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Examples in Material Flow Analysis

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The inputs and outputs of water, carbon and CaO are used as examples of Material Flow Analysis (MFA) at CSC. The intensities of water and CO_2 as well as the output for steelmaking slag are discussed. Current CO_2-Intensities are influenced by in-plant coke storage, sold energy products, purchased scrap, degree of cold rolling, purchased crude steel/roll and crude steel production etc. The adjusted CO_2- Intensities for 2010 to 2013 at CSC are reported in discussion. This paper also highlights that steelmaking slag has become an output bottleneck at CSC and therefore needs better management.

Keywords: MFA analysis, water, CaO, CO_2, Steelmaking slag

1. INTRODUCTION

Material Flow Analysis (MFA) is a tool for analyzing the inputs and the outputs of a material in a boundary. The materials can be divided into two categories, namely the main materials or the pollutants, whereas the boundary can be set as a nation, an area or a company depending on what is to be analyzed. In this report, some preliminary applications are studied on the MFA of main materials such as water, carbon and CaO, while the boundary is set at the Hsiao Kang Factories of China Steel (CSC).

2. MAJOR MFA ANALYSES

2.1 Main streams

The main streams of CSC in 2013 can be shown in Fig.1[1].

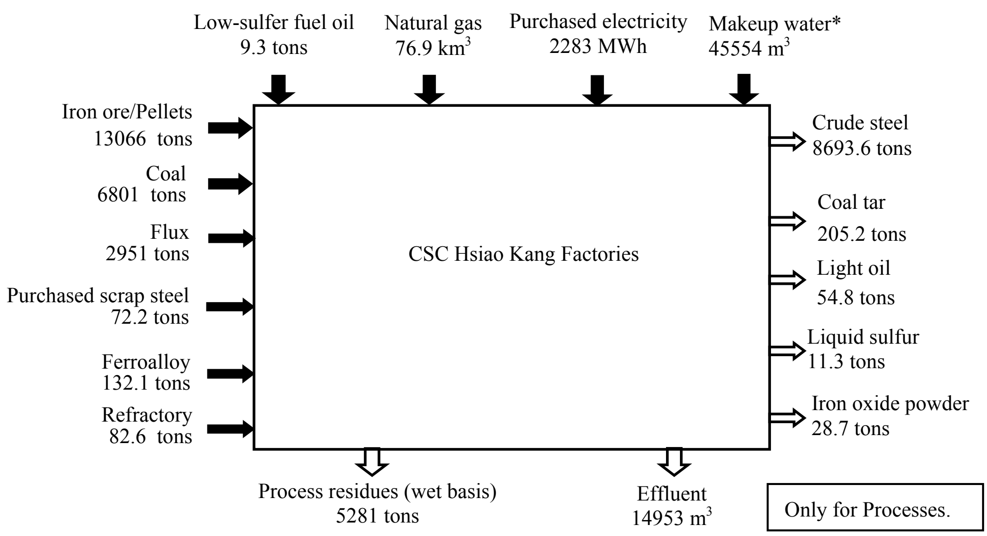

Fig.1. Main inputs and outputs of CSC in 2013 (Unit: 10^3).

2.2 Water MFA

The water recirculation rate at CSC in 2013 was 98.3%. As shown in Fig.2[(2)], the water used at CSC totaled 48820 x 10^3 m^3 in which the inputs (including power plant cooling) were mainly from makeup water (98.1%) with small amounts from rain water (0.6%), purchased condensed water (0.5%) and tap water (0.8%). The outputs mainly come from evaporation loss (56.4%), effluent (30.6%), with the remaining from yard spray or BF (Blast Furnace) slag quenching (8.6%) and sold steam (4.5%).

2.3 Carbon MFA

The carbon inputs at CSC's Hsiao Kang factory are much more diversified, as shown in Fig.3[(3)]. The carbon via emissions, totaled 5719.7 x 10^3 tons carbon (91.7%), is equal to the total carbon inputs 6234.6 x 10^3 tons (100%) minus other carbon outputs 514.9 x 10^3 tons (8.3%).

2.4 CaO MFA

The main CaO inputs and outputs are shown in Fig.4[(4,5)].

It can be seen that the major inputs of CaO are limestone/marble (62.7%), dolomite (13.8%) and lime (10.3%), whereas the CaO outputs are mainly BF slag (62.3%) and steelmaking slag (26.1%). Ground Granulated BF Slag (GGBS) can be used as a major constituent of cement or as an addition in cement clinker with low costs. Hence BF slag becomes an important carbon reduction material and its sales have no problems in the present climate. However, the steelmaking slag is becoming the main problem and is very difficult to find suitable utilizations in Taiwan. Therefore, studies on the proper uses of steelmaking slag are considered critical.

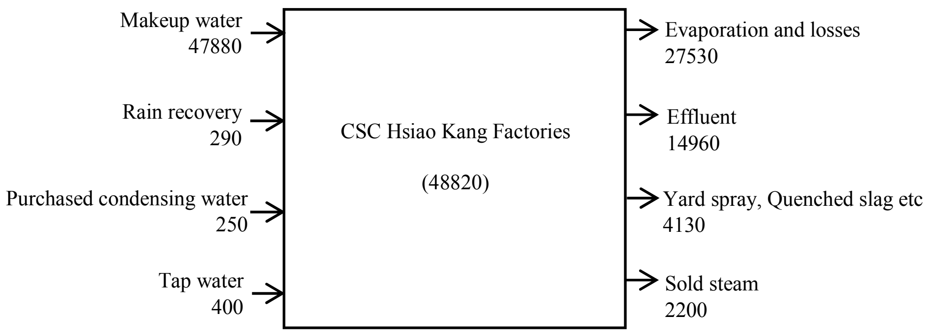

Fig.2. Water MFA in 2013 (Unit: 10^3 m^3).

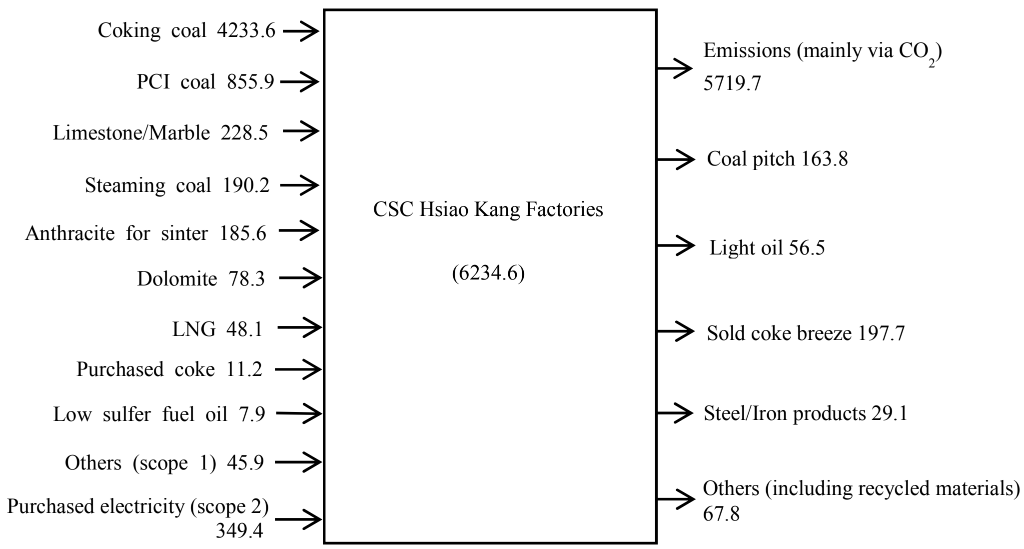

Fig.3. Carbon MFA in 2013 (Unit: 10^3 tons, does not consider coke storage).

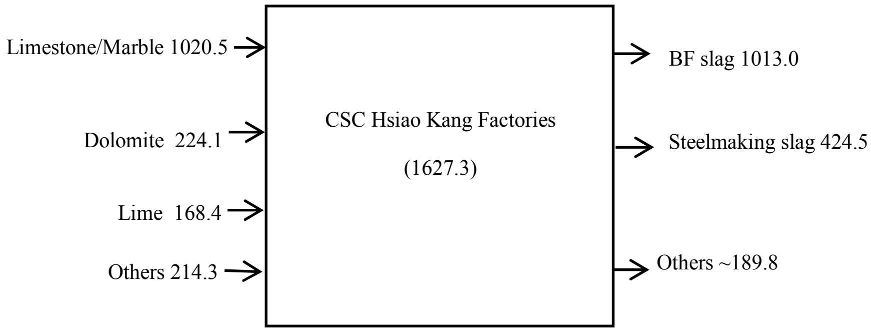

Fig.4. CaO MFA in 2013 (Unit:10^3 tons).
(CaO content estimates: limestone/marble ~53.6% CaO, Dolomite ~33.9% CaO; Lime ~90.0% CaO; BF slag ~41.0% CaO, Steelmaking slag ~43.0% CaO; BF slag and Steelmaking slags have ~5% more moisture)

2.5 MgO, Al_2O_3 and SiO_2

The material flow of MgO, Al_2O_3 and SiO_2 are similar to that of CaO with different input emphases. For example, dolomite and serpentine are the main inputs for MgO, iron ore and coal fly-ash are the main inputs for Al_2O_3, while iron ores, serpentine and gravel/sand are the main inputs for SiO_2. The outputs of MgO, Al_2O_3 and SiO_2, like CaO, are also mainly BF slag and steelmaking slag. Therefore, the bottleneck lies in steelmaking slag at CSC.

3. DISCUSSIONS

3.1 Water MFA and Intensity

Since adaptation to extreme weather becomes more and more important for the future because of global warming effects, it is desirable to reduce water risks by diversifying water supply. Alternative makeup water will come mainly from treated sewage. Other supplies include subsurface water and/or desalinization of sea water.

The makeup water in Fig.2, 47880 x 10^3 m^3, is a little higher than 45554 x 10^3 m^3 shown in Fig.1. The reason is that the boundaries are a little different: Figure 2 includes sold steam to nearby chemical plants, sold water to China Steel Chemical Corp. (CSCC) etc, while Figure 1 only discloses the water consumed in CSC processes. The intensity of the latter is 5.24 m^3/ton crude steel, including the water used for power plant cooling.

3.2 The purpose of CO_2- Inventory

CO_2- Inventories can be used for the following two purposes:

(1) National CO_2- Inventory: it is only required to add up all direct emissions (scope 1). It should be noted that CO_2 emissions embedded in purchased electricity (scope 2) or sold energy products (scope 3) are only indirect and are all cancelled out in calculating National CO_2- Inventory.

(2) Business' CO_2- Intensity: scope 1, scope 2 (purchased energy) and scope 3 (credits) CO_2- Inventories are all required for this purpose since they are what actually happened. worldsteel[6] and GHG Protocol (Draft)[7] also suggested that credits should be considered in scope 3.

It's quite reasonable to describe scopes 1, scope 2 (purchased energies) and scope 3 (sold energies) separately in CO_2- Inventories and use them differently according to the purpose.

3.3 Interferences in CO_2- Intensity

At CSC, the trend of CO_2- Intensity and CO_2- Inventory in 2010 to 2013 can be shown in Fig.5, both taken from disclosed CSC 2013 Corporate Sustainability Report (CSR)[8]. It is quite apparent that the CO_2- Intensities from 2010 to 2013 show a different trend to that of CO_2- Inventories.

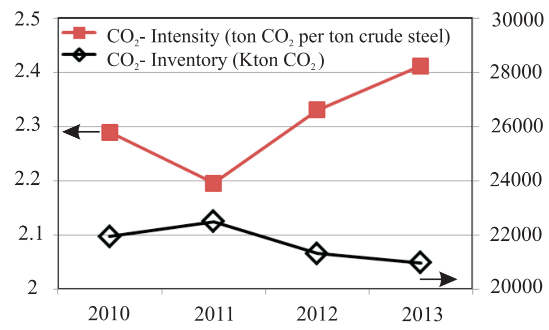

Fig.5. CO_2- Intensity and CO_2- Inventory in 2010-2013.

This CO_2- Intensity trend is very peculiar since energy saving and CO_2 reduction have been a primary concern over the last years. Therefore, some doubts have arisen about the interferences of CO_2- Intensity for 2010 to 2013. The CO_2- Intensity and CO_2- Inventory can be expressed as shown in Eq.(1) (with the same boundary):

$$CO_2\text{- Intensity} = (CO_2\text{- Inventory})_{CSC\ Plant} \div (\text{Crude Steel Production})_{CSC\ Plant} \quad \cdots\cdots (1)$$

The main interferences on $(CO_2\text{- Inventory})_{CSC\ Plant}$ (i.e. the numerator of Eq.1) can be discussed as follows (other interferences are small and negligible at CSC, e.g. in rolling stainless steel or from raw materials):

(1) In-plant coke storage: In an integrated steel mill, it is usually assumed that in-plant coke storage is equal. But this assumption is no longer held in a case where extra coke is stored (extra coke storage means CO_2 is not emitted even if coals are consumed). This is especially true when a BF is relined over a longer period of time and the coke storage is increased. The adjustments were already made for 2010 and 2011 but not for 2012 or 2013, therefore the adjustments for 2012 and 2013 for in-plant coke storage are reasonable(9), corresponding to +0.017 and -0.041 tons/ton Crude Steel in CO_2- Intensities.

(2) Energies sold to Nearby plants: Sold energies known as "Energy Integration (or Energy Synergy)" has been a major means to increase energy efficiency at CSC. The sold energies at CSC could be covered as scope 3 (credit) in a CO_2- Inventory, as suggested by worldsteel(6) and GHG Protocol(7). If this credit were considered in the 2010 to 2013 CSC CO_2-Inventory, they would introduce -0.058, -0.053, -0.062 and -0.058 tons/ton Crude Steel in CO_2- Intensities respectively(10).

(3) Purchased scrap steel: Purchased scrap steel emits much less CO_2 than iron ore or pellet, and therefore decreases $(CO_2\text{- Inventory})_{CSC\ Plant}$. This can be seen more clearly from Figure 6 where the main inputs and outputs of Fe are shown. The gradually decreased purchased scrap from 313 x 10^3 tons in 2010, 210 x 10^3 tons in 2011, 60.3 x 10^3 tons in 2012 and 72.2 x 10^3 tons in 2013, will show its effect on Fe-MFA (Fig.6).

The energy difference between scrap steel and iron ore is taken as 15402 MJ/ton (or 3683 MCal/ton)(11). For a more fair comparison, the purchased scrap steel is taken as 0%.

(4) Degree of cold rolling: Extended cold rolling not only increases in-plant scrap (hence the decrease in purchased scrap) but also increases energy consumption per ton of crude steel, while keeping $(\text{Crude Steel Production})_{CSC\ Plant}$ the same. Therefore, extended cold rolling results in an increased CO_2-Intensity. The degrees of cold rolling are 31.0%, 37.7%, 40.8% and 43.7% respectively for 2010 to 2013(12) at CSC. In order to avoid this interference, the adjustments are based on 0% cold rolling (100% hot roll).

(5) Purchased crude steel or roll: This increases the numerator of Eq.1 but not its denominator. Therefore, the adjustment to 0% purchased crude steel or roll would be more rational. The quantity of purchased crude steel or roll is routinely reported(13) while 380 MCal/ton of crude steel or roll is estimated(14).

(6) Crude Steel Production: The crude steel production may also contribute to CO_2 intensities as one can imagine. The crude steel production of CSC(12) in 2010 (to 9.582 million tons), 2011 (to 10.244 million tons), 2012 (to 9.143 million tons) and 2013 (to 8.694 million tons) were quite different because of market conditions and some of the BF's were being relined. But this effect is not quantifiable for the time being.

By adjusting (1) to (5), the CO_2- Intensities will become 2.165, 2.068, 2.176 and 2.175 tons/ton Crude Steel for 2010 to 2013. A more detailed study about the rationalization process and a proposed standardization of CO_2- Intensity will be presented elsewhere(15).

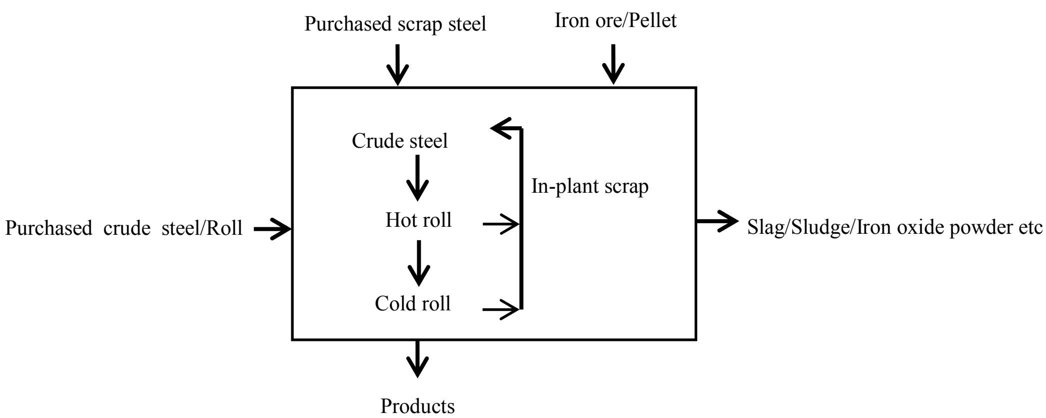

Fig.6. Purchased scrap steel v.s. iron ore/pellet in the main Fe-MFA.

3.4 Steelmaking slag

From sections 2.4 and 2.5, it can be noted that steelmaking slag is the output bottleneck at CSC for CaO, MgO, Al_2O_3 and SiO_2. Since the uses of steelmaking slag in suitable applications are also quite important in European Union countries, its advances in using steelmaking slag[(16)] and the Waste Framework Directive[(17)] can be used as sources of good reference. A detailed study on how the major countries are using steelmaking slag was also reported in a different article[(18)].

Among the possible uses, steelmaking slag is easy to contaminate the soil, hence the rational revision of soil pollution regulations in Taiwan is considered critical. The background of this revision, the global trend of soil control regulations, as well as some suggestions are also reported in a more focused way[(19)].

4. CONCLUSION

(1) The main inputs and outputs as well as water, carbon, CaO MFA at CSC are reported for 2013. The intensities of water and CO_2 as well as the importance of finding suitable outputs for steelmaking slag are discussed.

(2) There are interferences in CO_2- Intensities over the last few years. The interferences include in-plant coke storage, sold energy products, purchased scrap, degree of cold rolling, purchased crude steel/roll, and crude steel production. The adjusted CO_2- Intensities are 2.165, 2.068, 2.176 and 2.175 tons/ton Crude Steel for 2010 to 2013, excluding the influence of crude steel production.

(3) Output of steelmaking slag is quite critical to the MFA of CaO, MgO, Al_2O_3 and SiO_2. The possible uses of steelmaking slag need to be dealt with more urgently and carefully. Since steelmaking slag is easy to contaminate the soil, a rational revision of the soil pollution control regulations in Taiwan is considered important.

REFERENCES

1. 2013 Corporate Sustainability Report of CSC, China Steel, p. 10 for quantities of Production of Crude Steel and p. 39 for Inputs and Outputs for 1.0 ton of Crude Steel.
2. Ibid, p. 69 Water Balance Diagram.
3. 2010 to 2013 CSC Greenhouse Gas Inventory Report, 99+% of Greenhouse emissions is from Hsiao Kang Factories; CO_2 emission factor for purchased electricity were 0.612 kg/kwh for 2010 to 2011 and 0.532 kg/kwh for 2012 to 2013 (in Chinese).
4. Input Quantities are from “2013 Annual Report of Production Planning Department, Production Division of CSC”, p. W7-27 to 28 “Annual Raw Material Consumption Report”.
5. Output Quantities are from “2013 Corporate Sustainability Report of CSC”, China Steel, p. 50, Major By-products.
6. worldsteel, CO_2 Emissions Data Collection User Guide, Version 6. https://www.worldsteel.org/dms/internetDocumentList/downloads/steel-by-topic/Data-collection-user-guide_v6/document/Data%20collection%20user%20guide.pdf
7. Guidance for Calculating Scope 3 Emissions, Draft For Public Comment, 08, 2011. http://www.ghgprotocol.org/files/ghgp/tools/GHG%20Protocol%20Guidance%20for%20Calculating%20Scope%203%20Emissions%20-%20DRAFT%20August%202011.pdf
8. 2013 Corporate Sustainability Report of CSC, China Steel, p. 62 GHG emission trend.
9. 2010 to 2013 Financial Annual Inventory Reports of CSC (in Chinese).
10. 2013 Annual Energy Report, p. 32, Greenhouse Reduction Effect of Sold Steam (in Chinese).
11. worldsteel, Enery Use in the Steel Industry (2014), p.163 average energy intensity is 22164 MJ/t slab, and p. 165 Table 10.1 Energy Intensity for EAF (100% scrap steel) is 6762 MJ/t.
12. 2010 to 2013 Annual Report of Production Division, China Steel, p. W-1 (in Chinese).
13. 2013 Annual Report of Production Planning Department, Production Division, China Steel, p. W7-13 (in Chinese).
14. 380 MCal/ton of crude steel is estimated from 2013 Annual Energy Report (in Chinese), published by Energy Conservation Committee of China Steel.
15. K. C. Liu, Rationalization of CO_2-Intensity at CSC, A presentation in 2014 ASEAN Iron and Steel Forum, 24 to 26, November 2014, Singapore, South East Asia Iron and Steel Institute.
16. Position Paper on the Status of Ferrous Slag, European Slag Association and European Steel Association (2012). http://www.euroslag.com/fileadmin/_media/images/Status_of_slag/Position_Paper_April_2012.pdf
17. EU Directive 2008/98/EC on waste (Waste Framework Directive). http://ec.europa.eu/environment/waste/framework/
18. K. C. Liu, Trend of Soil Pollation Standards of Chromium in Major Countries--Also Discussing Steelmaking Slag Uses and a proposal for Soil Pollution Prevention, Taiwan Steel and Iron Association, Special Edition for its 50th Anniversary, 2013 (in Chinese).
19. K. C. Liu, to be published as “Rationalization of Soil Pollution Control Standard in Taiwan”, Technology and Training, China Steel, vol. 39, no. 4, 2014 (in Chinese). □