

# Biodiesel Combustion and Heat Exchanger Unit Operations Lab

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Submitted to  
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*This report represents work of WPI undergraduate students submitted to the faculty as evidence  
of a degree requirement*

## **Abstract**

The goals of this project were to design an apparatus for testing biodiesel, to assess the viability of using that apparatus to teach students in a laboratory environment, and to determine if the apparatus duplicates the teaching potential of the existing WPI heat exchanger experiment. The team achieved these goals by developing a biodiesel compatible combustion system that includes a plate heat exchanger, and experimentally validated that the system shows a difference between the heat duty of diesel and biodiesel comparable to the fuels' actual energy content. The team identified the dependence of the heat exchanger's heat duty and found that the overall heat transfer coefficient increased with increasing cooling water flow rates.

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## 1.0 Introduction

In the recent past, the global community has become increasingly more cognizant of its carbon footprint. These environmental concerns have propelled scientists to research cleaner alternative energy sources that can reduce the world's dependence on petroleum based fuels. One type of alternative fuel is biodiesel, which is produced using renewable resources. Biodiesel is produced commercially around the globe, but it is a maturing technology where researchers continue to optimize existing production methods and develop new ones. Currently, the Worcester Polytechnic Institute (WPI) Chemical Engineering Department has the ability to produce and purify biodiesel. However, the department lacks the means of quantifying the thermal properties of the biodiesel that it produces. An experimental apparatus that would combust biodiesel and yield thermodynamic data would expand the department's research and educational capabilities.

Currently the WPI Chemical Engineering Department uses a shell and tube heat exchanger to provide undergraduate students firsthand experience with analyzing the heat transfer through a heat exchanger. This heat exchanger utilizes steam and a simple shell and tube exchanger design. The steam is produced by the large campus-wide steam plant and requires the system to be brought online in the early fall to supply the existing experiment. There was potential for a new heat exchanger experiment to be developed that would require a smaller energy input. The team recognized that an experimental apparatus could be designed to both test biodiesel and to duplicate the teaching potential of the existing heat exchanger system in the department.

Our goals for this project were to design an apparatus for testing biodiesel, assess the viability of using that apparatus to teach students in a laboratory environment, and to determine if the apparatus duplicates the teaching potential of the existing WPI heat exchanger experiment. The team achieved this goal by:

1. Developing a biodiesel compatible combustion system that includes a plate heat exchanger
2. Validating that the system shows a difference between the heat released by diesel and biodiesel comparable to the fuels actual energy content
3. Identifying the dependence of the heat exchanger's heat duty and overall heat transfer coefficient on the flow rate of the cooling water in the system
4. Testing WPI produced and refined biodiesel in the new apparatus

The team tested diesel fuel and three different biodiesels to validate the capabilities of the system. One of these biodiesels was produced at WPI using the existing equipment for producing and purifying biodiesel. The apparatus built during this project completes the WPI Chemical Engineering Department's ability to produce, purify and test biodiesels.

## 2.0 Background

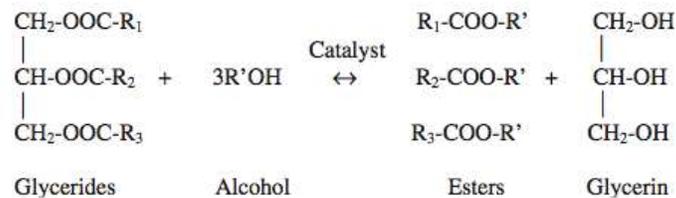
This chapter presents an overview of biodiesel, its chemical make-up, and techniques of how to produce and purify the fuel. It further explains heat transfer in regards to heat exchangers and how it can be analyzed in different kinds of heat exchangers. Finally, it concludes with an exploration of the potential for an online educational program for students in the Chemical Engineering Department.

## 2.1 Biodiesel

Due to finite petroleum reserves there is much interest in researching renewable alternatives to fossil fuels. One such alternative is biodiesel. Biodiesel is an oxygenated fuel comprised of fatty acid methyl esters (FAMES). These esters are derived from triglycerides. The common source of these triglycerides is vegetable oils or animal fats (Demirbas, 2008). These oils and fats can be produced in a renewable and sustainable way, hence leading to biodiesel's potential as a renewable energy source.

### 2.1.1 Biodiesel Chemistry

Biodiesel is produced using transesterification, a chemical process in which a triglyceride is cleaved to produce three mono-fatty acid-esters and a glycerol molecule. This occurs when the triglyceride reacts with an alcohol, usually methanol or ethanol, through a reversible reaction in the presence of a catalyst. The means of catalysis vary and include heat, acids, bases, enzymes and lipids (Marchetti & Errazu, 2007). The most common catalysts at the commercial level are alkali salts (Saleh, Tremblay & Dube, 2010). Figure 1 below illustrates the generic overall reaction of transesterification, where  $R_1$ ,  $R_2$ , and  $R_3$  are long hydrocarbon chains and  $R'$  is the hydrocarbon portion of the alcohol reagent (Gerpen, 2005). The exact chemical makeup of the FAME fuel depends on the triglycerides.



**Figure 1: General Chemical Reaction Process of a Triglyceride (Meher et. al., 2006)**

Each triglyceride molecule is attacked sequentially by three alcohol molecules. Each alcohol will result in the production of an ester molecule and a glyceride molecule with one less fatty acid chain (i.e. diglycerides and monoglycerides). The third alcohol will result in glycerol as the non-ester product.

The next step in producing usable biodiesel is to separate the glycerol from the esters. Most of the glycerol can be removed by utilizing the fact that products of transesterification separate into two phases: a heavier glycerol rich phase and lighter FAME rich phase. If the reaction products are left undisturbed for a period of time, the bulk liquid will settle out into these two phases and

the lighter FAME phase can be siphoned off the top. This separation can be accomplished faster using a centrifuge. However, the FAME phase will be contaminated with excess catalyst, alcohol and glycerol. The FAME requires further purification before it can be used in internal combustion engines. Several purification methods exist, including distillation, membrane separation and ion-exchange resins (Kiss & Ignat, 2012; Morales, Lopez, & Rios, 2013; Saleh et al., 2010).

### **2.1.2 Feedstocks for Biodiesel Production**

Biodiesel can be produced from any triglyceride. However, not all feedstocks are economically viable or sustainable. Most commercial biodiesel is produced from vegetable oils, which are liquid at ambient temperatures and thus require less energy to mix with the alcohol and catalyst. Vegetable oils are more readily available in the large quantities required for commercial production (Demirbas, 2008). The most common feedstock varies globally based on local agriculture. Soybean oil is mostly used in the US, palm and coconut oil in tropical countries, and rapeseed and canola in Europe (Santos et al., 2013).

A major issue facing biodiesel is that most commercial biodiesel is produced using oils sourced from arable land that could otherwise be used to feed consumers. The United States produces over 23 billion pounds of vegetable oils per year and consumes roughly ten times that amount of diesel fuel (Gerpen, 2004). Recognizing that one pound of vegetable oil yields about one pound of biodiesel, America does not possess the ability to produce enough biodiesel to displace all diesel consumption even if all the vegetable oil produced was shifted from food production to biodiesel production (Santos et. al., 2013).

To overcome the food versus fuel debate, biodiesel is commercially produced from waste oil that has already been used to cook food and researchers are investigating the feasibility of inedible vegetable oils as a supply source. Some inedible oils include jatropha, rubber seed, and microalgae oils (Demirbas, 2008).

### 2.1.3 Advantages & Disadvantages of Biodiesel

The greatest advantage of biodiesel is that it is a renewable liquid fuel that can replace diesel in most applications with minimal modifications to existing equipment. The team assembled a list of the major advantages and disadvantages of biodiesel as a fuel. This list is not all-inclusive and serves only to outline the various parameters concerning the production and use of biodiesel. The list is shown in Table 1 below.

**Table 1: Comparison of Biodiesel to Diesel**

| Advantages   | Disadvantages  |
|--|--|
| <ul style="list-style-type: none"><li>• Easily storable</li><li>• Usable in most current diesel applications with minimal modification to equipment</li><li>• High lubricity</li><li>• Renewable</li><li>• Lower emissions of SO<sub>x</sub>, N<sub>2</sub>O, and aromatic compounds</li><li>• Can be mixed with diesel fuel</li></ul> | <ul style="list-style-type: none"><li>• Higher viscosity than petrol diesel</li><li>• High NO<sub>x</sub> emissions</li><li>• Increased engine wear and corrosion</li><li>• Difficult to use in cold environments</li><li>• Current availability of triglyceride feedstock negatively impacts economic viability</li></ul> |
| Bozbas, 2008; Demirbas, 2008   |  |

### 2.1.4 Biodiesel Production at WPI

In recent years, WPI has developed means of producing biodiesel in order to conduct research and provide students with hands on experience with biofuels. The system is housed within the WPI Unit Operations lab. The system contains two computer-controlled reactors, each equipped with stirrers and a hot water bath. Currently methanol is used as the alcohol and potassium hydroxide is used as the catalyst. The methanol and KOH are mixed together in the first reactor vessel and brought to a set temperature. Vegetable oil is warmed in the second reactor vessel. Once the desired temperature is achieved, the alcohol-catalyst mixture is automatically pumped into the second vessel and transesterification occurs. The automated water baths allow for the reaction to be carried out in an isothermal environment at any temperature between 55°C and 60°C. Once the reaction is complete, the system is allowed to cool to room temperature and the contents of the reactor are allowed to separate into a two phase system. The reactor vessel is drained from the bottom to first remove the glycerol rich phase and then recover the FAME rich phase. A typical two hour long production run will yield about 400ml of unpurified FAME.

The students working on the Unit Operations lab currently conducted with this reactor system are to perform several pre-lab exercises that allow them to develop their knowledge of both the experiment and reaction. The students perform several safety procedures such as locating the Material Safety Data Sheet (MSDS) for KOH as well as reading an article pertaining to a combustion accident on the basis of biodiesel production. The third and fourth objectives in the

pre-lab are to understand the theory behind the reactions behind the experiment. One objective requires them to show how to obtain the coefficients for a rate expression using the glycerol concentration as a function of time. The students also explain how to use the equipment described above as well as how they plan to use it to study the temperature dependence and evaluate the activation energy for conversion of canola oil to biodiesel. The theory behind the experiment involves determining that the production depends on the type of feedstock oil, the free fatty acids, water content and the type of catalyst, the oil to alcohol ratio, and the varying operating conditions (Clark, 2013).

### 2.1.5 Biodiesel Purification at WPI

Currently WPI possess the ability to purify biodiesel using an ion-exchange resin. This system was designed to extract the glycerol, methanol and leftover catalyst that contaminates the FAME phase recovered from the biodiesel production system discussed earlier. The resin is used to wash the biodiesel by adsorbing both the glycerol and the methanol left over from the production lab. The resin is setup as a dry-washing system that does not introduce water into the biodiesel. Dry-washing has several key advantages over wet-washing, which involves a resin system and the addition of water. Some of these advantages include a shorter production time, the absence of water in the process, and the ability to be reused. A simple rinse of methanol will restore some of the adsorbent capabilities of the dry-wash method system. The resin that was chosen was Dudalite DW-R10 Ion Exchange Resin. This resin was thought to have a better adsorption rate than the other resins discussed previously (Beck, 2013). The current system allows the WPI produced biodiesel to meet the ASTM standard for biodiesel.

Table 2 below shows the necessary requirements for B100 biodiesel in ASTM D6751 that the resin column affects.

**Table 2: ASTM D6751 Standard for B100**

| Requirements for Biodiesel (B100) Blend Stock ASTM D6751 |             |         |        |
|--|-------------|---------|--------|
| Property   | Test Method | Limits  | Units  |
| Free glycerin  | D6584       | 0.020   | % mass |
| Total glycerin   | D6584       | 0.240   | % mass |
| Methanol content   | EN14110     | 0.2 max | vol %  |

## 2.2 Heat Transfer

Efficient heat transfer between two independent fluid streams is accomplished using a heat exchanger. The streams do not mix but are able to exchange thermal energy across a thermally thin solid interface. Heat exchangers are indispensable to industrial processes. Streams can be either liquid or gaseous and may undergo a phase change inside the heat exchanger. There are three main types of heat exchangers that are used for industrial heat exchange. These three categories of heat exchangers are double-pipe, shell and tube, and plate heat exchangers.

### 2.2.1 Heat Transfer in a Heat Exchanger

In a heat exchanger two fluids are separated by a barrier made of a material with a high thermal conductivity, like copper. The heat from the fluid that is at a higher temperature is transferred to the cooler fluid. There is no work performed in a heat exchanger and thus a change in enthalpy explains the entirety of the net change in a stream's internal energy between its entrance and exit from the exchanger. The amount of heat that enters or exits a stream as it passes through an exchanger in turn equals the enthalpy change of the stream. The enthalpy is calculated as an extensive property and then multiplied by the flow rate of the stream to determine the bulk heat duty. This enthalpy change can be calculated in two ways. For sensible heat transfer the change in enthalpy equals the product of the stream's specific heat capacity and the temperature change of the stream between the inlet and outlet. For a stream undergoing a phase change, the flow rate is multiplied by the latent heat of the fluid in order to calculate the heat duty. The mass flow rate of streams is commonly used and the other terms have corresponding units. Equation 1 below is for sensible heat transfer and Equation 2 is for latent heat transfer.

#### Equation 1

$$\dot{Q} = \dot{m}C_p\Delta T$$

Where:

$$\dot{Q} = \text{Heat Transfer (kW)}$$

$$\dot{m} = \text{Flow Rate of Fluid } \left(\frac{\text{kg}}{\text{s}}\right)$$

$$C_p = \text{Specific Heat of Fluid } \left(\frac{\text{kJ}}{\text{kg K}}\right)$$

$$\Delta T = T_{In} - T_{Out} \text{ (K)}$$

### Equation 2

$$\dot{Q} = \dot{m}\lambda$$

Where:

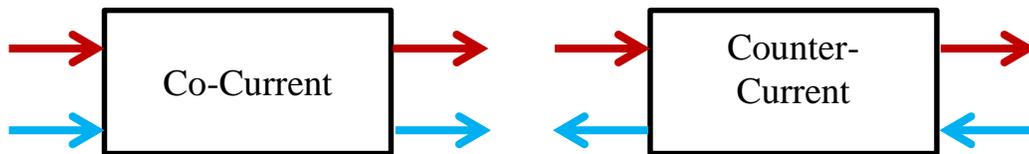
$\dot{Q}$  = Heat Transfer (kW)

$\dot{m}$  = Flow Rate of Fluid ( $\frac{kg}{s}$ )

$\lambda$  = Latent Heat of Fluid ( $\frac{kJ}{kg}$ )

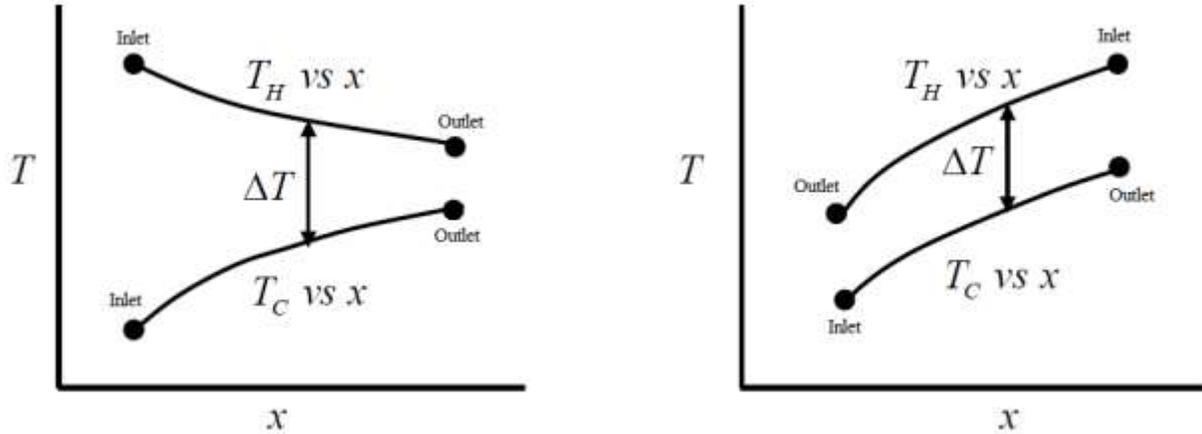
#### 2.2.2 Co-Current and Counter-Current Flow

The two main types of flow patterns in heat exchangers are the co-current and counter-current flow. Co-current operation is when both streams are flowing in the same direction along the solid interface. Counter-current operation is when the streams flow in opposite directions relative to the interface. Both flow patterns can be seen below in Figure 2, where the red arrows denote the “hot” stream and the blue arrows denote the “cold” stream.



**Figure 2: Schematic of inlet and outlet flows in co-current (L) and counter-current (R) heat exchangers.**

Counter-current flow is more efficient for a particular heat exchanger because co-current flow will result in the streams' exiting temperatures approaching an asymptotic average of their inlet temperatures.



**Figure 3: Temperature profiles of co-current (L) and counter-current (R) flow with heat exchanger length (Subramanian, 2014).**

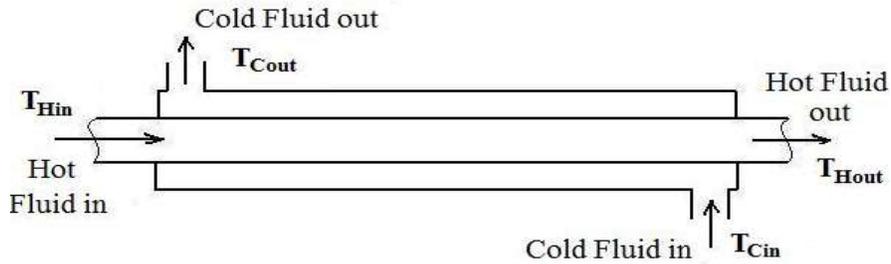
Figure 3 shows how counter-current flow allows for the outlet temperature of the hot stream to be lower than the outlet temperature of the cold stream. The amount of heat that can be transferred in an exchanger depends on the temperature difference between the streams at any given point. Co-current flow's asymptotic outlet temperature difference is the limiting feature and once the two streams reach that temperature difference, there will be insufficient driving force to exchange heat between the streams. Counter-current heat exchangers have a larger normalized temperature change along their length and thus have a greater capacity to transfer heat across a given area (Baehr, 2006). The normalized temperature change in the exchanger is calculated using the log-mean temperature difference.

### 2.2.3 Types of Heat Exchangers

The three major classes of heat exchangers are double-pipe, shell and tube, and plate heat exchangers. Each differs in geometry and flow pattern.

#### Double-pipe:

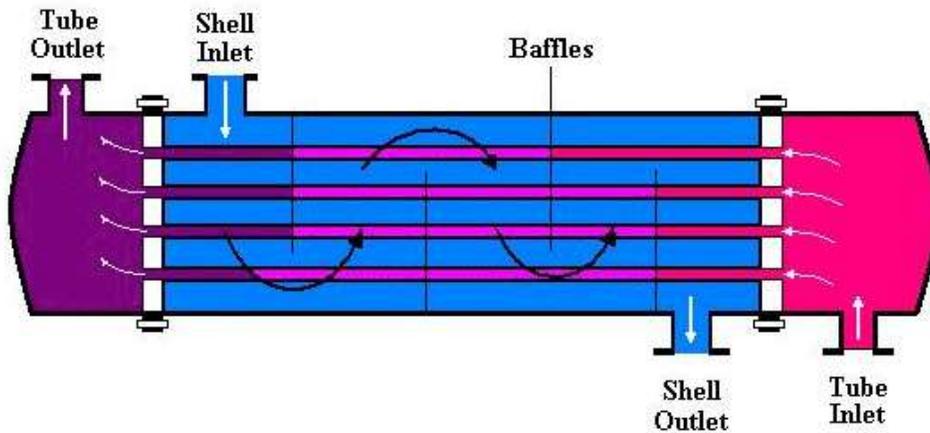
Double-pipe (also known as tube-in-tube) heat exchangers are the most basic of heat exchangers. The exchanger is in essence a smaller pipe placed inside a large pipe. One stream flows through the inner pipe while the other fluid flows through the annulus formed between the two pipes. Heat is transferred through the inner pipe that separates the fluids. Figure 4 displays a double-pipe heat exchanger, which contains two concentric tubes where the hot fluid flows through the interior tube and the cold fluid flows through the annulus.



**Figure 4: Double-pipe heat exchanger with counter-current flow (Baehr, 2006).**

### Shell and Tube:

A shell and tube heat exchanger (S&T) is designed similar to that of the double-pipe heat exchanger, but many interior tubes are present inside a single shell instead of a smaller pipe inside a larger one. The use on many tubes instead of a single pipe greatly increases the heat transfer area per volume of exchanger. This higher relative heat transfer area results in shell and tube heat exchangers being far more efficient than double-pipe exchangers with the same external dimensions. Unlike double-pipe and plate heat exchangers, shell and tube exchangers do not strictly have counter-current or co-current flow patterns. The shell side fluid typically does not run in a parallel manner to the tube-side fluid. A down side to shell and tube heat exchangers relative to double-pipe exchangers is increased capital cost. Figure 5 displays a S&T heat exchanger where the hot fluid enters the tubes and is cooled by the fluid on the shell side.

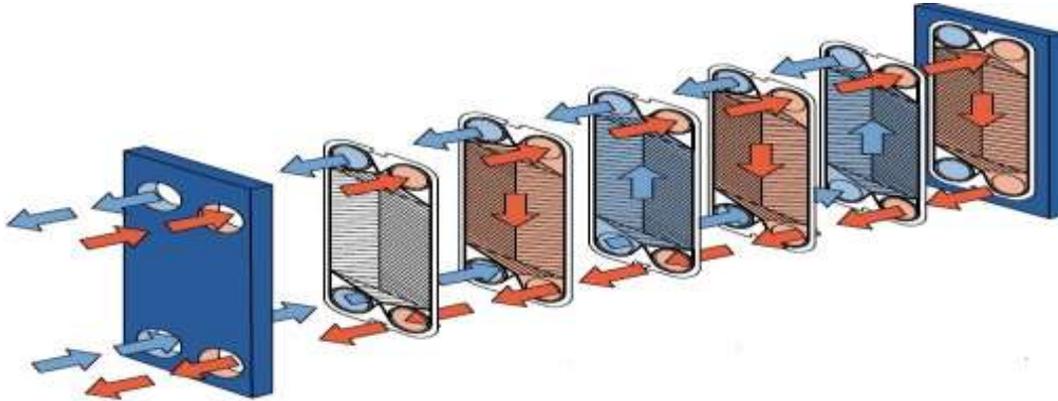


**Figure 5: Shell and Tube Heat Exchanger with Counter-Current Flow (Haslego, 2010).**

### Plate Heat Exchanger:

A plate heat exchanger has fluids flowing through narrow rectangular channels formed by closely spaced plates instead of through pipes as in the other two classes of exchangers. Plate

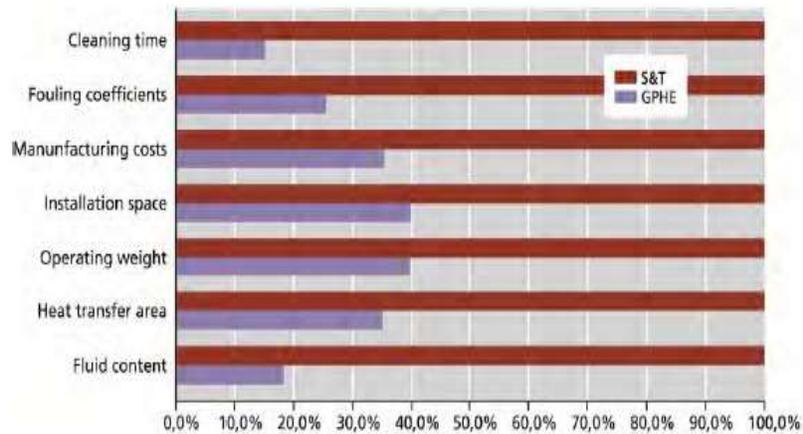
heat exchangers are assembled by brazing, welding or clamping the plates together. A plate has a hole in each corner and may have chevron patterned ridges along its face to increase turbulence. Spacers between plates insure that only one fluid flows through a particular channel and are arranged so that a fluid will flow through every other channel in the exchange stack. Figure 6 depicts an expanded view of a six-plate heat exchanger and the fluid flow paths through the exchanger.



**Figure 6: Plate heat exchanger in counter-current flow pattern (Separation Equipment Co., 2009).**

#### **2.2.4 Comparing Shell and Tube and Plate Heat Exchangers**

Plate heat exchangers compete with shell and tube exchangers for the place as the most efficient class of exchangers. The advantages of plate heat exchangers over the traditional shell and tube heat exchanger are their compact size, greater heat transfer surface area per volume of heat exchanger, and ease of cleaning due to the ability to completely remove and replace worn plates (Kananeh, n.d.). According to Kananeh and Peschel, plate exchangers are superior to S&T exchangers in the following categories: cleaning time, fouling coefficients, manufacturing costs, installation space, operating weight, heat transfer area, and fluid content. Figure 7 compares Kananeh and Peschel's findings for PHE performance compared to S&T performance. Figure 7 uses percentages to compare the two types of heat exchangers. For example, if a S&T heat exchanger costs \$100 to produce, then the cost of manufacturing a PHE is 35% of the cost to manufacture a S&T heat exchanger, which is \$35.



**Figure 7: Comparison of PHE with S&T heat exchangers (Kananeh, n.d.).**

### 2.2.5 Parameters of Interest

The two most important parameters for analyzing a heat exchanger are the heat duty exchanged in the exchanger and the overall heat transfer coefficient of the exchanger at a particular steady state operation. The heat absorbed by the cold stream and removed from the hot stream can be calculated using Equation 1. The calculation can be done twice, once with each stream's flow rate and temperature change. Assuming that the exchanger is adiabatic with regards to the surrounding environment, the heat duty calculated for the hot stream should match the heat duty of the cold stream in magnitude. A higher heat duty indicates that more heat is transferred by the heat exchanger under particular conditions.

The overall heat transfer coefficient accounts for the ease of energy transfer between the various layers that compose a heat exchanger. These layers are the fluid boundary layers and the solid interface between the two fluids. The overall heat transfer coefficient is inversely proportional to the thickness of each of these three components. Accounting for the fact that the thickness of a fluid boundary layer is inversely related to the velocity of the bulk fluid, as the flow rate of either fluid is increased, the overall heat transfer coefficient will increase.

The overall heat transfer coefficient can be calculated using Equation 3:

**Equation 3**

$$U = \frac{\dot{Q}}{A\Delta T_{lm}}$$

Where:

$$\Delta T_{lm} = \frac{(T_{H-in} - T_{C-out}) - (T_{H-out} - T_{C-in})}{\ln\left(\frac{T_{H-in} - T_{C-out}}{T_{H-out} - T_{C-in}}\right)}$$

$\dot{Q}$  = Heat transfer rate

$U$  = Overall heat transfer coefficient

$A$  = Area of heat exchanger

$\Delta T_{lm}$  = the temperature log mean difference of the system.

$T_{H-in}$  = Temperature of the hot fluid entering the heat exchanger

$T_{H-out}$  = Temperature of the hot fluid exiting the heat exchanger

$T_{C-in}$  = Temperature of the cooling fluid entering the heat exchanger

$T_{C-out}$  = Temperature of the cooling fluid exiting the heat exchanger

The heat transfer rate and the overall heat transfer coefficient are key parameters in characterizing heat transfer within an experiment. A higher overall heat transfer coefficient denotes a smaller required surface area to achieve the same heat duty as an exchanger with a lower coefficient. The prior calculations all depend on the heat exchanger operating at steady state.

The current heat exchanger laboratory at WPI uses a double-pipe heat exchanger with saturated steam condensing in the annulus and water flowing through the inner pipe. The steam is assumed to provide a constant temperature latent heat source along the length of the exchanger. Students vary the flow rate of the water and observe the effect on the heat duty, overall heat transfer coefficient and the heat transfer coefficient of the cooling water. The overall heat transfer coefficient should increase as the water flow rate increases due to a thinning of the boundary layer that provides resistance to heat transfer. Similarly, students should observe that the heat transfer coefficient of the water alone increases with increasing water flow rate. Students calculate the individual heat transfer coefficient of the water using the Wilson Method. This method requires that only one of the two fluid streams is manipulated at a time

### 2.2.6 Online Experiments

Web-based laboratory experiments are gaining in popularity due to the demand in easily controllable laboratory experiments. They provide remote access to real life measurable equipment while using resources in a very efficient way.

Several universities have already begun to develop web-based experiments for their students. At MIT, a web-based heat exchanger system was created with Armfield Ltd. and tested with students. Three different types of well-known heat exchangers were used, double pipe, flat plate or PHE, and a shell and tube, which were modified for remote control access. A service unit was used to control the flow of the inlets and outlets as well as the ability to switch between heat exchangers quickly. The heat exchangers are controlled via a USB connection with a windows computer. Pressure regulators and thermocouples monitor the inlet and outlet pressures and temperatures. Flowmeters measure the flow rates of the hot and cold streams as well. All these devices interface with the software on the computer via a software driver. An important factor about this particular web-based system is the real time feature. The controllable parameters could be changed as soon as the parameter in the computer is changed. A display of the system they used is shown in Figure 8 below (Colton, 2003). Real time parameters can also be monitored and recorded.

I-LAB HEAT EXCHANGER SCHEMATIC DIAGRAM

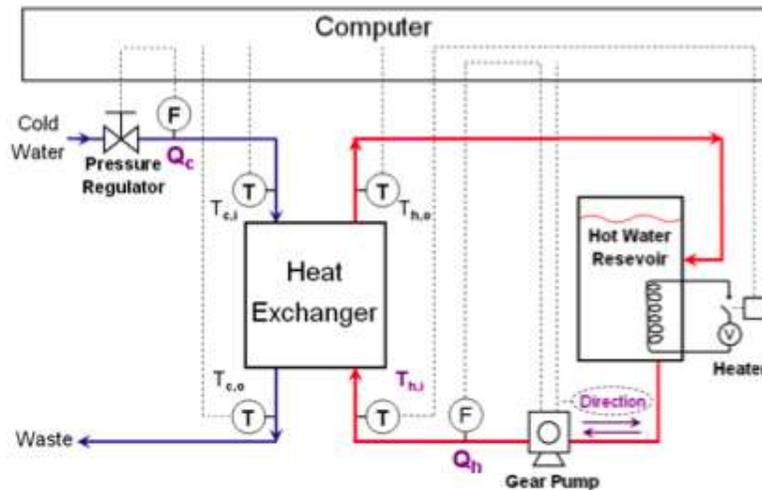


Figure 8: Heat Exchanger Schematic Diagram for a Computerized Process

### 3.0 Methodology

Our goals for this project were to design an apparatus for testing biodiesel, assess the viability of using that apparatus to teach students in a laboratory environment and to determine if the apparatus duplicates the teaching potential of the existing WPI heat exchanger experiment. By designing a process that consisted of a heating system along with a plate heat exchanger we aimed to understand the techniques and experiments necessary in analyzing the differences between diesel and biodiesel fuels. In addition, it was anticipated that a Unit Operations Laboratory would be designed for educational purposes in the WPI Chemical Engineering Department.

In order to achieve our goal, we completed the following objectives:

1. Developed a biodiesel compatible combustion system that includes a plate heat exchanger
2. Validated that the system shows a difference between the heat released by diesel and biodiesel comparable to the fuels actual energy content
3. Identified the dependence of the heat exchanger's heat duty and overall heat transfer coefficient on the flow rate of the cooling water in the system
4. Tested biodiesel in the new apparatus that was produced and purified at WPI

The team's data collection and analysis included both qualitative and quantitative techniques in order to obtain the information necessary to achieve the stated goal. The following sections describe the methods that were implemented in order to accomplish each of the objectives.

### 3.1 Process Development

The team began designing the process with the requirements that the process combust fuel in a continuous manner, involve a heat exchanger, and use the tap water available in the WPI Unit Operations Laboratory as the source of cooling for the exchanger. A diesel fuel heater manufactured by a company named Espar fulfilled the first requirement. A model, the Hydronic M-8, was identified that had the ability to run diesel and biodiesel fuels without any modification. The heater worked by burning fuel to produce a constant flame. This flame was contained inside a cylindrical vessel with a jacket surrounding it. The heater would automatically pump a coolant through this jacket and heat from the flame would be transferred into the coolant. The Espar heater was within budget, rated to consume less than a liter of fuel per hour and produced a heat duty in the coolant that would be easily handled in a heat exchanger using the tap water as the cold stream. The team proceeded to design the system around the Espar M-8 heater.

The core of the system, as seen in Figure 9, was a closed loop of coolant that would be heated in the Espar heater and cooled in a heat exchanger. The coolant was a 40% ethylene glycol mixture. A pump would force the coolant around the loop. A proprietary control unit maintained control over the heater, the coolant pump and the fuel pump. These four units were obtained directly from Espar. The fuel pump inlet was connected to a three-way valve, which in turn was connected to two fuel tanks. This setup allowed the team to switch between two fuel types

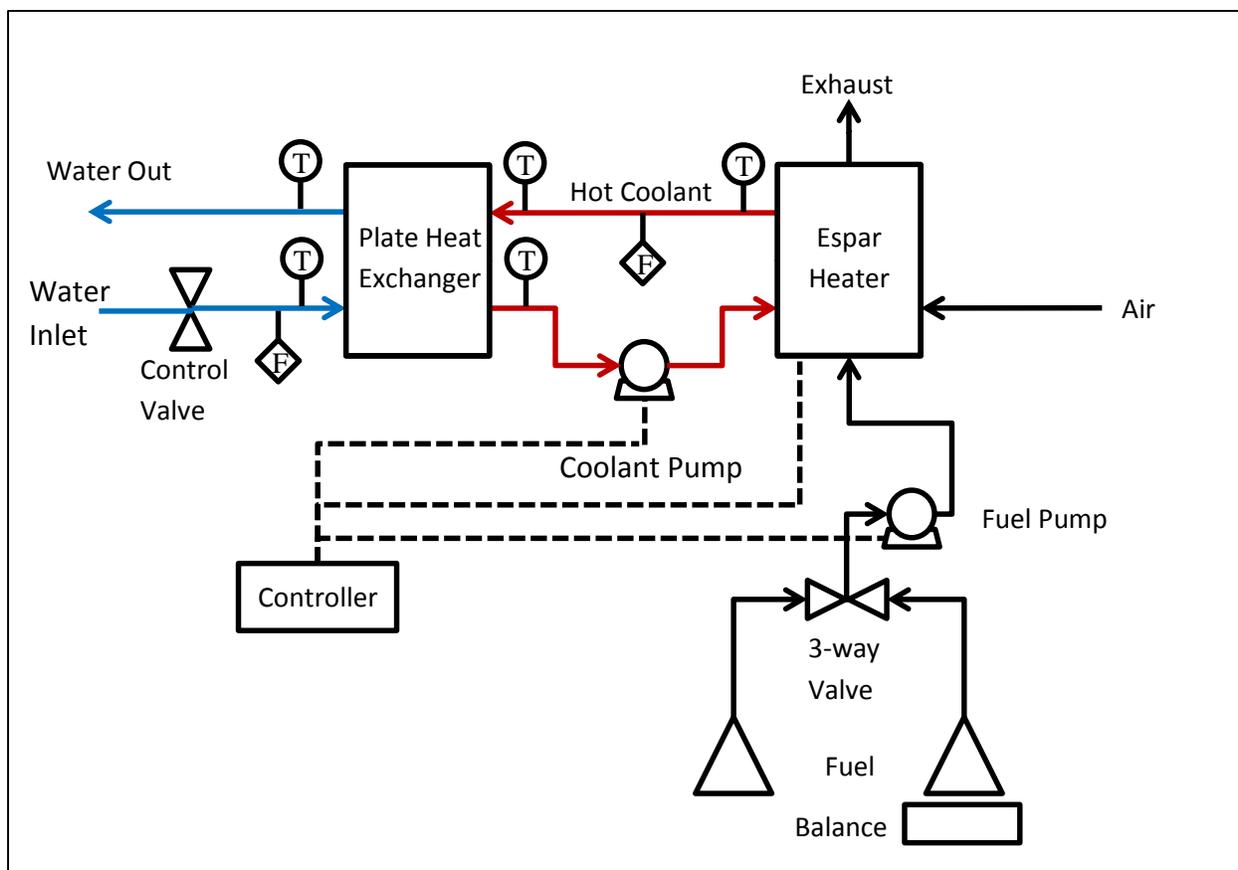
without interrupting the continuous supply of fuel demanded by the heater. An electronic balance served to measure the fuel consumption of the fuel.

A plate heat exchanger was chosen as the type of heat exchanger in order to provide the chemical engineering department with a plate heat exchanger to demonstrate to students. The team estimated the heat duty, cooling water flow rate and maximum allowable pressure drop for the heat exchanger. Based on these requirements, a 20 plate heat exchange was purchased from DudaDiesel for use in the apparatus. The existing tap water supply in the lab included a shutoff valve, a pressure regulator, and a control valve. This control valve allowed the team to control the water flow rate. The apparatus would have two independent variables, the water flow rate and the fuel type.

The team recognized that calculating the heat duty and overall heat transfer coefficient would require the ability to measure the temperatures and flow rates of the streams as they passed through the heat exchanger. To this end, a glass rotameter and pressure gauge were installed upstream of the plate heat exchanger for the water flow. The flow rate of the coolant was measured by a glass rotameter and a pressure gauge located between the heater and the heat exchanger. A thermocouple was installed on each of the exchanger's inlet and outlet lines. An additional thermocouple was located at the immediate outlet of the coolant line leaving the Espar heater so that the team could monitor if there was any heat loss in the line between the heater and the plate heat exchanger. The thermocouples were all linked to a continuous data logger that recorded the thermocouples twice a second and displayed the temperatures of the thermocouples in real time on a computer placed next to the apparatus.

The rest of the design consisted of adding valves to aid in the filling and emptying of the system, an air scoop to help purge the coolant line of air bubbles, and an expansion tank and a pressure relief valve to prevent the system from being compromised by high pressure. The air scoop and expansion tank were placed in the coolant loop as the coolant flowed from the heater to the heat exchanger. The pressure relief valve was placed along the line immediately after it left the heater. For safety, an expansion tank set for 12 psig and a pressure relief valve set for 30 psig. The hookups to the heater unit for the coolant loop were standard  $\frac{3}{4}$ " SAE fittings and the team proceeded to source all pieces of the coolant loop with similar size fittings.

As shown in Figure 9, the completed experiment consists of a heater that burns fuel to heat circulating coolant. This coolant is cooled in a plate heat exchanger by tap water. The flow rates of the coolant and the cooling water entering and exiting the heat exchanger are measured, along with the temperatures of the streams. This data allows calculation of the heat duty exchanged in the heater and the overall heat transfer coefficient. The system allows for the comparison of diesel and biodiesel because the heater burns fuel at a constant rate and thus any difference in the heat duty observed in the plate heat exchanger is caused by differences in the heat content of the fuel. The two independent variables the experimenter controls are the fuel type and the flow rate of the cooling water.



**Figure 9: Process Diagram**

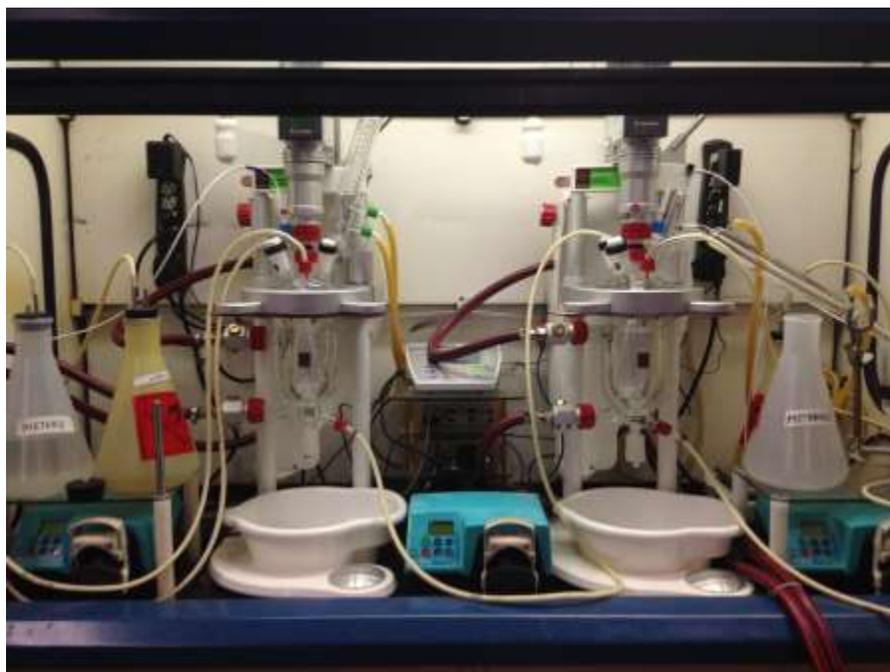
### 3.2 Production and Refining of Biodiesel within the Unit Operations (UO) Lab

The following section describes the procedure that was taken in order to experimentally produce biodiesel in the Unit Operations Laboratory. Additionally it discusses how the laboratory grade biodiesel was refined using a resin column.

#### 3.2.1 Production of Biodiesel

A process within the UO lab allows for the production of biodiesel using canola oil, methanol, and a KOH catalyst. The procedure for the production of biodiesel is as follows: 400 mL of canola oil was measured out and placed in the bioreactor, shown on the right in Figure 10, using the designated funnel and graduated cylinder. The stirrer was turned on to 750 rpm; the temperature control was then set to 55°C, and was allowed to reach the appropriate temperature. 100 mL of methanol was then obtained using the labeled graduated cylinder and placed in a labeled flask. 1.8g of KOH was measured carefully and put into the methanol flask and allowed to dissolve. It took about 20 minutes for the KOH to fully dissolve into the methanol. After a temperature of 55°C was reached, the final solution of KOH and methanol was put into the bioreactor using the appropriate funnel. The mixture was left to react for an hour and a half at a

steady temperature of 55°C and stirrer rate of 750 rpm. When the reaction was complete, the product was left to settle into two phases, a glycerol rich phase and a biodiesel rich phase. The solution was given an hour to settle and then the glycerol rich phase was allowed to drain into the waste container. An appropriate container was used to collect the biodiesel rich phase, which was syphoned from the drain outlet after the glycerol rich phase. The final product was kept in a safe location for storage until it could be run through the ion exchange resin.



**Figure 10: WPI Biodiesel Reactor Setup**

### **3.2.2 Purification of Biodiesel**

Currently, WPI has a process for refining biodiesel using a resin column designed by a past WPI MQP group. The setup consists of a pump, a column containing resin, a container for the unwashed biodiesel, and a container for the washed biodiesel. A picture of the setup is shown in Figure 11. To refine the biodiesel, first the unwashed biodiesel was placed in the container connected to the pump that pumps it through the resin. It was important to leave at least an inch of biodiesel above the resin to prevent the resin from drying out. In order to do this, there must be a balance of flow rate coming into the system and the flow rate coming out of the system. There is a clamp on the end of the column that should be adjusted if the biodiesel is running too fast or too slow through the column. A flow rate of 92 ml/hr was used since this was determined by the earlier project group to be the highest flow rate that provided efficient adsorption in the column. Depending on the amount of biodiesel that has to be run, this process could take between 4-8 hours, sometimes longer. During this time, it was important to monitor the process

carefully to avoid drying of the resin bed. Once the biodiesel was run through the resin, it was cleaned of most glycerol, KOH, soap, and methanol and was safe to run through the heater unit in the unit operations lab.



**Figure 11: Ion-exchange Resin for Biodiesel Purification at WPI**

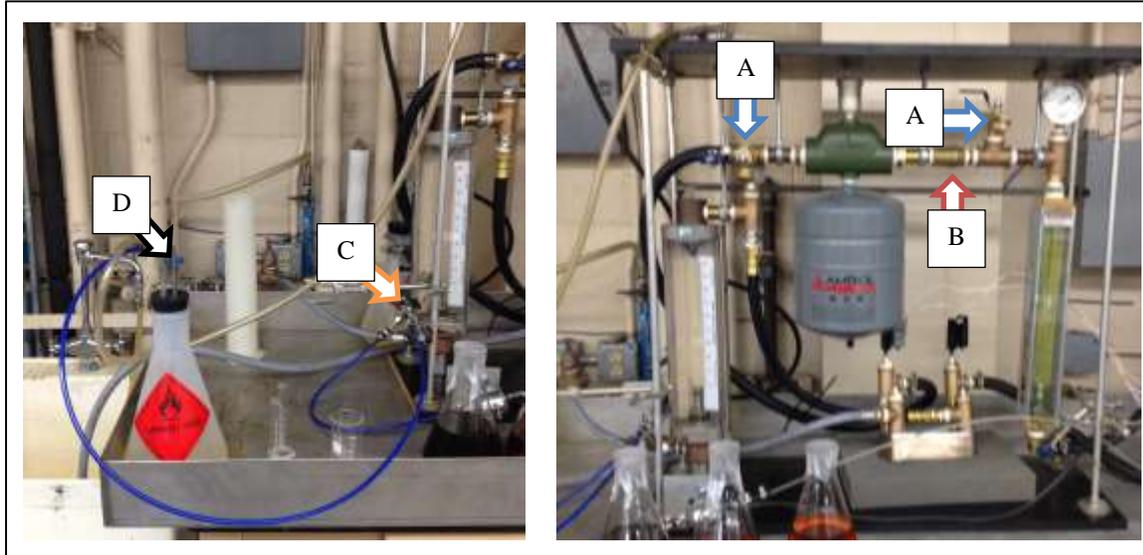
### 3.2.3 Selection of Biodiesel for Testing

There were several types of biodiesel used to validate the experiment designed for the Unit Operations Lab at WPI. The first biodiesel obtained came from a gas station in Acton, MA. No information was available on the original source of this product, but it was assumed to have been produced from waste vegetable oil. The biodiesel was obtained in October and otherwise had no defining trait to it, thus it was named October biodiesel for the purpose of experimentation. Since it was obtained in October and not used until early March, there was some concern about degradation of performance due to exceeding the expected shelf life. To ensure a valid comparison of fresh biodiesel to diesel fuel, another biodiesel was obtained from Newport Biodiesel. This biodiesel was obtained in February and used shortly thereafter so there was no concern about its possible shelf life. Newport Biodiesel uses waste vegetable oil as a feedstock, processes it through esterification with an acid catalyst followed by transesterification with sodium methoxide and methanol, and refines the product with an ion exchange resin. The October biodiesel and the Newport biodiesel were compared to the WPI biodiesel which was made from a slightly different process.

A final proof of concept test that was conducted was running a series of diesel-biodiesel mixtures. The biodiesel sourced from Newport Biodiesel was mixed with the diesel supply on a volume basis. The three mixtures tested were 1:3, 1:1 and 3:1 parts diesel to biodiesel.

### 3.3 Comparing the Heat Contents of Diesel and Biodiesel

A system consisting of a heating engine and plate heat exchanger was designed in order to determine the difference in heat content of diesel and biodiesel as shown in Figure 12. Initially the heat content of diesel was analyzed using this system.



**Figure 12: Components of experimental apparatus**

#### 3.3.1 Filling and Emptying Coolant System

1. Brass covers were removed from the valves marked as A in Figure 12
2. PLEX tubes were screwed onto each port of the valves marked A and their other ends were placed in a one gallon container filled with an ethylene glycol/water mixture
3. The tube leading to the valve on the left of the expansion tank was fitted to the peristaltic pump
4. The ball valve to the left of the expansion tank was closed and the one to the right of the tank was opened
5. The pump was turned on and the system was filled with coolant
6. The valve to the right, marked B in Figure 12 of the tank was partially closed to raise the pressure of the coolant to 12 psig and then backed off
7. The left hand valve was opened to allow coolant to fill the entire system and then closed slowly
8. Steps 6 and 7 were repeated several times to ensure that the maximum amount of coolant was in the system
9. The pump was turned off
10. The two ball valves were closed
11. The tubes were disconnected and drained

12. To empty the system, the tubes and pump was hooked up. The tube not attached to the pump was run into a jug while the tube attached to the pump was left out to pump air into the system. Through manipulating the valves the system was purged of coolant
13. The valve marked B was moved to the open position

### 3.3.2 Experimental Run Procedure

1. Began by starting the thermo couple data logger program and making sure that all thermocouples functioned properly
2. Loaded the appropriate fuel containers with diesel and biodiesel fuel
3. Zeroed the electronic balance. The diesel fuel container was placed on the scale and its initial weight was recorded.
4. Valve C from Figure 12 was set to feed diesel fuel. Diesel fuel was used to fuel the system in the initial part of each run because diesel fuel was easier to obtain
5. Controller was connected to the system and locked into its mount
6. The power supply was plugged into the wall outlet
7. The system was inspected for leaks and faults
8. Ball valve with yellow handle was opened to supply house water to the system
9. Blue handled valve, marked D in Figure 12 was opened to allow water to flow through the system. The water flow rate was set by adjusting this valve until the cooling water rotameter read at the desired level
10. The power supply was turned on
11. The red power button on the controller was pressed twice to turn on the heater. At the same time the data logger software was turned on along with a stopwatch. The heater would immediately start pumping the coolant through the system
12. After 100 seconds the system would begin to pump fuel. The system was allowed to reach steady state. Steady state conditions were recognized by the real-time temperature plots in the data logger software reaching a plateau
13. The weight of the fuel container, the coolant rotameter and the pressure of the coolant was collected at regular intervals
14. Cooling water exit flow rate was collected using a stop watch and a graduated cylinder in order to check that the flow rate was the same as the expected flow rate
15. Once steady state data had been collected, one of two process changes was enacted:
  - a. The cooling water flow rate was adjusted to a new level
  - b. The fuel supply would be switched between diesel or biodiesel using Valve C in Figure 12
16. System was allowed to come to steady state again before Step 8 was repeated
17. When testing was finished, the red power button on the controller was pressed and the heater began its shutdown procedure
18. The heater immediately shut off the fuel pump so that no fuel enters the heater and approximately 5 minutes later the coolant would stop being circulated

19. After the coolant rotameter had returned to zero, the cooling water valve was closed
20. The power supply was then turned off and the controller unit was removed
21. The temperature data was saved and exported to Excel

### 3.3.3 Data Analysis

The raw data collected during the experimental runs was used to calculate the heat duty and the overall heat transfer coefficient in the plate heat exchanger. The heat transfer coefficient and the heat duty were calculated for each steady state period of operation that the apparatus operated under during each run. The heat duty was calculated independently for the cooling water stream and the coolant streams. The first step was to convert the rotameter readings to volumetric flow rates. The following two equations were used:

For the cooling water rotameter:

$$\dot{V}_W = 0.1793 \frac{L}{(min)\%} (Rotameter\ \%) - 0.1759 \frac{L}{min}$$

For the coolant rotameter:

$$\dot{V}_C = (Rotameter\ \%) \left( 0.062 \frac{GPM}{\%} \right) \left( 3.780 \frac{L}{Gal} \right) \left( \frac{1\ min}{60\ s} \right) \sqrt{\frac{(Coolant\ pressure) + 14.7\ psi}{14.7\ psi}}$$

The term under the square root was a correction factor for the pressure of the system. This was used because there was air present in the coolant line.

The second step in determining the heat duty was to calculate the heat capacity of the fluids. This was accomplished using power series approximations. The following power series was used for the cooling water:

$$C_{p,W} = 4.1868 \frac{kJ}{(kg)K} \left[ 1.0038 - 2.2459 \times 10^{-3} \frac{T_{W,out} - T_{W,in}}{2} + 2.6257 \times 10^{-6} \left( \frac{T_{W,out} - T_{W,in}}{2} \right)^2 \right]$$

The following power series was used for the coolant, with an estimated composition of 40% by volume of ethylene glycol:

$$C_{p,C} = 4.1868 \frac{kJ}{(kg)K} \left[ 0.85858 + 6.2639 \times 10^{-3} \frac{T_{W,in} - T_{W,out}}{2} \right]$$

The heat duty was then calculated using the volumetric flow rate, specific gravity, heat capacity and change in the stream temperature. A heat duty was calculated for the cooling water stream and again for the coolant stream. The equation used for the water stream was as follows:

$$\dot{Q}_W = \dot{V}_W \rho_W C_{p,W} (T_{W,out} - T_{W,in}) \frac{1 \text{ min}}{60 \text{ s}}$$

The density was  $1.0 \frac{\text{kg}}{\text{L}}$  and the final heat duty was in kW.

The following equation was used for the coolant heat duty:

$$\dot{Q}_C = \dot{V}_C \rho_C C_{p,C} (T_{C,in} - T_{C,out})$$

The density of the 40% ethylene glycol solution was taken to be  $1.07 \frac{\text{kg}}{\text{L}}$  and the final heat duty was in kW. Despite numerous efforts, complete removal of air in the coolant fluid was not obtained. To account for the remaining finely dispersed air bubbles that were observed in the coolant, the coolant side heat duty was also calculated using a weighted average of the  $C_{p,C}$  value and the heat capacity of air. The equation for this heat duty was as follows:

$$\dot{Q}_C = \dot{V}_C \rho_C (T_{C,in} - T_{C,out}) [(1 - x_{air}) C_{p,C} + x_{air} C_{p,Air}]$$

The heat capacity of air was taken to be  $1.005 \frac{\text{kJ}}{(\text{kg})\text{K}}$  and  $x_{air}$  represents the volume fraction of air in the coolant stream.

The overall heat transfer coefficient was calculated using the data collected from the cooling water stream. The coefficient was calculated using the following formula:

$$U = \frac{\dot{Q}_W}{A(\Delta T_{LM})}$$

$$\text{Where } \Delta T_{LM} = \frac{(T_{C,in} - T_{W,out}) - (T_{C,out} - T_{W,in})}{\ln\left(\frac{T_{C,in} - T_{W,out}}{T_{C,out} - T_{W,in}}\right)}$$

An area of  $0.24 \text{ m}^2$  was used and the units of the overall heat transfer coefficient were  $\frac{\text{kW}}{\text{m}^2\text{K}}$ . The fouling factor was ignored because the heat exchanger was new and was assumed to lack any fouling.

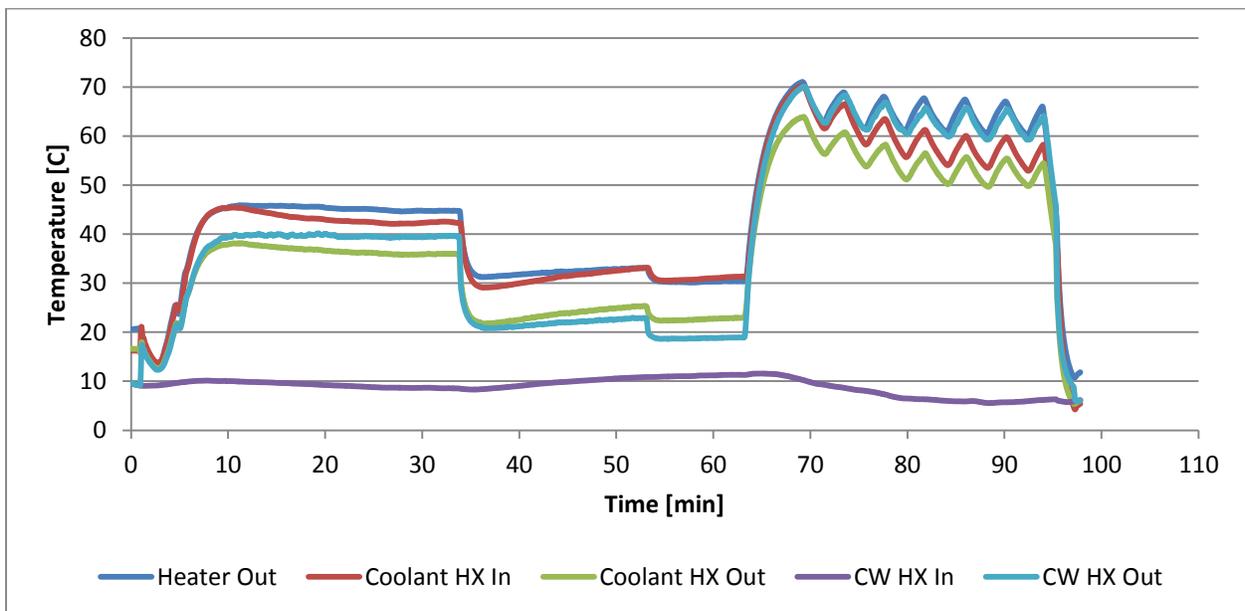
The densities of the four fuels tested by the team were determined using a 5ml graduated cylinder, a pipette and an electronic balance. Dividing the volume dispensed into the cylinder by the mass of the fuel yielded the density of a fuel.

## 4.0 Results and Analysis

The following section presents the results of the experimental runs conducted by the group. The results include the temperature and fuel profiles measured over time that were used to establish a basis for further analysis. Data is presented on the effects of the cooling water flow rate on the heat transfer rate, heat transfer coefficient, and coolant flow rate. Discussion about the effect of the fuel type is presented. Finally, the results of an experiment that analyzed three different fuel mixtures of diesel and biodiesel to determine if the mixture compositions could be estimated is presented.

### 4.1 Temperature Profiles

The initial runs with the experimental apparatus served to determine the conditions under which steady state operation was achieved. The data collected by the temperature logging device was plotted against the time elapsed during the run as shown in Figure 13. During the run, different cooling water flow rates were used. The plot below is the temperature trend from the run on January 31<sup>st</sup>.

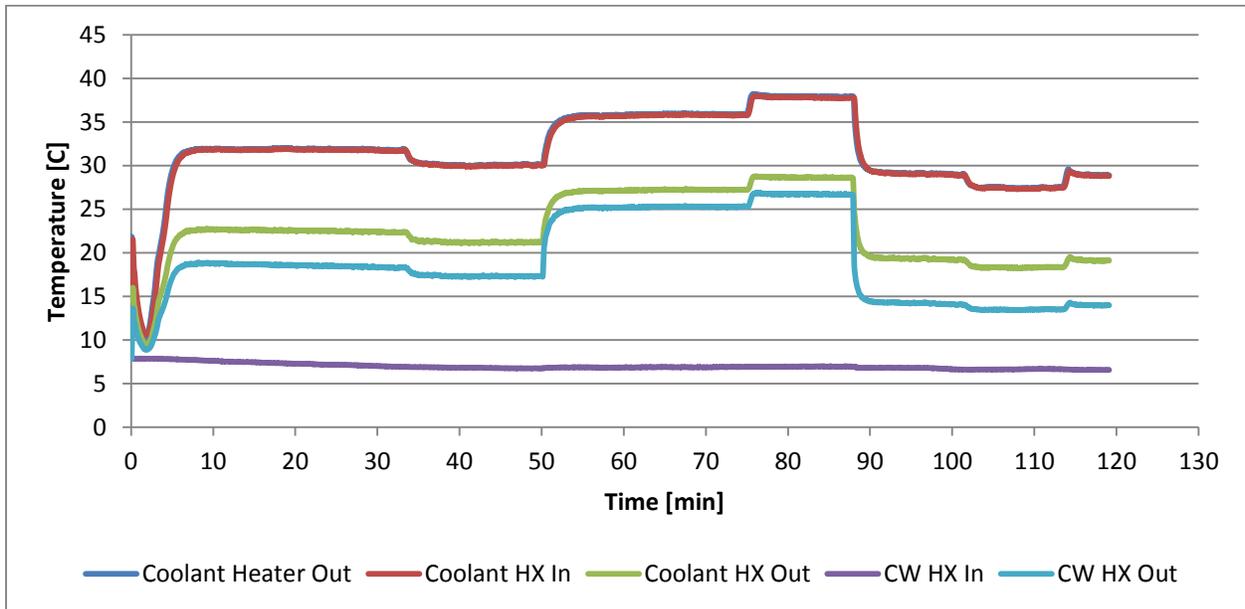


**Figure 13: Transient Operation of Apparatus**

The initial climb in temperature is due to the system heating up from ambient temperature. The water flow rate was increased at approximately 32 minutes and again at 53 minutes. The system responded by a rapid drop in temperatures followed by a period of the system slowly trending back to a steady state. The oscillatory behavior observed after the one hour mark was caused by the water flow rate being turned down to approximately 0.5GPM. The control unit on the heater responded to the water's reduced ability to remove heat from the coolant by periodically reducing the rate of diesel fuel consumption. The temperatures of the coolant stream would in turn slowly drop over a few minutes before the controller turned the heater back up to its

maximum fuel combustion rate. This behavior was consistent with the manufacture’s predicted behavior of the heater being able to run at discrete levels of fuel consumption. From this run, the group determined that steady state behavior could not be determined at water flow rates below 0.75GPM and all subsequent runs were conducted with flows greater than this.

An example of the temperature-time trend from later runs with both diesel and biodiesel combustion is the run from March 25<sup>th</sup>. The plot is shown below in Figure 14.



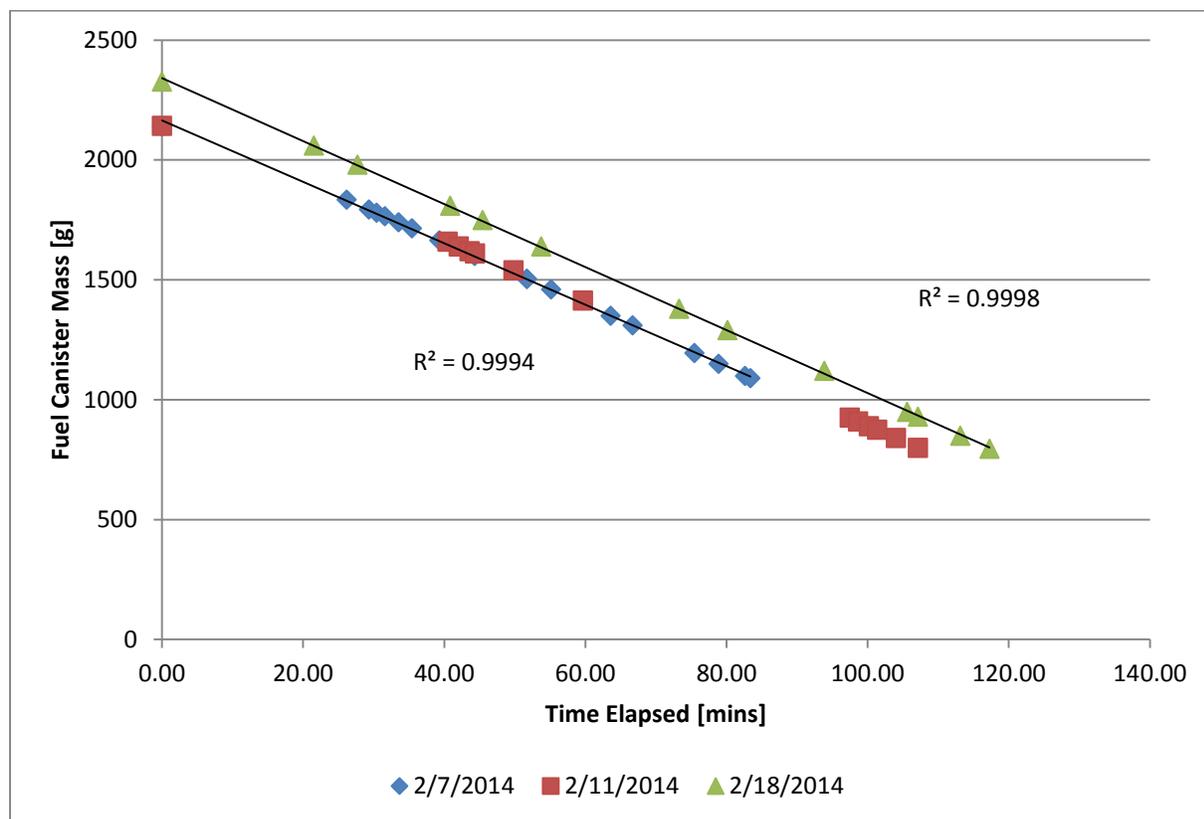
**Figure 14: Steady State Operation of Apparatus**

The system came to an acceptable degree of steady state at each water flow. The water flow rate was initially 50% of the rotameter maximum flow with the fuel being diesel. At approximately 32 minutes the fuel was switched to Newport Biodiesel in which the temperatures of the coolant and the water effluent dropped. At 50 minutes the water flow rate was reduced to 30%. At 75 minutes the fuel was switched back to diesel. At 88 minutes the flow rate was raised to 75% and at 101 minutes the fuel was switched to biodiesel. The rise in temperatures at 115 minutes was due the heater being switched back to diesel in order to displace biodiesel from the fuel pump before the system was shut down. As expected, the biodiesel resulted in lower temperatures when compared to the temperatures produced by the diesel.

#### 4.2 Fuel Consumption Profile

A critical assumption the team made in designing the experimental setup was that the apparatus would consume fuel at a constant volumetric rate. This constant fuel rate was important to enable comparisons of the system’s steady state behavior at different cooling water flow rates or with different fuel types. Such an assumption would be consistent with a constant slope for the fuel

vessel weight versus time trend. Figure 15 below depicts these trends for three different runs. Diesel was the only fuel used in these runs and each run included at least three different cooling water flow rates.

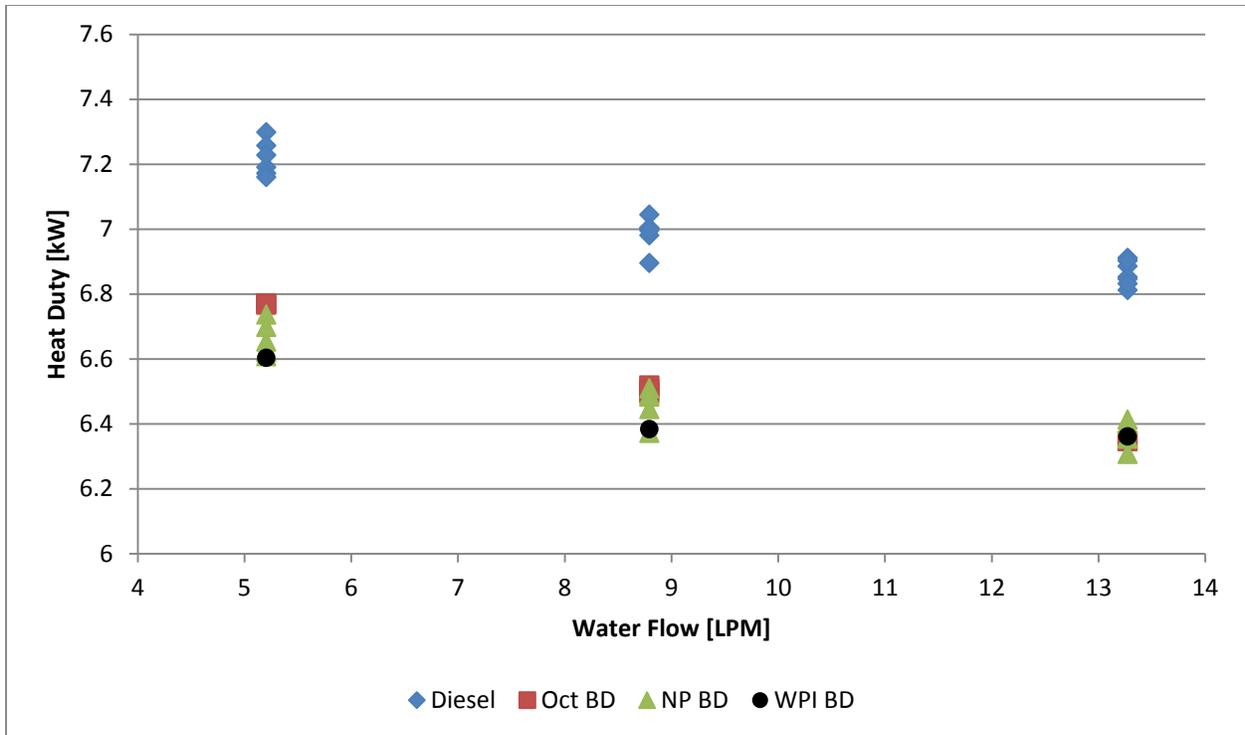


**Figure 15: Fuel Consumption over Time**

The parallel slopes of the trends indicate that diesel fuel was consumed at a constant mass flow rate. The constant density of the fuel between the three runs means that fuel was consumed at a constant volumetric rate as well. The fuel consumption rate was independent of the cooling water flow rate. The three trends do not share the same vertical intercept because the initial mass of fuel in each run varied.

### 4.3 Thermodynamic Analysis

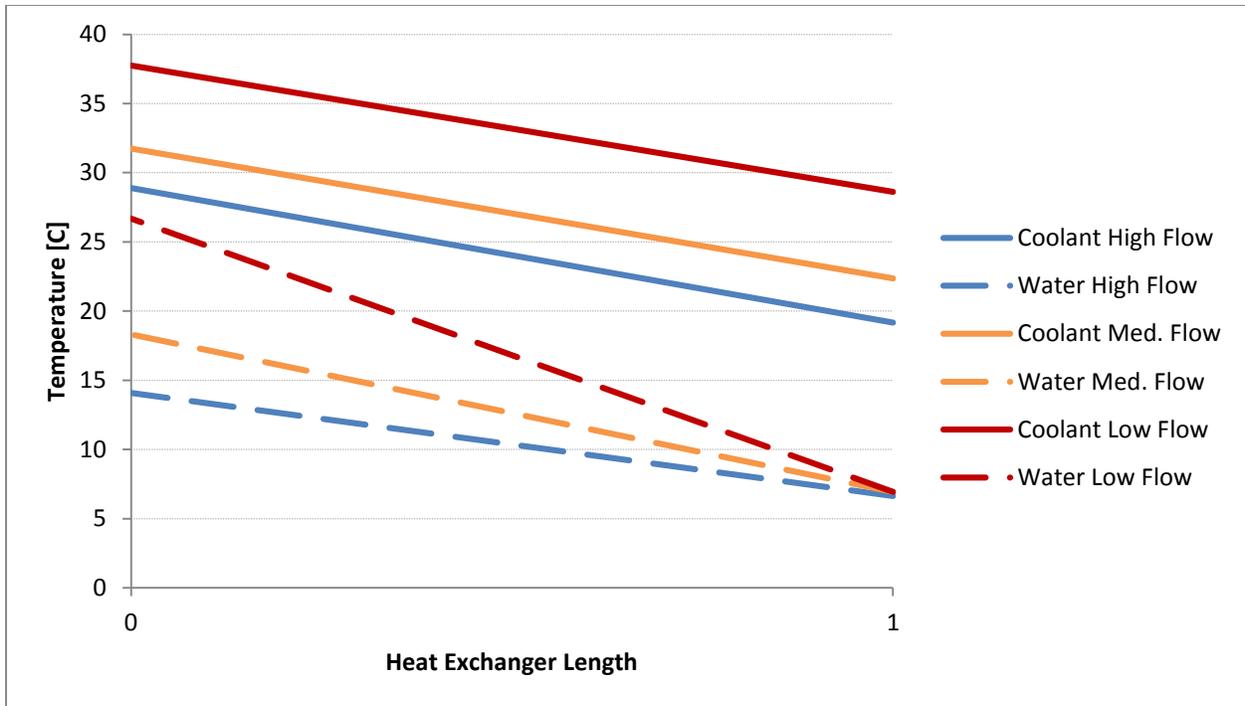
The heat duty of the plate heat exchanger was calculated for both the cooling water and the circulating coolant. The heat duty determined from the temperatures and flow rate of the cooling water was compared to the flow rate of the water to determine if there was a dependence on the water flow rate. Figure 16 below depicts this trend for diesel and each of the three biodiesels tested.



**Figure 16: Heat Duty versus Water Flow**

For each fuel type, the heat duty of the exchanger dropped with an increase in the cooling water flow rate. The drop in the heat duty was relatively equal for each of the fuels. The deviation between the diesel fuel and the biodiesels is constant and is consistent with the expected drop in energy content of biodiesel compared to petrol diesel. The variation among the data for a particular fuel at a constant water rate is due to slight variations in the actual water flow rate. The water flow rate had to be manually adjusted using a valve and the glass rotameter. Combined with the fact that the data was collected over many days, the actual water flow rate varied slightly from day to day because the rotameter was only accurate to one percent of its maximum flow. Data was collected only once per flow rate during a given run and thus the actual water flow rate varied slightly from run to run. The standard deviation of the heat duty at a particular water flow rate was independent of the water flow rate.

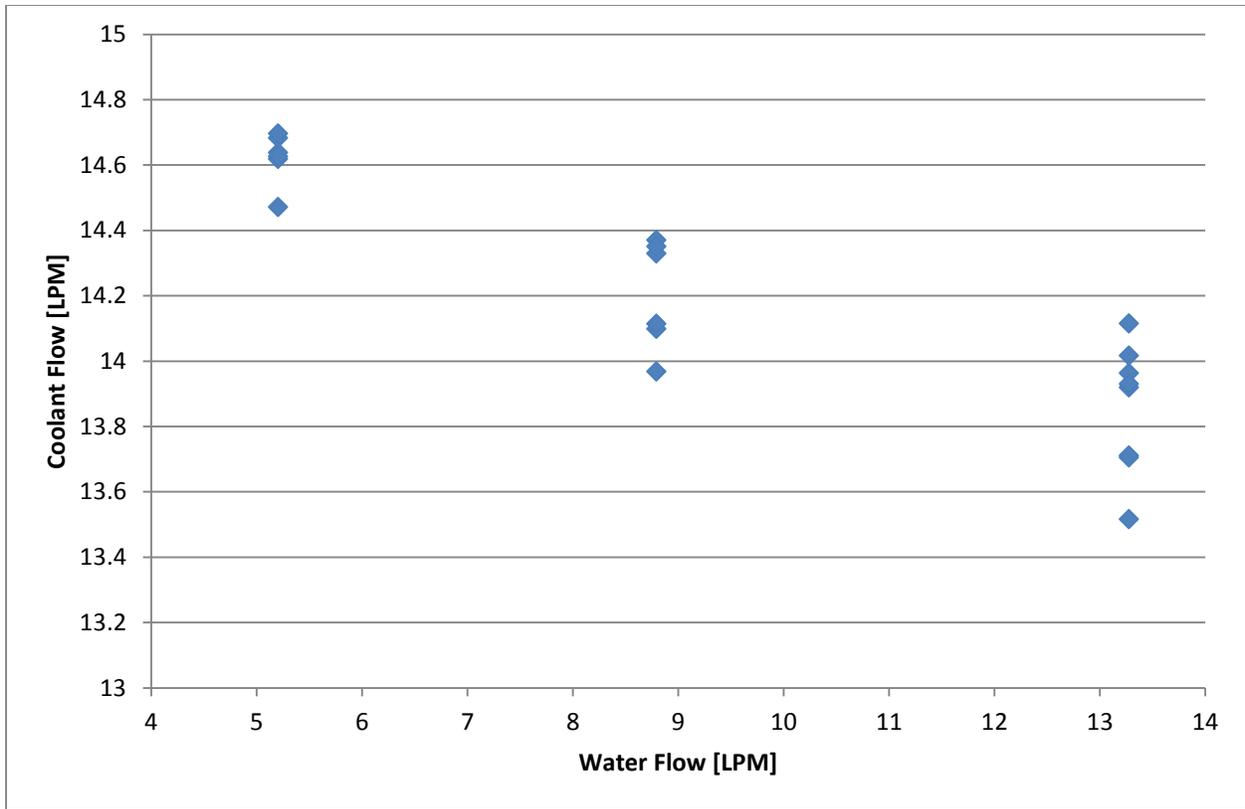
The root cause of the measured heat duty being negatively correlated to the water flow rate was identified by looking at two further sets of data – the coolant flow rate’s dependence on the water flow rate and the effect of cooling water flow rate on the temperatures of the streams in the plate heat exchanger. The latter is presented below in Figure 17. The data is from the diesel fuel steady state points on March 25<sup>th</sup>.



**Figure 17: Temperature versus Heat Exchanger Length**

There are three important aspects of the temperature trends across the heat exchanger. First, the inlet cooling water temperature remained constant. Second, the other three temperatures decreased as the cooling water flow rate increased. Third, the change in temperature of the coolant across the heat exchanger remained constant and did not vary as the cooling water flow changed. The controller unit monitoring the coolant's inlet and outlet temperature on the heater caused this third aspect. The controller adjusted the heater parameters in order to maintain this constant temperature differential. Figure 17 shows that the controller was successful in achieving this differential at each steady state operation of the system.

The way the controller achieved this constant differential was the driving force behind why the heat duty exchanged in the plate heat exchanger dropped with increasing cooling water flow. Figure 18 below shows the behavior of the coolant flow rate with respect to the cooling water flow rate.



**Figure 18: Coolant Flow versus Water Flow**

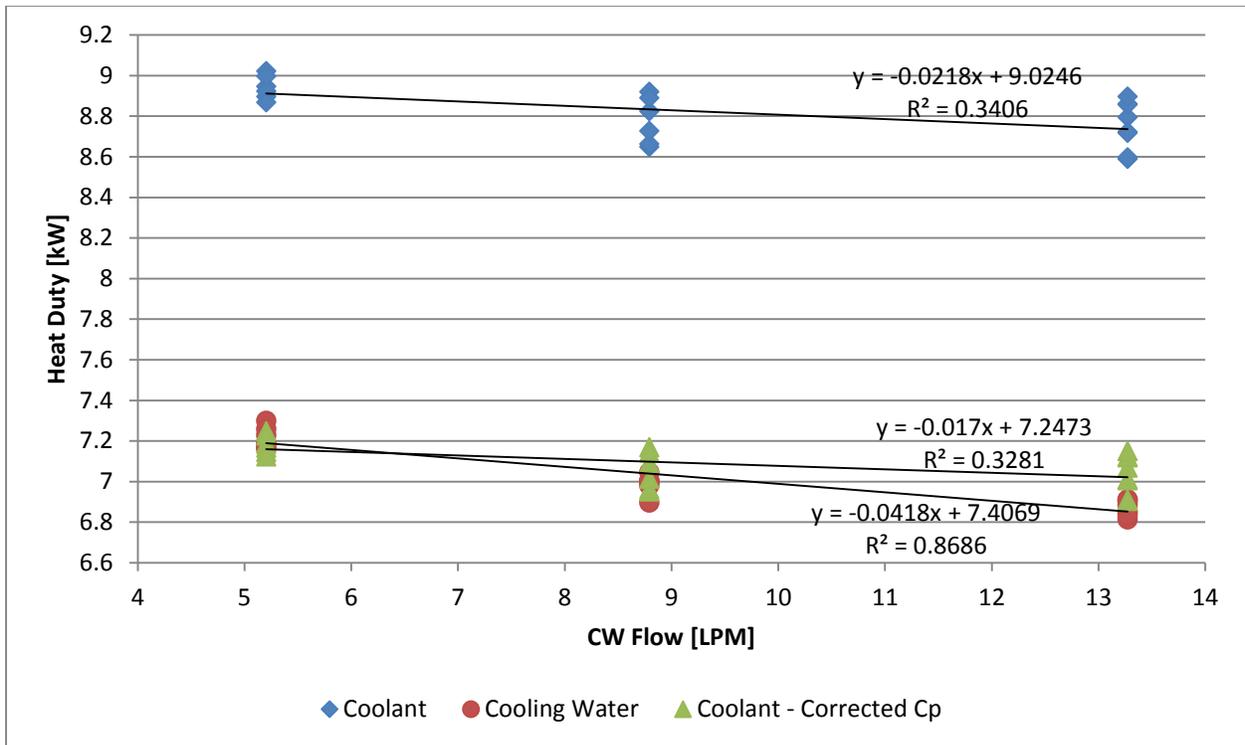
As the cooling water flow rate increased, the coolant flow rate dropped. The relationship appeared to be linear. The standard deviation of the coolant flow rate increased as the cooling water flow rate increased but the absolute values of the coolant flow decreased. The increased spread was due to the use of a glass rotameter to measure the coolant flow rate. At the higher water flow rates, the float in the rotameter would move around every few seconds even when the thermocouple logger indicated steady state temperatures. Each data point expressed in Figure 18 for such flow rate was the average of several rapid readings of the rotameter.

The controller maintained the constant coolant temperature difference observed in Figure 18 by dropping the coolant flow rate. The controller was able to manipulate the fuel flow rate and the coolant flow rate. It was established previously that the fuel flow rate did not vary with the water flow rate. Thus the controller manipulated the coolant flow rate. The dropping coolant flow, coupled to the dropping temperatures observed in Figure 18 and the corresponding drop in the coolant's heat capacity, mean that less heat was entering the plate heat exchanger as the cooling water flow rate increased. This lower heat content of the coolant caused less heat to be exchanged between the coolant and cooling water.

The reason why the controller dropped the coolant flow rate with increasing water flow rate is not clear. The specifications of the Espar heater are unknown and the team was unable to estimate its heat transfer area, flow configuration, or if the coolant flows in a turbulent or laminar

regime. The team believes that a drop in the coolant flow rate resulted in a lower overall heat transfer coefficient between the combustion gases and the coolant in the Espar heater. Coupled with the heater running at its maximum capacity at the lower water flow rates, the lower coefficient of transfer resulted in the gas stream and coolant streams leaving the exchanger portion of the heater before all available heat was exchanged. This could explain why less heat entered the coolant at higher water flow rates.

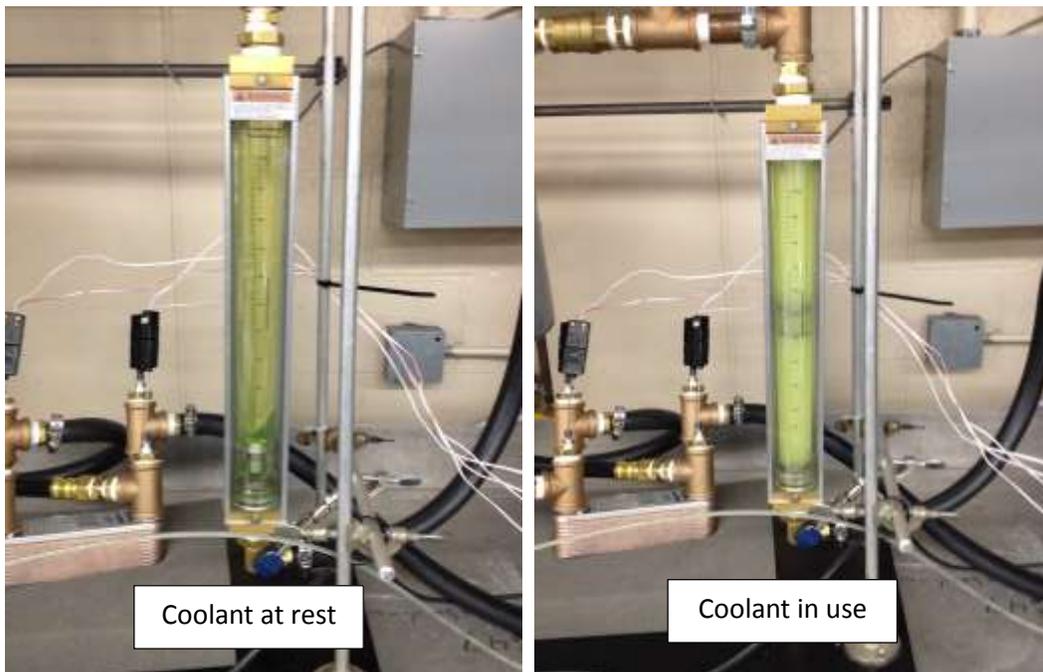
The results of the independent heat duty calculations are presented below in Figure 19. The data is for diesel fuel only and includes no biodiesel data.



**Figure 19: Heat Duty versus Water Flow for Diesel Fuel**

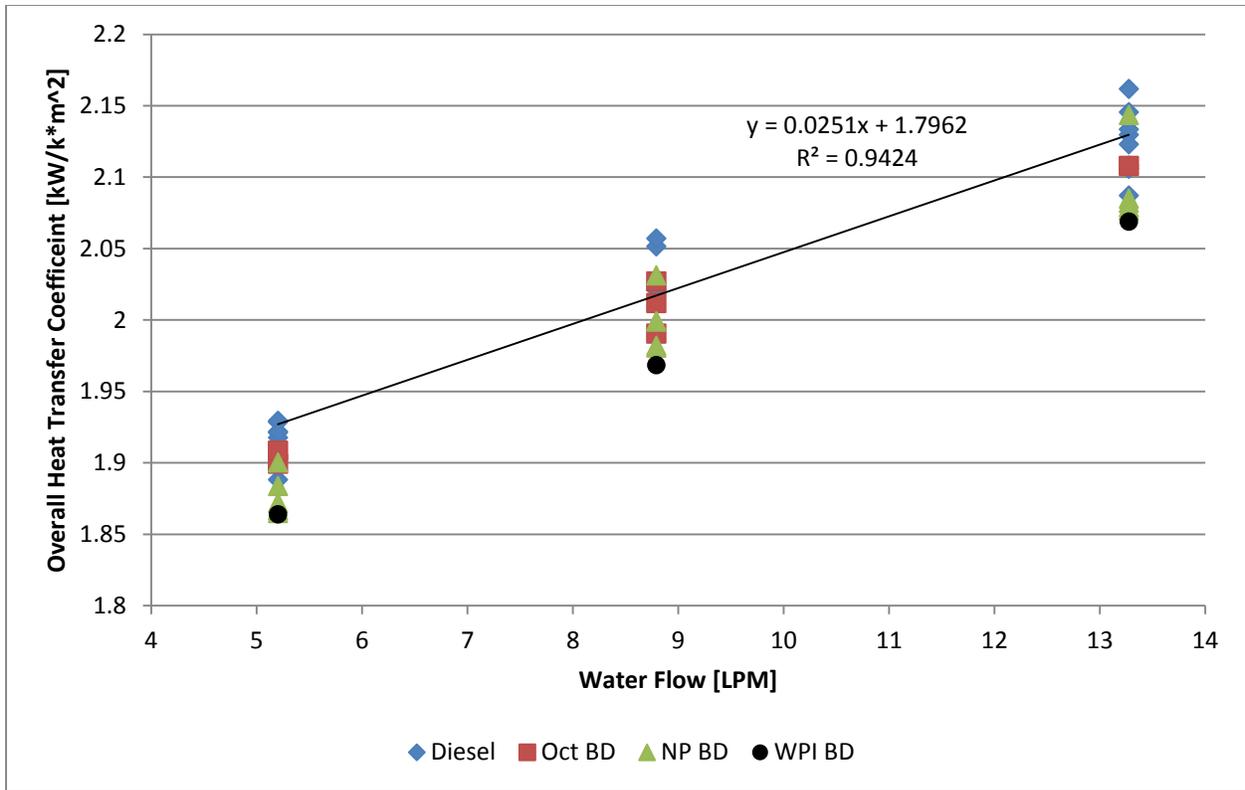
The heat duties calculated for the cooling waterside are identical to those seen in Figure 16, with values ranging from around 7.2 kW at low water flow to 6.9 kW at high water flow. The calculated heat lost from the coolant stream ranged from 8.9 to 8.7 kW at the same flow conditions when a heat capacity for a mixture of only water and antifreeze was used. The resulting heat duties were far higher than the cooling water and exceeded the manufacturer’s specified max heat duty of the heater at 8kW. The difference between the two trends was not caused by heat loss to the surroundings because the team observed that the exterior of the plate heat exchanger was cool to the touch and thus any heat transfer with the surroundings would have entailed heat flowing into the exchanger and raising the heat duty of the cooling water stream. The trend observed by the team was the opposite of this.

Air bubbles were present in the coolant circuit in unknown amounts. The heat capacity of air is approximately 1.005 kJ/kg\*K. It was assumed that the air lowered the heat capacity of the bulk coolant by approximately the weighted average of the water & ethylene glycol phase and the air bubbles on a volumetric basis. This assumption was valid because the air appeared to be present in constant amounts in the coolant circuit and was dispersed as fine microbubbles. An air volume of 27% of the total volume of the coolant circuit resulted in the data trend marked as Coolant – Corrected  $C_p$  in Figure 19. This trend has similar heat duties as the independently calculated cooling water heat duties. The line of best fit for this corrected coolant series is poor because the varied coolant flow rate resulted in a wide spread of heat duties at the high water flow rate. The air bubbles are clearly visible below in Figure 20.



**Figure 20: Comparison of Coolant at rest and in operation**

The overall heat transfer coefficient was calculated using the data collected from the cooling water stream. The coefficients were then plotted against the cooling water flow rate to identify any dependence on the water flow. Figure 21 below depicts this trend for all fuel types.



**Figure 21: Overall Heat Transfer Coefficient versus Water Flow**

The overall heat transfer coefficient had a clear positive, linear correlation to the cooling water flow rate. This is consistent with theory that a higher water flow rate leads to more turbulence and thus less resistance to convective heat transfer in the water stream. The absolute value of the coefficient at any water flow was independent of the fuel type. The biodiesel steady state operation had no deviation from the diesel steady state operation in terms of the heat transfer coefficient. The drop in the heat duty between diesel and biodiesel was compensated by a proportional drop in the log mean temperature difference. The resistance to heat transfer was primarily a function of the mass flow rates of the streams and the properties of the heat exchanger. The heat exchanger remained constant and the drop in the coolant flow rate was an order of magnitude below the change in the cooling water flow rate. Thus the change in the heat transfer coefficient depended primarily on the cooling water flow rate.

A final validation of the differences in the heat duty observed in the heat exchanger was performed using the averages of the heat duties of the four fuels tested at the lowest of the three water flow rates. These heat duties were then converted to the average heat recovered per volume of fluid using the densities of the fuels. These values were compared to the average heat content of diesel and biodiesel fuels as reported by the U.S. Department of Energy's Alternative Fuels Data Center (AFDC). The experimental results were compared to the AFDC values in two ways – the relative percentage of the AFDC's biodiesel energy content to the AFDC's diesel energy content was compared to similar values for the three biodiesels tested by the team and then

percentage that the heat content of each of the experimental fuels was of the corresponding AFDC fuel energy content value was calculated. This data is presented below in Table 3.

**Table 3: Comparison of Fuel Type and Heat Content**

| Prior Research                                 | Heat Content<br><i>kJ/L</i>    | Heat Content<br>of Diesel     |                        |                             |
|--|--------------------------------|-------------------------------|------------------------|-----------------------------|
| Diesel   | 36150 <sup>a</sup>             | -                             |                        |                             |
| Biodiesel                                      | 33020 <sup>a</sup>             | 91.3%                         |                        |                             |
| a: Data from the Alternative Fuels Data Center |                                |                               |                        |                             |
| Experimental Results                           | Average Heat Duty<br><i>kW</i> | Heat Recovered<br><i>kJ/L</i> | Heat Content of Diesel | Predicted Heater Efficiency |
| Diesel   | 7.22                           | 28430                         | -                      | 78.7%                       |
| October BD                                     | 6.77                           | 26220                         | 92.2%                  | 79.4%                       |
| Newport BD                                     | 6.66                           | 25810                         | 90.8%                  | 78.2%                       |
| WPI BD   | 6.60                           | 25400                         | 89.3%                  | 76.9%                       |

The average heat duties of the four fuels show that the three biodiesels were distinctly different from the diesel heat duty value. The AFDC values indicate that the potential energy by volume of biodiesel is about 91% of that of diesel fuel. The three biodiesels tested with the experimental apparatus showed comparable values of 89% to 92%. The most tested biodiesel, the fuel from Newport Biodiesel, had a heat content of 90.8% compared to the 91.3% calculated from the ADFC values. This indicates that the experimental setup can produce results nearly identical to results derived by laboratories using state-of-the-art calorimetry equipment.

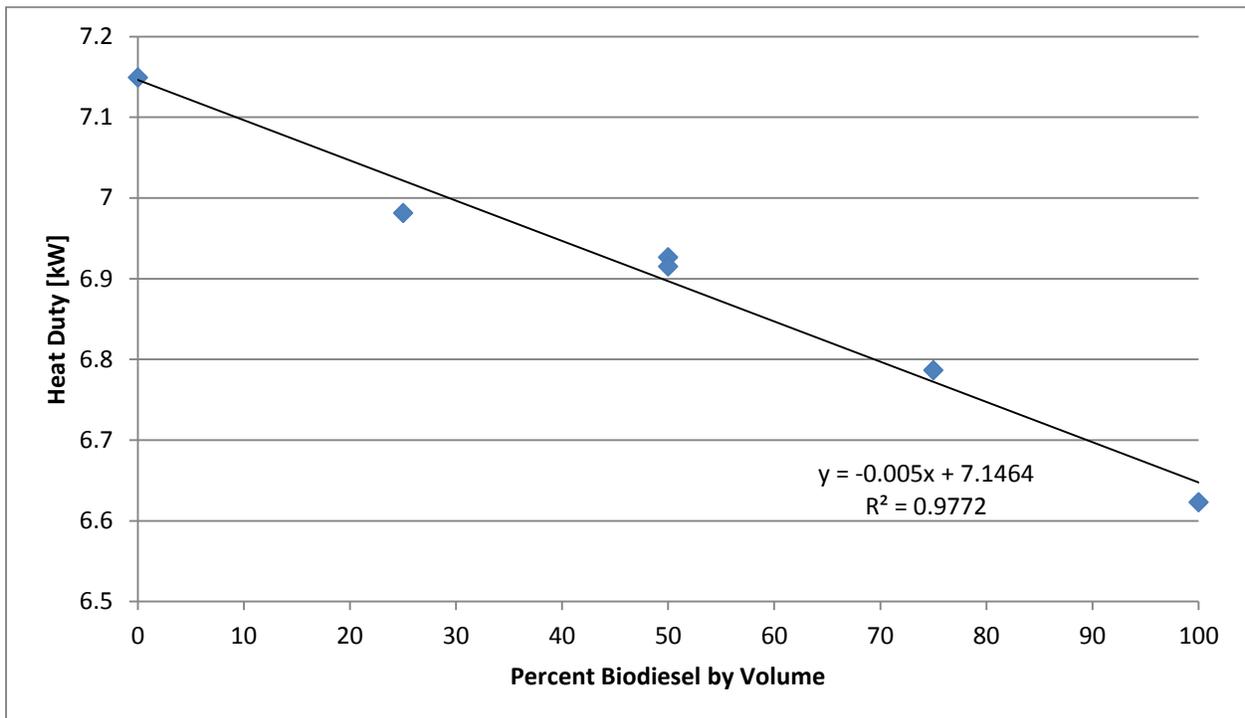
As shown in Table 3, the predicted heat efficiency was effectively constant between fuel types. The efficiencies ranged from 76.9% to 79.4%. This indicates that Espar heater transferred only about 78% of the heat released by the combusting fuel into the coolant loop at the low water flow rate. This amount did not depend on the fuel type and thus the team recognized that the heat recovered in the heat exchanger, and the heat duty of the plate heat exchanger, were a constant fraction of the actual heat content of the fuel being tested at any time. The team could thus use the trends in heat duty to illustrate trends in heat content between fuels without having to determine the exact heat content of each fuel.

The three biodiesels all had similar averages for the heat duty measured. Considering that the two commercial diesels were manufactured from waste cooking oil and contained unknown impurities while the WPI produced fuel was made using high purity reagents in a clean

environment, the overlapping data indicates that the energy content of the commercial fuels were not limited by the quality of their feedstock.

#### 4.4 Diesel-biodiesel Mixture Analysis

To prove the viability of using the apparatus for a biodiesel laboratory, the team tested how the composition of a diesel-biodiesel blend would affect the heat content of a blend. The pure fuels along with 1:3, 1:1 and 3:1 parts biodiesel blends were tested at a constant water flow rate of 8.8 liters / min (50% reading on the rotameter). The five fuels were tested in the same two-hour experimental run.



**Figure 22: Heat Duty versus Biodiesel Content**

The heat duties showed a linear dependence on the fuel composition. The data did not vary enough to indicate a nonlinear relationship. The six data points showed that a single two-hour run is sufficient to determine this trend.

## 5.0 Conclusions and Recommendations

After thorough analysis of the results, the team was able to formulate several conclusions and recommendations. The conclusions deal with both the success of the team achieving the goals of the project and observations made by the team during the operation of the apparatus. The recommendations are divided into two groups: those that would help future researchers further validate the team's findings and those that would broaden the capabilities of the current experimental setup. Finally, the feasibility of using the current apparatus as a Unit Operations Laboratory is discussed.

### 5.1 Conclusions

The experimental apparatus consistently showed a difference between diesel fuel and the biodiesel fuels. The apparatus showed a consistent efficiency between the heat recovered in the plate heat exchanger and the actual heat content of the fuels found in the literature. Data was collected over a two-month period and any changes in the local indoor environment or cooling water temperature had no effect on the data that was collected from the apparatus. The team repeatedly collected data for multiple fuels and cooling water flow rates within two hour blocks and thus future students could collect enough data in the typical four hour lab period to observe the relationship of the heat duty and the heat transfer coefficient with water flow rate and fuel type.

The team determined that the heat duty observed in the plate heat exchanger was negatively correlated with the cooling water flow rate. This correlation was caused by the proprietary control unit for the heater, which aimed to maintain the temperature difference of the coolant as it passed through the heater. The controller consistently reached this goal and achieved it by lowering the coolant flow rate as the cooling water flow rate increased. This lower coolant flow rate resulted in less heat being exchanged into the coolant from the combustion gases and thus the lower observed heat duty in the plate heat exchanger.

The overall heat transfer coefficient did increase as the cooling water flow rate was increased. This result was consistent with the theory and replicates the trend students see with the current WPI Unit Operations Laboratory heat exchanger. The trend is highly linear. The team was unable to determine the individual water side and coolant side heat transfer coefficients in the plate heat exchanger. This was because of a lack of information regarding the thickness, geometry and material of construction of the plates in the heat exchanger. Coupled with the lack of a constant coolant flow rate, no calculations using the Wilson Method or any variation of it were feasible.

The apparatus demonstrated its capability for determining the composition of diesel-biodiesel mixtures. The mixtures showed a linear trend between the heat recovered in the cooling water and the composition of a mixture. Data for this was collected in a two-hour block and it would be feasible for students in a Unit Operations lab to perform a similar test. The team believes that WPI chemical engineering students would be able to obtain and observe this linear relationship.

## 5.2 Recommendations for Future Experimental Testing

Our results prove that further testing is necessary for better understanding of the combustion and heat exchanger system. There were some discrepancies that were found in our results and from those we were able to identify ways to solve these issues and improve experimental run analyses.

### 5.2.1 Determine the Heat Content of Fuel by a Calorimetry

Analyzing the heat content of fuels in a calorimeter would provide more accurate information regarding the efficiency of the Espar heater. The team used heat content information sourced from the Department of Energy's Alternative Fuels Data Center and noted that different sources reported variations in the heat content of both diesel and biodiesel. Experimentally derived heat contents would allow for the heat contents of a particular sample of fuel to be determined.

### 5.2.2 Changes and Additions to Process Equipment

#### a. Installation of a Thermocouple in the Heater's Exhaust Pipe

During testing, the team determined that the heat transfer in the heat exchanger trended negatively with increasing water flow for all fuel types. The team believes that the heater's controller is responsible for this negative trend. The controller lowers the coolant flow rate to achieve its temperature differential goals. This drop in coolant flow causes less heat to be transferred into coolant. Conservation of energy indicates that most of the energy not transferred from the combustion gases exits the system in heater exhaust. The group suggests that a thermocouple be installed in the engine exhaust line. If there is a positive correlation between the temperature of the exhaust and the cooling water flow rate, then it will be clear that the engine controller is responsible for the negative trend in heat duty with increasing water flow rate.

#### b. Installation of Continuous Digital Log of Coolant Flow

In addition to the installation of a thermocouple in the heater's exhaust pipe, a continuous digital log of the coolant flow can help determine the controller's influence on the flow rate of the coolant. The apparatus currently has a glass rotameter for measuring the coolant flow with an accuracy of 2% of the rotameter's max flow. The team observed that the float in the rotameter moved around constantly within a 2% range at high cooling water flow rates and did not possess this oscillatory pattern when the system operated at a lower water flow rate. The magnitude of the drop in the rotameter with increasing water flow was also small. At the lower water rate, the rotameter read a continuous 60% of the max flow. At the high water flow rate; it oscillated between 56% and 58.5%. The team suggests adding a digital flowmeter that is setup to output data at least once a second to a data logger. Doing so would allow for a more accurate characterization of the coolant flow rate's dependence on the cooling water flow rate and thus provide further insight into the behavior of the heater controller. It would help solidify the team's hypothesis that the controller is responsible for the negative trend in heat transfer rate through the heat exchanger.

**c. Installation of a Second Type of Heat Exchanger**

The current apparatus is fully capable of supporting a full-scale Unit Operations Laboratory for future students. With further additions, it could support two full labs – one that focuses on identifying differences between biofuels and petrol fuels and another that focuses on heat exchanger design. A second heat exchanger could be added to the current system in parallel to the existing plate heat exchanger. Valves could be placed to allow students to isolate coolant flow to one exchanger or the other. Making the second exchanger a shell and tube pattern exchanger would provide a strong illustration to students about the differences between the two most common types of heat exchangers that they will encounter in their careers. The new heat exchanger would have to be of comparable size to the current plate exchanger in order for a valid comparison to be conducted. The team recommends that the new exchanger matches the current one in surface area. The addition of the new exchanger would open up the possibility of a new lab focused exclusively on heat exchangers and would have a structure similar to that of the fluid circuit lab, where students study the flow of water through pipes of different sizes, configuration, and compare the flow through an orifice and venturi meter.

**d. Installation of Emission Sensors**

The current experimental apparatus succeeds at quantifying the differences in thermal properties between diesel and biodiesel fuels. An improvement that would drastically expand the capability of the apparatus is the addition of emission testing sensors. Quantifying the level of CO emissions would show differences in the extent of complete combustion of a fuel. Sensors that identify sulfur and nitrogen compounds would provide significant information on the potential environmental and health impacts of using one fuel over another. The apparatus burns fuel at a constant volumetric flow rate and thus comparisons could easily be drawn between fuels.

**e. Eliminating Air from Coolant Line**

The testing performed by the team in the validation of the apparatus was done with a coolant loop filled only once. There was clearly a pocket of air present in the loop in an unknown, but constant amount. While in operation, the air became uniformly dispersed in the liquid coolant as small bubbles. This system of small air bubbles dispersed in an ethylene glycol and water solution has no known empirical estimation of specific heat capacity. The lack of a known heat capacity caused difficulty in accurately calculating the heat duty of the plate heat exchanger using the data collected from the coolant stream. The team advises that the coolant loop be drained and refilled before further testing is conducted. The coolant was not refilled during this project because of the desire to maintain a constant coolant composition between all trials.

### 5.3 Modifying Experimental Procedure for Making Biodiesel

Currently, the WPI Unit Operations Lab uses methanol in the biodiesel reactor to produce biodiesel from canola oil. The team recommends that the production process be switched from methanol to ethanol. There are several dangers with using methanol in the current production process. Methanol is highly flammable and toxic. Methanol burns in the ultraviolet spectrum and there is a significant danger of a fire starting without people's knowledge. Methanol exposure can lead to blindness, headaches, drowsiness, and other effects to the central nervous system (Honeywell, 2006). Ethanol, however, has less harmful effects than methanol. Though it is still a flammable liquid, it burns in the visible spectrum and thus people handling it will be able to see if there is a fire. Its health effects are moderate eye and skin irritation and it may cause damage to the liver, kidney, and heart if ingested (Fisher Scientific, 2001). Some disadvantages to switching to ethanol is the reaction time in the production process. Methanol has a faster reaction time than ethanol within the production process (Marchettii, 2007). This may mean that the students producing the biodiesel may not have enough time to complete the experiment if ethanol were used instead of methanol. More experiments between the effects of these alcohols on biodiesel production using the current WPI equipment need to be done to see if the potential to switch the alcohols is feasible.

### 5.4 Educational Design of Unit Operations Laboratory

The major goal of this project was to develop an apparatus that would be useable in a Unit Operations lab. The team succeeded in doing this and is confident that the current experimental setup could be used as-is in a Unit Operations lab. A successful lab must meet several criteria: can be completed in a four hour timeframe, include theory that is understandable to students who have completed the prerequisite classes, and requires students to apply the knowledge that they have acquired from such classes. Students will learn little if they can't understand the theory behind the lab or can complete the lab by simply following directions and not apply theory. The team is confident that such a lab could be developed that uses the apparatus created during this project.

The goals of the potential experiment could be for students to determine the dependence of the overall heat transfer coefficient on the cooling water flow rate and the dependence of the heat duty on the fuel composition. Students would be given an overview of the apparatus. They would then be asked to obtain the overall heat transfer coefficient at three different water flow rates using diesel fuel and then asked to determine the heat duty of the plate heat exchanger when biodiesel and an unknown mixture of diesel and biodiesel. These later two data points would be collected at a constant water flow rate and that flow rate would be one of the three previously tested for the diesel fuel. This procedure would require that students achieve five steady states with the apparatus, which the team routinely did in less than *two* hours. Students should easily be able to collect five good data points in the four-hour lab even with no prior experience operating the system.

The three diesel data points would show the drop in heat duty and the increase of the heat transfer coefficient with increasing water flow rate. Students would not be explicitly notified of the negative heat duty trend but would be expected to discover it on their own. The calculation of the heat duty and the heat transfer coefficient would require application of theory every student in the lab course should know. Identification and explanation of the heat duty trend, as well as the transfer coefficient trend, would require application of heat transfer beyond the students' previous classes and would provide a real world test of their mastery of heat transfer theory.

The biodiesel data, along with the corresponding diesel data point, would provide students with experience dealing with alternative energy. Students will encounter many fantastic claims for, or against, alternative energy technology during their careers. The Chemical Engineering Department at WPI should seek to educate students on how to assess alternative energy technologies in an informed and logical manner. The biodiesel testing component of the proposed lab will require students to quantify the heat contents of diesel and biodiesels. The students will then be able to discuss why there is a difference between the two fuels and how such a difference would affect the viability of biodiesel. Technologies will come and go over students' professional careers, but this lab would require that they apply skills that they can apply to all technologies.

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## Appendix A: Equipment Descriptions

This section describes the pieces of equipment used in our heater system. A description for each piece of equipment is described below.

- A) CO Detector – A Kidde brand CO detector was mounted in proximity to the system’s exhaust pipe in order to alert the team to potential hazards.
- B) Data Logger – A Data Translation DT9828 data logger was used to continuously record the system’s thermocouple readings. Each thermocouple was polled twice a second. The data was recorded and displayed in real time on a computer connected to the data logger.
- C) Electronic Balance – A Denver Instrument SI-4002 electronic balance with a max weight of 4000 grams was used to weigh the fuel containers.
- D) Espar Heater – The coolant heater used in the experimental setup is a Hydronic M-8 Heater produced by Espar. The main device is housed within a metal box mounted atop a base. The housing has hookups for coolant into and out of the heater, as well as a fuel inlet and electrical hookups for powering and controlling the heater. At its core, the heater is a heat exchanger that heats up the circulating coolant stream from the hot combustion products of a fuel air mixture. Fuel is pumped into the heater by an external pump. An internal fan draws in air and the fuel stream is injected into the air stream after the fan to produce a fuel-air mixture. Mixture passes over a glowplug and is ignited. Hot combustion gases pass through a cylindrical chamber where heat is exchanged with the circulating coolant. The gases then pass through a muffler and are expelled through an exhaust line into a building-wide ventilation system. The coolant is circulated through the heater, and the entire apparatus, by a pump directly bolted to the main heater component. The external fuel pump, internal coolant pump, air intake fan, and glowplug are controlled by an external proprietary controller from Espar. The controller used in lab can only be set by the user to run the heater for a certain amount of time, not limits on coolant temperature and flow rate or fuel consumption can be set. The controller attempts to maintain a 10°C temperature difference between the coolant pumped into the heater and the coolant leaving the heater. The heater is capable of operating using either diesel or biodiesel fuels. The team chose the particular heat model because it is rated to run pure biodiesel and potentially pure vegetable oil.
- E) Expansion Tank – The particular expansion tank that was used in the project is commonly used in home water heating systems as a safety measure against over-pressurizing the system. An expansion tank is a vessel that contains a diaphragm that segregates the bottom half of the tank from the top half. The bottom half of the tank contains air at 12 psi, and the area above the diaphragm contains the process fluid, which in this cases is the ethylene glycol-water mixture used to cool the heater. The tank was added to the system to protect against over pressurization of the system in the event that the coolant mixture becomes pressurized. The maximum allowable pressure of the expansion tank is 100 psi.

- F) Plate Heat Exchanger – Please see Chapter 2 for a more detailed description of a plate heat exchanger.
- G) Power Supply – The Espar heater was designed for use in automotive applications and thus required a 12V power supply. A Trak Power Speed Equipment TKPP5500 power supply was used to supply the heater with 12V of power.
- H) Pressure Release Valve – The pressure release valve was added to the system as another measure of safety against over pressurization of the system. This valve is situated at the exit of the coolant mixture from the engine, and at this point the coolant should be at its highest pressure. The pressure release valve is rated to open at 30 psi.
- I) Rotameter – A rotameter is used to measure the flow rates of fluids, and consists of a tube and a float. As the fluid flow increases the float is raised in the tube, where the height of the float measures the flow through the pipe in a percentage of the total allowable pipe flow. For example if a 10 gal/min rotameter float reads 80% then there is 8 gal/min of fluid flowing through the system. There are two rotameters in the system the first is measures the cooling water flow to the heat exchanger and the second measures the flow of the coolant mixture leaving the heater.
- J) Thermocouple – A thermocouple is a sensor which measures the temperature of a fluid of interest. Thermocouples were used to find the change in temperatures of the fluid streams exiting the heat exchanger to determine the overall heat transfer.

## Appendix B: Data Tables

**Table 4: Complete Diesel Data, Part 1**

| Date | Fuel Type | Elapsed Time | Set % | Set <i>lpm</i> | Temperature <i>K</i> |               |                |          |           | $\Delta T$<br><i>K</i> | CW<br>$C_p$<br>$\frac{kJ}{kgK}$ | $\dot{Q}$<br><i>kW</i> |
|------|-----------|--------------|-------|----------------|----------------------|---------------|----------------|----------|-----------|------------------------|---------------------------------|------------------------|
|      |           |              |       |                | Heater Out           | Coolant HX In | Coolant HX Out | CW HX In | CW HX Out |                        |                                 |                        |
| 2/6  | Diesel    | 42           | 20    | 3.41           | 45.41                | 43.29         | 37.19          | 8.97     | 39.50     | 30.53                  | 4.186                           | 7.265                  |
| 2/6  | Diesel    | 68           | 30    | 5.20           | 38.66                | 38.40         | 31.05          | 9.67     | 29.88     | 20.21                  | 4.188                           | 7.341                  |
| 2/6  | Diesel    | 82           | 40    | 7.00           | 35.23                | 35.74         | 27.91          | 10.57    | 25.38     | 14.81                  | 4.189                           | 7.236                  |
| 2/7  | Diesel    | 51           | 60    | 10.58          | 32.73                | 33.38         | 25.48          | 12.03    | 21.25     | 9.23                   | 4.190                           | 6.819                  |
| 2/7  | Diesel    | 86           | 75    | 13.27          | 31.14                | 32.73         | 24.26          | 11.89    | 19.58     | 7.69                   | 4.191                           | 7.128                  |
| 2/11 | Diesel    | 58           | 50    | 8.79           | 33.24                | 34.30         | 26.54          | 11.24    | 22.87     | 11.64                  | 4.190                           | 7.142                  |
| 2/11 | Diesel    | 106          | 30    | 5.20           | 39.04                | 39.03         | 31.77          | 10.92    | 30.84     | 19.91                  | 4.188                           | 7.232                  |
| 2/12 | Diesel    | 105          | 50    | 8.79           | 34.26                | 34.89         | 27.27          | 12.17    | 23.68     | 11.52                  | 4.189                           | 7.068                  |
| 2/12 | Diesel    | 129          | 20    | 3.41           | 47.98                | 44.53         | 39.20          | 10.48    | 41.57     | 31.09                  | 4.186                           | 7.398                  |
| 2/18 | Diesel    | 54           | 50    | 8.79           | 33.21                | 34.06         | 26.21          | 10.76    | 22.63     | 11.87                  | 4.190                           | 7.285                  |
| 2/18 | Diesel    | 96           | 30    | 5.20           | 39.27                | 38.46         | 31.77          | 10.72    | 31.10     | 20.39                  | 4.188                           | 7.404                  |
| 2/18 | Diesel    | 119          | 20    | 3.41           | 46.66                | 44.36         | 38.77          | 10.35    | 41.41     | 31.06                  | 4.186                           | 7.391                  |
| 2/28 | Diesel    | 71           | 50    | 8.79           | 31.18                | 31.07         | 21.70          | 6.32     | 17.71     | 11.38                  | 4.193                           | 6.991                  |
| 2/28 | Diesel    | 111          | 75    | 13.27          | 28.42                | 28.36         | 18.84          | 6.32     | 13.83     | 7.51                   | 4.194                           | 6.966                  |
| 3/4  | Diesel    | 39           | 30    | 5.20           | 37.48                | 37.34         | 28.24          | 6.29     | 26.38     | 20.08                  | 4.190                           | 7.298                  |
| 3/4  | Diesel    | 84           | 50    | 8.79           | 31.03                | 30.93         | 21.52          | 6.07     | 17.47     | 11.40                  | 4.193                           | 7.004                  |
| 3/4  | Diesel    | 103          | 75    | 13.27          | 28.19                | 28.14         | 18.57          | 6.01     | 13.43     | 7.34                   | 4.195                           | 6.812                  |
| 3/18 | Diesel    | 34           | 50    | 8.79           | 32.23                | 32.10         | 22.74          | 7.35     | 18.82     | 11.47                  | 4.192                           | 7.045                  |
| 3/18 | Diesel    | 70           | 30    | 5.20           | 38.36                | 38.19         | 29.13          | 7.36     | 27.34     | 19.97                  | 4.190                           | 7.257                  |
| 3/18 | Diesel    | 84           | 75    | 13.27          | 29.37                | 29.26         | 19.58          | 7.20     | 14.63     | 7.42                   | 4.194                           | 6.886                  |
| 3/18 | Diesel    | 107          | 75    | 13.27          | 29.10                | 29.00         | 19.46          | 6.98     | 14.43     | 7.45                   | 4.194                           | 6.912                  |
| 3/19 | Diesel    | 35           | 50    | 8.79           | 32.80                | 32.68         | 23.39          | 8.12     | 19.53     | 11.41                  | 4.192                           | 7.004                  |
| 3/19 | Diesel    | 84           | 30    | 5.20           | 39.41                | 39.24         | 30.18          | 8.67     | 28.47     | 19.79                  | 4.189                           | 7.191                  |
| 3/19 | Diesel    | 96           | 75    | 13.27          | 30.52                | 30.40         | 20.93          | 8.74     | 16.13     | 7.39                   | 4.193                           | 6.852                  |
| 3/19 | Diesel    | 25           | 50    | 8.79           | 32.26                | 32.16         | 22.87          | 7.70     | 18.93     | 11.23                  | 4.192                           | 6.896                  |
| 3/19 | Diesel    | 67           | 30    | 5.20           | 38.75                | 38.60         | 29.46          | 7.98     | 27.72     | 19.74                  | 4.189                           | 7.173                  |
| 3/19 | Diesel    | 80           | 75    | 13.27          | 29.68                | 29.62         | 20.08          | 7.68     | 15.13     | 7.45                   | 4.193                           | 6.910                  |
| 3/19 | Diesel    | 109          | 75    | 13.27          | 28.95                | 28.88         | 19.20          | 6.77     | 14.15     | 7.38                   | 4.194                           | 6.847                  |
| 3/21 | Diesel    | 29           | 50    | 8.79           | 31.57                | 31.49         | 22.13          | 6.71     | 18.08     | 11.37                  | 4.193                           | 6.981                  |
| 3/19 | Diesel    | 90           | 30    | 5.20           | 38.39                | 38.23         | 29.07          | 7.42     | 27.31     | 19.89                  | 4.190                           | 7.228                  |
| 3/21 | Diesel    | 101          | 75    | 13.27          | 29.46                | 29.35         | 19.66          | 7.38     | 14.74     | 7.36                   | 4.194                           | 6.832                  |
| 3/25 | Diesel    | 33           | 50    | 8.79           | 31.89                | 31.74         | 22.37          | 6.94     | 18.33     | 11.39                  | 4.193                           | 6.996                  |
| 3/25 | Diesel    | 86           | 30    | 5.20           | 37.92                | 37.79         | 28.65          | 6.98     | 26.69     | 19.71                  | 4.190                           | 7.161                  |
| 3/25 | Diesel    | 100          | 75    | 13.27          | 28.98                | 28.90         | 19.17          | 6.64     | 14.08     | 7.44                   | 4.194                           | 6.902                  |

**Table 5: Complete Diesel Data, Part 2**

| Date | Fuel Type | LMTD<br>K | U<br>$\frac{kW}{m^2K}$ | Coolant<br>Flow<br>Rate<br>% | Coolant<br>Pressure<br>psig | Heater<br>$\Delta T$<br>K | Coolant<br>Flow<br>L/s | Coolant<br>C <sub>p</sub><br>$\frac{kJ}{kgK}$ | Coolant<br>$\dot{Q}$<br>kW | Coolant<br>C <sub>p</sub> -<br>Corrected<br>For Air<br>$\frac{kJ}{kgK}$ | Coolant<br>$\dot{Q}$ -<br>Corrected<br>For Air<br>kW |
|------|-----------|-----------|------------------------|------------------------------|-----------------------------|---------------------------|------------------------|---|----------------------------|---|--|
| 2/6  | Diesel    | 12.17     | 2.49                   | 62                           | 2.25                        | 6.11                      | 0.278                  | 3.700   | 6.287                      | 2.971   | 5.048  |
| 2/6  | Diesel    | 13.98     | 2.19                   | 60                           | 2                           | 7.34                      | 0.267                  | 3.686   | 7.234                      | 2.961   | 5.811  |
| 2/6  | Diesel    | 13.55     | 2.22                   | 59                           | 1                           | 7.83                      | 0.255                  | 3.678   | 7.343                      | 2.955   | 5.899  |
| 2/7  | Diesel    | 12.77     | 2.22                   | 59.5                         | 1.5                         | 7.90                      | 0.261                  | 3.672   | 7.573                      | 2.950   | 6.085  |
| 2/7  | Diesel    | 12.76     | 2.33                   | 59                           | 1                           | 8.47                      | 0.255                  | 3.669   | 7.920                      | 2.949   | 6.365  |
| 2/11 | Diesel    | 13.27     | 2.24                   | 59                           | 1.5                         | 7.76                      | 0.259                  | 3.674   | 7.382                      | 2.952   | 5.931  |
| 2/11 | Diesel    | 13.55     | 2.22                   | 61                           | 2                           | 7.26                      | 0.272                  | 3.688   | 7.275                      | 2.962   | 5.844  |
| 2/12 | Diesel    | 13.06     | 2.26                   | -                            | -                           | 7.62                      | -                      | 3.676   | -                          | 2.954   | -  |
| 2/12 | Diesel    | 11.33     | 2.72                   | -                            | -                           | 5.33                      | -                      | 3.704   | -                          | 2.974   | -  |
| 2/18 | Diesel    | 13.34     | 2.28                   | 59                           | 1.5                         | 7.85                      | 0.259                  | 3.674   | 7.469                      | 2.952   | 6.001  |
| 2/18 | Diesel    | 13.03     | 2.37                   | 60                           | 2                           | 6.69                      | 0.267                  | 3.687   | 6.591                      | 2.961   | 5.294  |
| 2/18 | Diesel    | 11.24     | 2.74                   | 61.5                         | 3                           | 5.59                      | 0.282                  | 3.704   | 5.844                      | 2.974   | 4.692  |
| 2/28 | Diesel    | 14.35     | 2.03                   | 58                           | 1.5                         | 9.37                      | 0.254                  | 3.664   | 8.737                      | 2.945   | 7.022  |
| 2/28 | Diesel    | 13.50     | 2.15                   | 58                           | 1.1                         | 9.52                      | 0.251                  | 3.657   | 8.750                      | 2.939   | 7.033  |
| 3/4  | Diesel    | 15.82     | 1.92                   | 60                           | 2                           | 9.09                      | 0.267                  | 3.681   | 8.946                      | 2.957   | 7.187  |
| 3/4  | Diesel    | 14.43     | 2.02                   | 59                           | 1.5                         | 9.41                      | 0.259                  | 3.663   | 8.920                      | 2.944   | 7.169  |
| 3/4  | Diesel    | 13.61     | 2.09                   | 58                           | 1.1                         | 9.57                      | 0.251                  | 3.656   | 8.794                      | 2.939   | 7.069  |
| 3/18 | Diesel    | 14.31     | 2.05                   | 58                           | 1.2                         | 9.36                      | 0.252                  | 3.667   | 8.649                      | 2.947   | 6.951  |
| 3/18 | Diesel    | 15.68     | 1.93                   | 60                           | 1.9                         | 9.06                      | 0.266                  | 3.683   | 8.895                      | 2.959   | 7.146  |
| 3/18 | Diesel    | 13.47     | 2.13                   | 57                           | 1                           | 9.68                      | 0.246                  | 3.659   | 8.722                      | 2.941   | 7.011  |
| 3/18 | Diesel    | 13.50     | 2.13                   | 57                           | 1                           | 9.54                      | 0.246                  | 3.658   | 8.588                      | 2.941   | 6.903  |
| 3/19 | Diesel    | 14.19     | 2.06                   | 59                           | 1.5                         | 9.29                      | 0.259                  | 3.668   | 8.824                      | 2.948   | 7.091  |
| 3/19 | Diesel    | 15.53     | 1.93                   | 60                           | 2                           | 9.06                      | 0.267                  | 3.686   | 8.923                      | 2.961   | 7.167  |
| 3/19 | Diesel    | 13.21     | 2.16                   | 58                           | 1.1                         | 9.47                      | 0.251                  | 3.662   | 8.718                      | 2.943   | 7.007  |
| 3/19 | Diesel    | 14.18     | 2.03                   | 58                           | 1.5                         | 9.28                      | 0.254                  | 3.667   | 8.663                      | 2.947   | 6.962  |
| 3/19 | Diesel    | 15.58     | 1.92                   | 60                           | 2.1                         | 9.14                      | 0.268                  | 3.684   | 9.022                      | 2.959   | 7.247  |
| 3/19 | Diesel    | 13.42     | 2.15                   | 58                           | 1.4                         | 9.54                      | 0.254                  | 3.660   | 8.857                      | 2.942   | 7.119  |
| 3/19 | Diesel    | 13.55     | 2.11                   | 56                           | 1.1                         | 9.69                      | 0.243                  | 3.658   | 8.597                      | 2.940   | 6.910  |
| 3/21 | Diesel    | 14.39     | 2.02                   | 58                           | 1.5                         | 9.36                      | 0.254                  | 3.665   | 8.727                      | 2.945   | 7.014  |
| 3/19 | Diesel    | 15.68     | 1.92                   | 59.5                         | 2.2                         | 9.16                      | 0.267                  | 3.683   | 8.997                      | 2.959   | 7.227  |
| 3/21 | Diesel    | 13.41     | 2.12                   | 57                           | 1.5                         | 9.68                      | 0.250                  | 3.659   | 8.860                      | 2.941   | 7.122  |
| 3/25 | Diesel    | 14.40     | 2.02                   | 59                           | 1.5                         | 9.37                      | 0.259                  | 3.666   | 8.890                      | 2.946   | 7.144  |
| 3/25 | Diesel    | 15.80     | 1.89                   | 59                           | 2.1                         | 9.14                      | 0.264                  | 3.682   | 8.868                      | 2.958   | 7.124  |
| 3/25 | Diesel    | 13.64     | 2.11                   | 57                           | 1.5                         | 9.72                      | 0.250                  | 3.658   | 8.896                      | 2.940   | 7.151  |

**Table 6: Complete Biodiesel Data, Part 1**

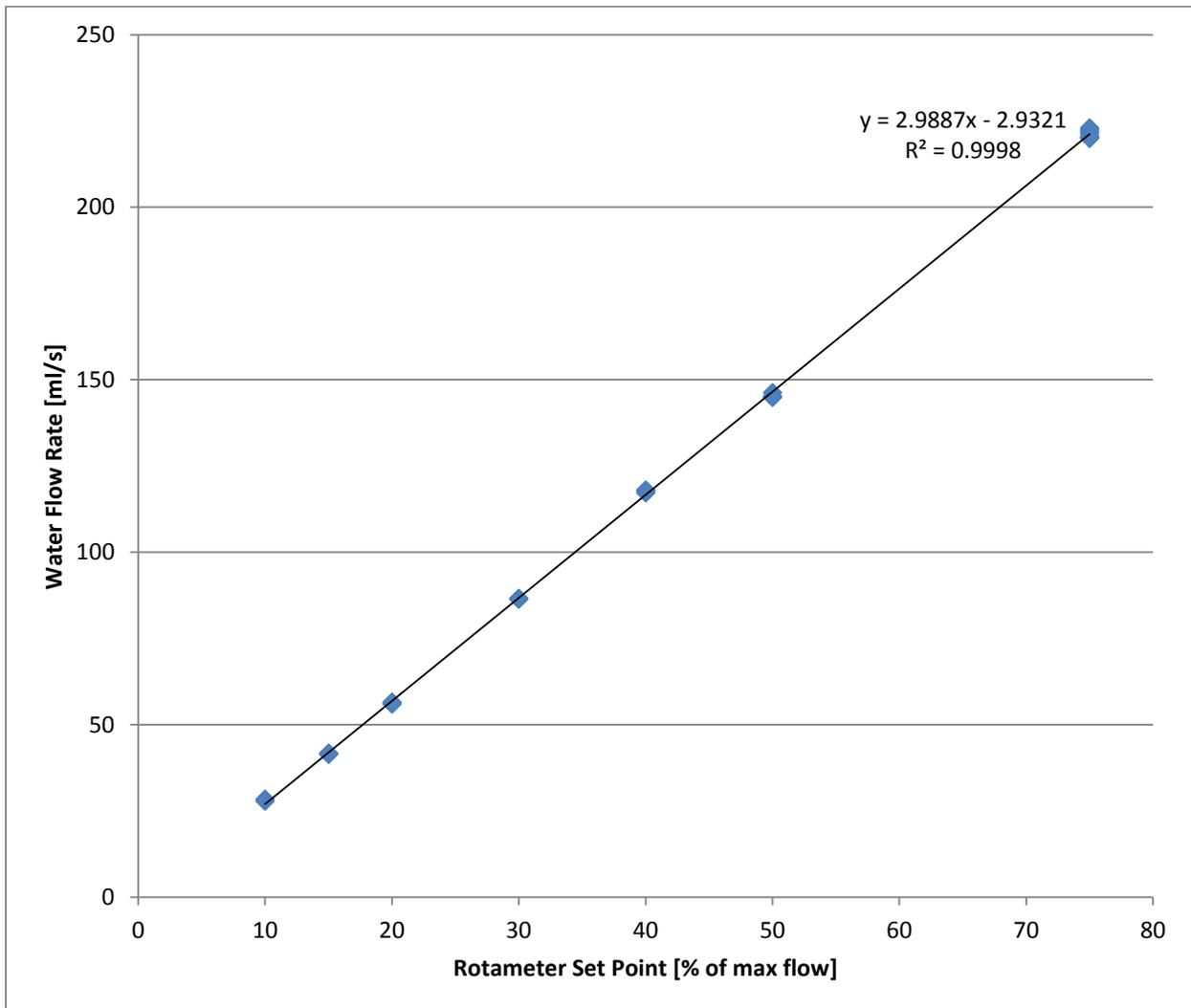
| Date | Fuel Type | Elapsed Time | Set % | Set <i>lpm</i> | Temperature <i>K</i> |               |                |          |           | $\Delta T$<br><i>K</i> | CW<br>$C_p$<br>$\frac{kJ}{kgK}$ | $\dot{Q}$<br><i>kW</i> |
|------|-----------|--------------|-------|----------------|----------------------|---------------|----------------|----------|-----------|------------------------|---------------------------------|------------------------|
|      |           |              |       |                | Heater Out           | Coolant HX In | Coolant HX Out | CW HX In | CW HX Out |                        |                                 |                        |
| 2/28 | BD Oct    | 33           | 50    | 8.79           | 30.21                | 30.13         | 21.41          | 7.04     | 17.66     | 10.61                  | 4.193                           | 6.519                  |
| 3/4  | BD Oct    | 55           | 30    | 5.20           | 35.33                | 35.21         | 26.69          | 6.21     | 24.84     | 18.63                  | 4.191                           | 6.771                  |
| 3/4  | BD Oct    | 69           | 50    | 8.79           | 29.47                | 29.39         | 20.51          | 6.05     | 16.62     | 10.57                  | 4.193                           | 6.495                  |
| 3/18 | BD Oct    | 46           | 50    | 8.79           | 30.51                | 30.42         | 21.59          | 7.21     | 17.81     | 10.59                  | 4.193                           | 6.507                  |
| 3/18 | BD Oct    | 59           | 30    | 5.20           | 36.40                | 36.26         | 27.74          | 7.35     | 25.97     | 18.62                  | 4.190                           | 6.767                  |
| 3/18 | BD Oct    | 94           | 75    | 13.27          | 27.76                | 27.67         | 18.73          | 7.21     | 14.05     | 6.84                   | 4.194                           | 6.347                  |
| 3/19 | NPBD      | 51           | 50    | 8.79           | 31.42                | 31.32         | 22.59          | 8.34     | 18.91     | 10.57                  | 4.192                           | 6.489                  |
| 3/19 | NPBD      | 67           | 30    | 5.20           | 37.15                | 37.01         | 28.56          | 8.61     | 26.83     | 18.22                  | 4.189                           | 6.622                  |
| 3/19 | NPBD      | 108          | 75    | 13.27          | 28.93                | 28.87         | 20.03          | 8.53     | 15.43     | 6.90                   | 4.193                           | 6.399                  |
| 3/19 | NPBD      | 35           | 50    | 8.79           | 30.64                | 30.54         | 21.80          | 7.68     | 18.06     | 10.38                  | 4.192                           | 6.372                  |
| 3/19 | NPBD      | 54           | 30    | 5.20           | 36.61                | 36.48         | 28.00          | 8.00     | 26.19     | 18.19                  | 4.190                           | 6.608                  |
| 3/19 | NPBD      | 100          | 75    | 13.27          | 27.71                | 27.63         | 18.60          | 6.96     | 13.81     | 6.85                   | 4.194                           | 6.355                  |
| 3/21 | NPBD      | 42           | 50    | 8.79           | 30.03                | 29.96         | 21.08          | 6.70     | 17.19     | 10.49                  | 4.193                           | 6.446                  |
| 3/19 | NPBD      | 52           | 30    | 5.20           | 35.97                | 35.83         | 27.22          | 7.00     | 25.31     | 18.31                  | 4.190                           | 6.654                  |
| 3/21 | NPBD      | 119          | 75    | 13.27          | 27.93                | 27.85         | 18.80          | 7.27     | 14.07     | 6.80                   | 4.194                           | 6.308                  |
| 3/25 | NPBD      | 47           | 50    | 8.79           | 30.12                | 30.04         | 21.25          | 6.76     | 17.36     | 10.60                  | 4.193                           | 6.510                  |
| 3/25 | NPBD      | 75           | 30    | 5.20           | 36.77                | 36.11         | 27.43          | 6.92     | 25.45     | 18.54                  | 4.190                           | 6.737                  |
| 3/25 | NPBD      | 112          | 75    | 13.27          | 27.51                | 27.40         | 18.33          | 6.66     | 13.52     | 6.85                   | 4.194                           | 6.358                  |
| 3/26 | NPBD      | 22           | 50    | 8.79           | 30.53                | 30.48         | 21.69          | 7.16     | 17.71     | 10.56                  | 4.193                           | 6.484                  |
| 3/26 | NPBD      | 50           | 30    | 5.20           | 36.46                | 36.34         | 27.67          | 7.35     | 25.78     | 18.43                  | 4.190                           | 6.699                  |
| 3/26 | NPBD      | 75           | 75    | 13.27          | 28.21                | 28.12         | 18.93          | 7.17     | 14.08     | 6.91                   | 4.194                           | 6.414                  |
| 3/26 | NPBD B25  | 41           | 50    | 8.79           | 31.60                | 31.50         | 22.21          | 7.06     | 18.10     | 11.05                  | 4.193                           | 6.785                  |
| 3/26 | NPBD B100 | 54           | 50    | 8.79           | 30.27                | 30.16         | 21.22          | 6.79     | 17.27     | 10.48                  | 4.193                           | 6.438                  |
| 3/26 | NPBD B50  | 67           | 50    | 8.79           | 30.94                | 30.84         | 21.57          | 6.57     | 17.53     | 10.96                  | 4.193                           | 6.732                  |
| 3/26 | NPBD B75  | 87           | 50    | 8.79           | 30.50                | 30.37         | 21.28          | 6.55     | 17.29     | 10.74                  | 4.193                           | 6.597                  |
| 3/26 | NPBD B50  | 101          | 50    | 8.79           | 31.12                | 30.99         | 21.64          | 6.66     | 17.60     | 10.94                  | 4.193                           | 6.721                  |
| 3/26 | WPI BD    | 33           | 50    | 8.79           | 30.46                | 30.38         | 21.50          | 7.22     | 17.61     | 10.39                  | 4.193                           | 6.384                  |
| 3/26 | WPI BD    | 64           | 30    | 5.20           | 36.12                | 35.95         | 27.46          | 7.33     | 25.50     | 18.17                  | 4.190                           | 6.604                  |
| 3/26 | WPI BD    | 84           | 75    | 13.27          | 27.96                | 27.85         | 18.73          | 7.02     | 13.87     | 6.86                   | 4.194                           | 6.362                  |

**Table 7: Complete Biodiesel Data, Part 2**

| Date | Fuel Type    | LMT<br>D<br>K | U<br>$\frac{kW}{m^2K}$ | Coolant<br>Flow<br>Rate<br>% | Coolant<br>Pressure<br>psig | Heater<br>$\Delta T$<br>K | Coolant<br>Flow<br>L/s | Coolant<br>C <sub>p</sub><br>$\frac{kJ}{kgK}$ | Coolant<br>$\dot{Q}$<br>kW | Coolant<br>C <sub>p</sub> -<br>Correct<br>ed For<br>Air<br>$\frac{kJ}{kgK}$ | Coolant<br>$\dot{Q}$ -<br>Correcte<br>d For Air<br>kW |
|------|--------------|---------------|------------------------|------------------------------|-----------------------------|---------------------------|------------------------|---|----------------------------|---|---|
| 2/28 | BD Oct       | 13.40         | 2.03                   | 58                           | 1                           | 8.72                      | 0.251                  | 3.662   | 8.001                      | 2.943   | 6.430   |
| 3/4  | BD Oct       | 14.85         | 1.90                   | 60                           | 2                           | 8.53                      | 0.267                  | 3.676   | 8.378                      | 2.953   | 6.731   |
| 3/4  | BD Oct       | 13.60         | 1.99                   | 58                           | 1.3                         | 8.88                      | 0.253                  | 3.660   | 8.223                      | 2.942   | 6.609   |
| 3/18 | BD Oct       | 13.48         | 2.01                   | 58                           | 1.1                         | 8.82                      | 0.251                  | 3.663   | 8.121                      | 2.944   | 6.527   |
| 3/18 | BD Oct       | 14.77         | 1.91                   | 60                           | 1.6                         | 8.52                      | 0.264                  | 3.679   | 8.279                      | 2.955   | 6.651   |
| 3/18 | BD Oct       | 12.55         | 2.11                   | 56.5                         | 1                           | 8.94                      | 0.244                  | 3.656   | 7.976                      | 2.939   | 6.412   |
| 3/19 | NPBD         | 13.31         | 2.03                   | 59                           | 1.5                         | 8.73                      | 0.259                  | 3.665   | 8.283                      | 2.946   | 6.657   |
| 3/19 | NPBD         | 14.52         | 1.90                   | 59                           | 2                           | 8.44                      | 0.263                  | 3.681   | 8.169                      | 2.957   | 6.563   |
| 3/19 | NPBD         | 12.44         | 2.14                   | 57                           | 1.1                         | 8.84                      | 0.247                  | 3.659   | 7.987                      | 2.941   | 6.420   |
| 3/19 | NPBD         | 13.28         | 2.00                   | 58                           | 1.5                         | 8.74                      | 0.254                  | 3.663   | 8.145                      | 2.944   | 6.546   |
| 3/19 | NPBD         | 14.62         | 1.88                   | 60                           | 2                           | 8.48                      | 0.267                  | 3.679   | 8.342                      | 2.956   | 6.702   |
| 3/19 | NPBD         | 12.70         | 2.09                   | 56.5                         | 1                           | 9.03                      | 0.244                  | 3.655   | 8.052                      | 2.938   | 6.473   |
| 3/21 | NPBD         | 13.56         | 1.98                   | 58                           | 1.5                         | 8.88                      | 0.254                  | 3.662   | 8.271                      | 2.943   | 6.648   |
| 3/19 | NPBD         | 14.85         | 1.87                   | 59                           | 2                           | 8.61                      | 0.263                  | 3.677   | 8.319                      | 2.954   | 6.684   |
| 3/21 | NPBD         | 12.62         | 2.08                   | 56.5                         | 1.5                         | 9.05                      | 0.248                  | 3.656   | 8.200                      | 2.939   | 6.592   |
| 3/25 | NPBD         | 13.57         | 2.00                   | 56.5                         | 1.5                         | 8.78                      | 0.248                  | 3.662   | 7.973                      | 2.943   | 6.408   |
| 3/25 | NPBD         | 15.05         | 1.87                   | 56.5                         | 1.5                         | 8.69                      | 0.248                  | 3.678   | 7.919                      | 2.955   | 6.362   |
| 3/25 | NPBD         | 12.74         | 2.08                   | 56.5                         | 1.5                         | 9.08                      | 0.248                  | 3.655   | 8.224                      | 2.938   | 6.611   |
| 3/26 | NPBD         | 13.63         | 1.98                   | 57                           | 1.5                         | 8.79                      | 0.250                  | 3.663   | 8.057                      | 2.944   | 6.475   |
| 3/26 | NPBD         | 14.91         | 1.87                   | 59                           | 2.1                         | 8.67                      | 0.264                  | 3.679   | 8.405                      | 2.955   | 6.752   |
| 3/26 | NPBD         | 12.87         | 2.08                   | 56                           | 2.1                         | 9.19                      | 0.250                  | 3.656   | 8.408                      | 2.939   | 6.759   |
| 3/26 | NPBD<br>B25  | 14.26         | 1.98                   | 58                           | 1.6                         | 9.28                      | 0.255                  | 3.665   | 8.685                      | 2.946   | 6.980   |
| 3/26 | NPBD<br>B100 | 13.64         | 1.97                   | 58                           | 1.6                         | 8.94                      | 0.255                  | 3.662   | 8.357                      | 2.943   | 6.717   |
| 3/26 | NPBD<br>B50  | 14.13         | 1.98                   | 57.5                         | 1.6                         | 9.26                      | 0.253                  | 3.663   | 8.585                      | 2.944   | 6.900   |
| 3/26 | NPBD<br>B75  | 13.89         | 1.98                   | 57.5                         | 1.6                         | 9.10                      | 0.253                  | 3.662   | 8.430                      | 2.944   | 6.776   |
| 3/26 | NPBD<br>B50  | 14.17         | 1.98                   | 58                           | 1.6                         | 9.35                      | 0.255                  | 3.664   | 8.744                      | 2.945   | 7.028   |
| 3/26 | WPI BD       | 13.51         | 1.97                   | 57                           | 1.5                         | 8.88                      | 0.250                  | 3.663   | 8.131                      | 2.944   | 6.535   |
| 3/26 | WPI BD       | 14.76         | 1.86                   | 59                           | 2.1                         | 8.49                      | 0.264                  | 3.678   | 8.231                      | 2.955   | 6.613   |
| 3/26 | WPI BD       | 12.81         | 2.07                   | 56                           | 1.5                         | 9.12                      | 0.246                  | 3.656   | 8.191                      | 2.939   | 6.584   |

## Appendix C: Cooling Water Calibration Curve

A calibration curve was developed for the cooling water rotameter once the experimental apparatus was assembled. At least three repeated measurements were collected for each set point of the rotameter, with more measurements taken at the higher water flow rates. The resulting calibration curve is shown below in Figure 23.



**Figure 23: Calibration Curve for Cooling Water Rotameter**

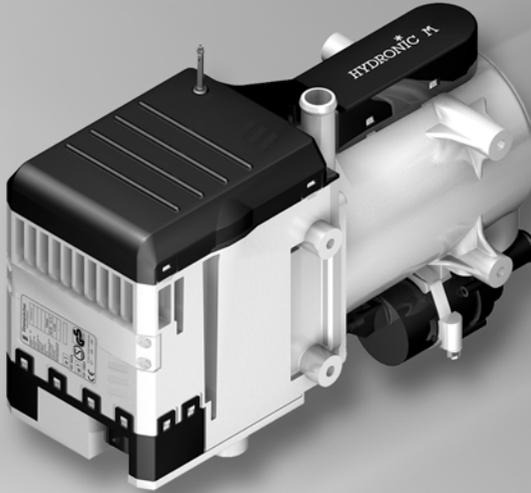
The resulting line of best fit was used to calculate the water flow rate for subsequent calculations during the data analysis portion of the project.

## **Appendix D: ESPAR Heater Manual & Relevant Safety Documentation**

Documents included in this appendix are the heater manual, the controller manual and MSDS sheets for diesel and biodiesel.

# HYDRONIC M-II

Technical description, installation,  
operation and maintenance instructions.



| Heater                | Order no.             | Heater       | Order no.             |
|-----------------------|-----------------------|--------------|-----------------------|
| Hydronic M8 Biodiesel | 12 V 25 2470 05 00 00 | Hydronic M12 | 12 V 25 2472 05 00 00 |
|                       | 24 V 25 2471 05 00 00 |              | 24 V 25 2473 05 00 00 |
| Hydronic M10          | 12 V 25 2434 05 00 00 |              |                       |
|                       | 24 V 25 2435 05 00 00 |              |                       |

**Water heater for diesel,  
operating independently of the engine.**



**Eberspächer**  
A world of comfort

# 1 Introduction

## Contents

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# 1 Introduction

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## Concept of this manual

This manual aims to support the service company installing the heater and to provide the user with all important information about the heater. The manual has been divided into 8 chapters to make it easier to find the corresponding information quickly.

### 1 Introduction

Here you will find important introductory information about installation of the heater and about the structure of the manual.

### 2 Product information

Here you will find information about the scope of supply, the technical data and the dimensions of the heater.

### 3 Installation

Here you will find important information and instructions referring to installation of the heater.

### 4 Operation and function

Here you will find information about the operation and function of the heater.

### 5 Electric system

Here you will find information about the electronic system and electronic components of the heater.

### 6 Troubleshooting / maintenance / service

This section contains information on possible faults and malfunctions, troubleshooting, maintenance and the service hotline.

### 7 Environment

Here you will find information about certification and disposal of the heater together with the EU Declaration of Conformity.

### 8 Lists

Here you will find the key word list and abbreviations list.

# 1 Introduction

## Special text structure, presentation and picture symbols

This manual uses special text structures and picture symbols to emphasise different contents. Please refer to the examples below for the corresponding meanings and associated actions.

### Special structure and presentations

A dot (•) indicates a list which is started by a heading. If an indented dash (–) follows a dot, this list is subordinate to the dot.

### Picture symbols



#### Regulation!

This picture symbol with the remark “Regulation” refers to a statutory regulation. Failure to comply with this regulation results in expiry of the type permit for the heater and preclusion of any guarantee and liability claims on J. Eberspächer GmbH & Co. KG.



#### Danger!

This picture symbol with the remark “Danger!” refers to the risk of a fatal danger to life and limb. Under certain circumstances, failure to comply with these instructions can result in severe or life-threatening injuries.



#### Caution!

This picture symbol with the remark “Caution!” refers to a dangerous situation for a person and/or the product. Failure to comply with these instructions can result in injuries to people and / or damage to machinery.

#### Please note!

These remarks contain application recommendations and useful tips for installation of the heater.

## Important information before starting work

### Range of application of the heater

The water heater operating independently of an engine is intended for installation in the following vehicles, depending on its heating output:

- Vehicles of all kinds
- Construction machinery
- Agricultural machinery
- Boats, ships and yachts

#### Please note!

- Installation of the heater is permitted in vehicles used for the transport of dangerous goods as per ADR.
- The heater is not approved for installation in vehicle compartments used by persons (more than 8 passenger spaces) in Class M<sub>2</sub> and M<sub>3</sub> vehicles (vehicles for the transport of passengers / commercial buses).
- The heater is not approved for installation in the driver or passenger compartments of Class M<sub>1</sub> vehicles (vehicles for the transport of passengers / cars) and Class N vehicles (vehicles for the transport of goods).

On account of its functional purpose, the heater is **not** permitted for the following applications:

- Long-term continuous operation, e.g. for pre-heating and heating of:
  - Residential rooms
  - Garages
  - Work huts, weekend homes and hunting huts
  - Houseboats, etc.



#### Caution!

### Safety instructions for application and proper purpose

The heater must only be used and operated for the range of application stated by the manufacturer in compliance with the “Operating instructions” included with every heater.



# 1 Introduction

## Statutory regulations

The Federal Motor Transport Authority has issued an "EC type approval", "EMC type-approval" and the approval for a component according to ECE R122 and ECE-R10 for the heater for installation in motor vehicles with the following official type-approval marks, noted on the heater name plate.

|              |   |
|--------------|---|
| Heater type: | Hydronic M-II   |
| Test mark:   |   |
| EC           |  00 0215                       |
| EMC          |  03 5075                       |
| ECE          |  122R – 000215<br>10R – 035075 |



### Regulations!

**Extract from Directive 2001 / 56 / EC Annex VII and ECE Regulation No. 122 of the European Parliament and of the Council**

#### General regulations

##### • Operating state display

- A clearly visible operating display in the user's field of vision must indicate when the heater is switched on and off.

#### Regulations concerning installation in the vehicle

##### • Scope

- Subject to differing stipulations in the following section, combustion heaters must be installed according to the provisions of Directive 2001 / 56 / EC Annex VII.
- It is assumed that Class O vehicles with heaters for liquid fuel conform to the provisions of Directive 2001 / 56 / EC.

##### • Position of the heater

- Parts of the structure and other components near the heater must be protected from excessive heat exposure and possible fuel or oil contamination.
- The heater must not pose a fire hazard even when it overheats. This requirement is deemed to be fulfilled if adequate clearance is ensured for all parts during installation, sufficient ventilation is provided and fireproof materials or heat shields are used.
- The heater must not be mounted in the passenger compartment of vehicles in class M<sub>2</sub> and M<sub>3</sub>. However, a heater in a hermetically sealed enclosure which also complies with the aforementioned conditions may be used.
- The factory nameplate or duplicate of it must be affixed so that it can still be easily read when the heater is installed in the vehicle.

- All appropriate precautions must be taken when arranging the heater to minimise the risk of injuries to persons or damage to other property.

##### • Fuel supply

- The fuel intake connection must not be located in the passenger compartment and must be sealed with a properly closing lid to prevent any fuel leaks.
- In heaters for liquid fuel where the heater fuel is separate from the vehicle fuel, the type of fuel and intake connection must be clearly identified.
- A warning sign is to be fixed to the intake connection indicating that the heater must be switched off before refuelling.

##### • Exhaust system

- The exhaust outlet must be arranged so as to prevent any penetration of exhaust fumes into the vehicle interior through the ventilation system, warm air intakes or open windows.

##### • Combustion air intake

- The air for the heater's combustion chamber must not be sucked in from the vehicle's passenger compartment.
- The air intake must be arranged or protected in such a way that it cannot be blocked by other objects.

##### • Automatic control of the heating system

- If the engine fails, the heating system must be automatically switched off and the fuel supply stopped within 5 seconds. The heater may remain in operation if a manual device has already been activated.

#### Please note!

The heater is **not** approved for installation in the driver's cab or passenger compartment of Class M<sub>1</sub> vehicles (vehicles for passenger transport / cars) and N vehicles (vehicles for the transport of goods).

# 1 Introduction

## Statutory regulations



### Regulations

#### Additional regulations for certain vehicles named in Directive 94 / 55 / EC of the ADR Agreement

##### Scope

This annex applies to vehicles to which the special provisions of Directive 94 / 55 / EC of the ADR Agreement for combustion heaters and their installation apply.

##### Definition of terms

The vehicle designations "EX / II", "EX / III", "AT", "FL" and "OX" according to Chapter 9.1 of the ADR Agreement Directive are used for the purposes of this annex.

##### Technical regulations

#### General provisions (EX / II, EX / III, AT, FL and OX vehicles)

##### Avoid heating and ignition

The combustion heaters and their exhaust gas routing shall be designed, located, protected or covered so as to prevent any unacceptable risk of heating or ignition of the load. This requirement shall be considered as fulfilled if the fuel tank and the exhaust system of the appliance conform to provisions in 3.1.1.1 and 3.1.1.2. Compliance with these regulations shall be checked in the complete vehicle.

##### Fuel tanks

Fuel tanks for supplying the heater shall conform to the following regulations:

- In the event of any leakage, the fuel shall drain to the ground without coming into contact with hot parts of the vehicle or the load;
- fuel tanks containing petrol shall be equipped with an effective flame trap at the filler opening or with a closure enabling the opening to be kept hermetically sealed.

##### Exhaust system and exhaust pipe layout

The exhaust system as well as the exhaust pipes shall laid out or protected to avoid any danger to the load through heating or ignition. Parts of the exhaust system situated directly below the fuel tank (diesel) shall have a clearance of at least 100 mm or be protected by a thermal shield.

##### Switching on the combustion heater

The combustion heater may only be switched on manually. Automatic switching on via a programmable switch is not permitted.

#### EX / II and EX / III vehicles

Combustion heaters for gaseous fuels are not permitted.

#### FL vehicles

Combustion heaters must be able to be taken out of service/disabled at least by the methods described in the following:

- a) Switching off manually in the driver's cabin
- b) Switching off the vehicle's engine; in this case the heater may be manually switched back on by the vehicle driver;
- c) Starting up of a feed pump installed in the vehicle for the dangerous goods carried.

#### Combustion heater after-run

After-running of the switched off combustion heater is permitted. In the cases named in the „FL vehicles“ paragraph under letters b) and c) the supply of combustion air must be interrupted by suitable means after a maximum after-run period of 40 seconds. Only combustion heaters whose heat exchangers are verifiably not damaged by the reduced after-run period of 40 seconds beyond their usual use period may be used.

#### Please note!

- Compliance with the statutory regulations, the additional regulations and safety instructions is prerequisite for guarantee and liability claims. Failure to comply with the statutory regulations and safety instructions and incorrect repairs even when using original spare parts make the guarantee null and void and preclude any liability for J. Eberspächer GmbH & Co. KG.
- Subsequent installation of this heater must comply with these installation instructions.
- The statutory regulations are binding and must also be observed in countries which do not have any special regulations.
- When the heater is to be installed in vehicles not subject to the German Ordinance for the Registration of Motor Vehicles (StVZO), for example ships, the specially valid regulations and installation instructions for these special applications must be observed.
- Installation of the heater in special vehicles must comply with the regulations applying to such vehicles.
- Other installation requirements are contained in the corresponding sections of this manual.



# 1 Introduction

## Safety instructions for installation and operation



### Danger!

#### Risk of injury, fire and poisoning

- Disconnect the vehicle battery before starting any kind of work.
- Before working on the heater, switch the heater off and let all hot components cool down.
- The heater must not be operated in enclosed rooms, e.g. in the garage or multi-storey car park.



### Caution!

#### Safety instructions for installation and operation

- The heater must only be installed by a JE partner authorised by the manufacturer according to the instructions in this manual and possibly according to special installation recommendations; the same applies to any repairs to be carried out in the case of repairs or guarantee claims.
- Repairs by non-authorised third-parties or with not original spare parts are dangerous and therefore not allowed. They result in expiry of the type permit of the heater; consequently, when installed in motor vehicles they can cause expiry of the vehicle operating licence.
- The following measures are not allowed:
  - Changes to components relevant to the heater.
  - Use of third-party components not approved by J. Eberspächer GmbH & Co. KG.
  - Nonconformities in installation or operation from the statutory regulations, safety instructions or specifications relevant to safe operation as stated in the installation instructions and operating instructions. This applies in particular to the electrical wiring, fuel supply, combustion air system and exhaust system.
- Only original accessories and original spare parts must be used during installation or repairs.
- Only the controls approved by Eberspächer may be used to operate the heater. The use of other controls can result in malfunctions.
- Before the heater is installed again in another vehicle, rinse the heater parts carrying water with clear water.
- When carrying out electric welding on the vehicle, the plus pole cable at the battery should be disconnected and placed at ground to protect the controller.

- Do **not** operate the heater anywhere where there are readily flammable materials (e.g. dry grass, leaves, paper, etc.) in the area of the exhaust system or where ignitable fumes and dust can form, e.g. near a
  - fuel depot
  - coal depot
  - wood depot
  - grain depots, etc.
- The heater must be switched off when refuelling.
- When the heater is mounted in a safety housing etc., the installation compartment of the heater is not a stowage compartment and must be kept clear. In particular fuel canisters, oil cans, spray cans, gas cartridges, fire extinguishers, cleaning rags, items of clothing, paper etc. must not be stored or transported on or next to the heater.
- Defect fuses must only be replaced by fuses with the prescribed rating.
- If fuel leaks from the heater fuel system, arrange for the damage to be repaired immediately by a JE service partner.
- When topping up the coolant, only use the coolant permitted by the vehicle manufacturer, see the vehicle operating manual. Any blending with unpermitted coolant can cause damage to the engine and heater.
- After-running of the heater must not be interrupted prematurely e.g. by pressing the battery disconnecting switch, apart from in the case of an emergency stop.

#### Please note!

Following installation, attach the "Switch off heater before refuelling!" sticker near the tank filler neck.

## Accident prevention

General accident prevention regulations and the corresponding workshop and operation safety instructions are to be observed.

## 2 Product information

### Scope of supply

| Quantity / Designation       | Order number     |
|------------------------------|------------------|
| 1 Hydronic M8 Biodiesel      |                  |
| 12 Volt                      | 25 2470 05 00 00 |
| 24 Volt                      | 25 2471 05 00 00 |
| 1 Hydronic M10               |                  |
| 12 Volt                      | 25 2434 05 00 00 |
| 24 Volt                      | 25 2435 05 00 00 |
| 1 Hydronic M12               |                  |
| 12 Volt                      | 25 2472 05 00 00 |
| 24 Volt                      | 25 2473 05 00 00 |
| To be ordered separately:    |                  |
| 1 Universal installation kit | 25 2435 80 00 00 |
| 1 Control unit*              | –                |

\* For details of control units, please refer to the price list or product information.

#### Please note!

- Please refer to the production information if any other parts are required for the installation.

### Parts list for the „Scope of supply“ figure on page 9

#### Hydronic M8 Biodiesel heater scope of supply

| Picture-No. | Designation                       |
|-------------|-----------------------------------|
| 1           | Heater                            |
| 2           | Metering pump                     |
| 3           | Relay 12 V / Relay 24 V           |
| 21          | Tube, Ø 6 x 1, length 6 m         |
| 22          | Transition piece Ø 3.5 / 5, (2 x) |
| –           | Hose clamp Ø 10, (4 x)            |

#### Hydronic M10 / M12 heater scope of supply

| Picture-No. | Designation             |
|-------------|-------------------------|
| 1           | Heater                  |
| 2           | Metering pump           |
| 3           | Relay 12 V / Relay 24 V |

#### Universal installation kit scope of supply

| Picture-No. | Designation                          |
|-------------|--------------------------------------|
| 4           | Exhaust silencer                     |
| 5           | Cable tree, heater                   |
| 6           | Bracket, heater                      |
| 7           | Flexible exhaust pipe                |
| 8           | Cable ties (1 set)                   |
| 9           | Pipe, Ø 6 x 1, length 1,5 m          |
| 10          | Hose, Ø 5 x 3, length 0,5 m          |
| 11          | Pipe, Ø 4 x 1, length 6 m            |
| 12          | Hose, Ø 3,5 x 3, length 5 cm (2 No.) |
| 13          | Intake silencer for combustion air   |
| 14          | Water hose                           |
| 15          | Bracket                              |
| 16          | Lead harness, metering pump          |
| 17          | Lead harness, blower                 |
| 18          | Bracket, metering pump               |
| 19          | Bracket                              |
| –           | Small parts                          |

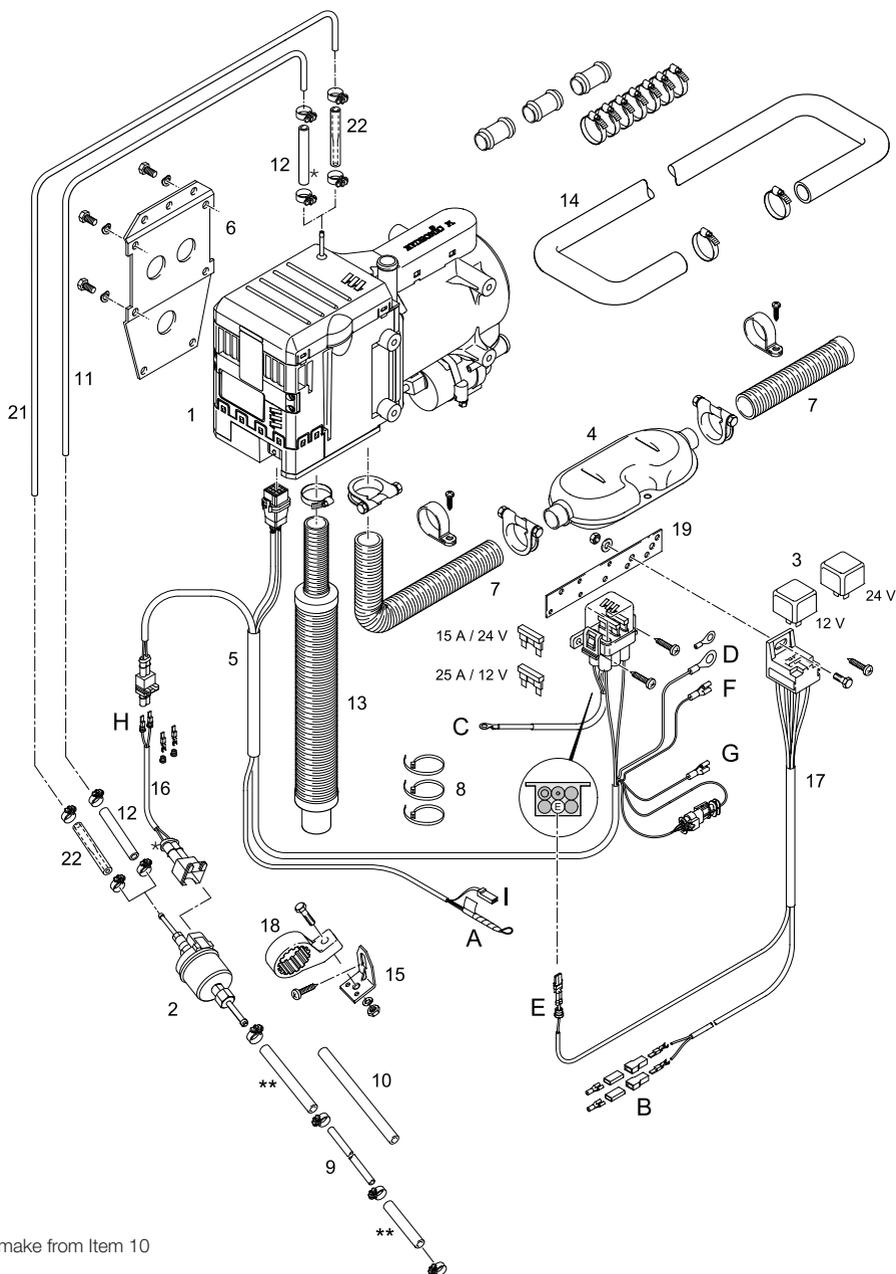
#### Cable harnesses

- A „Controls“ lead harness
- B „Blower control“ lead harness
- C Positive cable
- D Negative cable
- E Connection, blower relay positive supply cable at the fuse holder
- F Connection at blower relay, terminal 85 (1-pole, brown)
- G Connection at blower relay, terminal 86 (1-pole, red/yellow)
- H Metering pump connection
- I ADR feedback

## 2 Product information



### Scope of supply



## 2 Product information

### Technical data

|   |  |                  |                  |       |
|---|--|------------------|------------------|-------|
| Heater type   | <b>Hydronic M-II</b>   |                  |                  |       |
| Heater  | Hydronic M8 Biodiesel  |                  |                  |       |
| Version   | D 8 W  |                  |                  |       |
| Heating medium  | Mixture of water and antifreeze<br>(Proportion of antifreeze at least 10 % up to 50 % maximum)     |                  |                  |       |
| Control of the heat flow  | Power  | Large            | Medium           | Small |
| Heat flow (watt)<br>Figures for operation with diesel fuel. If operated with FAME the heat flow can reduce by up to 15 %.   | 8000   | 5000             | 3500             | 1500  |
| Fuel consumption (l/h)  | 0.90   | 0.65             | 0.40             | 0.18  |
| Electrical power (watt)   | in operation   |                  |                  |       |
|   | 55   | 46               | 39               | 35    |
|   | at start – after 25 Sek.   |                  |                  |       |
|   | 200  |                  |                  |       |
|   | in the control phase "OFF"   |                  |                  |       |
|   | 32   |                  |                  |       |
| Rated voltage   | 12 Volt  |                  | 24 Volt          |       |
| Operating range   | 10 Volt  |                  | 20 Volt          |       |
| <ul style="list-style-type: none"> <li>Lower voltage limit: An undervoltage protection in the controller switches the heater off on reaching the voltage limit.</li> <li>Upper voltage limit: An overvoltage protection in the controller switches the heater off on reaching the voltage limit.</li> </ul> | 15 Volt  |                  | 30 Volt          |       |
| Tolerable operating pressure  | up to 2 bar overpressure   |                  |                  |       |
| Flow rate of the water pump at 0.14 bar   | 1400 l/h   |                  |                  |       |
| Minimum water flow rate of the heater   | 500 l/h  |                  |                  |       |
| Fuel – see also "Fuel quality diesel heaters" page 27   | Commercially available diesel (DIN EN 590)<br>FAME – for diesel engines according to DIN EN 14 214 |                  |                  |       |
| Tolerable operating temperature   | Operation  |                  | Not running      |       |
| Heater / Control box  | Diesel   | -40 °C to +80 °C | -40 °C to +85 °C |       |
|   | FAME   | -8 °C to +80 °C  | -40 °C to +85 °C |       |
| Metering pump   | Diesel   | -40 °C to +50 °C | -40 °C to +85 °C |       |
|   | FAME   | -8 °C to +50 °C  | -40 °C to +85 °C |       |
| Interference suppression class  | interference suppression class 5 to DIN EN 55 025  |                  |                  |       |
| Weight with controller and water pump, without metering pump  | approx. 6.2 kg   |                  |                  |       |



#### Caution!

#### Safety instructions for technical data

Failure to comply with the technical data can result in malfunctions.

#### Please note!

Provided no limit values are given, the technical data listed is subject to the tolerances usually applicable to heaters of  $\pm 10\%$  for nominal voltage, ambient temperature 20 °C and reference altitude Esslingen.



## 2 Product information

### Technical data

|   |  |                  |                  |       |    |
|---|--|------------------|------------------|-------|----|
| Heater type   | <b>Hydronic M-II</b>   |                  |                  |       |    |
| Heater  | Hydronic M10   |                  |                  |       |    |
| Version   | D 10 W   |                  |                  |       |    |
| Heating medium  | Mixture of water and antifreeze<br>(Proportion of antifreeze at least 10 % up to 50 % maximum) |                  |                  |       |    |
| Control of the heat flow  | Power  | Large            | Medium           | Small |    |
| Heat flow (watt)  | 9500   | 8000             | 3500             | 1500  |    |
| Fuel consumption (l/h)  | 1.2  | 0.9              | 0.4              | 0.18  |    |
| Electrical power (watt)(V)  | in operation   | 86               | 60               | 39    | 35 |
|   | at start – after 25 Sek.   | 120              |                  |       |    |
|   | in the control phase "OFF"   | 32               |                  |       |    |
| Rated voltage   | 12 Volt  |                  | 24 Volt          |       |    |
| Operating range   | 10 Volt  |                  | 20 Volt          |       |    |
| <ul style="list-style-type: none"> <li>• Lower voltage limit: An undervoltage protection in the controller switches the heater off on reaching the voltage limit.</li> <li>• Upper voltage limit: An overvoltage protection in the controller switches the heater off on reaching the voltage limit.</li> </ul> | 15 Volt  |                  | 30 Volt          |       |    |
| Tolerable operating pressure  | up to 2 bar overpressure   |                  |                  |       |    |
| Flow rate of the water pump at 0.14 bar   | 1400 l/h   |                  |                  |       |    |
| Minimum water flow rate of the heater   | 500 l/h  |                  |                  |       |    |
| Fuel – see also "Fuel quality diesel heaters" page 27   | Commercially available diesel (DIN EN 590)   |                  |                  |       |    |
| Tolerable operating temperature   | Operation  |                  | Not running      |       |    |
|   | Heater / Control box   | -40 °C to +80 °C | -40 °C to +85 °C |       |    |
|   | Metering pump  | -40 °C to +50 °C | -40 °C to +85 °C |       |    |
| Interference suppression class  | interference suppression class 5 to DIN EN 55 025  |                  |                  |       |    |
| Weight with controller and water pump, without metering pump  | approx. 6.2 kg   |                  |                  |       |    |



#### Caution!

#### Safety instructions for technical data

Failure to comply with the technical data can result in malfunctions.

#### Please note!

Provided no limit values are given, the technical data listed is subject to the tolerances usually applicable to heaters of  $\pm 10\%$  for nominal voltage, ambient temperature 20 °C and reference altitude Esslingen.

## 2 Product information

### Technical data

|  |  | <b>Hydronic M-II</b>   |       |                  |             |                  |       |     |
|--|--|--|-------|------------------|-------------|------------------|-------|-----|
| Heater type  |  | Hydronic M12   |       |                  |             |                  |       |     |
| Heater   |  | Hydronic M12   |       |                  |             |                  |       |     |
| Version  |  | D 12 W   |       |                  |             |                  |       |     |
| Heating medium   |  | Mixture of water and antifreeze<br>(Proportion of antifreeze at least 10 % up to 50 % maximum) |       |                  |             |                  |       |     |
| Control of the heat flow   |  | Power  | Large | Medium 1         | Medium 2    | Medium 3         | Small |     |
| Heat flow (watt)   |  | 12000  | 9500  | 5000             | 3500        | 1500             | 1200  |     |
| Fuel consumption (l/h)   |  | 1.5  | 1.2   | 0.65             | 0.40        | 0.18             | 0.15  |     |
| Electrical power (watt)(l)<br>in operation   |  | 132  | 86    | 46               | 39          | 35               | 34    |     |
|  |  | at start – after 25 Sek.   |       |                  |             |                  |       | 120 |
|  |  | in the control phase "OFF"   |       |                  |             |                  |       | 32  |
| Rated voltage  |  | 12 Volt  |       |                  | 24 Volt     |                  |       |     |
| Operating range  |  | 10 Volt  |       |                  | 20 Volt     |                  |       |     |
| <ul style="list-style-type: none"> <li>Lower voltage limit: An undervoltage protection in the controller switches the heater off on reaching the voltage limit.</li> </ul> |  | 15 Volt  |       |                  | 30 Volt     |                  |       |     |
| <ul style="list-style-type: none"> <li>Upper voltage limit: An overvoltage protection in the controller switches the heater off on reaching the voltage limit.</li> </ul>  |  |  |       |                  |             |                  |       |     |
| Tolerable operating pressure   |  | up to 2 bar overpressure   |       |                  |             |                  |       |     |
| Flow rate of the water pump at 0.14 bar  |  | 1400 l/h   |       |                  |             |                  |       |     |
| Minimum water flow rate of the heater  |  | 500 l/h  |       |                  |             |                  |       |     |
| Fuel – see also "Fuel quality diesel heaters" page 27  |  | Commercially available diesel (DIN EN 590)   |       |                  |             |                  |       |     |
| Tolerable operating temperature  |  | Operation  |       |                  | Not running |                  |       |     |
|  |  | Heater / Control box   |       | -40 °C to +80 °C |             | -40 °C to +85 °C |       |     |
|  |  | Metering pump  |       | -40 °C to +50 °C |             | -40 °C to +85 °C |       |     |
| Interference suppression class   |  | interference suppression class 5 to DIN EN 55 025  |       |                  |             |                  |       |     |
| Weight with controller and water pump, without metering pump   |  | approx. 6.2 kg   |       |                  |             |                  |       |     |



#### Caution!

#### Safety instructions for technical data

Failure to comply with the technical data can result in malfunctions.

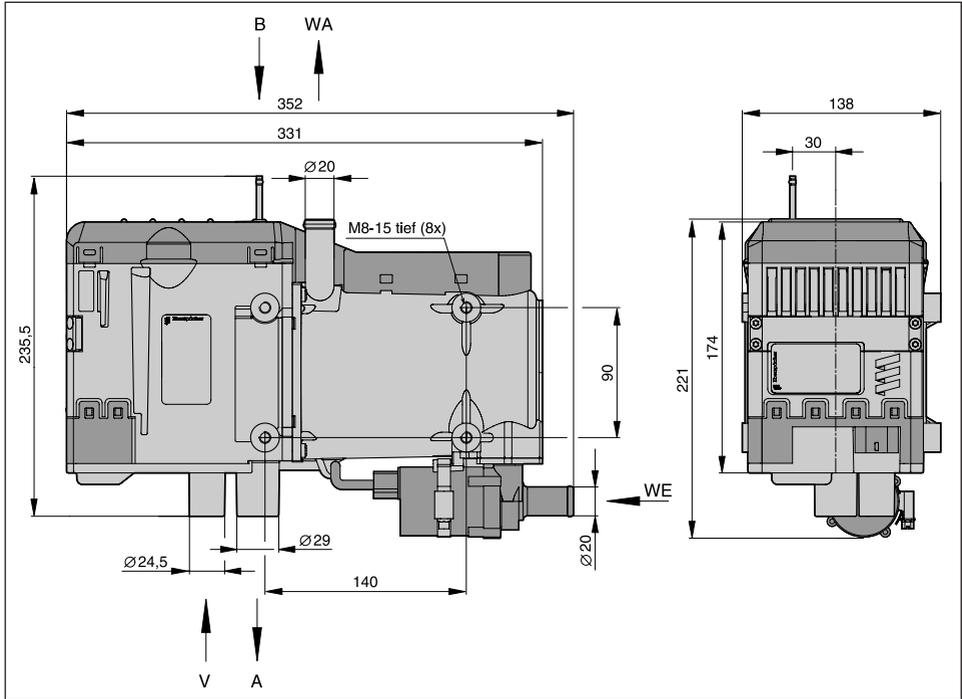
#### Please note!

Provided no limit values are given, the technical data listed is subject to the tolerances usually applicable to heaters of  $\pm 10\%$  for nominal voltage, ambient temperature 20 °C and reference altitude Esslingen.



## 2 Product information

### Main dimensions



- A Exhaust
- B Fuel
- V Combustion air
- WA Water outlet
- WE Water inlet

### 3 Installation

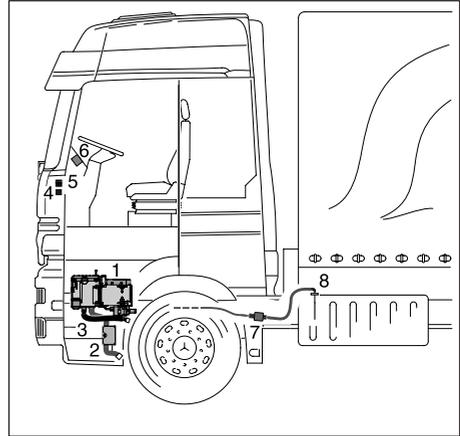
#### Installation location

The installation location for the heater is the engine compartment. The heater must be mounted below the min. cooling water level (compensation tank, cooler, vehicle heat exchanger) for automatic venting of the heat exchanger of the heater and the water pump.

#### Please note!

- In a truck, the water heater is preferably fastened underneath the driver's cab in the longitudinal beam near the vehicle engine.
- The regulations and safety instructions to be observed for this chapter are stated on page 4 – 7.
- The installation suggestions made in the installation instructions are examples. Other installation locations are possible if they correspond to the installation requirements stated in these installation instructions.
- Other installation information (e.g. for boats and ships) is available from the manufacturer on request.
- Please take note of the installation locations together with the operating and storage temperatures.

#### Installation example heater in a truck



- 1 Heater
- 2 Exhaust pipe with exhaust silencer
- 3 Combustion air intake silencer
- 4 Fan relay
- 5 Fuse bracket
- 6 Controls
- 7 Metering pump
- 8 Tank connection

#### Installing the 24 V heater in a vehicle for the transport of dangerous goods as per ADR

For installation of the heater in vehicles for the transport of dangerous goods, the regulations of ADR / ADR99 must be observed.

With the appropriate electrical wiring the heater fulfils the ADR regulations, see the "Additional Regulations" on Page 6, the "Control and Safety Devices" on Page 29 and the "Circuit Diagrams" on Page 34 and 39.

Detailed information about the ADR regulations is contained in leaflet no. 25 2161 95 15 80.



### 3 Installation

#### Possible installation positions

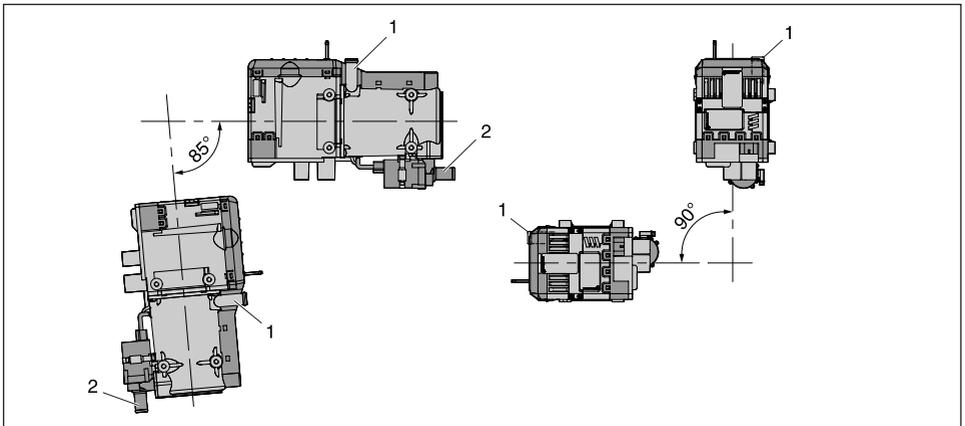
The heater should preferably be installed in the normal position, horizontal with the exhaust connection down to the bottom.

Depending on the installation conditions, the heater can also be mounted in the permitted swivel range, see diagram.

When the heater is operating, the shown normal or maximum installation positions can be varied briefly by up to +15° in all directions. Such deviations caused by the inclined position of the vehicle do not impair the heater functions in any way.

#### Normal position with permitted swivel range

- Swivel range from the normal position swivelled up to max. 85° downward – the heater's water outlet socket is horizontal. The water pump's water inlet socket must face downward.
- Swivel range from the normal position swivelled up to max. 90° to the left about the longitudinal axis – the water outlet socket is at the top of the heater and faces the left.

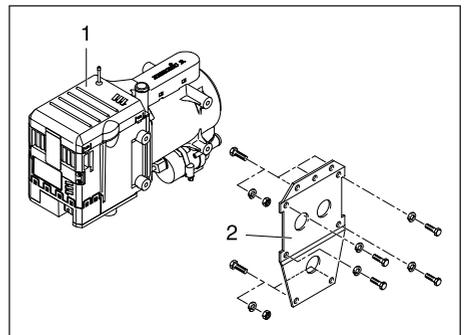


- 1 Water outlet socket, heater  
2 Water inlet socket, water pump

#### Mounting and fastening

Fix the unit holder from the installation kit to the heater using 4 hexagon screws M8 and 4 spring washers (tightening torque 12<sup>+0.5</sup> Nm).

Fix the heater and the mounted unit holder in a suitable place in the vehicle using 5 hexagon screws M8, 5 spring washers and 5 hexagon nuts M8 (tightening torque 12<sup>+0.5</sup> Nm).



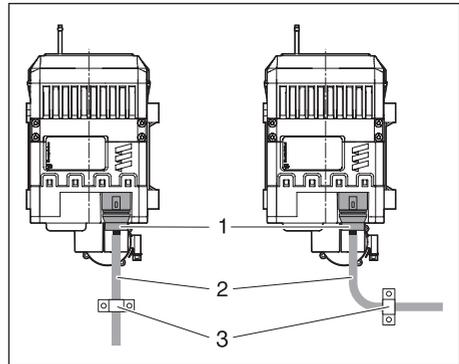
- 1 Heater  
2 Heater bracket

### 3 Installation

#### Connect and lay cable harness to heater

Connect the 12-pin connector of the cable harness to the heater.

Always route the cable harness straight out of the unit connector and fix it so that no forces can be exerted on the connector via the cable harness.



- 1 12-pin connector
- 2 Cable harness
- 3 Fixing

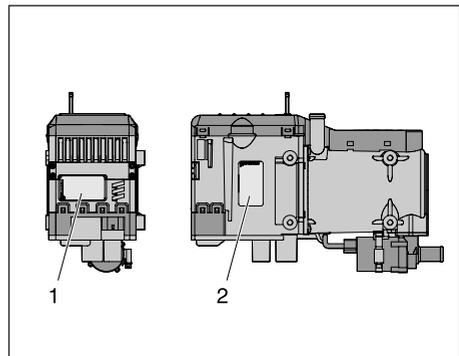
#### Nameplate

The nameplate is on the front and the 2<sup>nd</sup> nameplate (duplicate) is fixed to the side of the control box / fan unit.

If required, the installer can stick the duplicate nameplate in a clearly visible position elsewhere on the heater or near to the heater.

**Please note!**

The regulations and safety instructions to be observed for this chapter are stated on page 5.



- 1 Original nameplate
- 2 2<sup>nd</sup> nameplate (duplicate)



## 3 Installation

### Connection to the cooling water circuit

The heater is connected to the cooling water circuit in the water feed pipe from the vehicle engine to the heat exchanger. There are three possible alternative installations here.

The alternatives are described on pages 16 – 18.



#### **Danger!**

#### **Risk of injuries and burns!**

It is possible for the coolant and components of the coolant circuit to get very hot.

- Parts conveying water must be routed and fastened in such a way that they pose no temperature risk to man, animals or material sensitive to temperature from radiation / direct contact.
- Before working on the coolant circuit, switch the heater off and wait until all components have cooled down completely, if necessary where safety gloves.

#### **Please note!**

- When installing the heater, please take note of the direction of flow of the coolant circuit.
- Fill the heater and water hose with anti-freeze before connecting to the cooling water circuit.
- Route the water hoses without any kinks, and in a rising position if possible.
- Where possible, the water circuit must be installed so that a cooling water temperature of approx. +60 °C is achieved after approx. 30 min.
- When routing the water pipes, observe a sufficient clearance to hot vehicle parts.
- Protect all water hoses / water pipes from chafing and from extreme temperatures.
- Secure all hose connections with hose clips. (tightening torque = 1.5 Nm)
- After the vehicle has been operating for 2 hours or travelled 100 km, tighten the hose clips again.
- The minimum water flow rate is only guaranteed if the temperature difference of the heating medium does not exceed 15 K between water inlet and water outlet during heating.
- Only overpressure valves with an opening pressure of min. 0.4 – max. 2 bar may be used in the coolant circuit.
- The cooling water must contain at least 10 % anti-freeze all year round as corrosion protection.
- During cold periods the cooling water must contain sufficient antifreeze.
- Before commissioning the heater or after changing the cooling liquid, the whole coolant circuit including heater must be vented free of bubbles according to the instructions issued by the vehicle manufacturer.
- Only top up with antifreeze approved by the vehicle manufacturer.

### 3 Installation

#### Connection to the cooling water circuit

##### Integrate the heater with non-return valve in the coolant circuit

Disconnect the water feed pipe from the vehicle engine to the vehicle heat exchanger and insert the non-return valve. Connect the heater with its water pipes to the non-return valve.

##### Advantage:

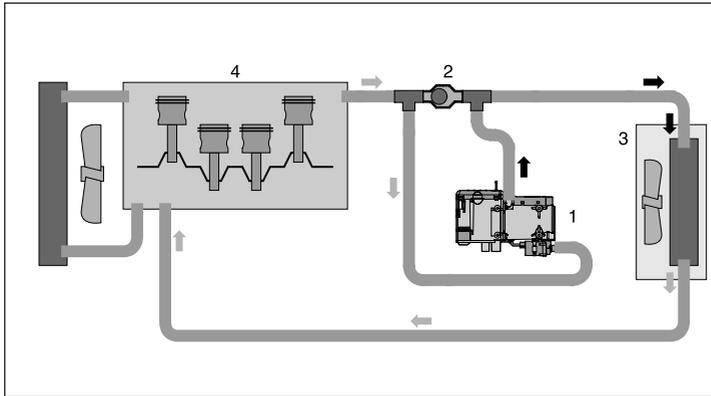
Simple installation.

##### Disadvantage:

The coolant flows through the vehicle engine constantly so that in large vehicle engines, adequate cab heating is scarcely possible.

##### Heating characteristics:

When the heater is switched on, the heat flows through the vehicle heat exchanger and the vehicle engine. Once the cooling water has reached a temperature of approx. 55 °C, depending on the selected fan setting the vehicle fan is switched on and the heat is also conveyed to the passenger compartment.



- 1 Heater
- 2 Non-return valve
- 3 Heat exchanger
- 4 Vehicle engine

#### Please note!

Non-return valve must be ordered separately, please refer to the product information for the Order No.



### 3 Installation

#### Connection to the coolant circuit

##### Integrate the heater with non-return valve, thermostat and T-piece in the coolant circuit

Disconnect the water feed pipe from the vehicle engine to the vehicle heat exchanger and insert the non-return valve.

Disconnect the water return pipe from the heat exchanger to the vehicle engine and insert the T-piece.

Connect the heater and thermostat with water hoses to the non-return valve and T-piece as shown in the diagram.

##### Option:

In addition a solenoid can be fitted in the water circuit. When open, this bypasses the thermostat and pre-heats the engine as soon as the heater starts to work.

##### Heating characteristics

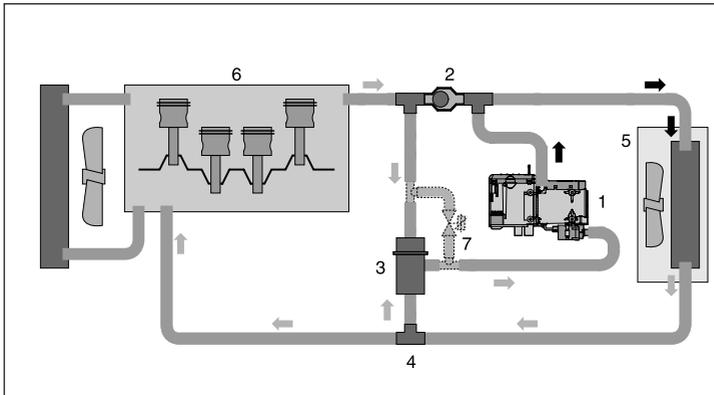
##### • Small coolant circuit: fast heating of the passenger compartment

Initially the heat produced by the heater is only conveyed to the vehicle heat exchanger up to a cooling water temperature of approx. 70 °C.

The vehicle fan switches on at approx. 55 °C.

##### • Large cooling water circuit: heating of the passenger compartment and additional engine pre-heating

If the cooling water temperature continues to increase, the thermostat slowly changes over to the large circuit (full change-over at approx. 75 °C).



- 1 Heater
- 2 Non-return valve
- 3 Thermostat
- 4 T-piece
- 5 Heat exchanger
- 6 Vehicle engine
- 7 Solenoid (option)

#### Please note!

The thermostat, non-return valve and T-piece must be ordered separately, please refer to the product information for the Order No.

The solenoid valve has to be purchased through the trade.

#### Thermostat functions

##### Small coolant circuit

Cooling water temperature < 70 °C:

Connection no. 1: open to the heater

Connection no. 2: open to the T-piece

Connection no. 3: closed to the non-return valve

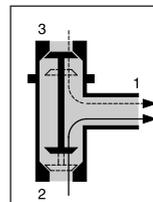
##### Large coolant circuit

Cooling water temperature > 75 °C:

Connection no. 1: open to the heater

Connection no. 2: closed to the T-piece

Connection no. 3: open to the non-return valve



- 1 Connection to the heater
- 2 Connection to the T-piece
- 3 Connection to the non-return valve

#### Please note!

Integrate the thermostat into the water circuit with connections (1) (2) and (3) as shown in the diagram.

### 3 Installation

#### Connection to the coolant circuit

##### Integrate the heater with a solenoid in the coolant circuit

Disconnect the water flow hose from the vehicle's engine to the vehicle's heat exchanger and insert two T-pieces. Connect the T-pieces with a hose. Disconnect the water return pipe from the heat exchanger to the vehicle engine and insert the solenoid. Connect the heater and the solenoid to the T-piece with water pipes, as shown in the diagram.

##### Option:

In addition, a non-return valve with connection hoses between the two T-pieces can be inserted in the cooling water circuit.

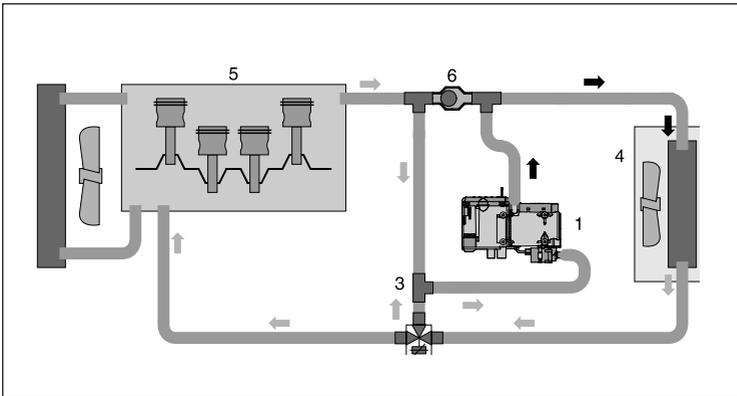
This prevents the loss of effective vehicle heating when the heater is switched off.

##### Heating characteristics

By installing the electric solenoid valve, temperature-independent choice between the small cooling water circuit (driver's cab) and large cooling water circuit (vehicle engine with driver's cab) is possible.

Alternatively, a plus signal from the 12-pin connector B2, PIN B1 to relay 2.5.7 can be used to control the solenoid valve; this enables automatic changeover of the solenoid valve (see circuit diagrams page 32 and 34). Changeover to the large cooling water circuit at a cooling water temperature of 68 °C, if the temperature drops to 58 °C.

Changeover to the small cooling water circuit at a cooling water temperature of 63 °C, if the temperature drops to 45 °C.



- 1 Heater
- 2 Solenoid
- 3 T-piece
- 4 Heat exchanger
- 5 Vehicle engine
- 6 Non-return valve (option)

#### Please note!

T-pieces (tees) and non-return valve must be ordered separately, please refer to the product information for the Order No.

The solenoid valve has to be purchased through the trade.



## 3 Installation

### Exhaust system

(Exhaust diagram see page 22)

#### Mounting the exhaust system

The universal installation kit includes a flexible exhaust pipe, inner  $\varnothing$  30 mm, 1300 mm long and an exhaust silencer.

The exhaust silencer must be installed.

The flexible exhaust pipe can be shortened to 20 cm or lengthened to max. 1.8 m, depending on the installation conditions (See sketch on page 22).

Fasten the exhaust silencer to a suitable position in the vehicle.

Route the flexible exhaust pipe from the heater to the exhaust silencer and fasten with pipe clips.

If necessary, also fasten the flexible exhaust pipe with pipe clips at suitable positions in the vehicle.

Connect the exhaust end pipe to the exhaust silencer with an end sleeve and fasten with a pipe clip.



#### **Danger!**

#### **Risk of injuries and burns!**

Every type of combustion produces high temperatures and toxic exhaust fumes. This is the reason why the exhaust system must be installed according to these instructions.

- Do not perform any work on the exhaust system while the heater is working.
- Before working on the exhaust system, first switch the heater off and wait until all parts have cooled down completely, wear safety gloves if necessary.
- Do not inhale exhaust fumes.



#### **Caution!**

#### **Safety instructions for the exhaust system!**

- The exhaust outlet must end in the open air.
- The exhaust pipe must not protrude beyond the lateral limits of the vehicle.
- Install the exhaust pipe sloping slightly downwards. If necessary, make a drain hole approx.  $\varnothing$  5 mm at the lowest point to drain off condensation.
- Important functional parts of the vehicle must not be impaired (keep sufficient clearance).
- Mount the exhaust pipe with sufficient clearance to heat-sensitive parts. Pay particular attention to fuel pipes (plastic or metal), electrical cables and brake hoses etc.!
- Exhaust pipes must be fastened safely (recommended clearance of 50 cm) to avoid damage from vibrations.
- Route the exhaust system so that the emitted fumes are not sucked in with the combustion air.
- The mouth of the exhaust pipe must not get clogged by dirt and snow.
- The mouth of the exhaust pipe must not point in the direction of travel.
- Always fasten the exhaust silencer to the vehicle.

#### **Please note!**

- Comply with the regulations and safety instructions for this chapter on page 4 – 7.
- The exhaust end pipe should be much shorter than the flexible exhaust pipe from the heater to the exhaust silencer.
- Use pipe clips to secure all connections in the exhaust system.
- To avoid contact corrosion, the clips for fixing the exhaust pipe must be made of stainless steel. Please refer to the product information for the Order No. of the stainless steel fixing clips.

### 3 Installation

#### Combustion air system

##### Mounting the combustion air system

The universal installation kit includes an intake silencer, inner  $\varnothing$  25 mm for the combustion air.

The intake silencer must be installed and, for heating mode up to 1500 m asl, can be extended by up to 2 m max. using a flexible pipe (inner  $\varnothing$  25 mm) and a connection pipe (outer  $\varnothing$  24 mm) – not included in the scope of supply.

Fasten the intake silencer and where applicable the flexible pipe at suitable points in the vehicle using fastening clips and cable ties.

##### Please note!

- Comply with the regulations and safety instructions for this chapter on page 4 – 7.
- Extension of the intake silencer is not allowed if mainly heating mode is used at high altitudes (over 1500 m asl).
- Use pipe clips to secure all connections in the combustion air system.
- For installation in ships and boats, see marine catalogue, if necessary consult the manufacturer.

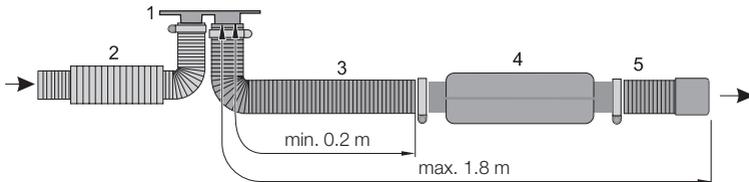


##### Caution!

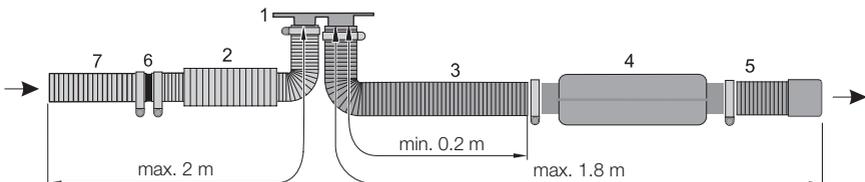
##### Safety instructions for the combustion air system!

- The combustion air must be drawn from an area in which the maximum allowable temperature for the combustion air, of 45 °C, is not exceeded.
- The combustion air opening must be free at all times.
- Position the combustion air intake to be sure that exhaust fumes cannot be sucked in with the combustion air.
- The combustion air intake must not get clogged with dirt and snow.
- Install the combustion air intake system sloping slightly downwards.
- If necessary, make a drain hole approx.  $\varnothing$  5 mm at the lowest point to drain off condensation.
- Avoid tight bends when laying the intake silencer and flexible pipe.

##### Allowable combustion air and exhaust pipe length



With a combustion air system consisting only of one intake silencer, heating mode is possible up to an altitude 3500 m asl (with Hydronic M10 / M12 only).



With a combustion air system consisting of one intake silencer and an extension, heating mode is possible up to an altitude of 1500 m asl (all heater models).

- |  |  |
|--|--|
| 1 Heater flange  | 4 Exhaust silencer                           |
| 2 Intake silencer, 565 mm long<br>(Order No. 20 1689 80 05 00) | 5 Flexible exhaust end pipe                  |
| 3 Flexible exhaust pipe  | 6 Connector (Order No. 25 1226 89 00 31)     |
|  | 7 Flexible pipe (Order No. 10 2114 21 00 00) |



## 3 Installation

### Fuel supply

#### Mounting the metering pump, routing the fuel pipes and mounting the fuel tank

The following safety instructions must be observed when mounting the metering pump, routing the fuel pipes and mounting the fuel tank.



#### **Danger!**

#### **Risk of fire, explosion, poisoning and injuries!**

Caution when handling fuel.

- Switch off the vehicle engine and heater before refuelling and before working on the fuel supply.
- No naked lights when handling fuel.
- Do not smoke.
- Do not inhale fuel vapours.
- Avoid any contact with the skin.

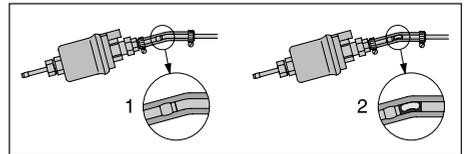


#### **Caution!**

#### **Safety instructions for routing the fuel pipes!**

- Only use a sharp knife to cut off fuel hoses and pipes. Interfaces must not be crushed and must be free of burrs.
- The fuel pipe from the metering pump to the heater should be routed at a continuous rise.
- Fuel pipes must be fastened safely to avoid any damage and / or noise production from vibrations (recommended clearance of approx. 50 cm).
- Fuel pipes must be protected from any mechanical damage.
- Route the fuel pipes so that any distortion of the vehicle, engine movements etc. cannot have any lasting effect on the service life.
- Parts carrying fuel must be protected from interfering heat.

- Never route or fasten the fuel pipes to the heater or vehicle exhaust system. When the systems cross, always ensure there is a sufficient heat clearance. If necessary, install heat deflection plates.
- Dripping or evaporating fuel must never be allowed to collect on hot parts or ignite on electric systems.
- When connecting fuel pipes with a fuel hose, always mount the fuel pipes in a butt joint to prevent any bubbles from forming.



- 1 Correct connection
- 2 Incorrect connection – bubble formation

#### **Please note!**

- Deviations from the instructions stated here are not allowed.
- Failure to comply can result in malfunctions.
- When replacing the Hydronic M (Hydronic 10) with the Hydronic M-II, the metering pump must be replaced too.

#### **Safety instructions for fuel pipes and fuel tanks in buses and coaches**

- In buses and coaches, fuel pipes and fuel tanks must not be routed through the passenger compartment or driver's cab.
- Fuel tanks in buses and coaches must be positioned in such a way that the exits are not in direct danger from a possible fire.

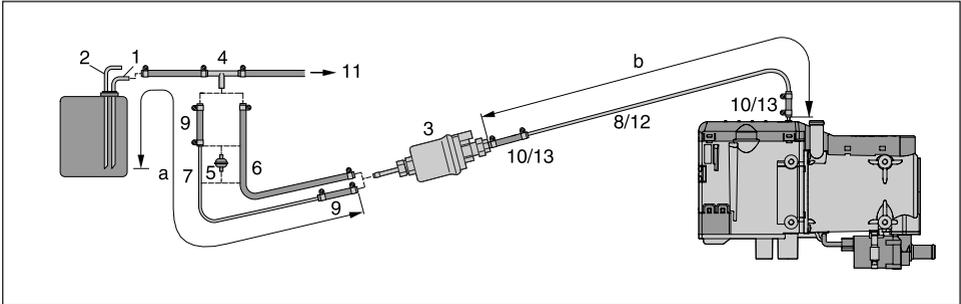
#### **Please note!**

Comply with the regulations and safety instructions for this chapter on page 4 – 7.

### 3 Installation

#### Fuel supply

Fuel feed point with T-piece from the fuel supply line from the tank fitting to the vehicle engine



- 1 Fuel feed pipe from tank connection
- 2 Fuel return pipe to the tank connection
- 3 Metering pump
- 4 T-piece
- 5 Fuel filter
- 6 Fuel hose, 5 x 3 (di = Ø 5 mm)
- 7 Fuel pipe, 6 x 1 (di = Ø 4 mm)
- 8 Fuel pipe, 4 x 1 (di = Ø 2 mm)
- 9 Fuel hose, 5 x 3 (di = Ø 5 mm), approx. 50 mm long
- 10 Fuel hose, 3,5 x 3 (di = Ø 3.5 mm), approx. 50 mm long
- 11 To the engine, mechanical fuel or injection pump.

Required for Hydronic M8 biodiesel for operation with FAME only.

- 12 Fuel pipe blue, 6 x 1 (di = Ø 4 mm)
- 13 Transition piece 3,5 / 5

#### Possible pipe lengths

**Intake side**  
a = max. 2 m

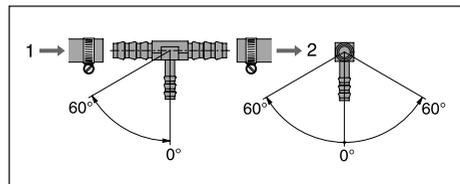
**Pressure side**  
b = min. 1.5 m – max. 6 m

#### Please note!

- Insert the T-piece, Item (4), in the fuel flow line, upstream of the feed pump. T-piece is not included in the "Installation kit" scope of supply. For Order No. please refer to product information.
- Fuel filter, Item (5), is required for contaminated fuel only. Fuel filter is not included in the "installation kit" scope of supply. For Order No. please refer to product information.
- Items (12) and (13) are only included in the "Hydronic M8 Biodiesel" heater's scope of supply.

#### Installation position of the T-piece

Use the installation positions shown in the diagram when inserting a T-piece.



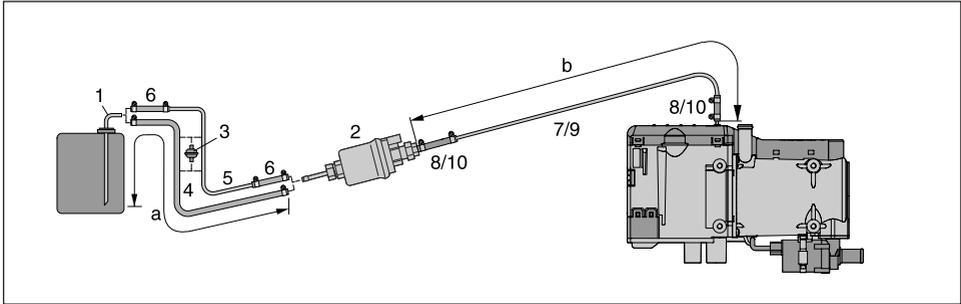
- 1 Direction of flow from the fuel tank
- 2 Direction of flow to the vehicle engine



### 3 Installation

#### Fuel supply

Fuel feed point with tank connection –  
ascending pipe, integrated in the vehicle tank



- 1 Tank connection for metal tank –  
di = Ø 4 mm, da = Ø 6 mm
- 2 Metering pump
- 3 Fuel filter
- 4 Fuel hose, 5 x 3 (di = Ø5 mm)
- 5 Fuel pipe, 6 x 1 (di = Ø 4 mm)
- 6 Fuel hose, 5 x 3 (di = Ø 5 mm), approx. 50 mm long
- 7 Fuel pipe, 4 x 1 (di = Ø 2 mm)
- 8 Fuel hose, 3,5 x 3 (di = Ø 3.5 mm), approx. 50 mm long

Required for Hydronic M8 biodiesel for operation with FAME only.

- 9 Fuel pipe blue, 6 x 1 (di = Ø 4 mm)
- 10 Transition piece 3,5 / 5

#### Possible pipe lengths

**Intake side**  
a = max. 2 m

**Pressure side**  
b = min. 1.5 m – max. 6 m

#### Please note!

- Item (1), tank connection for metal tank, is not included in the “installation kit” scope of supply. For Order No. please refer to product information.
- Fuel filter, Item (3), is required for contaminated fuel only. Fuel filter is not included in the “installation kit” scope of supply. For Order No. please refer to product information.
- Items (9) and (10) are only included in the “Hydronic M8 Biodiesel” heater’s scope of supply.
- When installing tank connection maintain a minimum distance of  $50 \pm 2$  mm from the end of the riser pipe and the bottom of the tank.



#### Caution!

#### Safety instructions for the fuel supply!

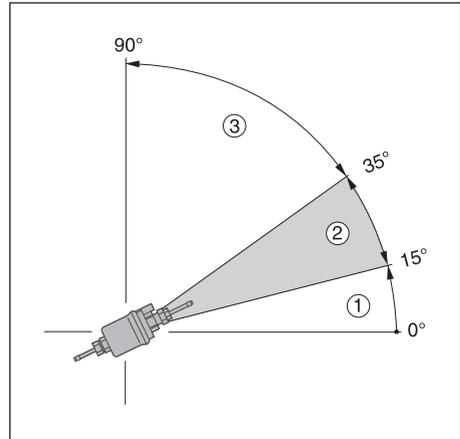
- The fuel must not be conveyed by gravity or overpressure in the fuel tank.
- Withdrawal of fuel after the vehicle’s fuel pump is not allowed.
- When the pressure in the fuel pipe is more than 0.2 bar or there is a non-return valve in the return pipe (in the tank), a separate tank connection must be used.
- When using a T-piece in a plastic pipe, always use support sleeves in the plastic. Connect the T-piece and the plastic pipe with corresponding fuel hoses and secure with hose clips.

### 3 Installation

#### Fuel supply

##### Installation position of the metering pump

Always mount the metering pump with the pressure side rising upwards. Every installation position over 15° is allowed, although an installation position between 15° and 35° is preferable.



- 1 Installation position between 0° and 15° is not allowed.
- 2 Preferred installation position in range 15° to 35°.
- 3 Installation position in range 35° to 90° is allowed.

##### Possible intake and pressure height of the metering pump

Pressure height from vehicle tank to metering pump:  
a = max. 1000 mm

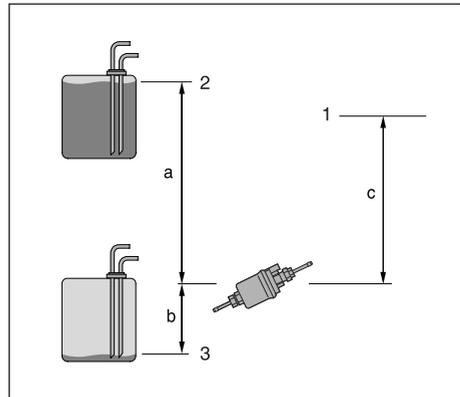
Intake height for non-pressurised vehicle tank:  
b = max. 750 mm

Intake height for a vehicle tank with withdrawal by negative pressure (valve with 0.03 bar in the tank lid):  
b = max. 400 mm

Pressure height from the metering pump to the heater:  
c = max. 2000 mm

#### Please note!

Check tank venting.



- 1 Connection to heater
- 2 Max. fuel level
- 3 Min. fuel level



#### Caution! Safety instructions for installing the metering pump

- Always mount the metering pump with the pressure side rising upwards – minimum incline 15°.
- Protect the metering pump and filter from intolerable heat, do not mount near to the silencers and exhaust pipes.



## 3 Installation

### Fuel supply

#### Fuel quality

- Hydronic M8 Biodiesel, M10 and M12 heaters easily process standard diesel fuel to EN 590. During the winter months the diesel fuel is adapted to low temperatures from 0 °C to -20 °C. Problems can therefore only arise if outdoor temperatures are extremely low – which also applies to the vehicle's engine – please refer to the vehicle manufacturer's regulations.
- In special cases and at outdoor temperatures above 0 °C the heater can also be run on heating oil EL according to DIN 51603.
- If the heater is run from a separate tank, please comply with the following rules:
  - If outdoor temperatures over 0 °C:  
Use diesel fuel according to DIN EN 590.
  - If outdoor temperatures from 0 °C to -20 °C:  
Use winter diesel fuel according to DIN EN 590.
  - If outdoor temperatures -20 °C to -40 °C:  
Use Arctic Diesel or Polar Diesel.

#### Please note!

- It is **not** permitted to add used oil!
- After refuelling with winter or cold diesel or the listed blends, the fuel pipes and the metering pump must be filled with the new fuel by letting the heater run for 15 mins!

#### Operation with biodiesel (FAME for diesel engines according to DIN EN 14 214)

#### Hydronic M8 Biodiesel

The heater is approved for operation with biodiesel up to a temperature of -8°C (the flowability reduces at temperatures below 0 °C).

#### Please note!

- When using 100 % biodiesel, the heater should be run on diesel fuel twice a year (in the middle and at the end of a heating period) to burn off possibly accumulated biodiesel deposits. To do so, let the vehicle tank run almost empty and fill with diesel fuel without adding any biodiesel. While running on this tank filling, switch the heater on 2 to 3 times for 30 minutes at a time at the highest temperature setting.
- If constantly operated with diesel / biodiesel mixtures of up to 50 % biodiesel, intermediate operation with pure diesel fuel is not necessary.

#### Hydronic M10 / Hydronic M12

Both heaters are **not** approved for operation with biodiesel.  
Up to 10 % biodiesel may be added.

## 4 Operation and function

### Operating instructions

The heater is operated by a control unit. The control unit is accompanied by detailed operating instructions which you will receive from the company installing the heater.

### Initial commissioning

The following points are to be checked by the company installing the heater during initial commissioning.

- After installation of the heater, the coolant circuit and the whole fuel supply system must be vented carefully. Comply with the instructions issued by the vehicle manufacturer.
- Open the coolant circuit before the trial run (set the temperature control to "WARM").
- During the trial run of the heater, check all water and fuel connections for leaks and firm fitting.
- If the heater shows a fault during operation, find and eliminate the cause of the fault using a diagnosis unit (Contact JE service partner).

### Important instructions for operation

#### Safety checks before the start

After a longer interval in operations (after the summer months) the fuse must be put in position and / or the heater connected up to the battery. Check that all parts fit firmly (tighten screws where necessary). Check the fuel system visually for any leaks.

#### Before switching on

Before switching on or pre-programming the heater, adjust the heating control in the vehicle to "WARM" (maximum setting) and the fan to "SLOW" (low power consumption).

In vehicles with automatic heating, adjust the heating control to "MAX" and open the heating vents before switching the ignition off.

#### Temperature drop (optional)

The control stages are reached earlier and the heater's control action is adjusted to the lower heat requirement. It is possible to lower the temperature by connecting a plus signal to the 12-pin connector B2, PIN C3, if necessary by integrating an ON-OFF switch (see circuit diagram page 32).

The switch-on temperature (55 °C) and switch-off temperature (40 °C) of the cooling water for switching on or off the vehicle fan are lowered by 10 °C.

### Heating mode at high altitudes – up to 3500 m asl

The combustion behaviour of the heater changes with increasing altitude, due to the lower air density.

The heater has an automatic altitude detection device which it uses to automatically compensate for the change in air density, i.e. the combustion ratio between fuel and air is adapted to the ambient conditions by reducing the fuel quantity.

#### Please note!

- The usual switching limit for altitude detection lies between 1000 m asl and 2000 m asl and solely depends on the local climatic conditions.
- The maximum heating output of the Hydronic M10 / M12 in "Altitude Mode" is 8.5 kW.
- The Hydronic M8 Biodiesel does not have an altitude detection device. Unrestricted heating mode is possible up to 1500 m asl.
- Heaters suitable for high altitudes have "H Kit" marked on the side of the nameplate.

### Description of functions

#### Switching on

On being switched on, the switch-on check is displayed in the control unit. The heater starts, whereby the water pump and the combustion air blower start up first.

The glow phase of the glow pencils begins simultaneously with distribution of the combustion air.

The metering pump starts fuel feed somewhat delayed. The glow pencils are switched off if a stable flame has formed in the combustion chamber.

#### Heating mode

After starting, the heater runs with "POWER" stage until the water temperature exceeds the "POWER" / "HIGH" changeover threshold.

#### Hydronic M8 Biodiesel / M10

Then, depending on the heat requirement, the heater switches to the "HIGH – MEDIUM – LOW – OFF" stages.

#### Hydronic M12

Then, depending on the heat requirement, the heater switches to the "HIGH – MEDIUM 1 / MEDIUM 2 / MEDIUM 3 – LOW – OFF" stages.

If the heating requirement in the "LOW" stage is so small that the cooling water temperature reaches 86 °C, the heater switches from "LOW" to "OFF".

An after-run of approx. 180 seconds follows.

The water pump remains active until the controlled start. If the cooling water has cooled to approx. 72 °C, the Hydronic M8 / M10 heater starts in "MEDIUM" stage, the Hydronic M12 heater starts in "MEDIUM 1" stage.

If the cooling water temperature reaches 55 °C, the vehicle fan switches on; if the temperature drops to 40 °C, the vehicle fan switches back off again.



## 4 Operation and function

### Switching off

After switching off, the heater briefly switches to “LOW” stage to reduce emissions and smoke formation.

This process can take up to 40 seconds maximum if the fuel quantity is constantly reduced.

Once this process has finished the heater starts the after-run for 180 seconds.

During the after-run both glow plugs are switched on alternately.

#### Please note!

In independent heater mode (vehicle engine and heater are switched on), always ensure that the heater is completely switched off before entering a petrol station area.

### Control and safety devices

The heater is equipped with the following control and safety devices:

- If the heater does not ignite within 74 seconds after starting the fuel pump, the start is repeated. If the heater still does not ignite after another 65 seconds, the heater is switched off.\*  
After an unacceptable number of failed start attempts, the controller is locked.\*\*
- If the flame goes off by itself during operation, the heater is restarted. If the heater does not ignite within 74 seconds after the fuel pump has started again, the heater is switched off.\*  
After an unacceptable number of failed start attempts, the controller is locked.\*\*
- In the case of overheating (e.g. lack of water, poorly vented coolant circuit), the overheating sensor triggers, the fuel supply is interrupted and the heater switched off.\*  
Once the cause of overheating has been eliminated, the heater can be re-started by switching off and on again (on condition that the heater has cooled down again sufficiently, cooling water temperature <72 °C).  
After the heater has been switched off for overheating an unacceptable number of times, the controller is locked.\*
- The heater is switched off if the upper or lower voltage limit is reached.\*
- The heater does not start up if the electric cable to the metering pump is interrupted.
- If one of the two glow plugs is defective the start sequence takes place with one glow plug only.

- The speed of the fan motor is monitored continuously. If the blower motor does not start up if it is blocked, or if the speed differs by > 12.5 % from the desired speed a safety lockout (shutdown on faults) takes place after 60 sec.\*

- The water pump's function is continuously monitored.

\* This status can be remedied by briefly switching off and on again.

\*\*For details of how to cancel the lock and to read out errors, refer to the Troubleshooting and Repair instructions of the heater.

#### Please note!

Do not switch the heater off and on again more than twice.

### Forced shut-down for ADR operation

In vehicles for the transport of dangerous goods (e.g. tanker trucks), the heater must be switched off before the truck drives into a danger area (refinery, fuel service station, etc.)

Failure to comply results in the heater switching off automatically when:

- The vehicle engine is switched off.
- An additional unit is started up (e.g. auxiliary drive for unloading pump etc.).

The fan then runs on for max. 40 seconds.

#### Emergency shutdown – EMERGENCY OFF

If an emergency shutdown – EMERGENCY OFF – is necessary during operation, proceed as follows:

- Switch the heater off with the control or
- pull the fuse out or
- disconnect the heater from the battery.

## 5 Electrical system

### Heater wiring

The heater is to be connected up electrically according to the EMC directives.



#### Caution! Safety instructions for wiring the heater

EMC can be affected if the heater is not connected up correctly. For this reason, comply with the following instructions:

- Ensure that the insulation of electrical cables is not damaged. Avoid: chafing, kinking, jamming or exposure to heat.
- In waterproof connectors, seal any connector chambers not in use with filler plugs to ensure they are dirt- and water-proof.
- Electrical connections and ground connections must be free of corrosion and firmly connected.
- Lubricate connections and ground connections outside the heater interior with contact grease.

#### Please note!

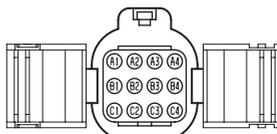
Comply with the following when wiring the heater and the control element:

- Electrical leads, switchgear and controllers must be arranged in the vehicle so that they can function perfectly under normal operating conditions (e.g. heat exposure, moisture etc.).
- The following cable cross sections are to be used between the battery and heater. This ensures that the max. tolerable voltage loss in the cables does not exceed 0.5 V for 12 V or 1 V for 24 V rated voltage. Cable cross sections for a cable length of:
  - up to 5 m (plus cable + minus cable) = cable cross section 4 mm<sup>2</sup>
  - from 5 to 8 m (plus cable + minus cable) = cable cross section 6 mm<sup>2</sup>
 Connection of the cables (plus cable and minus cable) to connector B2 requires a reduction in the cable cross-section to 2.5 mm<sup>2</sup>.
- If the plus cable is to be connected to the fuse box (e.g. terminal 30), the vehicle cable from the battery to the fuse box must be included in rating the overall cable length and possibly re-dimensioned if necessary.
- Insulate unused cable ends.

### Notes on rewiring the 12-pin cable harness connector

If, on replacing the Hydronic M (Hydronic 10) with the Hydronic M-II, the cable harness already installed in the vehicle is to be reused it is necessary to remove the 12-pin connector using the AMP release tool and to rewire it according to the following table (AMP Order No. 1-1579007-4).

#### 12-pin connection pin assignment



Connector is shown from the cable entry side.

| Connection                                   | Cable harness<br>Hydronic M<br>Cross-section<br>Cable colour | Rewiring<br>12-pin connector |                      |
|--|--|------------------------------|----------------------|
|  |  | Hydronic M<br>PIN            | Hydronic M-II<br>PIN |
| Metering pump                                | 1,5 <sup>2</sup><br>gn                                       | C4 →                         | A1                   |
| Terminal 31                                  | 4 <sup>2</sup><br>br   | C3 →                         | A2*                  |
| Terminal 30                                  | 4 <sup>2</sup><br>rt   | C2 →                         | A3*                  |
| Plus signal to the battery power switch      | 1,5 <sup>2</sup><br>ws/rt                                    | C1 →                         | A4                   |
| Plus signal to the relay solenoid valve      | –  | B4 →                         | B1                   |
| Diagnosis                                    | 1 <sup>2</sup><br>bl   | B3 →                         | B4                   |
| Plus signal from the ADR auxiliary drive     | 1 <sup>2</sup><br>vi   | B2 →                         | B3                   |
| External control Water pump                  | –  | B1                           | remains unused**     |
| Relay, blower                                | 1 <sup>2</sup><br>rt/ge                                      | A4 →                         | C1                   |
| Plus signal (D+) to the heater – in ADR mode | 1 <sup>2</sup><br>vi/gn                                      | A3 →                         | C2                   |
| Temperature drop                             | –  | A2 →                         | C3                   |
| Heater ON                                    | 1 <sup>2</sup><br>ge   | A1 →                         | C4                   |

\* Connection of the cables to connector B2 requires a reduction in the cable cross-section to 2.5 mm<sup>2</sup>.

\*\* External control of the water pump is not planned for Hydronic M-II.



## 5 Electrical system

### Parts list for the circuit diagrams Hydronic M-II, 12 Volt / 24 Volt, normal and ADR version

- 1.1 Burner motor
- 1.2 Glow plug 1
- 1.2.1 Glow plug 2
- 1.5 Overheating switch
- 1.12 Flame sensor
- 1.13 Temperature sensor
- 2.1 Controller
- 2.2 Fuel metering pump
- 2.5.7 Relay, for control of vehicle fan
- 2.5.18 Relay, for control of electrical solenoid valve in the water circuit – optional
- 2.7 Main fuse 12 volt = 20 A  
24 volt = 15 A
- 2.7.1 Fuse, actuation 5 A
- 2.7.5 Fuse, vehicle fan 25 A
- 2.12 Water pump
- 5.1 Battery
- 5.2.1 Battery main switch
- 5.2.2 Battery isolating switch
- 5.10 Vehicle fan
- a) Connection, control units
  - a1) ADR feedback
  - a2) Diagnosis
  - a3) Switch-on signal S+
  - a4) Power supply, positive (+) terminal 30
  - a5) Power supply, minus (-) terminal 31
  - a6) (+) Control battery disconnecting switch (diode: order no. 208 00 012)
    - EasyStart R+ / R / T: use the 0.752 bl/ws cable, 12-pin connector B2, PIN B4
    - Use the 0.752 ge cable, 12-pin connector B2, PIN C4 for all other control units
- b) For ADR D+ (dynamo)
- c) For ADR HA+ (auxiliary drive/ secondary drive) minus circuit, if not present, route lead to +
- d)
  - Fused positive control for relay 2.5.18 at terminal 30
  - Positive control for electrical solenoid valve, terminal 87

#### e) Connection heater

##### 12-pin connection pin assignment (external)

| PIN-No. | Connection               | Conductor cross-section<br>mm <sup>2</sup> / Cable colour |
|---------|--------------------------|---|
| A1      | Metering pump            | 1 / gn  |
| B1      | Solenoid valve, optional | 1.0 / –   |
| C1      | Relay, blower            | 1.0 / rt/ge   |
| A2      | Terminal 31              | 2.5 / (4.0) br  |
| B2      | –                        | –   |
| C2      | ADR D+                   | 1.0 / vi/gn   |
| A3      | Terminal 30              | 2.5 / (4.0) rt  |
| B3      | ADR HA+                  | 1.0 / vi  |
| C3      | Temperature drop         | 1.0 / –   |
| A4      | Plus signal output       | 1.5 / ws/rt   |
| B4      | Diagnosis (HELJED)       | 0.75 bl/ws  |
| C4      | Heater ON                | 0.75 ge   |

- f) Temperature drop with positive signal at the 12-pin connector B2, PIN C3.  
Temperature drop
  - Control stages by 7 °C
  - Vehicle blower switching on and off temperature by 10 °C
- g) If only one switching element is used for items 5.2.1 and 5.2.2, it is necessary to ensure that on pressing the battery disconnecting switch (EMERGENCY OFF function in ADR), the switch always breaks contact immediately (regardless of the heater condition) and all the heater's circuits are disconnected from the battery.
- i) Connection, EDiTH diagnostics tool
- x) Disconnect lead

#### Please note!

- In 12 V relay 2.5.7 (from terminal 30 to terminal 87a), a maximum power consumption of 40 A is allowed; i.e. the value of the vehicle's own fan fuse may not be > 40 A.
- Connectors and bush housings are shown from the cable inlet side.
- See page 32 for circuit diagram.

#### Cable colours

- rt = red
- bl = blue
- ws = white
- sw = black
- gn = green
- gr = grey
- ge = yellow
- vi = violet
- br = brown





## 5 Electrical system

### Parts list for the circuit diagrams for the control elements EasyStart R+ / EasyStart R / EasyStart T and EasyStart T – ADR

- 2.15.1 Temperature sensor (room temperature)  
(included in the EasyStart R+ scope of supply,  
optional for EasyStart T)
- 2.15.9 External temperature sensor
- 3.1.7 "ON / OFF" button
- 3.1.16 Radio remote control button
- 3.2.15 EasyStart T timer
- 3.3.9 EasyStart R radio remote control  
(stationary unit)
- 3.3.10 EasyStart R+ radio remote control  
(stationary unit)
- 3.6.1 Adapter cable
- 3.8.3 Antenna
  
- c) Terminal 58 (lighting)
- e) EasyStart T timer connection
- g) External "ON / OFF" button (optional)
- x) ADR jumper

#### Please note!

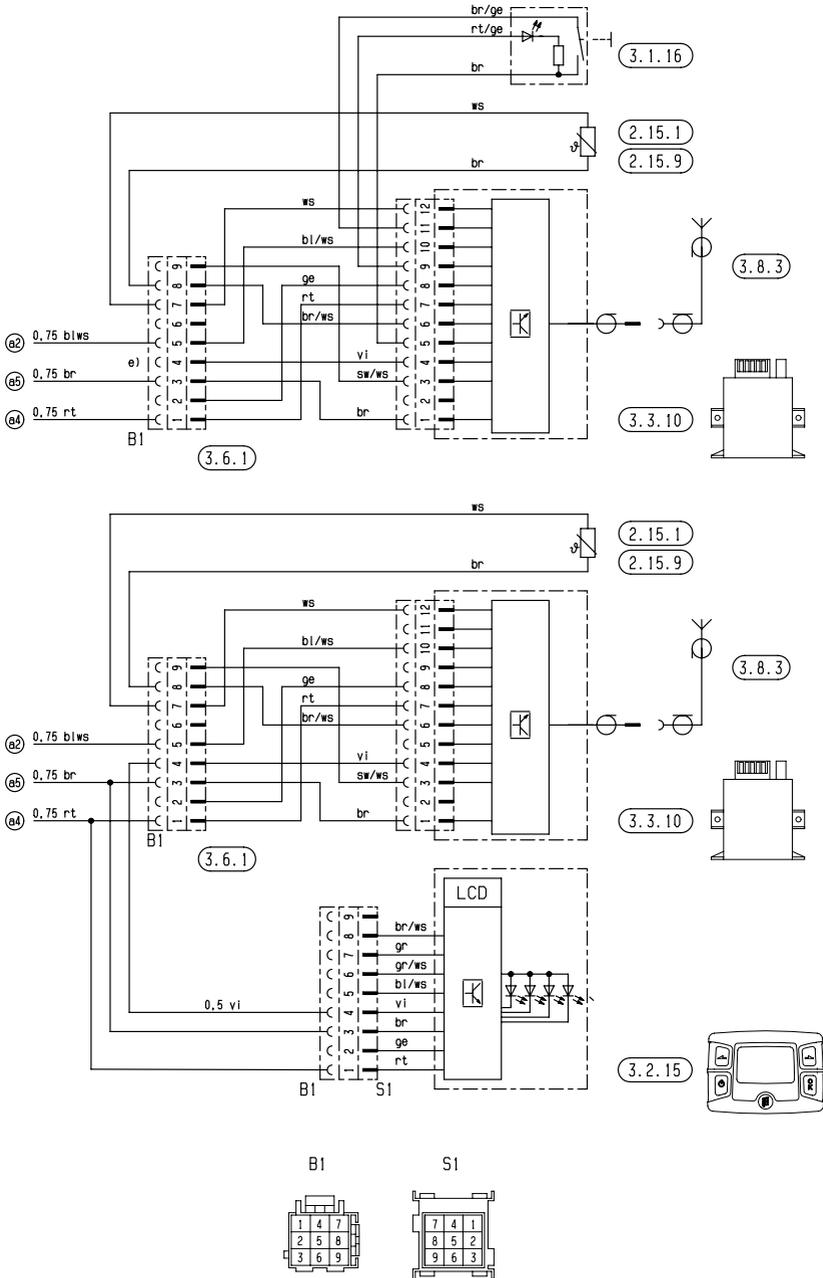
- The timer / radio remote control must be connected in accordance with the circuit diagrams (page 36 – 39).
- Insulate unused cable ends.
- Connectors and bush housings are shown from the cable inlet side.

#### Cable colours

- rt = red
- bl = blue
- ws = white
- sw = black
- gn = green
- gr = grey
- ge = yellow
- vi = violet
- br = brown

# 5 Electrical system

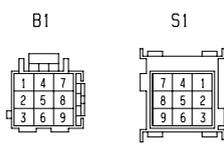
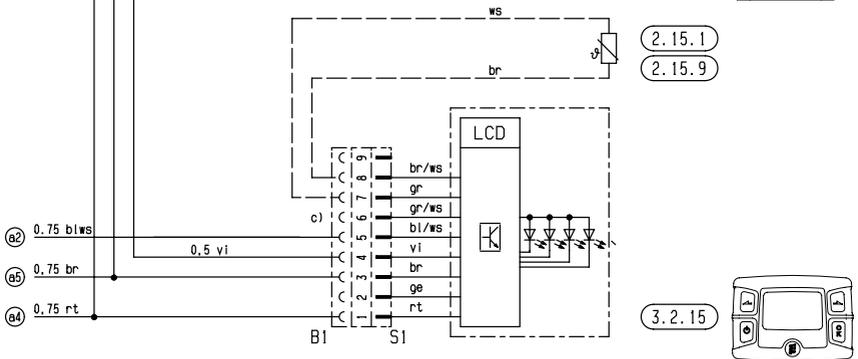
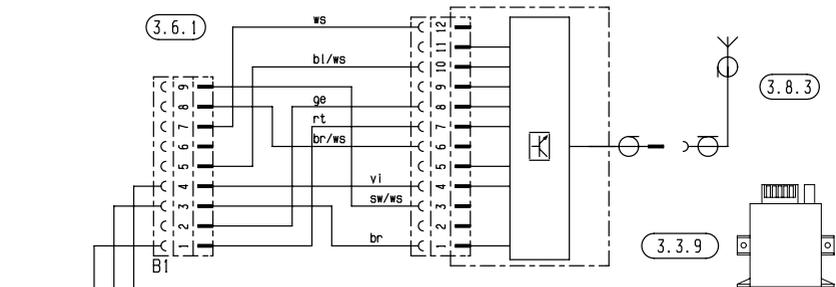
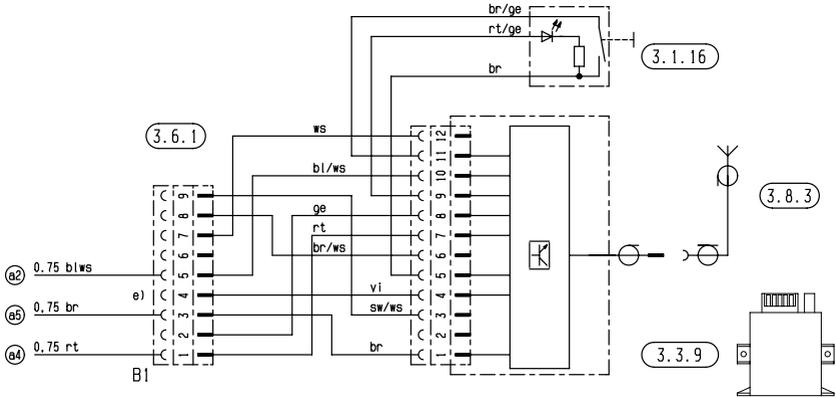
## Circuit diagram for the control element EasyStart R<sup>+</sup>



# 5 Electrical system

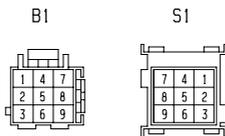
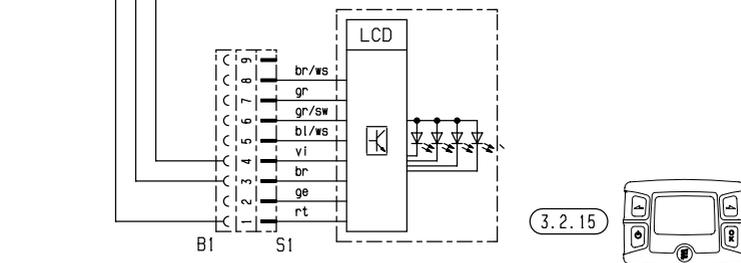
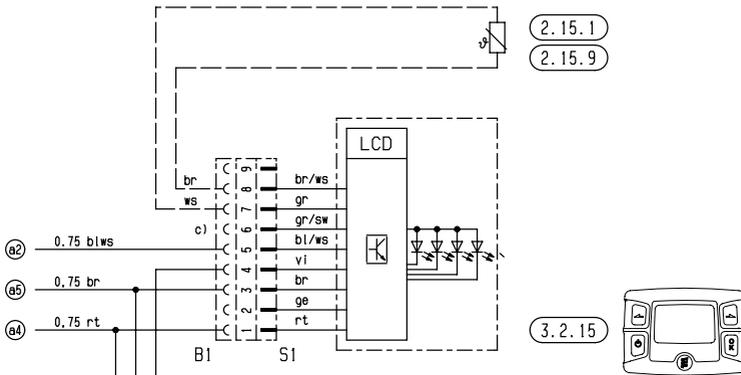
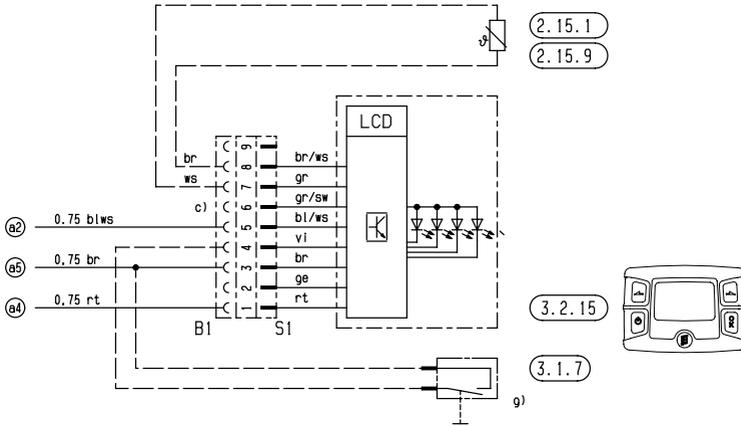


## Circuit diagram for the control element EasyStart R



# 5 Electrical system

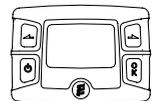
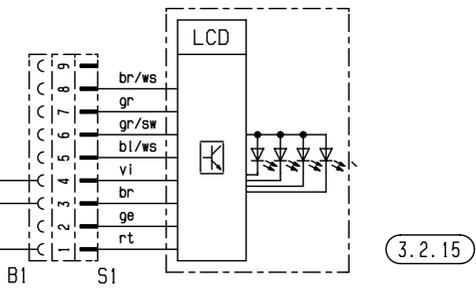
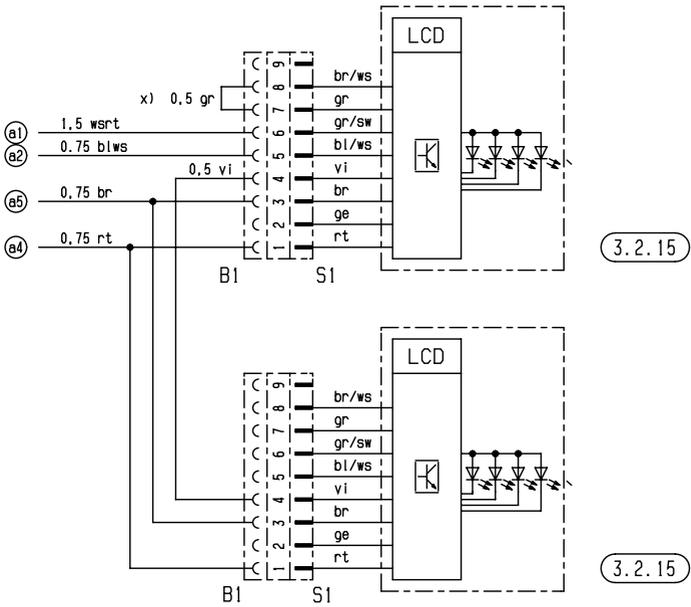
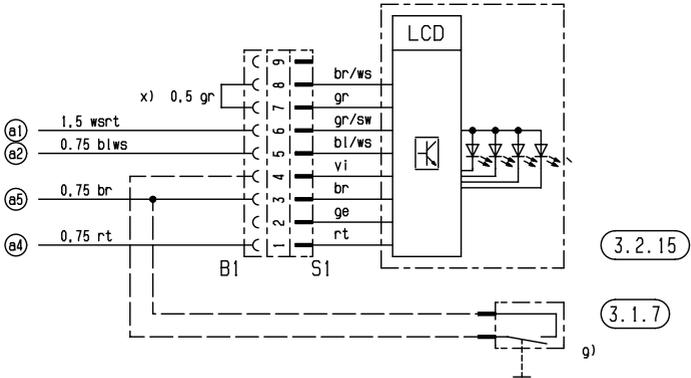
## Circuit diagram for the control element EasyStart T





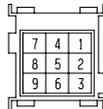
# 5 Electrical system

## Circuit diagram for the control element EasyStart T – ADR



B1

S1



## 6 Troubleshooting / Maintenance / Service

---

### In case of faults, please check the following points

- If the heater does not start after being switched on:
  - Switch the heater off and on again.
- If the heater still does not start, check whether:
  - There is fuel in the tank?
  - The fuses are OK?
  - The electrical cables, connections etc. are OK?
  - Anything is clogging the combustion air supply or exhaust system?
- Check the openings of the combustion air supply and exhaust system after longer standstill periods, clean if necessary!

### Troubleshooting

If the heater remains faulty even after these points have been checked, or another malfunction occurs in your heater, please contact:

- For installation ex works, your contract workshop.
- For subsequent installation, the workshop who installed your heater.

#### **Please note!**

Please note that warranty claims can become void if the heater is changed by a third party or by this installation of third party parts.

### Maintenance instructions

- Switch the heater on once a month for about 10 minutes, even outside the heating period.
- Before the heating period starts, the heater should undergo a trial run. If persistent extreme smoke develops, unusual burning noises or a clear fuel smell can be perceived or if electric / electronic parts heat up, the heater must be switched off and put out of service by removing the fuse.  
In this case, the heater should not be started up again until it has been checked by qualified staff who have been trained on Eberspächer heaters.

### Service

If you have any technical queries or problems with your pre-heater, dial the following service phone number:

Hotline  
Phone 0800 / 12 34 300

Fax hotline  
Fax 01805 / 26 26 24

Outside of Germany, please contact the respective national Eberspächer service agent.



## 7 Environment

### Certification

The high quality of Eberspächer's products is the key to our success.

To guarantee this quality, we have organised all work processes in the company along the lines of quality management (QM).

Even so, we still pursue a large number of activities for continuous improvement of product quality in order to keep pace with the similarly constantly growing requirements made by our customers.

All the steps necessary for quality assurance are stipulated in international standards.

This quality is to be considered in a total sense.

It affects products, procedures and customer/supplier relationships.

Officially approved public experts assess the system and the corresponding certification company awards a certificate.

Eberspächer has already qualified for the following standards:

**Quality management as per  
DIN EN ISO 9001:2000 and ISO/TS 16949:1999**

**Environment management system as per  
DIN EN ISO 14001:1996**

### Disposal

#### Disposal of materials

Old devices, defect components and packaging material can all be separated and sorted into pure-grade fractions so that all parts can be disposed of as required in an environment-friendly manner or recycled where applicable.

Electric motors, controllers and sensors (e.g. temperature sensors) are deemed to be "electronic scrap".

#### Dismantling the heater

The heater is dismantled according to the repair stages in the current troubleshooting / repair instructions.

#### Packaging

The packaging of the heater can be kept in case it has to be sent back.

### EU Declaration of Conformity

The manufacturer:

**J. Eberspächer GmbH & Co. KG**

Address:

Eberspächerstraße 24

D-73730 Esslingen

herewith declares that the following product:

|               |                                |
|---------------|--------------------------------|
| Product name: | <b>Vehicle heater</b>          |
| Type          | <b>Hydronic M-II</b>           |
| Version       | <b>D 8 W / D 10 W / D 12 W</b> |

fulfils the requirements of the following EC Directives:

- Heating systems directive 2001/56/EC,  
Revision status 2006/119/EC
- Radio interference (EMC) of vehicles 72/245/EEC,  
Revision status 2006/96/EC
- Heater control ECE-R 122,  
Revision status 00
- EMC of vehicles ECE-R 10,  
Revision status 03

The following EC Directives and UN regulations have been used to assess the product:

2001/56/EC; 72/245/EEC; ECE-R 10; ECE-R 122

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## List of abbreviations

### ADR

European agreement about the international transport of dangerous goods on the road.

### EC type approval / EMC type approval

Permit awarded by the Federal Vehicle Office for the production of a heater for installation in motorised vehicles.

### EMC directive

Electromagnetic compatibility.

### JE partner

J. Eberspächer partner.

### FAME (Biodiesel)

(FAME for diesel engines according to DIN EN 14 214)

[www.eberspaecher.com](http://www.eberspaecher.com)

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D-73730 Esslingen  
Telefon 0711 939-00  
Telefax 0711 939-0643  
info@eberspaecher.com



**Eberspächer®**

# Multi-function (7 Day Timer) Manual



Espar Heater Systems

**Installation Instructions**  
**Operating Instructions**

Espar Products, Inc.  
(905) 670-0960  
(800) 387-4800 Canada & U.S.A.  
(905) 670-0728 Fax

[www.espar.com](http://www.espar.com)

## Timer only

P/N 22 1000 30 36 00 (Coolant heater 12/24 volt)

P/N 22 1000 30 40 00 (Air heater 12/24 volt)

## Timer kit w/mounting bracket

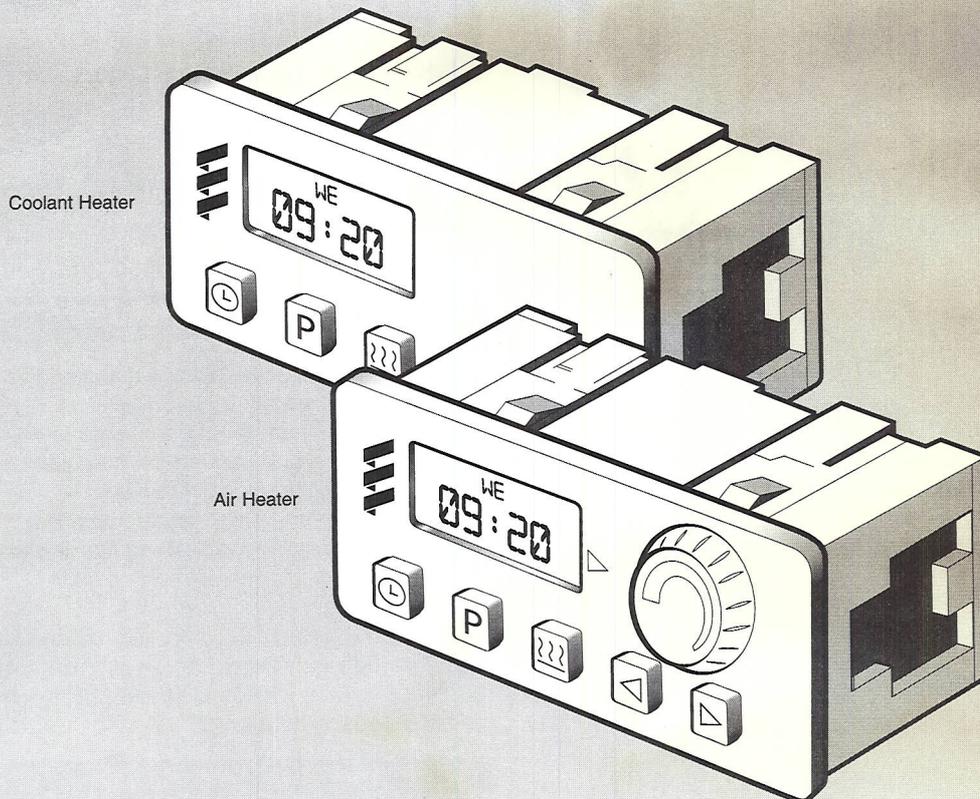
P/N 20 2900 70 02 30 (Coolant heaters)

P/N 20 2900 70 02 35 (Air heaters)

## Timers with adaptor but no relay

P/N 20 2900 70 02 01 (Coolant heater 24 volt)

P/N 20 2900 70 02 10 (Air heater 12 volt)



P/N: 20.2900.81.3104.0Z

02.2008 Subject to Change

Printed in Canada



## Using the Timer with the Vehicle Ignition "Off"

Push button.

will appear on the display as well as the operation count-down timer.

The running time is factory set to maximum of 120 minutes. This running time can be reset once or permanently as desired.

## Adjusting Preheat Time Once

Press button.

The will appear in the display and the preselected run time will appear in the display (maximum time of 120 minutes). Use the or to adjust the desired run time.

## Adjusting the Heater Preheat Time Permanently

(Maximum Preheat Time of 120 minutes)

Push and hold (about 3 seconds) until the display lights up and flashes. Release button.

Use or to set the new fixed preheat time.

When the display goes off the new preheat time is set.

**Note:** At the end of a preheat cycle the timer will turn the heater off. The heater will complete a cool down cycle and turn itself off

## Using the Heater Manually with the Vehicle Accessory "On"

(Optional wire on pin 10 is connected to the ignition lock)

Push button.

The symbol will appear in the display next to the time of day.

The time of day will remain displayed during ignition on operation.

The heater will function continually as long as the vehicle ignition is "On".

When the vehicle ignition is turned "Off" the heater will continue to operate for an additional 15 minutes.

The run time can be altered by pressing the or buttons. The heater can be turned off by pressing button.

## Set Preheat Times into Memory

Press button until the desired memory location is shown in the display (Three memory locations are available). Using the or buttons set the desired preheat start time of day.

When the time stops flashing the time of day is set.

Using the or buttons set the desired day of the week. When the day of the week stops flashing the day is set.

## To Use Preset Start Times

Press the button until the desired memory location appears in the display.

The heater will start at the day and time displayed.

The display will go off in 15 seconds. The memory location number will stay displayed (1, 2 or 3).

**Note:** When preset is chosen this symbol will flash red.

## To Turn Heater "Off"- All Modes

Press the button once.

The heat signal to the heater will be turned "Off".

The heater will do a normal cooldown and turn itself "Off".

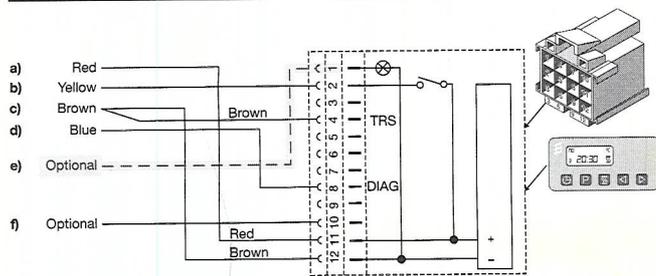
**Note:** When the vehicle lights are turned "On" the timer backlight will come "On" also.

**Note:** This timer is equipped to display fault code numbers if the heater should shut down due to an operating fault. The fault code will show in the timer display next to the flashing heat wave symbol. This applies to all current model heaters when the blue diagnostic wire is connected.

**Note:** If the timer is purchased without the harness kit, the following heaters will need a load relay installed (D8Lc, D7W, D12W, D24W and D30W). These heaters carry a load on the switch wire. (i.e. fuel metering pump or solenoid valve).

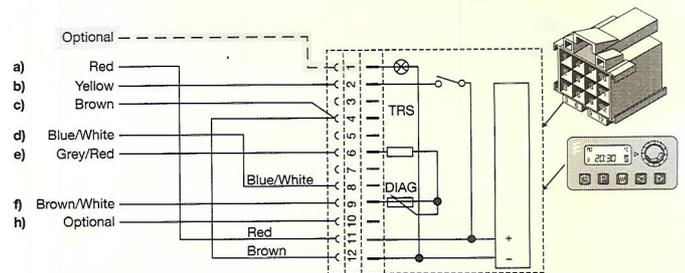
**Note:** An outside temperature sensor is available as an option.

Coolant Heater Timer Connections



- a) Power from battery "+"
- b) Switch control to heater
- c) Power from battery "+"
- d) Diagnostic from heater
- e) To vehicle dimmer switch for light display
- f) To vehicle ignition accessories for continuous operation of heater and for unlocking heaters ECU

Air Heater Timer Connection



- a) Power from battery "+"
- b) Switch control to heater
- c) Power from battery "+"
- d) Diagnostic from heater
- e) Temperature setting "+"
- f) Temperature setting "-"
- g) To vehicle dimmer switch for light display
- h) To vehicle ignition accessories for continuous operation of heater and for unlocking heaters ECU

# Multi-function (7 Day Timer) Manual



Espar Heater Systems

Installation Instructions  
Operating Instructions

Espar Products, Inc.  
(905) 670-0960  
(800) 387-4800 Canada & U.S.A.  
(905) 670-0728 Fax

[www.espar.com](http://www.espar.com)

## Timer only

P/N 22 1000 30 36 00 (Coolant heater 12/24 volt)

P/N 22 1000 30 40 00 (Air heater 12/24 volt)

## Timer kit w/mounting bracket

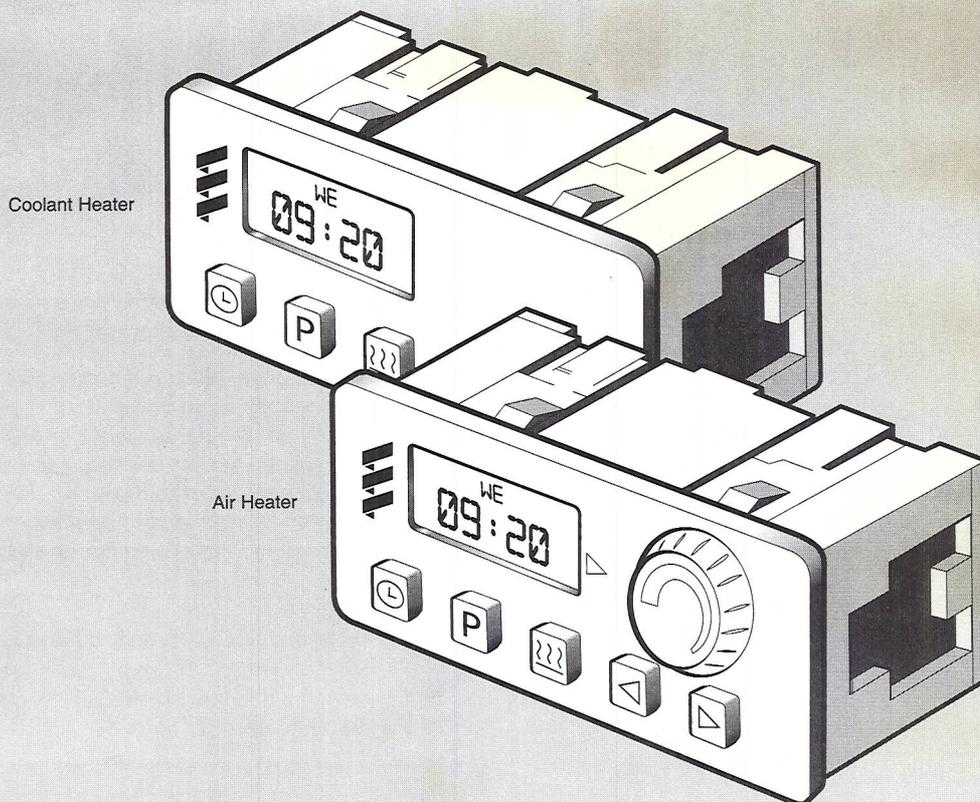
P/N 20 2900 70 02 30 (Coolant heaters)

P/N 20 2900 70 02 35 (Air heaters)

## Timers with adaptor but no relay

P/N 20 2900 70 02 01 (Coolant heater 24 volt)

P/N 20 2900 70 02 10 (Air heater 12 volt)





## Using the Timer with the Vehicle Ignition "Off"

Push button.  
 will appear on the display as well as the operation count-down timer.  
 The running time is factory set to maximum of 120 minutes.  
 This running time can be reset once or permanently as desired.

## Adjusting Preheat Time Once

Press button.  
 The will appear in the display and the preselected run time will appear in the display (maximum time of 120 minutes).  
 Use the or to adjust the desired run time.

## Adjusting the Heater Preheat Time Permanently

(Maximum Preheat Time of 120 minutes)

Push and hold (about 3 seconds) until the display lights up and flashes. Release button.  
 Use or to set the new fixed preheat time.  
 When the display goes off the new preheat time is set.

**Note:** At the end of a preheat cycle the timer will turn the heater off. The heater will complete a cool down cycle and turn itself off

## Using the Heater Manually with the Vehicle Accessory "On"

(Optional wire on pin 10 is connected to the ignition lock)

Push button.  
 The symbol will appear in the display next to the time of day.  
 The time of day will remain displayed during ignition on operation.  
 The heater will function continually as long as the vehicle ignition is "On".  
 When the vehicle ignition is turned "Off" the heater will continue to operate for an additional 15 minutes.  
 The run time can be altered by pressing the or buttons.  
 The heater can be turned off by pressing button.

## Set Preheat Times into Memory

Press button until the desired memory location is shown in the display (Three memory locations are available).  
 Using the or buttons set the desired preheat start time of day.  
 When the time stops flashing the time of day is set.  
 Using the or buttons set the desired day of the week.  
 When the day of the week stops flashing the day is set.

## To Use Preset Start Times

Press the button until the desired memory location appears in the display.  
 The heater will start at the day and time displayed.  
 The display will go off in 15 seconds. The memory location number will stay displayed (1, 2 or 3).  
**Note:** When preset is chosen this symbol will flash red.

## To Turn Heater "Off"- All Modes

Press the button once.  
 The heat signal to the heater will be turned "Off".  
 The heater will do a normal cooldown and turn itself "Off".

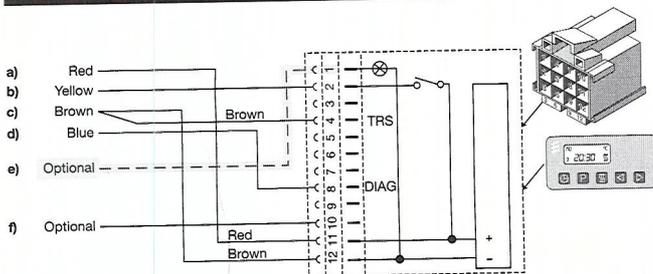
**Note:** When the vehicle lights are turned "On" the timer backlight will come "On" also.

**Note:** This timer is equipped to display fault code numbers if the heater should shut down due to an operating fault. The fault code will show in the timer display next to the flashing heat wave symbol. This applies to all current model heaters when the blue diagnostic wire is connected.

**Note:** If the timer is purchased without the harness kit, the following heaters will need a load relay installed (D8Lc, D7W, D12W, D24W and D30W).  
 These heaters carry a load on the switch wire. (i.e. fuel metering pump or solenoid valve).

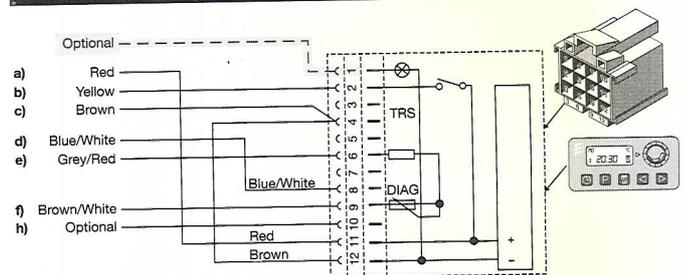
**Note:** An outside temperature sensor is available as an option.

Coolant Heater Timer Connections



- a) Power from battery "+"
- b) Switch control to heater
- c) Power from battery "-"
- d) Diagnostic from heater
- e) To vehicle dimmer switch for light display
- f) To vehicle ignition accessories for continuous operation of heater and for unlocking heaters ECU

Air Heater Timer Connection



- a) Power from battery "+"
- b) Switch control to heater
- c) Power from battery "-"
- d) Diagnostic from heater
- e) Temperature setting "+"
- f) Temperature setting "-"
- g) To vehicle dimmer switch for light display
- h) To vehicle ignition accessories for continuous operation of heater and for unlocking heaters ECU



## 1. Product and company identification

|                                      |   |
|--------------------------------------|---|
| <b>Product name</b>                  | DIESEL FUEL NO. 2   |
| <b>MSDS #</b>                        | 11155   |
| <b>Code</b>                          | 11155   |
| <b>Product use</b>                   | Fuel.   |
| <b>Synonyms</b>                      | Ultra Low Sulfur No. 2 Amoco Premier Diesel Fuel, Ultra Low Sulfur No. 2 Amoco Premier Diesel Fuel – Winterized, Ultra Low Sulfur No. 2 BP Supreme Diesel, Low Sulfur No. 2 BP Diesel Fuel, Ultra Low Sulfur No. 2 BP Diesel Fuel, Ultra Low Sulfur No. 2 BP Diesel Fuel – Winterized |
| <b>Supplier</b>                      | BP Products North America Inc.<br>150 West Warrenville Road<br>Naperville, Illinois 60563-8460<br>USA   |
| <b>EMERGENCY HEALTH INFORMATION:</b> | 1 (800) 447-8735<br><br>Outside the US: +1 703-527-3887 (CHEMTREC)  |
| <b>EMERGENCY SPILL INFORMATION:</b>  | 1 (800) 424-9300 CHEMTREC (USA)   |
| <b>OTHER PRODUCT INFORMATION</b>     | 1 (866) 4 BP - MSDS<br>(866-427-6737 Toll Free - North America)<br>email: <a href="mailto:bpcares@bp.com">bpcares@bp.com</a>  |

## 2. Hazards identification

|                                 |  |
|---------------------------------|--|
| <b>Physical state</b>           | Liquid.  |
| <b>Color</b>                    | Colorless. to Various Colors. (May be dyed Red., Light Green. ,Yellow. )   |
| <b>Emergency overview</b>       | <p>WARNING !</p> <p>COMBUSTIBLE LIQUID AND VAPOR.<br/>VAPOR MAY CAUSE FLASH FIRE.<br/>HARMFUL IF SWALLOWED.<br/>ASPIRATION HAZARD.<br/>HARMFUL OR FATAL IF LIQUID IS ASPIRATED INTO LUNGS.<br/>MAY CAUSE RESPIRATORY TRACT IRRITATION.<br/>INHALATION CAUSES HEADACHES, DIZZINESS, DROWSINESS, AND NAUSEA, AND MAY LEAD TO UNCONSCIOUSNESS.</p> <p>Combustible liquid. Harmful if swallowed. Aspiration hazard if swallowed. Can enter lungs and cause damage. Keep away from heat, sparks and flame. Avoid exposure - obtain special instructions before use. Do not breathe vapor or mist. Do not ingest. If ingested, do not induce vomiting. Avoid contact with eyes, skin and clothing. Contains material which may cause cancer, based on animal data. Risk of cancer depends on duration and level of exposure. Use only with adequate ventilation. Keep container tightly closed and sealed until ready for use. Wash thoroughly after handling.</p> |
| <b>Routes of entry</b>          | Dermal contact. Eye contact. Inhalation. Ingestion.  |
| <b>Potential health effects</b> |  |
| <b>Eyes</b>                     | Slightly irritating to the eyes.   |
| <b>Skin</b>                     | Prolonged or repeated contact can defat the skin and lead to irritation and/or dermatitis.   |
| <b>Inhalation</b>               | May cause respiratory tract irritation. Inhalation causes headaches, dizziness, drowsiness and nausea and may lead to unconsciousness. See toxicological information (section 11).   |

|                                       |                                  |  |
|---------------------------------------|----------------------------------|--|
| <b>Product name</b> DIESEL FUEL NO. 2 | <b>Product code</b> 11155        | <b>Page:</b> 1/8                             |
| <b>Version</b> 2                      | <b>Date of issue</b> 07/20/2010. | <b>Format</b> US-COMP                        |
|                                       | <b>(US-COMP)</b>                 | <b>Language</b> ENGLISH.<br><b>(ENGLISH)</b> |

## Ingestion

Harmful if swallowed. Aspiration hazard if swallowed. Can enter lungs and cause damage. See toxicological information (section 11).

[See toxicological information \(section 11\)](#)

### 3. Composition/information on ingredients

| Ingredient name   | CAS #       | %        |
|---|-------------|----------|
| Petroleum distillates (Diesel Fuel No. 2)                               | 68476-34-6  | 95 - 100 |
| Contains one or more of the following biodiesels:                       | Varies      | 0 - 5    |
| soybean oil, me ester   | 67784-80-9  | .        |
| Fatty acids, sunflower-oil, Me esters                                   | 68919-54-0  | .        |
| Fatty acids methyl esters   | 67762-38-3  | .        |
| Fatty acids, vegetable-oil, Methyl esters                               | 68990-52-3  | .        |
| rape oil, me ester  | 73891-99-3  | .        |
| Fatty acids, canola-oil, Me esters                                      | 129828-16-6 | .        |
| fatty acids, tallow, me esters  | 61788-61-2  | .        |
| Contains:   |             |          |
| Naphthalene   | 91-20-3     | 1 - 3    |
| May also contain small quantities of proprietary performance additives. |             |          |

### 4. First aid measures

|                     |  |
|---------------------|--|
| <b>Eye contact</b>  | In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Get medical attention.  |
| <b>Skin contact</b> | Flush contaminated skin with plenty of water. Remove contaminated clothing and shoes. Wash clothing before reuse. Clean shoes thoroughly before reuse. Get medical attention if irritation develops. |
| <b>Inhalation</b>   | If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention immediately.   |
| <b>Ingestion</b>    | Aspiration hazard if swallowed. Can enter lungs and cause damage. Do not induce vomiting. Never give anything by mouth to an unconscious person. Get medical attention immediately.                  |

### 5. Fire-fighting measures

|                                       |  |
|---------------------------------------|--|
| <b>Flammability of the product</b>    | Combustible liquid.  |
| <b>Auto-ignition temperature</b>      | 257°C (494°F)  |
| <b>Flash point</b>                    | Closed cup: >38°C (>100.4°F) [Pensky-Martens.]   |
| <b>Explosion limits</b>               | Lower: 0.6%<br>Upper: 7.5%   |
| <b>Fire/explosion hazards</b>         | Combustible liquid and vapor. Vapor may cause flash fire. Vapors may accumulate in low or confined areas or travel a considerable distance to a source of ignition and flash back. Runoff to sewer may create fire or explosion hazard.  |
| <b>Unusual fire/explosion hazards</b> | Explosive in the presence of the following materials or conditions: open flames, sparks and static discharge and heat.   |
| <b>Extinguishing media</b>            |  |
| <b>Suitable</b>                       | In case of fire, use water fog, foam, dry chemicals, or carbon dioxide.  |
| <b>Not suitable</b>                   | Do not use water jet.  |
| <b>Fire-fighting procedures</b>       | Promptly isolate the scene by removing all persons from the vicinity of the incident if there is a fire. No action shall be taken involving any personal risk or without suitable training. Move containers from fire area if this can be done without risk. Use water spray to keep fire-exposed containers cool. |
| <b>Hazardous combustion products</b>  | Combustion products may include the following:<br>carbon oxides (CO, CO <sub>2</sub> ) (carbon monoxide, carbon dioxide)   |
| <b>Protective clothing (fire)</b>     |  |

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Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode.

### Special remarks on fire hazards

Do not use water jet.

---

## 6. Accidental release measures

### Environmental precautions

Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers. Inform the relevant authorities if the product has caused environmental pollution (sewers, waterways, soil or air).

### Personal protection in case of a large spill

Chemical splash goggles. Chemical-resistant protective suit. Boots. Chemical-resistant gloves. Self-contained breathing apparatus (SCBA) should be used to avoid inhalation of the product. Suggested protective clothing might not be adequate. Consult a specialist before handling this product. CAUTION: The protection provided by air-purifying respirators is limited. Use a positive pressure air-supplied respirator if there is any potential for an uncontrolled release, if exposure levels are not known, or if concentrations exceed the protection limits of air-purifying respirator.

### Methods for cleaning up

#### Large spill

Stop leak if without risk. Eliminate all ignition sources. Move containers from spill area. Approach release from upwind. Prevent entry into sewers, water courses, basements or confined areas. Wash spillages into an effluent treatment plant or proceed as follows. Contain and collect spillage with non-combustible, absorbent material e.g. sand, earth, vermiculite or diatomaceous earth and place in container for disposal according to local regulations (see section 13). Use spark-proof tools and explosion-proof equipment. Dispose of via a licensed waste disposal contractor. Contaminated absorbent material may pose the same hazard as the spilled product. Note: see section 1 for emergency contact information and section 13 for waste disposal.

#### Small spill

Stop leak if without risk. Eliminate all ignition sources. Move containers from spill area. Absorb with an inert material and place in an appropriate waste disposal container. Use spark-proof tools and explosion-proof equipment. Dispose of via a licensed waste disposal contractor.

---

## 7. Handling and storage

### Handling

Do not ingest. Never siphon by mouth. If ingested, do not induce vomiting. Put on appropriate personal protective equipment (see section 8). Workers should wash hands and face before eating, drinking and smoking. Do not get in eyes or on skin or clothing. Do not breathe vapor or mist. Use only with adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Do not enter storage areas and confined spaces unless adequately ventilated. Store and use away from heat, sparks, open flame or any other ignition source. Use explosion-proof electrical (ventilating, lighting and material handling) equipment. Use non-sparking tools. Take precautionary measures against electrostatic discharges. To avoid fire or explosion, dissipate static electricity during transfer by grounding and bonding containers and equipment before transferring material.

### Storage

Store in accordance with local regulations. Store in a segregated and approved area. Store away from direct sunlight in a dry, cool and well-ventilated area, away from incompatible materials (see section 10). Eliminate all ignition sources. Separate from oxidizing materials. Keep container tightly closed and sealed until ready for use. Containers that have been opened must be carefully resealed and kept upright to prevent leakage. Do not store in unlabeled containers. Use appropriate containment to avoid environmental contamination.

---

## 8. Exposure controls/personal protection

### Occupational exposure limits

#### Ingredient name

#### Occupational exposure limits

Petroleum distillates

**ACGIH TLV (United States). Absorbed through skin.**

TWA: 100 mg/m<sup>3</sup>, (measured as total hydrocarbons) 8 hour(s). Issued/Revised: 1/2002 Form: Total hydrocarbons

Naphthalene

**ACGIH TLV (United States).**

STEL: 79 mg/m<sup>3</sup> 15 minute(s). Issued/Revised: 5/1996

STEL: 15 ppm 15 minute(s). Issued/Revised: 5/1996

TWA: 52 mg/m<sup>3</sup> 8 hour(s). Issued/Revised: 5/1996

TWA: 10 ppm 8 hour(s). Issued/Revised: 5/1996

**OSHA PEL (United States).**

TWA: 50 mg/m<sup>3</sup> 8 hour(s). Issued/Revised: 6/1993

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While specific OELs for certain components may be shown in this section, other components may be present in any mist, vapor or dust produced. Therefore, the specific OELs may not be applicable to the product as a whole and are provided for guidance only.

**Some states may enforce more stringent exposure limits.**

**Control Measures**

Use only with adequate ventilation. Use process enclosures, local exhaust ventilation or other engineering controls to keep worker exposure to airborne contaminants below any recommended or statutory limits. The engineering controls also need to keep gas, vapor or dust concentrations below any lower explosive limits. Use explosion-proof ventilation equipment.

**Hygiene measures**

Wash hands, forearms and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Wash contaminated clothing before reusing.

**Personal protection**

**Eyes**

Avoid contact with eyes. Safety glasses with side shields.

**Skin and body**

Avoid contact with skin and clothing. Wear suitable protective clothing.

**Respiratory**

Use only with adequate ventilation. Do not breathe vapor or mist. If ventilation is inadequate, use a NIOSH-certified respirator with an organic vapor cartridge and P95 particulate filter.

CAUTION: The protection provided by air-purifying respirators is limited. Use a positive pressure air-supplied respirator if there is any potential for an uncontrolled release, if exposure levels are not known, or if concentrations exceed the protection limits of air-purifying respirator.

**Hands**

Wear gloves that cannot be penetrated by chemicals or oil.

The correct choice of protective gloves depends upon the chemicals being handled, the conditions of work and use, and the condition of the gloves (even the best chemically resistant glove will break down after repeated chemical exposures). Most gloves provide only a short time of protection before they must be discarded and replaced. Because specific work environments and material handling practices vary, safety procedures should be developed for each intended application. Gloves should therefore be chosen in consultation with the supplier/manufacturer and with a full assessment of the working conditions.

Consult your supervisor or Standard Operating Procedure (S.O.P) for special handling instructions.

## 9. Physical and chemical properties

|                                  |  |
|----------------------------------|--|
| <b>Physical state</b>            | Liquid.  |
| <b>Color</b>                     | Colorless. to Various Colors. (May be dyed Red., Light Green. ,Yellow. ) |
| <b>Odor</b>                      | Petroleum  |
| <b>Flash point</b>               | Closed cup: >38°C (>100.4°F) [Pensky-Martens.]                           |
| <b>Explosion limits</b>          | Lower: 0.6%<br>Upper: 7.5%   |
| <b>Auto-ignition temperature</b> | 257°C (494°F)  |
| <b>Specific gravity</b>          | <1 [Water = 1]   |
| <b>Density</b>                   | 820 to 875 kg/m <sup>3</sup> (0.82 to 0.875 g/cm <sup>3</sup> )          |
| <b>Viscosity</b>                 | Kinematic: 1.7 to 4.1 mm <sup>2</sup> /s (1.7 to 4.1 cSt) at 40°C        |
| <b>Solubility</b>                | negligible <0.1%   |

## 10. Stability and reactivity

|  |   |
|--|---|
| <b>Stability and reactivity</b>                | Stable under recommended storage and handling conditions (see section 7).   |
| <b>Possibility of hazardous reactions</b>      | Under normal conditions of storage and use, hazardous reactions will not occur.                                       |
| <b>Conditions to avoid</b>                     | Keep away from heat, sparks and flame. Avoid all possible sources of ignition (spark or flame).                       |
| <b>Incompatibility with various substances</b> | Reactive or incompatible with the following materials: oxidizing materials, acids and alkalis. halogenated compounds. |

|                                       |                                  |                          |
|---------------------------------------|----------------------------------|--------------------------|
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**Hazardous decomposition products**carbon oxides (CO, CO<sub>2</sub>) (carbon monoxide, carbon dioxide)**Hazardous polymerization**

Under normal conditions of storage and use, hazardous polymerization will not occur.

## 11. Toxicological information

**Acute toxicity****Classification**

| Product/ingredient name        | IARC    | NTP           | OSHA   |
|--------------------------------|---------|---------------|--------|
| Naphthalene fuel, diesel no. 2 | 2B<br>3 | Possible<br>- | -<br>- |

IARC :  
2B - Possible carcinogen to human.  
3 - Not classifiable as a human carcinogen.

NTP :  
Possible - Reasonably anticipated to be human carcinogens.

**Other Toxicity Data**

Aspiration of this product into the lungs can cause chemical pneumonia and can be fatal. Aspiration into the lungs can occur while vomiting after ingestion of this product. Do not siphon by mouth.

Middle distillate: From skin-painting studies of petroleum distillates of similar composition and distillate range, it has been shown that these types of materials often possess weak carcinogenic activity in laboratory animals. In these tests, the material is painted on the shaved backs of mice twice a week for their lifetime. The material is not washed off between applications. Therefore, there may be a potential risk of skin cancer from prolonged or repeated skin contact with this product in the absence of good personal hygiene. This particular product has not been tested for carcinogenic activity, but we have chosen to be cautious in light of the findings with other distillate streams.

Occasional skin contact with this product is not expected to have serious effects, but good personal hygiene should be practiced and repeated skin contact avoided. This product can also be expected to produce skin irritation upon prolonged or repeated skin contact. Personal hygiene measures taken to prevent skin irritation are expected to be adequate to prevent risk of skin cancer.

Diesel exhaust particulates have been classified by the National Toxicological Program (NTP) to be a reasonably anticipated human carcinogen. Exposure should be minimized to reduce potential risk.

Naphthalene has been reported to cause developmental toxicity in mice after oral exposure to relatively high dose levels, but developmental toxicity was not observed in NTP (National Toxicology Program) sponsored studies in rats and rabbits. Ingestion or inhalation of naphthalene can result in hemolysis and other blood abnormalities, and individuals (and infants) deficient in glucose-6-phosphate dehydrogenase may be especially susceptible to these effects. Inhalation of naphthalene may cause headache and nausea. Airborne exposure can result in eye irritation. Naphthalene exposure has been associated with cataracts in animals and humans.

**Other information****Potential chronic health effects****Carcinogenicity**

Contains material which may cause cancer, based on animal data. Risk of cancer depends on duration and level of exposure.

## 12. Ecological information

**Ecotoxicity**

No testing has been performed by the manufacturer.

**Mobility**

Spillages may penetrate the soil causing ground water contamination.

**Bioaccumulative potential**

This product is not expected to bioaccumulate through food chains in the environment.

|                                       |                                  |                          |
|---------------------------------------|----------------------------------|--------------------------|
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|                                       |                                  | <b>(ENGLISH)</b>         |

## 13. Disposal considerations

### Waste information

The generation of waste should be avoided or minimized wherever possible. Empty containers or liners may retain some product residues. This material and its container must be disposed of in a safe way. Dispose of surplus and non-recyclable products via a licensed waste disposal contractor. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers.

**NOTE: The generator of waste has the responsibility for proper waste identification (based on characteristic(s) or listing), transportation and disposal**

## 14. Transport information

### International transport regulations

| Regulatory information          | UN number | Proper shipping name | Class | Packing group | Additional information                                      |
|---------------------------------|-----------|----------------------|-------|---------------|---|
| <b>DOT Classification</b>       | NA 1993   | Diesel fuel          | 3     | III           | -   |
| <b>TDG Classification</b>       | UN 1202   | Gas oil              | 3     | III           | -   |
| <b>IMDG Classification</b>      | UN 1202   | Gas oil              | 3     | III           | <b>Remarks</b><br>Marine pollutant                          |
| <b>IATA/ICAO Classification</b> | UN 1202   | Gas oil              | 3     | III           | <b>Remarks</b><br>Environmentally hazardous substance mark. |

## 15. Regulatory information

### U.S. Federal Regulations

#### United States inventory (TSCA 8b)

All components are listed or exempted.

TSCA 12(b) one-time export: Naphthalene

**SARA 302/304/311/312 extremely hazardous substances:** No products were found.

**SARA 302/304 emergency planning and notification:** No products were found.

**SARA 302/304/311/312 hazardous chemicals:** Naphthalene

**SARA 311/312 MSDS distribution - chemical inventory - hazard identification:** DIESEL FUEL NO. 2: Fire hazard, Immediate (acute) health hazard, Delayed (chronic) health hazard

#### SARA 313

|   | Product name   | CAS number | Concentration   |
|---|--|------------|-----------------|
| <b>Form R - Reporting requirements</b>                                    | Naphthalene  | 91-20-3    | 1.0035 - 3.0111 |
| <b>Supplier notification</b>  | Naphthalene  | 91-20-3    | 1.0035 - 3.0111 |
| <b>CERCLA Sections 102a/103 Hazardous Substances (40 CFR Part 302.4):</b> | CERCLA: Hazardous substances.: o-Xylene: 1000 lbs. (454 kg); Naphthalene: 100 lbs. (45.4 kg); benzo[def]chrysene: 1 lb. (0.454 kg); Ethylbenzene: 1000 lbs. (454 kg); xylene: 100 lbs. (45.4 kg); Cumene: 5000 lbs. (2270 kg); Phenol: 1000 lbs. (454 kg); Benzene: 10 lbs. (4.54 kg); Alkylaryl sulfonic acid: 1000 lbs. (454 kg); Toluene: 1000 lbs. (454 kg); Methanol: 5000 lbs. (2270 kg); 2-Butoxyethanol; |            |                 |

### State regulations

|                                       |                                  |                          |
|---------------------------------------|----------------------------------|--------------------------|
| <b>Product name</b> DIESEL FUEL NO. 2 | <b>Product code</b> 11155        | <b>Page:</b> 6/8         |
| <b>Version</b> 2                      | <b>Date of issue</b> 07/20/2010. | <b>Format</b> US-COMP    |
|                                       | <b>(US-COMP)</b>                 | <b>Language</b> ENGLISH. |
|                                       |                                  | <b>(ENGLISH)</b>         |

**Massachusetts Substances**

The following components are listed: NAPHTHALENE

**New Jersey Hazardous Substances**

The following components are listed: DIESEL FUEL; # 2 HEATING OIL; NAPHTHALENE; MOTH FLAKES

**Pennsylvania RTK Hazardous Substances**

The following components are listed: NAPHTHALENE

**California Prop. 65**

**WARNING:** This product contains a chemical known to the State of California to cause cancer. Naphthalene; Ethylbenzene; benzo[def]chrysene

**WARNING:** This product contains a chemical known to the State of California to cause birth defects or other reproductive harm. Toluene

**WARNING:** This product contains a chemical known to the State of California to cause cancer and birth defects or other reproductive harm. Benzene

Prop 65 chemicals will result under certain conditions from the use of this material. For example, burning fuels produces combustion products including diesel exhaust, a Prop 65 carcinogen, and carbon monoxide, a Prop 65 reproductive toxin.

**Inventories**

- Canada inventory** Not determined.
- Europe inventory** At least one component is not listed.
- Australia inventory (AICS)** At least one component is not listed.
- China inventory (IECSC)** Not determined.
- Japan inventory (ENCS)** At least one component is not listed.
- Korea inventory (KECI)** At least one component is not listed.
- Philippines inventory (PICCS)** At least one component is not listed.

---

**16. Other information**

**Label requirements** WARNING !  
COMBUSTIBLE LIQUID AND VAPOR.  
VAPOR MAY CAUSE FLASH FIRE.  
HARMFUL IF SWALLOWED.  
ASPIRATION HAZARD.  
HARMFUL OR FATAL IF LIQUID IS ASPIRATED INTO LUNGS.  
MAY CAUSE RESPIRATORY TRACT IRRITATION.  
INHALATION CAUSES HEADACHES, DIZZINESS, DROWSINESS, AND NAUSEA, AND MAY LEAD TO UNCONSCIOUSNESS.

**HMIS® Rating :**  
Health \* 1  
Flammability 2  
Physical 0  
Hazard  
Personal protection X

**National Fire Protection Association (U.S.A.)**



**History**  
**Date of issue** 07/20/2010.  
**Date of previous issue** 07/20/2010.  
**Prepared by** Product Stewardship  
**Notice to reader**

|                                       |                                  |  |
|---------------------------------------|----------------------------------|--|
| <b>Product name</b> DIESEL FUEL NO. 2 | <b>Product code</b> 11155        | <b>Page:</b> 7/8                             |
| <b>Version</b> 2                      | <b>Date of issue</b> 07/20/2010. | <b>Format</b> US-COMP                        |
|                                       | <b>(US-COMP)</b>                 | <b>Language</b> ENGLISH.<br><b>(ENGLISH)</b> |

All reasonably practicable steps have been taken to ensure this data sheet and the health, safety and environmental information contained in it is accurate as of the date specified below. No warranty or representation, express or implied is made as to the accuracy or completeness of the data and information in this data sheet.

The data and advice given apply when the product is sold for the stated application or applications. You should not use the product other than for the stated application or applications without seeking advice from us.

It is the user's obligation to evaluate and use this product safely and to comply with all applicable laws and regulations. The BP Group shall not be responsible for any damage or injury resulting from use, other than the stated product use of the material, from any failure to adhere to recommendations, or from any hazards inherent in the nature of the material. Purchasers of the product for supply to a third party for use at work, have a duty to take all necessary steps to ensure that any person handling or using the product is provided with the information in this sheet. Employers have a duty to tell employees and others who may be affected of any hazards described in this sheet and of any precautions that should be taken.

**Product name** DIESEL FUEL NO. 2

**Product code** 11155

**Page:** 8/8

**Version** 2      **Date of issue** 07/20/2010.

**Format** US-COMP

**Language** ENGLISH.

(US-COMP)

(ENGLISH)



# Safety Data Sheet

SDS ID NO.: 0282MAR019  
Revision date: 04/01/2014

## 1. CHEMICAL PRODUCT AND COMPANY INFORMATION

**Product name:** Marathon Petroleum Biodiesel B100  
**Synonym:** B100 Biodiesel; Virgin Biodiesel; Soy Biodiesel; Rapeseed Biodiesel; Tallow Biodiesel; Canola Biodiesel; Soybean Esters B100 Biodiesel, SME, Soy Methyl Ester, Biodiesel, Biomass Based Diesel, Fatty Acid Methyl Esters  
**Chemical Family:** Fatty acid methyl esters  
**Formula:** Mixture  
**Manufacturer Name:** Marathon Petroleum Company LP  
539 South Main Street  
Findlay OH 45840

**SDS information:** 419-421-3070  
**Emergency telephone number:** 877-627-5463

## 2. COMPOSITION/INFORMATION ON INGREDIENTS

Biodiesel is a complex mixture of C16-C18 methyl esters derived from the processing of vegetable oils.

### Product Information:

| Name                    | CAS Number    | Weight % | ACGIH Exposure Limits: | OSHA - Vacated PELs - Time Weighted Avg. | Other: |
|-------------------------|---------------|----------|------------------------|--|--------|
| Marathon Biodiesel B100 | CAS NO. BELOW | 100      |                        |  |        |

### Component Information:

| Name                                 | CAS Number  | Weight % | ACGIH Exposure Limits:   | OSHA - Vacated PELs - Time Weighted Avg. | Other: |
|--------------------------------------|-------------|----------|--|--|--------|
| Biodiesel (Tallow derived)           | 61788-61-2  | 0-100    |  |  |        |
| Biodiesel (Soybean derived)          | 67784-80-9  | 0-100    |  |  |        |
| Biodiesel (Rapeseed derived)         | 73891-99-3  | 0-100    |  |  |        |
| Biodiesel (Fatty Acid, Methyl Ester) | 68937-84-8  | 0-100    |  |  |        |
| Biodiesel (Canola derived)           | 129828-16-6 | 0-100    |  |  |        |
| Methanol (Methyl Alcohol)            | 67-56-1     | 0-0.2    | 200 ppm TWA<br>250 ppm STEL<br><br>Skin - potential significant contribution to overall exposure by the cutaneous route. | 200 ppm TWA                              |        |

**Notes:** The manufacturer has voluntarily elected to provide exposure limits contained in OSHA's 1989 air contaminants standard in its SDSs, even though certain of those exposure limits were vacated in 1992.

### 3. HAZARDS IDENTIFICATION

#### EMERGENCY OVERVIEW

COMBUSTIBLE LIQUID

WARNING!

MAY BE HARMFUL OR FATAL IF SWALLOWED.

MAY CAUSE LUNG DAMAGE.

MAY CAUSE ALLERGIC SKIN REACTION.

VAPORS, FUMES, OR MISTS FROM HEATED MATERIAL MAY CAUSE RESPIRATORY TRACT IRRITATION.

#### POTENTIAL HEALTH EFFECTS FROM OVEREXPOSURE

##### Inhalation:

Excessive inhalation of mist may result in respiratory irritation. Overheating may produce vapors which may cause respiratory irritation, dizziness and nausea.

##### Ingestion:

Ingestion of large amounts may cause gastrointestinal disturbances.

##### Skin contact:

Prolonged and repeated liquid contact can cause defatting and drying of the skin and can lead to irritation and/or dermatitis. May cause sensitization upon repeated skin contact.

##### Eye contact:

Produces little or no irritation on direct contact with the eye.

#### Carcinogenic Evaluation:

##### Product Information:

| Name                                     | IARC Carcinogens: | NTP Carcinogens: | ACGIH - Carcinogens: | OSHA - Select Carcinogens: |
|--|-------------------|------------------|----------------------|----------------------------|
| Marathon Biodiesel B100<br>CAS NO. BELOW | Not Listed        | Not Listed       | Not Listed           | Not Listed                 |

##### Notes:

##### Component Information:

| Name   | IARC Carcinogens: | NTP Carcinogens: | ACGIH - Carcinogens: | OSHA - Select Carcinogens: |
|--|-------------------|------------------|----------------------|----------------------------|
| Biodiesel (Tallow derived)<br>61788-61-2           | Not Listed        | Not Listed       | Not Listed           | Not Listed                 |
| Biodiesel (Soybean derived)<br>67784-80-9          | Not Listed        | Not Listed       | Not Listed           | Not Listed                 |
| Biodiesel (Rapeseed derived)<br>73891-99-3         | Not Listed        | Not Listed       | Not Listed           | Not Listed                 |
| Biodiesel (Fatty Acid, Methyl Ester)<br>68937-84-8 | Not Listed        | Not Listed       | Not Listed           | Not Listed                 |
| Biodiesel (Canola derived)<br>129828-16-6          | Not Listed        | Not Listed       | Not Listed           | Not Listed                 |
| Methanol (Methyl Alcohol)<br>67-56-1               | Not Listed        | Not Listed       | Not Listed           | Not Listed                 |

## 4. FIRST AID MEASURES

|   |   |
|---|---|
| <b>Eye contact:</b>                               | Flush immediately with large amounts of water for at least 15 minutes. Eyelids should be held away from the eyeball to ensure thorough rinsing. Gently remove contacts while flushing. If symptoms occur, call a physician.   |
| <b>Skin contact:</b>                              | Wash with soap and large amounts of water. Remove contaminated clothing. If symptoms or irritation occur, call a physician.   |
| <b>Ingestion:</b>                                 | If swallowed, do not induce vomiting and do not give liquids. Immediately call a physician.   |
| <b>Inhalation:</b>                                | If affected, move person to fresh air. If breathing is difficult, administer oxygen and continue to monitor. If not breathing or if no heartbeat, give artificial respiration or cardiopulmonary resuscitation (CPR). Immediately call a physician. If symptoms or irritation occur with any exposure, call a physician.  |
| <b>NOTES TO PHYSICIAN:</b>                        | Do not induce vomiting. Low viscosity product can be sucked into the lungs and cause damage after swallowing or vomiting. Contains small amounts of methanol (0.2%). The metabolism of fatty acid methyl ester may release free methanol in the body that could induce metabolic acidosis with delayed effect. If a large amount of product is ingested, i.e. several ounces, consider the use of ethanol or fomepizole (Antizol) and hemodialysis. Consult standard literature or contact a poison control center for treatment details. |
| <b>Medical Conditions Aggravated By Exposure:</b> | Preexisting skin conditions and respiratory disorders may be aggravated by exposure to components of this product.  |

## 5. FIRE FIGHTING MEASURES

### Suitable extinguishing media:

For small fires, Class B fire extinguishing media such as CO<sub>2</sub>, dry chemical, foam or water spray can be used. For large fires, water spray, fog or foam can be used. Firefighting should be attempted only by those who are adequately trained and equipped with proper protective equipment.

### Specific hazards:

Spontaneous combustion may occur under high temperature, closed conditions if material is absorbed in various fiber matrices and oxygen is present (e.g. oily rags). Store wiping rags in metal cans with tightly fitting lids. Cool closed containers exposed to fire with water spray. Hazardous combustion products include carbon monoxide, carbon dioxide, aldehydes, ketones, and other oxidized hydrocarbons.

This product has been determined to be a combustible liquid per the OSHA Hazard Communication Standard and should be handled accordingly. Can ignite under moderate heating. Vapors are heavier than air and may accumulate in low lying areas. Vapors may accumulate in confined spaces. For additional fire related information, see NFPA 30 or the North American Emergency Response Guide 128.

### Special protective equipment and precautions for firefighters:

Avoid using straight water streams. Water spray and foam (AFFF/ATC) must be applied carefully to avoid frothing and from as far a distance as possible. Avoid excessive water spray application. Keep away from flames, hot surfaces, and other ignition sources. No smoking. Keep surrounding area cool with water spray from a distance and prevent further ignition of combustible material. Keep run-off water out of sewers and water sources.

As in any fire, wear self-contained breathing apparatus pressure-demand, MSHA/NIOSH (approved or equivalent) and full protective gear

### Flash point:

≥ 199°F (closed cup)

### Autoignition temperature:

No data available.

### Flammable limits in air - lower (%):

No data available.

### Flammable limits in air - upper (%):

No data available.

### NFPA rating:

Health: 1

Flammability: 2

Instability: 1

Other: -

## 6. ACCIDENTAL RELEASE MEASURES

**Personal precautions, protective equipment, and emergency procedures:** Isolate and evacuate area. Shut off source if safe to do so. Keep all sources of ignition away from released material. Advise authorities and National Response Center (800-424-8802) if the product has entered a water course or sewer.

All contaminated surfaces will be slippery. Use impervious gloves when handling contaminated material. Keep untrained personnel away from contamination.

**Environmental precautions:** Prevent further leakage or spillage if safe to do so. Do not allow material to contaminate ground water system or any surface water.

**Methods and materials for containment and cleaning up:** Absorb small spills with absorbent material. Recover large spills into approved containers. Clean contaminated surface thoroughly.

## 7. HANDLING AND STORAGE

### Handling:

Comply with all applicable EPA, OSHA, NFPA and consistent state and local requirements. Use appropriate grounding and bonding practices. Do not expose to heat, open flames, strong oxidizers or other sources of ignition. Do not cut, drill, grind or weld on empty containers since they may contain explosive residues.

Avoid repeated and prolonged skin contact. Never siphon this product by mouth. Exercise good personal hygiene including removal of soiled clothing and prompt washing with soap and water.

### Storage:

Avoid contamination by storing in water-free tanks with scheduled water drainage. Corrosion and microbial growth are promoted by the presence of water. Degradation can be avoided by preventing temperature extremes and air during storage. Contact with copper/alloys, lead, tin and zinc may result in increased sediment and deposits that can plug filters.

## 8. EXPOSURE CONTROLS / PERSONAL PROTECTION

### PERSONAL PROTECTIVE EQUIPMENT

- Engineering measures:** Ensure adequate ventilation, especially in confined areas. Local or general exhaust required when using at elevated temperatures that generate vapors or mists.
- Respiratory protection:** Breathing apparatus needed when aerosol or mist is formed. Observe respirator assigned protection factors (APFs) criteria cited in federal OSHA 1910.134. Self-contained breathing apparatus should be used for fire fighting.
- Skin and body protection:** Use chemical resistant gloves such as neoprene, nitrile, or PVA to prevent prolonged or repeated skin contact.
- Eye protection:** Where splashing is possible, wear safety glasses with side shields. Wear goggles and faceshield when handling hot material.
- Hygiene measures:** Handle in accordance with good industrial hygiene and safety practice.

## 9. PHYSICAL AND CHEMICAL PROPERTIES:

|   |                    |
|---|--------------------|
| <b>Appearance:</b>                              | Clear Liquid       |
| <b>Physical state (Solid/Liquid/Gas):</b>       | Liquid             |
| <b>Substance type (Pure/Mixture):</b>           | Mixture            |
| <b>Color:</b>                                   | Amber              |
| <b>Odor:</b>                                    | Slight             |
| <b>Molecular weight:</b>                        | No data available. |
| <b>pH:</b>                                      | Neutral            |
| <b>Boiling point/range (5-95%):</b>             | >140° C            |
| <b>Melting point/range:</b>                     | No data available. |
| <b>Decomposition temperature:</b>               | No data available. |
| <b>Specific gravity:</b>                        | 0.86-0.89 @25°C    |
| <b>Density:</b>                                 | 7.35 lbs/gal.      |
| <b>Bulk density:</b>                            | No data available. |
| <b>Vapor density:</b>                           | No data available. |
| <b>Vapor pressure:</b>                          | <1.0 mm Hg @22°C   |
| <b>Evaporation rate:</b>                        | No data available. |
| <b>Solubility:</b>                              | Negligible         |
| <b>Solubility in other solvents:</b>            | No data available. |
| <b>Partition coefficient (n-octanol/water):</b> | No data available. |
| <b>VOC content(%):</b>                          | No data available. |
| <b>Viscosity:</b>                               | 3.8-5.0 cSt @40°C  |

## 10. STABILITY AND REACTIVITY

|  |  |
|--|--|
| <b>Stability:</b>                        | The material is stable at 70° F, 760 mm pressure.  |
| <b>Polymerization:</b>                   | Will not occur.  |
| <b>Hazardous decomposition products:</b> | Hazardous combustion products include carbon monoxide, carbon dioxide, aldehydes, ketones, and other oxidized hydrocarbons |
| <b>Materials to avoid:</b>               | Strong oxidizers such as nitrates, chlorates, peroxides.<br>Incompatible with strong acids and bases                       |
| <b>Conditions to avoid:</b>              | Excessive heat, sources of ignition and open flames.<br>Water contamination during storage.                                |

## 11. TOXICOLOGICAL INFORMATION

### Acute toxicity:

#### Product Information:

| Name                    | CAS Number    | LD50 Oral | LD50 Dermal | LC50 Inhalation |
|-------------------------|---------------|-----------|-------------|-----------------|
| Marathon Biodiesel B100 | CAS NO. BELOW |           |             |                 |

#### Component Information:

| Name                                 | CAS Number  | LD50 Oral         | LD50 Dermal         | LC50 Inhalation                              |
|--------------------------------------|-------------|-------------------|---------------------|--|
| Biodiesel (Tallow derived)           | 61788-61-2  |                   |                     |  |
| Biodiesel (Soybean derived)          | 67784-80-9  | >5000 mg/kg (Rat) | >5000 mg/kg (Rat)   |  |
| Biodiesel (Rapeseed derived)         | 73891-99-3  |                   |                     |  |
| Biodiesel (Fatty Acid, Methyl Ester) | 68937-84-8  | >2000mg/kg (Rat)  |                     |  |
| Biodiesel (Canola derived)           | 129828-16-6 |                   |                     |  |
| Methanol (Methyl Alcohol)            | 67-56-1     | 5628mg/kg (Rat)   | 15800mg/kg (Rabbit) | 64000ppm (Rat) 4-hr.<br>83.2mg/L (Rat) 4-hr. |

#### Toxicology Information:

Biodiesel (Soybean derived):

Primary skin irritation test (Rabbits) 24 hour exposure with Primary Dermal irritation index of 1.6/8.0 (Nonirritating).

Primary eye irritation test (Rabbits) single exposure with scores of 0.7, 0 and 0 after 24, 48, and 72 hours (Nonirritating).

Dermal sensitization study (Guinea Pigs) repeat insult patch procedure with induction and challenge patches indicated a positive sensitization response.

## 12. ECOTOXICOLOGICAL INFORMATION

### Mobility

#### Mobility in soil

Insoluble and floats on water.

### Ecotoxicity

#### Aquatic Toxicity:

The 96-hour LC50 for biodiesel alone in bluegill fish is > 1000 mg/L. The 96-hour LC50 for biodiesel alone in rainbow trout fingerlings ranges from 390-707 mg/L. The 96-hour LC50 for biodiesel alone in rainbow trout fry is 455 mg/L. The 24-hour LC50 for biodiesel alone in Daphnia magna (water flea) juveniles is 4.65 mg/L.

#### Bioaccumulation:

This product is not expected to concentrate or accumulate in the food chain.

#### Persistence/Biodegradation:

##### Bioaccumulative Potential

If released to soil and water, this product is expected to be readily biodegradable under aerobic conditions.

## 13. DISPOSAL CONSIDERATIONS

**Description of waste residues, safe handling, and methods of disposal:** This product as produced is not specifically listed as an EPA RCRA hazardous waste according to federal regulations (40 CFR 260-271). However, if mixed or contaminated with a hazardous waste or other substance(s), the resulting material may meet the criteria of a hazardous waste when discarded. The user is responsible for determining if the material for disposal is hazardous according to federal, state, and local regulations.

Long-term storage may result in decomposition of the oil and could result in a rancid odor.

**Contaminated packaging disposal:** Empty containers should be transported/delivered using a registered waste carrier for local recycling or waste disposal.

## 14. TRANSPORT INFORMATION

49 CFR 172.101:

DOT:

**Transport Information:** This material when transported via US commerce is NOT REGULATED by DOT regulations when transported at or above 93°C or is not a hazardous substance, a hazardous waste or a marine pollutant.

## 15. REGULATORY INFORMATION

**US Federal Regulatory Information:**

US TSCA Chemical Inventory Section 8(b): This product and/or its components are listed on the TSCA Chemical Inventory.

OSHA Hazard Communication Standard: This product has been evaluated and determined to be hazardous as defined in OSHA's Hazard Communication Standard.

**EPA Superfund Amendment & Reauthorization Act (SARA):**

**SARA Section 302:** This product contains the following component(s) that have been listed on EPA's Extremely Hazardous Substance (EHS) List:

| Name                                 | CERCLA/SARA - Section 302 Extremely Hazardous Substances and TPQs |
|--------------------------------------|---|
| Biodiesel (Tallow derived)           | NA  |
| Biodiesel (Soybean derived)          | NA  |
| Biodiesel (Rapeseed derived)         | NA  |
| Biodiesel (Fatty Acid, Methyl Ester) | NA  |
| Biodiesel (Canola derived)           | NA  |
| Methanol (Methyl Alcohol)            | NA  |

**SARA Section 304:**

This product contains the following component(s) identified either as an EHS or a CERCLA Hazardous substance which in case of a spill or release may be subject to SARA reporting requirements:

| Name                                 | CERCLA/SARA - Hazardous Substances and their Reportable Quantities |
|--------------------------------------|--|
| Biodiesel (Tallow derived)           | NA   |
| Biodiesel (Soybean derived)          | NA   |
| Biodiesel (Rapeseed derived)         | NA   |
| Biodiesel (Fatty Acid, Methyl Ester) | NA   |
| Biodiesel (Canola derived)           | NA   |
| Methanol (Methyl Alcohol)            | NA   |

**SARA**

The following EPA hazard categories apply to this product:

None

**SARA Section 313:**

This product contains the following components, which if in exceedance of the de minimus threshold, may be subject to the reporting requirements of SARA Title III Section 313 Toxic Release Reporting (Form R).

| Name                                 | CERCLA/SARA 313 Emission reporting: |
|--------------------------------------|-------------------------------------|
| Biodiesel (Tallow derived)           | None                                |
| Biodiesel (Soybean derived)          | None                                |
| Biodiesel (Rapeseed derived)         | None                                |
| Biodiesel (Fatty Acid, Methyl Ester) | None                                |
| Biodiesel (Canola derived)           | None                                |
| Methanol (Methyl Alcohol)            | None                                |

**State and Community Right-To-Know Regulations:**

The following component(s) of this material are identified on the regulatory lists below:

## Biodiesel (Tallow derived)

|   |             |
|---|-------------|
| Louisiana Right-To-Know:  | Not Listed. |
| California Proposition 65:  | Not Listed. |
| New Jersey Right-To-Know:   | Not Listed. |
| Pennsylvania Right-To-Know:   | Not Listed. |
| Massachusetts Right-To Know:  | Not Listed. |
| Florida Substance List:   | Not Listed. |
| Rhode Island Right-To-Know:   | Not Listed. |
| Michigan Critical Materials Register List:                                | Not Listed. |
| Massachusetts Extraordinarily Hazardous Substances:                       | Not Listed. |
| California - Regulated Carcinogens:                                       | Not Listed. |
| Pennsylvania RTK - Special Hazardous Substances:                          | Not Listed. |
| New Jersey - Special Hazardous Substances:                                | Not Listed. |
| New Jersey - Environmental Hazardous Substances List:                     | Not Listed. |
| Illinois - Toxic Air Contaminants   | Not Listed. |
| New York - Reporting of Releases Part 597 - List of Hazardous Substances: | Not Listed. |

## Biodiesel (Soybean derived)

|   |             |
|---|-------------|
| Louisiana Right-To-Know:                            | Not Listed. |
| California Proposition 65:                          | Not Listed. |
| New Jersey Right-To-Know:                           | Not Listed. |
| Pennsylvania Right-To-Know:                         | Not Listed. |
| Massachusetts Right-To Know:                        | Not Listed. |
| Florida Substance List:                             | Not Listed. |
| Rhode Island Right-To-Know:                         | Not Listed. |
| Michigan Critical Materials Register List:          | Not Listed. |
| Massachusetts Extraordinarily Hazardous Substances: | Not Listed. |
| California - Regulated Carcinogens:                 | Not Listed. |

|   |             |
|---|-------------|
| Pennsylvania RTK - Special Hazardous Substances:                          | Not Listed. |
| New Jersey - Special Hazardous Substances:                                | Not Listed. |
| New Jersey - Environmental Hazardous Substances List:                     | Not Listed. |
| Illinois - Toxic Air Contaminants   | Not Listed. |
| New York - Reporting of Releases Part 597 - List of Hazardous Substances: | Not Listed. |
| Biodiesel (Rapeseed derived)  |             |
| Louisiana Right-To-Know:  | Not Listed. |
| California Proposition 65:  | Not Listed. |
| New Jersey Right-To-Know:   | Not Listed. |
| Pennsylvania Right-To-Know:   | Not Listed. |
| Massachusetts Right-To Know:  | Not Listed. |
| Florida Substance List:   | Not Listed. |
| Rhode Island Right-To-Know:   | Not Listed. |
| Michigan Critical Materials Register List:                                | Not Listed. |
| Massachusetts Extraordinarily Hazardous Substances:                       | Not Listed. |
| California - Regulated Carcinogens:                                       | Not Listed. |
| Pennsylvania RTK - Special Hazardous Substances:                          | Not Listed. |
| New Jersey - Special Hazardous Substances:                                | Not Listed. |
| New Jersey - Environmental Hazardous Substances List:                     | Not Listed. |
| Illinois - Toxic Air Contaminants   | Not Listed. |
| New York - Reporting of Releases Part 597 - List of Hazardous Substances: | Not Listed. |
| Biodiesel (Fatty Acid, Methyl Ester)                                      |             |
| Louisiana Right-To-Know:  | Not Listed. |
| California Proposition 65:  | Not Listed. |
| New Jersey Right-To-Know:   | Not Listed. |
| Pennsylvania Right-To-Know:   | Not Listed. |
| Massachusetts Right-To Know:  | Not Listed. |
| Florida Substance List:   | Not Listed. |
| Rhode Island Right-To-Know:   | Not Listed. |
| Michigan Critical Materials Register List:                                | Not Listed. |
| Massachusetts Extraordinarily Hazardous Substances:                       | Not Listed. |
| California - Regulated Carcinogens:                                       | Not Listed. |
| Pennsylvania RTK - Special Hazardous Substances:                          | Not Listed. |
| New Jersey - Special Hazardous Substances:                                | Not Listed. |
| New Jersey - Environmental Hazardous Substances List:                     | Not Listed. |
| Illinois - Toxic Air Contaminants   | Not Listed. |
| New York - Reporting of Releases Part 597 - List of Hazardous Substances: | Not Listed. |
| Biodiesel (Canola derived)  |             |
| Louisiana Right-To-Know:  | Not Listed. |
| California Proposition 65:  | Not Listed. |
| New Jersey Right-To-Know:   | Not Listed. |
| Pennsylvania Right-To-Know:   | Not Listed. |
| Massachusetts Right-To Know:  | Not Listed. |
| Florida Substance List:   | Not Listed. |
| Rhode Island Right-To-Know:   | Not Listed. |
| Michigan Critical Materials Register List:                                | Not Listed. |
| Massachusetts Extraordinarily Hazardous Substances:                       | Not Listed. |
| California - Regulated Carcinogens:                                       | Not Listed. |
| Pennsylvania RTK - Special Hazardous Substances:                          | Not Listed. |

|   |             |
|---|-------------|
| New Jersey - Special Hazardous Substances:                                | Not Listed. |
| New Jersey - Environmental Hazardous Substances List:                     | Not Listed. |
| Illinois - Toxic Air Contaminants   | Not Listed. |
| New York - Reporting of Releases Part 597 - List of Hazardous Substances: | Not Listed. |
| Methanol (Methyl Alcohol)   |             |
| Louisiana Right-To-Know:  | Not Listed. |
| California Proposition 65:  | Not Listed. |
| New Jersey Right-To-Know:   | Not Listed. |
| Pennsylvania Right-To-Know:   | Not Listed. |
| Massachusetts Right-To Know:  | Not Listed. |
| Florida Substance List:   | Not Listed. |
| Rhode Island Right-To-Know:   | Not Listed. |
| Michigan Critical Materials Register List:                                | Not Listed. |
| Massachusetts Extraordinarily Hazardous Substances:                       | Not Listed. |
| California - Regulated Carcinogens:                                       | Not Listed. |
| Pennsylvania RTK - Special Hazardous Substances:                          | Not Listed. |
| New Jersey - Special Hazardous Substances:                                | Not Listed. |
| New Jersey - Environmental Hazardous Substances List:                     | Not Listed. |
| Illinois - Toxic Air Contaminants   | Not Listed. |
| New York - Reporting of Releases Part 597 - List of Hazardous Substances: | Not Listed. |

**Canadian Regulatory Information:**

Canada DSL/NDSL Inventory: This product and/or its components are listed either on the Domestic Substances List (DSL) or are exempt.

**NOTE:** Not Applicable.

**16. OTHER INFORMATION**

**Additional Information:** No data available.

**Prepared by:** Toxicology and Product Safety

The information and recommendations contained herein are based upon tests believed to be reliable. However, Marathon Petroleum Company LP (MPC) does not guarantee their accuracy or completeness nor shall any of this information constitute a warranty, whether expressed or implied, as to the safety of the goods, the merchantability of the goods, or the fitness of the goods for a particular purpose. Adjustment to conform to actual conditions of usage may be required. MPC assumes no responsibility for results obtained or for incidental or consequential damages, including lost profits arising from the use of these data. No warranty against infringement of any patent, copyright or trademark is made or implied.

**End of Safety Data Sheet**