



REGENERATIVE BURNER

This case study demonstrates how a transient Flownex model of a regenerative burner was used to simulate cyclic heat storage and flow reversal in packed beds to quantify combustion air preheating and achieve a ~27% reduction in fuel consumption.

“ Being able to create compound components was particularly useful to ease the creation of a discretized model.

Bianca Ferreira
Engineer
CSIR, South Africa



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CHALLENGE:

While regenerative burners are widely used, accurately quantifying their performance is difficult due to several interacting phenomena:

- Heat is stored and released over time within the ceramic beds
- Flow direction changes periodically due to valve switching
- Temperature varies along the height of each bed
- System performance depends strongly on cycle timing, geometry, and material properties

The key challenge in this case study was therefore to build a model that could:

- Capture the time-dependent (transient) behaviour of the system
- Represent heat storage within the packed beds along their length
- Simulate valve switching between flow directions
- Predict how these effects influence combustion air preheating and fuel savings

A simple steady-state model would not capture these dynamics and would therefore fail to predict real system performance.

BENEFITS:

Flownex enabled the creation of a physically realistic model without requiring custom code. Key advantages included:

- Built-in thermal-fluid components: Allowed direct modelling of heat transfer between gas and solid materials inside the packed beds.
- Custom component capability (compound components): Each packed bed was broken into smaller sections along its height. This allowed the model to capture how temperature changes from the inlet to the outlet, instead of assuming a uniform temperature.
- Transient simulation capability: Made it possible to simulate the continuous switching of flow direction and track how heat is stored and released over time.
- Scripting tools: Enabled automated valve switching, replicating real burner operation.

SOLUTION:

The model predicted that, once cyclic steady operation was reached:

- Combustion air was preheated to 990–1070 °C
- This resulted in an approximate 27% reduction in burner fuel energy demand

These results demonstrate the value of regenerative burners and show how transient modelling can be used to quantify waste heat recovery and support energy efficiency improvements.

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INTRODUCTION

In many high-temperature industrial processes, such as furnaces and kilns, a large portion of the input energy is lost as hot exhaust gases. In South Africa, thermal processes account for roughly 70% of industrial energy use, yet 20–50% of that energy is typically rejected as waste heat.

A regenerative burner like the one in Figure 1 is designed to recover part of this wasted energy and reuse it within the process.

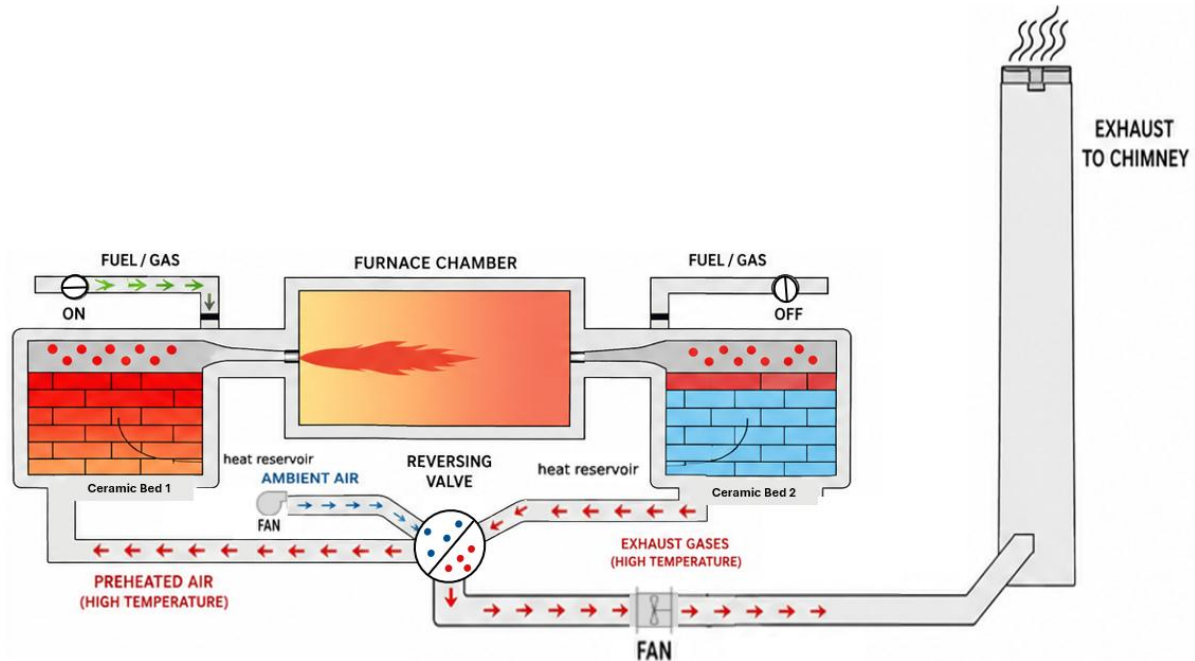


Figure 1: Bloom-type regenerative burner

In a typical Bloom-type regenerative burner system, two ceramic-packed beds are installed on either side of the furnace:

- Phase 1 (Heat storage): Hot exhaust gas from the furnace flows through one packed bed, heating the ceramic material.
- Phase 2 (Heat release): Clean, cold combustion air is then passed through the other hot bed, where it absorbs the stored heat before entering the burner.

The system periodically switches flow direction using valves so that each bed alternates between storing and releasing heat. This cycling allows the system to continuously:

- capture waste heat from exhaust gases, and
- reuse it to preheat incoming combustion air.

Preheating the combustion air significantly reduces the amount of fuel required to reach the desired furnace temperature.

MODELLING APPROACH & ASSUMPTIONS

The regenerative burner was modelled using a transient approach, with each packed bed represented as a series of segments along its height. This allowed the model to capture how temperature varies both along the bed and over time as heat moves through the system during repeated heating and cooling cycles.

Key operating assumptions were included to reflect realistic behaviour:

- The packed beds were modelled as alumina ceramic thermal storage media

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- Each bed was discretised into 10 segments to resolve temperature gradients along its length
- The system operated with periodic valve switching every 40 seconds, representing typical cyclic operation
- A 10% bypass to the stack was included to account for practical limitations such as pressure control and incomplete heat recovery
- Boundary conditions included a high-temperature exhaust stream ($\sim 1250^{\circ}\text{C}$) and ambient inlet air

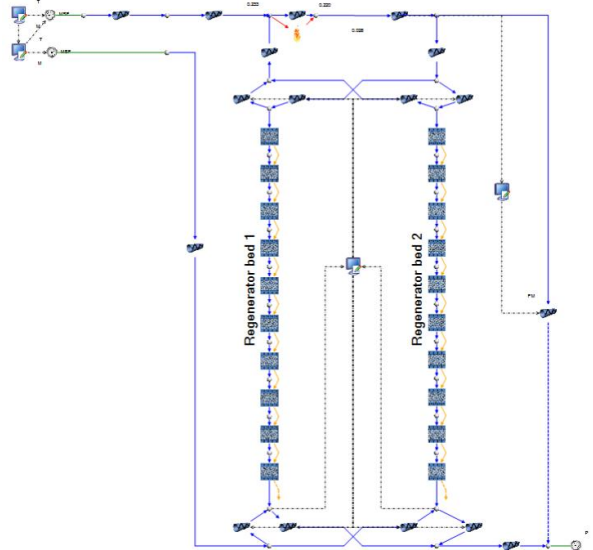


Figure 2: Flownex model

This approach ensured the model captured both the spatial distribution of temperature within the beds and the impact of real operating conditions on overall heat recovery performance.

RESULTS

In Figure 3 below, it is evident that after several switching cycles, the system reached a cyclic steady state, where temperature profiles within the packed beds repeated consistently from one cycle to the next. At this condition:

- The combustion air was preheated to $990\text{--}1070^{\circ}\text{C}$ before entering the burner
- Strong temperature gradients developed along the height of each packed bed, indicating effective heat storage and release

This behaviour occurs because heat is not uniformly stored in the beds. Instead, it propagates through the packed media over time, creating a moving thermal profile. During operation, each cycle transfers heat deeper into the bed while only partially cooling it during discharge. As a result, the beds retain a significant amount of energy between cycles, enabling consistently high preheat temperatures. In Figure 3 below, it is evident that the high preheat temperature has a direct impact on burner performance:

- Less energy is required from fuel to raise the combustion air to the desired flame temperature
- This reduces the overall thermal load on the burner

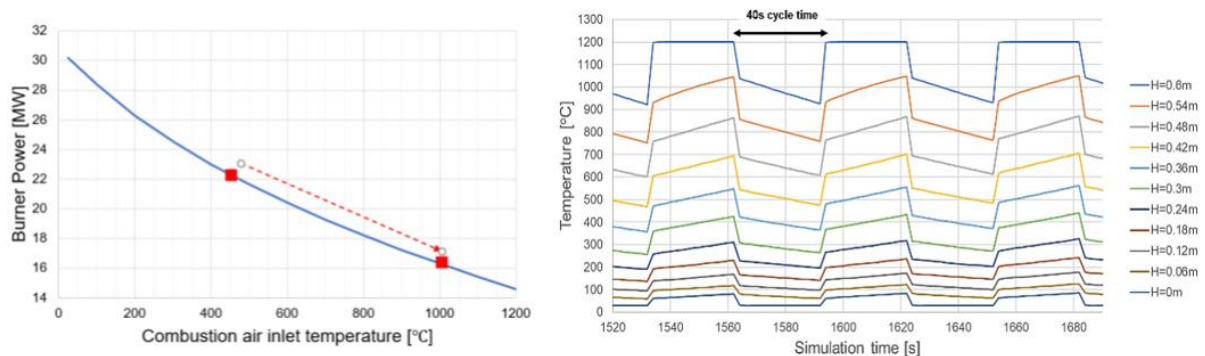


Figure 3: Stored heat in the beds reduced thermal load on the burner improving fuel consumption

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As a result, the model quantified an approximate 27% reduction in required fuel energy, demonstrating the effectiveness of regenerative burners for waste heat recovery.

These results highlight how transient thermal storage and flow cycling enable meaningful energy savings and show the importance of modelling these effects accurately when evaluating system performance.

TAKEAWAYS

These results highlight several important design considerations for regenerative burner systems. The choice of cycle time plays a critical role in performance, as switching too quickly can increase operational complexity while switching too slowly allows more heat to be lost, reducing recovery efficiency. Similarly, packed bed sizing must be carefully selected: beds that are too small cannot store sufficient thermal energy, while excessively large beds add cost and complexity without proportional gains in performance. Finally, the results demonstrate clear diminishing returns, as preheating temperatures approach the exhaust temperature, beyond this point, further efficiency improvements become marginal. Together, these findings show how modelling can be used to guide balanced, cost-effective design decisions.