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INVESTIGATION OF THE COOLING PROCESS WITH NANOFLUIDS ACCORDING TO ISO 9950 AND ASTM D 6482 STANDARDS

PREISKAVA POSTOPKA OHLAJANJA V NANOTEKOČINI PO STANDARDIH ISO 9950 IN ASTM D 6482

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Introducing nanofluids as liquid quenchants in order to improve the heat-transfer characteristics is a novel approach in heat treatment. These new liquid quenchants are called nanoquenchants and are colloid suspensions of nanoparticles in the base fluid (BF). For the purpose of this research standard liquid quenchants, such as water and polymer solution, were used as base fluids. Nanoparticles were added to the base fluid in order to increase its thermal properties without a significant effect on the viscosity of the fluid. The added nanoparticles cause an enhancement of the heat-transfer characteristics of the liquid quenchants. In this research TiO_2 nanoparticles, with the average size of 50 nm, were added to the base fluid. The cooling curves for every tested quenchant were recorded using the IVF SmartQuench system and the quenching process parameters were determined and compared. The tested quenchants were deionised water and polyalkylene-glycol (PAG) water solutions of (5, 10 and 20) % in volume fractions of polymer concentrations. Quenching experiments were first conducted in pure BFs without the addition of nanoparticles and without agitation according to the ISO 9950 standard. The experiments were then repeated with an addition of 0.2 g/l TiO_2 nanoparticles. The second series of experiments was conducted in a quenching bath with agitation according to the ASTM D 6482 standard. All of the recorded cooling curves were compared and the effects of the nanoparticle addition and agitation were investigated. The addition of the nanoparticles and quenching with agitation caused an increase in the maximum cooling rate and a shorter full-film stage.

Keywords: quenching, nanofluids, agitation, TiO_2 nanoparticles

Uvajanje nanotekočin za kaljenje za izboljšanje lastnosti prenosa toplote je nov način toplotne obdelave. Te nove tekočine za kaljenje se imenujejo nanokalilne tekočine, ki so koloidna suspenzija nanodelcev v osnovni tekočini (BF). Za preiskavo je bila kot standardna tekočina za kaljenje uporabljena mešanica vode in raztopine polimera. Nanodelci so bili dodani osnovni tekočini za povečanje termičnih lastnosti brez velikega učinka na viskoznost tekočine. Dodani nanodelci so povečali toplotno prevodnost tekočine za kaljenje. V tej raziskavi so bili dodani osnovni tekočini nanodelci TiO_2 povprečne velikosti 50 nm. Krivulje ohlajanja za vsako preizkušeno kalilno tekočino so bile posnete s sistemom IVF SmartQuench in procesni parametri kaljenja so bili določeni in primerjani. Preizkušene kalilne tekočine so bile deionizirana voda, vodna raztopina polialkilen glikola (PAG) z volumenskim deležem (5, 10 in 20) % polimera. Preizkusi kaljenja so bili najprej izvršeni v osnovni tekočini (BF) brez dodatka nanodelcev in brez premešavanja, skladno s standardom ISO 9950. Eksperimenti so bili nato ponovljeni z dodatkom nanodelecev 0,2 g/l TiO_2. Druga serija preizkusov je bila izvršena v kalilni kopeli s premešavanjem, kot določa standard ASTM D 6482. Vse posnete krivulje so bile primerjane in preiskovan je bil tudi učinek dodatka nanodelcev in premešavanja. Dodatek nanodelcev in kaljenje s premešavanjem sta povzročila povečanje maksimalne hitrosti hlajenja in krajše stanje popolnega prekritja s paro.

Ključne besede: kaljenje, nanotekočine, mešanje, nanodelci TiO_2

1 INTRODUCTION

Nanofluids (NFs) are colloidal suspensions of a base fluid (BF) and particles that are usually less than 100 nm in diameter[1]. The particles are added with the aim of improving the thermal properties of the pure base fluids, which primarily refers to the significant increase in the heat-transfer dynamics of the cooling process. It is important that the rheological properties of NFs do not change much[2–4]. Base fluids can be water, ethylene glycol, polyalkylene glycol (PAG) or quenching oil, while metal nanopowders (Cu, Au, Ag), oxide-ceramic particles (Al_2O_3, SiO_2, TiO_2), carbon powders and nanotubes are added to a base fluid. This is the reason why nanofluids are interesting as liquid quenchants. Physical properties of a quench-hardened work piece highly depend on the cooling rate during the quenching process. In order to achieve specific properties, different cooling rates have to be applied[5]. So far, several studies were conducted to demonstrate the efficiency of nanofluids as liquid quenchants[6–9]. The experiments showed that nanofluids exhibit a higher heat-transfer coefficient (HTC) and a better thermal conductivity than base fluids, but also a shorter full-film boiling phase. Further analysis of the cooling curves showed an increase in the critical heat flux (CHF) caused by an addition of nanoparticles to BF.

So far, all of the experiments were conducted according to the ISO 9950 standard. There are no published results regarding the quenching in nanofluids with mechanical agitation. For this reason a series of experiments according to the ASTM D 6482 standard were conducted to compare the cooling curves of BFs and NFs, but also to see the effect of agitation.

2 EXPERIMENTS

A standard test probe used in this set of experiments is in compliance with the international standards and is a part of the IVF SmartQuench system consisting of a data-acquisition unit, a certified standard test probe, a furnace and software. The data acquisition unit and software have the capacity of gathering 100 samples per second, which is considered to be high enough for registering all the rapid changes that occur during the quenching process. The experiments with still fluids were conducted in a one-litre beaker, and a two-litre quenching bath was constructed for the experiments with agitation. The electric-motor rotational speed is set to 1000 r/min and agitation is induced with a three-blade propeller. For the preparation of NFs, the titanium-oxide (TiO_2) particles produced by Degussa, Germany, were used. The average size of the nanoparticles was 50 nm, and they come in the form of a white powder. No dispersants, surfactants or activating agents were used. Pure TiO_2 nanoparticles were added to BFs and homogenized. The method of homogenization consisted of adding 0.2 g/l of TiO_2 nanoparticles to deionised (DI) water and then sonified for 60 min. This was the nanoparticle concentration for all of the tested nanoquenchants. This was followed by mixing the nanoparticles with a defined volume of PAG. The fluid was then sonified for additional 30 min and mechanically stirred from time to time. The ultrasonic bath, type BRANSONIC 220, with the frequency of 50 kHz and power of 120 W, was used to homogenize the nanofluids. With respect to the water-based polymer solution, polyalkylene glycol, known as Ucon Quenchant E, was added to water. Its tested concentrations were volume fractions (5, 10 and 20) % of PAG, while the concentration of nanoparticles was 0.2 g/l. The bath temperature of all liquid quenchants was 44 °C ± 1 °C.

3 RESULTS

A set of quenching experiments was conducted with and without agitation in order to determine the cooling characteristics of the liquid quenchants. First, the base fluids were tested. To see the effect of a nanoparticle addition, nanofluids were used as liquid quenchants in both still and agitated conditions. All of the recorded cooling curves are shown in **Figure 1**. Water and water-based nanofluids show very small differences in the cooling characteristics. The maximum cooling rate is within 10 % but the most significant influence is observed during the full-film phase. The transition temperature from the full-film phase to the nucleate boiling phase (T_{vp}) is much higher for NFs and for both

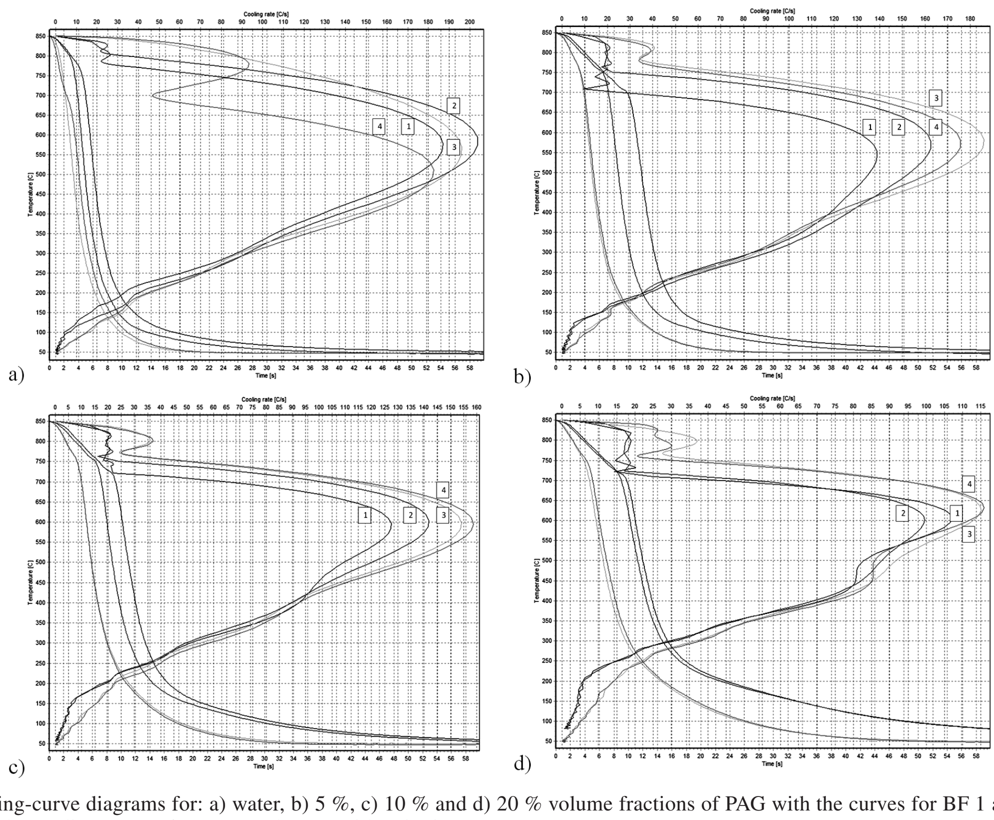

Figure 1: Cooling-curve diagrams for: a) water, b) 5 %, c) 10 % and d) 20 % volume fractions of PAG with the curves for BF 1 and NF 2 in still conditions and the cooling curves for BF 3 and NF 4 with agitation

Slika 1: Diagrami ohlajevalnih krivulj za: a) vodo, b) 5 %, c) 10 % in d) 20 % volumenskih deležev PAG s krivuljami za BF 1 in NF 2 v mirovanju in ohlajevalne krivulje za BF 3 in NF 4 s premešavanjem

Table 1: Resulted characteristics derived from the cooling curves
Tabela 1: Značilnosti, ki izhajajo iz ohlajevalnih krivulj

Quenchant	CR_{max}/(°C/s)	$T(CR_{max})$/°C	$t(CR_{max})$/s	T_{cp}/°C	T_{vp}/°C
Water	187.1	577.8	6.7	127.0	786.5
Water + 0.2 g TiO_2	209.5	584.0	4.9	152.6	843.4
Water with agitation	196.1	556.5	3.9	87.4	850.1
Water + 0.2 g TiO_2 with agitation	182.1	496.4	5.1	72.8	849.4
Water + 5 % PAG	138.8	535.7	12.5	134.5	707.8
Water + 0.2 g TiO_2 + 5 % PAG	162.5	564.7	9.2	127.5	757.1
Water + 5 % PAG with agitation	185.8	566.2	5.6	151.5	786.1
Water + 0.2 g TiO_2 + 5 % PAG with agitation	175.6	579.4	5.7	154.6	780.3
Water + 10 % PAG	127.5	585.9	11.3	181.8	727.6
Water + 0.2 g TiO_2 + 10 %PAG	141.8	596.2	9.1	164.3	757.8
Water + 10 %PAG with agitation	154.2	597.7	6.2	163.8	772.3
Water + 0.2 g TiO_2 + 10 %PAG with agitation	158.7	595.0	6.2	162.7	772.2
Water + 20 % PAG	107.1	604.2	11.9	241.0	717.0
Water + 0.2 g TiO_2 + 20 % PAG	99.6	605.0	11.2	206.9	728.2
Water + 20 % PAG with agitation	115.0	622.4	5.3	224.4	767.0
Water + 0.2 g TiO_2 + 20 % PAG with agitation	115.8	631.6	6.7	482.1	761.0

cases of quenching with agitation. All the specific values of the cooling curves for each quenching case are given in **Table 1**. The polymer solution with 5 % PAG shows that, in still conditions, an addition of nanoparticles shortens the full-film stage and causes a 17 % increase in the maximum cooling rate (CR_{max}).

When quenching with agitation, the cooling curves for BFs and NFs are almost identical. The full-film phase is more than 6 s shorter than BF and the increase in CR_{max} is 34 %. Note that the CR_{max} of BF is higher than in the case of NF. As the polymer concentration is increased, the difference between the cooling rates is getting smaller. All of the cooling curves with agitation show that an addition of nanoparticles does not cause better cooling characteristics. This means that agitation is the main cause of a shorter full-film phase and a higher CR_{max}. During the research it has been noted that the effect of the deposition of nanoparticles on the surface probe was more evident after the quenching in still conditions.

4 CONCLUSION

The research results led to the following conclusions:

- Quenching with agitation caused a shorter full-film phase and a higher CR_{max}.
- Nanofluids provided an enhancement of the heat-transfer characteristics in still conditions for all the cases except for the high polymer concentration.
- There is almost no difference between the cooling curves for BFs and NFs with agitation.
- Agitation, not an addition of nanoparticles, is the main cause for a shorter full-film phase and higher $CR_{max.}$
- The effect of an addition of nanoparticles becomes lower as the polymer concentration increases.

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