



**Brookes**  
**Bell**

# Liquefaction

## Theory and Reality

Daniel Sheard

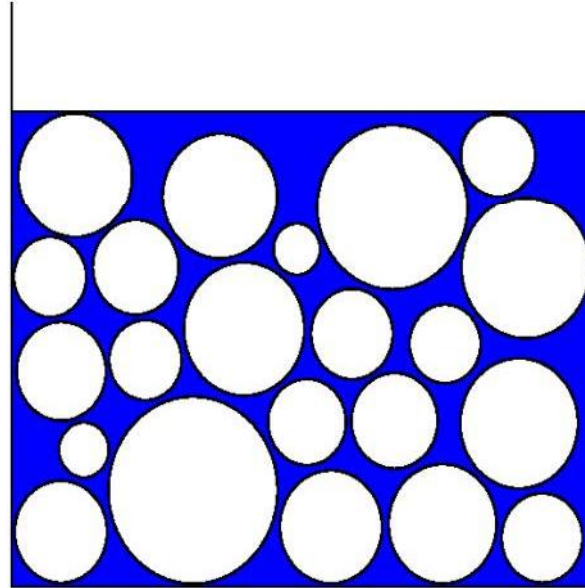
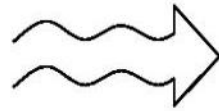
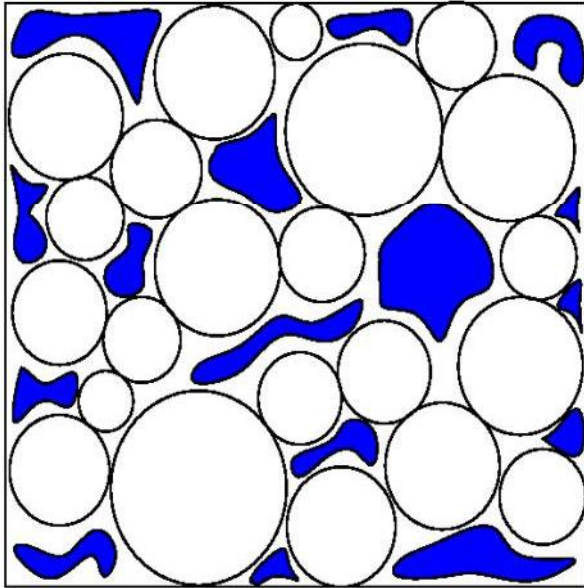
Brookes Bell

# Liquefaction

- Certain bulk cargoes can liquefy if overmoist
  - Small particles
  - Inherent moisture
- Metal sulphide concentrates
- Nickel ore
- Iron ore fines
- Minerals generally

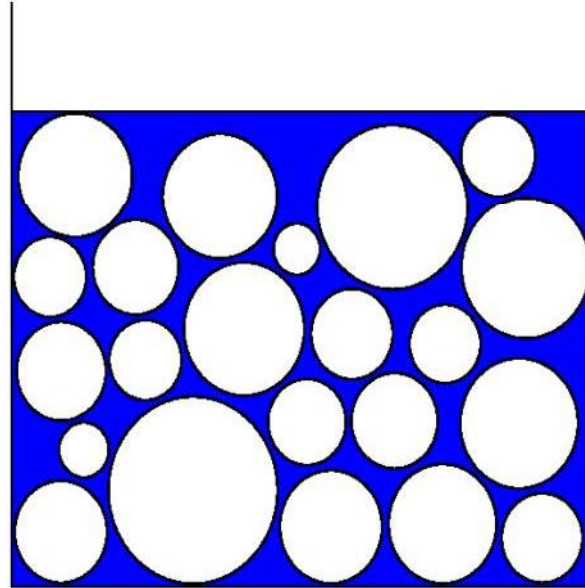
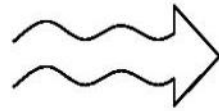
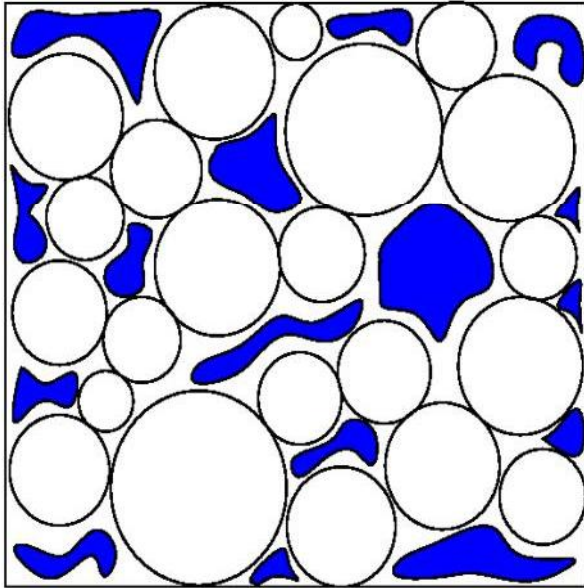
# What's it all about?

- Materials with small particles which look dry
- Can have moisture in between particles
  - Particles still in contact = physical strength



# What's it all about?

- Materials with small particles which look dry
- Can have moisture in between particles
  - Particles still in contact = physical strength
- Vibrations make the particles pack better
- Can have a situation where
  - Particles no longer in contact = no physical strength

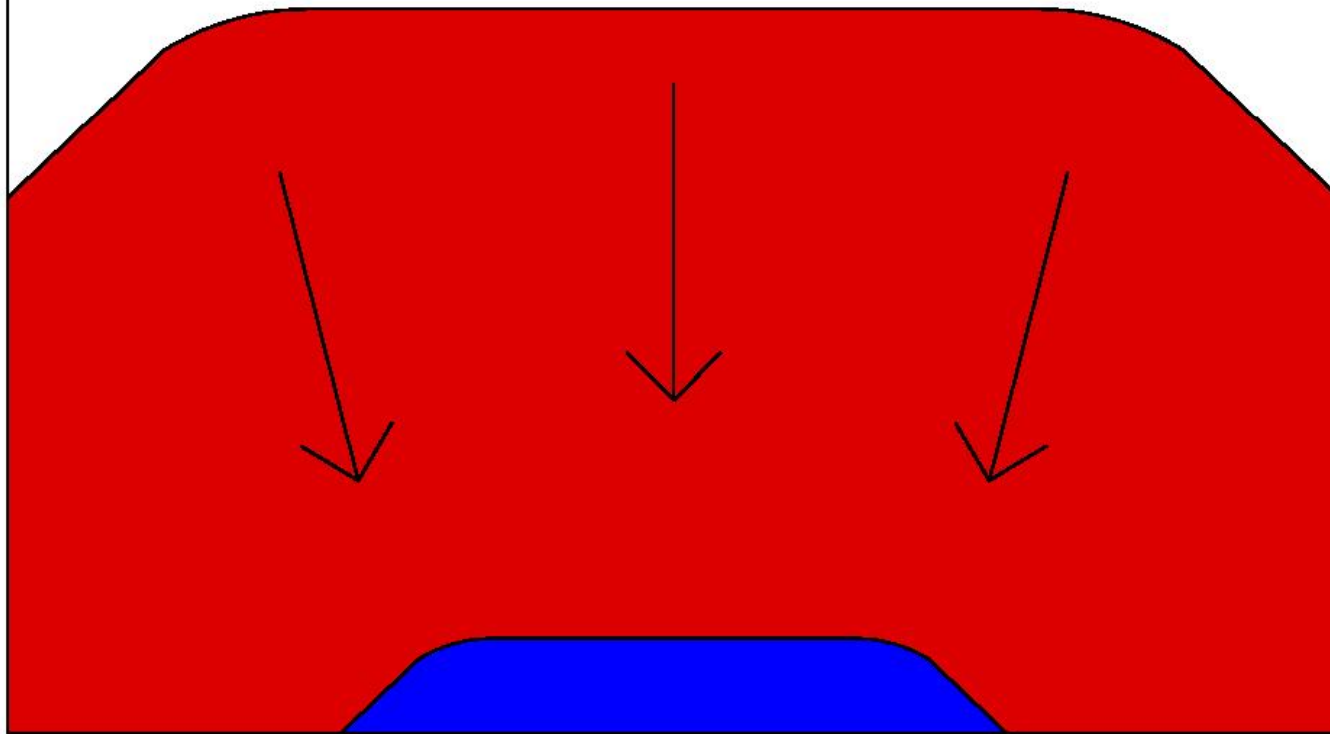


# When it goes wrong

- Cargo at loading often looks OK or overmoist at best
- Drainage
  - What's down below?



# DRAINAGE



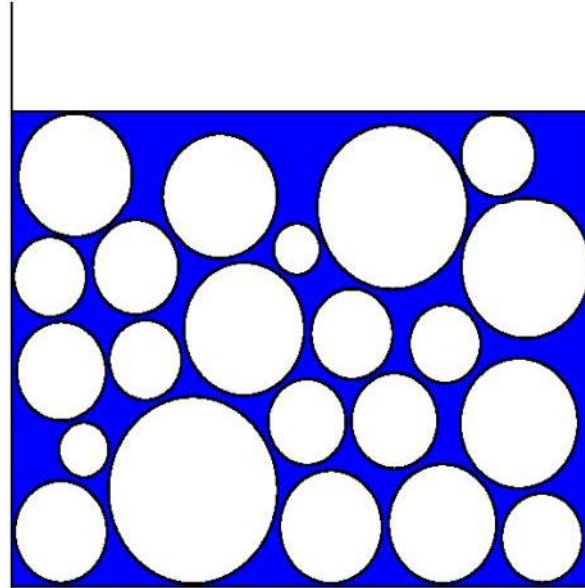
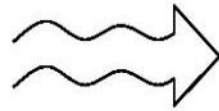
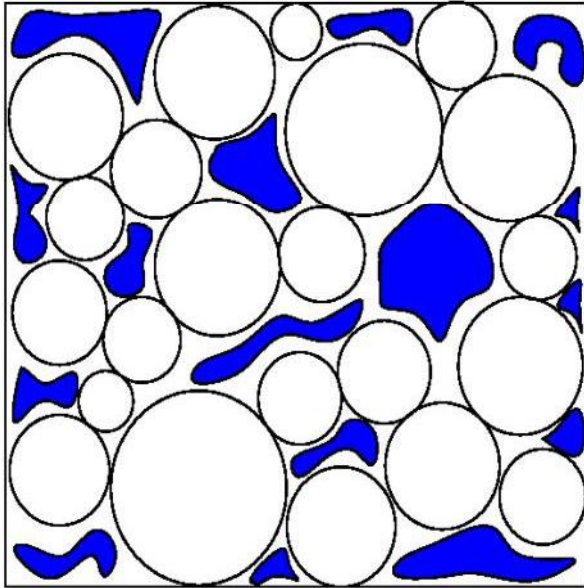






# When it really goes wrong

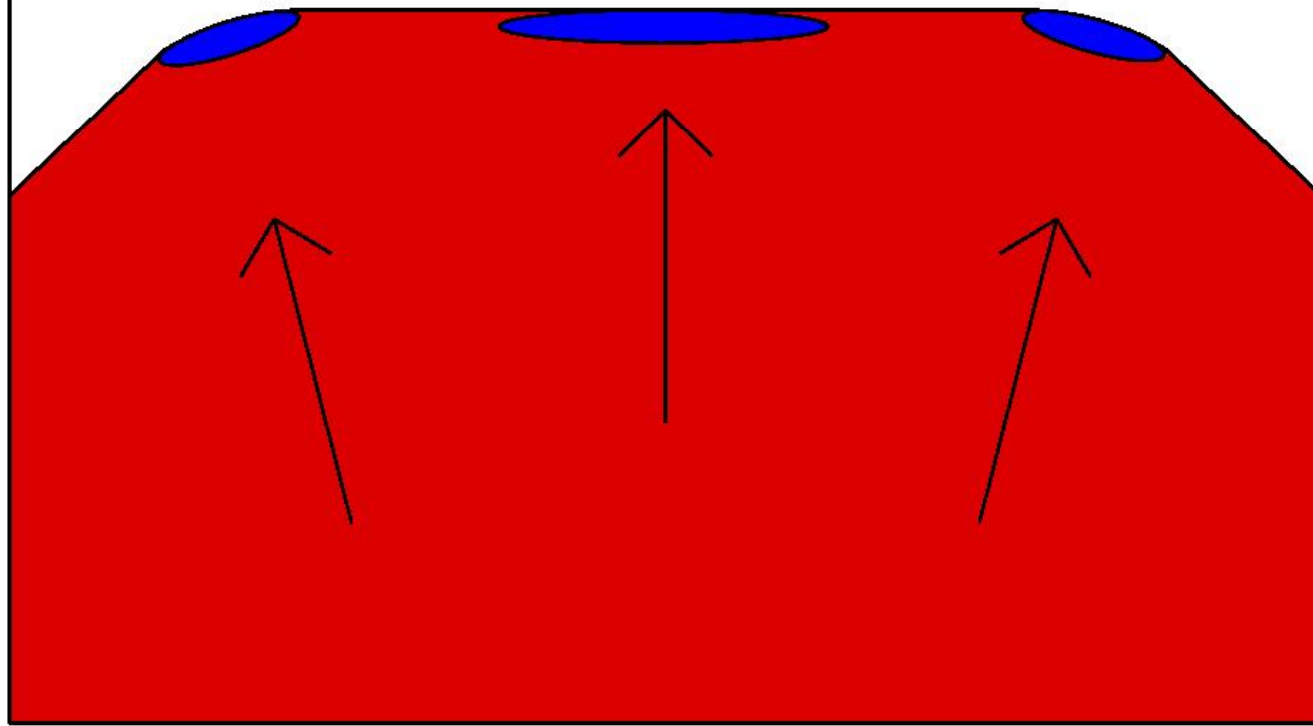
- Ship sails
- Vibrations
- Better packing



# When it really goes wrong

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- Upward migration of moisture

# MIGRATION





# When it really goes wrong

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- Liquefaction and flat surfaces



















# When it really goes wrong

- Ship sails
- Vibrations
- Better packing
- Upward migration of moisture
- Liquefaction and flat surfaces
- Progressive shift
- Capsize









# Rules

- SOLAS
- IMSBC Code
  - The essential document published by IMO to ensure safety of ships carrying bulk cargoes
  - Now mandatory under SOLAS, but always prudent
  - Classifies cargo behaviour in groups
  - Cargoes which can liquefy are Group A
  - No entry for iron ore fines - yet
  - No entry for nickel ore - yet

# IMSBC Code

- Places a responsibility on the shipper to provide before loading
  - A description of the cargo and its properties, including whether the cargo is Group A
  - For Group A cargoes a certificate of the moisture content and transportable moisture limit (TML)



# IMSBC Code

- Moisture must be measured on samples taken no more than 7 days before loading
- TML is not restricted to 7 days
- Both must be on samples which represent the cargo.
- 4.4.1 “Physical property tests on the consignment are meaningless unless they are conducted prior to loading on truly representative test samples”.

# Sampling

- Must be the cargo actually proposed for shipment
- Must be identifiable and capable of being sampled in a representative fashion
- Representative sampling needs to bear in mind “variations in moisture distribution throughout the consignment which may occur due to weather conditions, natural drainage...”

# Sampling

- Need to get samples from all parts of a stockpile
- Machinery required, access required
- Shippers' responsibility, but commonplace (and sometimes a requirement) for Owners to verify
- Distinct material to be sampled separately

# Testing

- Moisture test – oven drying at  $105^{\circ}$  to constant mass
- Flow moisture point FMP
  - The moisture level at which flow starts to take place with the input of energy
- Transportable moisture limit TML
  - 90% of FMP, a safety margin
- Add moisture until the material exhibits flow properties

# Testing - FMP

- Measure moisture of samples close to a flow state
- Bracketing – one just above, one just below
- Three standard methods
  - Flow Table Test
  - Penetration Test
  - Proctor/Fagerberg Test
  - Plus any other test sanctioned by the Competent Authority

# Statement of the Obvious

- THERE IS NO POINT SAMPLING, TESTING, AND ISSUING CERTIFICATION IF THE CARGO SUBSEQUENTLY GETS WET

# Flow Table Test

- IMO Flow table
  - Inputs energy into sample in a defined way





# Flow Table Test

- IMO Flow table
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- Sample loaded into mould and tamped







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# Flow Table Test

- IMO Flow table
  - Inputs energy into sample in a defined way
- Sample loaded into mould and tamped
- Dimensions measured
- Table dropped 50 times in 2 minutes
- Results examined









# Flow Table Test

- Needs the correct equipment
  - Poorly constructed flow tables
  - Mounting of the tables
  - Spring-loaded tamper
- Identification of flow state
  - Plastic deformation
  - Measurement of cone expansion





















# Flow table - issues

- Subjectivity
- Disagreement on end-point criteria
- “7mm”
  - Sieving?
  - Can be justified but needs to be done properly

# Flow table - issues

- Subjectivity
- Disagreement on end-point criteria
- “7mm”
  - Sieving?
  - Can be justified but needs to be done properly
- Can all nickel ore samples be tested?

# Penetration Test

- Vibrating table operated at a specified frequency and acceleration
- Large amount of sample in chamber
- Weighted plunger on surface
- If penetrates 50mm into the sample in 6 minutes the sample is said to flow





# Penetration Test - issues

- Less subjectivity
- Is an approved method
- Not widely available – yet
- Does it give repeatable, reliable answers?
- Does it give the same answer as the flow table?
- Does it have to?

Samples	PM	FTT
Copper Conc.	19.0	19.0
Lead Conc.	8.7	8.6
Pylite Conc.	8.8	8.6
Zinc Conc.	11.4	12.1
Barite Conc.	10.4	10.3
Iron Ore Sinter Fines	5.0	6.3
Zinc Sulphide	12.0	12.2
Miike Coal	13.1	—

# Digression – the can test

- Not a substitute for laboratory testing
- A useful tool
- Can be misleading
  - “If free moisture or fluid condition appears, arrangements should be made to have additional laboratory tests conducted on the material before it is accepted for loading.”













# Indian iron ore fines

- Not homogeneous
- Not consistent
- Often stored outside
- Monsoon rains
- Lumps/fines/oversize
- Time pressure









# Nickel ore

- Remote places
- Often wet when mined
- Solar drying
- Large stones
- Sampling
- Rain
- Problems with flow table test (7mm)
- In-house testing











# Nickel ore – STOP PRESS!

- New proposal developed in New Caledonia
- Discussed at IMO already and approved in principle
- VTPB test
  - Based on penetration test
  - STOP/GO test carried out from stockpile samples
  - No TML
- Only for New Caledonia initially

# Brazil

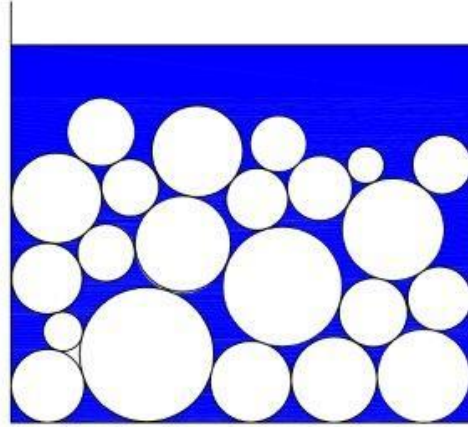
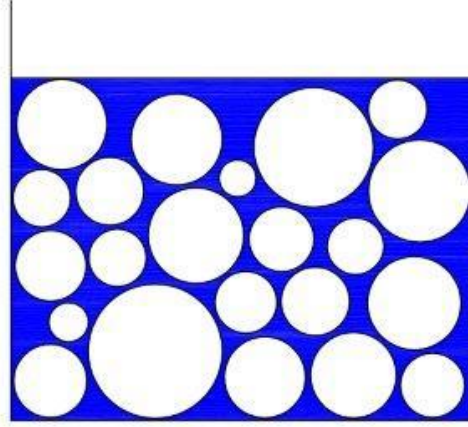
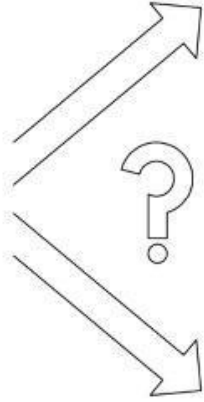
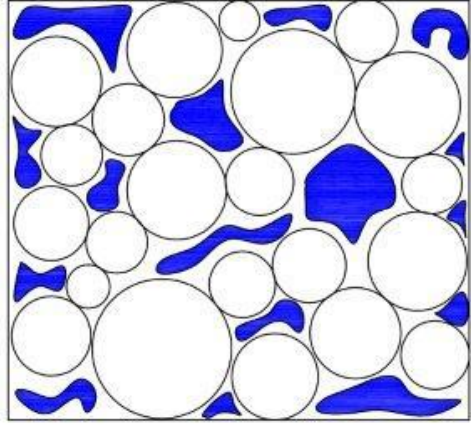
- Sinter feed or pellet feed
- Often declared as Group C
- Work in progress

# Brazil

- Is it liquefaction?









# Brazil

- Is it liquefaction?
- Are the properties such that it does not liquefy
- Testing taking place – measure pore pressure
- If it isn't liquefaction, is it safe anyway?



Generalized  
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