Development of an enhanced liquid for electronic cooling

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Abstract: Development of NEPCM (Nanoparticle Encapsulated Phase Change Material) nanofluids using low melting temperature metals is a very pertinent area of research in the context of effective thermal management solutions. Compared to a pure fluid, these nanofluids have a higher heat capacity during the phase change and it is possible to improve the heat transfer, as a result of this phase change. To appreciate the merits, in terms of energy, an energy Performance Evaluation Criteria (PEC) has been defined as the ratio of heat transfer rate at fixed pumping power. The numerical results obtained show an improvement around 20\% of this energetic criterion at low $\Delta T$ compared to the base fluid. A status of the development of these fluids in our laboratory is given in this paper. From an experimental point of view, a specific test loop has been developed in order to test thermo hydraulic performance in a controlled manner in laminar and turbulent conditions at imposed heat flux with a small volume of fluid (350 ml). The test loop was validated with pure water and the choice of materials used has been defined but not yet tested.

Key words: nanofluid, phase change material, physical properties, performance evaluation criteria

Nomenclature

\begin{itemize}
\item $Q$ heat flow rate, W
\item $W$ pumping power, W
\item $C_p$ specific heat capacity, J.kg\textsuperscript{-1}.K\textsuperscript{-1}
\item $d_i$ inner tube diameter, m
\item $d_e$ outer tube diameter, m
\item $M$ mass, kg
\item $q_m$ mass flow rate, kg.s\textsuperscript{-1}
\item $N_u$ Nusselt number
\item $Pr$ Prandtl number
\item $Re$ Reynolds number
\item $S$ heat exchange area, m\textsuperscript{2}
\item $V$ velocity, m.s\textsuperscript{-1}
\item $K$ consistency, Pa.s\textsuperscript{n}
\item $\mu$ dynamic viscosity, Pa.s
\item $\rho$ density, kg.m\textsuperscript{3}
\item $\Delta p$ pressure drop, Pa
\item $h$ heat transfer coefficient, W.m\textsuperscript{-2}.K\textsuperscript{-1}
\item $A$ Darcy coefficient
\item $v$ Sedimentation rate, m.s\textsuperscript{-1}
\item $l$ tube length, m
\item $k$ thermal conductivity, W.m\textsuperscript{-1}.K\textsuperscript{-1}
\item $P_e$ Peclet number
\item $T$ temperature, K, °C
\item $L$ latent heat of fusion, J.kg\textsuperscript{-1}
\item $\Lambda$ Darcy coefficient
\end{itemize}

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1. Introduction
The need for convective heat transfer enhancement has produced a considerable amount of research [1, 2]. Convective heat transfer can be improved either by changing flow geometry and boundary conditions, or by modifying the thermophysical properties of the heat transfer fluid. Enhancing specific heat and thermal conductivity allows heat transfer to be increased. There has been a lot of work to develop nanofluids using solid nanoparticles dispersed in a base fluid to increase the heat transfer properties of the fluid; however from an energetic point of view, the increase of thermal conductivity is always accompanied by an increase of viscosity leading to an energetic criterion lower than 1.

NEPCM (Nanoparticle Encapsulated Phase Change Material) slurry is dispersion where the PCM is dispersed in fluid. Compared to the base fluid, these nanofluids have a higher heat capacity during the phase change and a possible enhancement, as a result of this phase change, in the heat transfer phenomenon. We can greatly increase heat capacity during the phase change and then obtain an energetic criterion greater than 1. To develop a nanofluid for heat transfer purposes, it is necessary to have a global approach. We must look at an energetic criterion and not only the apparent specific heat enhancement or improvement of heat transfer. The energetic criterion chosen is the ration of heat transfer of the nanofluid to the base fluid at constant pumping power.

The study is divided into two parts in order to examine the effects of different materials on the energetic criterion and validate the experimental installation.

- The first part focuses on the theoretical research of good materials improving the energetic criterion.
- The second part validates the experimental set-up in the turbulent and laminar regime, using demineralized water. The system operates with a heat flow imposed and between 20 and 95 °C.

2. Theoretical study
2.1. Performance Evaluation Criteria (PEC)
It is known that the addition of nanoparticles in a fluid may increase heat exchange but usually this addition will increase the viscosity of the fluid. To see if the use of a nanofluid is beneficial from an energy point of view compared to the base fluid, we have to define Performance Evaluation Criteria (PEC). In the literature [3, 4], several studies have established a performance ratio:

$$\eta = \frac{Q_{nf} / W_{nf}}{Q_0 / W_0} \quad (1)$$

Where $Q$ is the heat flow rate and $W = q_m \Delta p / \rho$ the pumping power ($q$ denotes the base fluid and $nf$ the nanofluid). If this ratio is less than 1, using a nanofluid is not recommended from an energy point of view.

We assume that we can apply to NEPCM classical laws of thermo hydraulic taking the mixing properties of the nanofluid, this has been demonstrated in previous studies. As the intended applications are in turbulent regime, we can express the Nusselt numbers ($Nu$) determined with Colburn’s correlation, Reynolds number ($Re$), Prandtl number ($Pr$), exchange coefficient $h$, friction coefficient $f$:

$$Nu = 0.023 \cdot Re^{0.8} \cdot Pr^{0.33} \quad Re = \frac{\rho Vo d_i}{\mu} \quad f = 0.316 \cdot Re^{-0.25} \quad Pr = \frac{Cp \mu}{k} \quad h = \frac{Nu k}{d_i}$$

and therefore $h = 0.023 \cdot Re^{0.8} \cdot Pr^{0.33} \cdot \frac{k}{d_i} = 0.023 \cdot \rho^{0.8} \cdot V^{0.8} \cdot d_i^{-0.2} \cdot \mu^{-0.47} \cdot Cp^{0.33} \cdot k^{0.67} \quad (2)$

As defined in [4], the performance factor becomes:

$$\eta = h_{nf} / h_0 = h' = PEC \quad (3)$$
The performance factors thus allow us to evaluate the gain or loss of a nanofluid relative to a base fluid for hydraulic or thermal criterion. We can establish an energetic PEC based solely on the physical properties of nanofluids.

We will use here a PEC based on the heat exchange coefficient ratio where the geometry and the pumping power are fixed. The PEC used is:

$$ PEC = \rho^{0.582} \mu^{-0.543} C_p^{0.33} k^{0.67} $$  \hspace{1cm} (4)

With \( \rho' \) being the ratio of nanofluid to base fluid densities, \( \mu' \) the ratio for the viscosities, \( C_p' \) the ratio for apparent heat capacity (including phase change).

2.2. Model

To predict this performance factor we need to know the fluid properties.

2.2.1. Density

Typically, the mass conservation law is used to evaluate the density of a nanofluid [5]:

$$ \rho = \rho_0(1 - \phi) + \rho_{np}\phi = \rho_0[1 + \phi(\rho_{np}/\rho_0 - 1)] $$  \hspace{1cm} (5)

With \( \phi \) as the volume fraction of nanoparticles, \( \rho \) as the density (\( np \) denotes the nanoparticles).

2.2.2. Specific heat

To calculate the heat capacity of a nanofluid, it is common to take the formula adapted for liquid / solid dispersions:

$$ C_p = C_{p0}(1-\phi_{np}) + C_{pnp}\phi_{np} = \frac{\phi\rho_{np}C_{pnp} + (1-\phi)\rho_0C_{p0}}{\phi\rho_{np} + (1-\phi)\rho_0} $$  \hspace{1cm} (6)

With \( \phi_{np} \) as the mass concentration of the nanoparticle.

However, when the phase change is involved in estimating the heat transfer performance, the effect of latent heat must be taken in account so an effective specific heat is used [6], which can be written as:

$$ C_{p_{eff}} = C_p + (\phi_{np} L/\Delta T) $$  \hspace{1cm} (7)

With \( C_{p_{eff}} \) as the effective heat capacity, \( L \) as latent heat of fusion, and \( \Delta T \) as the temperature range of the change of state. Note that the effective specific heat is dependant of the temperature range.

2.2.3. Thermal conductivity

The suspension may be treated as a homogeneous material, we can use the Hamilton and Crosser formulation [7] to predict the thermal conductivity:

$$ k = \frac{k_{np} + (n-1)k_0 - (n-1)\phi(k_0 - k_{np})}{k_{np} + (n-1)k_0 + \phi(k_0 - k_{np})} $$  \hspace{1cm} (8)

Where \( n=3/\psi \) is the scale factor and \( \psi = 1 \) for spherical particles. This model is known to be conservative model that gives lower results than experimental measurements.

2.2.4. Dynamic viscosity

Einstein's model [8] determines the viscosity of a fluid containing particles in monodisperse suspension without interactions between them:

$$ \mu = \mu_0(1 + 2.5\phi_{hk}) \text{ valid for } \phi < 5\% $$  \hspace{1cm} (9)

Where \( \mu \) is the dynamic viscosity of the nanofluid, \( \mu_0 \) the dynamic viscosity of the base fluid, \( \phi_{hk} \) the hydrodynamic volume fraction of the particles: it takes into account the solvation shell around the particles in contrast to \( \phi \).
2.3. Results
This study gives an approach of the energetic criteria for several base fluid/PCM combinations in the range 20-100°C using organics, salts and metallic compounds with melting temperatures of less than 100°C. Heat transfer simulations have been performed with various water/materials. A transient model for melting of the PCM particle has been developed to verify the complete melting of the particle passing in the heat source.

Figure 1 shows the results of this study with $C_{pef}$ calculated with $\Delta T=20°C$. The thermophysical properties of the materials are given in Table 1.

![Figure 1](image1.png)

**Figure 1.** Influence of volume concentration of nanoparticles on the $PEC$ for various materials.

In this figure we can see that paraffin, material commonly used for heat storage, is very bad for the flowing fluids. This is due to the fact that the viscosity increases with the volume concentration while other physical properties increase with mass concentration. As can be seen in Figure 2, where the volume concentration was fixed at 5%, the more dense material will give better results. The heat of fusion is an important criterion because it increases the apparent $C_p$. Metallic compounds having a low melting point, are the best candidates for this. Paraffins are eliminated, their $PEC$ being less than 1.

![Figure 2](image2.png)

**Figure 2.** $PEC$ as a function of Density for $\phi_v=5\%$

![Figure 3](image3.png)

**Figure 3.** $PEC$ as a function of Melting temperature. The bubble surface is the price.
Figure 1 shows the evolution of the PEC for different materials but does not take into account the cost and volume of the capsule. Table 1 lists the various PCM properties. Their PEC is given for a volume concentration of 5%. Note that the price reflects the cost of bulk material [9], calculated with the mass of constituent materials. The price of manufacturing nanoparticles should be considered in further studies. These prices therefore enable us to give a first classification of different materials but not to estimate the real cost of nanofluid. Figure 3 attempts to synthesize this table. These shows the PEC as a function of melting temperature, the surface of the bubbles is the price of the alloy in €/kg. It is found that the smaller the melting temperature, the more expensive the alloy is.

**Table 1. Property existing alloys for lower melting temperature to 100°C.**

| Alloy Description | Liquidus [°C/°F] | Solidus [°C/°F] | Cp [J/kg/k] | Lpm [J/kg] | K [W/m/K] | Density [Kg/m³] | PEC [€/kg] | Price [€/kg] |
|-------------------|------------------|-----------------|------------|------------|-----------|----------------|----------|------------|
| 52 Bi, 31.5 Pb, 15.5 Sn | 78.0/172.6 | 75.0/167.0 | 585 | 290000 | 1.2 | 2180 | 1.071 | 4000 |
| 51 In, 32.5 Bi, 16.5 Sn | 62.0/144.0 | 60.0/140 | 585 | 290000 | 1.2 | 2180 | 1.071 | 518 |
| 61.72 In, 30.78 Bi, 7.5 Cd | 61.5/143 | 61.5/143 | 200 | 38179 | 57 | 8035 | 1.168 | 624 |
| 48.5 Bi, 25.4 Pb, 12.6 Sn, 9.5 Cd, 5 In | 65.0/149 | 57/134 | 159 | 45292 | 33 | 9445 | 1.205 | 63 |
| 49 Bi, 18.2 Pb, 16.5 Sn | 69.0/156 | 58.136 | 166 | 44104 | 33 | 9005 | 1.194 | 192 |
| 50 Bi, 26.7 Pb, 13.3 Sn, 10 Cd | 70.168 | 70.168 | 200 | 36757 | 52 | 9165 | 1.209 | 14 |
| 66.3 In, 33.7 Bi | 72.162 | 72.162 | 200 | 36757 | 52 | 9165 | 1.209 | 14 |
| 50.5 Bi, 27.8 Pb, 12.4 Sn, 9.3 Cd | 73.165 | 70.158 | 154 | 45774 | 31 | 9642 | 1.209 | 14 |
| 50 Bi, 25.2 Pb, 12.5 Sn, 12.5 Cd | 73.165 | 70.158 | 157 | 46751 | 32 | 9565 | 1.210 | 14 |
| 50 Bi, 24.95 Pb, 12.5 Sn, 12.5 Cd, 0.5 Ag | 73.165 | 70.158 | 158 | 47260 | 35 | 9525 | 1.210 | 14 |
| H3PO4 | 74 | 74 | 200 | 156000 | 20 | 1650 | 1.071 | 448 |
| BaBr2 | 75 | 75 | 256 | 61143 | 9.3 | 3340 | 1.170 | 44 |
| 50 Bi, 24.95 Pb, 12.5 Sn, 12.5 Cd | 73.165 | 70.158 | 157 | 46751 | 32 | 9565 | 1.210 | 14 |
| 50 Bi, 12.5 Sn, 15.4 Sn | 69/156 | 58/136 | 166 | 44104 | 33 | 9005 | 1.194 | 221 |
| 49 Bi, 18.2 Pb, 16.5 Sn | 69.0/156 | 58.136 | 166 | 44104 | 33 | 9005 | 1.194 | 221 |
| 50 Bi, 25.2 Pb, 12.5 Sn, 12.5 Cd | 73.165 | 70.158 | 157 | 46751 | 32 | 9565 | 1.210 | 14 |
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| 50 Bi, 24.95 Pb, 12.5 Sn, 12.5 Cd | 73.165 | 70.158 | 158 | 47260 | 35 | 9525 | 1.210 | 14 |
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| 49 Bi, 18.2 Pb, 16.5 Sn | 69.0/156 | 58.136 | 166 | 44104 | 33 | 9005 | 1.194 | 221 |
| 50 Bi, 12.5 Sn, 15.4 Sn | 69/156 | 58/136 | 166 | 44104 | 33 | 9005 | 1.194 | 221 |
| 49 Bi, 18.2 Pb, 16.5 Sn | 69.0/156 | 58.136 | 166 | 44104 | 33 | 9005 | 1.194 | 221 |
| 50 Bi, 12.5 Sn, 15.4 Sn | 69/156 | 58/136 | 166 | 44104 | 33 | 9005 | 1.194 | 221 |
| 49 Bi, 18.2 Pb, 16.5 Sn | 69.0/156 | 58.136 | 166 | 44104 | 33 | 9005 | 1.194 | 221 |
| 50 Bi, 12.5 Sn, 15.4 Sn | 69/156 | 58/136 | 166 | 44104 | 33 | 9005 | 1.194 | 221 |
| 49 Bi, 18.2 Pb, 16.5 Sn | 69.0/156 | 58.136 | 166 | 44104 | 33 | 9005 | 1.194 | 221 |
| 50 Bi, 12.5 Sn, 15.4 Sn | 69/156 | 58/136 | 166 | 44104 | 33 | 9005 | 1.194 | 221 |
| 49 Bi, 18.2 Pb, 16.5 Sn | 69.0/156 | 58.136 | 166 | 44104 | 33 | 9005 | 1.194 | 221 |

The materials giving good results are very high density metal alloys materials are very high density metal alloys. Sedimentation problems may appear if the particle diameter is not small enough.

Figure 4 shows the sedimentation rate $\nu$ according to temperature, calculated using the Stokes’s Law:

$$\nu = \frac{d^2 \cdot g \cdot \Delta \rho}{9 \mu} \tag{10}$$

Where $g$ is the gravity and $\Delta \rho$ is the density difference between the particle and the fluid. The effect of the particle diameter is clearly visible in this figure.
2.4. Conclusion

Different fluid/material PEC simulations have led to a choice of a water/metal nanofluids that give a \( PEC = 1.2 \), representing a 20% heat transfer increase at same pressure loss. A summary table is given. This allows us to select the right alloy having an adequate melting temperature. This melting temperature should be between the minimum and maximum temperature of the system to benefit from the increase in the apparent \( C_p \). The diameter of nanoparticle should be as small as possible to limit sedimentation, but greater than 20 nm to avoid supercooling problems.

3. Experimental setup

A specific experimental test loop (see Figure 5) has been developed in order to get thermo hydraulic performances in a controlled manner in laminar and turbulent conditions at imposed heat flux with a small volume of fluid (350 ml).

The test section is a circular tube with an imposed flux, with inlet temperatures ranging between 20 and 95°C. The test loop is composed of a fluid circuit, a heater unit, a temperature regulating unit and...
a control unit and measurement acquisition. The variable parameters are the type of fluid, the Reynolds number, the heat flow and the inlet temperature. The test section is composed of a stainless steel tube of length \( L = 0.475 \) m, inner diameter \( d_i = 1.28 \) mm and external diameter \( d_e = 1.54 \) mm. The test section is heated by Joule effect. The tube is connected to the terminals of a DC generator which generates a maximum power of 625 W. Ten micro thermocouples (Tpe) are attached to the outside of the tube in the longitudinal direction, their longitudinal positions (bottom to top of the tube) are given in Table 2. Two platinum sensors: Pt100, are located at the inlet and outlet of the tube from within the flow, to measure the inlet temperature "Ti" and outlet "To". Moreover, pressure sensors are also located before and after the heated section tube to measure the pressure drop \( \Delta p \) caused by fluid flow within the tube.

### Table 2. Location of the thermocouples

| Thermocouple | T1  | T2  | T3  | T4  | T5  | T6  | T7  | T8  | T9  | T10 |
|--------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Location (x,mm) | 8   | 56  | 106 | 160 | 217 | 277 | 323 | 375 | 428 | 462 |
| \( x/d_i \)   | 6   | 44  | 83  | 125 | 170 | 216 | 252 | 293 | 334 | 361 |

3.1. Analysis

The analysis of experimental data determines the thermohydraulic properties of the fluid (the heat transfer coefficient, the Nusselt number and the pressure drop). These will then be compared to the usual correlations.

The different dimensionless numbers necessary for analyses are defined below:

\[
Re = \frac{q_m d_i}{\mu S}
\]

\[
Pr = \frac{\mu C_p}{k}
\]

\[
h(x) = \frac{q_s}{T_{pin}(x) - T_f(x)}
\]

\[
Nu(x) = \frac{h(x) d_i}{k}
\]

Where \( q_m \) is the mass flow measured with a Coriolis flowmeter, \( d_i \) the inner diameter, \( S = \pi d_i^2/4 \) the area of the internal section of the tube, \( T_{pin} \) the temperature of the inner wall at the abscissa \( x \) and \( T_f \) the fluid temperature at \( x \).

Experimentally we have access only to the outer wall temperatures \( T_{pe}(x) \) at different abscissas \( x \), and \( Ti \) and \( To \) of the input and output temperature of the fluid. Therefore, it is necessary to establish two equations to determine the temperatures \( T_{pin}(x) \) and \( T_f(x) \), required in the evaluation of \( Nu \) and \( h \), from the measurement of temperatures \( Ti \) and \( T_{pe}(x) \). In our case:

\[
T_{pin}(x) = \frac{UI d_e^2}{4 \pi L \lambda (d_e^2 - d_i^2)} \left[ 2 \ln \left( \frac{d_i}{d_e} \right) + 1 - \left( \frac{d_i}{d_e} \right)^2 \right] + T_{pe}(x)
\]

(11)

and

\[
T_f(x) = \frac{q_s \pi d_i}{q_m C_p} x + Ti
\]

(12)

Where UI is the electric power and \( q_s = UI/\pi d_i L = q_m C_p \Delta T/\pi d_i L \) is the surface flux.

3.2. Nusselt number

With the above equations, \( T_{pin}(x) \) and \( T_f(x) \), two parameters for determining \( Nu \) were defined from temperature measurements \( Ti, To \) and \( T_{pe}(x) \). We can now calculate the experimental \( Nu \) and compare this to the usual correlations for different flow regimes. These correlations are defined in terms of Reynolds and Prandtl numbers.

3.2.1. Laminar flow

Figure 6 shows the experimental Nusselt (black squares) as a function of \( x/d \) for two \( Re \). These results are compared to the classical Shah correlation[10], valid in laminar flow which gives the local Nusselt number:

\[
Nu = 1.302 \left( \frac{x}{d} \right)^{1/3} - 0.5 \quad \text{if} \quad x^* \leq 0.003
\]
\[ Nu = 4.364 + 0.263 \left( x^+ / 2 \right)^{0.506} \exp \left( -41 \left( x^+ / 2 \right) \right) \text{ if } x^+ > 0.003, \text{ with } x^+=\frac{2(x/d)}{Re.Pr} \quad (13) \]

**Figure 6.** \( Nu \) as a function of \( x/d \).

We see in this figure a good agreement between experimental and theoretical temperatures located in the middle of the section. For thermocouples 1, 9 and 10, there are discrepancies attributed to thermal conduction edge effects that disturb the measurements. Finite element calculations were performed and clearly show the side effect of conduction in the tube, particularly at low Reynolds. Therefore, in laminar flow, only thermocouples 2 to 8 will be used to get correct results.

### 3.2.2. Turbulent flow

Figure 7 represents the local Nusselt determined experimentally as a function of the dimensionless length \( x/d \) for different Reynolds. The heat flux is respectively \( Uf=219\text{W}, 147\text{W} \) and \( 78\text{W} \).

**Figure 7.** Nusselt number as a function of \( x/d \) at different Reynolds.

**Figure 8.** Experimental Nusselt as a function of theoretical Nusselt.
We can see from figure 7 that the edge effects are negligible in the turbulent regime and all thermocouples can be used.

Figure 8 shows the mean Nusselt (thermocouples 1-10) determined experimentally as a function of theoretical $Nu$ calculated using Colburn’s correlation. For this figure, $Re$ is between 650 and 24,000.

The correlation of Colburn: $Nu = 0.023.Re^{0.8}.Pr^{1/3}$ is valid for $0.7 < Pr < 160$ and $10^4 < Re < 1.2 \times 10^5$ with $Re$ and $Pr$ calculated film temperature: $T_{film} = (T_{pin} + T_f)/2$.

We observe a good agreement between our experimental results and correlations. The experimental uncertainties were calculated for the case $Re=3300$, $Nu=22$ and $Re=23000$, $Nu=107$, the results are around ± 9% and ± 12.5%. This is reasonably good for this kind of correlation.

In conclusion, we can say that the tests with demineralised water show behaviour consistent with classical correlations for heat transfer.

3.3. Pressure drop

The regular pressure drop in a tube $\Delta p$ can be written in general:

$$\Delta p = \Lambda \left( \frac{L}{d_i} \right) \rho \frac{v^2}{2}$$

with $\Lambda = 64/Re$ for $Re \leq 2300$ (laminar flow) and $\Lambda = 0.3164/Re^{1/4}$ for $2300 \leq Re \leq 100,000$ (Blasius correlation for turbulent flow) [11].

However, these classical correlations have been established in the case of isothermal environments. To take into account the temperature variation in the axial direction of the tube, it is imperative to apply a correction factor:

$$\Lambda_c = \Lambda \left( \frac{\mu_j}{\mu_p} \right)^n$$

With $n=0.25$ in turbulent flow [11].

Figure 9 shows the experimental Darcy coefficient obtained with demineralised water and the Blasius correlation. The measurement uncertainties are represented by error bars.

![Figure 9. Evolution of the Darcy coefficient as a function of Reynolds number](image)

The conformity of the results of heat exchange and pressure to the demineralized water in the loop allows us to validate the measurement system. We can consider it also allows us to perform the same type of measurements applied to nanofluids with confidence.
4. Conclusions

Different fluid/material PEC simulations have led to a choice of a water/metal nanofluid that may increase heat transfer up to 20% at same pressure loss. A summary table is given. This allows to select the right alloy having an adequate melting temperature.

A specific experimental test loop has been developed in order to test thermo hydraulic performance in laminar and turbulent conditions at imposed heat flux with a small volume of fluid (350 ml). Tests have been performed with base fluid (water) in laminar and turbulent flow on this loop, the classical thermo hydraulic models for heat transfer and pressure loss have been verified thus validating the experimental method.

Note that the experimental results presented in the current paper are only for pure water and not for the proposed NEPCM fluids.

These fluids have a great potential for electronic cooling: for example at same junction temperature we can increase the maximum heat flux or decrease pumping power; it is also possible to increase reliability decreasing the junction temperature with the same cooling system.

Development and tests of some of these fluids are under way in our laboratory. Apart from physical properties and thermohydraulic characterizations, some problems as sedimentation, agglomeration of particles, fouling and so on have to be investigated.

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