Sustainable plastic waste management strategy: Optimization of plastic manufacturing plant waste (gas and product transition)

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Abstract. Production waste management has become the key to a sustainable manufacturing operation strategy. This study aims to analyse the waste gas and production waste from the polymerization process, especially the residual exhaust gas from the degassing unit and the final product from the product transition process that does not meet the requirements. Research using qualitative and quantitative methods. The analysis is done by calculating the amount of gas removed from the sweeping or degassing process and calculating the material balance of the production process to analyse the process loss. The results show that the largest contributor to the waste gas is from the degassing process and the pellets from the transition products. In addition, an optimization process is needed to recover exhaust gas with a recovery system and perform a trimming process or a mixing process to reduce the transition product to become prime product.

1. Introduction

Plastics are produced through the polymerization of synthetic or semi-synthetic materials derived from petroleum, natural gas, or coal. Plastics are composed of various elements such as carbon and hydrogen as the main constituent elements, as well as oxygen, nitrogen, chlorine, and sulphur[1]. Plastics are used for food packaging, industrial and health products, building construction, clothing, electronics, automotive and aeronautics[2]. Given the large need for plastics, the plastic industries also face challenges in handling plastic waste [3]. Since 1960, the cumulative total production of plastics has been estimated at around eight billion tons. Due to its non-degradable nature, unless incinerated or recycled, plastic waste will still exist [4, 5].

The biggest problem in plastic manufacturing plants is waste originating from gas flaring and downgrade products, namely the final product that does not meet specification standards [3]. Disposal of waste needs to be handled with further research, better technology, and more qualified resources so that the sustainability of the plastic industry can generate greater opportunities in the future [5]. This disposal activity is carried out through a series of material testing, recycling policies, and an increasing need for technology to separate and recycle plastic waste. This process will be able to produce secondary plastics that are more competitive than by continuing to consume or use pure polymers [4, 5]. Given that plastic waste is non-degradable, the waste will continue to pollute forever. With the
recycling technology, plastic waste will be reproduced in good quality without relying on the production of new plastic (virgin material).

Plastic waste has become one of the major environmental issues with its main polymer components being polyethylene and polypropylene [6]. Separation of plastic waste into individual polymers is expensive and complete sorting is often not possible. However, plastic waste (off spec product) can be recycled easily by turning it into polymer blends [7]. However, there are major limitations to PP which has a glass transition below room temperature and a high coefficient of linear thermal expansion. Thus, limiting dimensional stability and high temperature applications. One of the promising methods to reduce this deficiency is to blend or trimming polypropylene with thermoplastic techniques [8].

The polymerization process produces waste in the form of waste gas from the polymerization reaction and exhaust gas from the stripping or degassing process [9]. The exhaust gas is then burned in the flare system and then discharged into the atmosphere through flare networks. The main source of air pollution from industry is exhaust gas from the residual polymerization or gas that is intentionally released to maintain pressure when the polymerization process occurs, and from processes when abnormal situations occur such as plant shutdowns. In addition, the increasing demand for oil and gas production in the world results in gas burning or gas flaring [10].

Flaring or combustion from industry cannot be avoided but can be reduced [10]. Several ways to reduce flaring, for example by implementing procedures on how to adjust the process rate to prevent or minimize flaring [11]. The use of flare gas recovery is something that is very important in the industry. In addition to reducing the greenhouse effect and environmental pollution, it is also very useful in reducing costs or costs of hydrocarbon loss. One of the flare gas recovery techniques that can be applied is to change the gas to liquid with the compression method [11, 12].

Limitations of technology, technology costs, company vision and mission, and human mindset are the main factors outside government regulations that can determine a company's policy in managing assets, optimization and contribution to the implementation of waste management [3, 5, 8]. This study aims to discuss how to recycle wasted gas from the degassing process by separating nitrogen, light gases, and hydrocarbons. So that it can be reused in the degassing process and polymerization raw materials using flare gas recovery technology [11, 12]. This study seeks to design innovations on how to reduce or eliminate transitional products using mixing technology or trimming facilities. Based on the background description that has been stated, a way is needed to seek the benefits obtained from placing the flare recovery unit. Especially for sustainable waste management, an optimal strategy is needed to utilize the trimming facility in reducing or eliminating transitional products.

2. Materials and methods

This research uses the integration of qualitative and quantitative methods in the process of data collection and processing. This research was conducted to analyse the work system and process optimization in the flare recovery unit facility as part of sustainable waste management efforts. This study aims to determine the optimal amount of regression in process waste gas so that it can provide benefits both from a financial and environmental side. As well as finding the best solution in increasing the company's profit by utilizing a mixing facility or trimming facility from non-prime products to prime products. This research was conducted in several plastic production companies in the United Arab Emirates as one of the largest plastics producing countries in the world.

The technical method used is in the form of observation and data collection related to the degassing process. Data analysis was performed on monthly reports on energy balance and total gas wasted from each unit including the degassing system unit. Data collection on the number or total of transitional products resulting from each product changeover, the data is obtained from monthly reports where the number of prime and non-prime products is recorded. Monitoring is carried out on the sweeping process between nitrogen gas and hydrocarbons on the DCS (Distribute Control System) life screen to obtain Life Data. The analysis of the current system under study is focused on the degassing system where the exhaust gas from the degassing is the largest contribution of the wasted gas from the polymerization process. In addition, the running system that is optimized in this study is the
production of material transitions when a product change occurs. Data processing is carried out using descriptive graphical models such as pareto charts and fishbone in analysing the main problems and consequences. Data analysis is focused on the degassing process and other activities through graphics and histograms, especially related to reliability, FRU Load, Monthly CO₂ Reduction Chart, Percent HC & N₂ Base on Design Chart, and off grade comparation with or without trimming.

3. Results and discussion

The results of analysis and observation of the degassing system and flare recovery unit obtained data from four polyethylene plants such as the amount of nitrogen sent, the amount of feed gas available, utility consumption such as electricity or power, the cooling system (cooling water, glycol water, propylene refrigerant), plant water, steam, running hours and cost of the production process. Next, an analysis of recover nitrogen and hydrogen is performed and an analysis of the reliability of the system (% online to unplanned shutdown). The scheme and process of the degassing system are shown in figure 1.

3.1 Technical Analysis - Recover Nitrogen and Hydrocarbons

Figure 2 illustrates how the recovery unit provides the ability to recycle gas or feeds that enter the washing unit. The months of March and May, the chart shows zero point. This is because in that month no feeds were received due to the Plant Shutdown. Recovered hydrocarbons and nitrogen are taken from the analyser and smart flow meter from each membrane stage. Meanwhile, tons of recovered N₂/Hydrocarbons are taken from the calculation of recovered nitrogen / hydrocarbons from the flow meter compared to the total production produced per month.
3.2 Technical analysis - reliability of the system (% online to unplanned shutdown)

In Figure 3, there is a very significant difference between 2018 and 2019. In 2018 mechanical failure from compressors contributed the highest to around 76% of the total downtime of 3009 hours from 22 stops, followed by Turn Around about 14.5% and the rest from processes such as clogged filters and gas flow from the washing unit. The pareto analysis result show that the highest bar graph causes the amount of downtime is due to the reasons for both mechanical, electrical and instrument equipment. Damage to the membrane cartridge, rotor, problematic programable logic control, oil leakage, and heater problems are the most important elements that must be resolved.

The flare recovery unit vendor was brought in to repair the FRU system as a strategy to improve the flare recovery unit's performance. Meanwhile, 2019 shows an improvement. The results of the improvements made at the initial stage of start-up, namely in 2018 on the reliability and operability of the FRU, the total shutdown hour became 1503 hours with 15 stops. The results of the analysis for 2019, the shutdown contribution was caused by others causes such as Plant Turn Around which cannot be avoided, roughly 1257 hours. Plant Turn Around (TA) in this company is scheduled once every 5 years. Plant Turn Around itself is something that must be done by a company, especially a manufacturing company, to restore the direction of the company from a decline in performance or to restore company performance.

The next analysis is how to know that the flare recovery unit will last for the future, so the reliability of the flare recovery unit must be much better than the previous year. Figure 4 shows that the reliability of the flares-recovery unit experienced a very significant and stable improvement, except in May and October where plant shutdowns due to process and equipment were frequent. data is taken from 2018 to June 2019, showing that the average reliability is around 94% for 2019.
3.3 Environment Impact - CO₂ Footprint Analysis

Carbon footprint is the amount of greenhouse gas emissions produced by an organization, event, product or individual. To obtain the carbon footprint of the flare recovery unit, the total hydrocarbons recycled are divided by ethylene as the reference gas most contained in this recycling system:

\[
\text{CO}_2 \text{ footprint (kg)} = \left( \frac{\text{HC}_{\text{recover}}}{\text{C}_2\text{H}_4\text{mw}} \right) \times 2 \times \text{CO}_2 \text{ wm} \times 1000
\]  

(1)

Figure 5 show that adding exhaust gas to the flare recovery unit for recycling provides enormous benefits, apart from cost reduction as well as environmental issues. It appears that the greater the ability to recycle hydrocarbons, the more we contribute to reducing emissions, in other words the smaller the amount of CO₂ is wasted if the hydrocarbons are not burned.

3.4 Economic Analysis - Saving of Nitrogen and Hydrocarbon per Ton of Production

Figure 6 shows how the respective percent of nitrogen and hydrocarbon is recycled per month. Percent recovery is obtained from hydrocarbons and nitrogen recovered material against flare recovery recover design value. Hydrocarbon design recover is 2917 ton / month and design recover nitrogen is 5000 kg / month. There are several values on the graph showing a low percent recycled, this is because the factory was in a shutdown that month.
3.5 Economic Analysis - Variable cost Analysis
Design recovery capacity for hydrocarbons that were set was 291 tons and nitrogen at 5000 kg. The optimal operation of the flare recovery unit is the lower the operating costs and the greater the ability to recycle hydrocarbons and nitrogen. When the operating load from recovery is very low the need for utility consumption will remain, so the utility consumption costs will be high. Figure 7 uses the analytical method, from the data points, the regression lines are installed. Both the height R-squared line and the equation can be used to estimate the costs or benefits under different loads.

The break-even point analysis results show the minimum point at which the flare recovery loading or operating load must be or at least 42%. So that the higher the operation or loading of the flare recovery unit, the greater the profit and the lower the production costs. The total benefit line shows equivalent monetary benefits due to hydrocarbon and nitrogen recovery. Whereas the total cost line shows the operating costs of the FRU, excluding labour costs (the same labour is used to manage the FRU) and no additional labour is required.

3.6 Trimming System Data Analysis
Figure 8 shows a monthly comparison of% prime product in plant A and plant B. The trimming facility increases the% prime at both plants for total monthly production showing a significant difference in% prime before and after cutting (p <0.05). % prime increased by an average of 6% to 7% (absolute), which translates to millions of dollars in savings.
Based on several tests that have been carried out in mixing or trimming, it is known that the effect of quality in this case is that the melt flow of the prime product determines the final MFR. The result of methodology regression analysis shows that the quality of the prime MFR has a $p$-value of 0.04 indicating that there is an effect of the MFR value of the prime product which can influence the final value of the final MFR. From the results, a regression equation can be made as follows:

$$\text{Final MFR} = 1.49 \times \% \text{ non prime} \times 0.18 \times MFR_{\text{nonprime}} - 0.29 \times \% \text{ prime} \times 0.8 \times MFR_{\text{prime}}$$

The regression equation results in a prediction of how many final MFRs according to the regression of the final MFR results from offline check or laboratory. Based on available data (production grade mix and the main properties of the grades), a regression equation was developed to approximate the final MFR result based on the volume of non-prime and prime values and MFR of non-prime and prime respectively. Even though, the high $p$-value is close to 0.05 (indicating insignificance of the factors), the regression equation can be used to generally predict the resulting properties when blending or trimming. The regression calculation results show that the final MFR value is very close to the final MFR value generated from the laboratory results. However, it is recommended, however, to perform a regression analysis based on each prime product and the transition product to be trimmed with a higher amount of data.

3.7 Economic Analysis-saving for upgrade of the transition material

The number of material transitions successfully trimmed varies in number, depending on how many products must be produced for each product. In one month about 800 to 1200 tons of transition material are produced as a product change result. The price difference between transitional products and prime products is around 300 dollars per ton. The percentage (%) of material transitions that can be mixed or successfully trimmed is an input or profit for the company.

The more transitional products that can be trimmed, the more prime products that can be produced, thus the number of company savings or profits will increase. Apart from the product cycle, the length of the campaign of the product as well as the efficiency, reliability, and operability of trimming systems such as feeder performance, silo availability and of course online quality reading (online rheometer) must function properly.
Figure 9 shows the monthly savings after trimming between transitional products or it can be called near prime grade and products that have prime quality. Bar graphs show savings equivalent to million dollars while line charts show savings in units per ton of production. In 2018, the use of trimming was more conservative to confirm or prove if there was an influence on product quality. Trimming shows a significant increase in 2019 after the production and marketing parties are quite well established and successful in managing the trimming system operation while maintaining its quality. Savings in the first six months of 2019 were around 200 thousand USD higher than the savings throughout 2018. Apart from achieving a good working method of the trimming system, the difference in the amount of profit in 2019 was also caused by changes in product demand due to variations in supply and demand.

4. Conclusions
Most of the gas and petrochemical factories that have been running still have not utilized recycling technology for exhaust gas and reducing product offs with the trimming system. The flare recovery unit only accepts recycling from the low flare system, still requires further studies on how to utilize exhaust gases from other sources. Optimization of exhaust gas utilization through the flare recovery unit from continuous flaring resulting from the degassing process in the purge bin has a very significant progress. Only the emergency flaring gas cannot be utilized, while the maximum flare recovery unit intake pressure is below 1 bar. Meanwhile for intermittent flaring, optimum exhaust gas is recycled in the vent recovery system.

Trimming system is a solution to reduce or even eliminate transition products, making transition materials into prime products. The more transitional products that can be trimmed, the more prime products that can be produced, so that the number of company savings or profits will increase. In this study, it was found that the average final number of prime products increased between 6% to 7% after trimming. Apart from the role of production planning in scheduling product cycles, the reliability and operability of the trimming system are important factors in reducing or eliminating transition materials.

For further research, it is necessary to improve the flare recovery system process and trimming system. It is necessary to develop standard operating procedures, preventive maintenance and corrective maintenance as important elements that must be maintained. For the final product that passes through mixing or trimming, it is advisable to get one additional treatment in the pellet silo, for example, the addition of blending before the product is bagged or packed.

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