Process design of the Hydroesterification of meat processing dissolved air flotation sludge for biodiesel production: simulation study and preliminary economic assessment

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Motivation for the utilisation meat processing dissolved air flotation (DAF) sludge as a biodiesel feedstock

- Global challenges with respect to sustainability issues (GHG emissions, environmental concerns, resource depletion) are increasing
- Significant masses of readily available DAF sludge generation in New Zealand with 2.8×10^{9} kg of wet DAF sludge (>90% wt moisture content on a wet basis) generated annually
- Possibility of improving economic performance of existing biodiesel production processes
- Absence of associated costs of cultivation, harvesting or agricultural land use for biomass generation

Quality and composition of the DAF sludge derived oils

The following results were obtained:

- Free fatty acid content and moisture content was established as 22.3 kg of FFA/100 kg of oil extracted with an average moisture content of 0.92 kg/kg of the wet DAF sludge

This implied that,

- DAF sludge lipids were low grade oils since the value of 22.3% FFA content exceeds the maximum (0.5%) permitted in conventional transesterification processes to avoid unwanted saponification reactions when an alkali catalyst is used.

- The high moisture content suggested the requirement of a high energy input requirement for the preliminary drying required in conventional transesterification processes.

Average fatty acid distribution of DAF sludge derived lipid

Table 1: The relative composition of the major fatty acids in DAF sludge.

Major fatty acid	**Common name**	**Compound ID**	**Mole fractions**
Saturated fatty acids			
Tetradecanoic acid	Myristic acid	C14:0	0.0598
Hexadecanoic acid	Palmitic acid	C16:0	0.3162
Octadecanoic acid	Stearic acid	C18:0	0.3504
Total			**0.7264**
Unsaturated fatty acids			
11-Octadecenoic acid	Vaccenic acid	C18:1	0.0941
Cis-9-Octadecenoic acid	Oleic acid	C18:1	0.1795
Total			**0.2736**

Properties of the biodiesel product from the DAF sludge lipids

- The properties of the DAF sludge biodiesel as a function of the FAME distribution have been determined via thermodynamic and empirical models from the literature

- The validation of the approach achieved by analysing the statistical significance of the results (percentage average absolute deviation < 5%) based on previous studies utilising animal based lipid such as pork lard, chicken fat and beef tallow

Properties of the biodiesel product from the DAF sludge lipids

Hydroesterification has been proposed to avoid the unwanted saponification reactions:

- ✓ DAF sludge fatty acid + NaOH ↔ Na^{+}salt of DAF sludge fatty acid + H_2O

Properties of the biodiesel product	*Density (at 15°C) (kg/m³)*	*Viscosity (at 40 °C) (mm²/s)*	*HHV (MJ/kg)*	*Cetane Number*	*Cloud point (CP) (K)*	*Cold filter plugging points (CFPP)*
DSME	871.1	4.80	40.13	70.8	298.7	296.2
ASTM D6751[2]	ND	$1.9 \leq \upsilon \leq 6.0$	ND	≥ 47	CS	CS
EN 14214[1]	$860 \leq \rho \leq 900$	$3.5 \leq \upsilon \leq 5.0$	>35	≥ 51	CS	CS

ND: Not determined CS: Country specific

Major limitation identified in biodiesel derived from DAF sludge

DAF sludge derived biodiesel is expected to possess very poor flow (cold flow and the cold filter plugging) properties in a temperate climate like New Zealand suggesting the need for further improvement stages such as,

- ✓ Product blending with fossil diesel fuels
- ✓ Freezing point depression via the addition of toluene
- ✓ Winterisation
- ✓ Use of industrial additives such as BioFlow 875, Flozol 503 and MCC P205

Process simulation as an integration of an insitu lipid hydrolysis and reactive distillation process

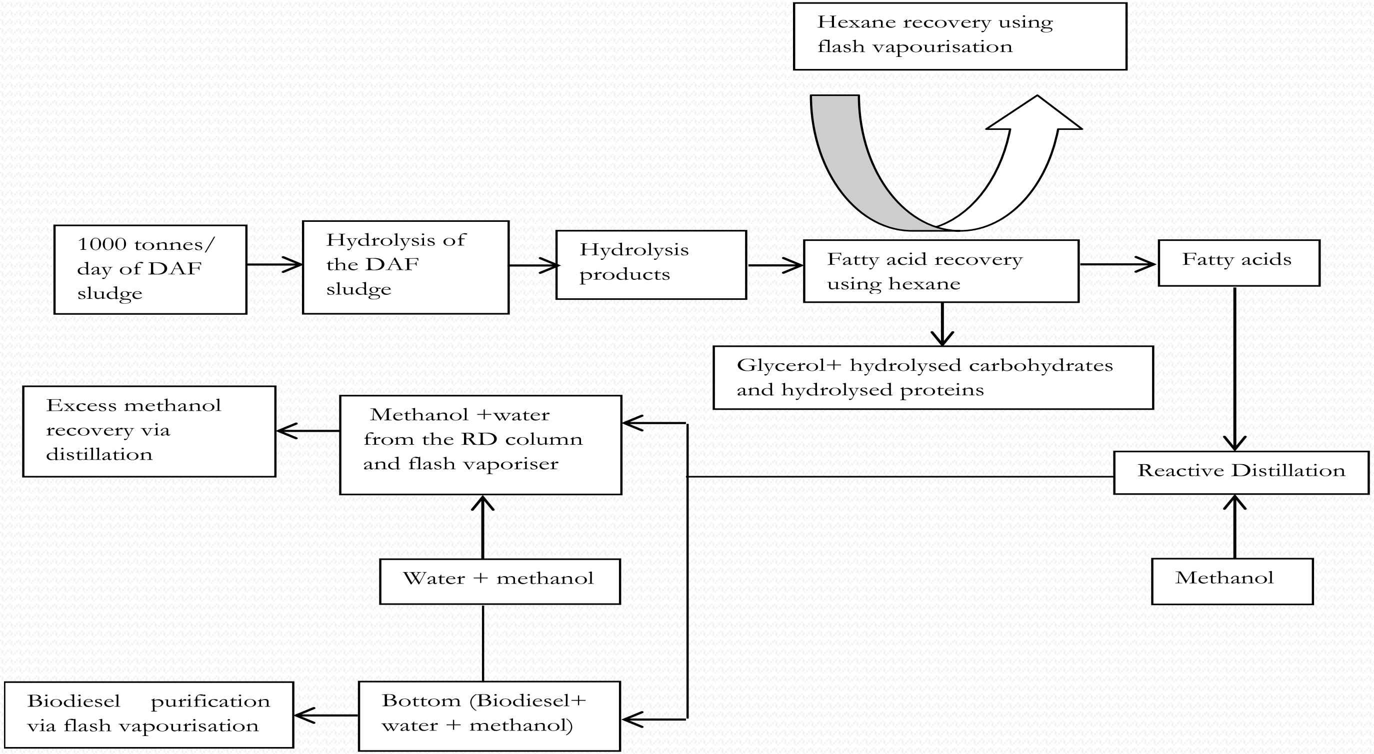

Figure 1: Process flow diagram for hydroesterification of locally sourced DAF sludge for biodiesel production

Techno economic assessment of the DAF sludge lipid to biodiesel production process

- Hydroesterification process simulation has been undertaken using Aspen plus V 8.0 for a plant assumed to operate for 7920 hours annually with wet DAF sludge fed at a rate of 1000tonnes/day
- The DAF sludge protein and carbohydrate have been modelled as l-phenylalanine* and glucose** respectively
- The DAF sludge lipids have been modelled using:
  - ✓ Espinosa's method for molecular formula determination
  - ✓ Chemical constituent fragment method for thermophysical property determination

* An essential protein found in most protein containing food. http://umm.edu/health/medical/altmed/supplement/phenylalanine <assessed 12/10/2016>

**Most representative carbohydrate form since it is found in both cellulose and starch. http://www.saylor.org/site/wp-content/uploads/2010/11/BIO101-Carbohydrates.pdf <assessed 12/10/2016>

Techno economic assessment of the DAF sludge lipid to biodiesel production process

- Biodiesel production has been achieved via integrated optimised insitu hydrolysis and esterification of the DAF sludge fatty acids as follows,
  - ✓ $\text{DAF sludge lipid} + 3H_2O \longrightarrow C_3H_8O_3 + 3\ \text{DAF sludge fatty acid}$
  - ✓ $\text{DAF sludge fatty acid} + CH_3OH \leftrightarrow \text{DSME} + H_2O$
- Modelling of the initial lipid hydrolysis has been achieved using the conversion model in Aspen
- Modelling of the esterification reaction has been achieved using the CSTR model in Aspen
- The chemical reaction rates for the lipid hydrolysis and esterification reactions were determined experimentally in our lab.

Techno economic assessment of the DAF sludge lipid to biodiesel production process

- Heat exchanger integration has been achieved via pinch analysis
- Technical feasibility has been analysed by considering the net energy balance ratio of the hydroesterification process as follows,

  - ✓ $$NEB\ ratio = \frac{Energy_{biodiesel}}{Energy_{net\ input\ to\ the\ system\ to\ produce\ the\ biofuels}},$$

  - ✓ NER >1 is a minimum value to indicate that the biodiesel system can help reduce dependency on fossil energy

Techno economic assessment of the DAF sludge lipid to biodiesel production process

- Economic assessment has been undertaken using the total annualised unit cost of production (TAUC),

  - ✓ $$TAUC\left[\frac{\$US}{kg\ of\ biodiesel}\right] = \frac{(AEC + annual\ operational\ cost)\left[\frac{\$US}{year}\right]}{Production\ capacity\left[\frac{kg\ of\ biodiesel}{year}\right]}$$

  - ✓ $$AEC\left[\frac{\$US}{year}\right] = I_{total} \times \left[\frac{(1+i)^n \times i}{(1+i)^n - 1}\right]$$ and

  - ✓ $$I_{total}[\$US] = 1.81 \times ISBL(equipment)$$

AEC is the annual equivalent cost and ISBL is the inside battery limit cost

Process simulation output for the hydroesterification biodiesel production process

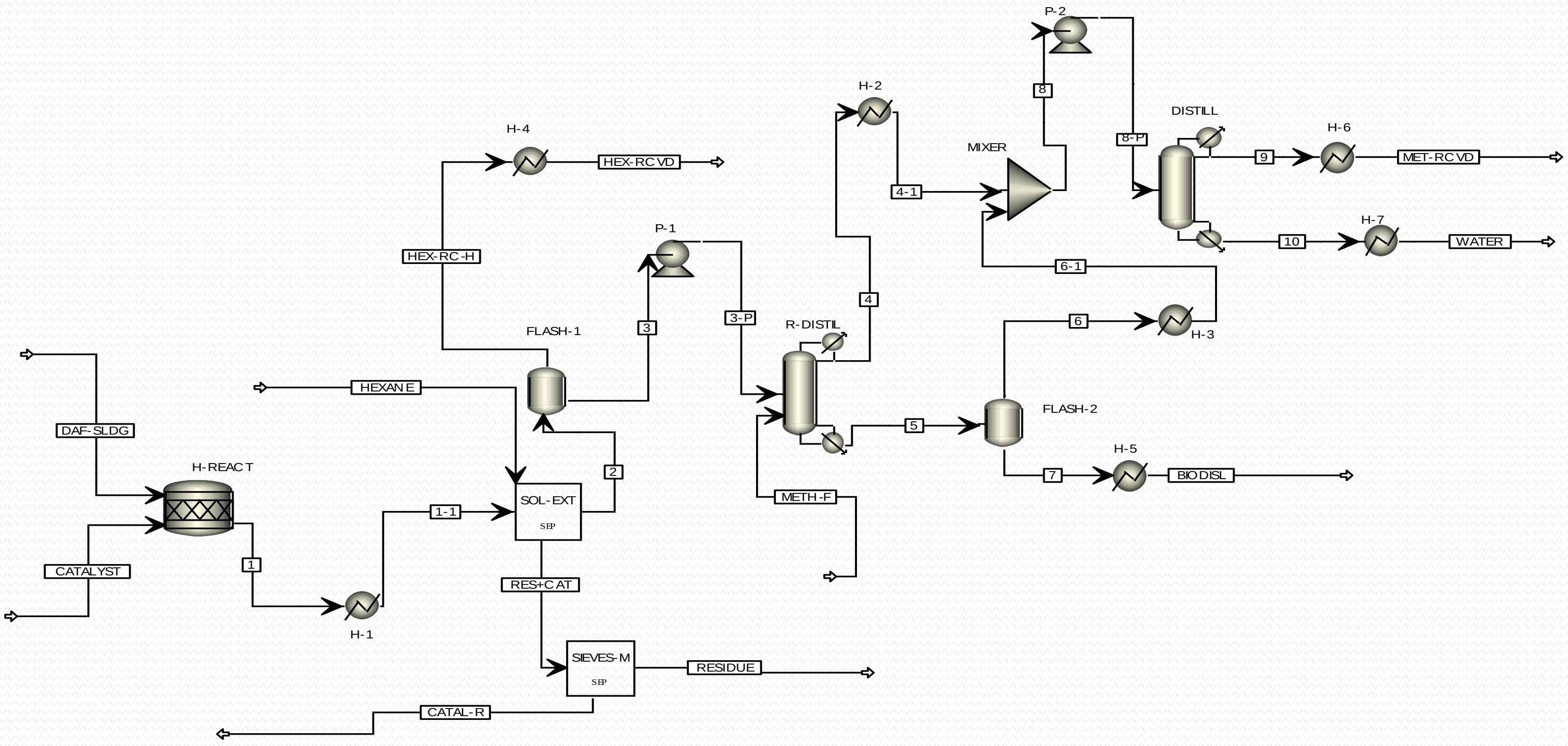

Figure 2: Simulated hydroesterification of DAF sludge process.

Conclusions

- It is theoretically possible to generate up to 3400 t/y of biodiesel at a NEB ratio of 1.33. This suggests that the overall system presented a favourable energetic performance and environmentally sustainable
- The estimated unit production cost of USD1.205 per kg of biodiesel is lower than the unit production costs when castor bean oil (USD1.56 per kg) and vegetable oil (USD1.568 per kg) are used
- However it is still significantly more than the retail price of diesel in the global market, about USD1.08 per kg in December of 2016. Improvements such as the application of the biorefinery concept on the large quantities of the residual biomass must be explored (Okoro, Sun, and Birch. J. Cleaner Production, V.142, pp1583-1608, 2017)

Thank you

Questions