Available online at www.sciencedirect.com
SCIENCE DIRECT
ELSEVIER
ENERGY
Energy 31 (2006) 1870–1882
www.elsevier.com/locate/energy

Effect of material flows on energy intensity in process industries

Liru Liu[a,b], Lu Aye[a,*], Zhongwu Lu[c], Peihong Zhang[d]

[a]*International Technologies Center (IDTC), Department of Civil and Environmental Engineering, The University of Melbourne, Victoria 3010, Australia*
[b]*Institute of Construction, Guangdong University of Technology, Guangzhou 510090, China*
[c]*Institute of Materials and Metallurgy, Northeastern University, Shenyang 110004, China*
[d]*Department of Municipal and Environmental Engineering, Shenyang Architecture University, Shenyang 110168, China*

Received 3 April 2005

Abstract

Many energy-intensive process industries have complex material flows, which have a strong effect on the overall energy intensity of the final product (OEIF). This problem, however, has only been recognised qualitatively due to the lack of quantitative analysis methods. This paper presents an in-depth quantitative analysis of the effect of material flows on energy intensity in process industries. Based on the concept of a standard material flow diagram (SMFD), as used in steel manufacturing, the SMFD for a generic process industry was first developed. Then material flow scenarios were addressed in a practical material flow diagram (PMFD) using the characteristics of practical process industries. The effect of each material flow deviating from a SMFD on the OEIF was analysed. The steps involved in analysing the effect of material flows in a PMFD on its energy intensity are also discussed in detail. Finally, using 1999 statistical data from the Chinese Zhenzhou alumina refinery plant, the PMFD and SMFD for this plant were constructed as a case study. The effect of material flows on the overall energy intensity of alumina (OEIA) was thus analysed quantitatively. To decrease OEIA, the process variations which decrease the product ratios could be employed in all except in multi-supplied fraction cases. In these cases, the fractions from the stream with lower energy intensities should be increased.

Keywords: Process industries; Energy intensity; Material flows

1. Introduction

Many process industries, such as alumina refining and steelmaking, are energy-intensive and have material flows, which have a strong effect on overall energy intensity of the final product (OEIF) [1–3]. This problem, however, has only been recognised qualitatively due to the lack of a comparative data and quantitative analysis. Recent efforts have mainly focused on developing calibrated models of energy and material consumption patterns in manufacturing processes [4] and applying them to the paper industry [5–7] and the steel industry [8]. The standard material flow diagram (SMFD) was specifically developed in the steel industry to quantitatively analyse the relationship between material flows and energy intensity of the final product

*Corresponding author. Tel.: +61 3 8344 6879; fax: +61 3 8344 6868.
E-mail address: lua@unimelb.edu.au (L. Aye).

0360-5442/$ - see front matter
doi:10.1016/j.energy.2005.07.003

Nomenclature

C_0	the product concentration of raw material, t final product/t-raw material
C_i	the product concentration of the unit process i, t final product/t (or m^3)-intermediate product
e_{0i}	standard energy intensity of unit process 'i', GJ/t (or m^3)-intermediate product
e_i	practical energy intensity of unit process 'i', GJ/t (or m^3)-intermediate product
E	practical overall energy intensity of final product, GJ/t-final product
E_0	standard overall energy intensity of final product, GJ/t-final product
E_1	overall energy intensity of final product with inputting final product-containing materials from surrounding to unit process 'i'
E_2	overall energy intensity of final product with recycling unqualified and waste product of a unit process to its upstream unit process for retreatment
E_3	overall energy intensity of final product with outputting unqualified products from a unit process to the surrounding
E_{CD}	overall energy intensity of alumina for caldron digestion method, GJ/t-Al_2O_3
E_{TD}	overall energy intensity of alumina for tube digestion method, GJ/t-Al_2O_3
G_{i-1}	the equivalent amount of final product input from the unit process '$i-1$' to unit process 'i', t
G_i	the equivalent amount of final product output from the unit process 'i' to unit process '$i+1$', t
p_{0i}	standard product ratio of unit process 'i', t (or m^3) intermediate product/t-final product
p_i	practical product ratio of unit process 'i'
p_{71}	the amount of evaporative spent liquor consumed by caldron digestion method, m^3/t-Al_2O_3
p_{72}	the amount of evaporative spent liquor consumed by tube digestion method, m^3/t-Al_2O_3
p_{81}	the amount of lime consumed by caldron digestion method, t/t-Al_2O_3
p_{82}	the amount of lime consumed by tube digestion method, t/t-Al_2O_3
α_i	the equivalent amount of final product input from surrounding to unit process 'i', t
β_{ji}	the equivalent amount of final product recycle from the unit process 'j' to unit process 'i' for retreatment, t
β_{im}	the equivalent amount of final product recycle from the unit process 'i' to its upstream unit process 'm' for retreatment, t
γ_i	the equivalent amount of final product output from the unit process 'i' to surrounding, t
ϕ_f	the supplied fraction of each parallel stream process, %
ϕ_{ih}	the allocation fraction of material flow h relative to unit process 'i', %
ϕ_{CD}	the supplied fraction of caldron digestion method, %
ϕ_{TD}	the supplied fraction of tube digestion method, %
ΔE	OEIA difference between PMFD and SMFD, GJ/t-final product
Δe_i	the effect of materials flow on energy intensity of unit process 'i', GJ/t (or m^3)-intermediate product
Δp_i	the effect of materials flow on product ratio of unit process 'i', t (or m^3) intermediate product/t-final product

Abbreviations

CD	high-pressure caldron digestion
OEIA	overall energy intensity of alumina
OEIF	overall energy intensity of final product
PMFD	practical materials flow diagram
SC	slurry preparation for high-pressure caldron digestion
SMFD	standard material flow diagram
SP	seed precipitation
ST	slurry preparation for tube digestion