SYSTEMATIZATION OF HYDRAULIC SYSTEMS
DESIGN FOR USE WITH BIODEGRADABLE FLUIDS

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Summary

1. Introduction

2. Biodegradable Fluids

3. Systematization of Hydraulic System Design with Biodegradable Fluids – SHBIO

4. Expert System Prototype

5. Conclusions
1. Introduction
1.1 Contextualization

European studies have identified the leak of hydraulic fluid as a major source of groundwater contamination (EICHENBERGER, 1991).

A very conservative estimate is that more than 600 to 900 million gallons of fluid from hydraulic systems enter the environment every year (HAMID, 2008).

- HPP Sayano accident: Oil spill of 30,000 litres into The Yenisei river (2009).

- The São Martinho sugar mill in 2003, 108,622 litres of hydraulic oil were wasted from harvesters, as a result of failures of hydraulic systems (Tomazela (2007)).
1.1 Contextualization

Systematization of Hydraulic Systems Design for use with Biodegradable Fluids

Yesid Asaff, Dr. Eng.
1.1 Contextualization

- In order to avoid or mitigate the issue of environmental risk, is identified in Brazil and the world, a way of incentives in search of systems development and/or environmentally friendly products.

- Some of these industrial applications and research activities have broken the paradigm to use mineral oil for hydraulic systems, providing solutions with biodegradable hydraulic fluids.
1.2 Problem

The focus of the problem identified for this work is the deficiency of design processes for hydraulic systems that fit for use with biodegradable fluids.
1.3 Justification

- In the context of development of Brazil, it is important to encourage the use and development of biodegradable fluids.
- There are not works found in the industrial and research scope that combine the design of hydraulic system together with biodegradable fluids.
- The value added to the use of biodegradable fluids is related to:
  - The fluid life
  - Reducing taxes for environmentally friendly policies, obtaining carbon credits
  - Prevent fines due to accidents related to oil spills in water or soil.
2. Biodegradable fluids
### 2.1 Timeline

- **Before 19th century**, lubricating oils were **natural**, based mainly on rape seed, soybean and castor oils or based on **animal fat** such as whale oil. *(WILSON, 1998)*

- **Rudolf Diesel** is credited as the inventor of the **first diesel engine** which was originally designed to run on fuel derived from **peanut oil**.

- **Incentive of the EU** for the use of **biodegradable fluids**.

- **Requirement of the German government** in specific applications.

- **Different applications** with **biodegradable fluids** in hydraulic systems
  - **Eco-labels**
2.2 Classification

- **HEPG** - Hydraulic Oil Environmental PolyGlycol.
- **HEES** - Hydraulic Oil Environmental Ester Synthetic.
- **HEPR** - Hydraulic Oil Environmental Polyalphaolefine and Related Products
- **HETG** - Hydraulic Oil Environmental TriGlyceride.
2.3 Definition

- High biodegradability
- Low toxicity
- High viscosity index
- High lubricity
- High flash point

- Thermal problems
- Low hydrolytic stability
- Low oxidation stability
- Cost

Ester, Polyglycol, Triglyceride (vegetable), Polyolefin
3. Systematization of Hydraulic System Design with Biodegradable Fluids - SHBIO
The inclusion of a new variable (biodegradable fluids) show the need for new methods of design support.

New or modified requirements require the support of various fields of knowledge.

This new systematization must allow the effective integration of project teams, establish common information and provide assurance to the designer in making decisions.

SHBIO

- Systematization of procedures
- Specifying and analyzing requirements of hydraulic systems
- Adapt and optimize the performance and component life, as well as the fluid itself.

Selection of fluids ➔ Selection of components ➔ Guidelines for monitoring
# 3.1 SHBIO - Proposal

## SHBIO – Systematization of Hydraulic System Design with Biodegradable Fluids

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
<th>Fluid Properties</th>
<th>Types of Fluid</th>
<th>International Eco-labels</th>
<th>Manufacturer's Data Sheet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Phase: Biodegradable fluid selection</td>
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<tr>
<td>2nd Phase: Selection of hydraulic components</td>
<td>Reservoir</td>
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<tr>
<td>3rd Phase: Monitoring of hydraulic system</td>
<td>Sensors</td>
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<td>Monitor points</td>
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<td>4th Phase: Solutions</td>
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<td>Final report</td>
</tr>
</tbody>
</table>

### Fluid Properties
- Temperature
- Viscosity
- Dielectric constant
- Counter particles

### Types of Fluid

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetable oil</td>
<td>100%</td>
</tr>
<tr>
<td>Algae</td>
<td>97%</td>
</tr>
<tr>
<td>Microalgae</td>
<td>98%</td>
</tr>
<tr>
<td>Algae and Microalgae</td>
<td>99%</td>
</tr>
</tbody>
</table>

### International Eco-labels
- BRD
- RDH
- Swiss
- USA

### Manufacturer's Data Sheet
- Technical specifications
- Performance data
- Maintenance guidelines

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Systematization of Hydraulic Systems Design for use with Biodegradable Fluids

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3.2 1st phase - Biodegradable fluid selection

**Activity 1.1 - Application field of the hydraulic system**
- **Industrial application:**
  - Testing and simulation equipment
  - Textile industry
  - Metal working, assembly system
  - Plastic industry
- **Mobile application:**
  - Mining
  - Lumber industry
  - Civil construction machinery
  - Agricultural machines

**Task 1.1.1**
- Robotic
- Hydroelectric power plants
- Marine

**Activity 1.2 - Real contact or interaction with water or mineral base residual oil**
- **Task 1.2.1**
  - Evaluation: real contact with water
  - ISO 15380: Teor agua < 0,1%
- **Task 1.2.2**
  - Evaluation: real contact with fluids ISO 15380
  - Fluid type |
  - Mineral oil |
  - Engine oil HLPD
  - HEES, HETG | <2% | <1%
  - HEGP, HEPR | <1% | <0.5%

**Activity 1.3 - International eco-labels (Environmental certification)**
- **Task 1.3.1**
  - In this task is requested to the user's preference using biodegradable fluids with or without international certificates (eco-label)

**Activity 1.4 - Biodegradability and toxicity**
- **Task 1.4.1**
  - Evaluation of biodegradability level (Manufacturer’s data sheet)
- **Task 1.4.2**
  - Evaluation of toxicity level (OECD standard – manufacturer’s data sheet)
Activity 1.1 Application field of the hydraulic system:
A series of applications where biodegradable hydraulic fluid can be used are listed.

**Industrial application:**
- Testing and simulation equipment
- Textile industry,
- Plastic industry
- Metal working
- Assembly system,
- Robotic
- Hydroelectric power plants
- Marine

**Mobile application:**
- Mining
- Lumber industry
- Agricultural machines
- Civil construction machinery

For most industrial applications, **HETG fluid is not recommended** because in practice, the operating requirements are often not satisfied.

For these applications, the biodegradable fluids recommended are **HEES, HETG and HEPR**.
3.2 1st phase - Biodegradable fluid selection

Activity 1.2 Real contact or interaction with water or mineral base residual oil: Probability of real contact or interaction with water or mineral base residual oil according to practices level of maintenance and design parameters are defined in this activity.

WATER

- New design: usual commercial components
- New design: Components tested to operate with biodegradable fluids
- Redesign: fluid change = HEPR, HEES

MINERAL OIL
3.2 1st phase - Biodegradable fluid selection

Activity 1.3 International certificates (eco-label):
In this activity, the user's preference is requested to use biodegradable fluids with or without international certificates (eco-label).

Activity 1.4 Biodegradability and toxicity
In this activity the desired levels are appointed to the fluid for these characteristics according to OECD standards

- Biodegradability high level: > 70% (OECD 301B), all major product components tested separately
- Biodegradability medium level: > 60% (OECD 301B), product may be tested in one test

Activity 1.5 Ageing properties
This activity has the objective of defining the aging stability level of the fluids due to the oxidation stability, hydrolysis stability and anti-wear properties.
3.2 1st phase - Biodegradable fluid selection

Activity 1.6 Viscosity grade
Viscosity grades ISO VG available for each biodegradable hydraulic fluid selected are recommended.

Operating temperature $<20^\circ$C = Viscosity ISO VG 22
Operating temperature $20^\circ$C $\leq t_{op} \leq 70^\circ$C = Viscosity ISO VG 32 e 46.
Operating temperature $>70^\circ$C = Viscosity ISO VG 68.

Seals compatibility with biodegradable fluids

<table>
<thead>
<tr>
<th>Fluid type</th>
<th>Viscosity grades ISO VG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>22</td>
</tr>
<tr>
<td>HEES</td>
<td>NBR FPM AU HNBR</td>
</tr>
<tr>
<td>HETG</td>
<td>NBR FPM AU HNBR</td>
</tr>
<tr>
<td>HEPG</td>
<td>NBR FPM HNBR</td>
</tr>
<tr>
<td>HEPR</td>
<td>NBR FPM HNBR</td>
</tr>
</tbody>
</table>

**NBR**: Nitrile Rubber or Buna-N  
**FPM (FKM)**: Fluorocarbon - Vitón  
**AU**: Polyurethane  
**HNBR (HSN)**: Hydrogenated Nitrile
3.2 1st phase - Biodegradable fluid selection

Activity 1.7 A partial report with the biodegradable fluids selected

- Fluid type:
- Fluid name:
- Manufacturer:
- ISO viscosity grade available:
- Seal compatibility:
- Temperature limits:
- Environmental certification (ecolabel):

List of defined attributes

- Activity 1
- Activity 2
- Activity 3

Partial report
3.3 2nd phase - Selection of hydraulic components

- Design requirements obtained through interaction with the user (user requirements)

**Industrial circuit:**
- Reservoir
- Hydraulic pump
- Accumulator
- Heat exchange
- Actuation system
- Cylinder
- Directional valve
- Filters

**Mobile circuit:**
- Reservoir
- Hydraulic pump/motor
- Accumulator
- Heat exchange
- Actuation system
- Cylinder
- Directional valve
- Valve blocks
- Filters

### Activity 2.1 - Application circuit

### Activity 2.2 - Reservoir

#### Task 2.2.1 Manufacturing material

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Materials manufacturing of hydraulic components</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEES</td>
<td>CS, SS, GS, AA, NAA, PLA</td>
</tr>
<tr>
<td>HEPG</td>
<td>CS, SS, GS, AA, NAA</td>
</tr>
<tr>
<td>HETG</td>
<td>CS, SS, GS, AA, NAA</td>
</tr>
<tr>
<td>HEPR</td>
<td>CS, SS, GS, AA, NAA</td>
</tr>
</tbody>
</table>

- Compatible
- Non-compatible
- Compatible, but not recommended

#### Task 2.2.2 Size

- $V_R = V_F + 10\% V_F$
- $V_F = (3 - 5.9q_i) + q_i c$
- $q_i = \text{Pump flow rate} [\text{l/min}]$
- $q_c = \text{Dead volume in cylinders and piping} [\text{l/min}]$
- $V_F = \text{Total volume of fluid} [\text{liters per minute}]$
- $V_R = \text{Reservoir volume} [\text{liters per minute}]$

Size reduced

Ideal size
3.3 2nd phase - Selection of hydraulic components

Activity 2.1 Application circuit:
This activity defines the hydraulic circuit which brings an inherent list of components that will be selected in the following activities. The list of components related to this circuit are:

- Reservoir
- Heat exchanger
- Accumulator
- Filters
- Hydraulic pump/motor
- Actuation system

Activity 2.2 Reservoir:
The main requirements of the reservoir are defined according to the rules and recommendations, which are presented in eight tasks.

- Manufacturing material
- Reservoir size
- Reservoir/pump layout
- Reservoir form
- Pump inlet line and outlet line
- Baffles
- Diffusers
- Desiccant silica gel breathers.
### Activity 2.2 Reservoir – Manufacturing material

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Materials manufacturing of hydraulic components</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CS</td>
</tr>
<tr>
<td>HEES</td>
<td>😊</td>
</tr>
<tr>
<td>HEPG</td>
<td>😊</td>
</tr>
<tr>
<td>HETG</td>
<td>😊</td>
</tr>
<tr>
<td>HEPR</td>
<td>😊</td>
</tr>
</tbody>
</table>

- **CS**: Carbon steel
- **SS**: Stainless steel
- **GS**: Galvanized steel
- **AA**: Anodized aluminum
- **NAA**: Non-anodized aluminum
- **PLA**: Plastics and composites
- 😊: Compatible
- 😊: Non-compatible
- 😊: Compatible, but not recommended
3.3 2\textsuperscript{nd} phase - Selection of hydraulic components

Activity 2.2 Reservoir – Reservoir size

\[ V_R = V_F + 10\% V_F \]

\[ V_F = (3 \rightarrow 5q_P) + q_{VC}.t \]

\[ q_P = \text{Pump flow rate (1/min)} \]
\[ q_{VC} = \text{Dead volume in cylinders and piping (1/min)} \]
\[ V_F = \text{Total volume of fluid (l)} \]
\[ V_R = \text{Reservoir volume(l) } \]
\[ t = \text{time (min)} \]

Air volume \(\approx 10\% V_F\)

Activity 2.2 Reservoir – Reservoir/pump layout
3.3 2nd phase - Selection of hydraulic components

Activity 2.2 Reservoir - Form

- Rectangular reservoir (horizontal)
- Rectangular reservoir (vertical)
- Cylindrical reservoir (vertical)
- Cylindrical reservoir (horizontal)

Activity 2.2 Reservoir - Baffles

- Vertical baffle (longitudinal)
- Horizontal baffle (longitudinal)
- Various vertical baffles
- Vertical baffle (cross)

Activity 2.2 Reservoir - Piping design

- Pump inlet line
- Outlet line

\[ D = \text{diameter} \]
\[ (2 \rightarrow 3)D \]
\[ 45^\circ \]

Activity 2.2 Reservoir - Diffuser

- Outlet line
- Screen
- Diffuser
- Cylindrical
Activity 2.3 Heating and cooling devices
The rules which recommend using heating and cooling devices in the hydraulic system with biodegradable fluids are presented according to the operating temperature expected in the hydraulic system which was defined in the 1st phase.

Activity 2.4 Accumulator
For applications of hydraulic systems using biodegradable fluids, it is recommended to use accumulators with separation between the air (Nitrogen) and the fluid.
It is recommended to use with the gas-loaded accumulator with separation for the bladder.
3.3 2\textsuperscript{nd} phase - Selection of hydraulic components

Activity 2.5 Filters
These criteria have to do with: types of filters (location), types of hydraulic filter media, ISO cleanliness recommendations from component manufacturers and filter efficiency.

Activity 2.5 Filters – Filter media type
According to the compatibility between manufacturing materials and the biodegradable fluids defined in the 1\textsuperscript{st} phase, the filter medias recommended are:
- Fiberglass
- Wire mesh

Activity 2.5 Filters – ISO cleanliness recommendations
Levels of cleanliness according to ISO 4406
3.3 2nd phase - Selection of hydraulic components

Activity 2.6 Hydraulic pump/motor

![Graph showing the selection of hydraulic components]
### Activity 3.1 Oil condition monitoring method

<table>
<thead>
<tr>
<th>Monitoring method</th>
<th>BASIC</th>
<th>ADVANCED</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level of reliability</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acceptable</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Pressure</td>
<td><img src="image" alt="Online" /></td>
<td><img src="image" alt="Online" /></td>
</tr>
<tr>
<td>Temperature</td>
<td><img src="image" alt="Online" /></td>
<td><img src="image" alt="Online" /></td>
</tr>
<tr>
<td>Viscosity</td>
<td><img src="image" alt="Online" /></td>
<td><img src="image" alt="Online" /></td>
</tr>
<tr>
<td>Solid particles counter</td>
<td><img src="image" alt="Online" /></td>
<td><img src="image" alt="Online" /></td>
</tr>
<tr>
<td>Water content / relative humidity</td>
<td><img src="image" alt="Online" /></td>
<td><img src="image" alt="Online" /></td>
</tr>
<tr>
<td>Dielectric constant</td>
<td><img src="image" alt="Online" /></td>
<td><img src="image" alt="Online" /></td>
</tr>
<tr>
<td>Total number acid (TAN) / pH</td>
<td><img src="image" alt="Online" /></td>
<td><img src="image" alt="Online" /></td>
</tr>
<tr>
<td>ICP Spectrometric Analysis</td>
<td><img src="image" alt="Online" /></td>
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</tbody>
</table>

**Basic:** This method keeps the use of biodegradable fluids and guarantees an acceptable level of reliability of the hydraulic system.

**Advanced:** The use of online oil condition sensors together with appropriate knowledge of physicochemical changes in oil allows the user to have constant overview of the oil quality and its properties.

Online monitoring ![Image](image) Laboratory oil analysis
3.4 3\textsuperscript{rd} phase - Monitoring of hydraulic system

Activity 3.2 Monitoring points

<table>
<thead>
<tr>
<th>Measurement parameters (sensors)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<tbody>
<tr>
<td>Pressure</td>
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<td>Temperature</td>
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<tr>
<td>Viscosity</td>
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<td>Solid particles counter</td>
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</table>

- Online monitoring point
- Online monitoring point and/or sampling point for oil analysis laboratory
- Sampling point for oil analysis laboratory

**Possible points of fluid condition monitoring and sampling point to oil analysis in the laboratory**
5.5 4th phase - Solutions

Phase 4 – Solutions

Activity 4.1 – Final report

Task 3.1.1

Design requirements obtained through interaction with the user (user requirements)

- Fluid type:
- Fluid name:
- Manufacturer:
- ISO viscosity grade available:
- Seal compatibility:
- Temperature limits:
- Environmental certification

Phase 1st
Biodegradable fluids selected

Phase 2nd
List of components selected

Phase 3rd
Monitoring

- Specifications
- Characteristics
- Recommendations

- Type of sensors
- Oil condition monitoring method
- Online monitoring point
- Sampling point for oil analysis laboratory
4. Expert System Prototype
4.1 Expert System Prototype – Final Report

Systematization of Hydraulic System Design with Biodegradable Fluids

SHBIO

FINAL REPORT

User answers

1st. Phase: Biodegradable fluid selected

2nd. Selection of hydraulic components

3rd. Monitoring of hydraulic system

Help

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### 4.1 Expert System Prototype - Fluids

**Fluid type:** Hydraulic Oil Environmental Ester Synthetic - HEES  
**Fluid name:** HLP Synth  
**Manufacturer:** Panolin  
**ISO viscosity grade available:** (22 32 46)  
**Seal compatibility:** (NBR FPM AU HNBR)  
**Temperature limits:** -30°C to 90°C (reservoir), < 100°C locally in the system  
**Environmental certification (ecolabel):** Blue Angel: Alemanha - Korea Eco-label: Corea do sul

**Fluid type:** Hydraulic Oil Environmental Ester Synthetic - HEES  
**Fluid name:** Naturelle HF-E  
**Manufacturer:** Shell  
**ISO viscosity grade available:** (32 46)  
**Seal compatibility:** (FPM HNBR NBR AU)  
**Temperature limits:** -30°C to 90°C (reservoir), < 100°C locally in the system  
**Environmental certification (ecolabel):** No certification

**Fluid type:** Hydraulic Oil Environmental PolyGlycol - HEPG  
**Fluid name:** Hydrosynth  
**Manufacturer:** Avia  
**ISO viscosity grade available:** (22 32 46)  
**Seal compatibility:** (FPM HNBR NBR)  
**Temperature limits:** -30°C to 90°C (reservoir), < 100°C locally in the system  
**Environmental certification (ecolabel):** No certification
4.1 Expert System Prototype - Components

**2nd Phase: Selection of hydraulic components**

- Application circuit
- Reservoir
- Heating and cooling devices
- Accumulator
- Filters
- Hydraulic pump/motor
- Actuation system
4.1 Expert System Prototype - Reservoir

### Reservoir

**Specification**

**Manufacturing material in the reservoir**

These parameters that you set are applicable to manufacturing material of all hydraulic components selected in this phase, which is defined according to the compatibility with the biodegradable fluids selected in the 1st phase.

According to biodegradable fluid selected on 1st phase, the carbon steel is a material compatible to use in the reservoir or any other on hydraulic component.

**Size of the reservoir**

This question solves the basic rules of dimensioning reservoir for industrial and mobile applications using biodegradable fluids. The application field that you selected on the 1st phase was a **Industrial** application field.

- For industrial hydraulic systems there is a rule of thumb, where the fluid volume is between three and five times the pump flow rate per minute that provide pressure in the system.
- For mobile hydraulic systems, the specification of a small reservoir can be required, which must be complemented for modifications that compensate the reduction of fluid volume.

These compensations are:
- Installation of a heat exchanger
- High capacity filters
- Use of baffles

The rule of thumb related to sizing of reservoir for **Industrial** application field can be visualized in the figure on the right.

**Reservoir/pump layout**

**Pump and motor mounted on top of reservoir (vertical):**

Current design trend has the electric motor mounted vertically, with the pump submerged in hydraulic fluid. This conserves space, because the reservoir can be made deeper and take up less floor space than one with traditional proportions. The submerged-pump design also eliminates external pump leakage, because any fluid leaking from the pump flows directly into the reservoir. In addition, the power unit is quieter, because the hydraulic fluid tends to damp pump noise.
5. Conclusions
5.1 Conclusions

- State-of-the-art biodegradable fluids ➔ Lack of scientific and industrial information related to biodegradable fluids ➔ This work is a starting point in this country, in identifying new research and development of systems and/or environmentally friendly products.

- The introduction of a new line of research in the Brazilian scientific community, which is directed to the study and application of biodegradable fluids to be used in hydraulic systems.

- A list of new or modified design requirements of hydraulic systems were identified.

- Rules and recommendations for the selection of fluids and components were established ➔ heuristics knowledge acquired from experts, standards, literature and technical information.

- SHBIO's proposed focus on the systematization of procedures for specifying and analyzing the requirements of hydraulic systems in order to adapt and optimize the performance and component life, as well as the fluid itself ➔ Selection of fluids – Selection of components - Guidelines for monitoring.
Thank you for your attention

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