CONSIDERATIONS IN THE SELECTION OF DRAWING LUBRICANTS FOR THE PRODUCTION OF COPPER WIRE AND ALUMINUM WIRE USED TO PRODUCE MAGNET WIRE AND POWER CONDUCTOR CABLE FOR ELECTRIC VEHICLES

By

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WIRE DRAWING LUBRICATION

FOR COPPER AND ALUMINUM WIRE PRODUCTION

I. Introduction

II. Wire Drawing - Lubrication Theory and Practice

III. Aluminum Wire Drawing Lubricants- Formulation Selection and Process Controls

IV. Copper Wire Drawing Lubricants – Formulation, Section and Process Controls

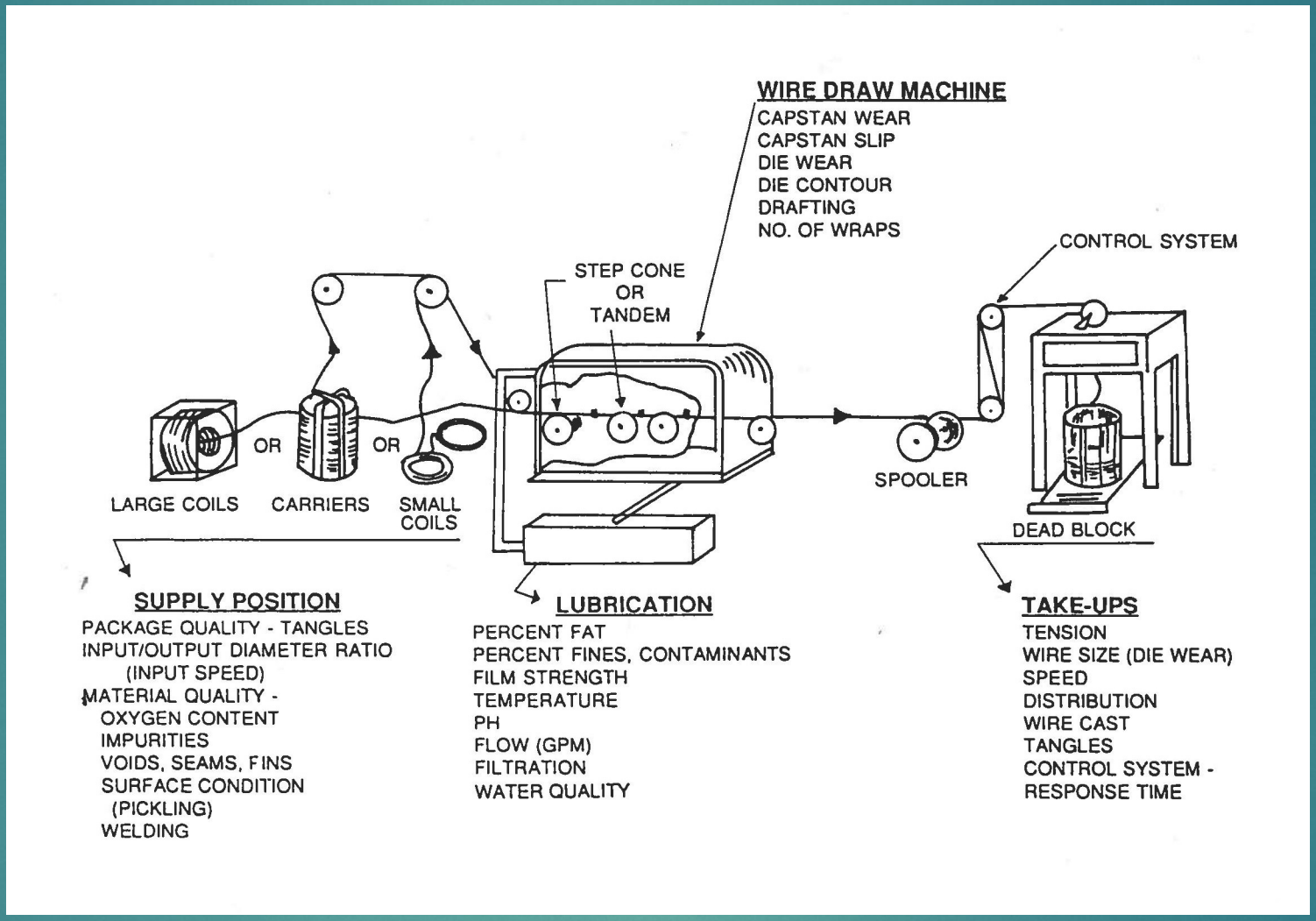
V. Testing in the Plant

VI. Summary and Conclusions

PROPERTIES OF WIRE USED TO PRODUCE MAGNET WIRE AND POWER CONDUCTOR CABLE

- Adequate Electrical Conductivity in the annealed condition
- Wire must respond to annealing during enameling to reach correct level of softness
- The wire must meet dimensional tolerances
- The wire surface must be free of contaminants or surface defects that can adversely affect enamel adhesion
- The first two conditions are related to the chemical composition of the metal and the latter two are sensitive to the type of lubricant used to draw the wire

WIRE DRAWING LINE OVERVIEW

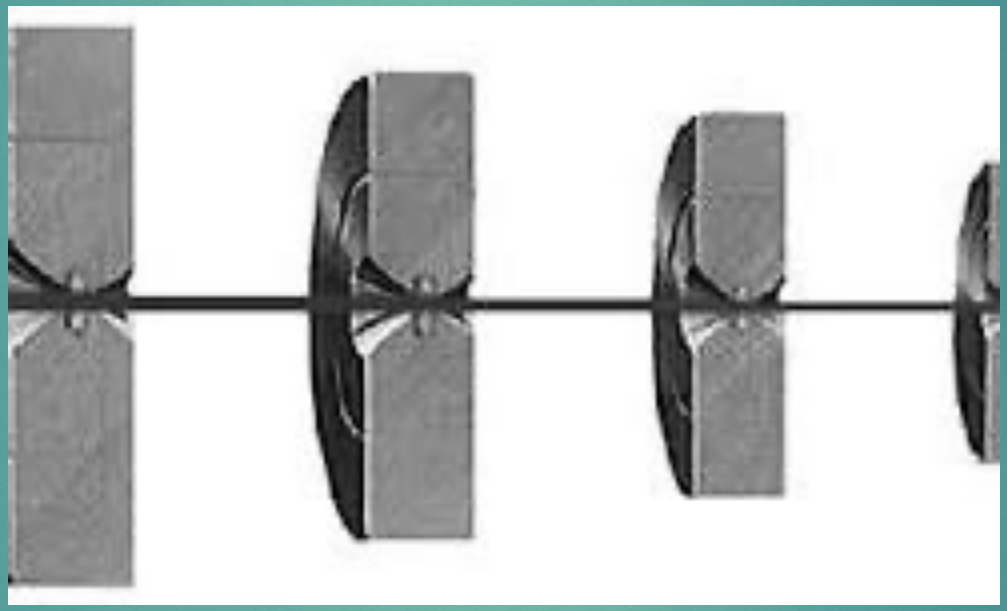


(O.J. Tassi, WAI, Non-Ferrous Wire Handbook)

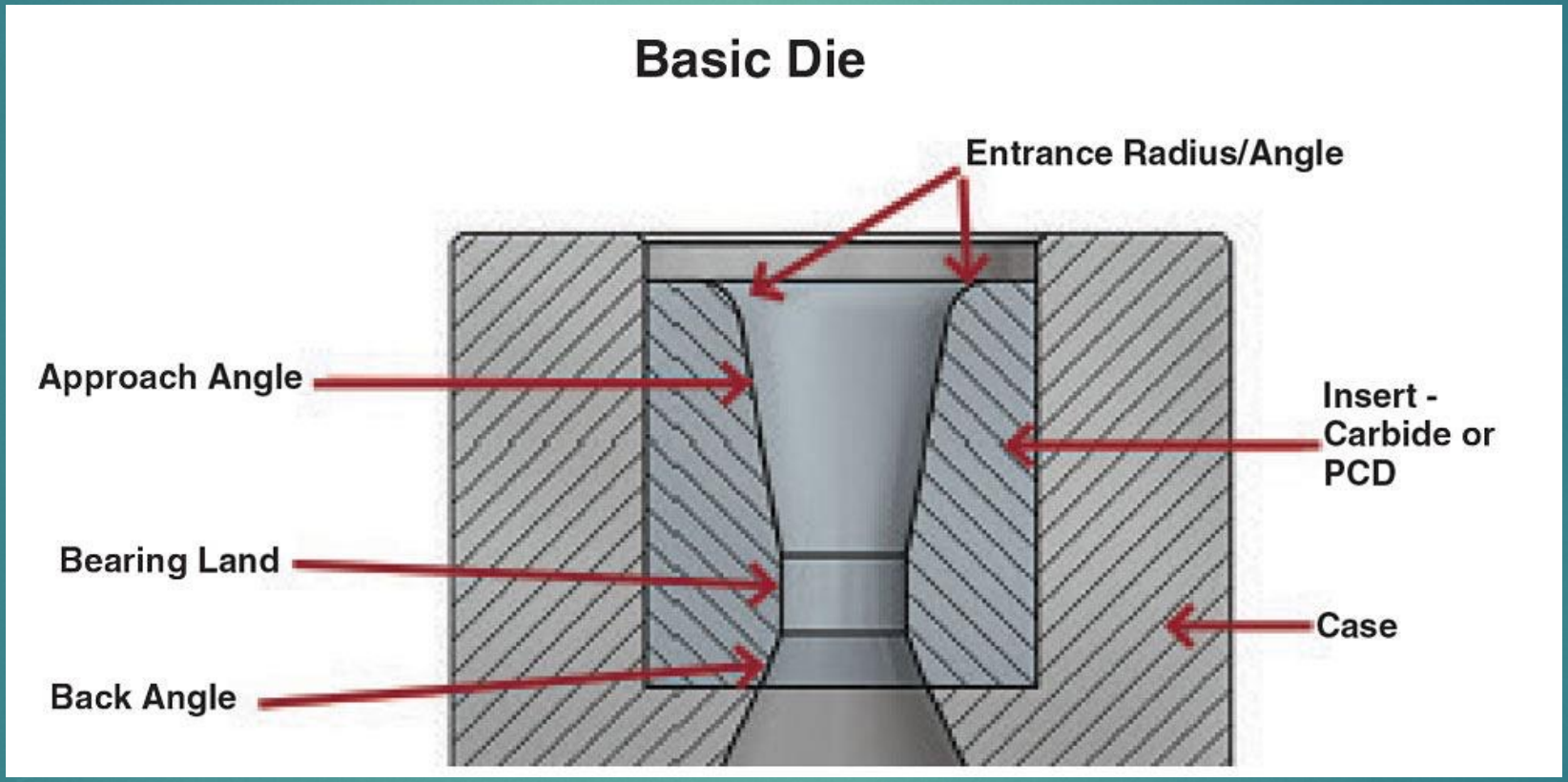
TANDEM BLOCK ROD BREAKDOWN MACHINE

MULTI-WIRE DRAWING MACHINE

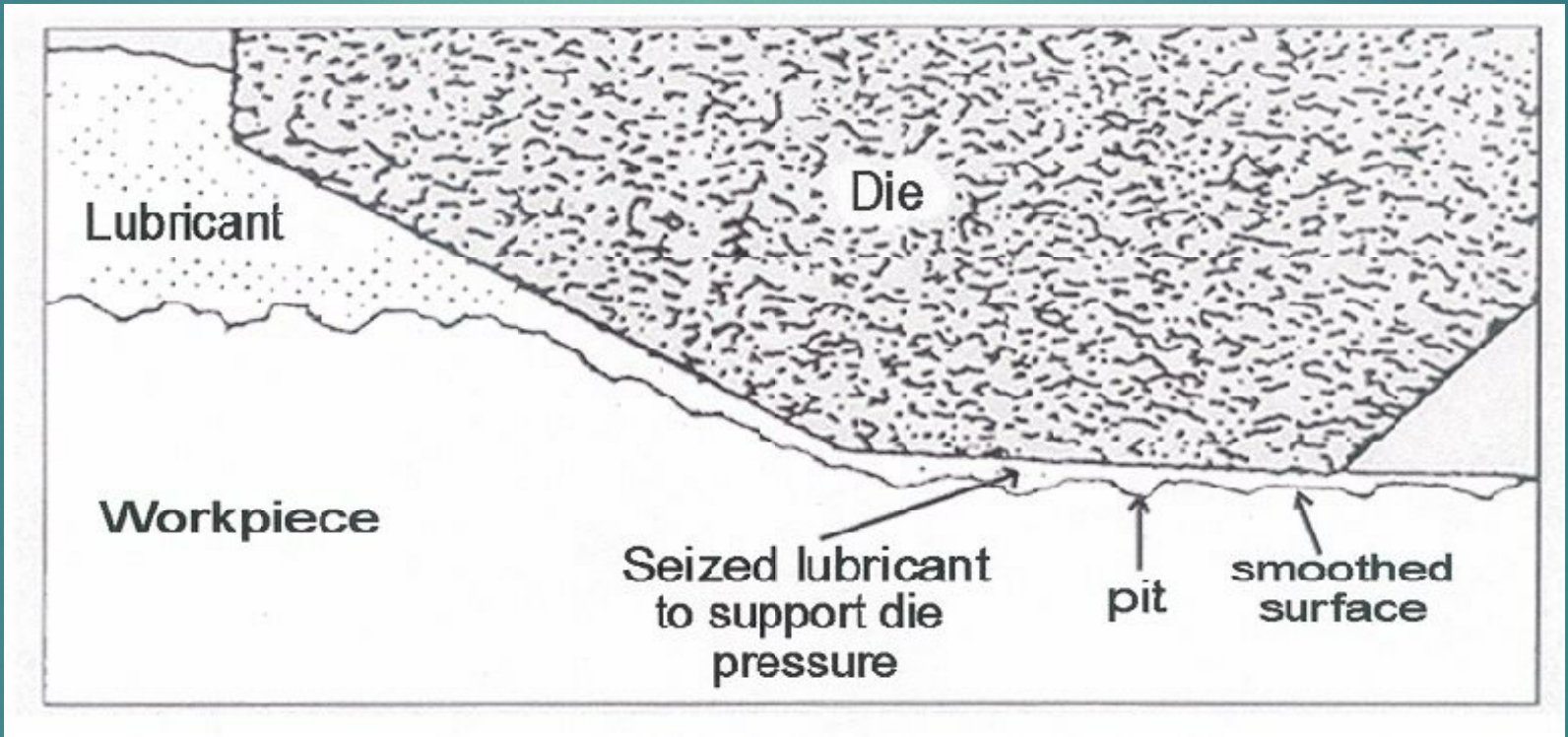
DRAW DIE SEQUENCE SHOWING WIRE ELONGATION



BASIC DRAW DIE DESIGN



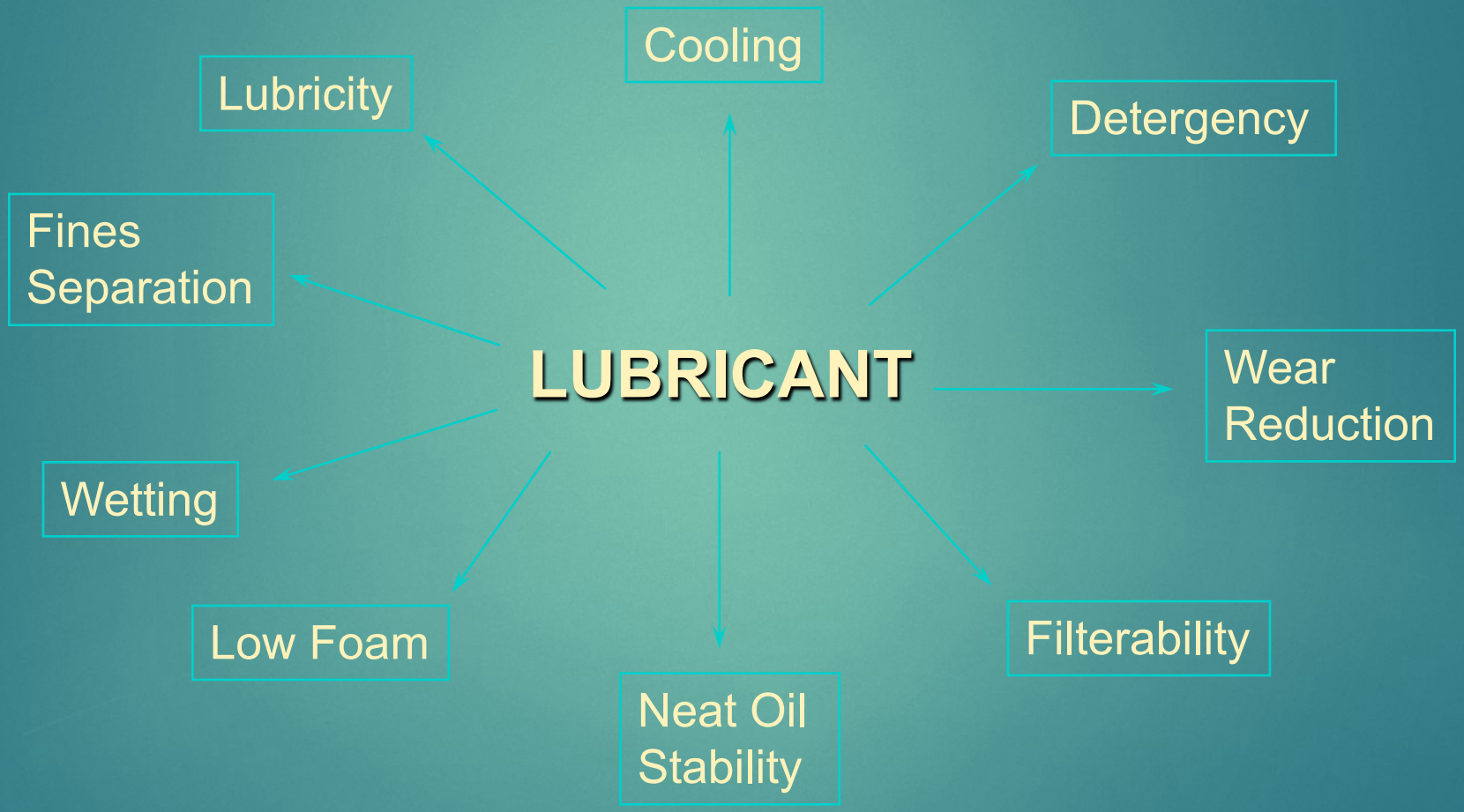
SCHEMATIC DIAGRAM ILLUSTRATING THE INTERFACE BETWEEN WORKPIECE AND DIE



TASKS OF LUBRICANTS

- Separation of frictional partners
- Reduction of friction between the partners
- Reduction of wear within the contact area
- Achieved by:
  - Lubrication
  - Cooling

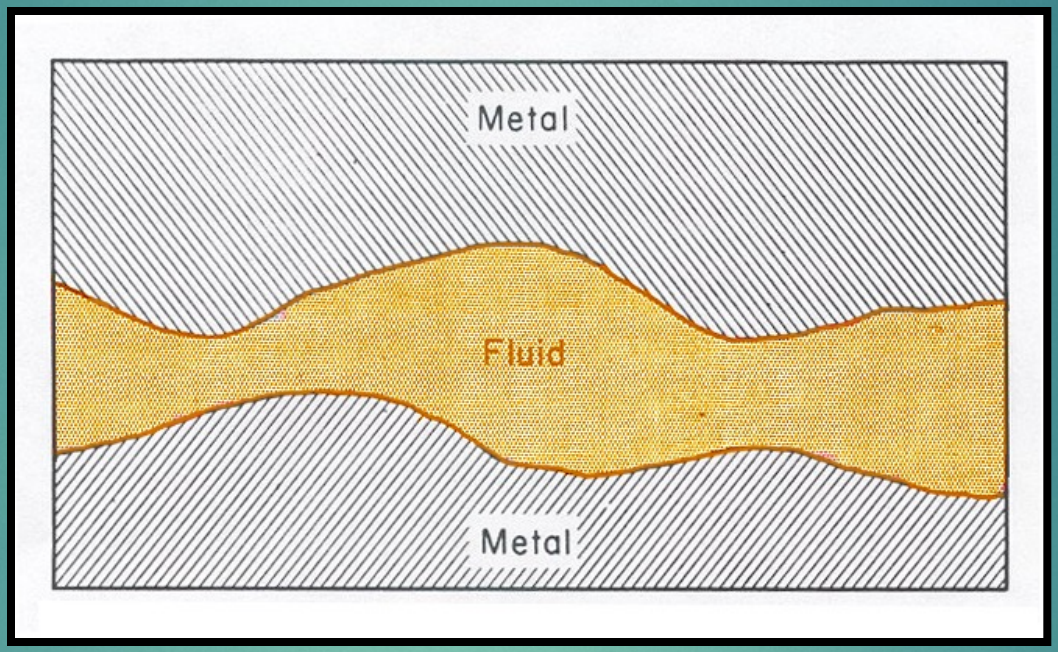
MULTI-FUNCTIONAL PROPERTIES OF MODERN LUBRICANTS



MODES OF LUBRICATION

- Three basic types of lubrication:
  - Hydro-dynamic lubrication
  - Boundary lubrication
  - Mixed film lubrication: combination of both

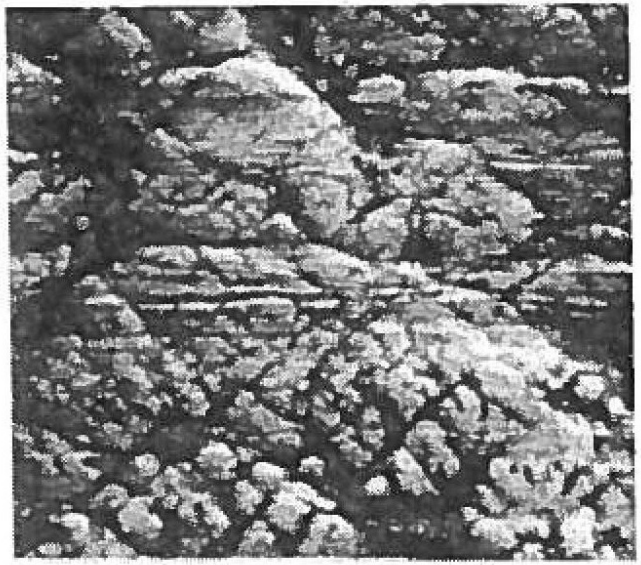
HYDRO-DYNAMIC LUBRICATION



- Metal surfaces separated by a continuous film thickness of lubricant.
- Film thickness greater than height of the surfaces of the metals
- Key form of lubrication in wire drawing

HYDRO-DYNAMIC LUBRICATION

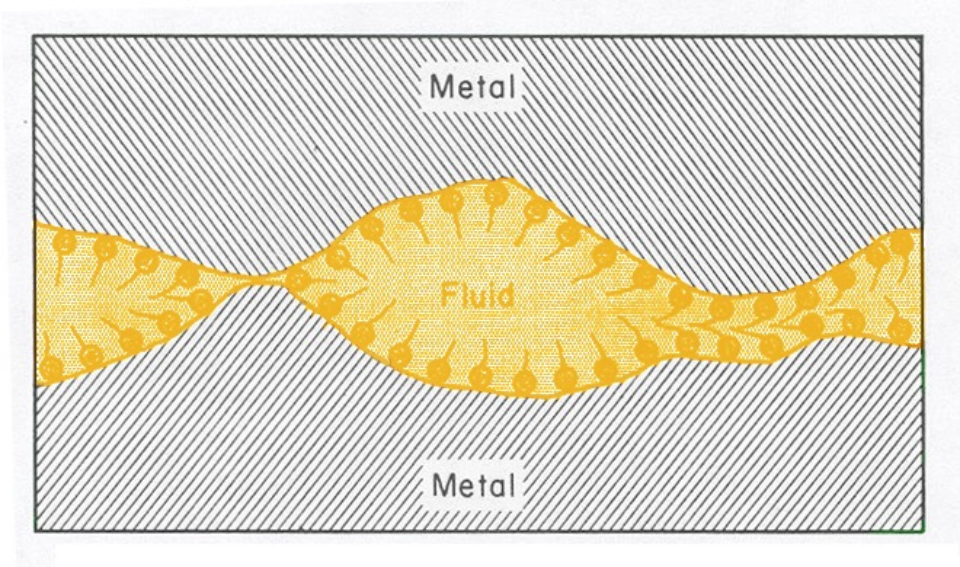
MICRO VIEW



35µm

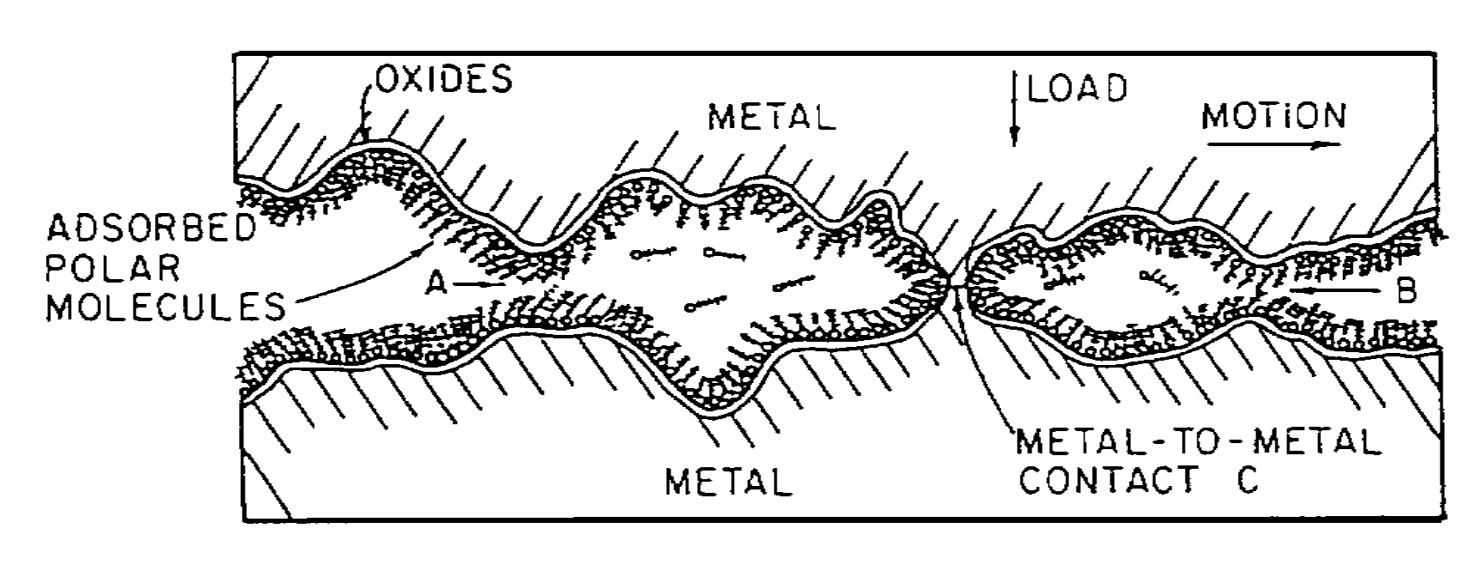
SEM micrograph of EC Al wire drawn in calcium stearate, displaying evidence of a thick film lubrication mode

BOUNDARY LUBRICATION



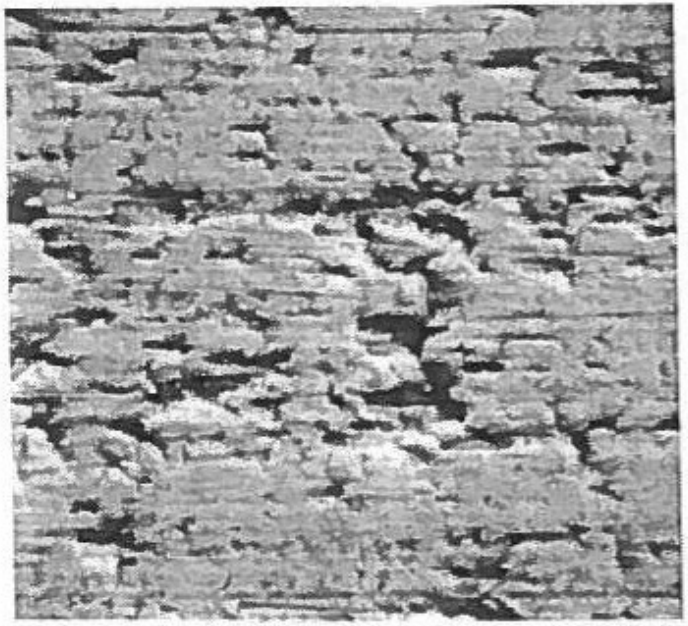
- Lubricant film to minimize metal to metal contact, noncontinuous
- Polar lubricants needed (fatty oils, fatty acids, soaps, etc.) = Polar Lubrication
- Film Thickness is irregular and thin

Schematic of Boundary - Lubricated Surfaces Showing effectively (A and B) and ineffective (C) Lubricated Contacts



MIXED FILM LUBRICATION

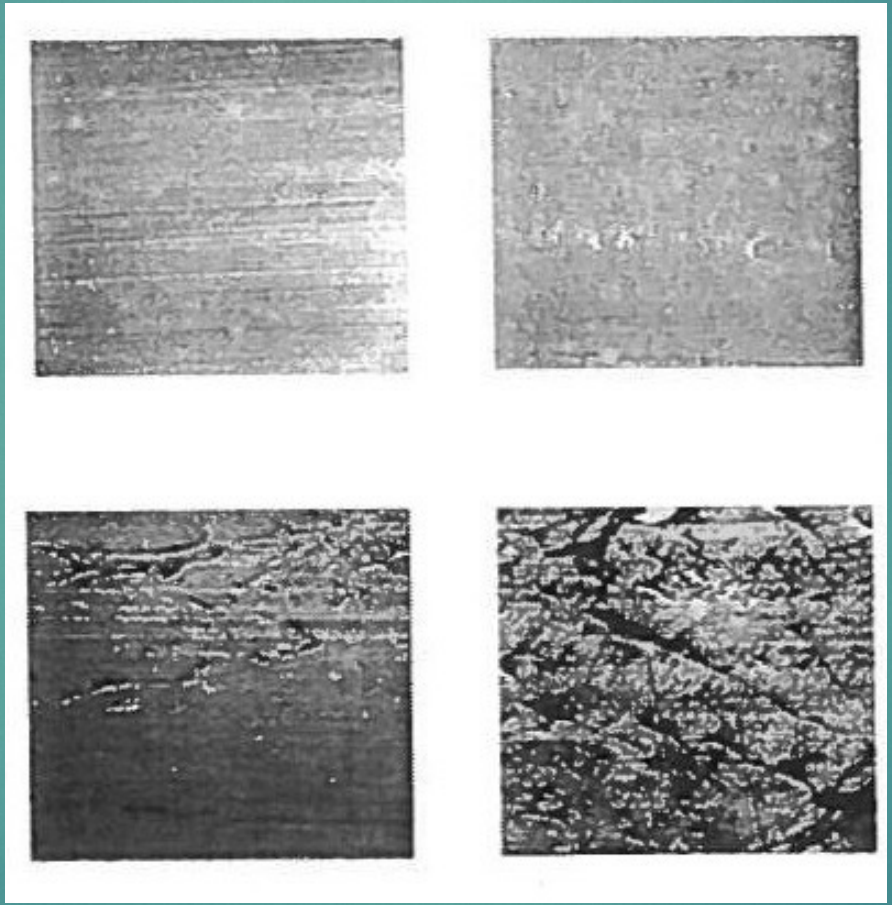
MICRO VIEW



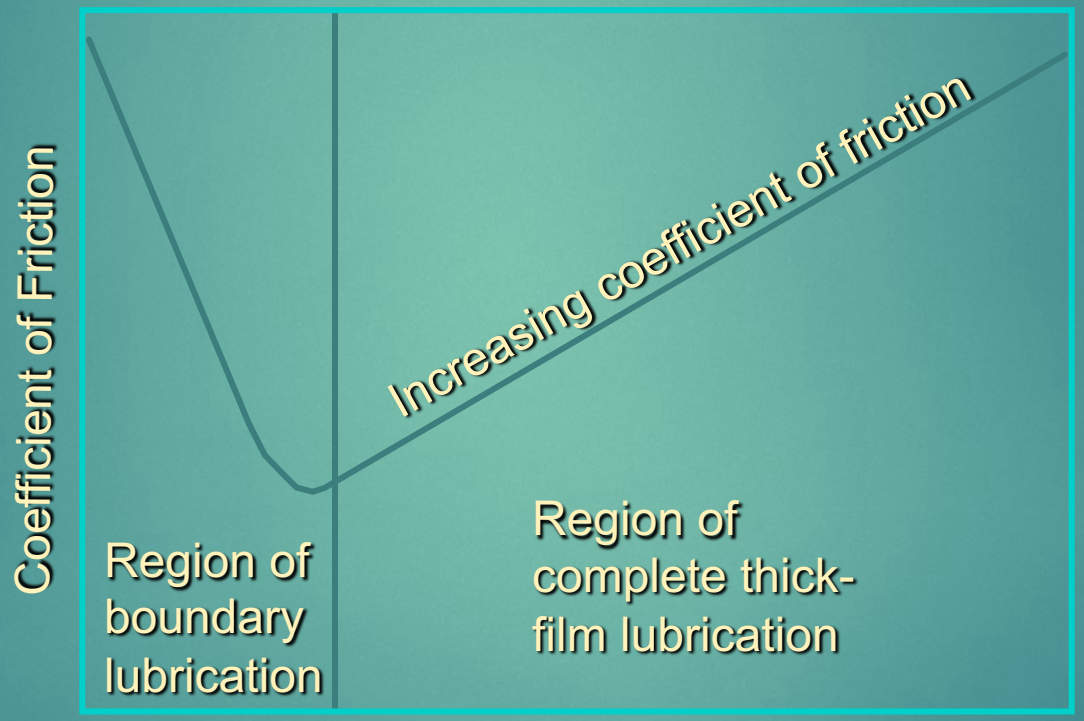
SEM micrograph of EC Al wire drawn in calcium stearate, showing evidence of thick film "pockets"

LUBRICATION FAILURE SEQUENCE

MICRO VIEW



STRIBECK CURVE



GENERAL REACTION PATHWAYS OF LUBRICANTS

- How does lubrication work?
  1. Physical Adsorption
  2. Chemical Adsorption

PHYSICAL ADSORPTION

- Based upon differences in surface energy:
  - Formation of monomolecular layers
  - Improved adsorption with increasing polarity

CHEMICAL ADSORPTION

- Based upon large differences in surface energy
- Strong chemical bonds with high binding energy
- High stability of reaction products generated at the work piece to tool interface
- Occurs over wide temperature range from literally 0 to 1,000 degrees C

FACTORS EFFECTING WIRE DRAWING LUBRICANT SELECTION

- Type of Material to be drawn
  - Non-ferrous – Copper Vs. Aluminum
- Speed and Draw Pass Reduction
- Method of production of Rod

FACTORS EFFECTING WIRE DRAWING LUBRICANT SELECTION

- Heat Treating
- Preparation of Material
- Post Cleaning and Heat Treating
- End Use of Wire
  - Finish
  - Geometry

Aluminum Wire Drawing Lubrication

- Formulation
- Selection
- Process Controls

OIL-BASED LIQUID LUBRICANT COMPONENTS

- Mineral Oil – Carrier for additives
- Polar Additives
  - Animal Fats
  - Vegetable Fats
- Other Frictional Modifier Additives
  - Ester-based Materials
- Viscosity Modifiers

ALUMINUM ROD PRODUCTION
IMPACT ON LUBRICATION SELECTION

- Rod Preparation
  - Continuous cast and rolled
  - Cast Billet rolled on rolling mill
  - Cast billet extruded into rod on extrusion press
- Differences in Surface Roughness
  - Impact upon lubricant effectiveness

PROCESS CONTROLS – NEAT OILS

A. Handling and Storage
B. Temperature
C. Viscosity
D. Water and Solids Content
E. Acid Number
F. Additive Content
G. Recordkeeping

PROCESS CONTROLS FOR NEAT OIL LUBRICANTS

TEMPERATURE

- Control is usually automated
  - Set point and temperature monitoring
  - Window to activate / deactivate cooling water flow to heat exchanger
- Importance of maintaining a consistent temperature of the Al wire drawing oil
- Effects of High & Low Temperature

TEMPERATURE EFFECTS ON COEFFICIENT OF FRICTION

Drawn schematically it can be seen that:

Poor Lubricity

↓

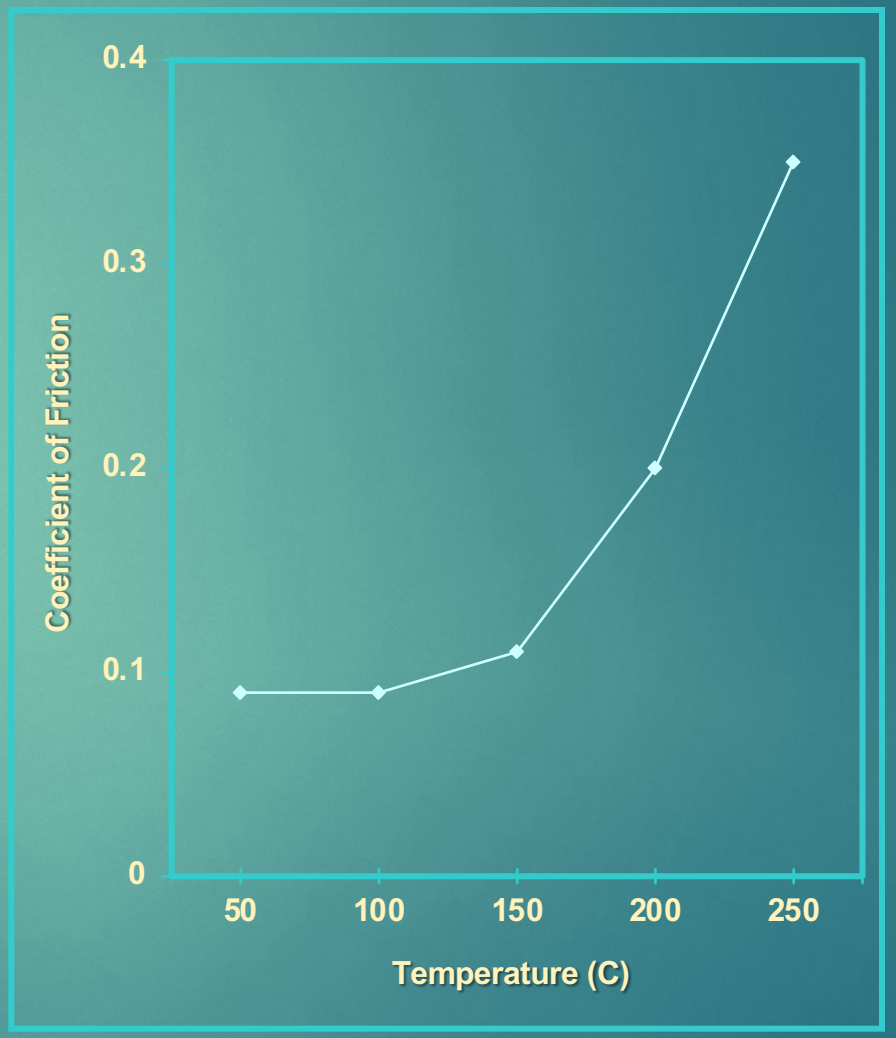
Excessive Temperature Rise (Poor Cooling)

↓

Increase Coefficient of Friction

↓

Wear



PROCESS CONTROLS FOR NEAT OIL LUBRICANTS

DIRT / PARTICULATE LEVEL

- Method: Volumetric
- Frequency of measurement
  - Sample taken after filtration
- Filtration efficiency
- Machine cleanliness

PROCESS CONTROLS FOR NEAT OIL LUBRICANTS

WATER LEVEL

- Method: Dean Stark apparatus or Karl Fisher automatic titration
- Frequency of measurement – Daily
- Effect of water upon lubrication efficiency
- Changing from copper wire emulsions to neat oils for aluminum wire to be drawn on the same machine

PROCESS CONTROLS FOR NEAT OIL LUBRICANTS

ADDITIVE LEVEL

- Methods: Acid number titration and Saponification Number titration
- Frequency of measurement – Monthly
- Effect of low acid number
- Effect of change of Saponification number

PROCESS CONTROLS FOR NEAT OIL LUBRICANTS

SYSTEM MAINTENANCE

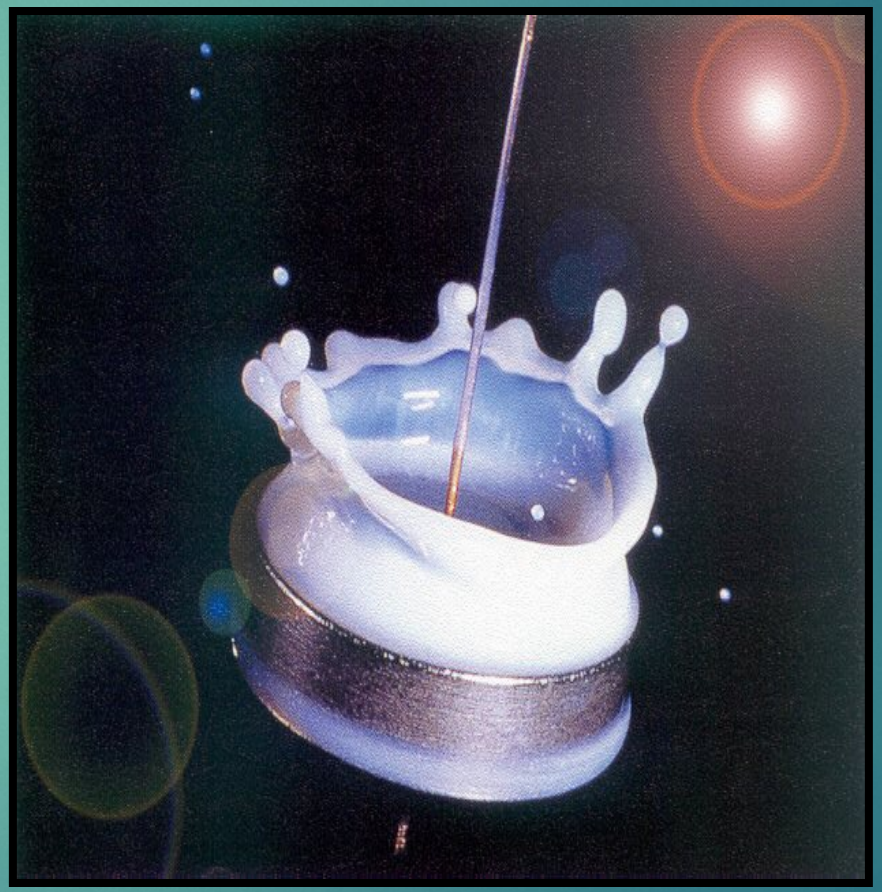
- Assign responsibility
- Check / Record / Act
- Keep records: Neat oil additions & additive additions
- Monitor water Level routinely
- Supplier on-site & off-site service

COPPER WIRE DRAWING LUBRICATION

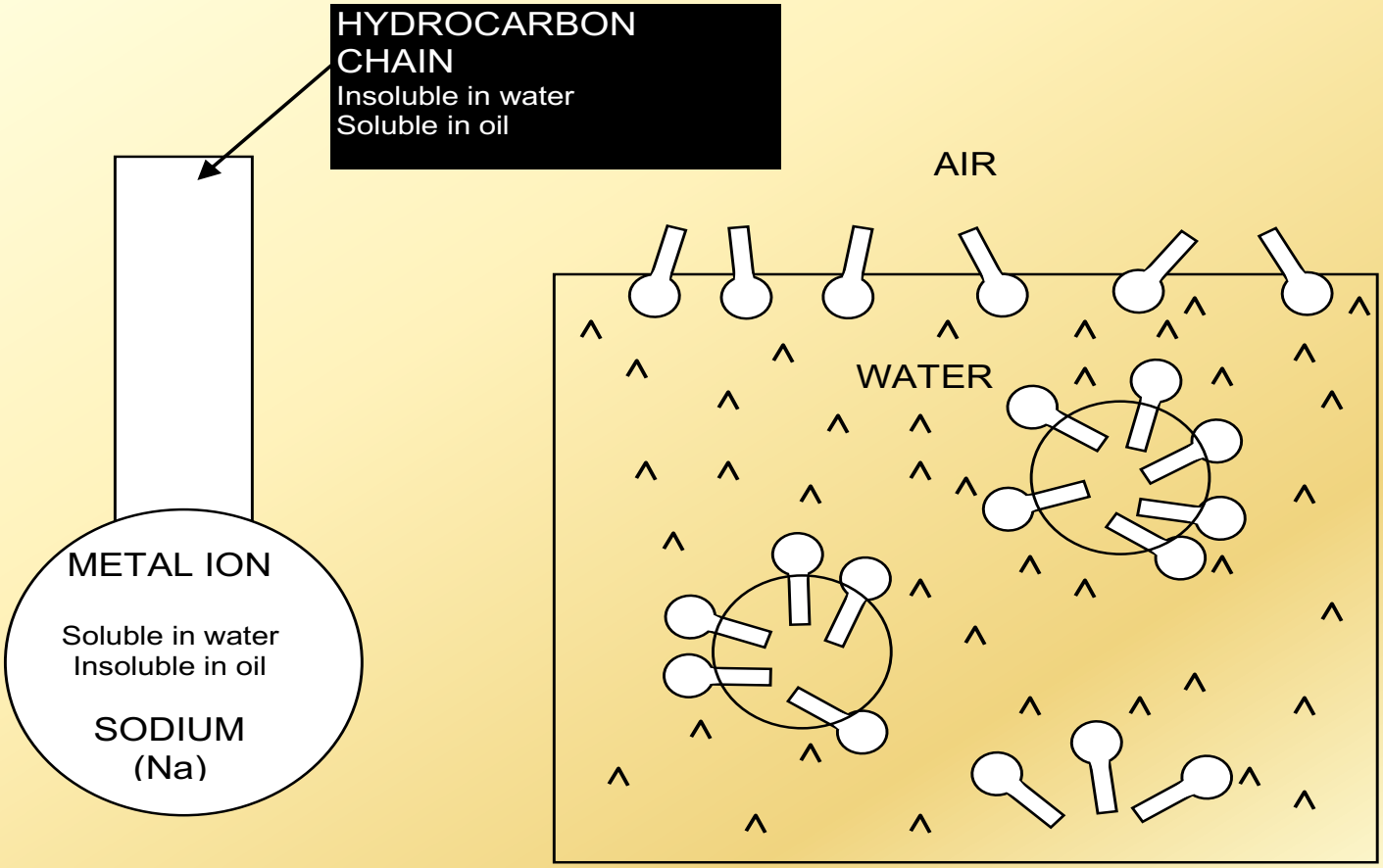
- Formulation
- Selection
- Process Controls

TYPES OF COPPER WIRE DRAWING LUBRICANTS

- Soap-Fat compounds
- Soluble oils
- Semi-synthetic solutions
- Synthetic solutions



SOAP-FAT



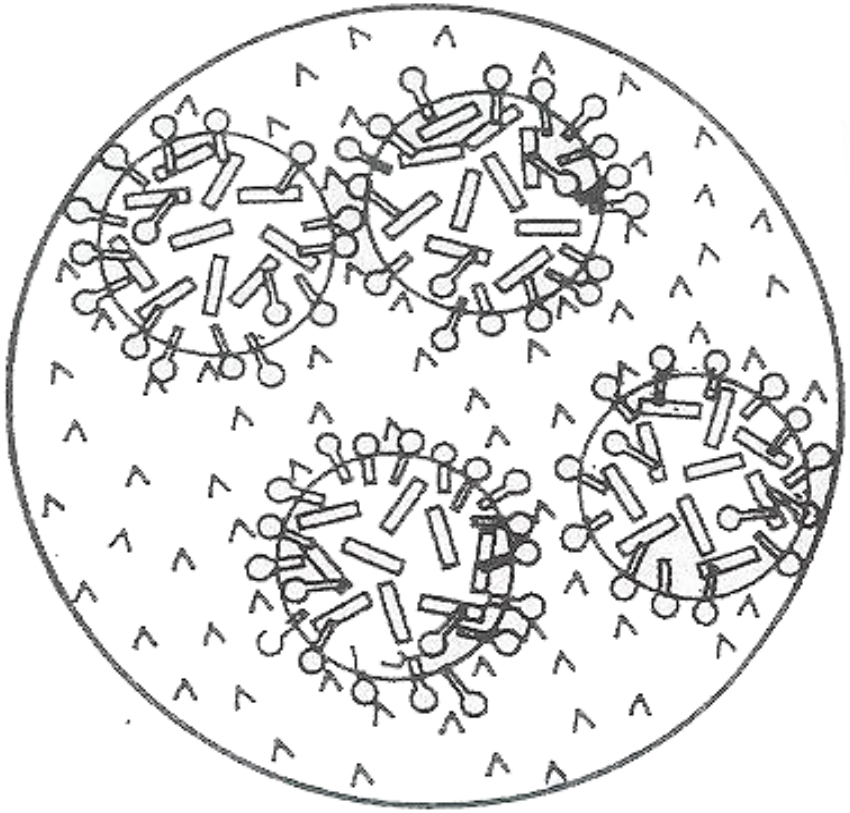
A SOAP MOLECULE

SOAP IN WATER

SOLUBLE OIL TYPE COPPER WIRE DRAWING LUBRICANTS

- Also known as emulsions
- Typically used for rod breakdown and intermediate size wire drawing operations
- Characteristics:
  - 60% to 80%: mineral oil
  - 20% to 40%: emulsifiers, lubricity additives, corrosion inhibitors, wetting agents, anti-foaming agents, biocides, esters
  - Milky in appearance

PICTORIAL REPRESENTATION OF EMULSIONS



= Oil Phase

= Water Molecule

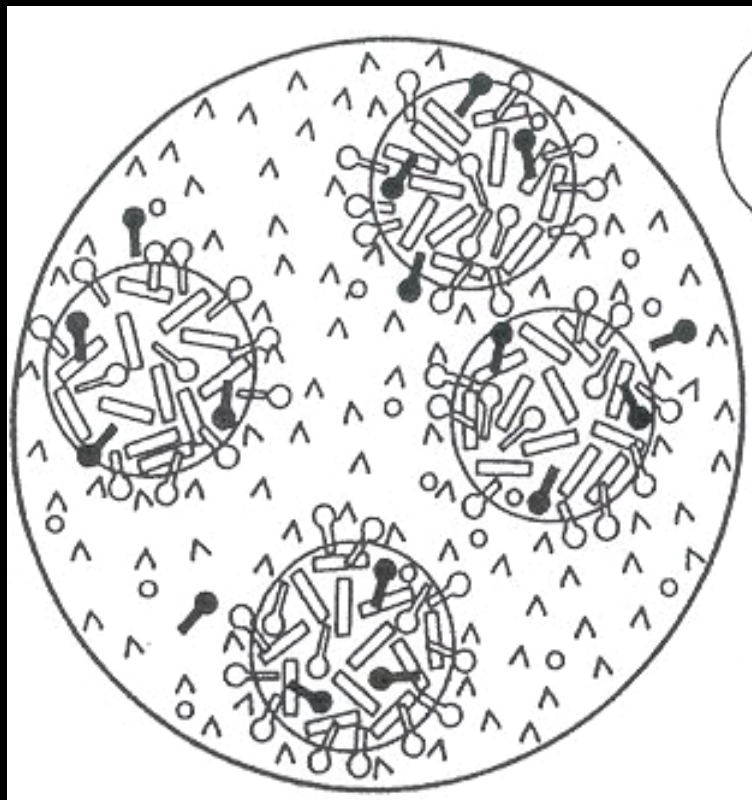
= Oil Molecule

= Surface-Active (emulsifying) molecule

SEMI-SYNTHETIC WIRE DRAWING LUBRICANTS

- Oils soluble in water/chemical emulsion
- Typically used in medium and fine wire drawing operations
- Characteristics:
  - 20% to 40%: mineral oil
  - 60% to 80%: emulsifiers, lubricity additives, corrosion inhibitors, wetting agents, anti-foaming agents, biocides, esters, and water
  - Translucent in appearance

SEMI-SYNTHETIC SOLUTIONS



= Oil Phase

= H_20 Molecule

= Oil Molecule

= Emulsifier

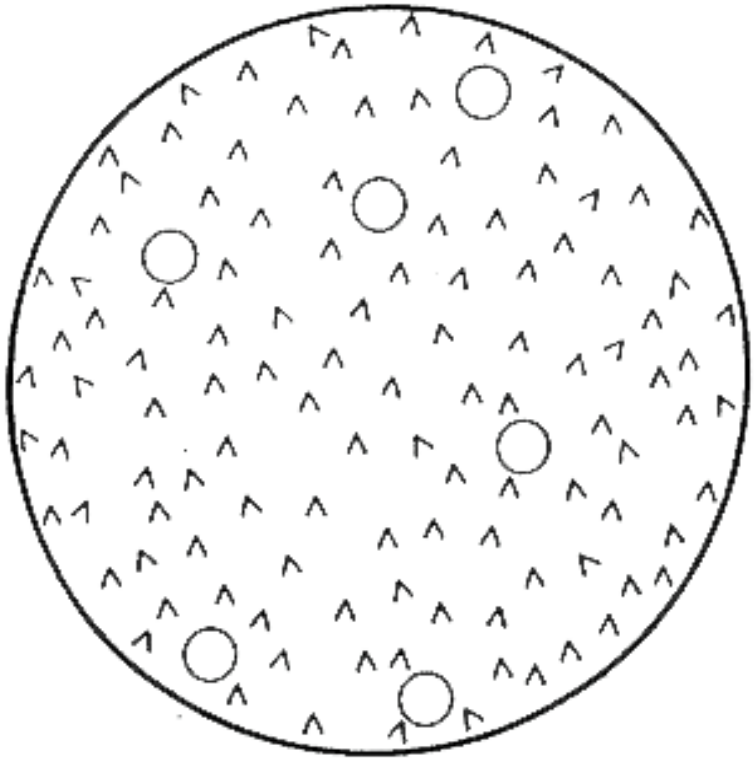
= Molecule of Water Soluble Additive

= Molecule of Dissolved Material

SYNTHETIC WIRE DRAWING LUBRICANTS

- Also known as solutions
- Zero percent mineral oil content
- Typically used for fine and ultra-fine wire drawing operations
- Characteristics:
  - Ingredients dissolve in water
  - Extremely active product
  - High detergency - cleanliness
  - Transparent in appearance

SYNTHETIC SOLUTION



○ = Molecule of Dissolved Material

Λ = H_20 Molecule

PROCESS CONTROLS FOR EMULSIFIABLE FLUIDS

- Handling and Storage
- Mixing
- pH Monitoring
- Concentration
- Conductivity
- Dirt/Particulate Levels
- Temperature
- Water Quality
- System Maintenance

PROCESS CONTROLS FOR EMULSIFIABLE FLUIDS

CONCENTRATION

- Methods
  - Refractometer
  - Titration and/or Babcock
- Frequency of measurement - daily
- Areas effected:
  - Lubricity
  - Tool life
  - Bio-resistance
  - Foam
  - Residue
  - Cleanliness
  - Corrosion
  - Overall cost

PROCESS CONTROLS FOR EMULSIFIABLE FLUIDS

DIRT / PARTICULATE LEVEL

- Method: volumetric
- Frequency of measurement
  - Sample taken after filtration
- Filtration efficiency
- Machine cleanliness
- Influence of “Micro-Dust” on machine cleanliness, die life and emulsion life

PROCESS CONTROLS FOR EMULSIFIABLE FLUIDS

TEMPERATURE

- Control is usually automated
  - Set point
  - Window to activate / deactivate cooling water flow to heat exchanger
- Importance of maintaining a consistent temperature of the wire drawing fluid
- Effects of High & Low Temperature

PROCESS CONTROLS FOR EMULSIFIABLE FLUIDS

WATER QUALITY ISSUES

- Check water quality - important component
- “Boiler effect”
- Varies based upon location, source, & season
- Effects performance
  - Lubricity
  - Corrosion
  - Cleanliness
  - Conductivity
  - Residue
  - Bio resistance
  - pH

PROCESS CONTROLS FOR EMULSIFIABLE FLUIDS

SYSTEM MAINTENANCE

- Assign responsibility
- Check/record/act
- Keep records: water additions, concentrate, & additives
- Monitor water quality routinely
- Minimize contamination
- Supplier on-site & off-site service

PRACTICAL PERFORMANCE INDICATORS

LIQUID LUBRICANTS

- Periodic control of die wear
- Periodic verification of the surface condition of the drawing capstans
- Excessive wire breaks/high speed
- Excessive copper dust in draw box
- Lubricant color change
- Lubricant odor change
- Change in foam level
- Excessive consumption of cooling water

TESTING IN THE PLANT

1. Measure Draw Pull thru use of load cells
2. Analysis of Wire Drawing Operation by use of sensors and compilation by Microcomputer

ALUMINIUM WIRE DRAWING LUBRICANTS
NEW DEVELOPMENTS

- Low Viscosity Drawing Oils
- Synthetic Hydrocarbons
- Water Based Emulsions to draw Intermediate size wire – the jury is still out
- New techniques to monitor level of lubricity additives by use of FTIR

ALUMINUM WIRE DRAWING LUBRICANTS
NEW GENERATION LOW VISCOSITY PRODUCTS

- Low viscosity allows better filtration
- Low viscosity oils allows less product drag-out on filter media
- Low viscosity allows the user to keep the lubricant cleaner through filtration which results in improved die life and minimal wire drawing lubricant residue on the finished wire

ALUMINUM WIRE DRAWING LUBRICANTS
VISCOSITY COMPARISONS

- Alloy Rod Breakdown oils
  - Conventional oils – 1,500 to 3,000 ssu
  - New generation products – 800 to 900 ssu
- EC Rod Breakdown oils
  - Conventional oils – 1,100 to 1,400 ssu
  - New generation products – 800 ssu

ALUMINUM WIRE DRAWING LUBRICANTS
VISCOSITY COMPARISONS

- Intermediate drawing oils
  - Conventional oils – 700 to 800 ssu
  - New generation products – 350 ssu
- Fine Wire drawing oils
  - Conventional oils – 200 ssu
  - New generation products – 150 ssu

WHY USE OIL-BASED LUBRICANTS ON ALUMINUM WIRE DRAWING OPERATIONS

- Oil type lubricants provide better wetting/lubricity at wire to die interface
- Aluminum oxides are hydrolyzed in water based drawing lubricants and these dissolved oxides act as abrasives to degrade the surface quality of the drawn wire and to reduce die life
- Poor surface quality of wire limits use of wire in terms of enameling for use as magnet Wire

COPPER WIRE DRAWING LUBRICANTS
NEW DEVELOPMENTS

- Synthetic Hydrocarbons
- New Generation of Complex Esters
- Microemulsions
- New techniques to monitor level of lubricity additives by titration

SUMMARY AND CONCLUSIONS

- Need to evaluate lubricants in use based on regular lab testing either on-site or off-site by vendor
- New generation low viscosity oils for aluminum wire drawing operations should be considered
- Improved maintenance and process controls should yield higher productivity and lower costs

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QUESTIONS & ANSWERS