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Supplementary material

A Theoretical and Experimental Approach to the Analysis of Hydrogen Generation and Thermodynamic Behavior in an In Situ Heavy Oil Upgrading Process Using Oil-Based Nanofluids

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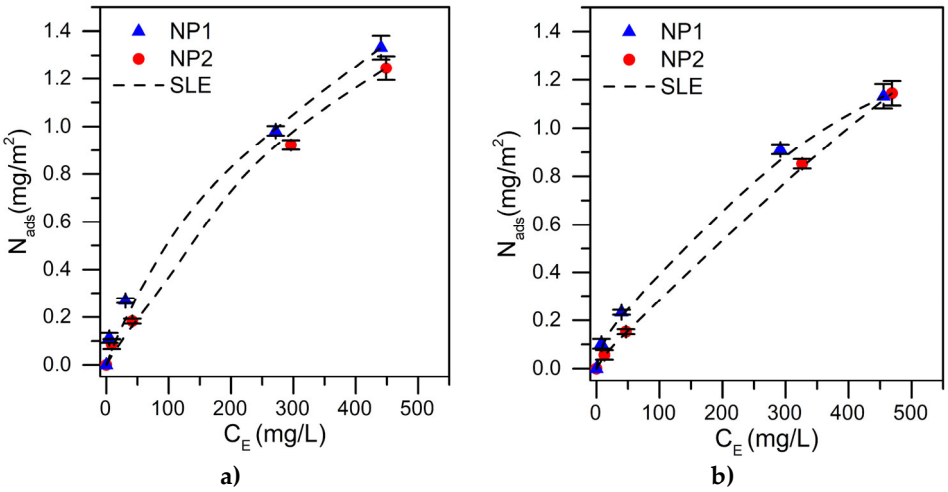

Figure S1. Experimental adsorption of *n*-C7 asphaltene isolated from a) HO1 and b) HO2 over NP1 and NP2 (dotted lines represent the SLE fitting).

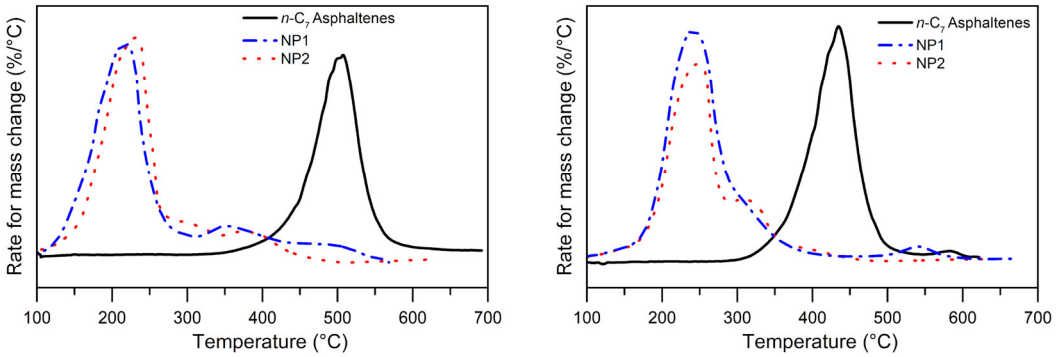

Figure S2. Rate for mass change profiles for steam gasification of *n*-C7 asphaltenes isolated mmmm a)HO1 and b)HO2, with and without NP1 and NP2. Heating rate: 10 °C·min^{-1}, N_2 flow: 100 ml·min^{-1}, $H_2O_{(g)}$ flow: 6.7 ml·min^{-1}and sample mass 1 mg.

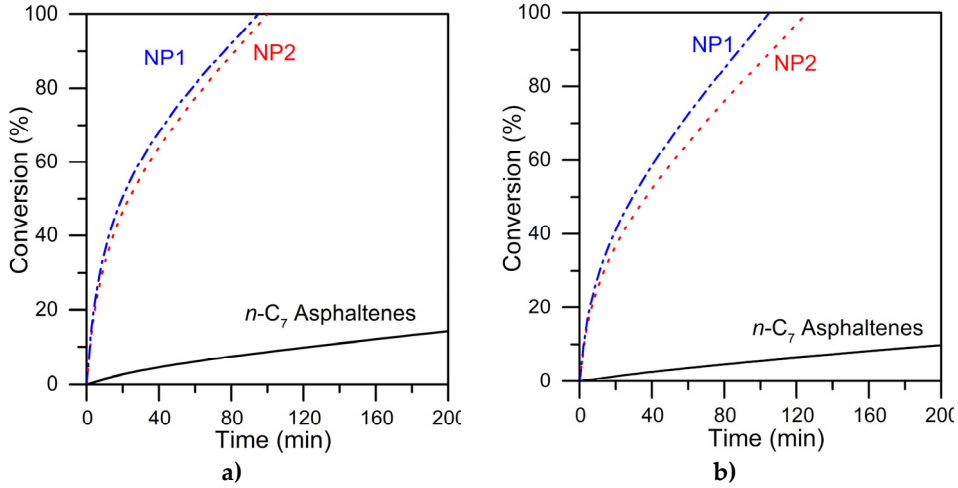

Figure S3. Isothermal conversion for steam gasification of *n*-C7 asphaltenes isolated form a)HO1 and b)HO2 with and without NP1 and NP2. Heating rate: 10 °C·min^{-1}, N_2 flow: 100 ml·min^{-1}, $H_2O_{(g)}$ flow: 6.7 ml·min^{-1}and sample mass 1 mg.

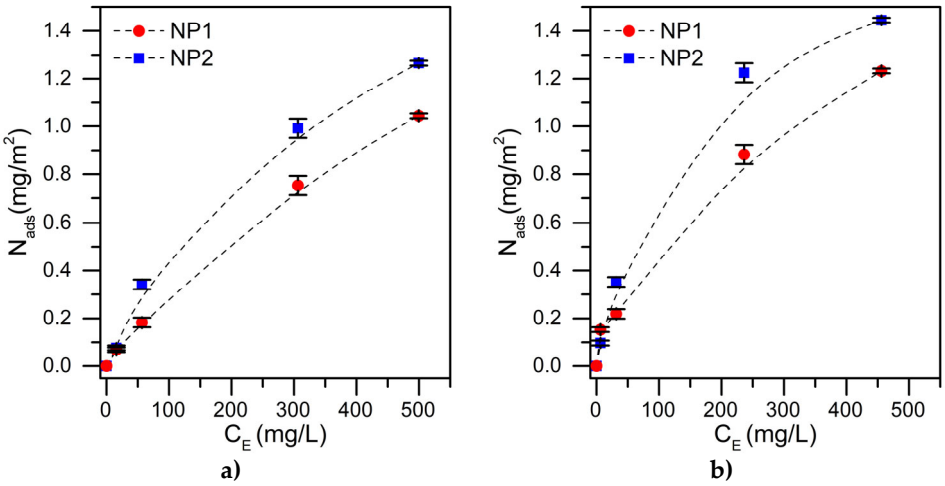

Figure S4. Experimental adsorption of resins isolated from a) HO1 and b) HO2 over NP1 and NP2 (dotted lines represent the SLE fitting).

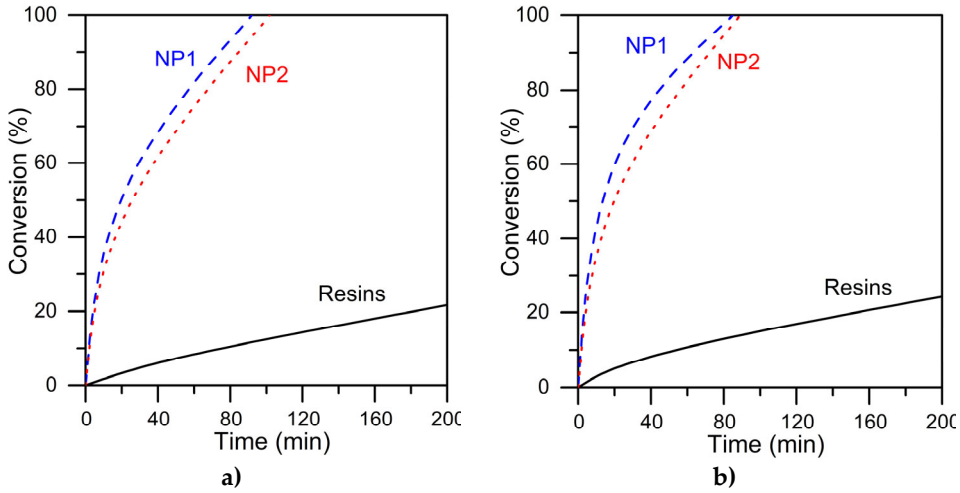

Figure S5. Isothermal conversion for steam gasification of resins isolated form a)HO1 and b)HO2 with and without NP1 and NP2. Heating rate: 10 °C·min^{-1}, N_2 flow: 100 ml·min^{-1}, $H_2O_{(g)}$ flow: 6.7 ml·min^{-1}and sample mass 1 mg.

Figure S6 shows the presence of characteristic bands of the hydroxyl functional groups (O-H) associated with the presence of alcohols at 3391 cm^{-1} wavelengths [53]. The vibration corresponding to the –CH bonds are also found at 2900 cm^{-1}, related to the presence of olefins, and finally, bands with C=C, C=O, C-N, C-C, C-O, and C-O-C bonds are recognized (1500 – 1700 cm^{-1}) [54]. The carrier comprises aliphatic hydrocarbons, with carboxylic acids, ester groups, amines, amides, and nitrogen groups [55].

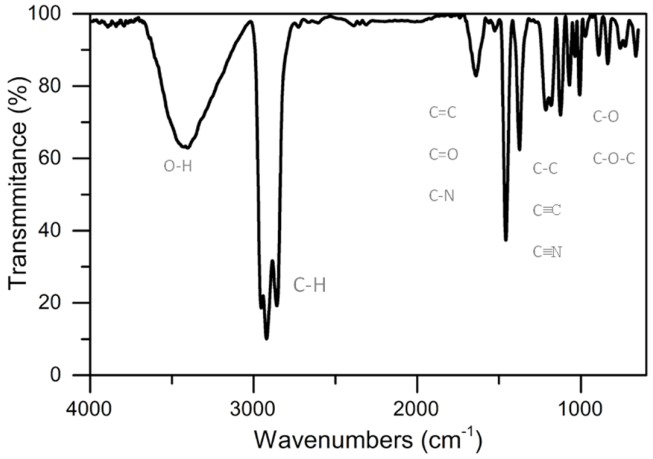

Figure S6. IR spectra for carrier used in the nanofluid for steam injection displacement.