**INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI**
**SHORT ABSTRACT OF THESIS**

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Thesis Title:

**Development of kaolin-based microporous membrane for energy efficient microalgal harvesting and effluent recycle under circular bioeconomic approach**

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## SHORT ABSTRACT

Biodiesel as a renewable energy source can provide an alternative to the alarmingly depleting energy from fossil fuels. Microalgae is an encouraging third-generation feedstock for the production of biodiesel as it has the capability of oil production throughout the year. Besides several advantages, commercial production of microalgal biomass feedstock is not considered sustainable due to its high production cost. In this context, recycling the culture media carry significant potential to reduce the overall cost for the long-term growth of microalgal industry. In this work, indigenous low-cost disc and tubular membranes were fabricated using naturally available kaolin as the key precursor. Different composition of kaolin (80-92 wt.%) and binder (8-20 wt.%) was used to optimize the raw material and binder composition. The optimized binder concentration in disc membrane was used to further fabricate tubular membranes. With increase in binder percentage from 8% to 20% in disc membranes, the percentage porosity, average pore size and water permeability decreased from 34.52% to 21.5%, 2.28 µm to 0.195 µm and $6.12\times10^{-9}$ to $1.69\times10^{-9}$ m $Pa^{-1}$ $s^{-1}$ respectively while flexural strength increased slightly from 7.1 MPa to 9.4 MPa. Hence, binder percentage of 8% i.e., 2% boric acid, 2% sodium metasilicate and 4% sodium carbonate was found to be optimum. Thereafter, tubular membranes will be fabricated using this binder concentration. The fabricated tubular membranes had porosity of ~26% - 47%, a pore diameter of 0.123-0.182 µm, water permeability of $4.2\times10^{-8}$ – $17.1\times10^{-8}$ $m^3$ $m^{-2}$ $s^{-1}$ $kPa^{-1}$, along with good mechanical and chemical strength.

The optimized membrane (77% kaolin, 2% boric acid, 2% sodium metasilicate, 4% sodium carbonate, and 15% calcium carbonate) was tested for microfiltration of microalgae *Monoraphidium* sp. KMC4 with 1.5 g $L^{-1}$ of initial concentration at a persistent cross-flow rate ($1.11 \times 10^{-5}$ $m^3$ $s^{-1}$) and various transmembrane pressures (69 kPa - 345 kPa). The separation results yielded an average permeate flux of $1.85\times10^{-5}$ $m^3$ $m^{-2}$ $s^{-1}$ at an optimized transmembrane pressure of 276 kPa. The corresponding volume reduction factor and permeate recovery were 1.38 and 28.17%, respectively. Complete algal cell recovery and substantial nutrient passage (>88%) were observed within the pressure range of 69 kPa to 345 kPa. Fouling mechanism was explained by fitting four distinct pore-blocking models, of which the cake filtration model provided the most accurate fit as compared to the complete, intermediate and standard pore-blocking models. Additionally, the total organic carbon varied in the range of 31.6-63.2 mg $L^{-1}$. This essentially explained the source of pore blocking. The elongated shape of *Monoraphidium sp.* KMC4 might have contributed to the enhanced fouling of membrane. Lastly, the nitrate passage was almost complete (~88% - 97%), highlighting the prospects of permeate stream in further cultivation process.

Henceforth, the suitability of cultivating *Monoraphidium* sp. KMC4 was exhibited in different effluent-based culture (EBC) media concentrations, the latter being treated with powdered activated carbon (PAC) with a loading of 5-50 mg $L^{-1}$. The optimum EBC media treated with 30 mg $L^{-1}$ PAC enhanced the biomass yield by 21.9% as compared to the untreated one (1.21 g $L^{-1}$). A recyclability study performed in five batches resulted in an optimal growth up to three batches with an overall biomass yield of 4.21 g and a total water savings of 30%. Additionally, physico-chemical characterization and FAME profile of the biomass from the recyclability study validated feedstock's energy potential. Moreover, this study proposes a biorefinery model which could recover nutrient rich liquid effluent (3.1 million litres) and solid residue for various applications along with the generation of 5760 kg of biomass followed by 113 L $d^{-1}$ biodiesel yield.

The economic feasibility of low-cost membrane fabrication, microalgal harvesting using the developed membrane and the energy efficient recycle process has been successfully assessed. The initial phase of cost estimation begins with assessing the expenses involved in membrane fabrication, which encompasses equipment costs and manufacturing expenses. The projected cost per square meter of membrane stands at 190.93 USD, falling within the category of low-cost membranes. Following this, the subsequent stage of cost estimation involves evaluating the cost of microalgal harvesting using the low-cost tubular kaolin membrane, both in lab scale as well as pilot scale. The lab scale setup consists of a single membrane with an effective filtration area of $15.71\times10^{-4}$ $m^2$, while the pilot scale comprises three parallel membrane housings, each containing seven membranes, with an effective filtration area of 0.0989 $m^2$. For the lab scale process, the total cost of harvesting one litre of microalgal culture was estimated to be 0.648 USD/L which lowered to 0.04 USD/L for the pilot scale harvesting setup.

The final step of cost estimation involved the energy efficient recycle process, both in lab scale as well as pilot scale. The cost per gram of biomass was calculated to be 7.02 USD/g for the lab scale configuration while it dropped to 0.1195 USD/g for the pilot scale setup.