) after the engine started, when the engine coolant temperature reaches 60°C
6. Before stopping the engine, open the hood, turn off the switch by pushing the button. The light will go off. Then turn both ball valves cw for 90° to change the fuel back to diesel. Let engine idle for 1 minute and stop the engine.

To run on Waste Vegetable Oil (WVO) without cold start (including when secondary battery is depleted):

1. Start the engine (on diesel fuel) and drive
2. When the engine coolant gets above 80°C (176°F), pull over the car, open the hood, turn on the switch (for WVO pump and high pressure line heating) and turn both ball valves ccw for 90° to change the fuel to WVO. Then drive away
3. Before stopping the engine, open the hood, turn off the switch and turn both ball valves cw for 90° to change the fuel back to diesel. Let engine idle for 1 minute and stop the engine.

Notes:

- When the environmental temperature is below 20°C (68°F), keep switches ②, ③ and ④ on at all time. Otherwise, keep switch ② on and switches ③ and ④ off at all time.
- For the function of each switch, refer to Figure 1.
- For the location of each temperature sensor, refer to Figure 2.
- The emergency switches (see Figure 3 for locations) are manual shut off switches for the heating elements (they do not control WVO pump or any gauges). They should be kept on at all time except for emergencies.
- Charge the secondary battery every time switch ① has been turned on for 15 minutes or more.

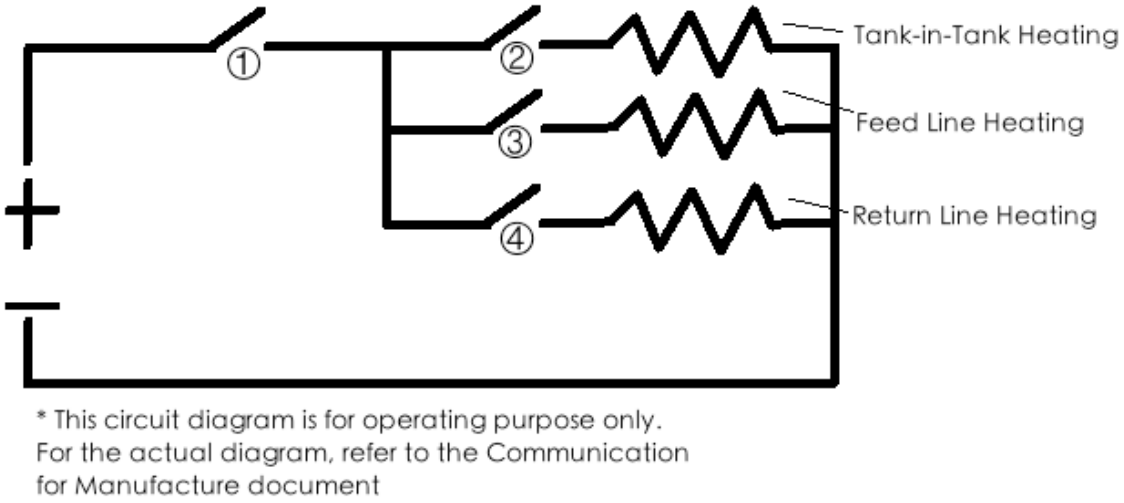

Figure 1: **circuit diagram explaining the function of each switch on the dashboard**

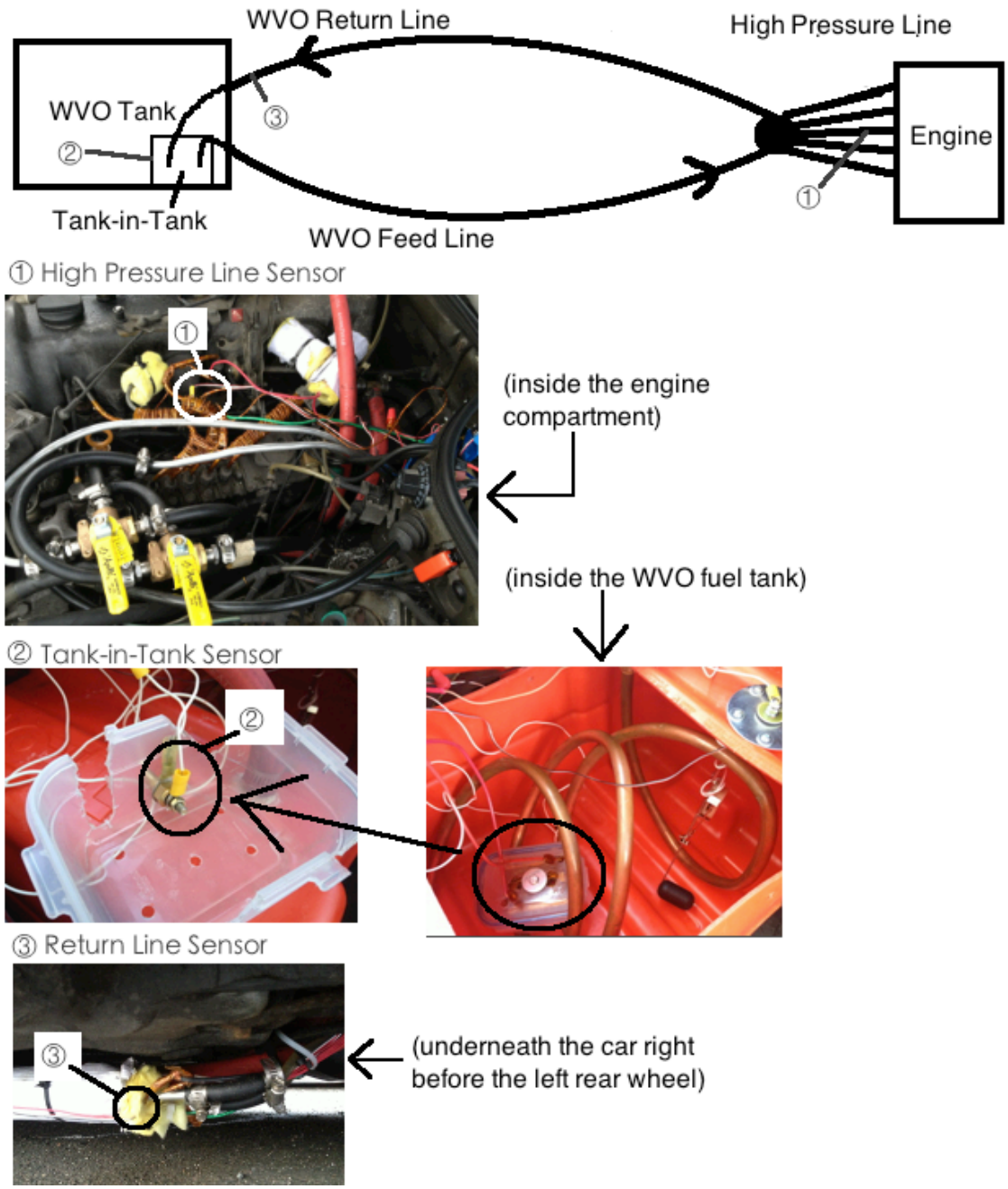

Figure 2: **Pictures showing the locations of each temperature sensor**

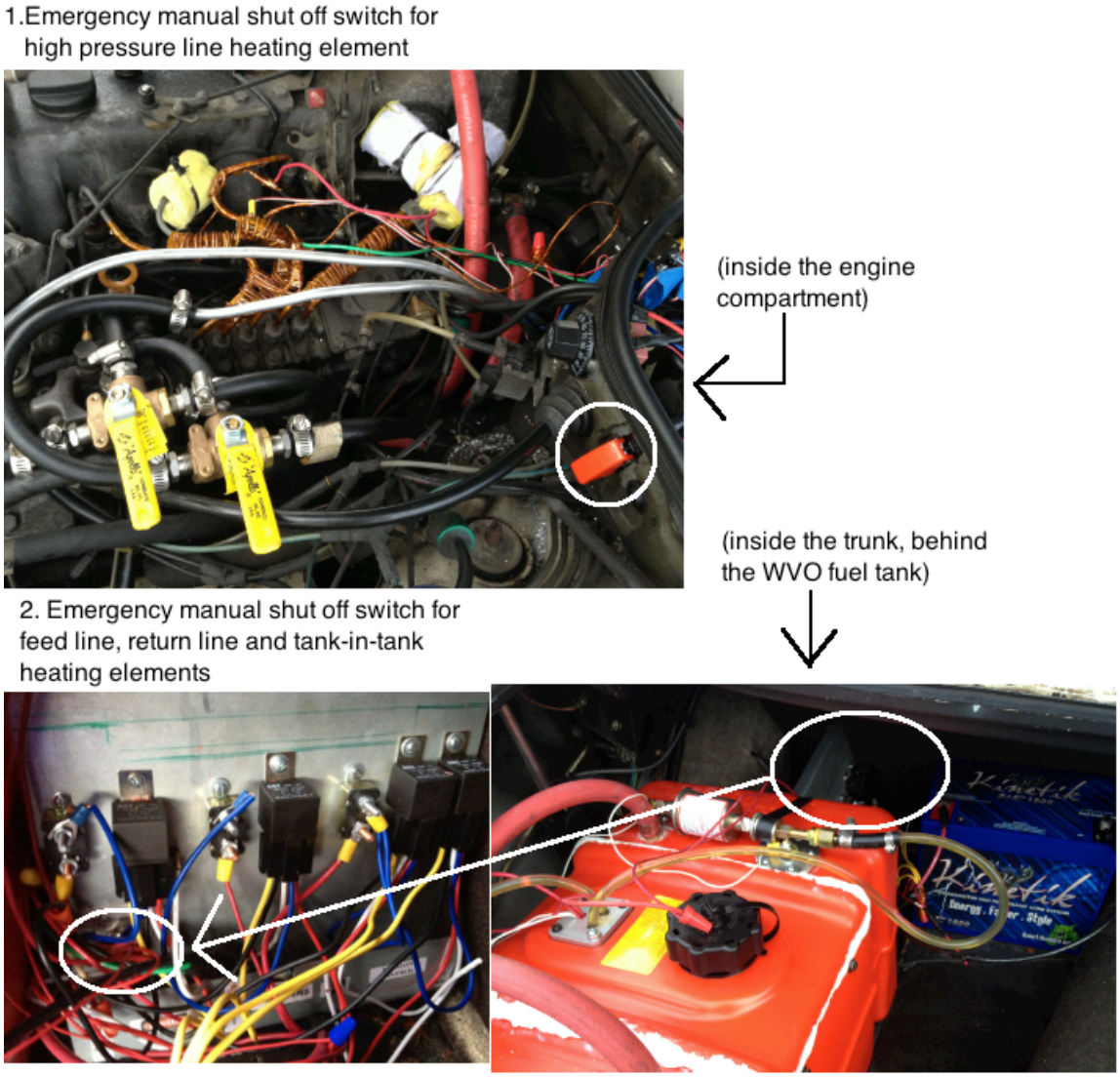

Figure 3: Pictures showing the locations of emergency shut off switches

Electrical System Troubleshooting Manual

- **Car Battery Powered Electric System: Circuit Diagram and Pictures for its Components**

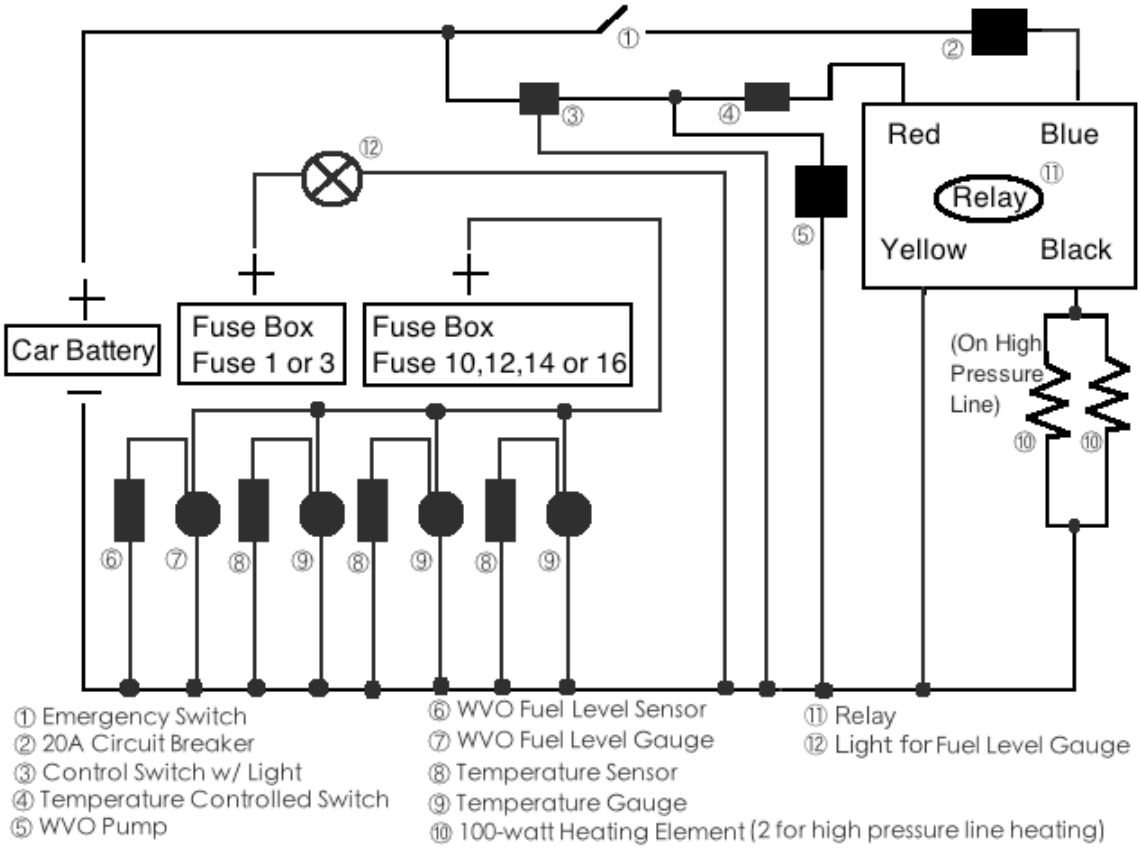

Figure 4: **Circuit diagram of the car battery powered system**

Figure 5: **Pictures of the components in the car battery powered electric system**

- **Secondary Battery Powered Electric System: Circuit Diagram and Pictures for its Components**

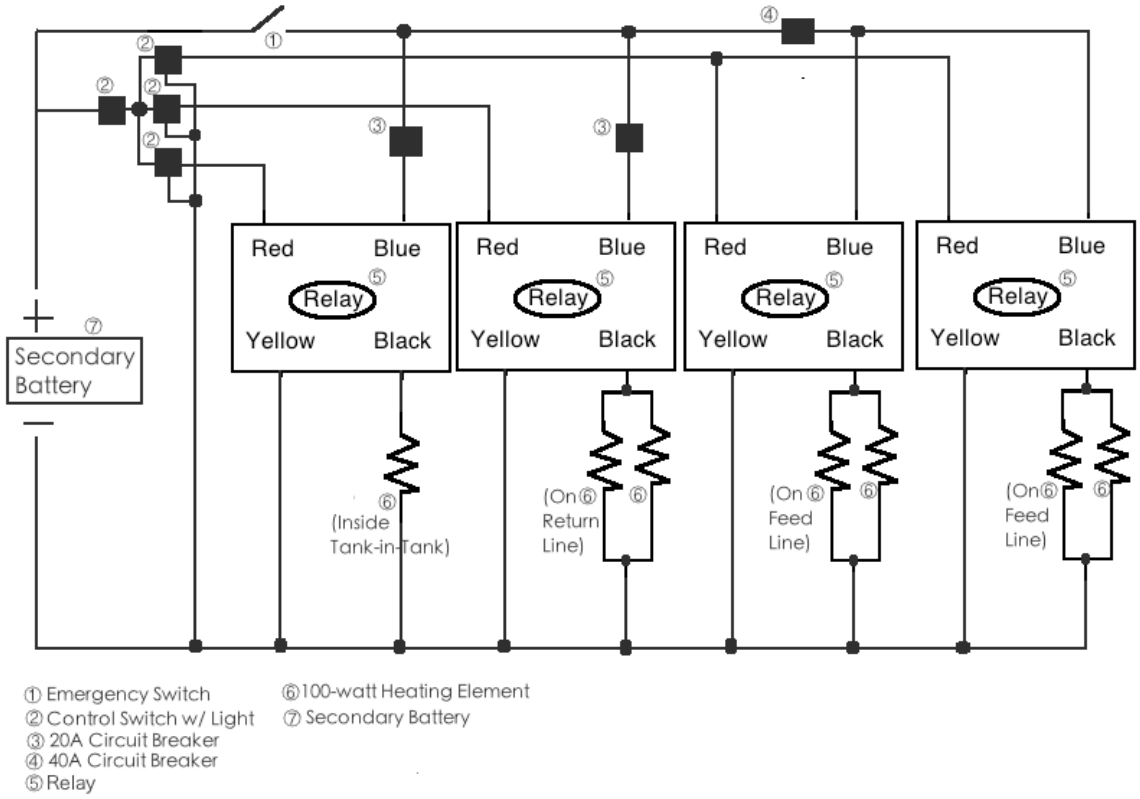

Figure 6: **Circuit diagram of the car battery powered system**

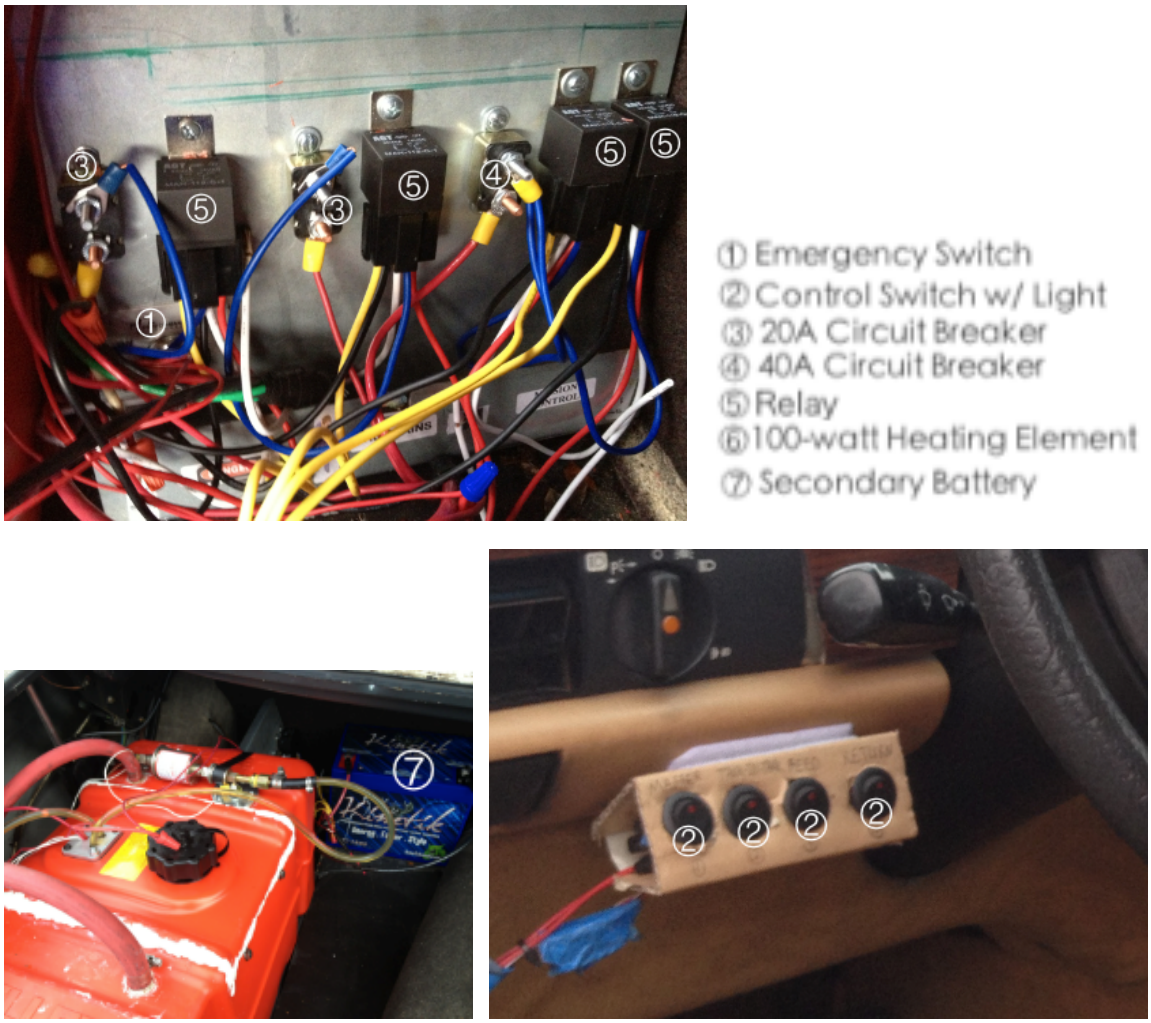

Figure 7: **Pictures of the components in the secondary battery powered electric system**

- **Normal temperature ranges for each temperature gauge**

	Cold Start	**Normal Operation with Warm Engine**
High Pressure Line Temperature	<40°C - 150°C	130°C - 150°C
Tank-in-Tank Temperature	<40°C - 70°C	<40°C - 70°C
Return Line Temperature	<40°C	<50°C

- **If the WVO pump does not work.**
  - Open the trunk; disconnect the two wires connected to the pump
  - Open the hood; turn off the high pressure line emergency switch. Turn on the button switch. The light will come on
  - Go back to the trunk and measure the voltage across the two wires that were connected to the pump
  - If the voltage is 0, then there is problem with the wiring between the pump and the switch. Find and fix the problem. If the voltage is + or – 12V, then the pump is broken. Replace the pump

- **If any component does not work properly**
  - Check the wiring according to the circuit diagram and pictures (Figures 4-7). Replace parts if necessary

- **Notes on emergency manual shut off switches**
  - They can be located using Figure 3
  - To turn off the emergency switch under the hood, push down the red cover
  - To turn off the emergency switch in the trunk, find the red knob and push down hard
  - They should be shut off when the temperatures are either too high or too low, because it means there is problem with the heating element
  - They should remain off while finding and fixing the problem, and be turned back on after the problem is fixed

- **Diagnosing and fixing fuses**
  - To diagnose the fuses, open the hood, and locate a black plastic box near the driver's side. That is the fuse box
  - Open the fuse box by hand (no tools needed), and visually inspect all fuses. Look for broken ones
  - If any broken ones are found, replace them with new ones

- **Diagnosing and fixing circuit breakers**
  - The circuit breakers automatically open the circuit when the current is too high, and automatically close the circuit when it cools down
  - To diagnose a circuit breaker, first make sure the emergency manual shut off switch is turned off
  - Wait for 30 minutes to make sure the circuit breaker is cooled down
  - Check the two terminals of the circuit breaker for open circuit
  - If there is open circuit, then the circuit breaker is broken and should be replaced, otherwise the circuit breaker is not broken
  - No matter whether the circuit breaker is broken or not, the rest of the heating circuit should be checked to make sure there is no short circuit