Targeting the Maximum Carbon Exchange for a Total Industrial Site

Sadiq Muhammad Munir, Zainuddin Abdul Manan and Sharifah Rafidah Wan Alwi

Process Systems Engineering Centre (PROSPECT), Faculty of Chemical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.

Email: zain@cheme.utm.my

Abstract

Researchers on carbon emission planning have recently utilized graphical approaches based on Pinch Analysis to determine potential emission reductions and renewable energy resource requirements. As alternatives to simple algebraic calculations, various “carbon emission composite curves” have been introduced. These include linear plots of fossil-based energy demands versus equivalent CO$_2$ emissions, and another plot of “economic value” versus CO$_2$ emissions. The current carbon emission pinch analysis (CEPA) approaches however are not based on the classical pinch concepts which include energy or material transfer, maximum energy/material recovery and bottleneck, minimum fresh utility or material targets, and design of heat and material recovery network. Improvements of a total site energy utilisation and distribution have been useful in contributing towards carbon footprint reductions. The emphasis was on reducing CO$_2$ emissions as a consequence of optimal heat integration as well as integration of renewable energy resources within a total site. The idea of carbon exchange was not the focus of these works. This paper presents a whole new procedure to systematically establish the minimum carbon emission targets using a new source and demand composite curves for which the CO$_2$ gas is not the main carrier fluid. A waste to resources approach for carbon planning is implemented to achieve carbon emission reduction through integration of proposed demand processes with emission point sources, and ultimately to design the maximum carbon exchange network for a total industrial site. The planned carbon demands not only have potential to reduce carbon emissions from the point sources, but also are expected to be sources of revenue for the industrial site. Application of this new technique on a case study demonstrates a potential emission reduction of up to 85%.

Keywords: composite curves, pinch analysis, carbon emissions reduction, total industrial sites

1. Introduction

Over the last five years, Pinch Analysis which was originally developed based on thermodynamic principles to identify optimal energy utilisation strategies for process
plants (Hohmann, 1971) has been extended to plan for carbon emissions reduction/minimisation. Graphical approaches based on Pinch Analysis have been used to determine potential emission reductions and renewable energy resource requirements (Tan and Foo, 2007, Zhelev and Semkov, 2004, Crilly and Zhelev, 2009). As alternatives to simple algebraic calculations, various “carbon emission composite curves” have been introduced. These include linear plots of fossil-based energy demands versus equivalent CO$_2$ emissions (Tan and Foo, 2007), and another plot of “economic value” versus CO$_2$ emissions (Tjan et al., 2010). The aim of developing the approach was to determine the minimum amount of zero carbon energy resource needed to meet the specified emission limits and also to determine how the energy sources should be allocated to meet the different demands while complying with emission limits. Subsequent graphical tools utilising pinch analysis for carbon emission planning especially in the energy sector were extensions of the work of (Tan and Foo, 2007).

Pinch analysis has also been used to further probe the influence of emission factors of renewable energy on both the energy resource mix and emission mix of the Irish electricity generation sector (Crilly and Zhelev, 2009). The approach was designed to give improved and more realistic energy and emission targets for renewables. Tan et al.(2009) developed a graphical pinch targeting methodology for preliminary planning of carbon capture and storage retrofits in the power generation sector. The approach can be used to determine how aggregate carbon emission targets for the power generation sector can be met while minimising the need for power plants retrofit. The method also provides a rapid intuitive insight on optimal retrofit allocation within a regions power sector, which can be essential for preliminary planning. Tjan et al.(2010) utilises the graphical pinch analysis technique for carbon footprint reduction for a chemical process. The approach decomposes the footprint into material and energy based components and also into internal and external components.

The carbon emission pinch analysis (CEPA) approaches mentioned however are not based on the classical pinch concepts which include energy or material transfer, maximum energy/material recovery and bottleneck, minimum fresh utility or material targets, and design of heat and material recovery network. Improvements of a total site energy utilisation and distribution have been useful in contributing towards carbon footprint reductions (Klemes et al., 1997, Perry et al., 2008, Varbanov and Klemes, 2010). The emphasis was on reducing CO$_2$ emissions as a consequence of optimal heat integration as well as integration of renewable energy resources within a total site. The idea of carbon exchange was not the focus of these works.

This paper presents an approach that uses pinch analysis to target the maximum carbon exchange of a total industrial site. The targeting procedure involves proposing suitable demand processes that could utilize CO$_2$ emissions from point sources within the stationary site. This will lead to added revenue for the site and at the same time the recovered CO$_2$ from emission point sources can lead to reduction to CO$_2$ emissions to atmosphere by the site.

2. Methodology
This section describes the methodology to establish targets for the maximum carbon exchange which consist of two main steps; (1) Carbon sources and demands data
Design of a Maximum Carbon Exchange Network for a Total Industrial Site

extraction (2) Targeting the maximum carbon exchange. Application of these steps is described using illustrative case study 1.

2.1. Step 1 - Carbon Sources and Demand Data Extraction

This step involves identification of CO\(_2\) point sources followed by planning of CO\(_2\) demands. Typical flue gas sources on industrial sites include furnace stack, boiler stack, drying towers, gas turbines, cogeneration plants, etc. with N\(_2\), O\(_2\), CO\(_2\), CO, NO\(_X\) and SO\(_X\) as the components of the flue gas depending on the type of fuel used and how complete the combustion is. The limiting data to be extracted from each source stream is the flue gas flow rate (\(F_T\)) and the composition of CO\(_2\) in the flue gas. In the case of CO\(_2\) demands, the required data include the flow rate of gases that can be accepted by the demand processes and the limiting CO\(_2\) composition in the gas.

Note that, it may not be possible to utilise all available carbon sources, especially those that contain hazardous substances and/or are remotely located within an industrial park, and have small CO\(_2\) concentrations. For these sources, the capital costs and the required blower duty can be very high such that they may not be cost-effective to be used for carbon exchange (van Straelen et al., 2010). Only sources that satisfy these geographical, safety and cost constraints and can reasonably contribute to the industrial park’s emission reduction in terms of quantity (flow rate) and quality (mass load) are selected for possible carbon exchange and minimisation. The remaining sources will go through treatment procedure as required.

Planning and design of the potential CO\(_2\) demands for integration with the emission point sources are performed once the CO\(_2\) sources have been selected. This step involves detailed survey and selection of compatible and potentially lucrative CO\(_2\)-consuming processes within the industrial park. Examples of such processes may include syngas manufacturing from CO\(_2\), microalgae cultivation, enhanced oil recovery, methanol production and a beverage manufacturing plant. Columns 1 to 4 of Table 2 show the data for CO\(_2\) sources and demands for an illustrative Case Study 1. The sources and demands data are arranged in decreasing CO\(_2\) composition.

**Table 1:** Data for Illustrative Case Study 1

<table>
<thead>
<tr>
<th>Sources</th>
<th>(F_T), t/hr</th>
<th>CO(_2) Composition (%</th>
<th>(F_{CO2}), T/hr</th>
<th>(F_{OG}), T/hr</th>
<th>Cum (F_{CO2}) T/hr</th>
<th>Cum (F_{OG}) T/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>S(_1)</td>
<td>45</td>
<td>80</td>
<td>36</td>
<td>9</td>
<td>36</td>
<td>9</td>
</tr>
<tr>
<td>S(_2)</td>
<td>70</td>
<td>70</td>
<td>49</td>
<td>21</td>
<td>85</td>
<td>30</td>
</tr>
</tbody>
</table>

Demands

<table>
<thead>
<tr>
<th>Demands</th>
<th>(F_T), t/hr</th>
<th>CO(_2)</th>
<th>(F_{CO2}), T/hr</th>
<th>(F_{OG}), T/hr</th>
<th>Cum (F_{CO2}) T/hr</th>
<th>Cum (F_{OG}) T/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>D(_1)</td>
<td>90</td>
<td>85</td>
<td>76.5</td>
<td>13.5</td>
<td>76.5</td>
<td>13.5</td>
</tr>
<tr>
<td>D(_2)</td>
<td>40</td>
<td>65</td>
<td>26</td>
<td>14</td>
<td>102.5</td>
<td>14</td>
</tr>
</tbody>
</table>
2.2. Step 2 - Targeting the Maximum Carbon Exchange

This step involves the construction of source and demand curves (SDC) for CO₂ targeting. Previous workers dealing with mass, gas and property pinch analysis have plotted the mass flowrate of a main/primary carrier fluid versus mass load/concentration of contaminants or minor components (components present in small amounts) present in a process stream. (Wan Alwi et al., 2009, Alves and Towler, 2002). This approach is not applicable when dealing with gaseous streams containing CO₂ since CO₂ may not be the main carrier fluid. For example, a flue gas stream can consist of CO₂ and a larger percentage of various other gases such as N₂, O₂, CO, NOₓ and SOₓ etc. Note that in the context of CO₂ targeting, using the conventional plot of primary gas flow rate versus the mass load of contaminant will yield the minimum flue gas emission target instead of the minimum carbon emission target. A new SDC has been introduced in this work to suit the unique carbon exchange problem. In the Illustrative Case Study 1, SDC is constructed by plotting the cumulative flow rate of other gases $F_{OG}$ (aside from CO₂) in the flue gas, versus cumulative flow rate of CO₂ $F_{CO2}$, for the sources and demands arranged in ascending concentration order (the flow rate of gases other than CO₂ in the flue gas will be termed as the mass load of other gases, $m$). The values of $F_{OG}$, cumulative $F_{OG}$ and cumulative $F_{CO2}$ are shown in Table 2, columns 5 to 7. To get the minimum fresh CO₂ and emission flow rate targets, the whole source curve is moved horizontally at zero mass load until it touches the demand curve at the SDC pinch point (cumulative $F_{OG}$ of 13.5 T/h) as shown in Figure 1. The horizontal gap between the demand and source curves at zero $F_{OG}$ gives the minimum fresh CO₂ flow rate (in this case, 30.50 T/h). The overshoot of the source curve gives the minimum CO₂ emission flow rate (in this case, 13 T/h). Since the total amount of other gases is also quite high, the concentration is not represented in ppm. The unit of the gradient is dimensionless ratio between tons of other gases/ton of CO₂ gas. For the Illustrative Case Study 1, the pinch point occurs at $F_{CO2}$ value of 76.5 T/h.

![Figure 1: Maximum Carbon Exchange Targets Using SDC](image-url)
3. Conclusion

An approach for targeting the maximum carbon exchange based on Pinch Analysis concept has been successfully developed and applied on an illustrative case study representing an industrial park. Integration of emission point sources within the industrial site with various demands yielded a CO$_2$ emission reduction potential of up to 85%. This procedure provide a friendly tool for policymakers and designers to plan towards an industrial park that can maximise CO$_2$ exchange and allow plant owners to generate revenue by converting their wastes into resources by designing sites with compatible CO$_2$ demands. Ultimately, this method will help minimise the industrial site carbon emissions.

4. References

D. Crilly & T. Zhelev, 2009, Further Emissions And Energy Targeting: An Application Of CO$_2$ Emissions Pinch Analysis To The Irish Electricity Generation Sector. Clean Technologies And Environmental Policy, 12, 177-189.