Material Flow Analysis to Optimize Production Process in Thermal Power (Case Study in Vietnam)

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Abstract

The purpose of this paper is to analyze the material flow in Viet Nam thermal power plants (TPP). Research is based on the material flow theory, the material balance for effective management of the production and material wastes during the manufacturing process. By analysing the case study in Quang Ninh TPP and Pha Lai TPP, this article identifies the flow of coal (the main material in TPP) as a basis for determining losses for business and society, from that we recommend some solutions to optimize the material flow and minimize the impact on the environment caused by using coal in TPP.

Keywords: Material flow analysis, Thermal power plants, Environmental impact.

1. Introduction

In Viet Nam, the TPP, under construction or in operation have all the characteristics of coal-fired technology when starting the boiler or when the boiler in low power. Twenty TPP in operation discharged more than 15.7 tons of ash slag and gypsum each year. Therefore, the TPP are always interested in research of production tools and management to best reponse the demand of customer and society, to minimize negative impact on the environment and to ensure sustainable production for the economy.

The production process in the enterprise is considered as a process of moving the material. In other words, this system includes a material flow that creates added value (from the input material through special manufacturing process to distribution of products to consumers). According to process management, manufacturing business is considered as a process of moving material. Material Flow Analysis – MFA is an important tool for managing production process through tracking the movement of materials that constitutes the product and waste. This tool also shows the impacts of each stage of material use on the environment. Research of material flow analysis can toward the whole economy, economic areas, enterprises or each type of material, each type of product or some kind of material.

Determining the flow of coal in the TPP could help to optimize the materials flow, reduce the wastage for enterprises and society. The paper will focus on: (1) The theory of MFA and material flow optimisation; (2) analyze the case study of the MFA in Quang Ninh TPP and Pha Lai TPP (coal-fired thermal power plant); (3) wastage of coal flows in TPP and solutions to reduce material losses and mitigate negative environmental impacts.

2. Optimizing materials flow during production and using materials flow analysis

2.1. Optimising materials flow during production

Materials are essential inputs to production. Therefore, enterprises need to research and develop materials flow analysis (MFA) during manufacturing processes in order to optimize company’s resources. According to the author's synthesis, some of the most commonly used approaches to materials flow optimization are presented below:

According to (Marko Starbek 2000), materials flow optimization is proposed through a management tool called materials flow analysis (MFA). MFA reflects the production system of the company and its value is determined at different levels in the organisation.
This tool is based on technology and information database to assess the flow of materials during various manufacturing phases. It could help the company to minimise the production costs.

The time for moving the materials among a manufaturing process is usually accounted for 95% of the working time and 5 % of the executive time in which 30% for real production and 70% for setting up machinery system, putting materials into production or standing by.

The purpose of MFA is to etablish a model to locate materials based on how these materials distribute or impact the manufacturing process. Following the flow of materials, organisational structure as well as business decisions could prepare technologies or etablish departments to support. The appropriate materials flow also results in production activities without technology involved (Marko Starbek 2000).

Support activities do not change the qualitative nature of the product formed in stages (eg, mechanical, chemical, electrical or plastic stage). However, they contribute significantly to the total production cost. Since the actual support activities are inefficient and are not counted towards the direct cost of final product, they must be reduced to a minimum.

2.2. Using materials flow analysis

MFA evaluates the efficiency of using materials and then determines wastes generated from certain resources and materials. According to (Brunner 2005), MFA is considered as a systematic assessment system that is performed on materials flow and materials in inventory within a certain range of scope and time. MFA ensures the connection between the material stock, the movement and the destination of materials flow. With the balance physical, MFA could be controled by comparing the analytical results of materials inflow, materials in inventory and materials outflow during production. Therefore, MFA can become an useful tool to guide decision making in resouces managemnt, wastes and environnement. However, while MFA focuses only on researching and analysing the volume of material (physical volume), monetary information is an important factor of making decision process.

Within enterprises, the physical balance of inputs and outputs is used more as part of environmental reports and provides significant information for environmental management. MFA is useful for developing the monitoring process in assessing the resoucre productivity and environmental performance at enterprise or factory level.

Furthermore, MFA helps to establish company's strategies for investment, emission; monitors available precious resources as well as the detriment of business or factory to supply chain discontinuation. The MFA of an industrial material such as metals could give more explaination for some definitions like resouce productivity and the relation with the working productivity, the materials price as well as the competition.

According to previous reseaches, MFA consists of material flow cost accounting (MFCA) and material flow indicators. Material flow accounting (MFA) is an accounting system using volume measurement (kilogrammes, tons) to describe materials flow from exploitating, manufacturing, processing, distributing to recycling scrap like wastes or gases emission into the environment (OECD 2009).

(i) Material flow cost accounting (MFCA) includes the elements such as inputs, output and materials in stock. MFCA monitors all the inputs of manufacturing process and measures the product as well as materials loss within physical units by using the ollowing equation:

Input = Product + Loss of raw materials (wastes)

Through MFCA, the material balance of input and output is linked to monetary units by allocating and / or tracing costs to all products and material losses. MFCA carries out four types of costs, all of which are allocated to both the product and the material loss:

- Material costs;
- Energy costs;
- System costs; and
- Waste management costs.

(ii) Material flow indicators (MFI) is calculated from accounts in the MFA accounting system (direct materials, total demand for materials and total used materials) to get a message across policies related to interesting parties (possibly not an expert) on the meaning of the material flow for economic and environmental issues.

According to (Marko Starbek 2000), the analysis of materials flow needs to be focused more in order to optimise the manufacturing process. Previous research has shown that MFA is based on macro analysis and micro analysis.

(i) Macro analysis: analyse the flow between pre-determined parts. It is considered as a standard materials flow. All stages during the production included direct and support activities need to be identified. The objectif is to clarify the movement of materials going into product from different stages and the fulfillment of technological requirements without etablishing in a single part.

(ii) Micro analysis: analyse in detail the movement of materials going into product manufactured by small groups of production; gather groups related to manufacturing components and production equipment from departments. This is effectively done through the MFA.

The materials flow in manufacturing companies could show how well the system of the company is organised. The material flow could also give a clear picture of the quality and the way the technological department contributes to the production. The final objective of MFA is to get a simplification of materials flow in the company. Some benefits of MFA are: getting higher productivity; reducing moving time of materials; simplifying production management, reducing stocks of materials. In addition, the modification perfomed by the MFA would ensure the minimum quantity of finished product if there is an unique production group.

The measurement of material flows could allow the company to switch from centralised production to cell production in which each team or 'cell' is responsible for a significant part of the finished article. Cell production may allow a firm to produce at various scale with the lowest time needed to prepare the production.

MFA is among the most useful management tool for a company. By determining the model of MFA, wastes in each stage of management, material movement and environmental impacts are appropriately identified.

2.3. Material flow cost accounting (MFCA) – a tool for optimizing cost management and wastes

According to (Hargroves 2012), MFCA does not only provide meterial information on MFA but also link this information to its value. This could result in clearly identifiing inefficient production during stages for the management.

The main purpose of MFCA is to save cost and reduce environmental impacts caused by enterprise's activities. It could also be served as a decision-making tool for corporations and managers. In fact, balance is the main principle of MFA. It means that the total inputs needs to be equal to the total outputs which is divided into two categories: production (semi-finished or finished products) and non-production (wasteful resources or recycled materials). In other words, the total inputs cost is equal to the total production and non-production cost.

Research in Taiwan's small and medium enterprises (SME) conducted by (Shen-Ho Chang 2015) has proven that MFCA is a feasile and useful tool for decision-making. The MFCA could also help to reduce the likelihood of abnomal decisions and determine which steps of stages need to be improved. Faulty products is a damage in the manufacturing process. Therefore, limiting these products by setting up checking points at the production stages will have a great effect on detecting defective products for reparation at that stage. This will reduce the cost of wastage at later stages of processing. A direct connection is created by the valuation on the same basis of data based on material information. This could provide more accurate and useful information for decision-making and control of output.

MFCA can be applied to identify production costs and material losses. In many cases, costs are more significant than previously assumed. At the same time, MFCA sets a final goal of "zero cost of material losses", which could encourage organizations to make promptly a revolutional improvement. Typical losses identified by MFCA are:

(1) Cost of waste treatment for material losses;

(2) Loss of materials sold to external recycling contractors;

(3) Systematic material losses: labor, depreciation, fuel, utilities and other expenses;

(4) Systematic cost needed to recycle materials internally

(5) Costs of materials and systems for products in stock, processed materials due to conversion to newer models or bad quality or expired products.

In reality, there is a few companies that control its auxiliary materials. Normally, these materials are controlled by a process or an equipment without valuation of inputs (and wastage). In some cases, auxiliary materials are carried out within the unit of production. The overall waste treatment cost is generally managed on a factory classified by type of waste. However, some companies determine such costs by type of material, product model and type of process. In addition, these companies have often no idea of the damages associated with reusable wastes because those are reused as resources and sometimes sold as valuable materials outside.

3. Material flow analysis in thermal power plants and meterial flow model in Vietnamese thermal power plants

3.1. Macro analysis of material flow in thermal power plants

According to (Bercen 2003), material flows and mateial losses in coal-fired thermal power plants are described below:

With the steam

Within TPP, the working process is almost done in a steam engine. During the process, water is heated, turns into steam and spins a steam turbine. In this turbine, heat energy is converted into mechanical energy which is used for generating electric power as the final product.

Energy generated will be used in the form of supplied water, evaporated water and condensed water. In this process, material problems could involve: temporary discharge of steam from the exhaust valve and safety equipment; removal of boiler sludge, drainage from water pipes and engine housing.

With the coal

The main raw material used to generate electricity in the TPP is coal, which is taken from the coal mine of the near-surface mining area. When using coal, some matters of wastes generated by processes are:

- Evaporation of water and volatiles due to the drying of coal in the open discharge area
- The release of dust from the open discharge area
- The creation of dust from the conversion and transportation of coal in the transportation system

With the crude oil

Crude oil in the TPP is used as an additional fuel when starting as well as in the plant that supports coal combustion. Especially in conditions where the coal is supplied to the combustion chamber / burner with low heat, or if the coal has a high non-flammable component (usually for high percentage coal), the only raw material used is crude oil.

With the gases

During combustion, a mixture of gases is formed, depending on the type of fuel used, its chemical characteristics and how it is combusted. Raw materials and materials are part of the combustion process including: coal, crude oil and air

Depending on the amount of output, structure / volume, physical and chemical properties of the basic elements of the waste, gas is one of the major polluting factors for the operation of thermal power plants. Exhaust gases, such as aerosols, may be components of: O2, CO2, CO, SO2, CO3, NOx, H2O ..., solid waste.

With the ash and slag

Ash and slag are products of combustion. Ash and slags include machinery and components where separate ash and slag are collected from the base gas stream with ash and slag for transportation to the open waste disposal area.

In reality, this is the collection, transportation and disposal of toxic substances, the materials used in this unit are: oils and lubricants, Air for lifters and air to moisturize ash transportation.

3.2. Characteristics of Vietnamese thermal power plants

According to the Power Planning VII, in the coming time, many large power centers will be built and put into operation such as Duyen Hai, Long Phu, Song Hau, Van Phong, Vinh Tan, Quang Tri, Vung Ang, Quang Trach, Nghi Son, Nam Dinh, Thai Binh, Hai Duong, etc.. This increase significantly the power generating capacity from thermal power sources. Total coal-fired thermal power capacity in 2020 will account for 48% of total installed capacity, producing about 46.8% of the electricity for manufacturing. By 2030, the figures are 51.6% and 56.4 % respectively. The total capacity of natural gas (including LNG) used by 2020 will account for 16.5% of the total installed capacity, producing about 24% of the electricity for manufacturing; by 20230, the numbers are 11.8% and 14.8% respectively.

By 2020, the total capacity of thermal power plants (coal and gas) will be planned about 64.5% of the total installed capacity, producing about 70.8% of the electricity and by 2030 the figures are 63.4% and 71.2% respectively. In TPPs, high fuel costs typically account for 53% of COGS. For coal-fired thermal power plants, coal is the main fuel (about 50% of cost price).

3.3. Characteristics of materials used in coal-fired thermal power plant

The main raw material in the TPP is coal. When coal is used for electricity generation, it is usually pulverized and then burned in a furnace with a boiler. The furnace heat converts boiler water to steam, which is then used to spin turbines which turn generators and create electricity.

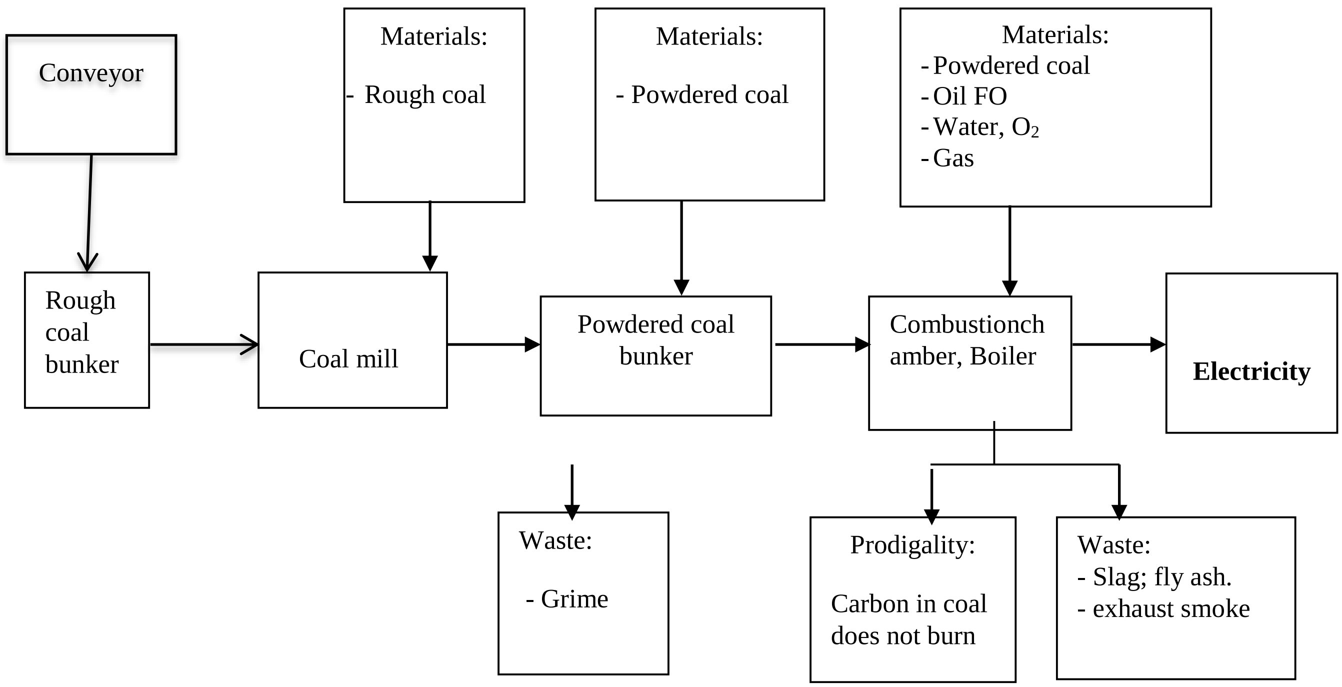
A coal-fired TPP consists of two main components: a boiler cluster that produces steam and a turbine-generator cluster to convert steam energy into electricity. There is also an auxiliary boiler for factory startup; cooling water system; fuel preparation system (coal storage, conveyor belt, coal mill); pneumatic production system; fly ash recovery system, bottom ash gathering, dust filtering and waste gas treatment.

3.4. The meterial flow model in Vietnamese thermal power plants

Coal is the main material of electricity production process in TPP. Rough coal is transported by conveyor direct to coal mill system or to coal bunker (indoor bunker or outdoor bunker). From the coal bunker, the coal is also transported to coal mill system by conveyor. Rough coal is dried, crushed, screened to size the diameter of coal powder less than 200 μm and transported to powdered coal bunker. Powdered coal is transported to the burners located in the combustion chamber by powdered coal supply at the bottom of the powdered coal bunker. Hot air pressure will push the coal into the combustion chamber to burn. There are powdered coal bunker at Quang Ninh TPP and at the first chain of Pha Lai TPP. At the second chain of Pha Lai TPP, the powdered coal from coal mill system is transported directly to the combustion chamber.

Products of the powdered coal burning process in combustion chamber consist of slag, fly ash, and exhaust smoke discharging through the slag disposal system at the bottom of the boiler and through the chimney. By the high pressure water pump, slag is pushed up the slag damp. Here, under the contract for selling slag, the slag is sold to units with different needs. Fly ash is retained by an electrostatic filter and stored in silos. Here, under the contract for selling fly ash, the fly ash is sold to units with different needs. Fly ash and slag are mainly used in construction. A part of the fire product as gas (SOx, NOx) are eliminated and retained by an desulphurization system (FGD) and by an NOx elimination system (SCR). The last remaining of fire product is exhaust reached environmental standards is pushed to the atmosphere.

Diagram 1: Model of coal flow analysis in thermal power plant



(Source: research by authors)

According to the actual survey of two Vietnamese TPPs, the MFA model is summarized in the Figure 1. In these plants, departments where manage materials are: Board of Directors, Department of material Planning, Department of engineering, Fuel plant, Boiler. During the process of electricity production, the waste comes mainly from: carbon in the un-burning coal; Emissions from slag, fly ash and flue gas. Waste (in technical terms is loss) is highly valued at the coal combustion (boiler). The highe rate of carbon in un-burning coal causes big waste in thermal power plants. The rate of non-standard burning is 6 - 7%, but the actual rate is higher and causes coal waste (loss) at the TPP.

According to materials flow model, the manufacturing process of electrical products consists of three stages as follows:

Stage 1: receiving charcoal from supliers, then transferring charcoal to the coal bunker (coal containing coal) for each coal mill to produce powder coal.

Stage 2: Then, powder coal is transferred to powder coal storage.

Stage 3: Charcoal in powder coal storage is moved to the combustion chamber of a boiler.

The powder coal is burned at this stage to generate electricity.

Materials flow like input fuel, output, material efficiency are managed at each stage of the main production process. Therefore, each manufacturing stage of this system is selected and identified as a production center for data collection used in MFCA.

Material waste is found in two stages:

(i) Coal mill:

- Coal losses: due to coal spillage during coal milling and transportation.
- Waste: Coal dust and impurities in the coal.

(ii) Coal burning:

- Coal losses: due to burning coal
- Waste: coal during combustion produces slag, fly ash and gas losses.

Currently, Quang Ninh TPP determines the materials cost and other expenses of the Company from 2014 to 2016 as follows:

Table 1. The summary costs of Quang Ninh TPP from 2014 to 2016

	Contents	Unit	2014		2015		2016	
			Cost	(%)	Cost	(%)	Cost	(%)
(1)	*(2)*	*(3)*	*(4)*		*(5)*		*(6)*	
I	**Actual sales**	**Million kWh**	**5,624**		**5,692**		**6,458**	
II	**Costs**	**Million vnd**	**7,316,227**	**100**	**7,569,465**	**100**	**8,107,362**	**100**
II.1	**Material costs**	**Million vnd**	**4,451,827**	**60.85**	**4,402,693**	**58.16**	**5,017,120**	**61.88**
1	Coal *(Consumption + Starting)*	**Million vnd**	4,151,117	56.74	4,217,618	55.72	4,796,314	59.16
2	Limestone	Million vnd	177	0,00	489	0.01	411	0.01
3	Bi grinding machine	Million vnd	17,811	0.24	17,777	0.23	18,951	0.23
4	Chemicals	Million vnd	3,545	0.05	7,897	0.10	4,766	0.06
5	Lubricants	Million vnd	6,782	0.09	6,632	0.09	5,636	0.07
6	FO oil (incineration + starter)	Million vnd	244,957	3.35	114,767	1.52	93,332	1.15
7	DO oil	Million vnd	319	0,00	104	0,00	12	0,00
8	Supplies for regular repairs	Million vnd	27,118	0.37	37,409	0.49	97,699	1.21
II.2	**Energy costs**	**Million vnd**	**58,119**	**0.79**	**96,247**	**1.27**	**42,125**	**0.52**
1	Idustrial water	**Million vnd**	3,256	0.04	2,697	0.04	2,975	0.04
2	Self-produced electricity for production (included technical electricity)	Million vnd	54,862	0.75	93,550	1.24	39,150	0.48
II.3	**Oher expenses**	**Million vnd**	**2,803,011**	**38.31**	**3,067,624**	**40.53**	**3,045,165**	**37.56**
1	Salary costs	Million vnd	135,979	1.86	162,739	2.15	222,040	2.74

	Contents	Unit	2014		2015		2016	
			Cost	(%)	Cost	(%)	Cost	(%)
(1)	*(2)*	*(3)*	*(4)*		*(5)*		*(6)*	
2	Depreciaton of fixed assets	Million vnd	1,697,915	23.21	1,950,838	25.77	1,954,219	24.10
3	Oher fixed costs	Million vnd	82,369	1.13	59,785	0.79	93,961	1.16
4	Financial costs	Million vnd	886,747	12.12	894,261	11.81	774,944	9.56
II.3	**Waste treatment costs**	**Million vnd**	**3,271**	**0.04**	**2,901**	**0.04**	**2,952**	**0.04**
1	Responding to oil spills	Million vnd	785	0.01	573	0.01	569	0.01
2	Garbage collection, waste treatment	Million vnd	683	0.01	742	0.01	602	0.01
3	Environmental sanitation Fine	Million vnd		0,00		0,00	360	0,00
4	Transportation of waste	Million vnd	452	0.01	342	0,00	274	0,00
5	Insecticide	Million vnd	425	0.01	398	0.01	383	0,00
6	Cleaning the ash	Million vnd	926	0.01	846	0.01	764	0.01

(Source: research by authors)

The application of MFCA at Quang Ninh TPP from 2014 to 2016 results in some figures on material and production costs as follow:

-Costs of raw materials of the Company include: coal, FO oil, DO oil, limestone, chemicals, grinding machine and supplies for regular repairs. Cost of raw materials accounts for the largest proportion of the total cost (from 58% to 62%) according to MFCA method. Among the cost of raw materials, the cost of coal accounts for 55% - 60% of the total cost, and the figure for fuel oil costs is 1.15% - 3.35%.

- System costs include: labor costs, depreciation of fixed assets, interest expenses, other fixed costs, maintenance and transportation costs. These cosrs account for from 37% to 41%, of the total cost according to MFCA method. In order to save money on this system, it is necessary to take controls from the purchase of input assets in the construction stage of the company.

- Energy costs in the Company such as electricity, water account for a small proportion of 0.5% - 1.3% of the total cost according to MFCA method. However, in number, the expenses represent relatively high cost (VND58.1 billion in 2014 and VND96.2 billion in 2015 and VND42.1 billion in 2016).

- Waste management cost: is the expense for "material wastage incurred in a volume center". Waste management includes management of emissions, sewage and solid waste. Waste management costs are the costs of carrying out activities within and outside the organization such as refurbishment of unsatisfactory products, recycling, waste tracking, storage, treatment or disposal. . In Quang Ninh TPP, the cost of waste includes some main types such as oil spill responding costs, garbage collection, waste treatment, waste transportation, insecticide cost, ash removal costs or environmental sanitation costs. Annually, the waste costs represents a very small proportion of the total cost, only 0.04%.

3.5. Assessment waste in material flow analysis in Vietnamese Thermal Power Plant

In general, coal wastes are incurred in two principal stages: Coal mill and coal burning at two thermal companies (Quang Ninh TPP and Pha Lai TPP). At Quang Ninh TPP, coal wastes are arised in coal burning. According to the survey, wastes are existed when coal is not burned fully in the boiler. The main causes are dued to the technology of bolier. The benchmarking unburned coal is 6-8% but it is difficult to achieve this rate. At Quang Ninh TPP, the real rate is 9 -15%. At Pha Lai TPP, the production line No 2 is better than the No1 and it has achieved the benchmark, but in the production line No 1 has been 17-18%.

According to the Table 1, wastes have not calculated fully, especially wastes are incurred from unburned coal, coal price (the price is fixed by government), movement coal.

4. Conclusions

MFA is a management tool to reduce waste in usage material and environmental impact. TPPs should apply MFA to ensure the physical balance, calculate full wastes, electricity cost and material losses. Using case study at two TPPs in Vietnamse North, the paper summary the stages and the manafuring costs to quantify the impact of material flow. Some causes of wastes are identified to require some adjustments in management of material flow (coal).

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