

# 8th Int. Conf. Petroleum Phase Behavior and Fouling June 10-14, 2007 – Pau – France

## "Phase inversion" phenomena in petroleum water-in-oil emulsion under turbulent conditions

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**TOTAL**



# Motivations

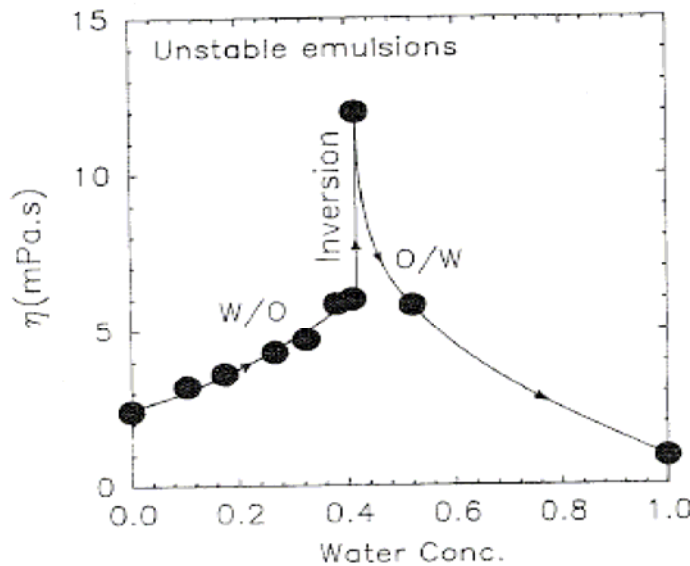


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- Continuous increase of water produced with crude oil during the life-time of field exploitation.
- ↑ Formation of crude oil emulsions at variable water-cut
- Major drawbacks ↑ Viscosity increase up to "phase inversion "
- Main cause for emulsion formation
  - ↑ Turbulence of the flow regime in particular at the choke valve at the wellhead

# Objective

- "Phase inversion" well-known labelling in production = drastic increase and decrease of the viscosity in the flow line



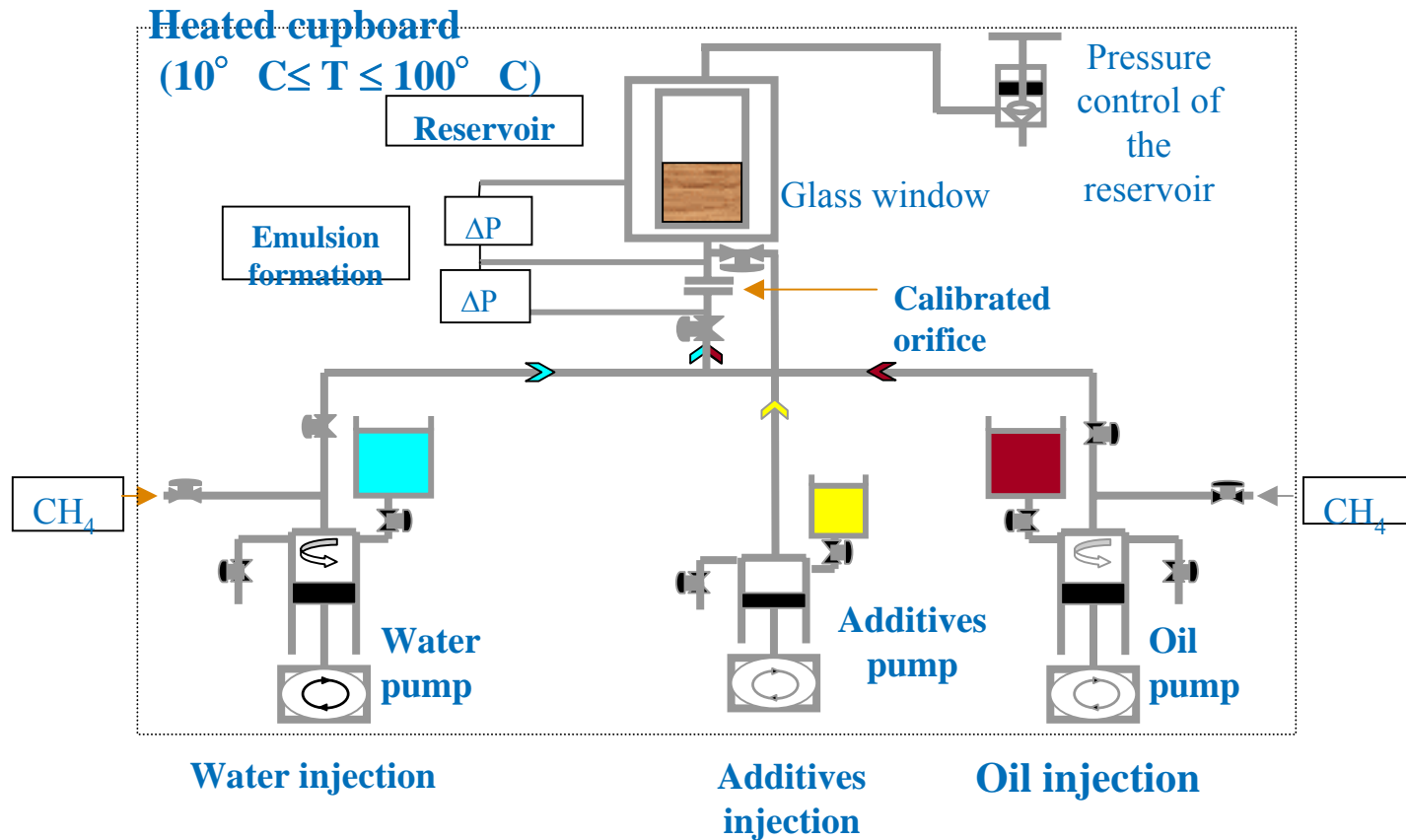
ref: Pal R. – AIChE J. 1993

-  understand/control emulsion formation in production facilities  
 Relation between  
Dissipated energy / volume and type of emulsion formed

# Materials / Methods

## DISPERSION RIG :

Emulsion formation under controlled flow condition : simultaneous injection of oil and water phases through an orifice



# Materials / Methods

Experimental conditions :

- ✓ Turbulent flow for Reynolds Number  $Re$  orifice  $\approx 300$  up to 3000
- ✓ Permanent pressure drop  $\Delta P_{perm}$   
→ dissipation of kinetic energy due to turbulence ( $\epsilon$ )

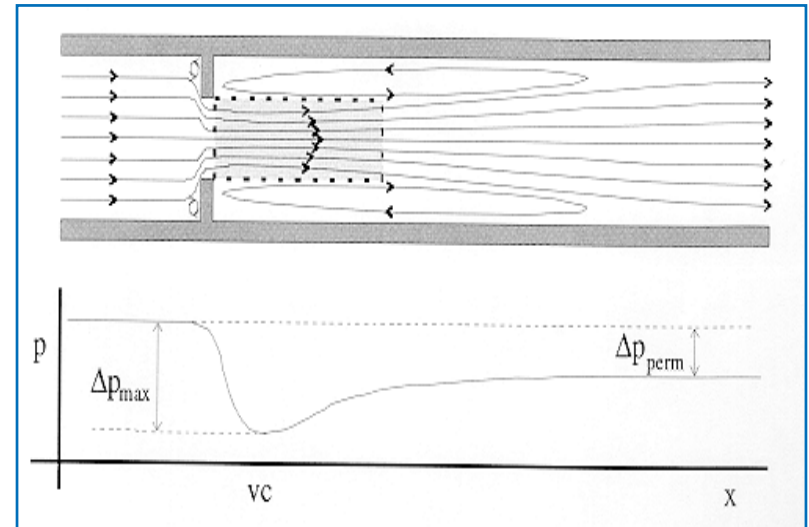
$$\Delta P_{perm} = \frac{1}{c_0^2} \frac{1}{2} \rho U_t^2 \left( \frac{1}{\beta^4} - 1 \right) (1 - \beta^2)$$

$C_0$ : orifice coefficient = 0.7

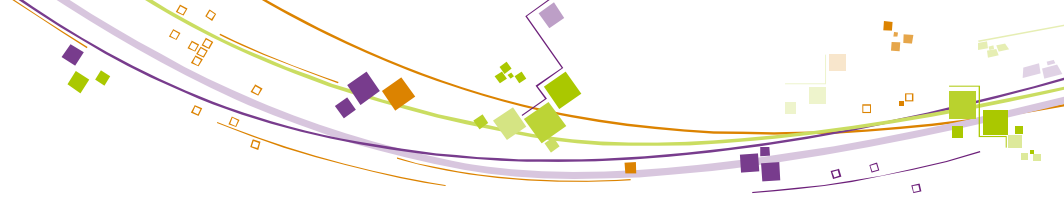
$\rho$ : fluid density,

$U_t$ : fluid velocity in the tube,

$\beta$ : orifice diameter/tube diameter = 0.125



# Materials / Methods



Experimental conditions :

- ✓ Discontinue process
- ✓ Dissipation of kinetic energy due to turbulence during very short time

→ ✓  $\epsilon$  = "Energy dissipation rate" equivalent to dissipated Power in Watt/kg

$$\bar{\epsilon} \approx \frac{\Delta P_{perm} U_o}{\rho L_{dis}}$$

$\Delta P_{perm}$ : Permanent pressure drop,

$\rho$ : fluid density,

$U_o$ : average fluid velocity in the orifice,

$L_{diss}$ : length of the zone of dissipation

Flow rate m3/h	$\Delta P$ bars	$\epsilon$ Watt/Kg	Energy Joule/m3	Time $10^{-3}$ sec.
0.02	3	$8.0 \cdot 10^5$	$2.1 \cdot 10^7$	31
0.12	117	$1.7 \cdot 10^8$	$7.5 \cdot 10^8$	5

# Materials / Methods



Experimental conditions :

- ✓ Conditions for droplet break-up :
- ✓ Disturbing Stress (inertial-  $We$ )  $\gg$  Restoring Stress (interfacial tension)
- ✓ Turbulent flow for Reynolds Number;  $Re_{\text{orifice}} > 1000$  –  $Re_{\text{droplet}} \gg 1$

Droplet size  $D_{\text{max}}$  versus Energy dissipation rate



Hinze relation  $D_{\text{max}} \approx C \cdot \varepsilon^{-2/5}$



Kolmogorov  
smallest eddies  $D_{\text{max}} \approx C \cdot \varepsilon^{-1/4}$

$$\bar{\varepsilon} \approx \frac{\Delta P_{\text{perm}} U_o}{\rho L_{\text{dis}}}$$

# Fluids

## Crude oil characteristics

<b>CRUDE OIL</b>	<b>A paraffinic</b>	<b>B asphaltenic</b>	<b>C heavy oil</b>
masse vol. 15°C	0.854	0.942	0.982
<b>% m C20-/C20+</b>	<b>44 / 56</b>	<b>35 / 65</b>	<b>13 / 87</b>
<u>Analysis C20+</u>			
% S	49.7	12	12
% A	38	41	37
% R	12.9	30	32
% Asph	<b>0.1</b>	<b>15</b>	<b>14</b>
<b>TAN mg KOH/g</b>	<b>0</b>	<b>0.12</b>	<b>3.3</b>
<b>Viscosity T°C –mPa.sec</b>	<b>10 – 25°C</b>	<b>30 - 60°C</b>	<b>8 - 60°C 50%diluted</b>

Water : NaCl 5g/l

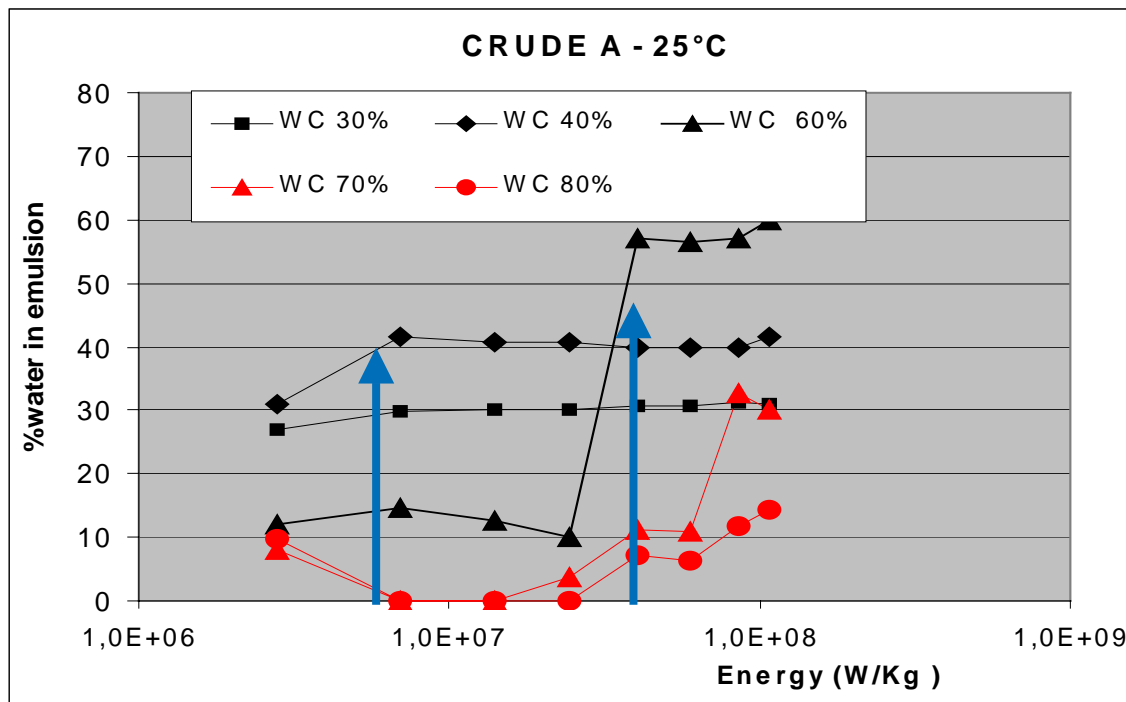
# Results



- Experimental conditions :
- For one crude oil/water system
- at each experiment : simultaneous injection of oil and water at fixed ratio (water-cut) : measurements of emulsion volume formed – water amount analysis in the emulsion – Droplet size by microscopy or DSC
- at fixed water-cut – variation of the flow rate or dissipated energy

# Results 1- water-cut versus dissipated energy rate

## ■ CRUDE A

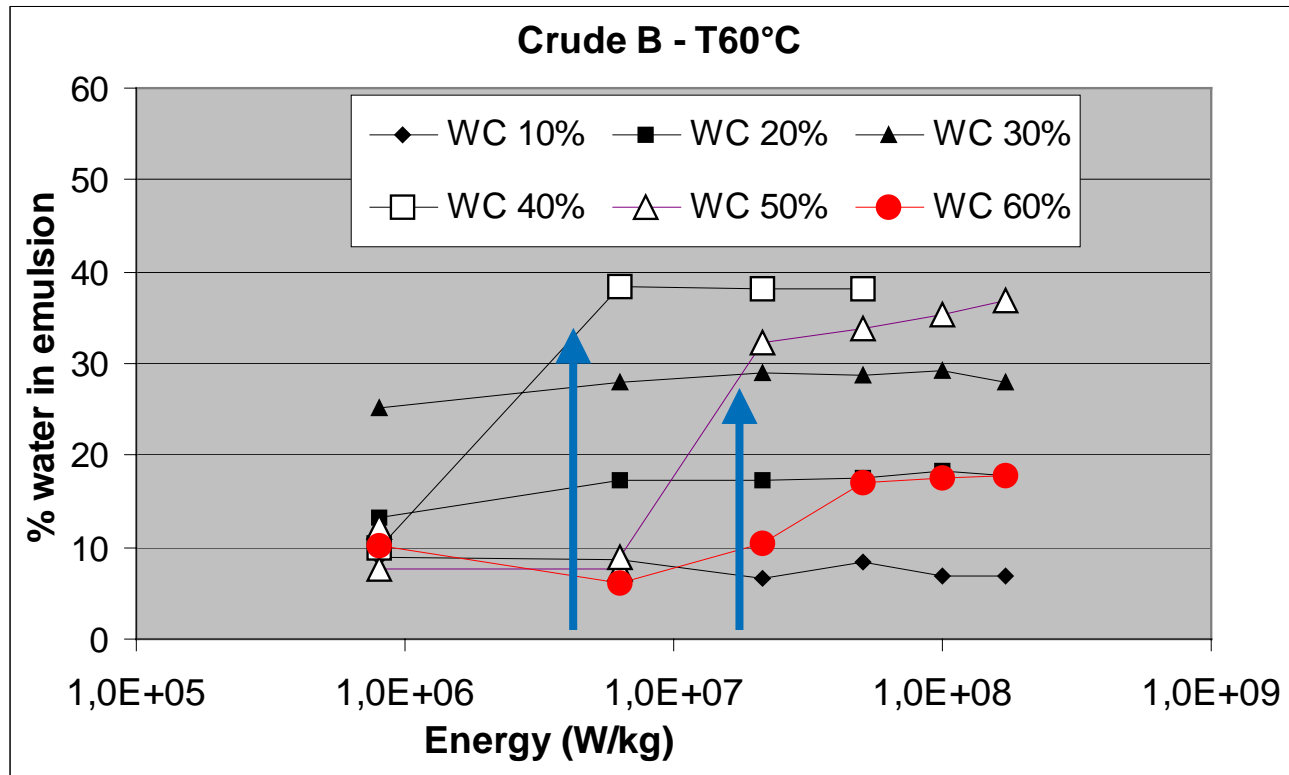


$WC \leq 60\%$  -  $E_c$  = Threshold value for Energy depending on initial water-cut oil/water system totally under emulsion form for energy  $> E_c$

$WC \geq 70\%$  - "Intermediate" emulsified phase with water amount  $\ll$  initial WC

# Results 1 – water-cut versus dissipated energy rate

## ■ CRUDE B

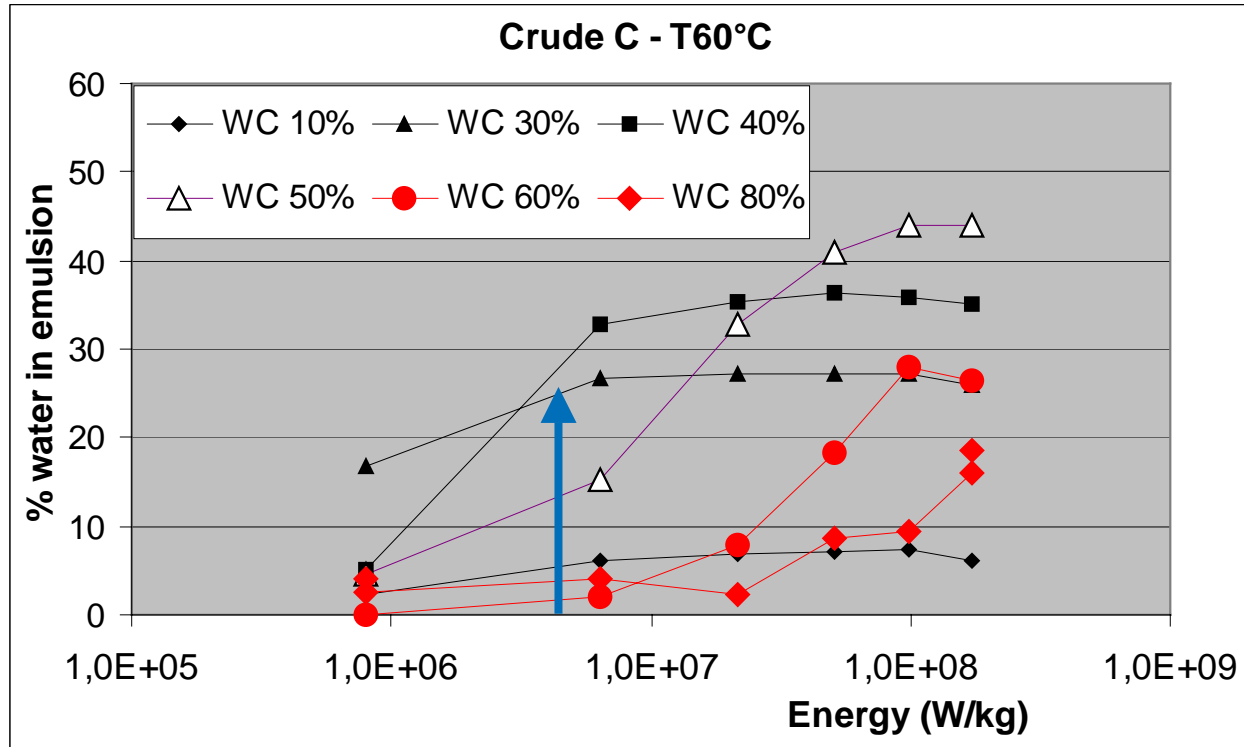


WC  $\leq$  50% -  $E_c$  = Threshold value for Energy depending on initial water-cut oil/water system totally under emulsion form for energy  $> E_c$

WC = 60% - "Intermediate" emulsified phase with water amount  $\ll$  initial WC

# Results 1-water-cut versus dissipated energy rate

## ■ CRUDE C



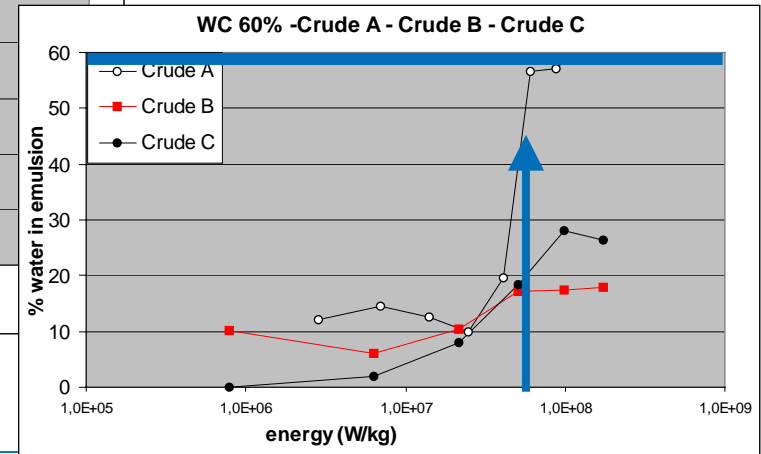
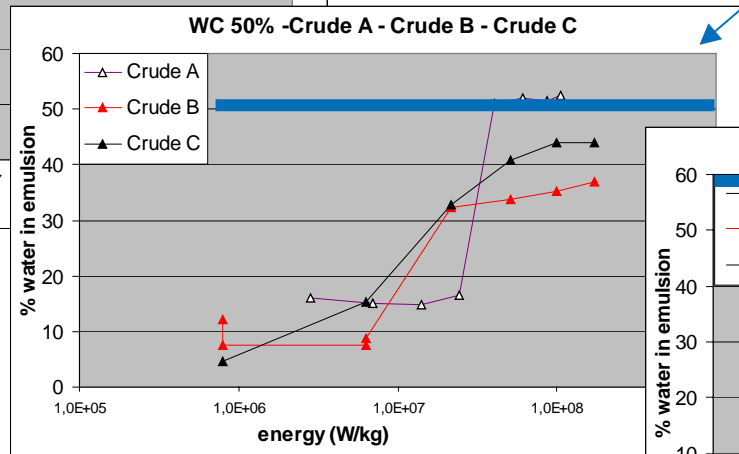
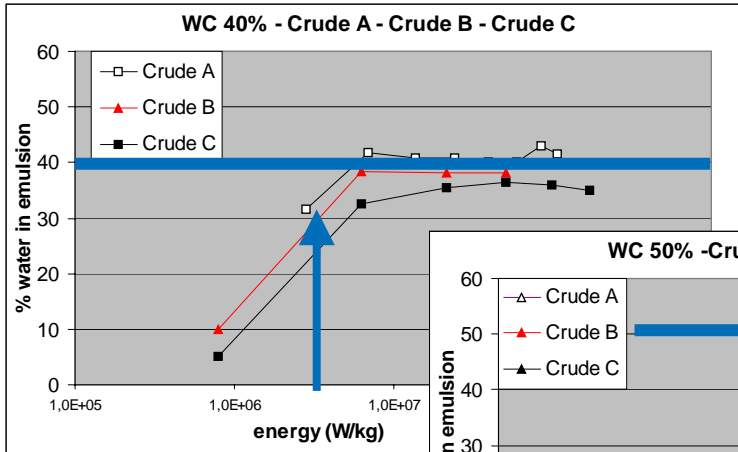
$WC \leq 40\%$  -  $E_c$  = Threshold value for Energy depending on initial water-cut oil/water system totally under emulsion form for energy  $> E_c$

$WC \geq 50\%$  - "Intermediate" emulsified phase with water amount  $\ll$  initial WC

# Results 1-water-cut versus dissipated energy rate

## CRUDE A,B,C

WC



Viscosity B>A>C

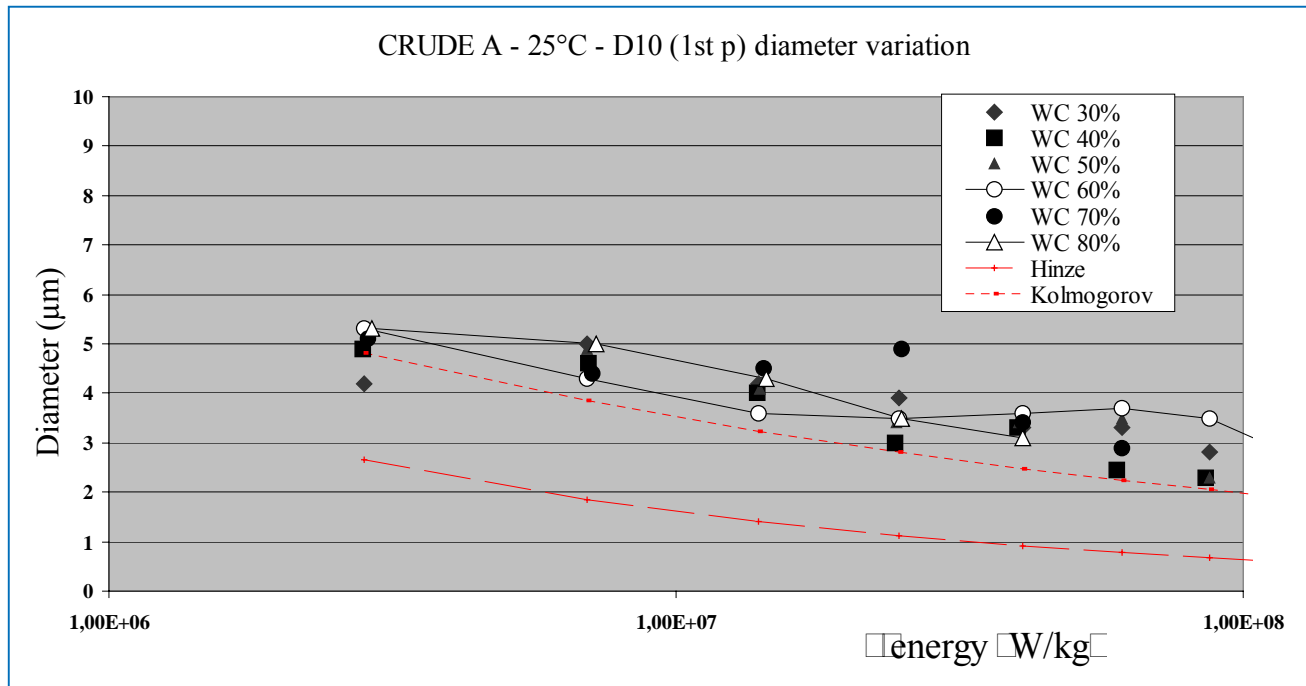
B Asphaltenic- A paraffinic- C diluted heavy oil

Ec = Threshold value for Energy depending on initial water-cut and oil composition

WC 50% - 60% crude B and C whatever the Energy water not totally incorporated

# Results 1—Droplet size versus dissipated energy rate

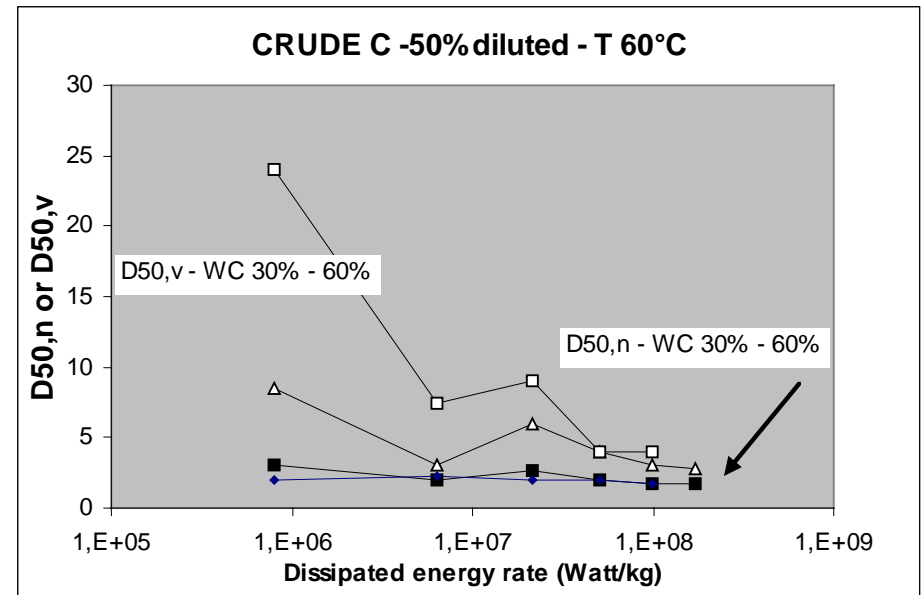
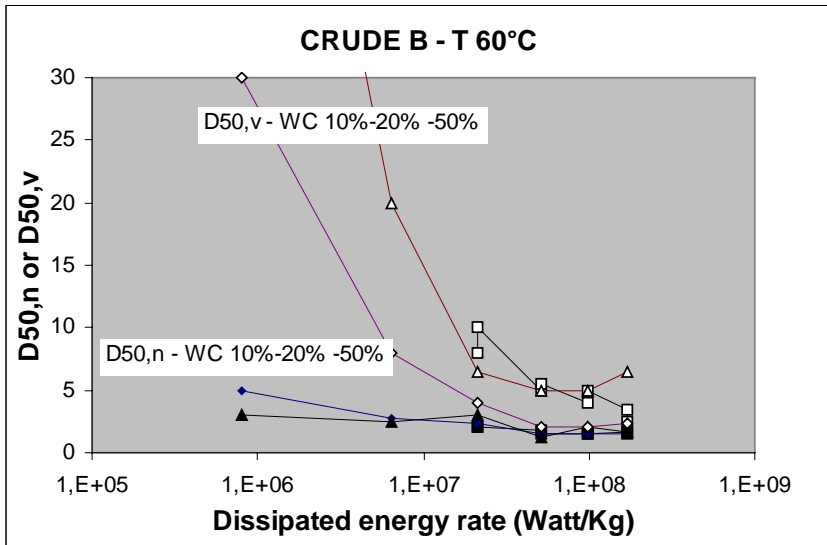
## ■ CRUDE A



Size of the water droplet in the emulsion phase versus Energy

# Results 1—Droplet size versus dissipated energy rate

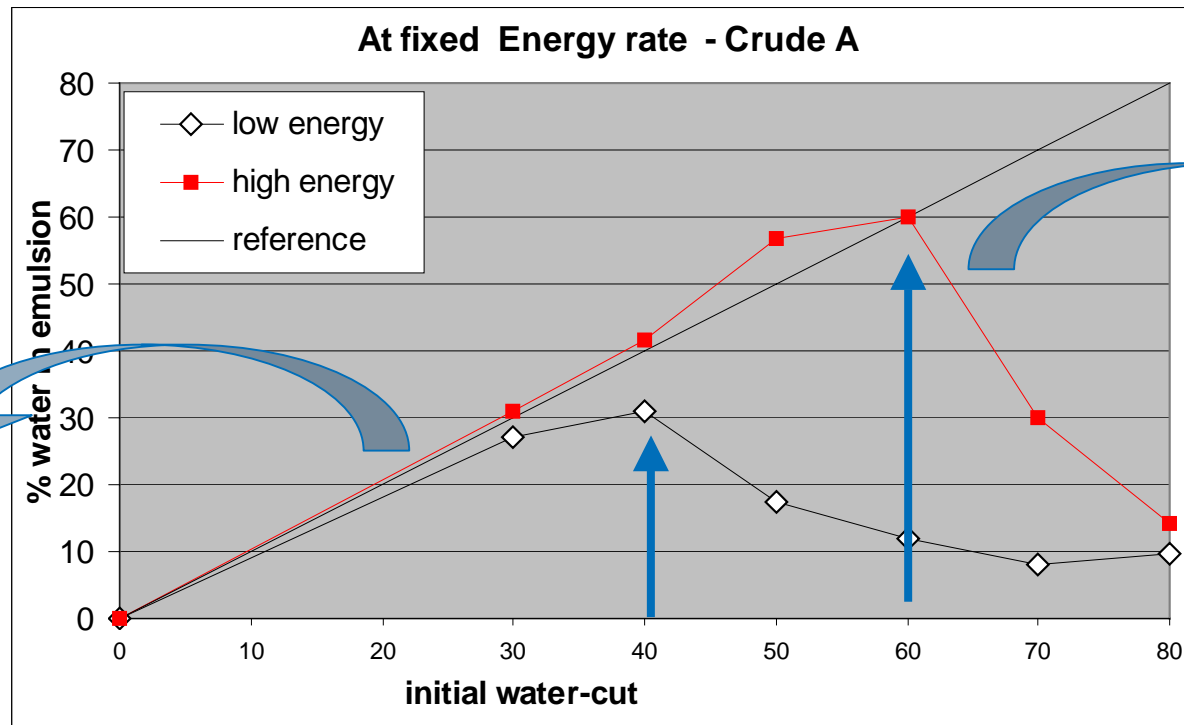
## ■ CRUDE B,C



Main remark: Droplet size polydispersity decrease  
WC < 60%

# Results 2 – at fixed dissipated energy rate -

## ■ CRUDE A



W-in-O

O +  
W-in-O

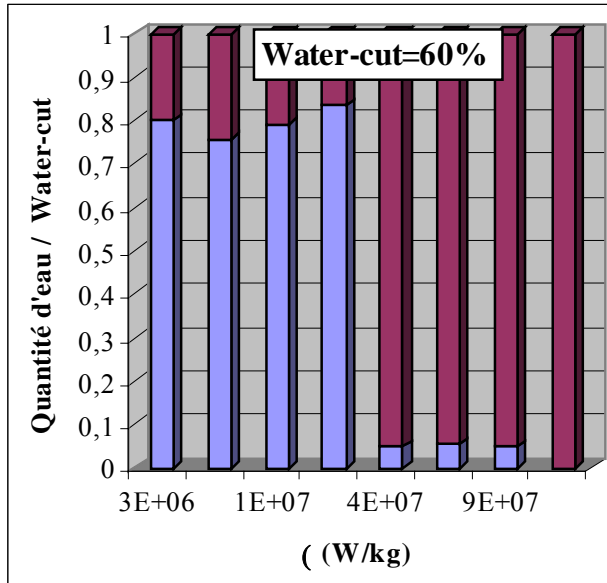
W

- ✓ For  $WC > \text{Water-cut limit}$  : presence of a free water phase
- ✓ Water-cut limit depending on dissipated energy rate
- ✓ no observation of "catastrophic" change =  
no chemical affinity change of surfactive component in oil

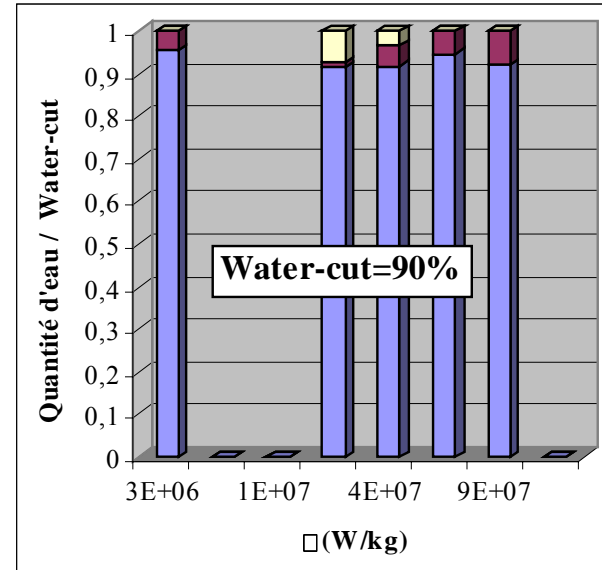
# Results 2

## ■ CRUDE A

W-in-O



????



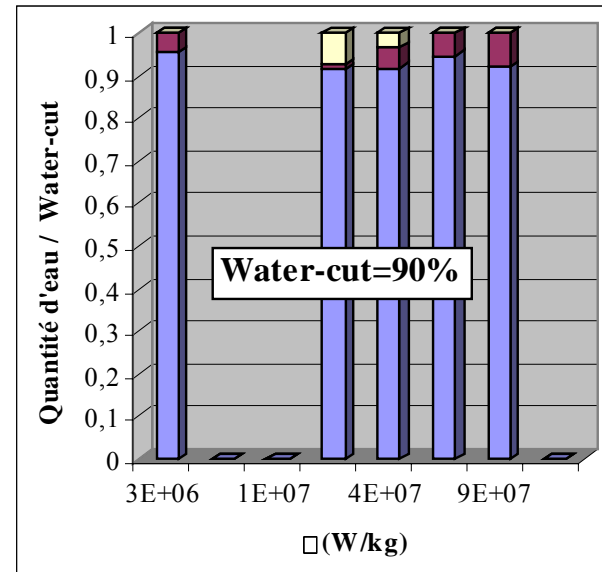
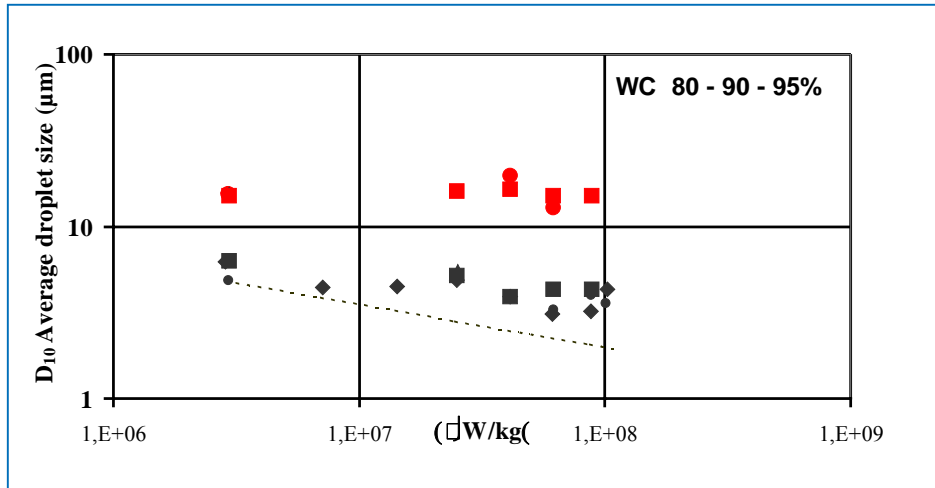
✓ At WC 60% - fine W-in-O emulsion

✓ At high water-cut 90% -95% presence of small amount of "intermediate" emulsified phase

# Results 2 – at fixed dissipated energy rate -

## ■ CRUDE A

????

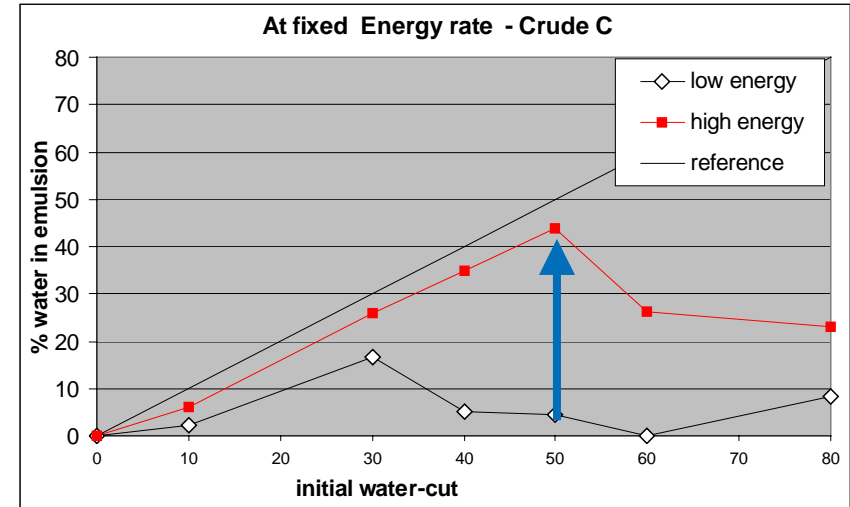
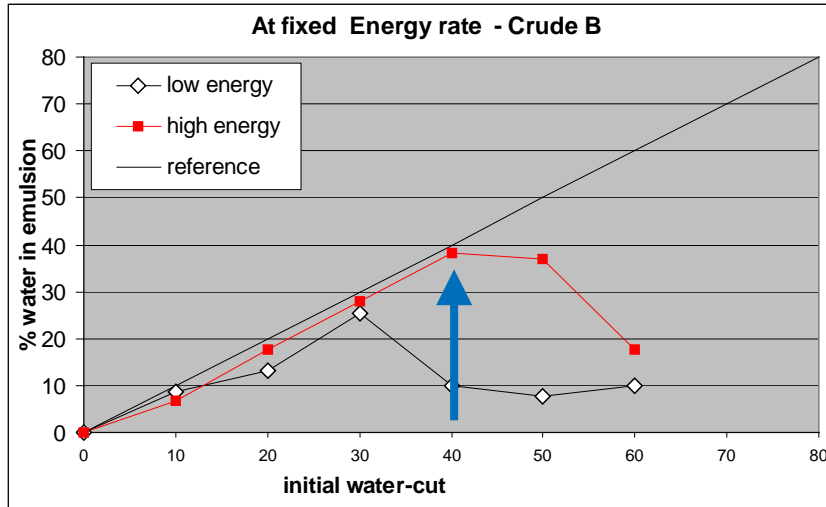


## Results from DSC : 2 peaks

- ✓ At high water-cut 90% -95% presence of
  - ✓ small amount of very fine droplet of W-in-O
  - ✓ intermediate emulsified phase – bigger water droplet surrounding by an oil film

# Results 2— at fixed dissipated energy rate -

## ■ CRUDE B and C



- ✓ Free water phase presence depending on energy rate
- ✓ At same high energy rate :  
apparition of free water phase depend on oil composition
- ✓ no observation of "catastrophic" inversion =  
no chemical affinity change of surfactive component in oil

# Concluding Remarks



- Experiments performed under turbulent flow conditions =  
break-up events overwhelm coalescence events
- $E_c$  = Threshold value for Dissipated Energy rate  
 $E_c$  value depending on initial water-cut and oil composition  
For Energy  $> E_c$  at fixed water-cut ( $< 50\%$ )  
Oil/water system totally under W-in-O emulsion form
- At fixed Dissipated Energy rate for  $WC > \text{Water-cut limit}$  : presence of a free water phase  
Water-cut limit depending on dissipated energy rate and oil composition
- No observation of "catastrophic" inversion =  
no chemical affinity change of surfactive component in oil
- At high water-cut  $> 80\%$  - "intermediate" emulsified phase