

# Thermoelectric device to allow diesel engine start-up at cold weather conditions

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## Abstract

Sometimes diesel engines cannot be started under low temperature conditions. The main reason is the obstruction of the fuel filter as a consequence of gasoil becoming solid paraffin as the temperature lowers. This paper describes a device based on thermoelectricity and eutectic compound that attached to the outside of the filter can melt paraffin quickly. While the engine is running and the fuel is warm, heat is stored in the eutectic compound. Then, when the user is about to start the engine at low temperature conditions, thermoelectric modules are used to transfer stored heat from the eutectic compound into the fuel, dissolving paraffin thus unblocking the filter. Thermodynamic simulations based on 3D finite element models show that just two minutes after connecting the device, the filter is ready to allow engine start-up. These results are obtained for standard gasoil, which solidifies at  $-5^{\circ}\text{C}$ , and starting the simulations at extreme initial conditions where the filter interior is considered a solid block of paraffin at  $-20^{\circ}\text{C}$ .

## Introduction

While antifreeze coolants used in motor vehicles can provide freezing protection below  $-35^{\circ}\text{C}$ , fuel solidifies at higher temperatures. If a car is stopped for a long time outside and the temperature in the environment is very low, paraffins can appear in the fuel circuit. This process is more likely in diesel engines since the solidification temperature of diesel fuel is higher. Some components in the fuel circuit, such as fuel pumps, can usually start moving the fuel and dissolving paraffins. However, paraffins in the filter block the whole fuel circuit and constitute the biggest problem when trying to start-up the engine. This is a problem that appears if the vehicle is not used for some hours, and the outside temperature is low. The fuel temperature after stopping the engine is about  $70^{\circ}\text{C}$ , but the heat is transferred to the environment and the fuel temperature decreases. If the ambient temperature is lower than the solidification temperature of the fuel, it is a matter of time that the fuel will form paraffins.

Some diesel cars include electrical resistor mounted on the base of the filter to supply heat during a cold engine start-up. These devices are useful but do not allow a quick start-up at extremely cold temperature conditions when the fuel is a solid block. The main reason is the low conductivity of the paraffin and the distance between the electrical resistor and fuel that must be melted to unblock the circuit. In addition, this device requires a significant amount of electrical energy from the

battery of the car. The application of thermoelectricity presented in this article has been focused on a gasoil filter where the filtering paper is arranged in star shape, with the fuel flowing in radial direction. In this configuration at least the upper part of the filter (as shown in Figure 1) must be liquefied to allow engine start-up.

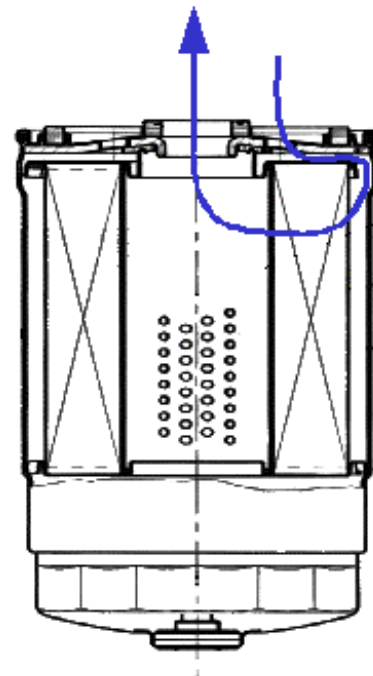


Figure 1: Scheme of the fuel filter

## Cooling Simulation

The base of the filter (shown on the top of Figure 1) screws on the mounting part where fuel pipelines are connected. Fuel enters the filter through the base in axial direction then it goes through the filtering paper in radial direction, and returns through the base. The bottom part of the figure is the chamber that collects water that may come dissolved in the fuel. After stopping the engine, the fuel pump does not move the gasoil so the fuel contained in the filter will remain there until the engine is started again. If the ambient temperature is low, the air surrounding the filter cools down the fuel contained in the filter, which eventually will reach the solidification temperature. It is possible to run simulations using finite element method and axi-symmetrical model of the filter in order to determine the time that a diesel car can be stopped at

low temperature before solidification of the fuel [6]. This time depends on the initial conditions and the thickness of the insulation. The resulting temperature profile 4 hours after stopping the engine are shown in Figure 2 for three different configurations: without insulation, partial insulation and fully insulated. Simulations were done assuming an initial fuel temperature of 70°C, ambient temperature of -20°C, and fuel solidifications temperature of -5°C.

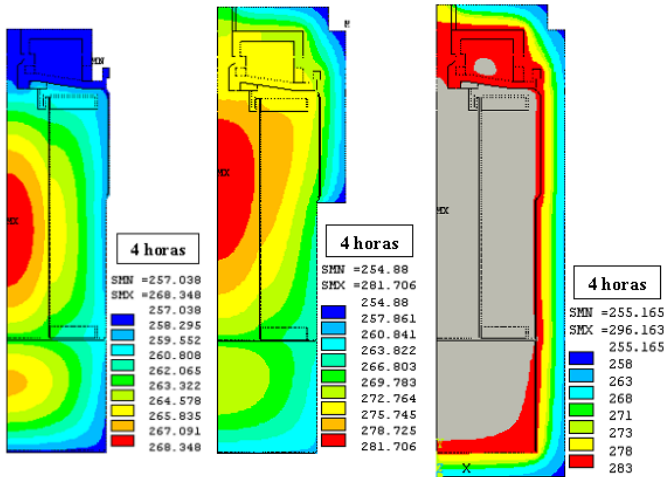


Figure 2: Temperature profile after 4 hours at -20°C

The thermal properties of the elements (density  $\rho$ , conductivity  $k$ , and specific heat  $c_p$ ) used for the simulations are shown on Table I.

Table I: Thermal properties

	$\rho$ $\left[ \frac{\text{Kg}}{\text{m}^3} \right]$	$k$ $\left[ \frac{\text{W}}{\text{m} \cdot \text{K}} \right]$	$c_p$ $\left[ \frac{\text{J}}{\text{Kg} \cdot \text{K}} \right]$
Galvanized Steel	7830	64	434
Gasoil	820	0.1	2180
Paraffin	820	0.1	2180
Insulation	60	0.04	2000
Rubber	1100	0.13	2010
Glue	1400	0.3	300

The consequence of the cooling simulations is that the fuel become completely paraffin solid after 4 hours without insulation, 6 hours with partial insulation, and 9 hours with total insulation. Hence, insulation alone does not avoid the obstruction of the filter long enough to allow engine start-up after a cold night. Adding more insulation increases the size of the filter and makes fuel refrigeration difficult in hot weather conditions.

### Thermoelectric Solution

The solution proposed by the authors is a small device containing a thermoelectric module and eutectic compound, which is attached to the filter near the base. Eutectic compounds require a lot of heat to change phase from liquid to

solid or vice versa [1][2]. Depending on the type of compound the energy for phase change varies between 200 and 300 kJ/kg, this is approximately the energy necessary to raise the temperature of 1kg of water from 0°C to 50÷70°C or 1kg of fuel from 0°C to 90÷140°C.

In the proposed device, the eutectic fluid is used to store heat and thermoelectric module is used to control the heat flow between the fuel and the eutectic based on the Peltier effect [5]. The system is designed to work in four stages (see Figure 3):

#### STAGE 1:

While the engine is running, heat from the fuel can flow to the eutectic compound. Fuel and eutectic reach 70°C at this stage.

#### STAGE 2:

After stopping the engine in a cold environment, the filter begins to cool. The eutectic tank is insulated to prevent heat loss while the rest of the filter is not insulated. It was decided not to insulate the whole filter to allow natural cooling when the engine is running in hot weather. Therefore paraffin will block the filter six hours after stopping the engine, according to the simulations presented above.

#### STAGE 3:

To inhibit excessive heat waste in the eutectic compound, thermoelectric modules will act as active insulation. Using a minimal amount of electricity, they can provide the amount of energy equal to the heat lost through the insulation. The objective of the active insulation is to keep the eutectic at a temperature higher than that of the phase change.

#### STAGE 4:

Just before trying to start-up the engine, thermoelectric modules are used to pump heat stored in the eutectic compound to the filter, in order to melt paraffin into fuel. At this stage, it is important to note that only the fuel located near the base of the filter must be dissolved; since a 10% of the flow section free of paraffin will allow enough fuel flow to start-up the engine. Once the engine is started the heat produced after the combustion process warms up the fuel, which circulating through the tank and the filter will melt the rest of the paraffin.

The advantage of using thermoelectricity is that a large amount of heat is injected into the fuel, but most of the heat comes from the eutectic compound. Using an electrical resistor the maximum power that can be transferred to the fuel is equal to the electrical power, while using thermoelectricity less electrical power is required to pump energy from a cold sink (eutectic) to a hot sink (fuel) [6].

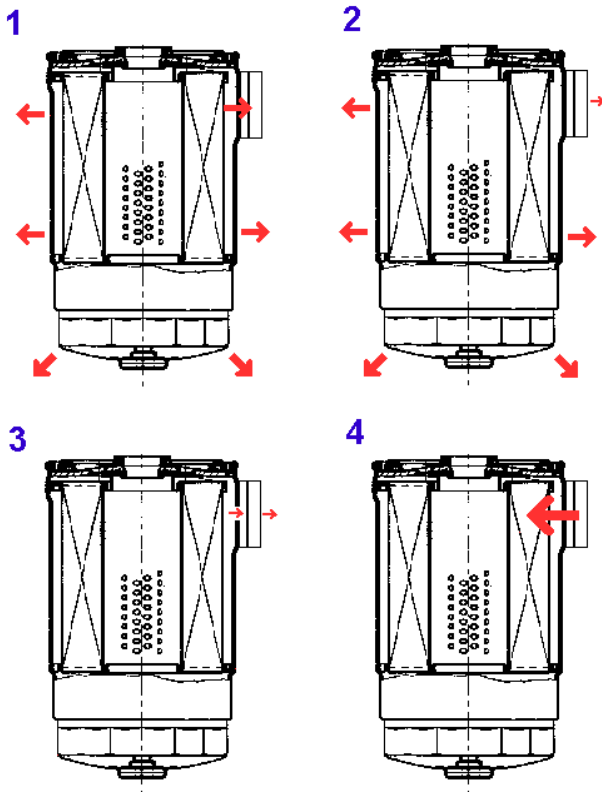


Figure 3: Four Stages of the Thermoelectric Device Operation

Instead of trying to avoid fuel solidification by adding insulation and large amounts of eutectic, our approach is to allow fuel solidification then transfer heat quickly to melt paraffin in stage 4. The thermoelectric device was designed to supply 75W to 100W of heat power. Just one commercial Peltier module fulfils this heat power using electric power as small as one tenth of the heat power. The amount of electricity required depends mainly on the difference of temperature and on the type of module, and the exact values can be obtained mathematically [3] or experimentally [4].

### Performance Results

Heating simulations were performed to evaluate if the thermoelectric device was able to allow engine start-up in less than two minutes at extreme conditions. In this case a 3D model was used to simulate the evolution of the temperature profile using finite element method. Finally three approaches are presented to mount the thermoelectric device in the filter.

The first approach is to mount the device outside the filter and apply the heat directly on the surface. Due to paraffin's low conductivity, applying heat to the outside panel of the filter raises the temperature of the thermoelectric module and the gasoil located next to the filter wall very quickly, while the fuel located in the middle of the filter remains solid. Figure 4 shows the temperature profile in a sector of filter after 2 minutes applying 75W of heat.

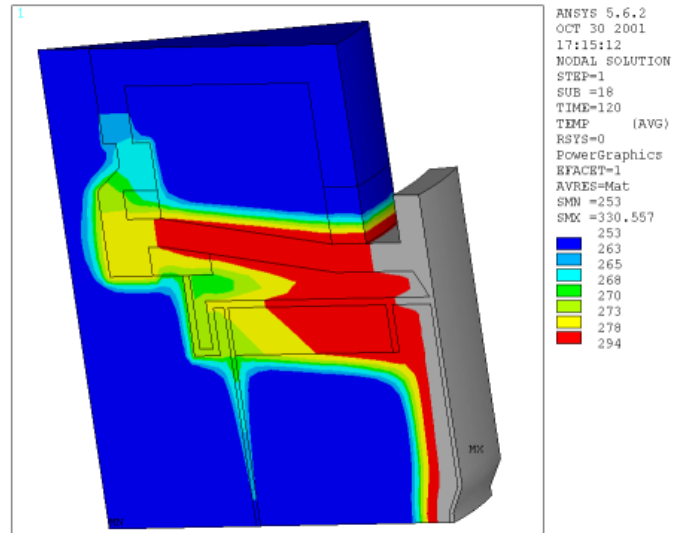


Figure 4: Device Mounted Outside, Without Modifying the Filter.

Applying more heat power will not solve the problem because the fuel located next to the filter wall will reach a dangerous temperature close to self-ignition before the center fuel becomes liquid. In addition the performance of the thermoelectric module is very bad if the temperature increases. The solution would be to supply lower heat power and wait longer time before trying to start the engine. Nevertheless, other approaches have been studied to allow quick start-up although they require modifications inside the filter.

The second approach consists on mounting high conductivity fins inside the filter in radial direction. These metal parts help transferring heat from the wall towards the center of the filter. After 2 minutes applying 75W of heat (see Figure 5) paraffin in the inner pipe has begun to melt while the fuel located next to the filter wall remains out of danger. Even applying 100W of heat the temperature reached next to the wall is kept in a safe level (see following approach).

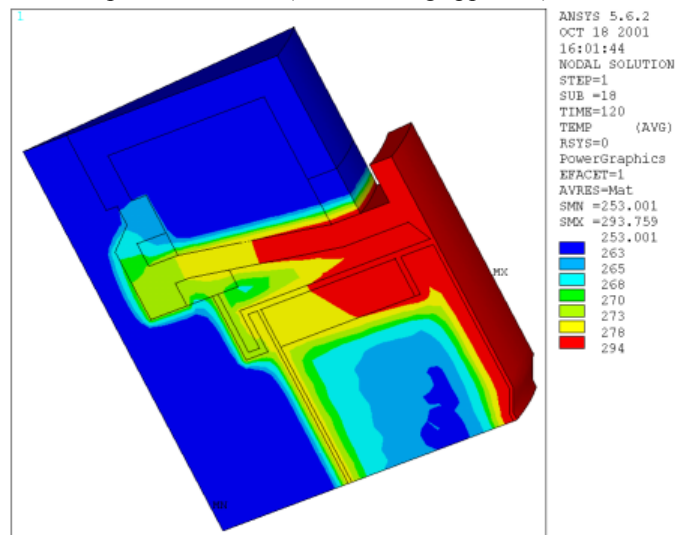


Figure 5: Adding Fins to Transfer Heat to the Center of the Filter.

Nevertheless, using this configuration it is not possible to start-up the engine two minutes after connecting the device,

because only a very small amount of the paraffin blocking the central pipe has been melted.

It is important to note that using stainless steel instead of galvanized steel, the conductivity is lower ( $k=14\text{W/mK}$ ) so the results obtained are worse than the results shown in the graph.

The third approach includes a hot wire located in the center of the filter to provide 1W of electrical heat to the fuel. Figure 6 shows the results of applying 100W using thermoelectric modules and 1W using the hot wire. In this case the engine can be started.

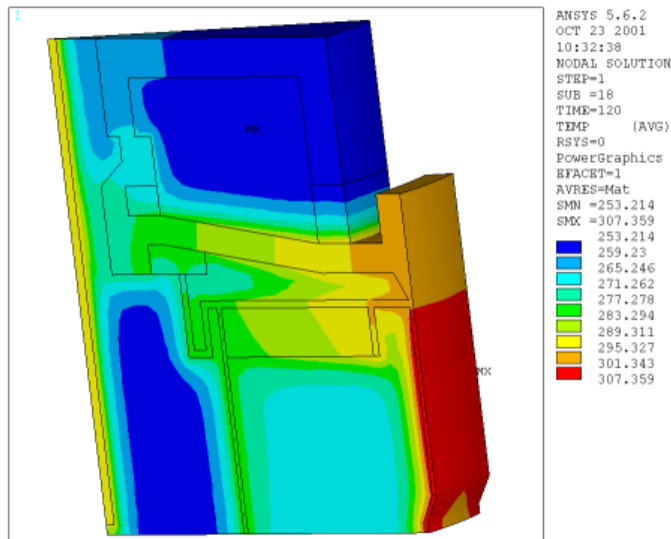


Figure 6: Adding a Hot Wire in the Interior of the Filter

In a real application the situation would be even better than that shown in Figure 6, because the convection effect of the liquid fuel have not been considered in the finite element simulation. Once the paraffin has been melted, the fuel is free to move in natural convection so the transfer capabilities of the liquid fuel is higher that in solid state. For the simulations presented, only heat conduction was considered.

The heat provided by the wire does not have the same advantage of low electric consumption as the thermoelectric heat pump, but the wire supplies heat just where it is needed to unblock the filter. The net increase of electric power is over 1% but it allows unblocking the central pipe. The same idea can also be used to melt paraffin in pipelines outside the filter. The hot wire is not fixed to the filter, it attached to the filter base, and so it has to be inserted into the filter when it is screw to the base. Then a thermoelectric device is attached to its outer wall (using and magnet or a strap).

## Conclusions

This paper has presented an application of thermoelectricity to solve a real problem in the automotive industry. The combination of thermoelectric modules, eutectic compound and a conventional hot wire resistor was the solution for this problem. Just insulating the filter or using eutectic compounds was not possible to keep the fuel in liquid state long enough, unless the dimensions of the filter are greatly modified. Using only thermoelectricity and eutectic it

is possible to unblock the fuel filter, though requiring more that two minutes. The addition of a hot wire inside the filter not only helped unblocking the filter, but it can also be used for pipes and other parts not considered in the project. The most important advantage of the device proposed is that it requires less electric power from the battery of the car to transfer the same amount of heat, as compared to a conventional resistor. This is because using a small amount of electricity the thermoelectric module can take heat from the eutectic and transfer it to the fuel, but they behave as insulation if no electricity is provided.

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