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And special thanks to The American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME) for their contribution to the program.
Crude Oil Emulsions: Everything You Wanted to Know But Were Afraid to Ask

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Saudi Aramco
Outline

- Emulsions
  - What are emulsions?
  - Types of emulsions
  - Where do they form?
  - Stability of emulsions
  - Challenges during oil production
- Reservoir and production aspects of emulsions
- Demulsification: oil-water separation
- Emulsion treatment programs
- Recommendations
Some Examples of Emulsions

Milk

Mayonnaise
Definitions

- **Emulsion**: An emulsion is a colloidal dispersion of one liquid (disperse phase) in another (continuous phase).

- **Types of Emulsion**:
  - Water-in-oil
  - Oil-in-water
  - Complex/multiple emulsions

- **Macroemulsions**, size > 0.1 µm
- **Microemulsions**, size < 0.1 µm

*Oil-field emulsions are water-in-oil macroemulsions*
Emulsion Photomicrographs

a) Water-in-oil emulsion

b) Oil-in-water emulsion

c) Water-in-oil-in-water emulsion

d) Presence of solids

10μ
Where do they form?
Where do we encounter emulsions?
Emulsion Stability

- Emulsions are inherently unstable
- Classified based on their kinetic stability
  - loose → few minutes
  - medium → tens of minutes
  - tight → hours, days
- Presence of emulsifying agents
- Films act as physical barriers to coalescence
- Factors Affecting Stability
Tight Emulsion  Loose Emulsion
An example of a very tight emulsion
Factors affecting stability

- Heavy polar material in the crude oil
- Fine solids including **organics** (asphaltenes, waxes) and **inorganics** (clays, scales, corrosion products)
- Temperature
- Droplet size and and droplet size distribution
- pH of the brine
- Brine composition
Mechanism of emulsion stabilization

Water droplet + Asphaltene aggregate → Asphaltene Stabilized water droplet

Droplets resist coalescence due to steric/colloidal stabilization
Photo-micrograph of an emulsion showing interfacial films
Measurement of stability

- Determines the ease of separation
- Most common is the bottle test
- Used for
  - water separation over time
  - water separation with demulsifier dosage
  - screening demulsifiers
- Standard ASTM method for BS&W
- Developed at Saudi Aramco: ESI or Emulsion Separation Index
Emulsion Challenges During Oil Production

● Negatives:
  ▪ Water and salt in sellable crude
  ▪ Oil in disposal water…injectivity concerns
  ▪ Flow assurance concerns
  ▪ Productivity decline in wells
  ▪ Higher demulsifier and treatment costs
  ▪ Equipment trips and upsets
  ▪ Higher oil production costs

● Positives:
  ▪ None!
Reservoir Aspects of Emulsions

- During drilling operations
- Acidization of wells
- Well treatments
- EOR/IOR operations
Drilling Operations

- Drilling muds can form tight emulsions
- May cause formation damage
- Incorrect estimation of reserves
- Most likely to form in reservoirs with:
  - Lower APIs (< 25°)
  - Lower temperatures (< 150°F)
  - Poorer rock quality (low porosities and permeabilities)
  - Higher amounts of asphaltenes
- Recommend compatibility studies
Acidization Operations

- pH affects emulsion stability
- Severe emulsion upsets after acid stimulation
- Occurs due to solid precipitates mainly asphaltenes
- Form very stable and tight emulsion and can kill a well
- Proper design of acid treatment is necessary to avoid emulsion upsets
Effect of pH on emulsion stability
EOR/IOR Operations

- Chemical (ASP) method prone to emulsion problems
- CO2 injection $\rightarrow$ asphaltene precipitation $\rightarrow$ tight emulsions
- Microbial $\rightarrow$ sludges
- Thermal $\rightarrow$ heavy oil $\rightarrow$ solid stabilized emulsions
- Much higher demulsifier treatment costs
Production Aspects of Emulsions

- High viscosities of emulsions → flow assurance issues
- Productivity declines
- Oil-water separation concerns
- Facilities operational concerns
- Off-spec crude and disposal water
Viscosity of emulsions

Water Cut, %

Relative Viscosity $\frac{\mu_e}{\mu_o}$

- Very tight emulsion
- Tight emulsion
- Medium emulsion
- Loose emulsion
- Very loose emulsion
Demulsification

- Breaking of a crude oil emulsion into oil and water phases
- From a process point of view:
  - Rate or speed of separation
  - Residual water in oil
  - Residual oil in water
- Oil should not contain more than 0.2% BS&W and 10 PTB salt
- Water should contain less than 100 ppm of oil
Mechanisms Involved in Demulsification

- Two step process
  - Flocculation (or aggregation, or agglomeration or coagulation)
  - Coalescence
- Either of these steps can be the rate determining step
Flocculation

- Droplets clump together forming “floccs”
- May not lose their identity
- Rate of flocculation depends on
  - Watercut of the emulsion
  - Temperature
  - Viscosity of the oil
  - Density difference
  - Electrostatic field
Coalescence

- Water droplets fuse or coalesce to form a larger drop
- Coalescence is enhanced by
  - High rate of flocculation
  - Absence of mechanically strong IFF
  - High interfacial tensions
  - High watercuts
  - Low oil viscosity
  - Low interfacial viscosity
  - Chemical demulsifiers
  - Higher temperatures
Methods of Emulsion Breaking

- Any or combination of:
  - Thermal…providing heat
  - Mechanical…residence time
  - Electrical…electrostatic grids
  - Chemical…adding demulsifiers

- Demulsification methods very application specific

- Dynamic process: emulsions and conditions change with time
Emulsion Video
Emulsion Treatment Program

- Very site specific
- Experience and engineering judgment
- Data needed:
  - Laboratory studies
  - Data from nearby wells/fields
  - Field trials
- Balance between chemical, thermal, mechanical and electrical
- Optimization
Emulsion Treatment Program

Questions?

- Are we using the best demulsifier?
- What is the retention time?
- What type of emulsion?
- What is the water cut?
- System heated, or can it be?
- Range of operating conditions?
- Feed constant or changing?
Emulsion Treatment Program

**Guidelines**

- Each production stream unique
- Laboratory tests with actual samples
- Incorporate flexibility during design
- Planning early
- Pilot and field trials
- Re-engineering and retrofitting
- Record data for diagnosis
- Review periodically
Emulsion Treatment Program

*Prevention*

- Fine solids management
  - Scales: Inhibit scale formation
  - Asphaltenes: management, dispersants
  - Corrosion products: inhibitors
- Acidization…review field performance
- Commingling of crudes…compatibility
- Mixing and shear…reduce, optimize
- Check compatibility of chemicals
Emulsion Treatment Program

*Demulsifier Selection & Optimization*

- Bottle tests...representative samples
- Field testing with promising demulsifiers
- Proper demulsifier mixing
- Demulsifier overdosaging
- Understanding the causes of tightness
- Evaluating the process
- Maintaining a database
- Demulsifier usage
  - Less than 5 ppm to over 200 ppm
  - Generally between 10 to 50 ppm
Demulsifier costs at a separation plant
Recommendations

- Diagnose... your emulsions and your hardware
- Retrofit... your vessels... after economic analysis
- Perform... field trials... periodically
- Monitor... performance
- Reduce... shear and fine solids... scales, asphaltenes, clays
- Maintain... records
- Proactive... in using new technology...
One thing to remember...

Crude Oil Emulsions:
Society of Petroleum Engineers
Petroleum Engineering Handbook
Volume 1, Chapter 12
THANK YOU!

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