"Towards Sustainable and Eco-Friendly Cutting Oils"

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About Indian Institute of Science

• Started in 1909 - Bangalore
• J. N. Tata – Steel and Power
• Largest number of Science and Engineering Ph.D. students in the country – 2,200
• All Sciences and Engineering
• Many interdisciplinary programs
• 350 faculty
• Annual budget of around $100 million
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Coconut Development Board, Kochi, Kerala
References


Why Sustainability?

- Limit to usage of materials
- Limit to the rate of usage
- Limit to trash the world can handle

Sustainability and Eco-Friendly are the key to the future
What and Why Eco-Friendly?

• Eco-friendly and bio-degradable should not be confused
• Eco-friendly need not be bio-degradable and bio-degradable need not be eco-friendly.
• Product can be eco-friendly but need not be bio-degradable
Everything is Cyclic!!

Everything is Interlinked

$O_2$ $\rightarrow$ Animals $\rightarrow$ $CO_2$

$CO_2$ $\rightarrow$ Plants $\rightarrow$ $O_2$

$10^{-15}$ Sec to $10^{18}$ Sec
In this vast darkness of space
When do we Recycle?

Time Scale

• Extraction – Disposal: Should be equal to the time of replenishment
  If the cycle is “open”
• The other cycles have to be “closed”

“Open” or “closed” is w.r.t. time scale
What time scale?
The farthest you can see!!
If it cannot be replenished!!

It has to be recycled

100% recycled

Imagine such a situation – Calls for a complete change in lifestyle

Inevitable – if we don’t, nature will make us do it.

Complete change in the process of design and development – A challenge !!

This is also a Challenge to Manufacturing and Material Scientists!!
Cutting Fluids

- Cool the tool and work piece
- Reduces the abrasion and adhesion
- Impart good surface finish, wash away chips, prevent rusting character
- Traditional cutting fluids are made from mineral oils
- Sulfur
- Chemically synthesized or modified emulsifiers
- Chemically synthesized additives enhance performance of cutting fluids
Cutting Fluids – The cycle followed

Extraction → Refining → Manufacturing → Mixing → USE → Condition → Disposal
Non biodegradable, non renewable, unsustainable and highly toxic to ecosystem

- Basically affects Aquatic system and ground water source
- Health impact associated with exposure to cutting fluids irritation of the skin, lungs, eyes, nose and throat
- Leading to more severe conditions such as dermatitis, acne, asthma, hypersensitivity pneumonitis, a variety of cancers
- Toxins produced by uncontrolled growth of bacteria
- Objectionable odor
Common organisms present in the emulsion oils

1. *Escherichia coli* - Gastroenteritis - Urinary tract infection - meningitis

2. *Staphylococcus aureus* - Food poisoning - Arthritis - Endocarditic - Pneumonia - Atopic Dermatitis

3. *Salmonella typhi* - Causes Typhoid/ Enteric fever

4. *Salmonella typhimurium* - Gastroenteritis - Typhoid fever
5. **Klebsiella pneumoniae**

- Pneumonia
- Urinary tract infections.
- Diarrhea
- Respiratory tract infections.
- Meningitis

6. **Pseudomonas aeruginosa**

- Pneumonia
- Septic shock
- Urinary tract infection
- Gastrointestinal infection
- Skin and soft tissue infections

Other Organisms includes:

- **Proteus vulgaris** - cause urinary infections and hospital-acquired infections.

- **Bacillus subtilis** - causes food poisoning.

- **Shigella sp.** - causes dysentery, fever, nausea, vomiting and stomach cramp.

- **Micrococcus Sp.** - septic shock, septic arthritis, endocarditis, meningitis, and cavitating pneumonia.
1. Dermatitis:
   Inflammation of the skin, either due to direct contact with an irritating substance, or to an allergic reaction. Symptoms of dermatitis include redness, itching, and in some cases blistering.

2. Folliculitis:
   It is the inflammation of one or more hair follicles. The condition may occur anywhere on the skin.
3. Oil Acne:
It is an occupational skin condition caused by exposure to oils used in industry.

4. Keratosis:
It is a lesion of keratin on the skin, caused due to exposure to metal working fluids.
5. Carcinomas:

It is a cancer that begins in a tissue that lines the inner or outer surfaces of the body

- **a. Throat Cancer**
- **b. Pancreatic Cancer**
- **c. Rectum Cancer**
- **d. Prostate Cancer**
Selection of Emulsifier and natural additives

Based on the aquatic toxicity

OECD 203 method

Zebra fish to analyze the aquatic toxicity

Fishes (Seven) exposed to a known concentration of test samples for a duration of 96 hours.

The mortality of fish was monitored in intervals of 24 hours.

The concentration of test sample is increased in a geometric series of 2.2 and the concentration which kills the 50 percent of the fish in 96 hours was noted.

<100mg/L - highly toxic and >1000mg/L - non-toxic
Zebra Fish maintaining tanks

Aquatic toxicity testing facility
<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Emulsifier name</th>
<th>HLB value</th>
<th>Toxicity level (LC50)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Emul -1</td>
<td>13</td>
<td>&lt;100mg/L</td>
</tr>
<tr>
<td>2</td>
<td>Emul -2a</td>
<td>5.5</td>
<td>&gt;1064mg/L</td>
</tr>
<tr>
<td>3</td>
<td>Emul -2b</td>
<td>3.8</td>
<td>&lt;484mg/L</td>
</tr>
<tr>
<td>4</td>
<td>Emul -3</td>
<td>2.9</td>
<td>&gt;1064mg/L</td>
</tr>
<tr>
<td>5</td>
<td>Emul -4</td>
<td>1.4</td>
<td>&gt;1064mg/L</td>
</tr>
<tr>
<td>6</td>
<td>Emul -5a</td>
<td>16.7</td>
<td>&gt;1064mg/L</td>
</tr>
<tr>
<td>7</td>
<td>Emul-5b</td>
<td>15.0</td>
<td>&gt;1064mg/L</td>
</tr>
<tr>
<td>8</td>
<td>Emul -6a</td>
<td>4.3</td>
<td>&gt;1064mg/L</td>
</tr>
<tr>
<td>9</td>
<td>Emul -6b</td>
<td>8.6</td>
<td>&gt;1064mg/L</td>
</tr>
<tr>
<td>10</td>
<td>Emul - 7a</td>
<td>11.0</td>
<td>&gt;1064mg/L</td>
</tr>
</tbody>
</table>

Aquatic toxicity of different emulsifiers
Aquatic toxicity for commercial cutting fluid with same method showed it is highly toxic.

Aquatic toxicity of natural additives used in the cutting fluid was also tested with same method. The natural additives were relatively non toxic to aquatic system.

<table>
<thead>
<tr>
<th>Sample Name</th>
<th>Toxicity level (LC50)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coconut oil</td>
<td>&gt;2342.56mg/L</td>
</tr>
<tr>
<td>Emul -5b</td>
<td>&gt;1064.8mg/L</td>
</tr>
<tr>
<td>Emul -6a</td>
<td>&gt;1064mg/L</td>
</tr>
<tr>
<td>ESNO-5</td>
<td>&gt;1064mg/L</td>
</tr>
<tr>
<td>ESNO-7</td>
<td>&gt;100 mg/L</td>
</tr>
<tr>
<td>Coconut oil Emulsion with Green Additives</td>
<td>&gt;1064mg/L</td>
</tr>
<tr>
<td>Commercial Cutting Fluid</td>
<td>&lt;100mg/L</td>
</tr>
</tbody>
</table>

Fish acute toxicity level of different cutting samples
HLB value or hydrophilic lipophilic balance of a molecule is a measure of degree to which it is hydrophilic or lipophilic.

HLB value is determined by measuring the ability of particular molecule to form a stable emulsion with series of emulsifiers with different range of HLB value.

A combination of test molecule, water and equal amount of emulsifier with different HLB values were mixed.

The HLB value which gives a stable emulsion with the test molecule is considered as its HLB value and used to create a stable emulsion.

<table>
<thead>
<tr>
<th>COCONUT OIL – 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESNO1 – 10</td>
</tr>
<tr>
<td>ESNO2 – 12</td>
</tr>
<tr>
<td>ESNO3 – 10</td>
</tr>
<tr>
<td>ESNO4 – 16</td>
</tr>
<tr>
<td>ESNO5 – 8</td>
</tr>
<tr>
<td>ESNO7 – 16</td>
</tr>
<tr>
<td>ESNO8 – 16</td>
</tr>
</tbody>
</table>
Stability of Emulsion
Emulsions of coconut oil were prepared by using the different combination of emulsifiers to evaluate the corresponding long term stability.

Combination of Emul-5b and Emul-7a was chosen, because of its stability as an emulsifier and emulsion with water.

<table>
<thead>
<tr>
<th>Sl. no.</th>
<th>Combination of emulsifier</th>
<th>Percentage Used</th>
<th>Stability for 15 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Emul-2a and Emul-5b</td>
<td>68 and 32</td>
<td>Not stable</td>
</tr>
<tr>
<td>2</td>
<td>Emul-2b and Emul-5b</td>
<td>73 and 27</td>
<td>Not stable</td>
</tr>
<tr>
<td>3</td>
<td>Emul-5b and Emul-6a</td>
<td>72 and 28</td>
<td>Stable</td>
</tr>
<tr>
<td>4</td>
<td>Emul-5b and Emul 7a</td>
<td>25 and 75</td>
<td>Stable</td>
</tr>
<tr>
<td>5</td>
<td>Emul-5b and Emul-6b</td>
<td>53 and 47</td>
<td>Not stable</td>
</tr>
<tr>
<td>6</td>
<td>Emul-5a and Emul-6a</td>
<td>42 and 58</td>
<td>Not stable</td>
</tr>
<tr>
<td>7</td>
<td>Emul-5a and Emul-6b</td>
<td>62 and 38</td>
<td>Not stable</td>
</tr>
<tr>
<td>8</td>
<td>Emul-3 and Emul-5b</td>
<td>25 and 75</td>
<td>Not stable</td>
</tr>
<tr>
<td>9</td>
<td>Emul-4 and Emul-5b</td>
<td>22 and 78</td>
<td>Not stable</td>
</tr>
</tbody>
</table>
Different ratios of Coconut oil: Emulsifier was tested to obtain a stable emulsion.

- Stability of emulsion was measured by measuring particle size and zeta potential.

- Lower particle size and higher zeta potential is considered as the ratio to be used to get a stable emulsion.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Ratios used (Emulsifier: oil)</th>
<th>Stability for fifteen days</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5:2.5</td>
<td>Not stable</td>
</tr>
<tr>
<td>2</td>
<td>1.8:2.5</td>
<td>Not stable</td>
</tr>
<tr>
<td>3</td>
<td>2.0:2.5</td>
<td>Stable</td>
</tr>
<tr>
<td>4</td>
<td>2.2:2.5</td>
<td>Not stable</td>
</tr>
</tbody>
</table>

Determination of emulsifier to coconut oil ratio for stability of emulsion
<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Sample Name</th>
<th>Particle Size (in nm)</th>
<th>Zeta Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coconut oil emulsion</td>
<td>251.30</td>
<td>-30.14</td>
</tr>
<tr>
<td>2</td>
<td>Coconut oil Emulsion+ESNO5</td>
<td>226.1</td>
<td>-22.48</td>
</tr>
<tr>
<td>3</td>
<td>Coconut oil Emulsion+ESNO7</td>
<td>196.8</td>
<td>-18.82</td>
</tr>
<tr>
<td>4</td>
<td>Coconut oil emulsion+ESNO5+ESNO7</td>
<td>214.80</td>
<td>-26.34</td>
</tr>
<tr>
<td>5</td>
<td>Commercial Cutting Fluid</td>
<td>252.90</td>
<td>-49.76</td>
</tr>
</tbody>
</table>

Particle size and Zeta potential of different samples
Measuring anticorrosive properties of emulsions

- Anti Corrosion tests were done by following ASTM D4627 method
- Cast iron chips are placed in a petri dish containing a filter paper and diluted metalworking fluid.
- The dish is covered and allowed to stand overnight.
- The amount of rust stain on the filter paper is an indication of the corrosion control provided by the fluid.
<table>
<thead>
<tr>
<th>Sample Name</th>
<th>Anticorrosion Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control / Reagent Water</td>
<td>1</td>
</tr>
<tr>
<td>Coconut oil Emulsion</td>
<td>3</td>
</tr>
<tr>
<td>Coconut oil Emulsion+ESNO5</td>
<td>3</td>
</tr>
<tr>
<td>Coconut oil Emulsion+ Esno7</td>
<td>2</td>
</tr>
<tr>
<td>Coconut oil Emulsion+Esno5+Esno7</td>
<td>3</td>
</tr>
<tr>
<td>Commercial Cutting Fluid</td>
<td>3</td>
</tr>
</tbody>
</table>

**Note:** 1-Highly corrosive, 2- Moderate Corrosive, 3- Low Corrosive, 4- Non Corrosive

**Anticorrosion properties of different cutting fluids**
Storage Stability of coconut oil was determined by measuring the peroxide value of emulsion before and after oven test.

Lipid molecules upon storage in room temperature or at higher temperature undergo auto oxidation resulting in the formation of peroxides.

Measuring the peroxide concentration indirectly provide information about storage stability of samples.

Cutting oil samples with natural additives showed lesser peroxide before and after oven tests.

Samples with additives can be stored for about three months with out much variation in peroxide value.
<table>
<thead>
<tr>
<th>Sample Name</th>
<th>1&lt;sup&gt;st&lt;/sup&gt; Week</th>
<th>2&lt;sup&gt;nd&lt;/sup&gt; Week</th>
<th>3&lt;sup&gt;rd&lt;/sup&gt; Week</th>
<th>4&lt;sup&gt;th&lt;/sup&gt; Week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coconut oil Emulsion</td>
<td>0.3988</td>
<td>0.1243</td>
<td>0.4136</td>
<td>0.4758</td>
</tr>
<tr>
<td>Coconut oil Emulsion+Esno5</td>
<td>0.1492</td>
<td>0.1975</td>
<td>0.2998</td>
<td>0.1996</td>
</tr>
<tr>
<td>Coconut oil Emulsion+ Esno7</td>
<td>0.1980</td>
<td>0.2994</td>
<td>0.3472</td>
<td>0.3912</td>
</tr>
<tr>
<td>Coconut oil Emulsion+Esno5+Esno7</td>
<td>0.1493</td>
<td>0.1997</td>
<td>0.1635</td>
<td>0.2013</td>
</tr>
<tr>
<td>Commercial Cutting Fluid</td>
<td>0.0672</td>
<td>0.0991</td>
<td>0.0968</td>
<td>0.1341</td>
</tr>
</tbody>
</table>

**Peroxide value of different cutting fluid samples**
<table>
<thead>
<tr>
<th>Sample Name</th>
<th>Amount of Oil (ml)</th>
<th>Amount of Emulsion (ml)</th>
<th>Amount of Water (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coconut oil Emulsion</td>
<td>4</td>
<td>2</td>
<td>94</td>
</tr>
<tr>
<td>Coconut oil Emulsion+Esno5</td>
<td>1</td>
<td>2</td>
<td>97</td>
</tr>
<tr>
<td>Coconut oil Emulsion+Esno7</td>
<td>2</td>
<td>8</td>
<td>90</td>
</tr>
<tr>
<td>Coconut oil Emulsion+Esno5+Esno7</td>
<td>6</td>
<td>2</td>
<td>92</td>
</tr>
<tr>
<td>Commercial Cutting Fluid</td>
<td>1</td>
<td>8</td>
<td>91</td>
</tr>
</tbody>
</table>

Results of Oven tests at 84°C for about 48 hours.
Flow chart for anti microbial activities of cutting fluids

Prepare bacterial culture
   37°C, 12 Hours

Inoculation of Bacterial Culture into sample
   37°C, 6 Hours

Pouring media into plate

Serial Dilution

Spread Plate Technique
   37°C, 12-18 Hours

Count the number of colonies
1. Distilled Water
2. Emulsifier+ Water
3. Coconut oil emulsion
4. Coconut oil emulsion + 0.1% of ESNO - 5 (I)
5. (I)+ 0.3% ESNO-7
6. (I)+ 0.5% ESNO-7
7. Commercial oil-I
8. Commercial oil-II

Staphylococcus aureus

0th Day

30th Day

45th Day

Date: 16-1-2012
1. Distilled Water
2. Emulsifier+ Water
3. Coconut oil emulsion
4. Coconut oil emulsion+ 0.1% of ESNO -5(I)
5. (I)+ 0.3% ESNO-7
6. (I)+ 0.5% ESNO-7
7. Commercial oil-I
8. Commercial oil-II
Salmonella typhimurium

1. Distilled Water
2. Emulsifier+ Water
3. Coconut oil emulsion
4. Coconut oil emulsion+ 0.1% of ESNO -5(I)
5. (I)+ 0.3% ESNO-7
6. (I)+ 0.5% ESNO-7
7. Commercial oil-I
8. Commercial oil-II

Date: 17-1-2012
Drilling experiments were performed by keeping work piece in submerged condition.

To compare the effect of cutting fluids on drilling, a set of dry cutting was performed on the Aluminium grade II plates with the thickness of 32mm.

One hundred holes of 30mm depth per plate were drilled with HSS-twist drill bits of 12 mm diameter.

Surface roughness of each drilled hole was measured with optical profilometer.

Tool life was measured by measuring surface roughness with optical profilometer for every 20 holes.

Chip size, shape and lengths were measured and compared with other cutting fluids.
The different parameters used during drilling experiments

<table>
<thead>
<tr>
<th>Different Parameters used in drilling of Aluminium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spindle Speed</td>
</tr>
<tr>
<td>Cutting speed</td>
</tr>
<tr>
<td>Feed</td>
</tr>
<tr>
<td>Feed Rate</td>
</tr>
<tr>
<td>Hole depth</td>
</tr>
</tbody>
</table>
Surface roughness of Different cutting fluids

Surface roughness of work piece with dry cutting and different cutting fluids
Surface Roughness of Dry Cutting

Surface Roughness of Coconut oil Emulsion +ESNO5

Surface Roughness of Coconut oil Emulsion +ESNO7
Surface Roughness of Commercial oil

Surface Roughness of Coconut oil Emulsion +ESNO5+ESNO7
Tool wear rate is determined by difference in roughness of tool at 50th hole and 100th hole.

Coconut oil with natural additives reduced the wear of tool and increased the tool life.

Commercial cutting fluid and coconut oil emulsion without additives showed increased tool roughness from 50th hole to 100th hole.
Highlights

- Developed product is a water soluble cutting fluid, which is readily biodegradable, relatively non-toxic, highly renewable and a sustainable product.

- Coconut oil is used as base oil for environment benign cutting fluid – 90-92% saturation and less oxidation.

- Naturally available additives are used to enhance the cutting fluid property.

- Natural additives are readily biodegradable, relatively non-toxic and highly renewable.

- Developed product has better particle size, aquatic toxicity, anticorrosion resistance and has a comparable zeta potential and machining performance with commercially available mineral oil based cutting fluids.
• In India, the manufacture of cutting oil amounted to around 200,000 kiloliters in 2001, of which the soluble type accounted for about 60-65%.

• Total consumption of metalworking fluids in the Asia-Pacific region is estimated at 891,330 tons, valued at USD 3,160 million in 2010 (2).

• In the United States alone, the market is 175 million gallons (1).

• The growth rate for metalworking fluids in the Asia-Pacific region is expected to be around 5%, with China showing the highest growth rate.

• Consumption of metalworking fluids in the Asia-Pacific region is expected to exceed 1 million tonnes by 2015 (2).

Reference:
Conclusion

- It is essential for tribologists and lubricant engineers to develop a complete green cutting fluid to avoid the environmental impact of conventional mineral oil based cutting fluid.

- Present work developed a complete green product with coconut oil as base oil and green additives to enhance the cutting fluid properties.

- Biodegradable emulsion with green additives showed comparable cutting and storage properties with conventional mineral oil based non biodegradable cutting fluids.

- Further study on mechanism of action for green additives may initiate the new era for complete green cutting fluids.
Eco-Friendly should be the purpose why are we living?

To lead a comfortable life. To be Happy and Successful.
But!!

IF YOU WANT HAPPINESS FOR A LIFETIME, LEARN TO LOVE WHAT YOU DO.
The Message

Science without Sustainability and Sustainability without Science are both Meaningless

CLOSE THE CYCLE

These should be the cornerstones of development

Efficiency/Power is secondary??!!
Activities of the Group

• Surface roughness and friction
• Fretting wear studies under controlled environment
• Sliding wear studies under controlled environment
• Development of eco-friendly lubricants, greases and cutting oils
• Characterization of Al foams
• Development of Ultra-fine grained material by FSP
• FSP of composites
• Dissimilar metal welding by FSW
• Water purification – design of packaging and cartridges
• Development of tools for the Indian farms
• Semi manual pottery making machine.......
Over view of the lab

• Ph.D. completed – 06
• Masters completed – 02
• Ph.D. ongoing – 12
• Masters ongoing – 01
• M.E./M.Des. Projects – 05
• B.Tech students > 20
Thank You!!