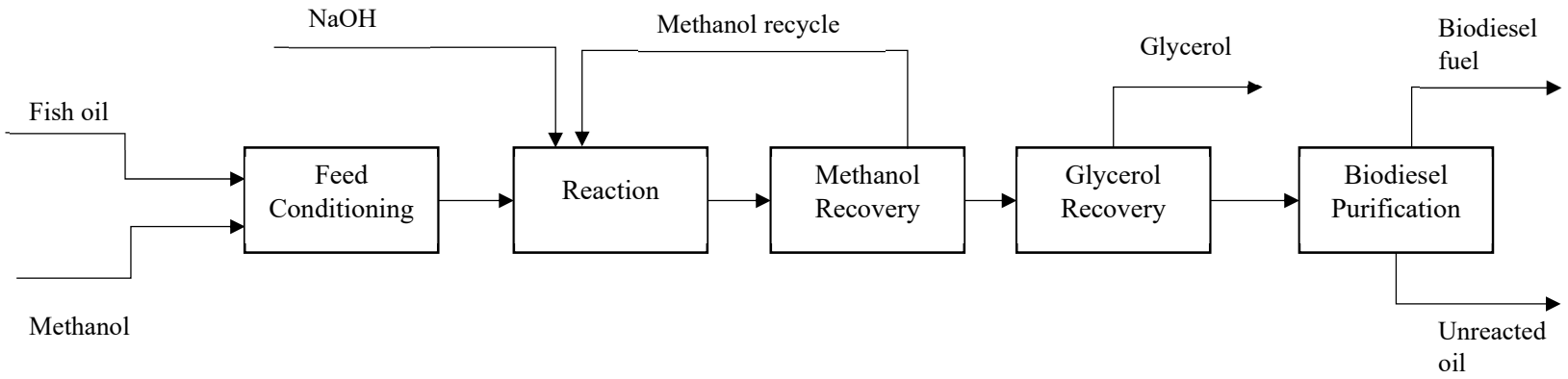


Figure S1: BFD for fish waste oil into biodiesel

Process Simulation Procedure:
the procedure of the design methodology can be summarized as follows:

- **Case Study:** data are collected for the process study, which includes the capacity of the fish waste oil, the flow rate of methanol, temperature, and pressure of the streams. Reactor data: kinetics, reaction type, reactor type, Activation energy, Arrhenius constant, type of cooling/heating, and isothermal/adiabatic scheme.
- **Process Simulation:** This step involves defining thermodynamic models and components. The thermodynamic fluid package in Aspen-HYSYS® (v14) handles flash and physical property calculations, aiding in the assessment of component properties and interactions. An NRTL fluid package is selected for simulating a biodiesel plant, as recommended for hydrocarbon compounds. Once the components, the thermodynamic package, and reaction kinetics are chosen, the feed streams are defined by specifying the process conditions (temperature, pressure, flow rate) and the composition. The feed streams are defined as Fish Waste Oil and Methanol reactants. The scheme shown in Fig. 1 illustrates the experimental procedure for converting fish waste oil into biodiesel. The procedure shown in the scheme is translated into a process flowsheet in the process simulation of the biodiesel plant. As shown, the extracted fish oil is esterified in a reactor unit at 60°C for 3 hours with a methanol-to-oil ratio of 9:1. The effluent stream from the mixture includes biodiesel, methanol (unreacted), glycerol, and fish oil (unreacted). After the reaction step, the mixture is separated by distillation into glycerol, biodiesel, methanol, and fish waste oil. Unreacted methanol and oil are recycled to the reactor unit to increase the overall yield.

The process flowsheet is built sequentially following the general phases of production shown in Fig. 1 and Fig. A1. The information required to complete the process simulation is the sequence of equipment, material streams, energy streams, pressure drops in equipment, the number of trays in distillation columns, and tray efficiencies. The production flowsheet is synthesized by identifying the necessary unit operations to convert the fish waste oil into biofuel and valuable byproducts, as shown in Fig. 1.

The unit operations defined are pumps, heat exchangers (heaters/coolers), mixers, a CSTR, valves, distillation columns, and recycle elements. For each unit operation, it is required to specify the necessary parameters to satisfy the degrees of freedom. Each parameter specification set reduces the degrees of freedom by 1. The number of active specifications must equal the number of unknown variables necessary for the simulation to converge.

An NRTL fluid package is excellent fit compared with other methods (e.g. UNIFACT) for modeling transesterification of fish oil systems, including highly non-ideal systems, polar/non-polar components and the presence of strong H-bonding. This model gives accurate phase behavior of liquid-liquid miscibility systems (alcohol/oil/glycerol). Fish oil transesterification systems normally comprise components of several categories such as:
Triglycerides: non-polar; Methanol: polar with hydrogen bonding; Glycerol: polar with strong H-bond; NaOH: heterogeneous. The main characteristics of these systems are strong polarity, significant non-ideal mixing between alcohols/glycerol/triglycerides, and the presence of H-bonds. NRTL is excellent for and can handle non-ideal liquid systems, predicts behavior of polar/non-polar systems accurately and can model partial miscibility between alcohol and oil phases. For these reasons, NRTL is selected to model the transesterification of fish waste oil systems. On the other hand, UNIFAC is less accurate for polar/non-polar systems, may underpredict activity of H-bonds and is moderate method of non-ideality.

The process flowsheet is synthesized and simulated following the schematic diagram shown in Fig. 2. The basic design for the production plant is shown in Fig. 4. The simulation results of material stream flow rates, energy requirement, and the process stream compositions are displayed in Tables S1–S3.

Table S1: Material stream flow rates for the transesterification process flowsheet

Material Streams											
		feed mix	to heat	hot influent	biodiesel+fish oil+glycerol	methanol recycle	glycerol	biodiesel+fish oil	to glycerol column	biodiesel	fish oil recycle
Vapour Fraction		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Temperature	C	25.00	25.03	60.00	366.6	65.39	333.2	417.8	366.7	393.2	412.9
Pressure	kPa	101.3	160.0	140.0	120.0	105.0	300.0	330.0	330.0	270.0	300.0
Molar Flow	kgmole/h	1.322	1.322	1.322	13.55	119.9	6.986e-002	13.48	13.55	0.1926	13.29
Mass Flow	kg/h	97.75	97.75	97.75	3819	3841	7.619	3811	3819	57.07	3754
Liquid Volume Flow	m3/h	0.1139	0.1139	0.1139	4.274	4.827	6.620e-003	4.267	4.274	6.507e-002	4.202
Heat Flow	kJ/h	-4.282e+005	-4.282e+005	-4.194e+005	-7.287e+006	-2.813e+007	-4.124e+004	-6.602e+006	-7.286e+006	-8.627e+004	-6.584e+006
		to biodiesel column	to reactor	oil recycl to react	oil recycle	vent	reaction outlet	methanol	fish oil	meth to recycl	
Vapour Fraction		0.0833	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	
Temperature	C	412.7	65.19	65.00	65.00	64.70	64.70	25.00	25.00	65.39	
Pressure	kPa	300.0	105.0	290.0	290.0	105.0	105.0	101.3	101.3	105.0	
Molar Flow	kgmole/h	13.48	133.5	13.28	13.29	0.0000	133.4	1.100	0.2217	118.9	
Mass Flow	kg/h	3811	7660	3750	3754	0.0000	7660	35.25	62.50	3812	
Liquid Volume Flow	m3/h	4.267	9.102	4.198	4.202	0.0000	9.101	4.429e-002	6.960e-002	4.790	
Heat Flow	kJ/h	-6.602e+006	-3.844e+007	-1.010e+007	-1.011e+007	-0.0000	-3.844e+007	-2.634e+005	-1.649e+005	-2.792e+007	

Table S2: Energy streams for the transesterification process flowsheet

Energy Streams											
		HP-feed	Qhhx	Qr-meth	Qc-meth	Qc-glyc	Qr-glyc	HP-glyc	Qc-biod	Qr-biod	Qchx
Heat Flow	kJ/h	8.200	8846	1.179e+007	8.772e+006	1.653e+004	6.590e+005	1726	1.241e+007	1.235e+007	3.526e+006

Table S3: Stream compositions for the transesterification process flowsheet

Compositions										
	feed mix	to heat	hot influent	biodiesel+fish oil+glycerol	methanol recycle	glycerol	biodiesel+fish oil	to glycerol column	biodiesel	fish oil recycle
Comp Mole Frac (Methanol)	0.8322	0.8322	0.8322	0.0000	0.9999	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (M-Oleate)	0.0000	0.0000	0.0000	0.0142	0.0000	0.0100	0.0142	0.0142	0.9898	0.0001
Comp Mole Frac (Glycerol)	0.0000	0.0000	0.0000	0.0047	0.0001	0.9116	0.0000	0.0047	0.0002	0.0000
Comp Mole Frac (LinoleicAcid)	0.0503	0.0503	0.0503	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (OleicAcid)	0.1174	0.1174	0.1174	0.9811	0.0000	0.0784	0.9858	0.9811	0.0100	0.9999
	to biodiesel column	to reactor	oil recycl to react	oil recycle	vent	reaction outlet	methanol	fish oil	meth to recycl	
Comp Mole Frac (Methanol)	0.0000	0.8988	0.0000	0.0000	0.8983	0.8983	1.0000	0.0000	0.9999	
Comp Mole Frac (M-Oleate)	0.0142	0.0000	0.0001	0.0001	0.0014	0.0014	0.0000	0.0000	0.0000	
Comp Mole Frac (Glycerol)	0.0000	0.0001	0.0000	0.0000	0.0006	0.0006	0.0000	0.0000	0.0001	
Comp Mole Frac (LinoleicAcid)	0.0000	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.3000	0.0000	
Comp Mole Frac (OleicAcid)	0.9858	0.1006	0.9999	0.9999	0.0997	0.0997	0.0000	0.7000	0.0000	

Table S4: Methanol recovery distillation column

Parameter	Unit	Section 1	Section 2
Number of stages	-	10	10
Column top pressure	kPa	105	
Column bottom pressure	kPa	120	
Feed stage	-	10	
Reflux ratio		0.5	
Condenser stage temperature	°C	65	
Reboiler temperature	°C	367	
Column section average diameter	m	2.39	2.21
Tray type	-	Sieve	Sieve
Tray spacing	m	0.61	0.61
Column section pressure drop	mbar	186.4	205.5
Section with weeping	-	None	None
Column section design flooding	%	80	80
Product purity (mole basis)	%	99	

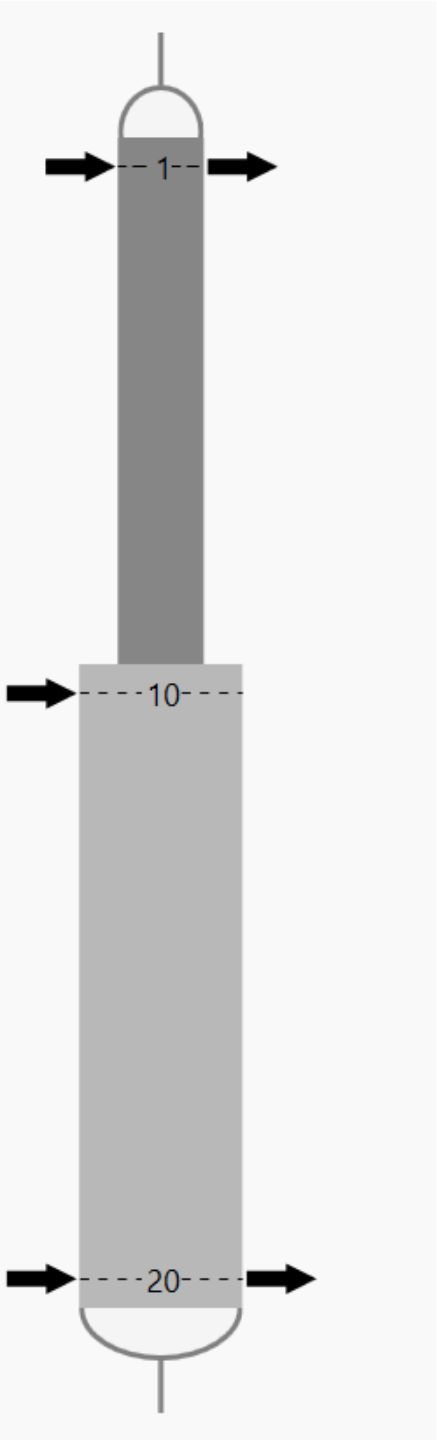


Table S5: Glycerol recovery distillation column

Parameter	Unit	Section
Number of stages	-	10
Column top pressure	kPa	300
Column bottom pressure	kPa	330
Feed stage	-	10
Reflux ratio		3
Condenser stage temperature	°C	300
Reboiler temperature	°C	330
Column section average diameter	m	0.52
Tray type	-	Sieve
Tray spacing	m	0.61
Column section pressure drop	mbar	130.6
Section with weeping	-	None
Column section design flooding	%	80
Product purity (mole basis)	%	98

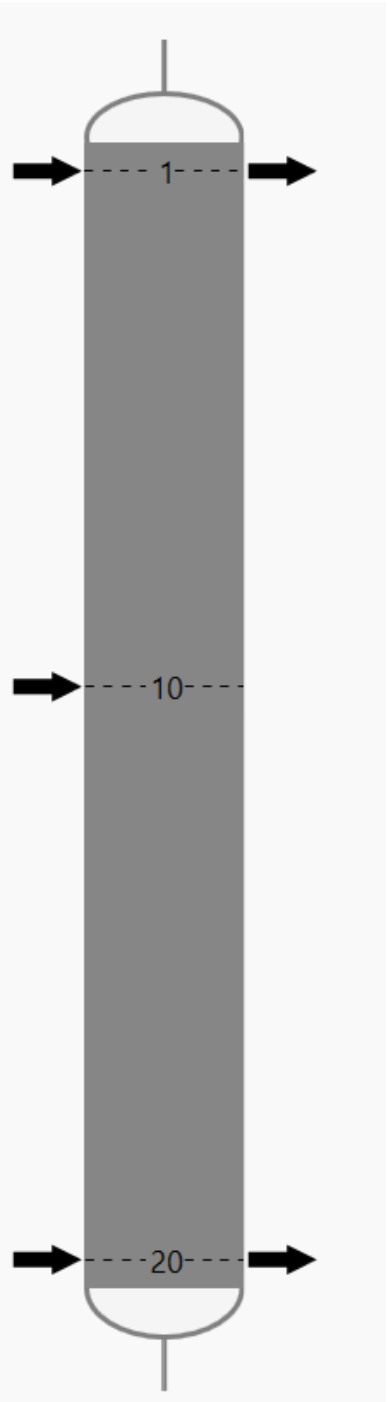


Table S6: Biodiesel recovery distillation column

Parameter	Unit	Section 1	Section 2
Number of stages	-	30	30
Column top pressure	kPa	270	
Column bottom pressure	kPa	300	
Feed stage	-	30	
Reflux ratio		10	
Condenser stage temperature	°C	393	
Reboiler temperature	°C	407	
Column section average diameter	m	1.119	2.133
Tray type	-	Sieve	Sieve
Tray spacing	m	0.61	0.61
Column section pressure drop	mbar	99.55	60.00
Section with weeping	-	None	None
Column section design flooding	%	80	80
Product purity (mole basis)	%	99	

