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# Aspen Plus based simulation for energy recovery from waste to utilize in cement plant preheater tower

Azad Rahman*, M.G. Rasul, M.M.K. Khan, S. Sharma

*School of Engineering and Technology*
*Central Queensland University*
*Rockhampton, QLD 4702, Australia*

**Abstract**

Cement manufacturing is an energy intensive and heavy pollutant emissions process. It is accountable for $CO_2$, $NO_X$, $SO_2$ emissions and some heavy metal discharge from the manufacturing process which causes severe greenhouse effects. Waste derived alternative fuels are widely used for substituting the thermal energy requirement from fossil fuels and reducing the pollutant emission. In the current study, a process model of the preheater tower is developed using Aspen Plus simulation software based on the combustion mechanism. Preheater tower is part of the modern energy efficient cement plant which is responsible for most of the $CO_2$ release as the calcination of the raw material occurs at high temperature in this section. The model is verified against measured data from industry and data available in the literature. This paper presents the effects of the flow rate of waste derived fuels on the energy efficiency and emission from the preheater tower. Three different waste derived fuels, namely tyre derived fuel, meat and bone meal and refuse derived fuel are considered for this study. Fixed substitution rate of conventional fuel by the alternative one has been considered to identify the differences among the selected alternative fuels. Results show that maximum 3% increase of energy efficiency and 2.5% reduction of $CO_2$ can be achieved by using tyre for about 25% of thermal energy requirement. Simulation results presented in this paper offer a guideline for implementing selected waste derived fuels in cement industry.


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*Keywords:* Cement, waste derived fuel, preheater tower, emission, simulation

## 1. Introduction

The production of cement requires approximately 3.2 to 6.3 GJ of energy and 1.7 tons of raw materials (mainly limestone) per ton of clinker produced [1, 2]. Energy costs are almost 60% of the production

* Corresponding author. Tel.: +61 749309313;
*E-mail address:* a.rahman2@cqu.edu.au.


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costs which makes cement industry one of the most energy intensive industries. Modern Portland cement manufacturing process basically includes quarry, raw meal preparation, preheating of raw meal, kiln, clinker cooling, grinding, storage and dispatch. In preheater tower chemical reaction starts with the decomposition of calcium carbonate ($CaCO_3$) at about 900°C to leave calcium oxide (CaO, lime) and liberate $CO_2$; this process is known as calcination. Generally fossil fuels such as coal, petcoke and natural gas is burnt to get the required thermal energy in the preheater tower which is about 60% of total thermal energy requirement [3]. Usage of alternative fuel becomes more warranted to the cement manufacturer due to increasing fossil fuel prices, limited fossil fuel resources and environmental concerns.

In order to reduce the risks of trialing a new alternative fuel, numerous approaches are going on to build computer process model to predict the effects of selected alternative fuel on the plant performance and emission. Kaantee et al. [4], Zhang et al.[5] and Rahman et al. [6] used Aspen Plus software to simulate the cement clinker production focusing on clinker chemistry and thermodynamics in the rotary kiln and in the calciner. Aspen Plus, Aspen HYSYS, Ansys FLUENT and ChemCad simulation packages are commonly used to model cement manufacturing process. Due to the nature of cement production, Aspen Plus is identified as the most suitable since this package has a rich database and has the ability to simulate chemical reactions within solid, liquid and vapour phases. The aim of this study was to build up a valid computational model of the precalciner-preheater tower based on the model proposed by Zhang et al. [5] and Rahman et al.[6]. Tyre derived fuel, Residue derived fuel (RDF) and meat and bone meal (MBM) have been selected as alternative fuels for the current study and the impact of using these alternative fuels has been studied by using the process model. The outcomes of the model simulation are focused on the emission of $CO_2$ and improving the energy efficiency of the plant.

## 2. Alternative fuels in preheater tower

In modern dry process cement manufacturing system, suspension preheater and precalciner is used to reduce the chance of fuel wastage. The main component of preheater is series of cyclones which contains 1 to 6 high efficient cyclones. Around 90% of calcination of raw feed occurs in the calciner by using 60% of the total thermal energy [3]. After calcination, the process materials enter to the kiln at around 750°-900°C temperature. As the calciner is operated in a lower temperature compared to kiln, fuel need not to be of as high quality as fuel burnt in the kiln.

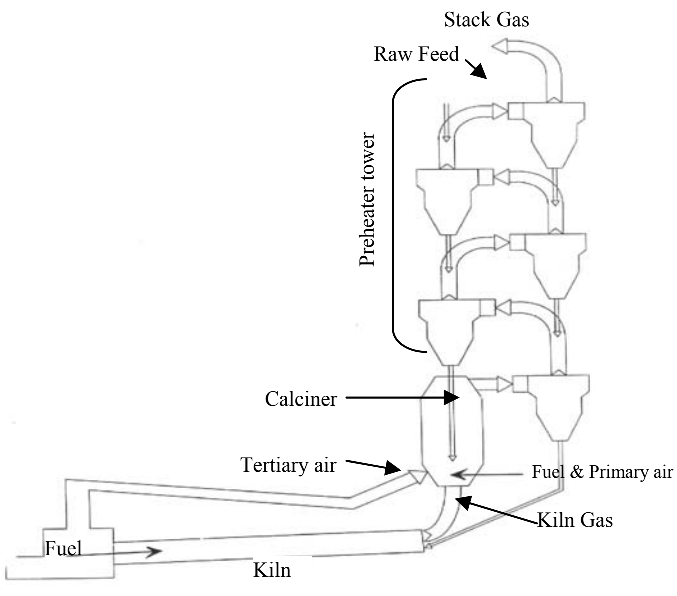


Figure 1: Schematic diagram of an ILC unit with single-string cyclone

There are two main types of calciners, which are in-line calciners (ILCs) and separate-line calciners (SLCs). In an ILC the tertiary air and kiln exhaust gas pass through the burning zone of the calciner. This type of calciner is useful to burn waste derived alternative fuel as well as coal and natural gases. The low-oxygen content of tertiary air makes the ILC more compatible with fuels that have relatively high volatile content. In the current study, in-line calciner prototype of capacity of 2150 ton/day is considered. Figure 1 shows the schematic diagram of an ILC unit with Single string cyclone which has been considered in this study.

In order to create a proper model, the full chemical breakdowns of the fuels were collected from the literature as well as from the local cement plant. Three potential alternative fuels, namely waste tyre, MBM and RDF were selected for the current study because of their availability. High carbon content, high heating value of 35.6 MJ/kg [7] and low moisture content make tyre derived fuel (TDF) one of the most used alternative fuels in cement industry around the world. Refuse derived fuels (RDF) cover a wide range of waste materials which includes residues from MSW recycling, industrial/trade waste, sewage sludge, industrial hazardous waste, biomass waste, etc. [8]. MBM is used as fuel in cement industry to ensure that any living organism is thermally destroyed and its energy potential is utilized [9]. The chemical breakdown of coal and selected alternative fuels has been collected from the literature [10-12].

## 3. Model development and validation

A model for the ILC along with single string of cyclone in the preheater tower has been developed based on the model proposed by Zhang et al. [5] and Rahman et al. [6]. Production rate of the modeled preheater tower is 2250t/d. A few basic assumptions are made to reduce the complexity of the model without affecting the simulation results. Figure 2 shows the preheater tower model flow sheet in Aspen Plus. Fuel combustion in the process model has been built using two separate unit operation blocks, RYIELD and RGIBBS. RYIELD reactor is used to decompose the fuel and then combustion takes place in subsequent RGIBBS reactor. In the heat exchange section, the cyclones are modeled by using cyclone separator with RStoic reactor at the inlet, in which the calcination reaction can take place [7]. To run the model properly, operating parameter for each block and streams need to be specified. Then input parameter for material and heat stream has to be installed in the model.

The model has been verified only for coal combustion by using available data from literature and local cement plant. Comparison of results in Table 1 indicates that the simulations results vary within ±2-5% of the published results with an exception in the case of CO which is negligibly small to be considered. Only in case 3 the outlet temperature is found little bit higher which is due to high amount of coal in the burning zone.

Table 1: Compression of simulation results and literature values

| **Input** | Literature data (Huang [13], Zhang et al. [5]) | | |
|---|---|---|---|
| Material streams (kg/s) | Ex 1 | Ex 2 | Ex 3 |
| Raw material | 44.69 | 48.84 | 56.24 |
| Coal | 2.1 | 2.12 | 3.13 |
| Tertiary air | 21.94 | 23.87 | 24.38 |
| Kiln gas | 15.34 | 14.84 | 19.56 |

| **Output** | Ex. 1 | | | Ex. 2 | | | Ex. 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| Parameter | Huang [13] | Zhang [5] | Simulation results | Huang [13] | Zhang [5] | Simulation results | Huang [13] | Zhang [5] | Simulation results |
| Outlet Temperature (K) | 1176 | 1175 | 1195 | 1163 | 1193 | 1166.6 | 1154 | 1194 | 1261.8 |
| NO (mg/Nm$^3$) | 776 | 774.7 | 772.1 | - | 765.3 | 656.6 | - | 498 | 554.8 |
| $O_2$ (%) | 2.282 | 2.47 | 2.39 | 1.35 | 1.14 | 1.97 | 1.46 | 1.65 | 1.58 |
| CO (%) | 0 | 1.54E-08 | 2.99E-05 | - | 2.43E-08 | 3.23E-05 | - | 1.63E-08 | 4.00E-05 |
| $CO_2$ (%) | - | 39 | 40.44 | 36 | 40.3 | 42.83 | 40.12 | 38.9 | 41.28 |

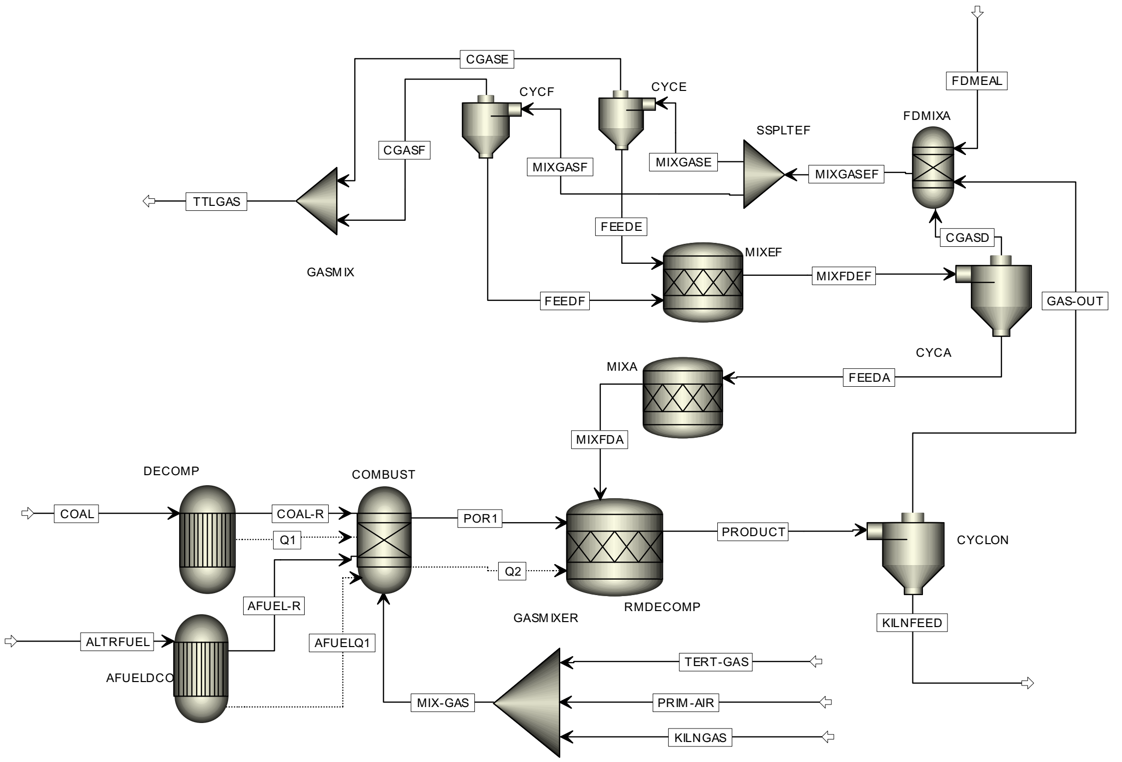


Figure 2: Preheater tower model for alternative fuel burning

## 4. Simulation results and discussion

An aspen plus process model for Precalciner -Preheater tower is built and verified by plant and literature data. Thermal energy substitution rate by the three selected alternative fuels have been set to vary from 5% to 25%. For modeling purpose it is assumed that only 80% of calcination occurs in the preheater tower. Concentrations of $CO_2$, and outlet temperature are examined from the simulation results.

Total $CO_2$ emissions from the pyroprocess depend on energy consumption and nearly 977 kg of $CO_2$ produced for each ton of clinker [14]. $CO_2$ emission results from simulation have been presented in Figure 3a. It was found from both the cases that using Tyre and RDF instead of coal, reduces $CO_2$ emission at large scale. As it is seen from Table 1 that the percentage of carbon is way lower in RDF compared to coal and waste tyre, the reduction of $CO_2$ emission is much anticipated. It is also found from Figure 3a that net $CO_2$ increases when MBM is used as substitute fuel. Though the carbon percentage is very low in MBM, it requires about twice amount of coal to replace the required thermal energy due to its low calorific value. This leads to higher $CO_2$ emission for the case of MBM. Outlet temperature is a good indication of at what temperature raw feed is calcined and liberate $CO_2$.

To complete the calcination up to a desired degree, temperature of the preheater raiser needs to be kept as high as 800$^oC$ (1075$^oK$). Figure 3b shows the outlet temperature of the modeled preheater tower. A rapid drop in the outlet temperature is observed when a usage of MBM and RDF increases. This is only because of high moisture content (about 15%) of RDF and low calorific value of MBM. It is suggested that RDF need to be air dried to enhance its efficiency. In the case of tyre the outlet temperature is slightly higher than only coal burning.

To examine the energy efficiency of the preheater tower the model was run to achieve a desired degree of calcination in a prescribed temperature. For current study the degree of calcination was set to 94% and the desired temperature in precalciner-preheater outlet was set to 900$^o$C. All three alternative fuels were tested with different substitution rate and different amount of excess air in the preheater. To get better results RDF was air dried by using a reactor block in the model and its moisture content was reduced to 5% by simulation. The results from the simulation are summarized in the Table 2. It was assumed that only 60% thermal energy is required in the preheater tower and the total energy requirement was calculated based on this assumption.

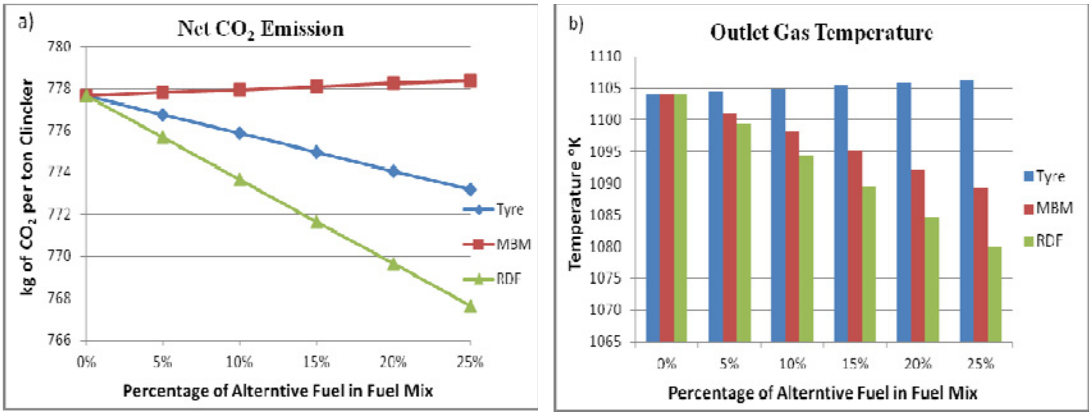


Figure 3: a) Net CO2 emision from calciner (kg/ton clinker), b) Outlet Temperature ($^o$K)

Table 2: Simulation results for energy efficiency

| **Fuels** (% of thermal energy) | Amount of excess air | Degree of calcination (Simulation Results) | Outlet temperature (Simulation Results) **°C** | Energy requirement **MJ/kg clinker** (Simulation Results) | $CO_2$ Emission **kg/ton clinker** (Simulation Results) |
|---|---|---|---|---|---|
| Only Coal | 7% | 94.1288% | 900.5 | 3.1784 | 854.9 |
| Tyre 25%+Coal 75% | 10% | 94.1276% | 900.9 | 3.0744 | 833.1 |
| RDF 15%+Coal 85% | 10% | 94.1269% | 900.3 | 3.1612 | 838.5 |
| MBM 5%+Coal 95% | 10% | 94.1269% | 900.2 | 3.1257 | 840.6 |

The results presented in the Table 2 shows that all three alternative fuels are capable to reduce the energy requirement as well as the $CO_2$ emission. Tyre could be used up to 25% while air dried RDF and MBM can be used up to 15% and 5% respectively to get some advantage over using only the fossil fuel coal. It is found that using 25% of tyre increases the energy efficiency up to 3% and $CO_2$ reduce about 2.5%. In terms of energy efficiency MBM is found more energy efficient than RDF. The substitution rate of RDF can be increased if it is fed in the burning zone after drying by hot air. MBM can only be used up to 5% of total thermal energy requirement due to its low calorific value. $CO_2$ emissions are found to be lower for the three selected alternative fuels up to some extent. From the amount of excess air in the burning zone it is clear that for complete combustion additional air is required for all the selected alternative fuels.

## 5. Conclusion

This study focused on three solid fuels to maximize their usage in cement manufacturing. Process engineering software Aspen Plus was used to build a model for a preheater tower to simulate the operating condition and effect of alternative fuels on emission and energy efficiency. Model was validated for coal burning and then run with selected alternative fuels with different substitution rates. The results obtained from this study suggest that waste tyre, air dried RDF and MBM could replace 25%, 15% and 5% of thermal energy respectively to gain advantages in terms of $CO_2$ emission and energy efficiency over using only coal. Energy efficiency can be achieved up to 3% by using tyre for about 25% of the thermal energy requirement. $CO_2$ emission can be reduced by using any of the selected alternative fuel. The substitution rate of RDF can be increased if it is fed in the burning zone after drying by hot air. Little extra air need to be supplied in the burning zone to ensure the complete combustion and getting maximum benefits from the alternative fuels. This study is limited only to the gaseous emission; emission in other forms including heavy metal emission is not considered. Before introducing any alternative fuel there chemical constituent and heating value need to be considered along with the possible pollutant emission. Aspen Plus has a shortcoming regarding the graphical representation of results compare to Ansys FLUENT, still it can produce graphs in simple forms. The model presented in this study is proved to be a useful tool for determining the impact of new alternative fuels on emissions in cement industry.

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