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Pinch Analysis Approach to Determine In-Between Carbon Emission Caps in Production Planning

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Production planning is an essential step to meet the continuous growing demand in the world. During production activities a lot of carbon emission takes place which produces negative impacts to the environment. In order to minimize the negative impacts to the environment carbon emission need to be restricted within certain limits. Practically, these limits cannot be reduced beyond certain values which are governed via technologies available for production. In order to calculate the carbon emission limits, a graphical methodology is presented in this paper. The methodology determines in-between carbon emission capping which provide the limits for carbon emission using pinch analysis while carrying out the production activities. In-between caps are calculated using the Forecasted Emission Demand Curve which provides a clear visualization of the emission via production in the tenure of production planning. Technologies are dynamic in nature and changes in these technologies are very much expected. The proposed methodology is able to include such dynamism of technologies. In order to demonstrate proposed methodology, an example is presented in which in-between carbon emission caps are calculated according to forecasted production demand.

1. Introduction

The primary objective of production planning in process industries is to meet demand however due to increase in environmental concerns carbon emission minimization should be included in production planning. Production from process industries without planning may result into huge discharge of carbon to the atmosphere which raises atmospheric temperature by trapping solar energy. This increment of temperature changes the weather pattern, water supply, growing season for food crops and increases sea level. Thus, controlling carbon emission is becoming a challenging task as most of the processes in industries emit carbon to the environment. So, restrictions in carbon emission need to be included while production planning that may control the environmental damage to a large extent. Hence, constraining carbon emission from process industries may control the global warming in due course of time and reduces its impacts to the environment. In order to minimize the carbon emission to environment, process integration techniques have been successfully applied by researchers since last few decades. Tan and Foo (2007) proposed a Pinch analysis-based approach for the carbon constrained energy sector planning. Lee et al. (2009) presented Pinch targeting approach to locate minimum consumption of low-carbon sources for energy sector planning. Shenoy (2010) developed composite table algorithm based on Limiting Composite Curve to target the minimum clean energy resources for energy sector planning. Ooi et al. (2013) proposed Pinch analysis techniques for planning carbon capture and storage. Foo and Tan (2016) have presented a review of various process integration techniques for carbon emission and environmental footprint problem in the industries. Recently, Othman et al. (2017) developed technique for optimising landfill area using carbon emission pinch analysis for achieving sustainable land filling practice. These works mainly focus on carbon emission reduction using Pinch analysis. Note that, these research works do not include the determination of restrictions on carbon emission in production planning for process industries.
Production planning of process industries provides detail technique for carrying out the production activities. Planning may be done for various process industries including food, petroleum, textile, coal, cement, plastic,

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chemicals, beverages, pharmaceuticals, paper and paper products etc. For planning, Pinch analysis has become a very important tool that set the target prior to actual synthesis and detailed design. This approach has been applied in production planning by various researchers. Like, Singhvi and Shenoy (2002) solved Aggregate Production Planning (APP) problems based on the principles of Pinch analysis. Further, the work is extended by Singhvi et al. (2004) which proposes a graphical methodology based on Pinch analysis for an APP in which demand and supply data are represented as composite curves. Later, Foo et al. (2008) presented an algebraic technique to target the optimum production rate for aggregate planning in a supply chain. Tan et al. (2009) presented Pinch based methodology for planning retrofits for carbon capture and storage in the power generation sector. Chaturvedi and Bandyopadhyay (2015) proposed graphical methodology which is based on Pinch analysis for energy supply chain planning in order to address production strategy for a company to manage supply and demand. Patole et al. (2016) discussed Pinch analysis approach to energy planning using weighted composite quality index. Chaturvedi (2017) proposed a graphical method to calculate potential saving in energy and capital cost for multiple installations aggregate production planning. Recently, Sinha and Chaturvedi (2018) proposed dual objective approach in production planning for minimizing carbon emission and energy consumption. Note that, these research works do not include the aspect of calculating feasible carbon emission caps for the process industries

Process industries operations need to be planned before the start of production activities. All process industries emissions of a region add together for overall carbon emission in that region. This paper presents a new application of Pinch analysis for process industries to determine carbon emission restriction limits within tenure of production. The methodology is illustrated via an example in which restriction on the emission from industries is calculated and forecasted demand is satisfied. Proposed methodology has the capability to include dynamism of technology advancement within the method. Problem statement and graphical analysis are discussed in next sections.

2. Problem statement

The general problem of determining carbon emission caps in production planning is given next:

(i) Forecasted average emission factor (EF_i).

(ii) Forecasted production demand (P_i).

(iii) Time horizon (H)

The goal is to calculate in-between carbon emission caps for the given tenure of production plan. Calculating emission caps is very important as production activities may be carried out according to these caps. Proposed methodology divides the time horizon of production plan into different intervals and calculate feasible emission cap for these intervals using Pinch analysis. In-between caps are calculated by using forecasted cumulative carbon emission from different process industries for the entire time horizon, where forecasted cumulative carbon emission depends on the forecasted production demand and forecasted average carbon emission. These, in-between carbon emission caps fix the range of carbon emission for carrying out the production activities and provide a step-by-step target to emission control using the Pinch analysis to match overall emission target for the entire time horizon.

3. Graphical analysis

In this section, a graphical methodology is developed for determining in-between carbon emission caps for different time intervals in a production plan. Emission forecasting for each time point is obtained by multiplying forecasted average emission factor and production demand of corresponding time duration. Forecasted Emission Demand Curve (FEDC) is generated by joining the cumulative forecasted emission of each time point. A feasible production curve which meets the forecasted demand should be below FEDC. A line plotted which starts from origin ($t=t_s=0$) and is just below FEDC will give least carbon emission at the point where it touches FEDC. The point where the line touches FEDC may be referred as Pinch point (Wang and Smith, 1994). Figure 1 shows the FEDC for a production plan in general.

Note that in Figure 1, maximum emission need not be greater than ultimate emission limit (P_u) that corresponds to extreme point of FEDC. In-between caps can be identified in order to divide production planning in intervals. This can be done by using the Pinch points. Here, two emission caps can be seen in Figure 1, the first cap is from origin to P_1 (Pinch point), for the interval OP_1' and second cap is from P_1 to P_u, for the interval P_1'P_u'. There can be a possibility where more than one Pinch point may be observed. There are three possible cases while carrying out productions; these cases are as follows:

Case I: If the emission during production is higher than capped emission limit, then:

(a) Average emission factors may be needed to be reduced drastically for subsequent years which may not be possible as average emission factors may already include technological advancements, population growth, economic growth rate etc.
(b) There may be more products produced than the required amount.
Case II: If the emission during production is lesser than capped emission limit, then:
(a) There may be lesser products produced than the required amount.
Case III: If the emission during production is equal to the capped emission limit, then:
(a) Total production is equal to the required demand.
Hence, exceeding or decreasing in-between capped emission limit while satisfying demand is not recommended and Pinch point emission need to be matched. Therefore, it is suggested to the planner to follow in-between caps in order to satisfy the demand and restrict the maximum emission limit matching the cap. The proposed methodology is explained in detail in next section.

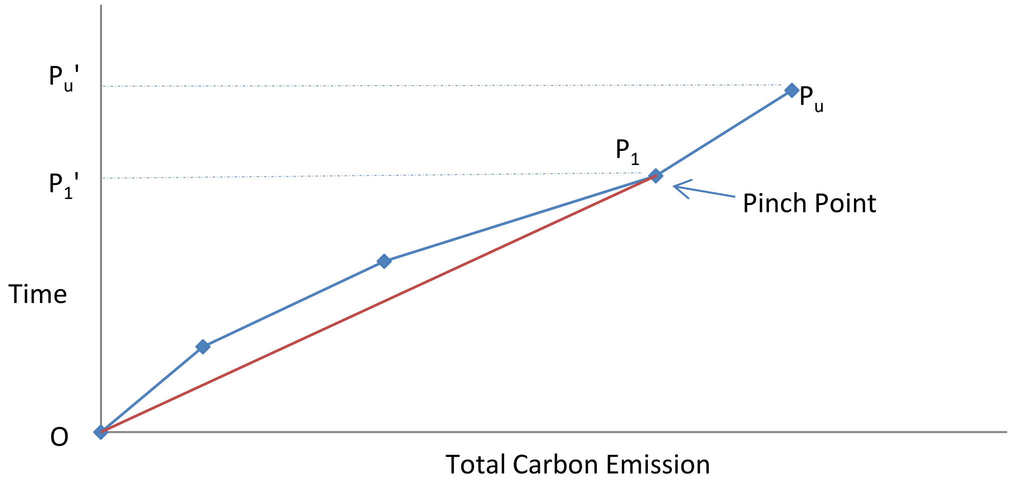

Figure 1: Forecasted Emission Demand Curve for Production Planning

3. Algorithm

Based on Section 3 following algorithm is proposed for calculation of in-between carbon emission caps.
Step 1: All the production demands and average emission factors are arranged in time horizon.
Step 2: Calculate the carbon emission of each time point by multiplying production demand and average emission factor.
Step 3: FEDC is generated by joining the cumulative forecasted carbon emission of each time point.
Step 4: A line is plotted staring from origin such that it is just below FEDC. The point where this line touches FEDC is the first Pinch point (say P_1). The carbon emission from origin to P_1 is the first in- between caps for the corresponding time interval.
Step 5: Next line is plotted starting from previously obtained Pinch point such that it just below FEDC, to obtain other Pinch point. The carbon emission between new Pinch point to previously obtained Pinch point is the next emission capping.
Step 6: Repeat step 5 where line will start from previously obtained Pinch point till end of FEDC in order to determine all in-between caps and their corresponding time intervals.
Figure 2 shows flowchart of proposed algorithm. Above methodology is discussed in detail with the help of illustrative example in next section.

5. Illustrative example

This section suggests in-between carbon emission caps for process industries in the given time duration with an example. Table 1 shows forecasted average emission factors from and production demands of a region. The time horizon considered in this example is 9 years. Table 2 shows the generation of FEDC for the given example problem. In Table 2, column 1 is time duration in year, column 2 is average emission factors and forecasted production demands are tabulated correspondingly in column 3. Carbon emission is obtained by multiplying the forecasted production demand with average emission factor for each year (Column 4). Column

5 is the cumulative carbon emission which is obtained by cascading the carbon emission for each year. Column 6 depicts the slope inverse from origin to subsequent years, showing maximum value at 5th year (1st Pinch point, P_1). Column 7 depicts the slope inverse values from 1st Pinch point to subsequent years, showing maximum value at 8th year (2nd Pinch point, P_2). Figure 3 shows the FEDC for production plan which is obtained by joining cascaded emission values for each year. It can be seen in Figure 3, three in-between caps are possible for entire time horizon. First carbon emission cap is between origin to P_1, second cap is between P_1 to P_2 and third cap is between P_2 to extreme maximum point of FEDC (P_u).

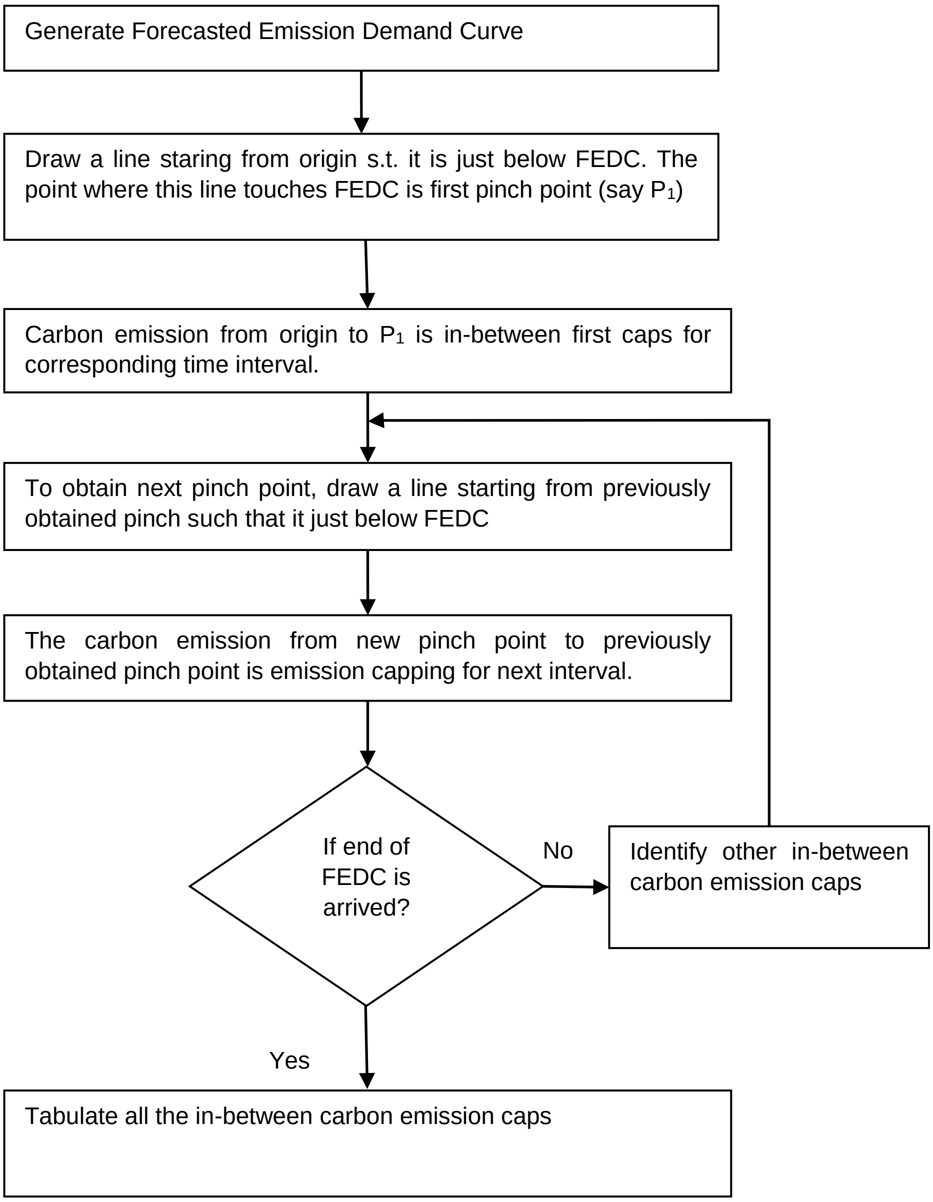

Figure 2: Flowchart for determining in-between carbon emission capping in production planning

Emission cap for first interval (from starting to 5th year) is 173,860 kg CO_2, for second interval (from 5th year to 8th year) is 66,000 kg CO_2 and for third interval (from 8th year to 9th year) is 18,000 kg CO_2. Exceeding or decreasing these capped limits while satisfying demand is not suggested and Pinch point emission needs to be matched.

Table 1: Forecasted production demands and average emission factors for example problem

Time (y)	Average Emission Factor (kg CO_2/ t product)	Production Demand (t product)
1	260	30
2	520	45
3	400	25
4	840	74
5	750	94
6	500	30
7	300	40
8	600	65
9	450	40

Table 2: Generation of Forecasted Emission Demand Curve of example problem

Time (y)	Average Emission Factor (kgCO_2/t product)	Production Demand (t product)	Carbon Emissions (kg CO_2)	Cumulative Carbon Emissions (kg CO_2)	Minimum Emission from origin (Slope inverse)	Minimum Emission from 1st Pinch (Slope Inverse)
0	0	0	0	0	0	
1	260	30	7,800	7,800	7,800	
2	520	45	23,400	31,200	15,600	
3	400	25	10,000	41,200	13,733.33	
4	840	74	62,160	103,360	25,840	
5	750	94	70,500	173,860	34,772	
6	500	30	15,000	188,860	31,476.67	15,000
7	300	40	12,000	200,860	28,694.29	13,500
8	600	65	39,000	239,860	29,982.5	22.000
9	450	40	18,000	257,860	28,651.11	21,000

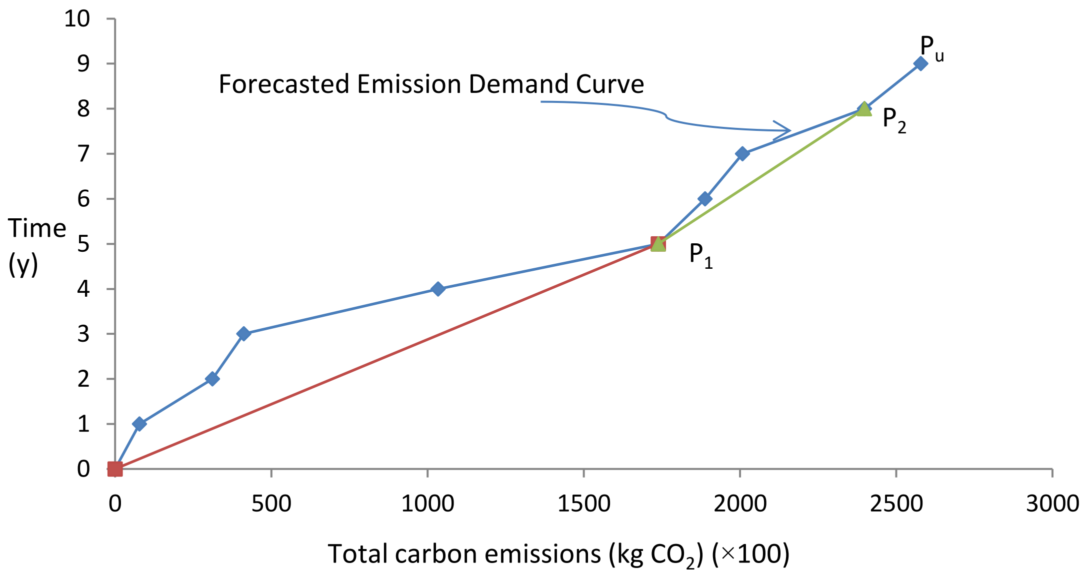

Figure 3: Forecasted Emission Demand Curve of the example problem

Thus, determination of emission caps divides the time horizon in three intervals for carrying out the production activities. Capped limit of emission in different time intervals may be used to determine the amount of production and duration of operation of production facilities to meet the demand. Thus overall emission can be restricted to three steps emission targeting, so that it can be easily matches with the overall emission target till the end of time horizon. Hence, it is suggested to the planner to follow in-between caps in order to satisfy the demand and to restrict the maximum emission limit within capped value.

6. Conclusions

Based on the overall outcome of the work, Pinch analysis is capable of reducing carbon emission from process industries for sustainable development. In this paper, a method is proposed to determine the limits of carbon emission in a production planning of process industries. Emission caps for different intervals using Pinch analysis are determined for the entire period of time horizon. Fixing the range of carbon emission for different intervals provide a step-by-step restriction on carbon emission from process industries. Demonstration of proposed methodology is illustrated via one example, where production planning is carried out for the period of 9 years and two pinch points are obtained in 5^{th} year and 8^{th} year. Based on pinch points three emission caps are obtained that are of 173,860 kg CO_2 for first five years, 66,000 kg CO_2 for next 3 years and 18,000 kg CO_2 for the last one year. All the three capped emission limits need to be match during production such that total carbon emission should be equal to 25,7860 kg CO_2. Therefore, it is suggested to the planner to carry out the production activities that matches the limits of carbon emission caps. Thus, if emission becomes higher or lower than capped values in one interval then it has to be adjusted with other forthcoming intervals such that overall emission should match with ultimate emission target. The current work does not include other environmental concerns related to process industries such as water pollution. Current research works are directed towards such issues.

References

Chaturvedi N.D., 2017, Minimizing energy consumption via multiple installations aggregate production planning, Clean Technologies and Environmental Policy, 19, 1977-1984.

Chaturvedi N.D., Bandyopadhyay S., 2015, Targeting aggregate production planning for an energy supply chain, Ind. Eng. Chem. Res., 54, 6941-6949.

Foo D.C.Y., Ooi M.B.L., Tan R.R., Tan J.S., 2008, A heuristic-based algebraic targeting technique for aggregate planning in supply chains, Computers and Chemical Engineering, 32, 2217-2232.

Foo D.C.Y., Tan R.R., 2016, A review on process integration techniques for carbon emissions and environmental footprint problems, Process Safety and Environmental Protection, 103, 291-307.

Ooi R.E.H., Foo D.C.Y., Ng D.K.S, Tan R.R., 2013, Planning of carbon capture and storage with Pinch analysis techniques, Chemical Engineering Research and Design, 91, 2721-2731.

Lee S.C., Ng D.K.S., Foo D.C.Y., 2009, Tan R.R., Extended Pinch targeting techniques for carbon-constrained energy sector planning, Applied Energy, 86, 60-67.

Othman K.I., Lim J.S., Ho W.S., Hashim H., Tan S.T., Ho C.S., 2017, Carbon emission Pinch analysis for sustainable landfill, Chemical Engineering Transactions, 56, 517-522.

Patole M., Tan R.R., Bandyopadhyay S., Foo D.C.Y., 2016, Pinch analysis approach to energy planning using weighted composite quality index, Chemical Engineering Transactions, 52, 961-966.

Shenoy U.V., 2010, Targeting and design of energy allocation networks for carbon emission reduction, Chemical Engineering Science, 65, 6155-6158.

Singhvi A., Shenoy U.V., 2002, Aggregate planning in supply chains by Pinch analysis, Chemical Engineering Research and Design, 80, 597-605.

Singhvi A., Madhavan K.P., Shenoy U.V., 2004, Pinch analysis for aggregate production planning in supply chains, Computers and Chemical Engineering, 28, 993-999.

Sinha R.K., Chaturvedi N.D., 2018, A graphical dual objective approach for minimizing energy consumption and carbon emission in production planning, Journal of Cleaner Production, 171, 312-321.

Tan R. R., Foo D.C.Y., 2007, Pinch analysis approach to carbon-constrained energy sector planning, Energy, 2007, 1422-1429.

Tan R.R., Ng D.K.S., Foo D.C.Y., 2009, Pinch analysis approach to carbon-constrained planning for sustainable power generation, Journal of Cleaner Production, 17, 940-944.

Wang Y.P., Smith R., 1994, Wastewater minimisation, Chemical Engineering Science, 49, 981-1006.