INTISARI

Industri pulp dan kertas merupakan salah satu sektor industri yang penting dan terus berkembang di dunia. Industri pulp umumnya menggunakan kayu serat pendek (*hardwood*) dan *white liquor* sebagai bahan baku produksi pulp Kraft, yang juga terintegrasi dengan pabrik kertas. Optimasi proses Kraft dilakukan untuk meningkatkan rendemen pulp dan meminimalkan konsumsi bahan kimia. Peningkatan produktivitas, kualitas pulp, dan efisiensi biaya produksi menjadi fokus utama dalam menghadapi persaingan global. Tantangan yang dihadapi industri pulp dan kertas saat ini adalah mengembangkan teknologi proses yang dapat memenuhi standar kualitas produk yang tinggi di pasar, meminimalkan biaya modal dan operasional, serta meminimalkan dampak terhadap lingkungan. Di samping banyaknya penelitian tentang pengaruh teknologi dan parameter proses terhadap kualitas pulp, penelitian mengenai pengaruh teknologi pemasakan pulp terhadap efisiensi produksi dan dampak terhadap lingkungan belum banyak dilakukan.

Penelitian ini bertujuan untuk menganalisis tekno-ekonomi produksi pulp Kraft dengan teknologi pemasakan kontinu *Low-Temperature Cooking* dan *Multiple Extraction Cooking*, serta menganalisis dampaknya terhadap lingkungan melalui metode analisis daur hidup (LCA). Biaya produksi pulp Kraft terdiri dari biaya bahan baku *wood chips*, bahan kimia kimia: *white liquor*, *caustic soda*, klorin dioksida, dan hidrogen peroksida, serta biaya utilitas untuk air, listrik, dan *steam*. Margin keuntungan diperoleh dari selisih antara harga jual pulp dengan biaya produksi. LCA dilakukan dengan menggunakan perangkat lunak OpenLCA dan ruang lingkup yang dikaji adalah *cradle-to-gate* dari proses transportasi bahan baku hingga produksi pulp dan *chemical recovery*. Penilaian potensi dampak lingkungan berfokus pada potensi pemanasan global (GWP), potensi penipisan abiotik-fosil (ADP-f), potensi hujan asam (AP), potensi eutrofikasi (EP), dan konsumsi air (WC). Karakterisasi dan penilaian dampak lingkungan dari masing-masing kategori kemudian dihitung menggunakan metode CML-IA (*Center of Environmental Science of Leiden University-Impact Assessment*) dan AWARE (*Available Water Remaining*).

Hasil penelitian menunjukkan bahwa teknologi *Multiple Extraction Cooking* lebih menguntungkan secara ekonomi dan memiliki dampak lingkungan yang lebih rendah dibandingkan dengan teknologi *Low-Temperature Cooking*. Produksi pulp Kraft dengan *Low-Temperature Cooking* memberikan margin keuntungan sekitar 116-135 USD/ADt, sedangkan *Multiple Extraction Cooking* memberikan margin keuntungan sekitar 154-169 USD/ADt. Proses pembakaran batu bara dan biomassa di *power boiler* memberikan dampak lingkungan paling besar ditinjau dari kategori dampak GWP, ADP-f dan AP. Sementara itu, tahap pemutihan pulp memberikan dampak lingkungan paling besar ditinjau dari kategori dampak EP dan WC. Secara keseluruhan dari kelima kategori dampak yang dianalisis, produksi pulp Kraft dengan teknologi *Low-Temperature Cooking* memiliki dampak lingkungan yang lebih besar dibandingkan dengan teknologi *Multiple Extraction Cooking*. Optimasi penggunaan biomassa untuk menggantikan batu bara sebagai bahan bakar di *power boiler* dapat menjadi strategi baik untuk mengurangi emisi gas rumah kaca dan penggunaan bahan bakar fosil. Di samping itu, penggunaan kembali *white water* dalam tahap pemutihan pulp dapat dilakukan untuk mengurangi konsumsi air dan jumlah air limbah.

Kata kunci: analisis daur hidup; analisis tekno-ekonomi; *Low-Temperature Cooking*; *Multiple Extraction Cooking*; pulp Kraft

ABSTRACT

Pulp and paper industry is one of the most important and growing industrial sectors in the world. The pulp industry generally uses hardwood and white liquor as raw materials for Kraft pulp production, which is also integrated with paper mills. Kraft process optimization is carried out to increase pulp yield and minimize chemical consumption. Improving productivity, pulp quality, and cost efficiency become the main focus in facing global competition. The challenge facing pulp and paper industry today is to develop process technologies that can meet high product quality standards in the market and minimize capital and operational costs, as well as environmental impact. Despite the abundant research on the influence of technology and process parameters on pulp quality, significantly fewer studies were conducted on the influence of pulp cooking technologies on production efficiency and the environmental impact.

This research evaluates the tecno-economics of Kraft pulp production through continuous Low-Temperature Cooking and Multiple Extraction Cooking technologies, as well as assesses its impact on the environment through the life cycle analysis (LCA) method. Kraft pulp production costs consist of raw material costs for wood chips, chemicals: white liquor, caustic soda, chlorine dioxide, and hydrogen peroxide, and utilities costs for water, electricity, and steam. The profit margin is obtained from the variance between the pulp sales price and production cost. LCA was carried out using OpenLCA software and the scope studied was cradle-to-gate from raw material transportation to pulp production and chemical recovery. The assessment of potential environmental impact focuses on global warming potential (GWP), abiotic depletion potential-fossil (ADP-f), acidification potential (AP), eutrophication potential (EP), and water consumption (WC). The characterization and environmental impact assessment of each category is then calculated using the CML-IA (Center of Environmental Science of Leiden University-Impact Assessment) and AWARE (Available Water Remaining) methods.

This research result shows that Multiple Extraction Cooking technology is more cost-effective and has lower environmental impact compared to Low-Temperature Cooking technology. Kraft pulp production through Low-Temperature Cooking gives profit margin around 116-135 USD/ADt, while Multiple Extraction Cooking gives profit margin around 154-169 USD/ADt. The coal and biomass burning process in the power boiler has the biggest impact on the environment in terms of the GWP, ADP-f, and AP categories. Meanwhile, the pulp bleaching stage has the biggest impact on environment in terms of EP and WC categories. Overall, based on the five impact categories above analyzed, Kraft pulp production through Low-Temperature Cooking technology has bigger environmental impact than Multiple Extraction Cooking technology. Optimizing the usage of biomass to substitute coal as fuel in the power boiler can be a good strategy to reduce greenhouse gases emissions and fossil fuels use. In addition, reusing white water in the pulp bleaching stage can be applied to reduce water consumption and the amount of wastewater to effluent.

Keywords: *Kraft pulp; life cycle assessment; Low-Temperature Cooking; Multiple Extraction Cooking; techno-economic analysis*