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Analisis Aliran Material dan Karbon pada Berbagai Produksi Baja di Indonesia
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INTISARI

Industri baja merupakan salah satu industri dengan kebutuhan material dan energi yang tinggi serta menghasilkan emisi karbon yang signifikan. Perbedaan jalur produksi baja menyebabkan perbedaan kebutuhan bahan baku, pemanfaatan material, dan emisi CO_2. Penelitian ini bertujuan untuk menganalisis dan membandingkan aliran material dan karbon pada tiga skenario produksi baja, yaitu rute *Blast Furnace-Basic Oxygen Furnace* (BF-BOF), *Full Scrap Electric Arc Furnace* (EAF), serta EAF dengan kombinasi 70% skrap dan 30% *hot metal*.

Analisis dilakukan menggunakan pendekatan Material Flow Analysis (MFA) dan Carbon Flow Analysis (CFA) dengan batas sistem *cradle-to-gate* dan unit fungsional 1 ton *crude steel billet*. Kinerja aliran material dievaluasi menggunakan *Raw Material Intensity* (RMI), *Resource Utilization Efficiency* (RUE), *Production Efficiency* (PE), *Reuse Efficiency* (RE), dan *System Loss Rate* (LR).

Hasil penelitian menunjukkan bahwa *Full Scrap EAF* membutuhkan 62,2% lebih sedikit bahan baku mentah dibandingkan BF-BOF, sedangkan skenario 70% skrap dan 30% *hot metal* membutuhkan 42,0% lebih sedikit bahan baku mentah. *Full Scrap EAF* juga menunjukkan kinerja pemanfaatan material terbaik, dengan RUE sebesar 88,12%, PE 84,31%, dan LR 11,88%. Dari sisi emisi, BF-BOF menghasilkan 1.607,52 kg CO_2/t *crude steel billet*, *Full Scrap EAF* sebesar 417,60 kg CO_2/t, dan skenario hibrida sebesar 952,80 kg CO_2/t. Nilai tersebut menunjukkan penurunan emisi sebesar 74,0% pada *Full Scrap EAF* dan 40,7% pada skenario hibrida dibandingkan BF-BOF. Secara keseluruhan, peningkatan penggunaan skrap dapat menurunkan kebutuhan bahan baku primer dan emisi CO_2, meskipun kinerja emisi rute EAF tetap dipengaruhi oleh sumber listrik yang digunakan.

Kata kunci : *Material Flow Analysis*, *Carbon Flow Analysis*, industri baja, skrap baja, dekarbonisasi baja

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ABSTRACT

The steel industry is characterized by high material and energy requirements as well as significant carbon emissions. Differences in steel production pathways result in different raw material requirements, material utilization, and CO_2 emissions. This study aims to analyze and compare material and carbon flows across three steel production scenarios, Blast Furnace-Basic Oxygen Furnace (BF-BOF) route, Full Scrap Electric Arc Furnace (EAF) route, and EAF route using a combination of 70% scrap and 30% hot metal.

The analysis was conducted using Material Flow Analysis (MFA) and Carbon Flow Analysis (CFA) within a cradle-to-gate system boundary and a functional unit of 1 tonne of crude steel billet. Material flow performance was evaluated using Raw Material Intensity (RMI), Resource Utilization Efficiency (RUE), Production Efficiency (PE), Reuse Efficiency (RE), and System Loss Rate (LR).

The results show that the Full Scrap EAF route requires 62.2% less raw material than BF-BOF, while the scenario using 70% scrap and 30% hot metal requires 42.0% less raw material. The Full Scrap EAF route also shows the best material utilization performance, with an RUE of 88.12%, PE of 84.31%, and LR of 11.88%. In terms of emissions, BF-BOF produces 1,607.52 kg CO_2/t crude steel billet, compared with 417.60 kg CO_2/t for Full Scrap EAF and 952.80 kg CO_2/t for the hybrid scenario. These values correspond to emission reductions of 74.0% for Full Scrap EAF and 40.7% for the hybrid scenario relative to BF-BOF. Overall, increasing scrap utilization can reduce primary raw material requirements and CO_2 emissions, although the emission performance of the EAF route remains influenced by the electricity source used.

Keywords: *Material Flow Analysis, Carbon Flow Analysis, steel industry, steel scrap, steel decarbonization.*