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Technology
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Enhanced Oil Recovery

Optimization of enhanced thermal recovery processes with steam injection with nano fluids

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Agenda

- Introduction
- On the concept of ISU
- Nanomaterials and related technologies
- Field trial
- Opportunities

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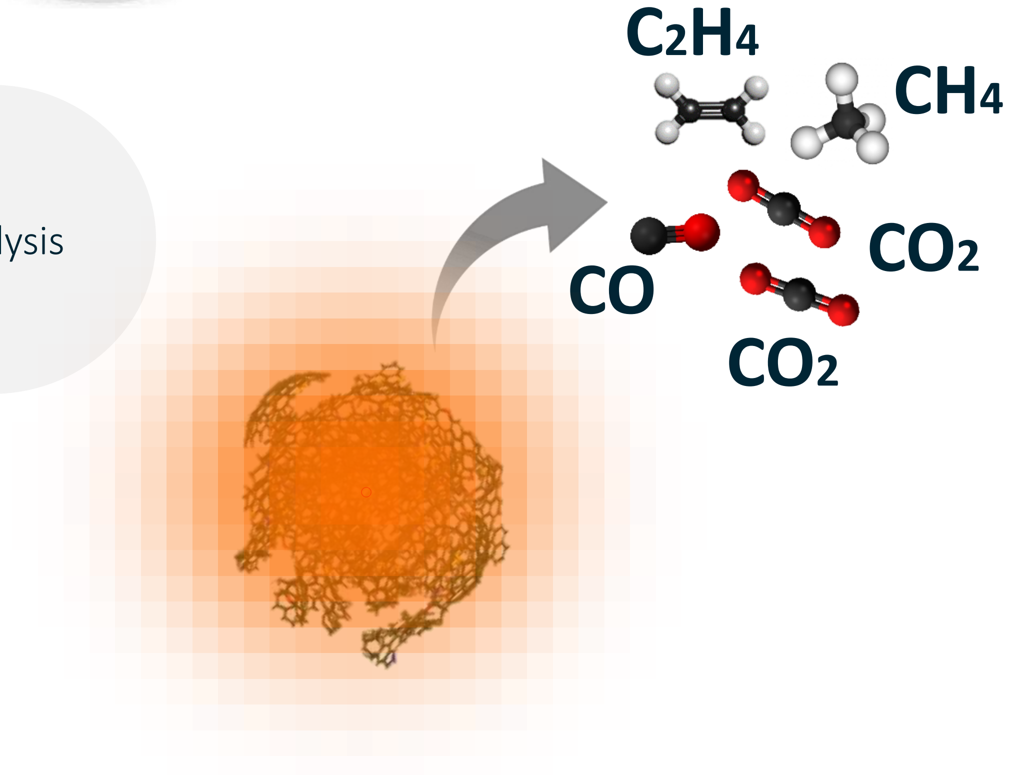
Partial oxidation

Gasification

Pyrolysis

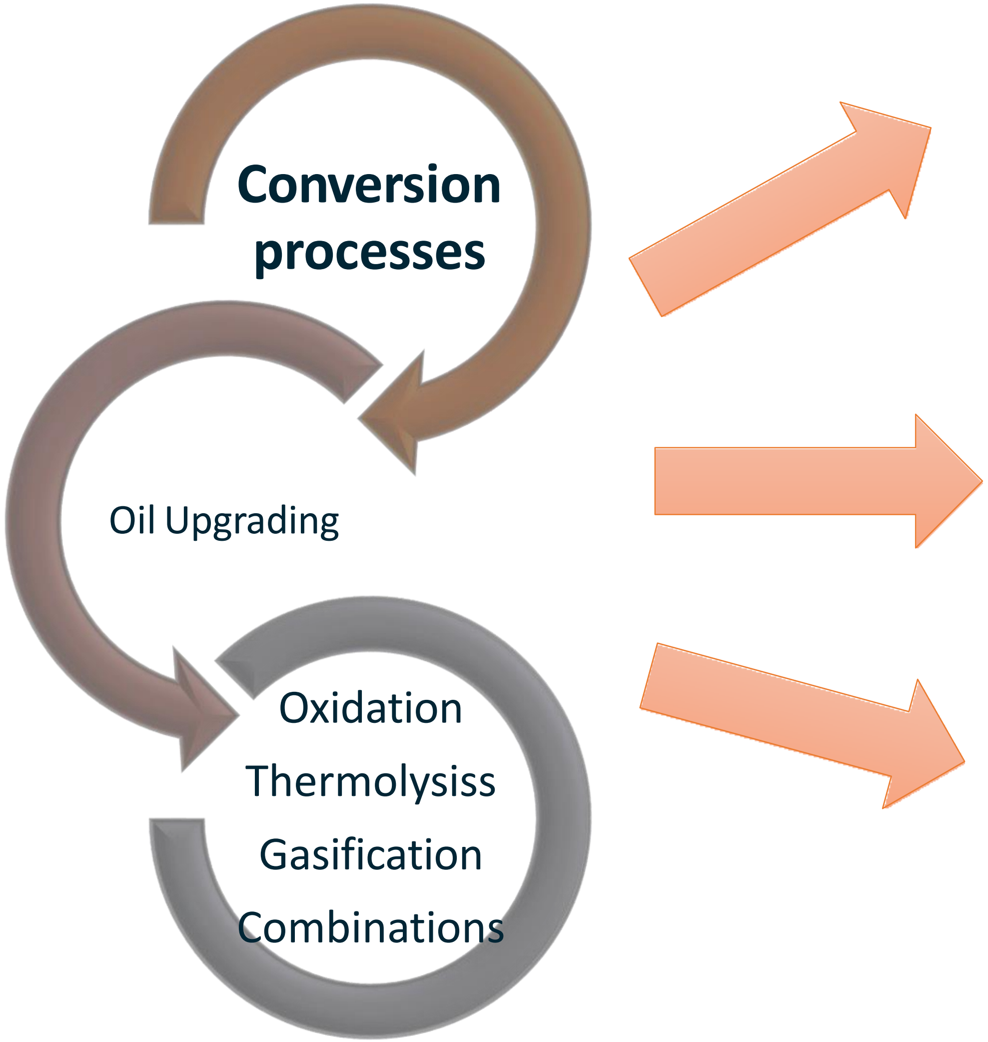
HEAVY OIL: *70% world oil reserves*



1 In-Situ

2 On-Site

Enhanced Oil Recovery



- Increasing in crude oil quality
- Increase of API

- Viscosity reduction

- Increase in distillable products. Lower penalization in $/bbl

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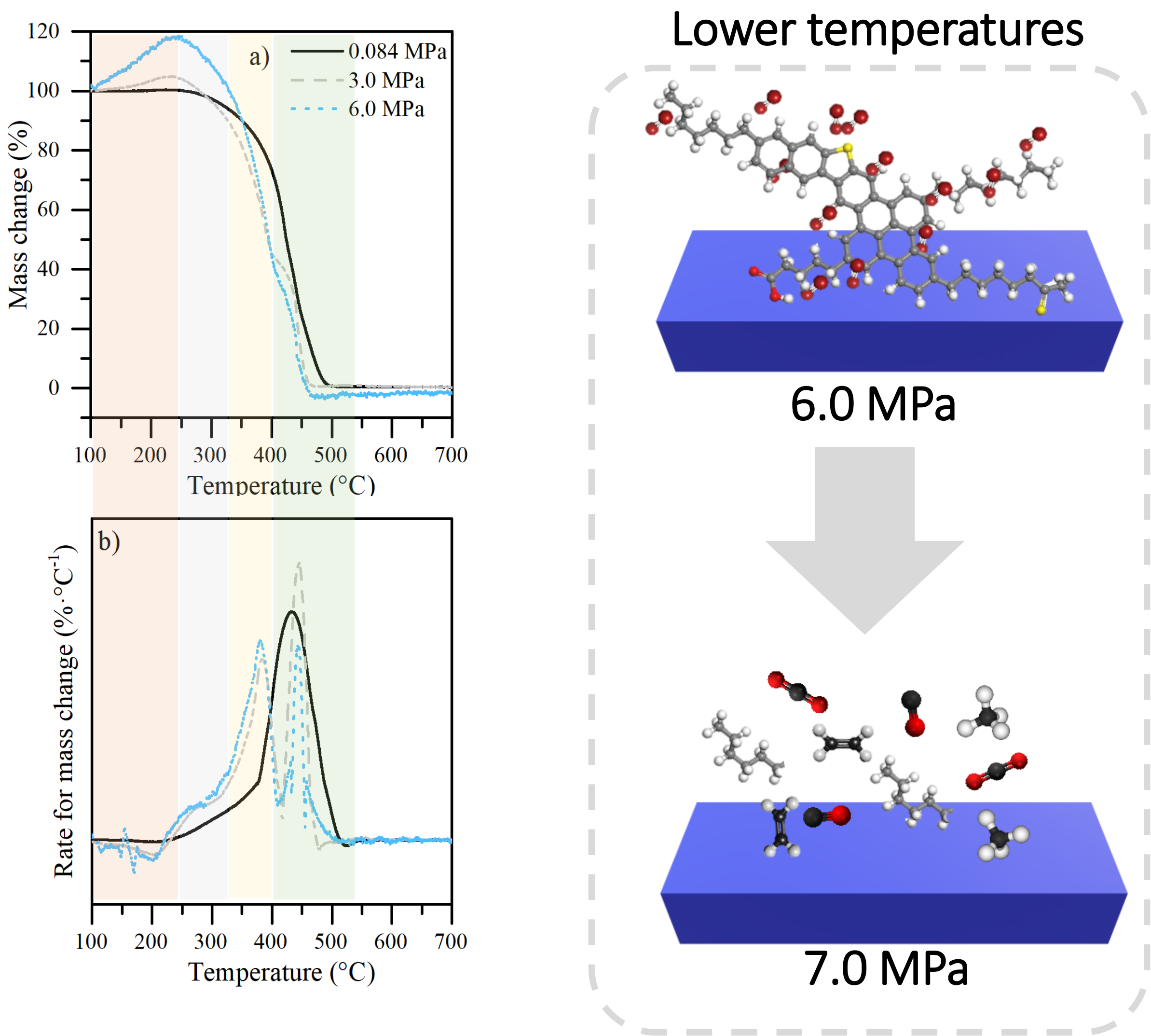


Enhanced Oil Recovery

Nanoparticles/nanofluids usage

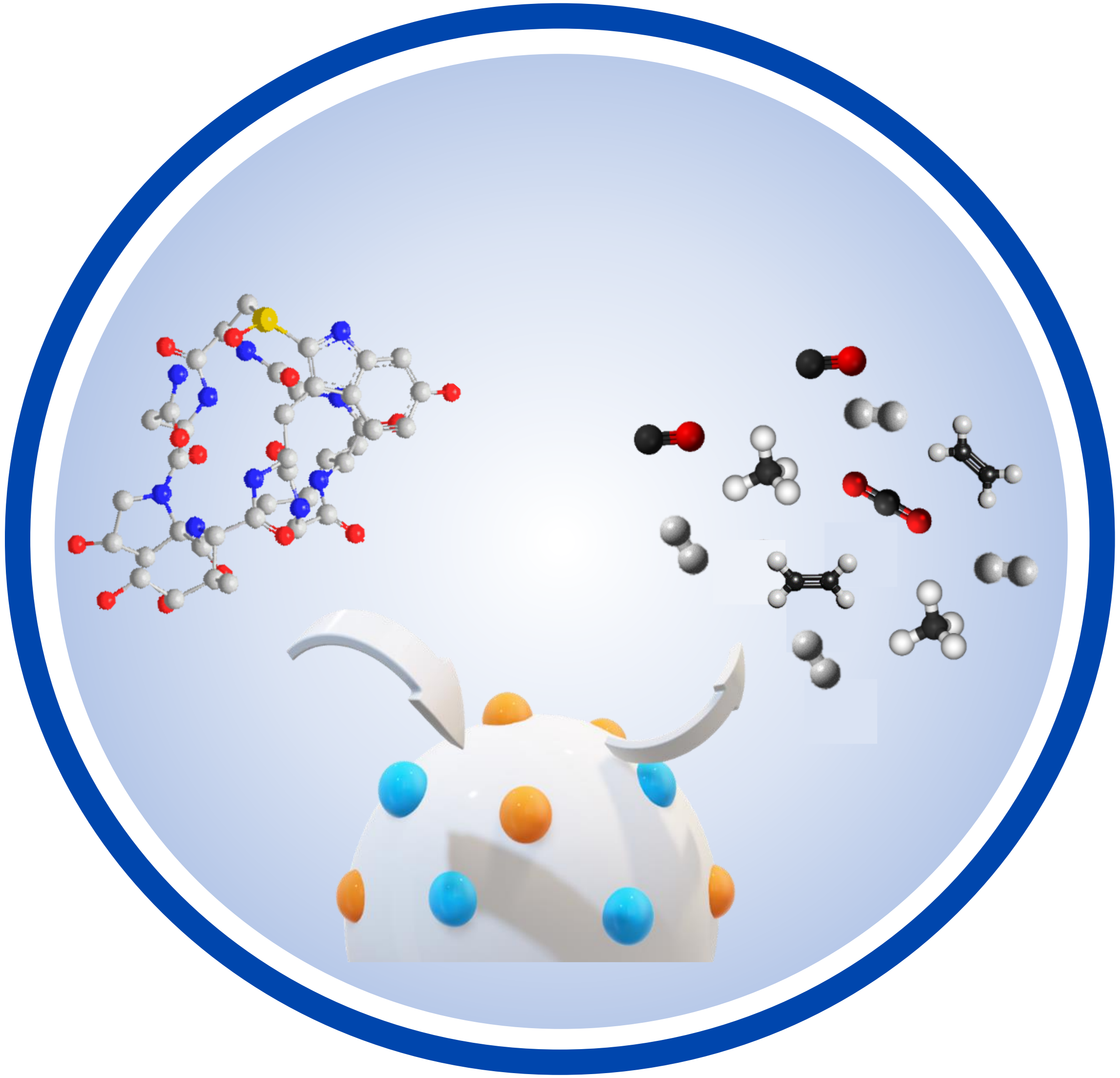
Excellent dispersibility

High thermal stability

High Surface area

Asphaltenes selectivity

Catalytic activity



Nassar et al. 2012
Nanoparticles can adsorb asphaltenes

Franco et al. 2014
Nanoparticles are capable of decomposing asphaltenes

Cardona et al. 2016
Nanoparticles generate crude oil upgrading at reservoir conditions

Medina et al. 2020
Nanoparticles promote the production of high calorific gases during asphaltene decomposition

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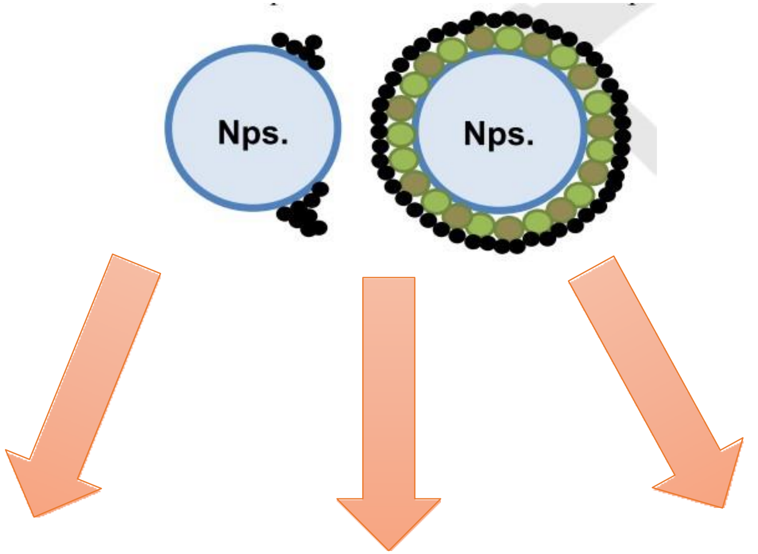
Nanoparticles selection – “*best in class*”

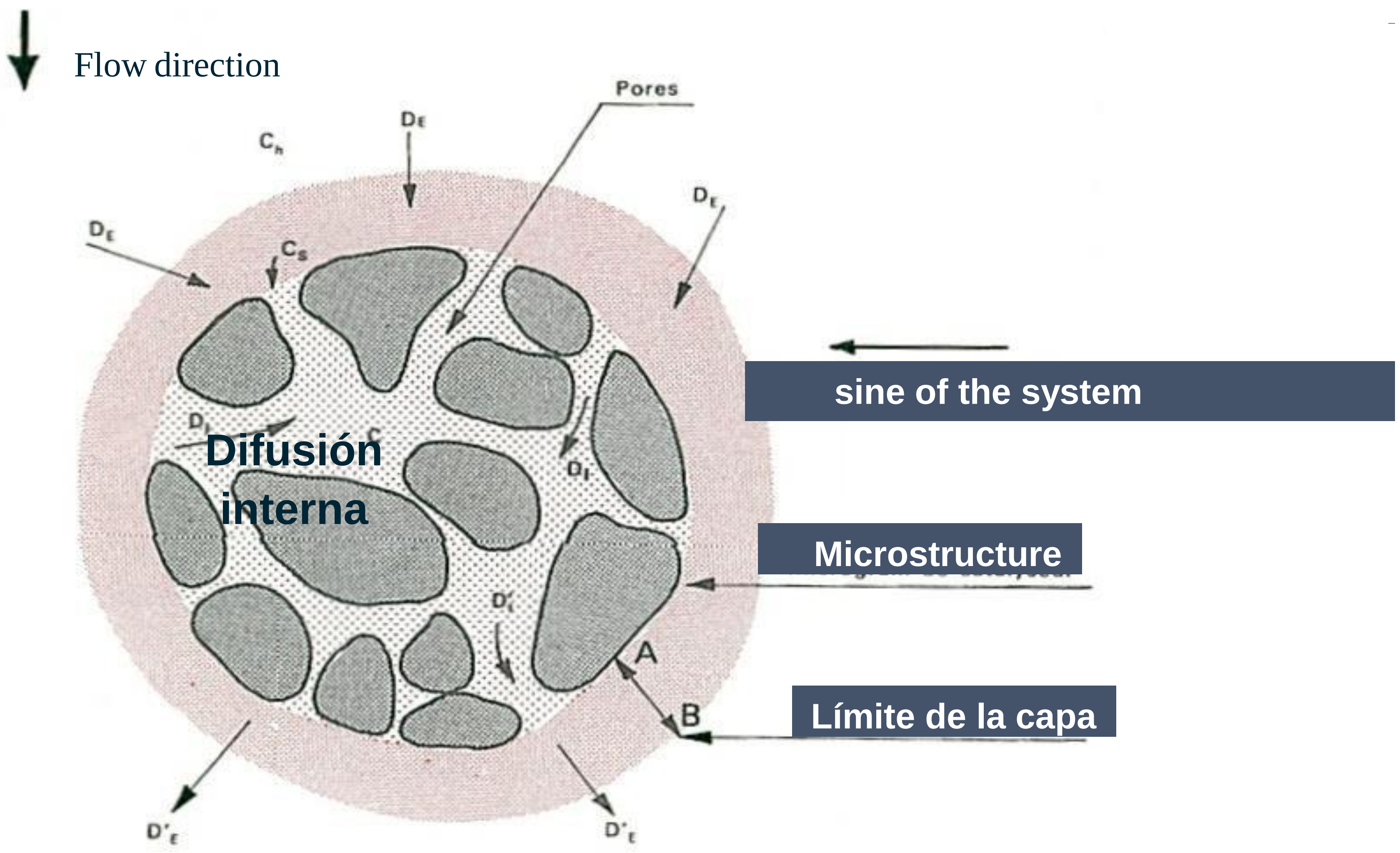
http://matiasoptnologo.bligoo.com/content/view/690676/La-paliza-que-viene.html#.U0Bka_mSyy4

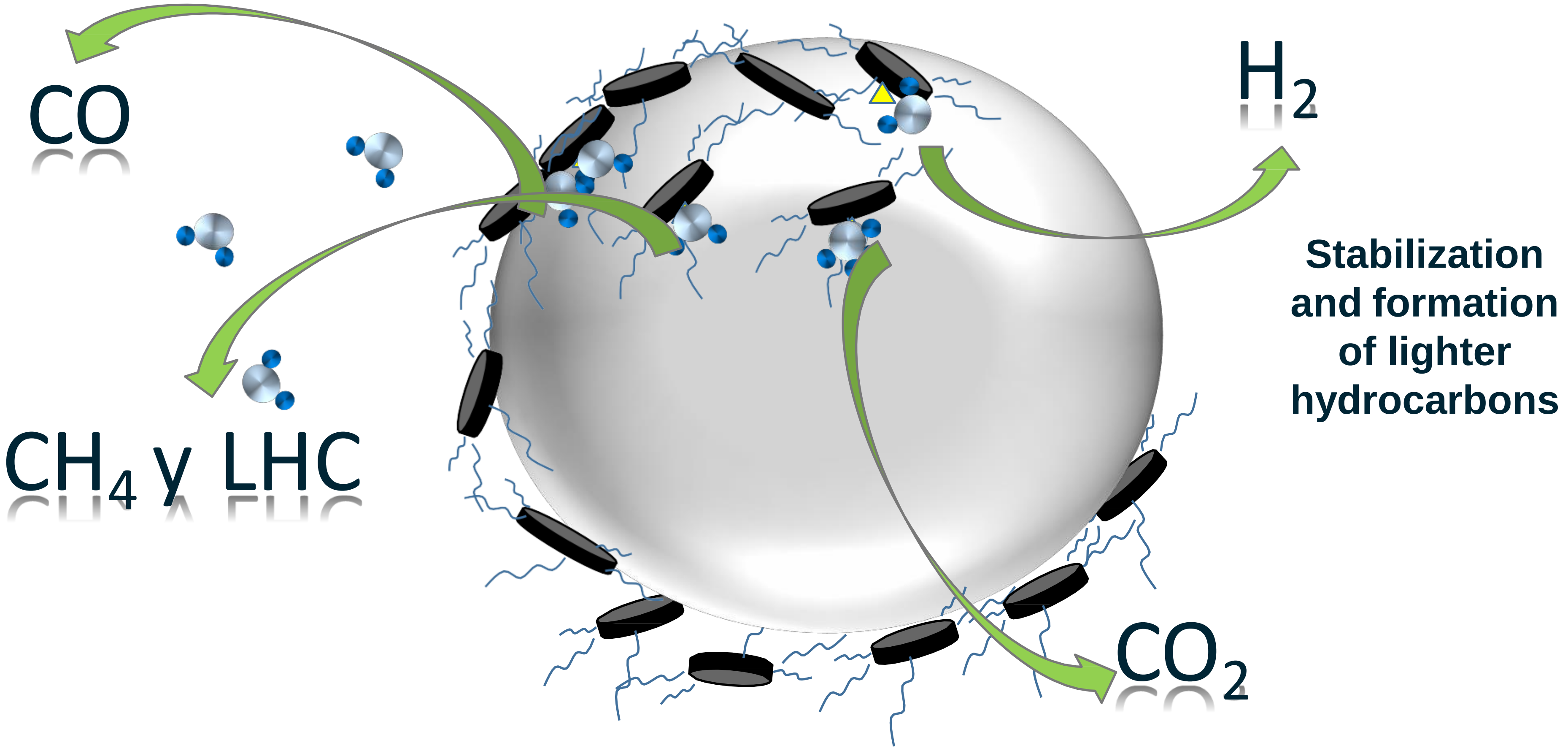


Easy obtention

High adsorptive capacity

Catalytically active materials


Flow direction
Pores
Difusión interna
sine of the system
Microstructure
A
B
Límite de la capa



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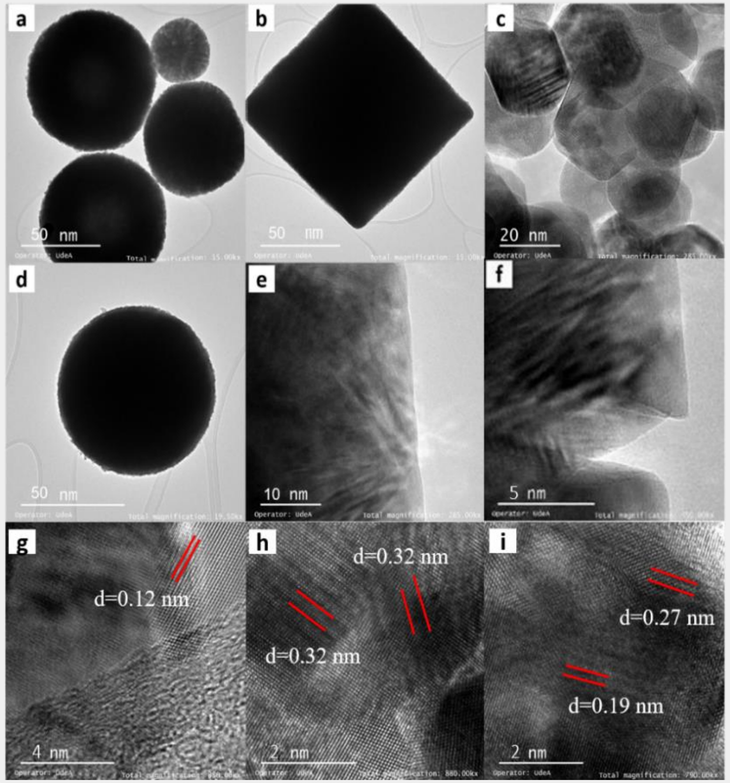
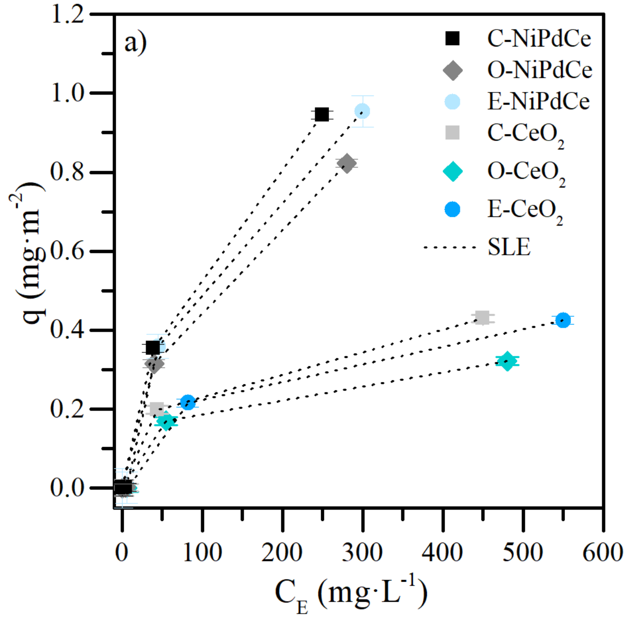
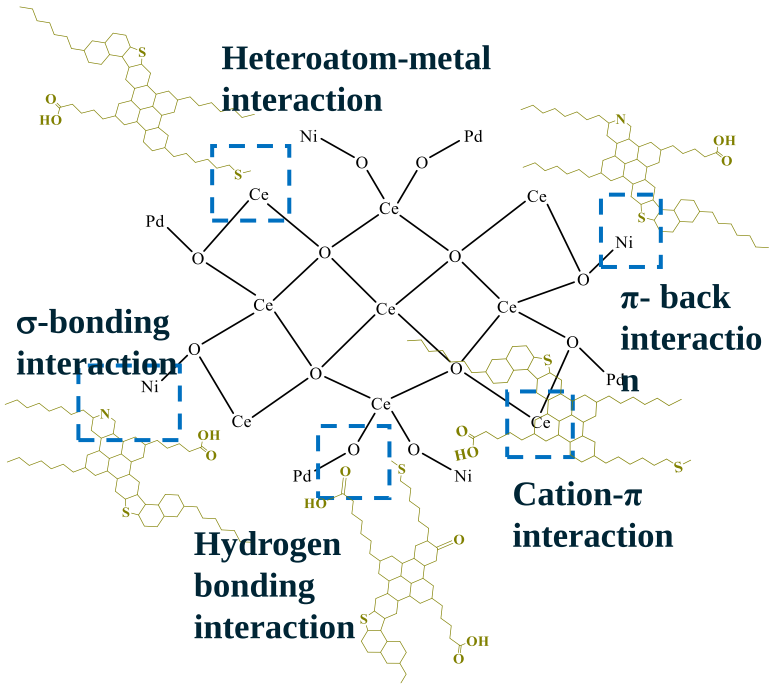
Adsorption isotherms

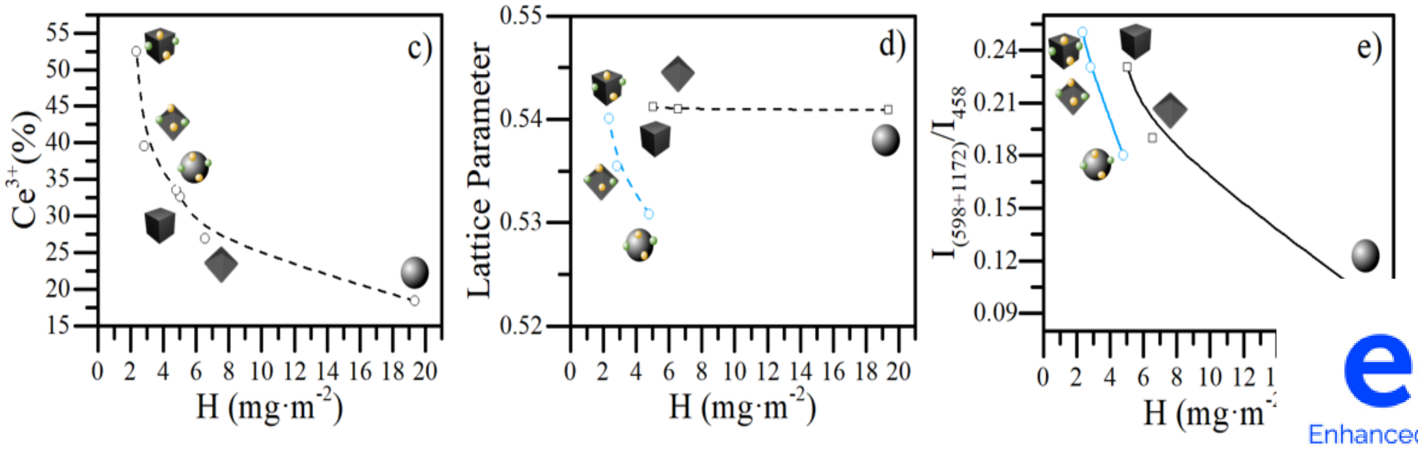
Nanocatalyst-Asphaltene Interactions

TEM









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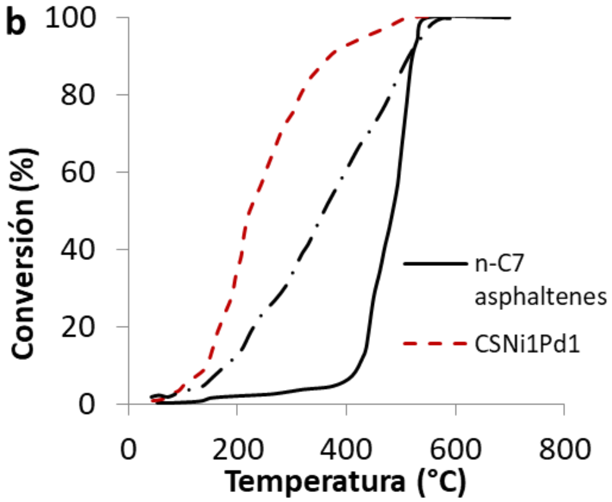
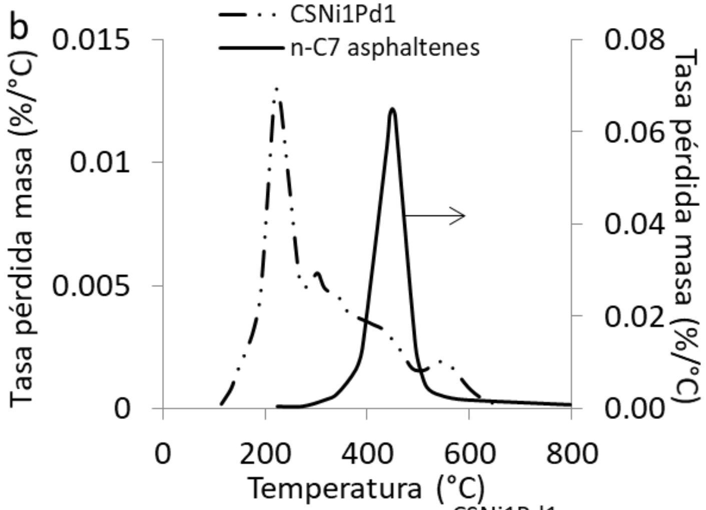
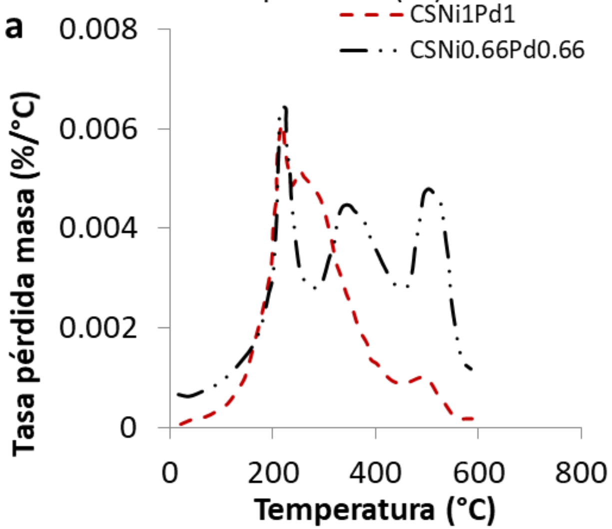
Descomposición







Tasa de pérdida de masa y conversión de asfaltenos en el proceso de oxidación en presencia de nanopartículas bimetálicas.

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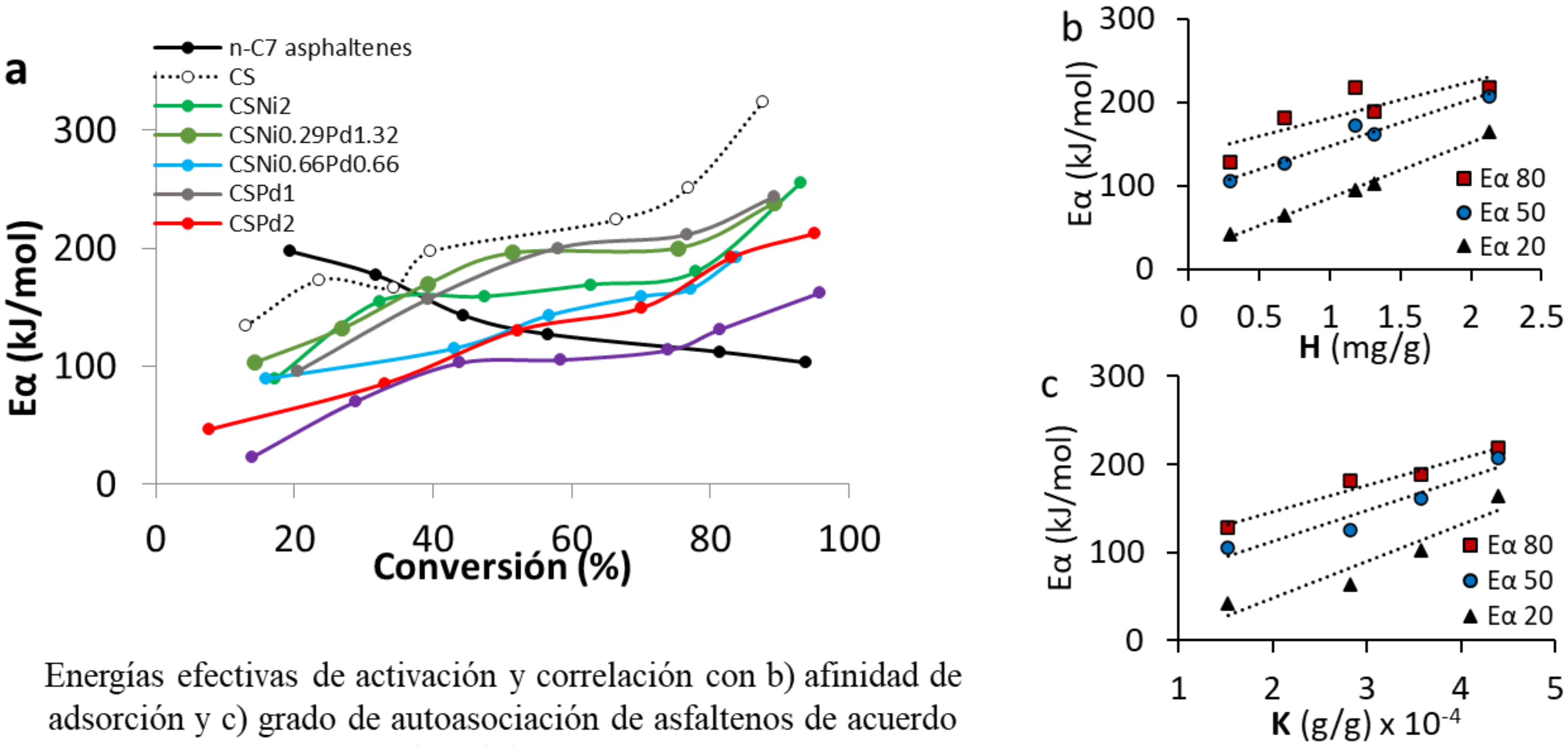
Descomposición de asfaltenos



Energías efectivas de activación y correlación con b) afinidad de adsorción y c) grado de autoasociación de asfaltenos de acuerdo al modelo SLE

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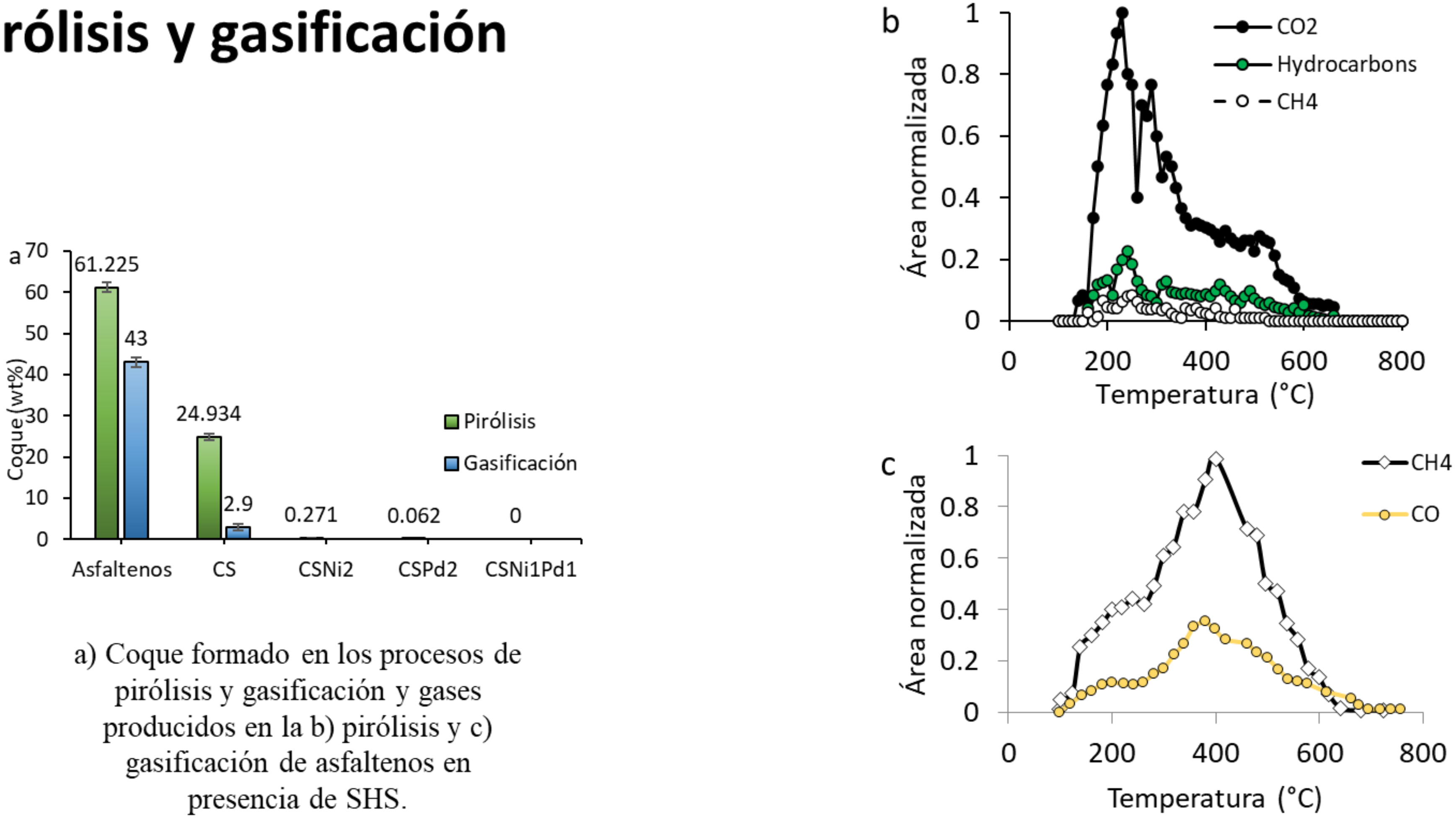
Pirólisis y gasificación



a) Coque formado en los procesos de pirólisis y gasificación y gases producidos en la b) pirólisis y c) gasificación de asfaltenos en presencia de SHS.

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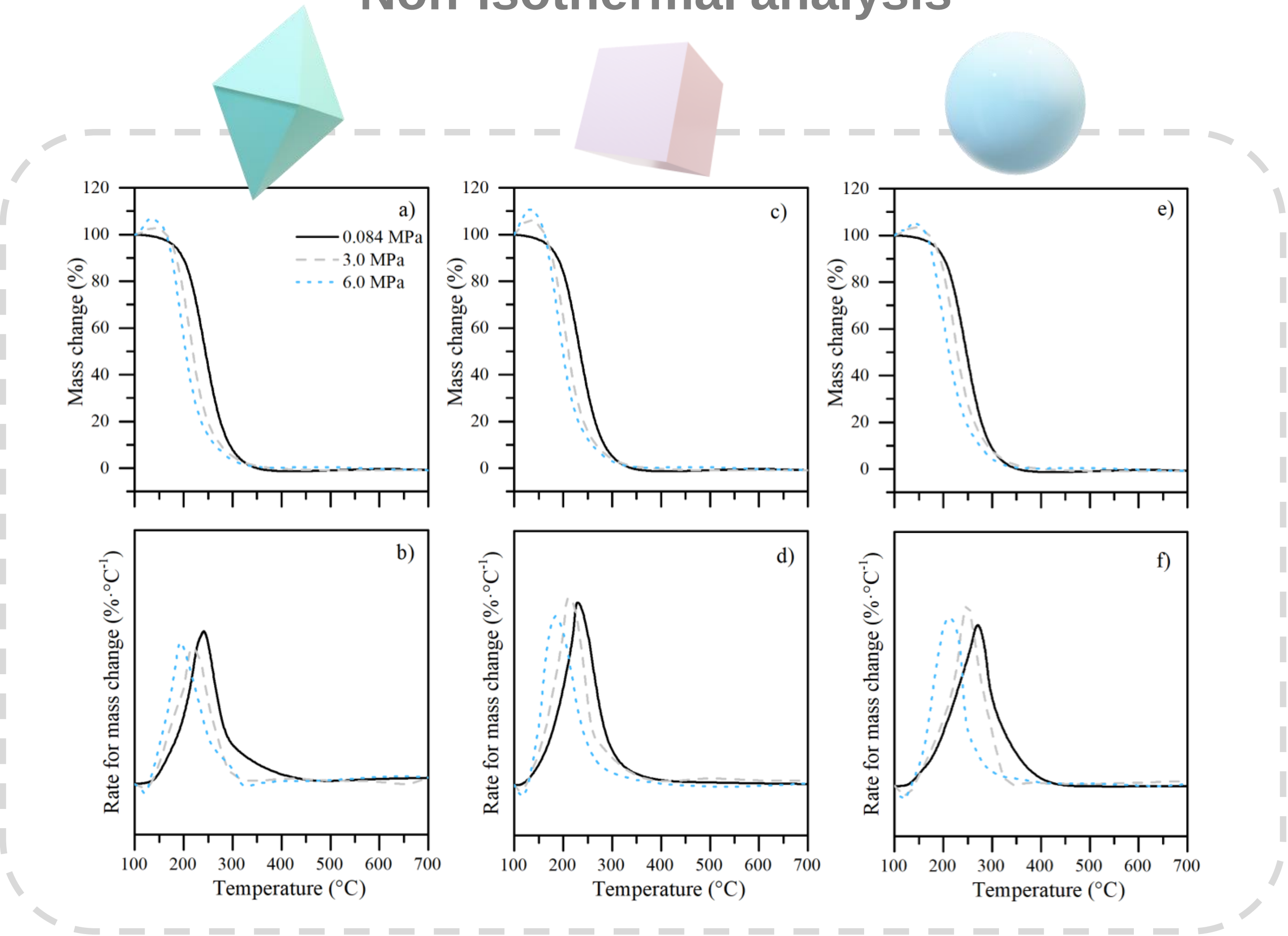
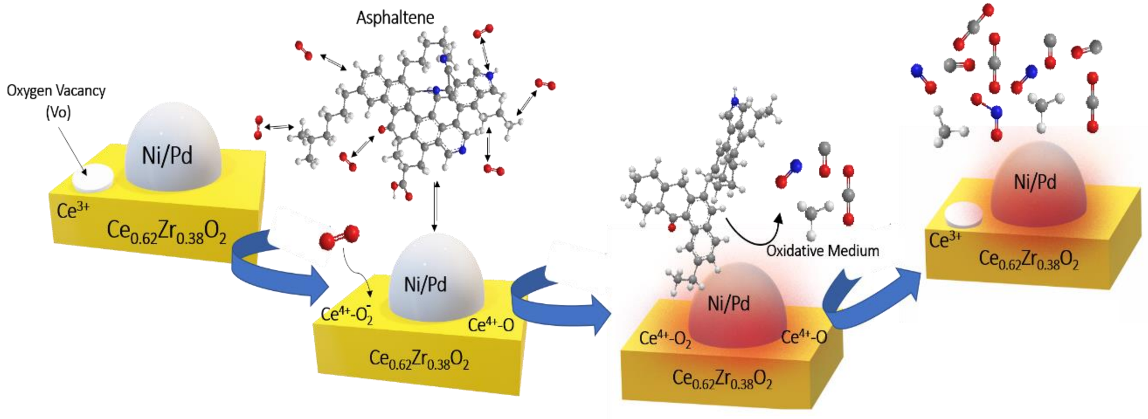
Non-isothermal analysis



Mejor consumo de oxígeno



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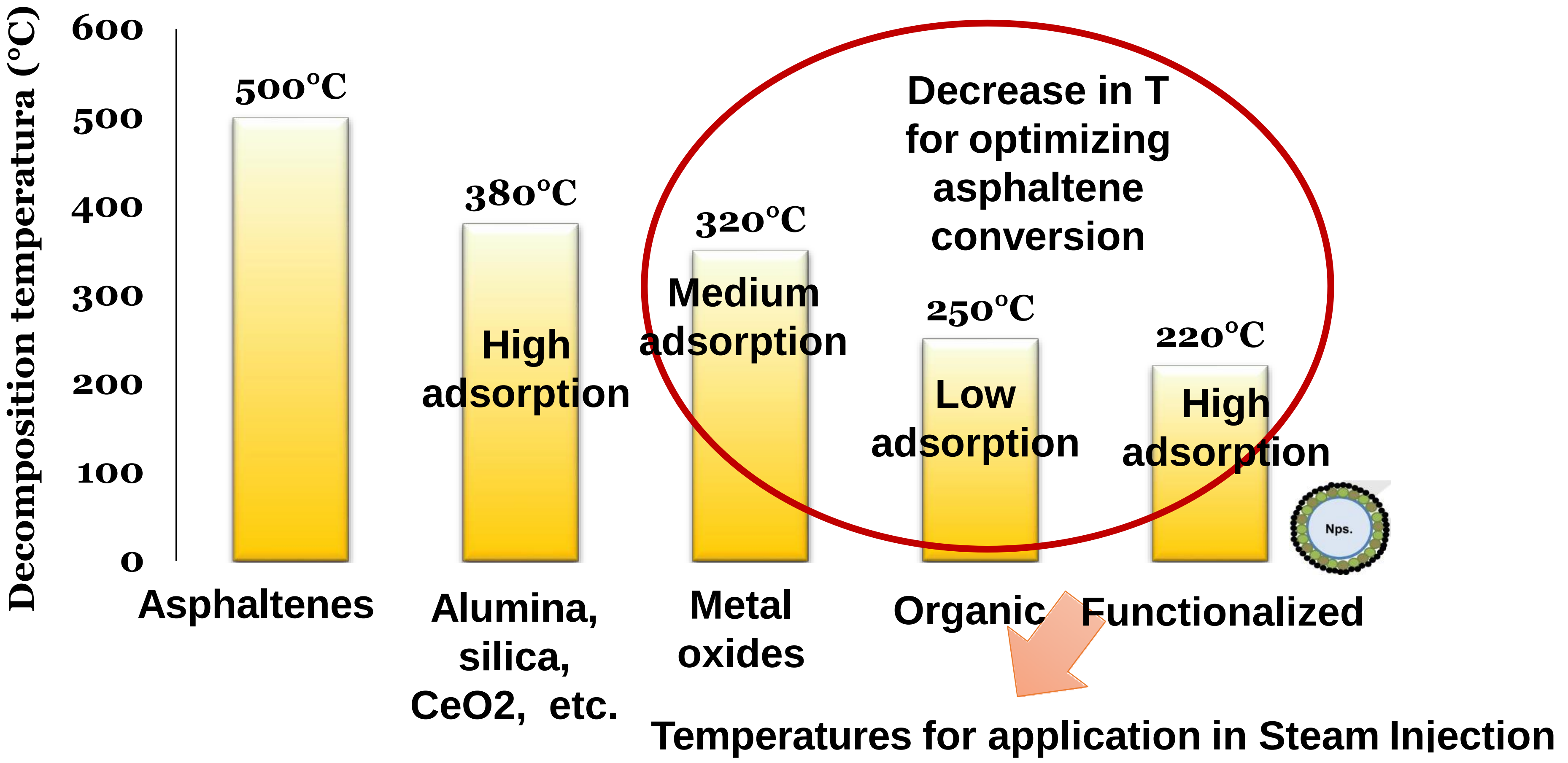
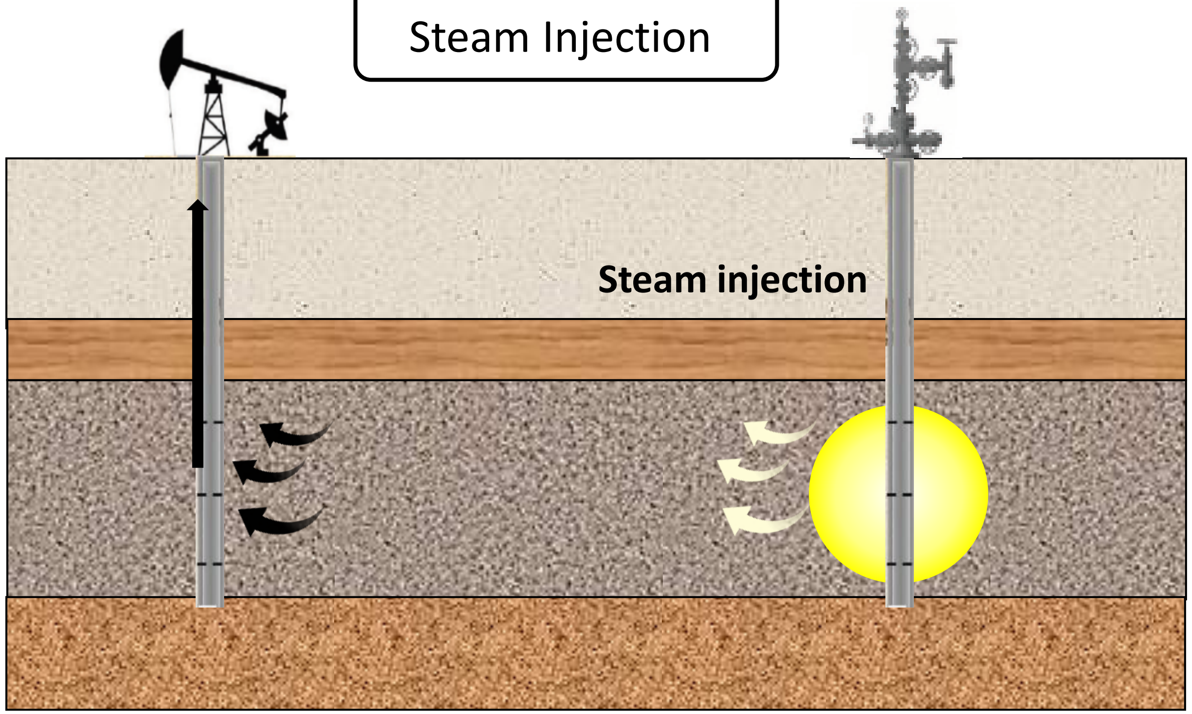
Nanoparticles selection – “*best in class*”



TEOR

Steam Injection



- Heavy residual oil
- Steam injection temperature < 300 °C
- Asphaltene decomposition > 450 °C

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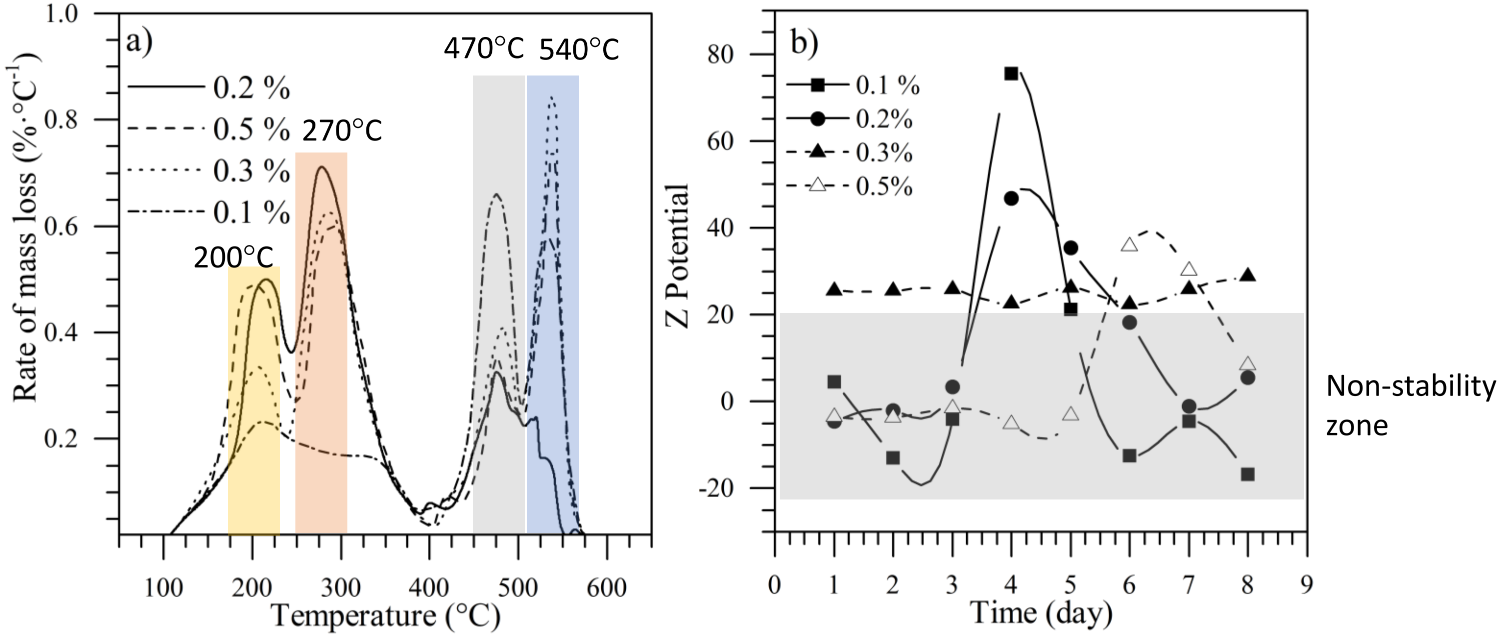
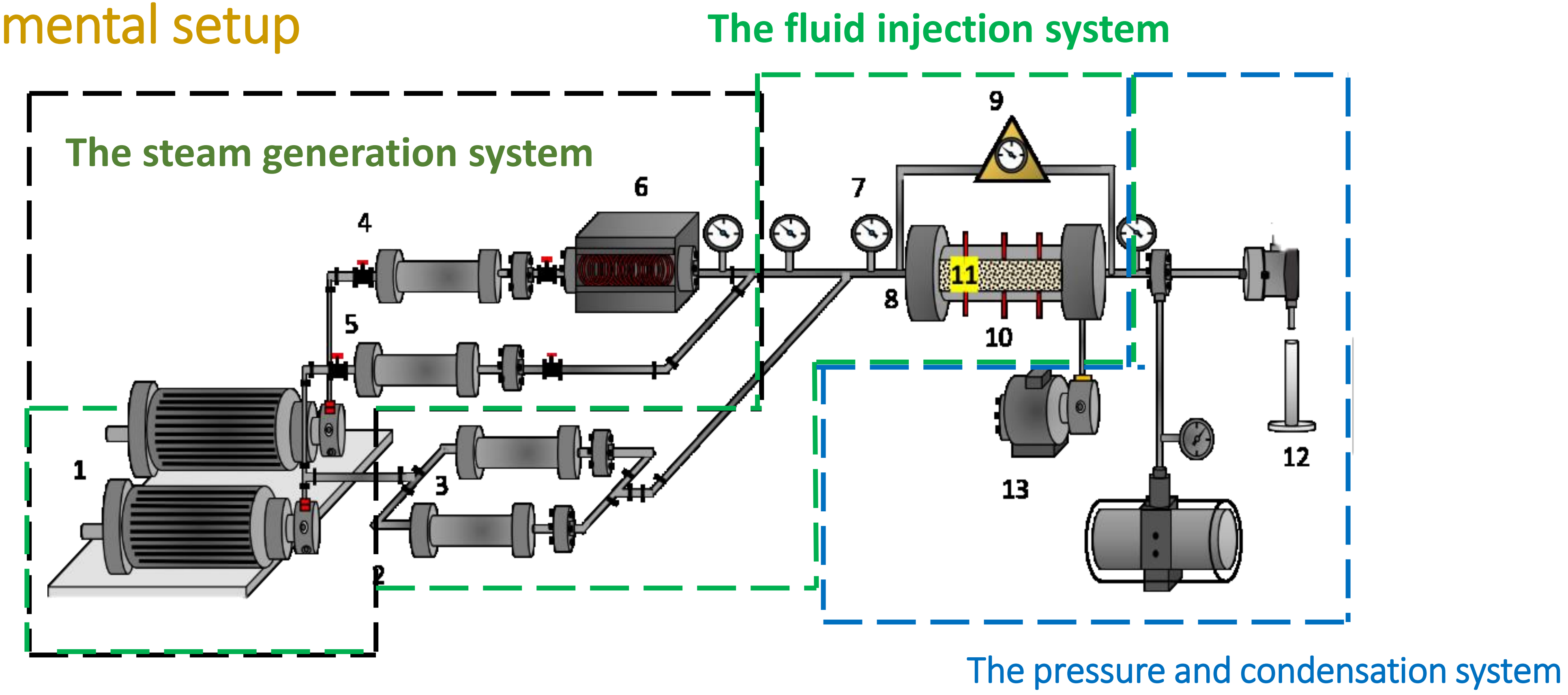
Nanofluid formulation



Thermogravimetric analysis and zeta potential measurements to select the best formulation of CeNi0.89Pd1.1 nanoparticles and Tween 80 surfactant varying its concentration from a fraction mass of 0.1% to 0.5 % of each one.

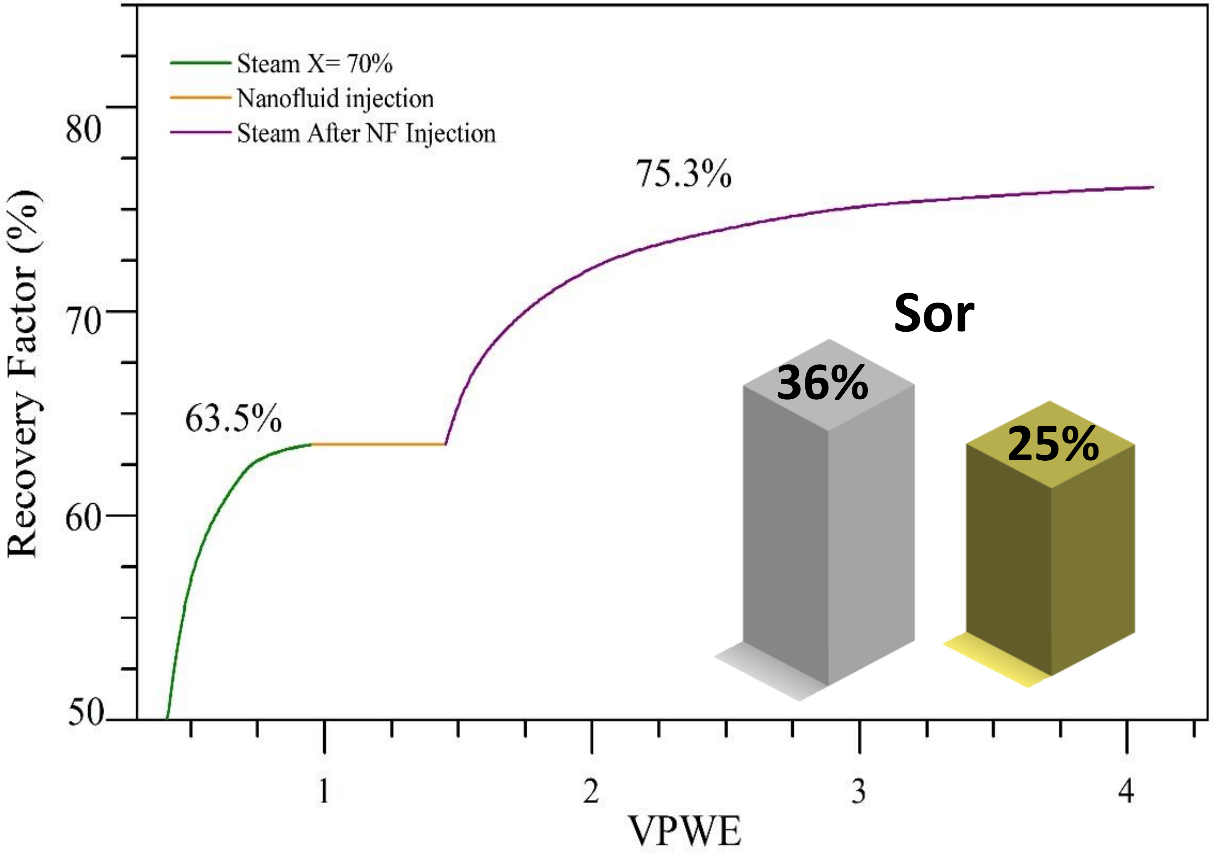
METHODOLOGY

Experimental setup



Experimental system for the displacement test. Legend: (1) positive displacement pumps, (2) oil-containing displacement cylinder, (2) brain-containing displacement cylinder, (4) water-containing cylinder, (5) nanofluid-containing cylinder, (6) tubular furnace, (7) manometers, (8) thermocouple, (9) pressure transducer, (10) slim tube, (11) sand packed bed, (12) sample output, and (13) hydraulic pu

Oil Recovery: Batch



Steam mechanism recovery

- Viscosity reduction
- Thermal expansion
- Capillary pressure and relative permeability
- Volatilization of light hydrocarbons
- Gravitational segregation

Steam assisted by CeNi0.89Pd1.1 NPs

The asphaltene position in the active phases of the support and metal oxides, generates its conversion into lower molecular weight hydrocarbons

Oil recovery curve for steam injection assisted by CeNi0.89Pd1.1 nanocatalyst through batch injection.

Viscosity Reduction: Batch

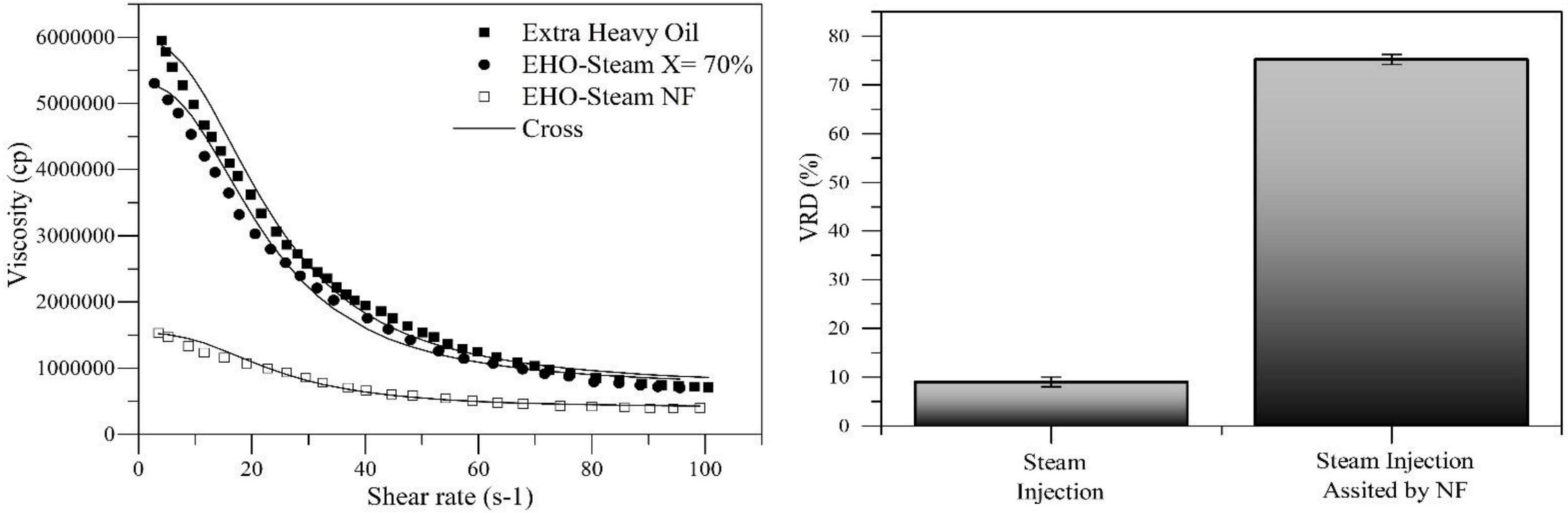
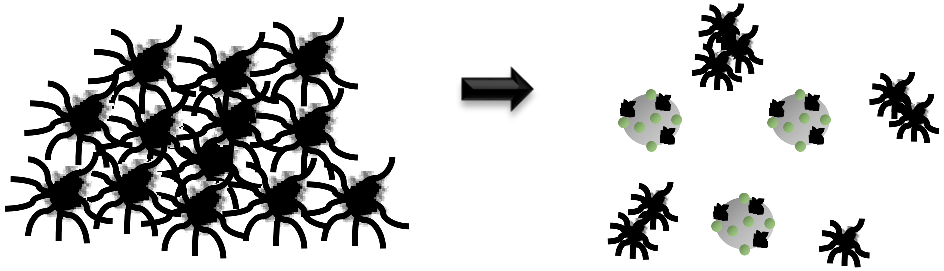


Figure 7. (a) Oil recovery curve for steam injection assisted by CeNi0.89Pd1.1 nanocatalyst. (b) Rheological behavior and (c) viscosity reduction of oil recovered in each stage

Asphaltenes aggregates which configure the HO internal structure in a complex **viscoelastic network**



Alteration of HO internal structure by nanoparticles addition and **asphaltenes adsorption**

Analytical Methods: Batch

Asphaltene content EHO: **28.9 %**
Asphaltene content Steam+NF: **12.9 %**

With CeNi0.89Pd1.1 nanoparticles, an increases in approximately **87%** in API values is observed.

Residual content for each stage were **38.3 %, 35.5 % and 27.1 %.**

a) b) c)

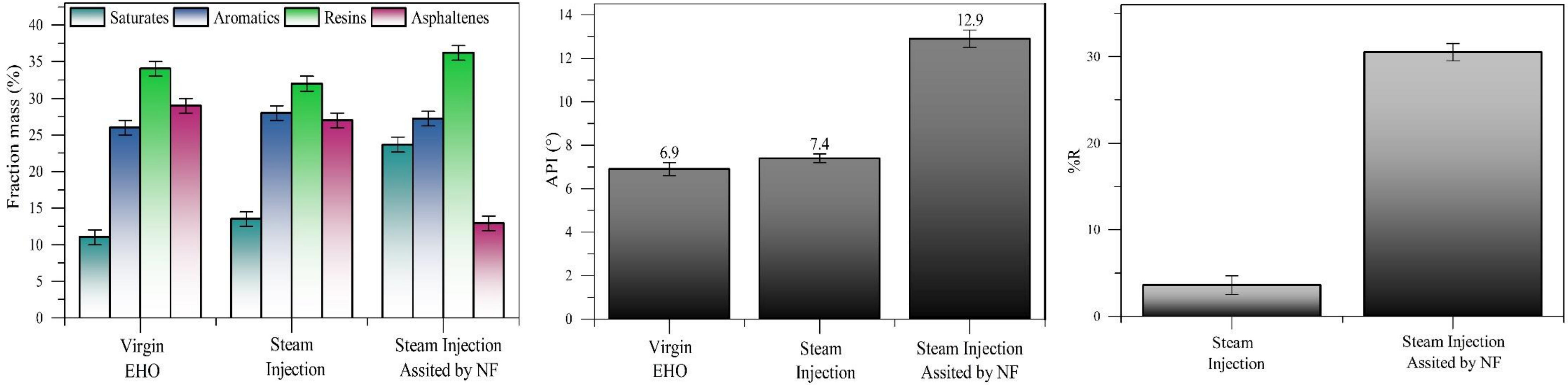


Figure 8. (a) Saturates, aromatics, resins and asphaltenes content and (b) API values and stage (c) residue (620 °C+) content. of oil recovered in each stage of NF injected in batch.

Enhanced Oil Recovery

Temperature profile

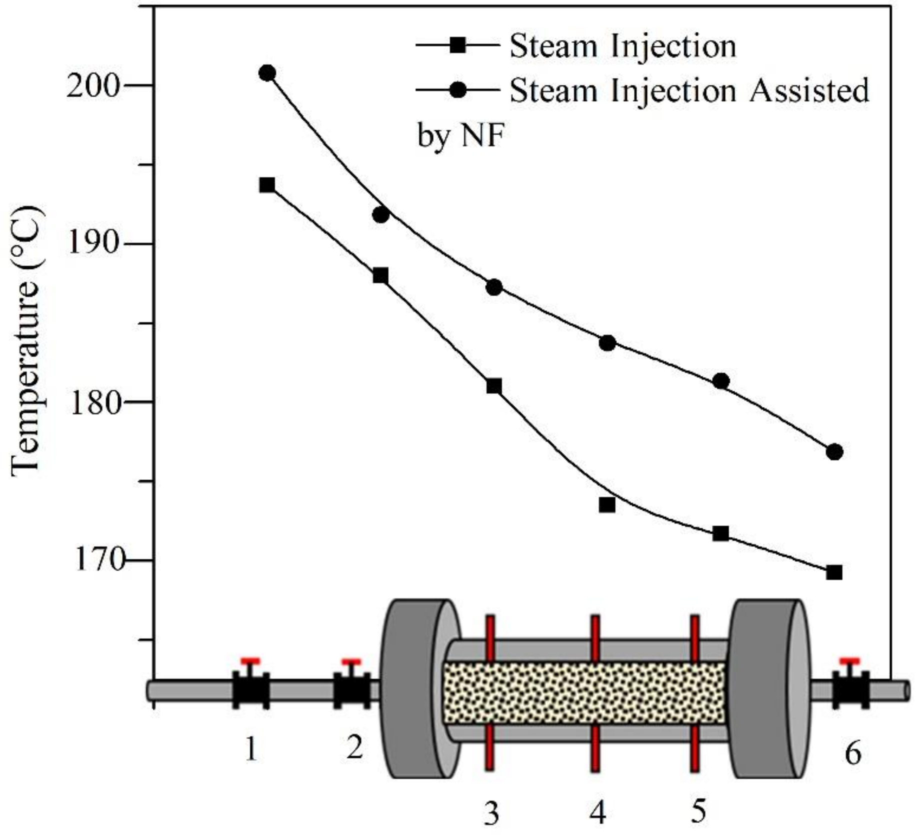


Figure 9. Temperature profile through 6 nodes located at the beginning, inside and at the exit of the porous media, for the steam injection scenarios in the presence and absence of CeNi0.89Pd1.1 nanocatalysts.

Tortuosity of the medium

Heat thieves

Energy transfer

Steam assisted by CeNi0.89Pd1.1 NPs

The change in temperature for the system after the nanofluid injection was lower than in the absence thereof.

The nanoscale metal oxides have the property to absorb heat very quickly and containing it for several hours, which generates an improvement in the heat capacity of the injected steam.

Oil Recovery: Dispersed

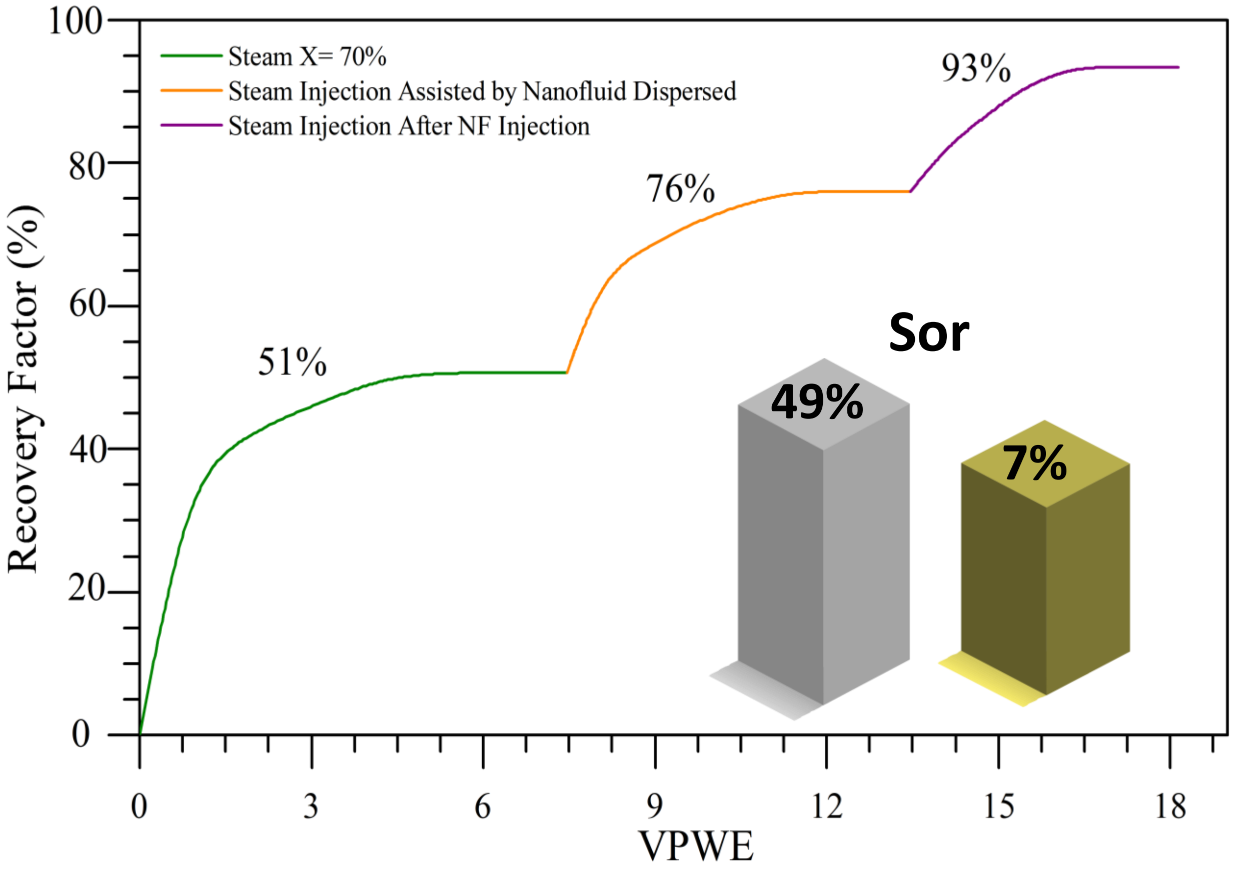


Figure 10. Oil recovery curve for steam injection assisted by CeNi0.89Pd1.1 nanocatalyst injected dispersed.

Steam assisted by CeNi0.89Pd1.1 NPs Dispersed in Steam Stream

Compared with steam injection assisted by CeNi0.89Pd1.1 nanocatalyst through batch injection, dispersed injection presents advantages in terms of recovery factor and residual oil saturation.

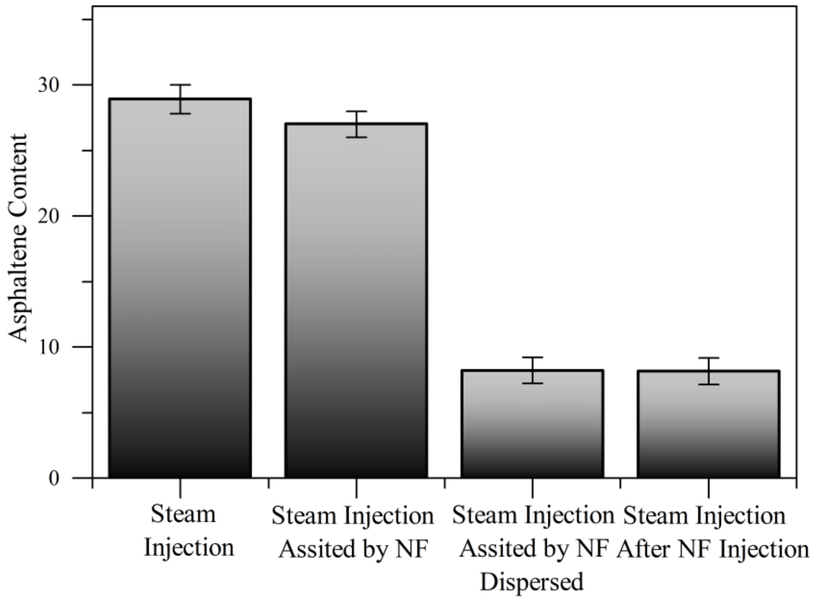
Enhanced Oil Recovery

Analytical Methods: Dispersed

Asphaltene content EHO: **28.9 %**
Asphaltene content after NF: **8.15 %**

With CeNi0.89Pd1.1 nanoparticles, an increases in approximately **130%** in API values is observed.

a)



b)

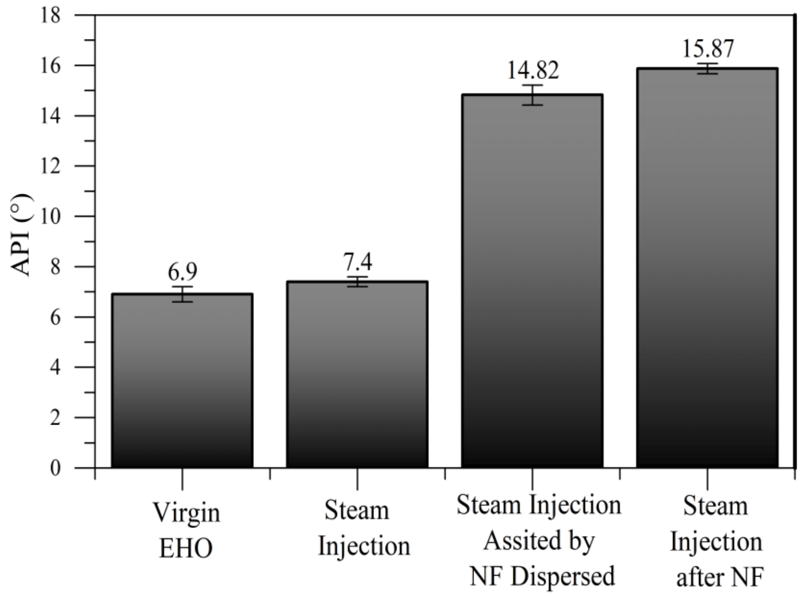


Figure 11. (a) asphaltene content and (b) API values and stage in each stage

Enhanced Oil Recovery

Technology readiness levels – TRL

- TRL-1 Basic principles observed
- TRL-2 Technology concept formulated
- TRL-3 Experimental proof of concept
- TRL-4 Technology validation in lab
- TRL-5 Technology demonstrated in relevant environment
- TRL-6 Upscaling
- TRL-7 Field trial application
- TRL-8 Pilot results validation
- TRL-9 Technology massification

The previous research were focused on the basics of nanoparticles/nanofluids effects on asphaltene decomposition and some experimental proof of concept regarding the phenomenology of the technique.

This work exposes the methodology applied for carrying out an upscaling from a technology readiness **level (TRL) of 3 up to a TRL–8** for the **nanotechnology implementation at a real field application in CSS**, going through the experimental design and the initial field trial results

FIRST WORLWIDE NANOFLUID APLICATION ON TEOR

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Field trial application

TRL-6 Upscaling

Process description

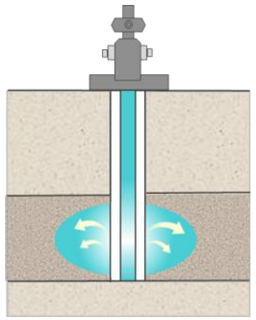
1

Baseline acquisition
(without nanofluid)

API and Viscosity measurements

2

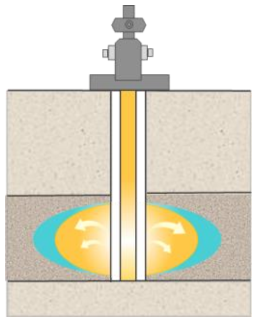
Nanofluid injection
(Liquid batch)



~200 bbl

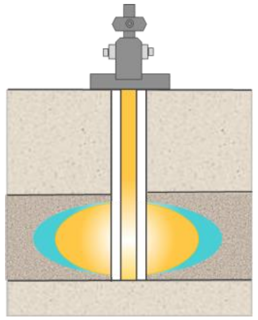
3

Steam injection
(80% quality)
45 MMBTU



4

Steam Soaking
(without nanofluid)



5

Oil production, perdurability tests and quality assurance

Production increase

Crude oil quality assurance (BSW, API, viscosity)

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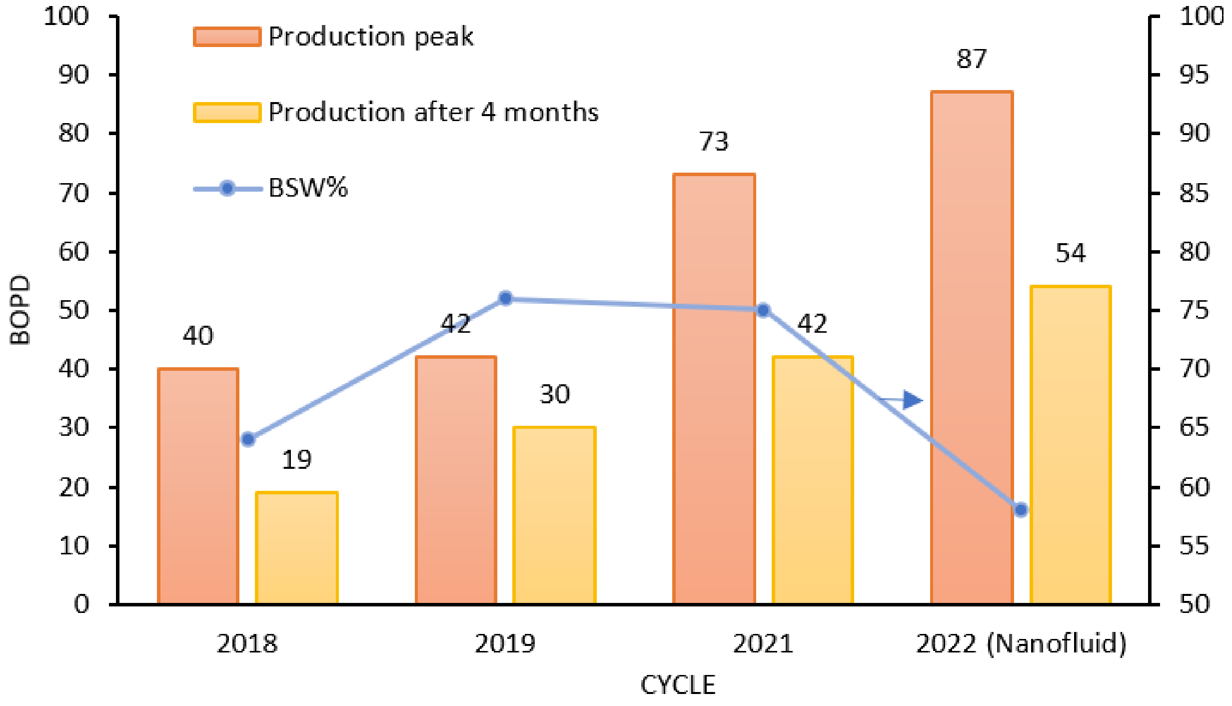
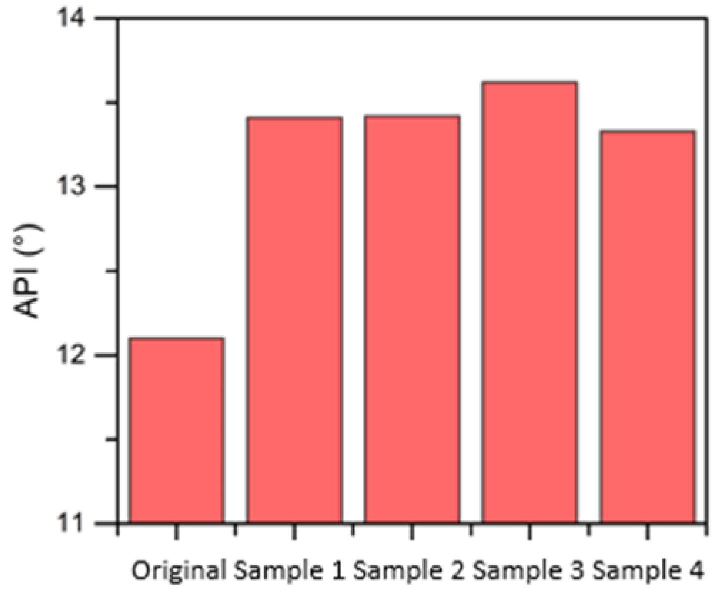
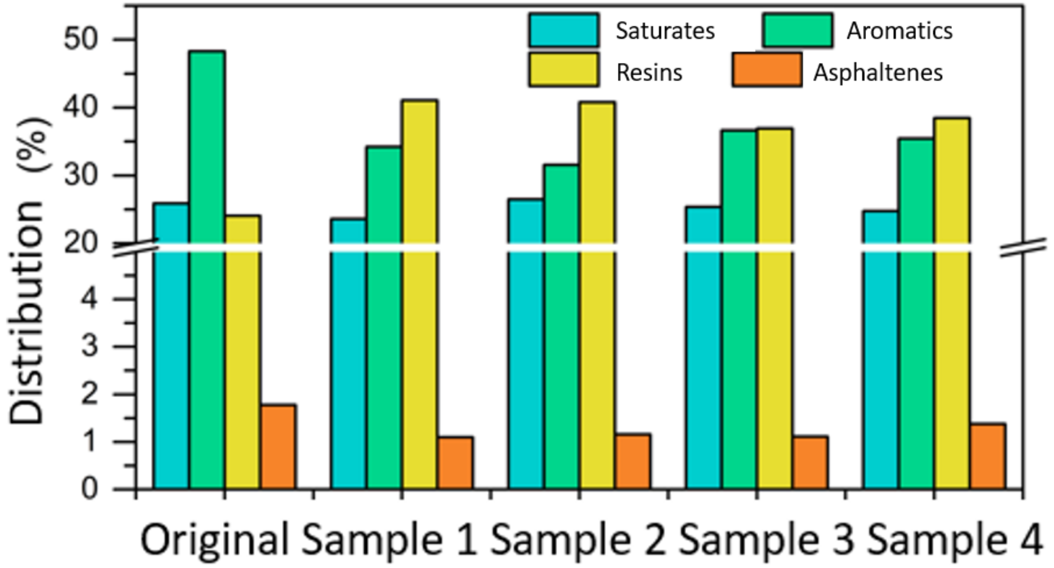
Field trial application







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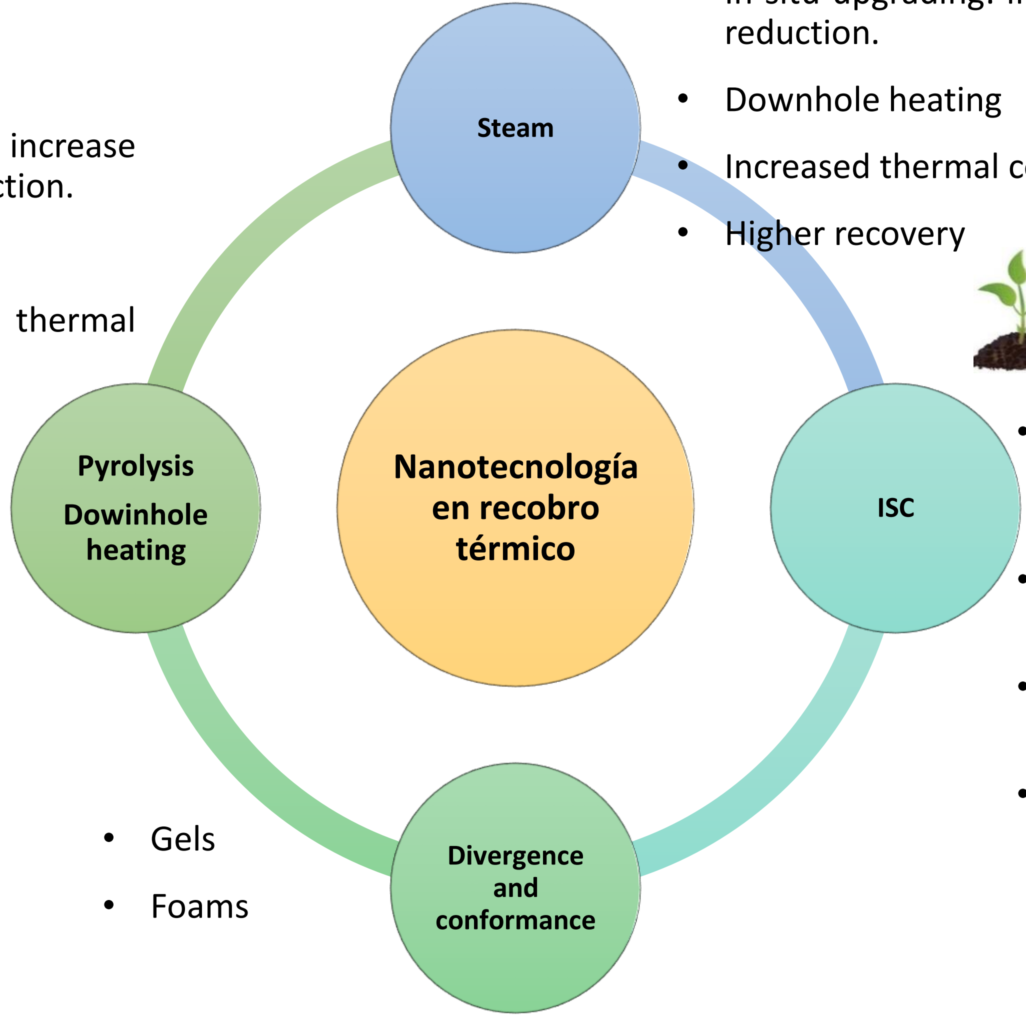
Ad portas +EOR

- In situ upgrading: increase API, viscosity reduction.
- Downhole heating
- Increased thermal conductivity
- Higher recovery



- In situ upgrading: increase API, viscosity reduction.
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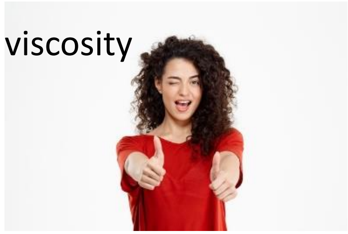
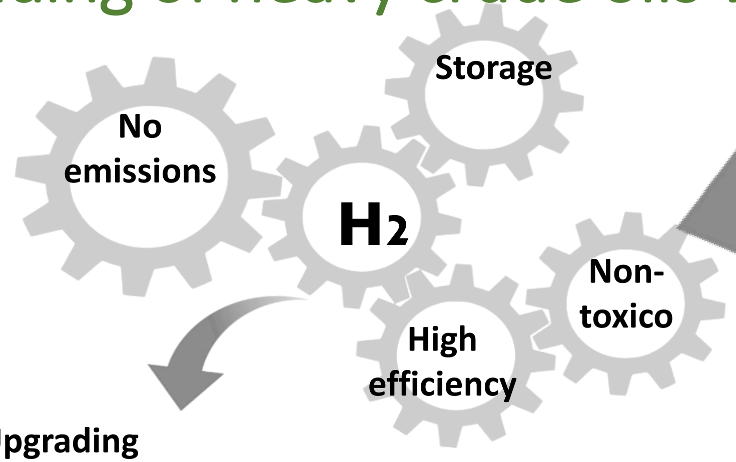


- In situ upgrading: increase API, viscosity reduction.
- Higher efficiency in Oxygen consume
- Increased thermal conductivity
- Higher recovery

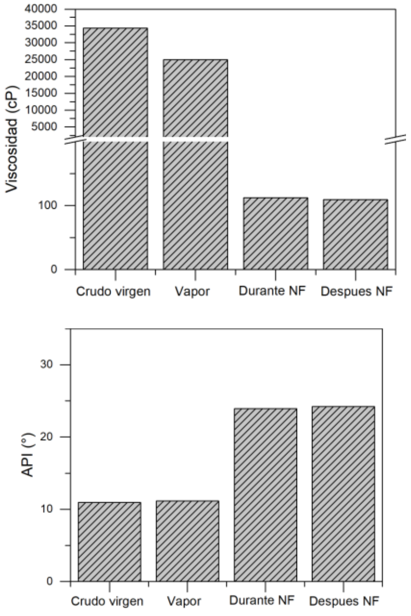
- Gels
- Foams

Enhanced Oil Recovery

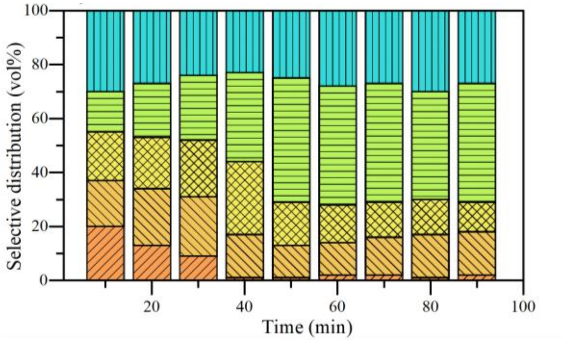
Co-existing energies: H2 production during in-situ and on-site upgrading of heavy crude oils with nanotechnology



Upgrading

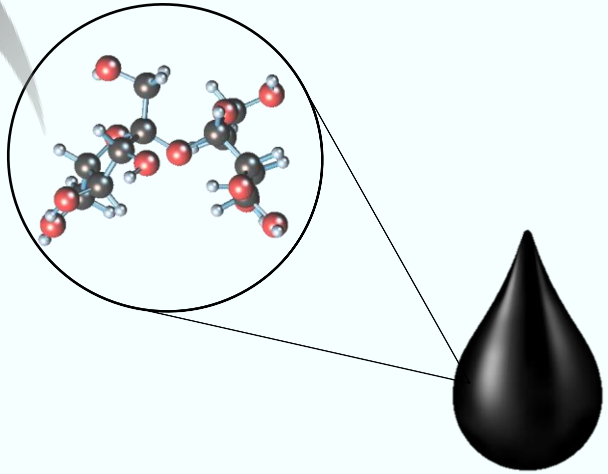


Hydrogen production with low CO2 content



Highly active nanomaterials

Energy transition



H2 RESERVOIR STORAGE

Co-existing energies: tEOR Geothermal

Table 9. Summary of Research in the Study of the Application of Geothermal Resources with Operations of Enhanced Thermal Recovery of Oil in Oilfields

title	authors	year	EOR method	power and thermal output/efficiency	energy utilization system	energy carried fluid	country
letting off steam and getting into hot water-harnessing the geothermal energy potential of heavy oil reservoirs	Teodoriu et al.[118]	2007	steam flooding, hot water flooding	24 kWe, 195 kWt/12%		water	
artificial geothermal energy potential of steam-flooded heavy oil reservoirs	Limpasurat et al.[117]	2011	steam flooding	134 kW		water	
cascade utilization of waste heat in heavy oil exploitation by SAGD technology	Liu et al.[126]	2013	steam assisted gravitational drainage	43,679 kW	ORC	water	China
creating enhanced geothermal systems in depleted oil reservoirs via in situ combustion	Cina[55]	2013	in situ combustion	11,000−3000 kW	geothermal flash plant	water	
modeling of geothermal power generation from abandoned oil wells using in-situ combustion technology	Tian et al.[56]	2018	in situ combustion	200−120 kW	ORC	water	China
the numerical simulation and wellbore modeling of steam injection and stored heat recovery from a light oil reservoir	Zafar et al.[123]	2021	steam injection	1831−708 kW		water	Pakistan

Cano et al. Power from Geothermal Resources as a Co-product of the Oil and Gas Industry: A Review. Just Accepted. ACS Omega. 2022

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