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Thermal fluids for the immersion cooling of battery-electric applications

Immersion cooling system

Thermal fluids for immersion cooling of batteries in electric vehicles are an innovative solution for improving temperature control and efficiency of battery systems. In this method, the battery cells are directly immersed in a thermal fluid, which allows very effective heat transfer. This cooling strategy ensures that the heat generated during battery operation is dissipated quickly and efficiently. This is particularly important to prevent overheating and optimise battery performance. The thermal fluids are usually dielectric, which means that they are poor electrical conductors. This minimises the risk of short circuits and other electrical problems that can occur when cooling batteries. Several types of thermal fluids can be used for immersion cooling. The main fluids are synthetic oils, special water-based fluids or fluorinated fluids, which are known for their excellent thermal properties. By directly cooling the battery cells, an even temperature distribution is achieved, which can extend battery life. In addition, immersion cooling systems can often be made more compact as they require less space for radiators and fans. The thermal fluids must be carefully matched to the specific requirements of the application, including temperature range, chemical stability and environmental compatibility.

The increased heat generated by batteries requires sophisticated thermal management, which means that battery cooling is also becoming increasingly important for safety reasons. The optimum temperature range for a lithium battery is between 20°C and 40°C. Outside this temperature range, undesirable temperature-dependent electrochemical and mechanical side reactions can occur, which in some cases massively reduce the life and capacity of the cells (degradation). [1]

One answer is immersion cooling. The idea is to place the electrical components to be cooled in direct contact with a dielectric thermal fluid. Due to the electrically insulating nature of these fluids, the insulators (and heat transfer resistances) required for water cooling can be avoided, resulting in better heat dissipation. In the case of the battery, this results in more uniform and lower cell temperatures during both cooling and heating of the cells. This allows the batteries to be charged and discharged more quickly and effectively without overheating, and extends their life. Another advantage is that the cells are protected against thermal runaway by the flame-retardant effect of the coolant. [2]

Dielectric coolants can also be used to directly cool and, depending on the design, lubricate electric motors. This enables higher continuous powers and power densities. The inverter or power electronics and charging cables can also be directly cooled. [3], [4]

Due to their direct contact with a wide range of components and increasing demands for efficiency and environmental compatibility, these fluids must fulfil certain properties [2]:

- Heat dissipation

  ➔ Mouromtseff number as a comparison between coolants, with density (ρ in kg/m³), thermal conductivity (λ in W/(m-K), specific heat capacity (c in J/(kg-K) and dynamic viscosity (μ in N-s/m²) as parameters:

  $$\mathrm{Mo} = \frac{\rho^{a} \cdot \lambda^{b} \cdot c^{d}}{\mu^{e}}$$

  The higher the figure of merit or the density, thermal conductivity and specific heat capacity and the lower the viscosity, the better the heat dissipation. This figure of merit is given in relation to water.

- Dielectric properties

  ➔ Low electrical conductivity (within a certain range to be non-conductive and prevent static charging)
  ➔ High dielectric strength
  ➔ Low water absorption
  ➔ Low dielectric dissipation factor
  ➔ Low permittivity

- Corrosion resistance

  ➔ Especially to copper

- Oxidation stability
- Material compatibility

  ➔ With elastomers and polymers in seals, sheaths, housings, etc.

- Pumping capability

  ➔ Lower viscosity means lower pump performance

➔ Low pour point depending on application

- Environmental aspects

  ➔ Biodegradability

- Safety concerns

  ➔ A higher flash point means greater safety
  ➔ Toxicity

Development of dielectric thermal fluids

As part of a cooperation between ROWE MINERALÖLWERK GmbH and Argomotive GmbH for the development of dielectric thermal fluids, promising products for immersion cooling have been developed and tested. The project started with a comprehensive analysis of the thermal fluid requirements to define the specific properties needed. This was followed by the development of prototypes and their testing under realistic conditions to evaluate the properties of the thermal fluids. The fluids were optimised by evaluating the test results and systematically adapting the development process. Product development has been carried out in compliance with safety and environmental regulations to ensure that the thermal fluids developed meet legal requirements.

The test methodology and some test results are given below as examples.

Investigation of thermal fluids for immersion cooling

The aim of the investigation and evaluation of thermal fluids for immersion cooling is to improve the efficiency and safety of battery systems. The following key issues will be considered

Thermal properties:

- Thermal conductivity (high thermal conductivity)
- Specific heat capacity (high specific heat capacity)
- Viscosity (low viscosity)

1. Dielectric properties:
   - Electrical conductivity (little to no electrical conductivity)
2. Chemical stability:
   - Corrosion resistance (inert to applied materials of battery cells and cooling system)
   - Thermal stability (stable at high temperatures)
3. Environmental impact:
   - Ecological compatibility (biodegradable or less harmful chemicals)
   - Safety aspects (risks such as flammability or toxicity)

Design and construction of a test rig for dielectric thermal fluids

A test stand was designed to test the influence of various fluid properties on the cooling and heating performance of different liquids. The centrepiece of the test stand consists of an immersion-tempered battery pack in a corresponding stainless steel housing (see Figs. 3 and 4), which is located in a temperature chamber. This is used to control the temperature of the ambient air around the battery. Furthermore, the dielectric fluid to be tested is tempered in a conditioner, which essentially consists of a pump, heater and cooling circuit. Figure 1 shows the schematic structure of the test bench and Figure 2 shows the implementation. The temperature data logger in Figure 1 is replaced on the real test bench by a measuring system from an engine test bench, which can read out the volume flow sensor as well as the temperatures. In addition, a battery management system is connected between the bidirectional laboratory power supply and the battery, which, among other things, monitors the voltages of individual cell blocks connected in parallel.

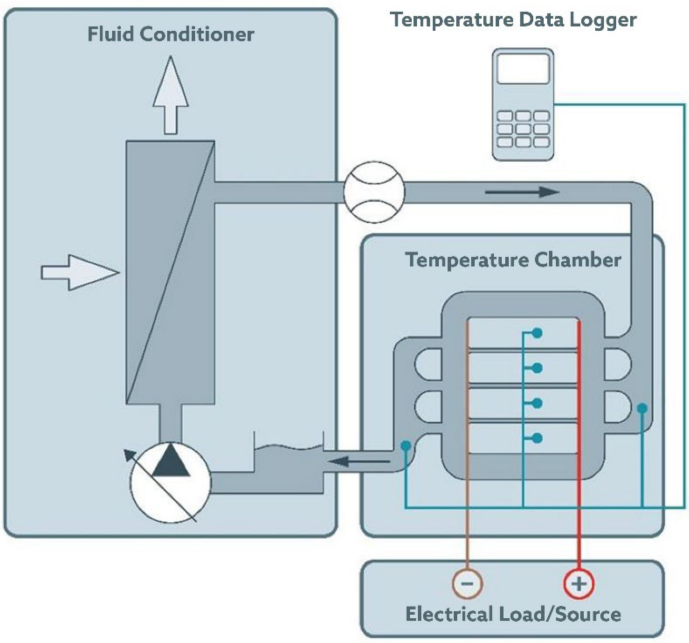

Fig. 1: Schematic diagram of the coolant test stand (Illustration: Argomotive GmbH)

Fig. 2: Realised setup of the test bench with bidirectional laboratory power supply, temperature chamber and liquid conditioner (from left to right) (Photo: Argomotive GmbH)

The housing, cell holders, cell connectors and power and sensor connectors have been designed and manufactured specifically for this assembly. This assembly (without cell connectors) is shown in Figure 3. The battery enclosure with all connected tubing and cables is shown in Figure 4. The battery consists of 96 21700 BAK cells (N21700CG-50) in a 12s8p configuration and is charged and discharged via a battery management system with a bi-directional laboratory power supply. This battery cell was selected for its relatively high internal resistance. Pt100 elements are mounted at the centre of four cell surfaces and two busbars, as well as at the input and output of the battery case, to record readings. Volume flow can also be recorded using a volume flow sensor. The pump power required for each fluid is also analysed for each test. Battery voltages and currents are also recorded via the laboratory power supply.

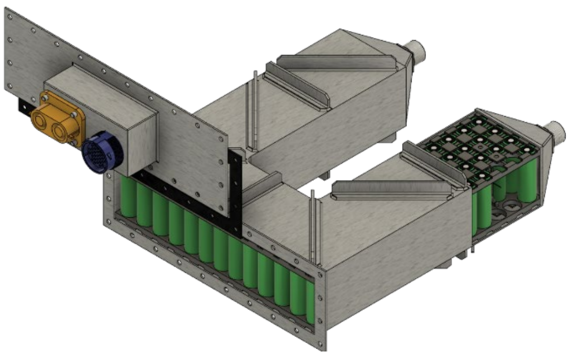

Fig. 3: 3D design view of the battery with cells, housing and plug connections (Illustration: Argomotive GmbH)

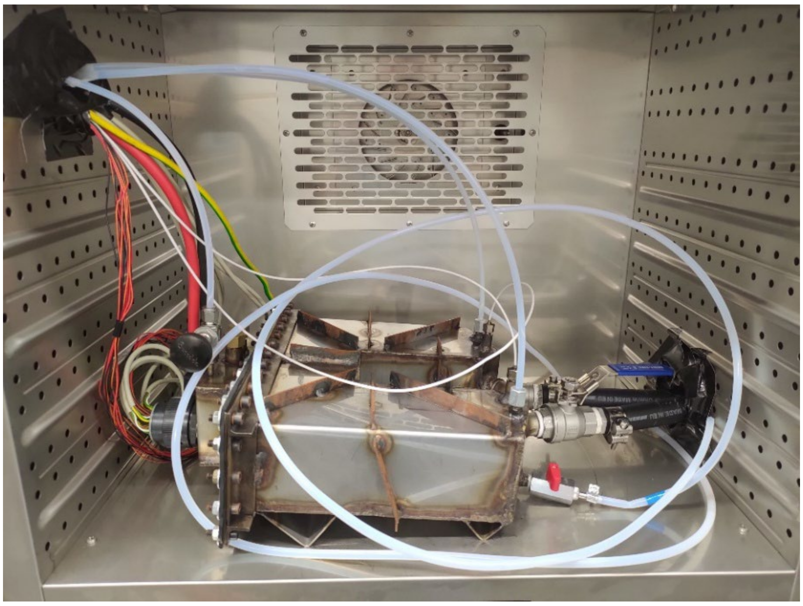

Fig. 4: Battery housing in the temperature chamber with liquid supply and drain lines, venting and draining hoses and power, sense and Pt100 cables (Photo: Argomotive GmbH)

Comparative analyses

A test programme for several fluids was carried out using this test set-up. The battery with case, or its ambient air, and the liquid were tempered to 20 °C and a constant flow of approximately 22 l/min was set through the eight-stage pump. At the start of the test, the battery was discharged at 2.5°C for 10 minutes. The target temperature set on the conditioner remained at 20°C, with cooling at a maximum of 150 W. The resulting maximum temperatures were compared between the fluids.

Between fluid changes, the system is flushed with a solvent to ensure that no residues of the previous fluid remain in the cooling circuit. The system is then flushed again with the new test fluid and finally filled for the test runs.

To ensure the repeatability of the measurements, several tests were carried out with two different fluids per test, as well as tests with rinses between tests. Standard deviations were less than 0.2 K.

Numerous tests showed that viscosity is the most important factor influencing cooling and pump performance. The lower the viscosity, the lower the maximum battery temperature and the lower the pump power required to circulate the fluid at a constant speed in the test rig (Table 1). Pump power is therefore very important, as the energy provided by the batteries to run the pump is not available for other purposes, such as driving the vehicle.

Figure 5 shows the average temperatures of all measuring points on the batteries for different immersion liquids. From this diagram it is possible to deduce which fluids are more suitable for battery temperature control. These observations can be estimated in advance using a theoretical figure of merit, where the Mouromtseff number (Mo) was found to be suitable.

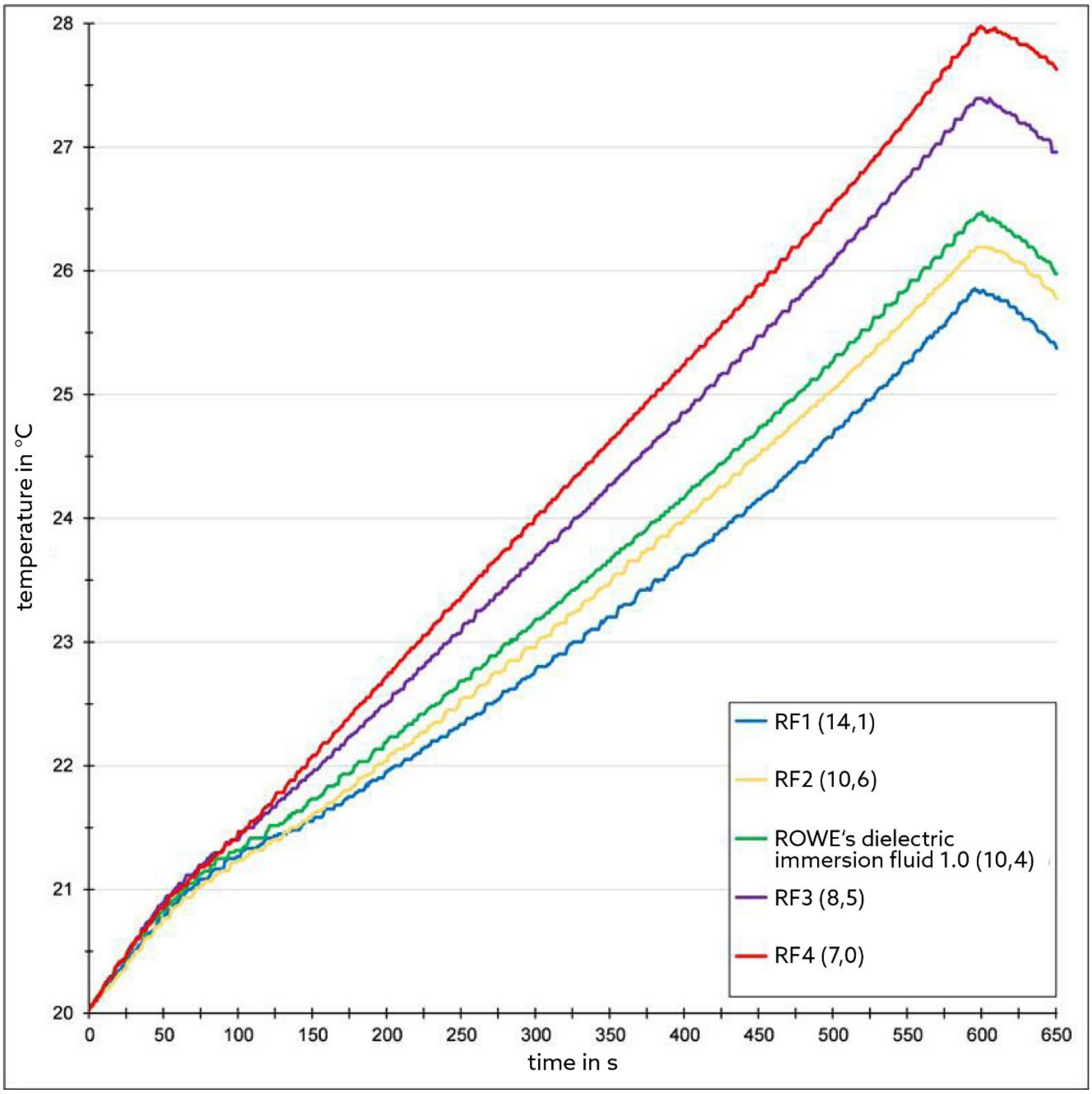

Fig. 5: Averaged temperature curves for the 20 °C test and the associated Mouromtseff numbers (Mo) (Illustration: Argomotive GmbH)

Although the temperature differences between the fluids are not as great as the differences in the quality coefficients, there are still very large differences in the flash points between the immersion fluids (Table 1).

In addition to specific resistance and dielectric strength, the flash point plays a critical role in operational safety and thermal runaway safety. Although no standards exist, 180°C or even 200°C is sometimes considered to be the minimum flash point for use in electric vehicles.

For comparison: Reference Fluid 4 (RF 4) has a kinematic viscosity of approximately 39 mm2/s at 20°C and a flash point of 218°C, while Reference Fluid 1 (RF 1), which has a much lower viscosity of approximately 6 mm2/s and therefore better cooling properties, has a flash point of only 135°C. Despite a high flash point of over 200°C, the ROWE immersion fluid showed very good cooling properties at low pump power due to its low viscosity. The ROWE coolant also proved to be an excellent cooling medium with regard to the above-mentioned important aspects for an immersion fluid, e.g. corrosion resistance or oxidation stability.

Table 1: Comparison of the different fluids

Fluid	Mo in %	Maximum battery temperature in °C	Pump power in W	Viscosity in mm^2/s (20 °C)	Flash point in °C
RF 1	14,1	25,9	63,7	6,1	135
RF 2	10,6	26,2	110,1	12,0	157
ROWE	10,4	26,5	110,5	13,8	203
RF 3	8,5	27,4	171,3	18,5	182
RF 4	7,0	28,0	246,7	39,1	218

Summary

Thermal management of electric drives and stationary applications will play an increasingly important role in the future, due in part to ever-increasing charging capacities and the drive to further improve efficiency. Immersion cooling of electrical components with dielectric thermal fluids can play an important role in the future.

The use of dielectric coolants helps to increase the efficiency and lifetime of batteries by preventing overheating and ensuring uniform temperature distribution. This is particularly important as high temperatures can have a negative impact on battery performance and lifetime [5].

In addition, dielectric coolants can be used in other applications such as electronics and machinery cooling where safe and effective heat removal is required. [6]

There are different types of dielectric coolants based on different chemical compositions and the selection of the right fluid depends on the specific requirements of the application.

The comparative tests on the thermal management test bench at Argomotive GmbH have shown the promising potential of the newly developed thermal fluids from ROWE Mineralölwerk GmbH. These fluids meet all the requirements for immersion cooling in terms of thermal management and are suitable for various applications such as battery electric drives, electronics, machines and computer technology.

The dielectric thermal fluids developed in cooperation between ROWE MINERALÖLWERK GmbH and Argomotive GmbH are innovative solutions that significantly improve the efficiency and safety of battery-electric applications.

Sources:

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