Resource efficient manufacturing: Can reduced energy efficiency lead to improved sustainability?

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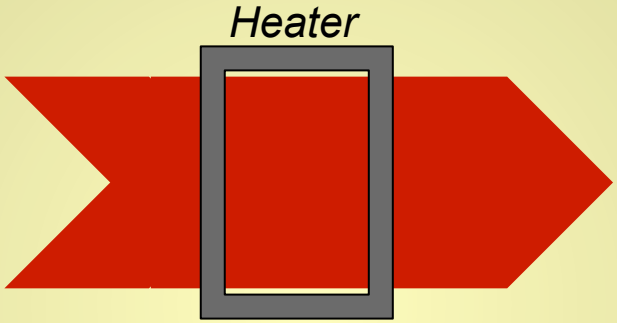
What is resource efficiency?

- A measure of how much value is created through a process during the conversion of non-renewable natural resources.
- Mass and energy flows.
- Reduce non-renewable **consumption**

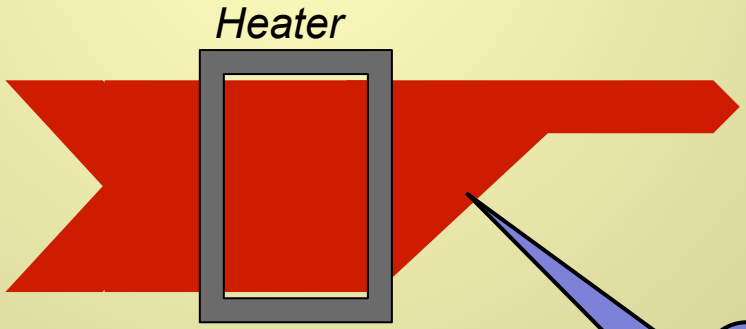
Energy transformations and loss of quality
Example – simple room electric heater

Energy 100J
(electricity)



Almost 100J low grade heat output
(Efficiency ≈100%)

Exergy 100J
(electricity)



Exergy < 10J
(Efficiency <10%

Exergy destruction quantifies the loss in quality

Classification of exergy forms

<table>
<tr><td colspan="6">Exergy</td></tr>
<tr><td colspan="4">Physical</td><td colspan="2">Chemical</td></tr>
<tr><td colspan="2">Mechanical</td><td colspan="2">Thermo-mechanical</td><td>Chemical reaction</td><td>Mixing and separation</td></tr>
<tr><td>Kinetic</td><td>Potential</td><td>Pressure based</td><td>Temperature based</td><td colspan="2"></td></tr>
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- Exergy is a well suited tool for quantifying resource efficiency

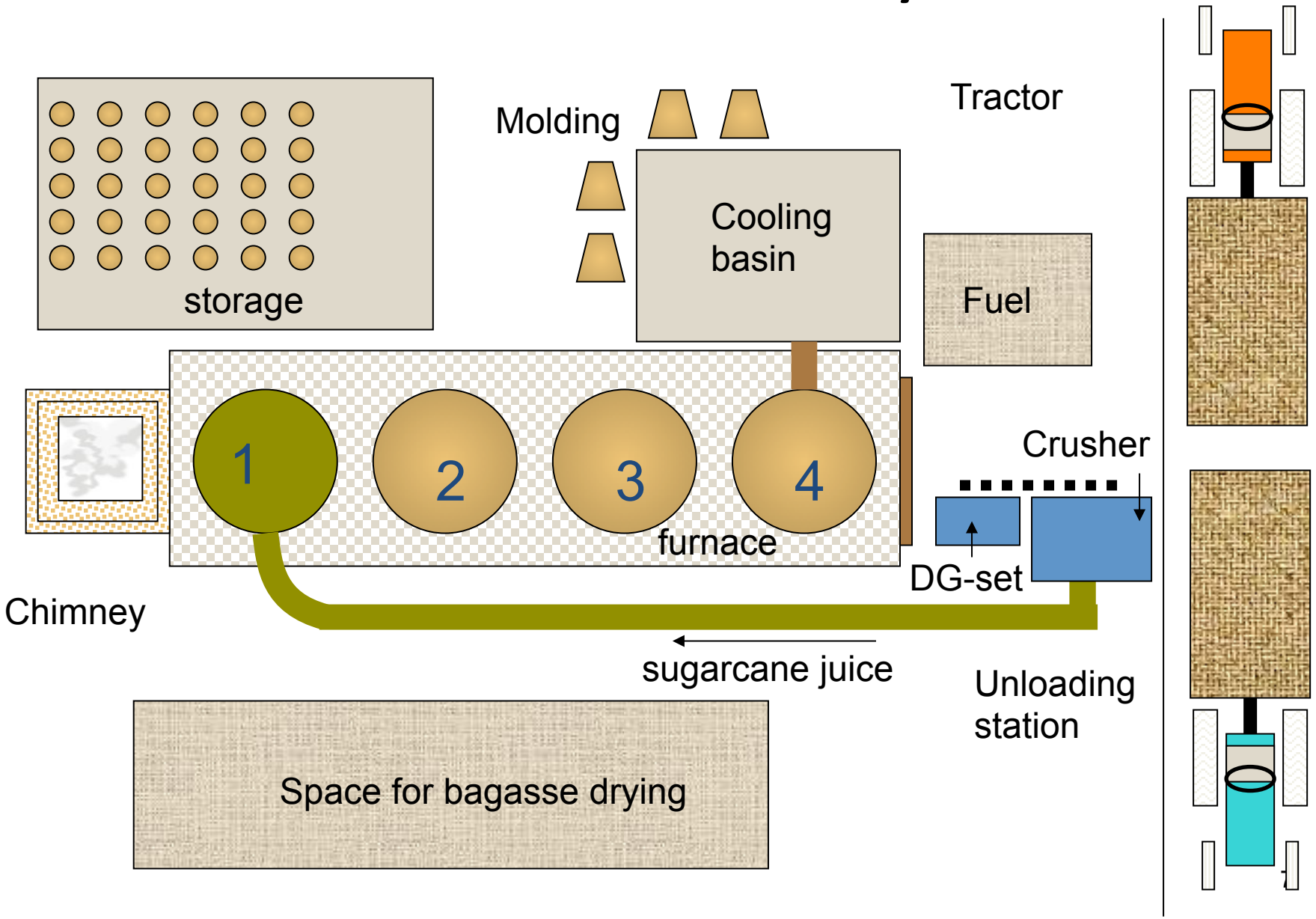
Jaggery production case study (exergy analysis)

- What is jaggery?
  - Jaggery is a sugar-cane based product
  - Brown sugar moulds with no or minute quantity of chemicals
  - Brown sugar will minimal chemicals

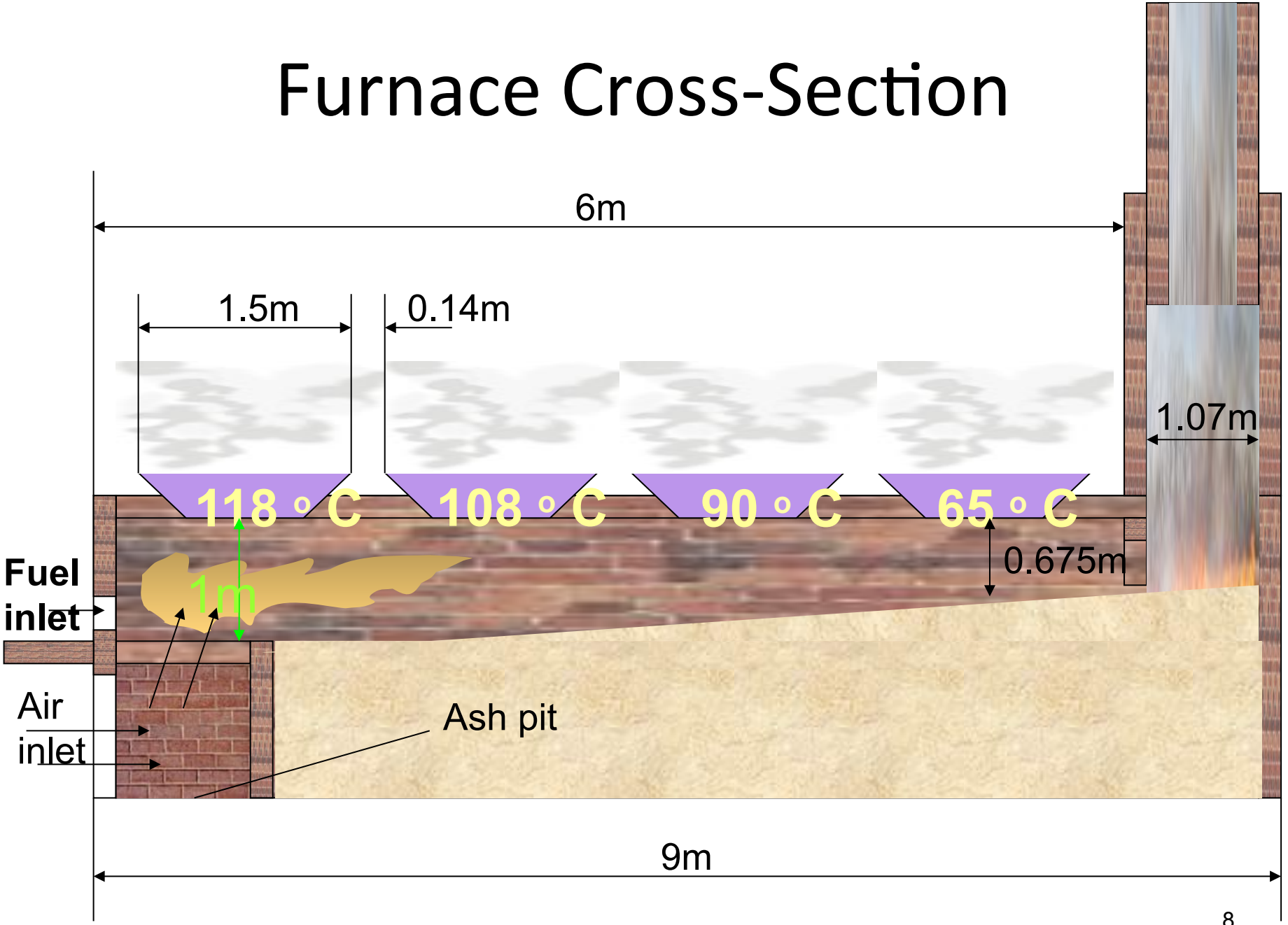
Approach to Problem (Experimental approach)

- Observation of operating practices
- Discussion with operating people
- Experimentation
  - Weighing Balance
  - Measuring tape
  - Volume measuring container
  - Stop watch
  - High temperature sensor (up to 800 ^{o}C)
  - Dry flue gas analyzer

Four Pan Plant Layout

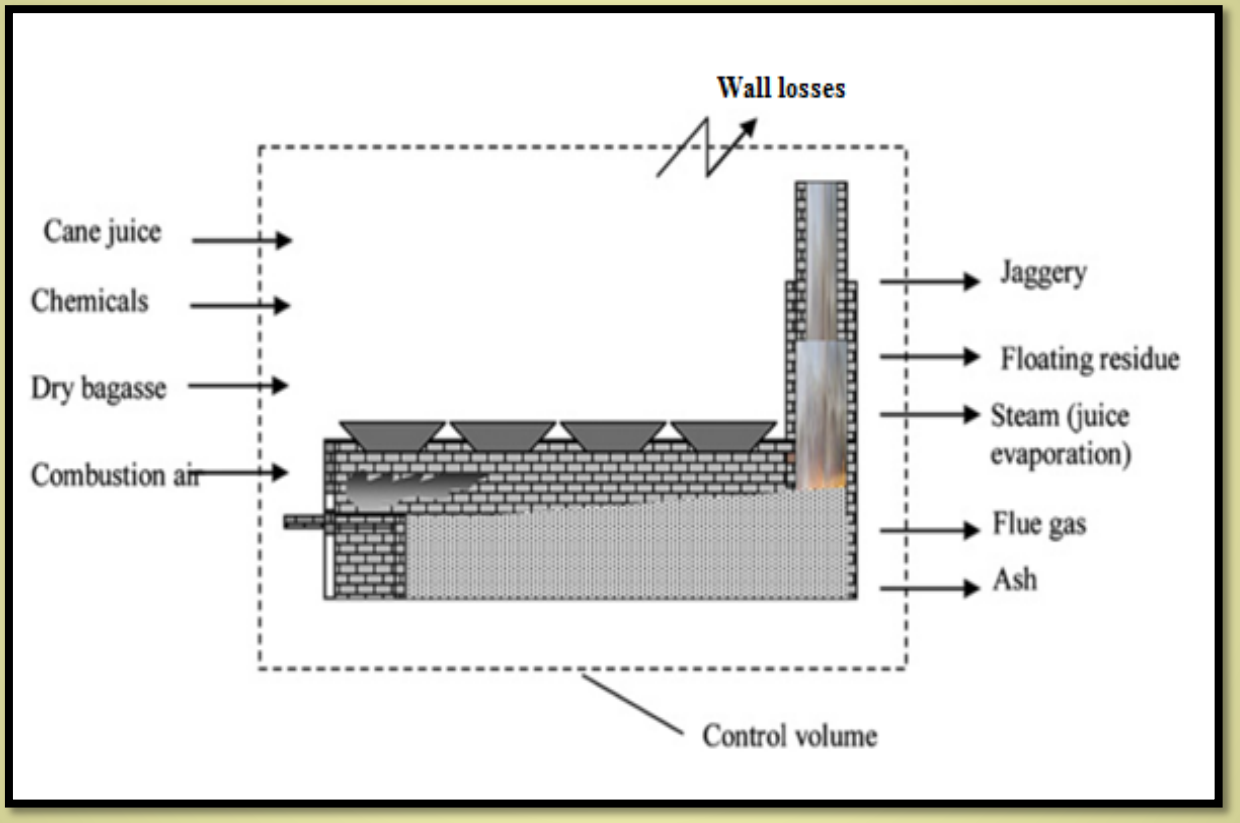


Furnace Cross-Section



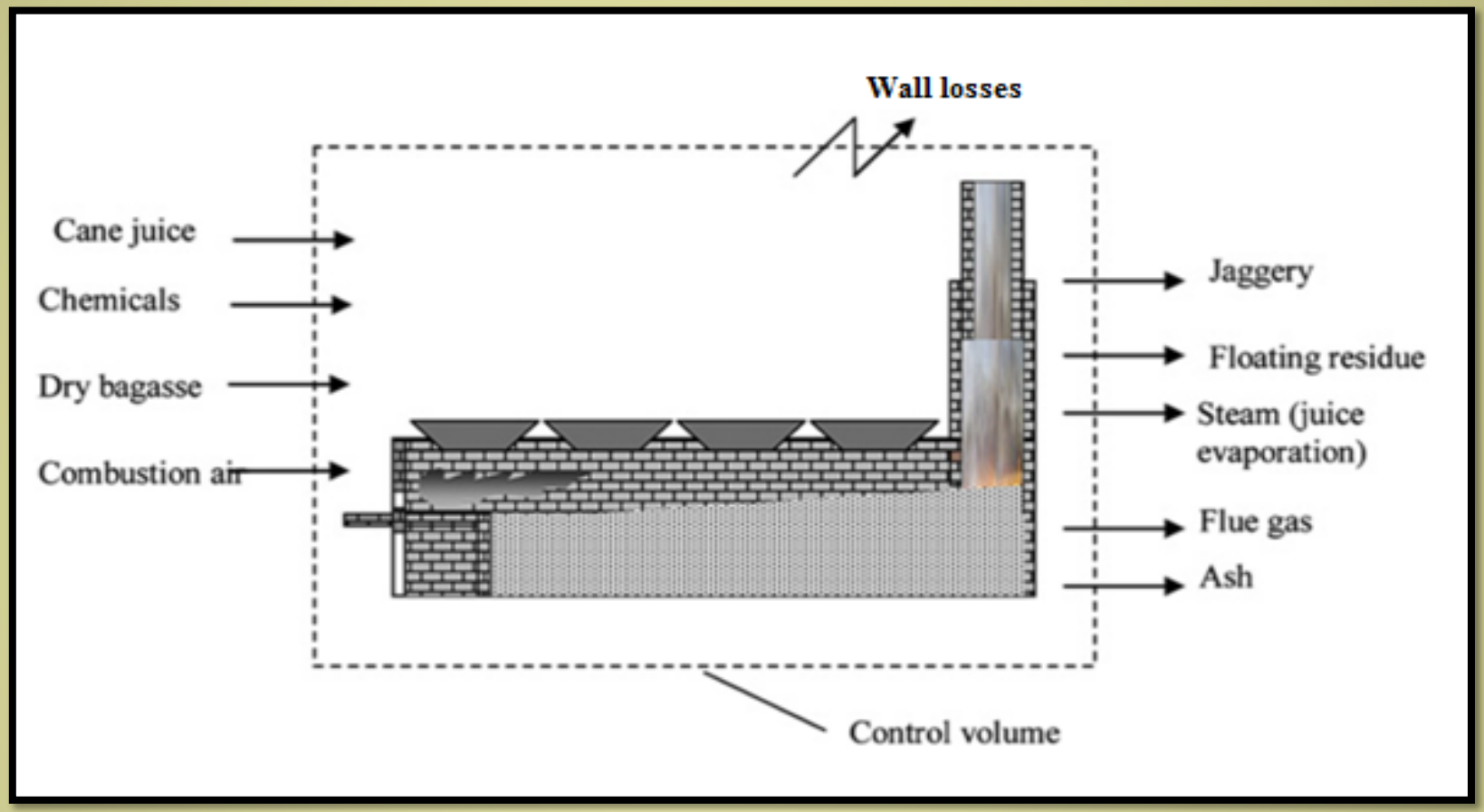
The furnace schematic (Sardeshpande et al., 2010)

Analysing the process



- Material and energy flows through the CV
- Mass balance , energy balance and exergy balance

The Exergy Balance

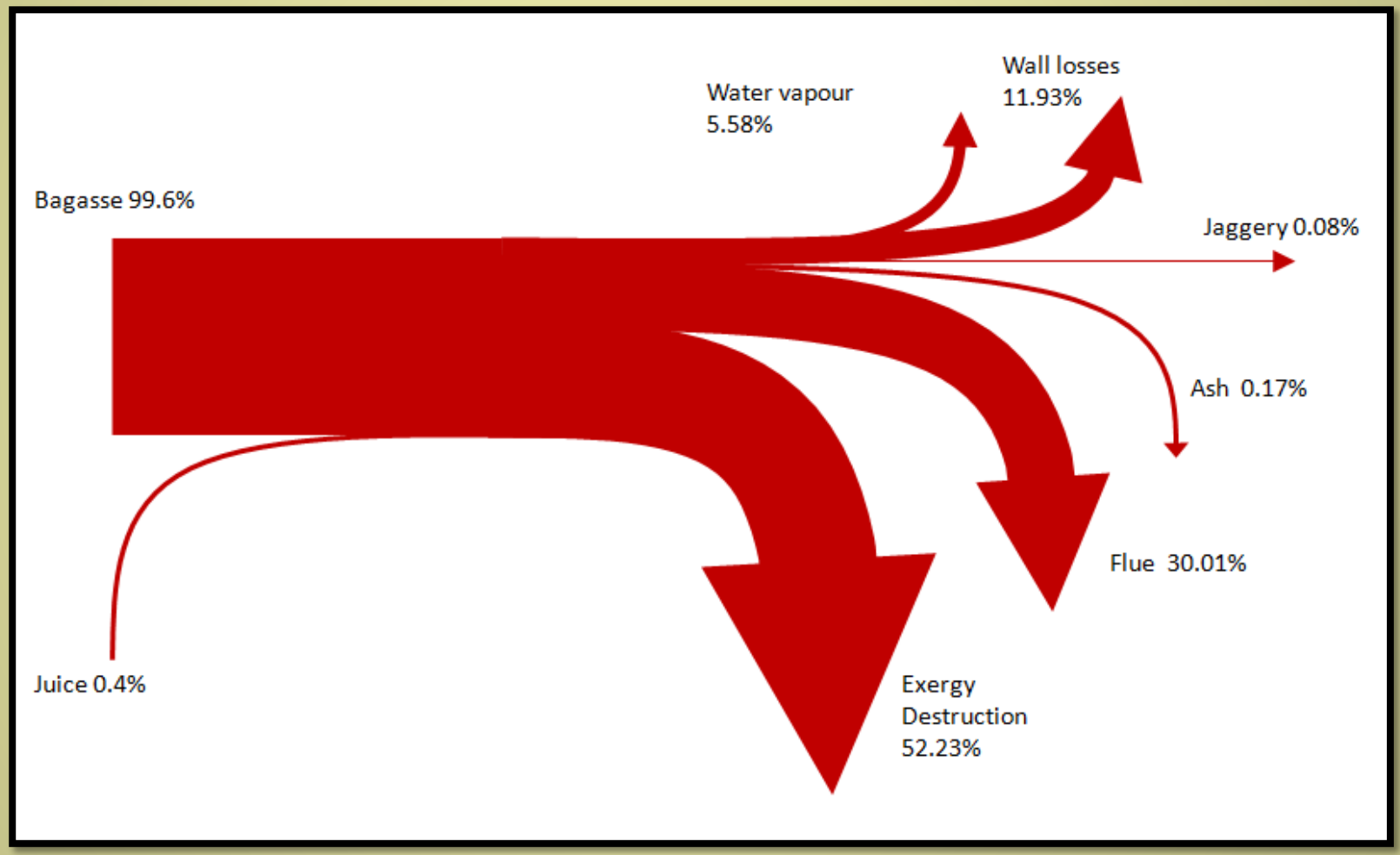


$$Exergy\ IN = Exergy\ OUT + Exergy\ destruction$$

$$Ex{\downarrow}juice + Ex{\downarrow}bagasse =$$

$$Ex{\downarrow}jaggery + Ex{\downarrow}flue + Ex{\downarrow}wall\ losses + Ex{\downarrow}ash$$

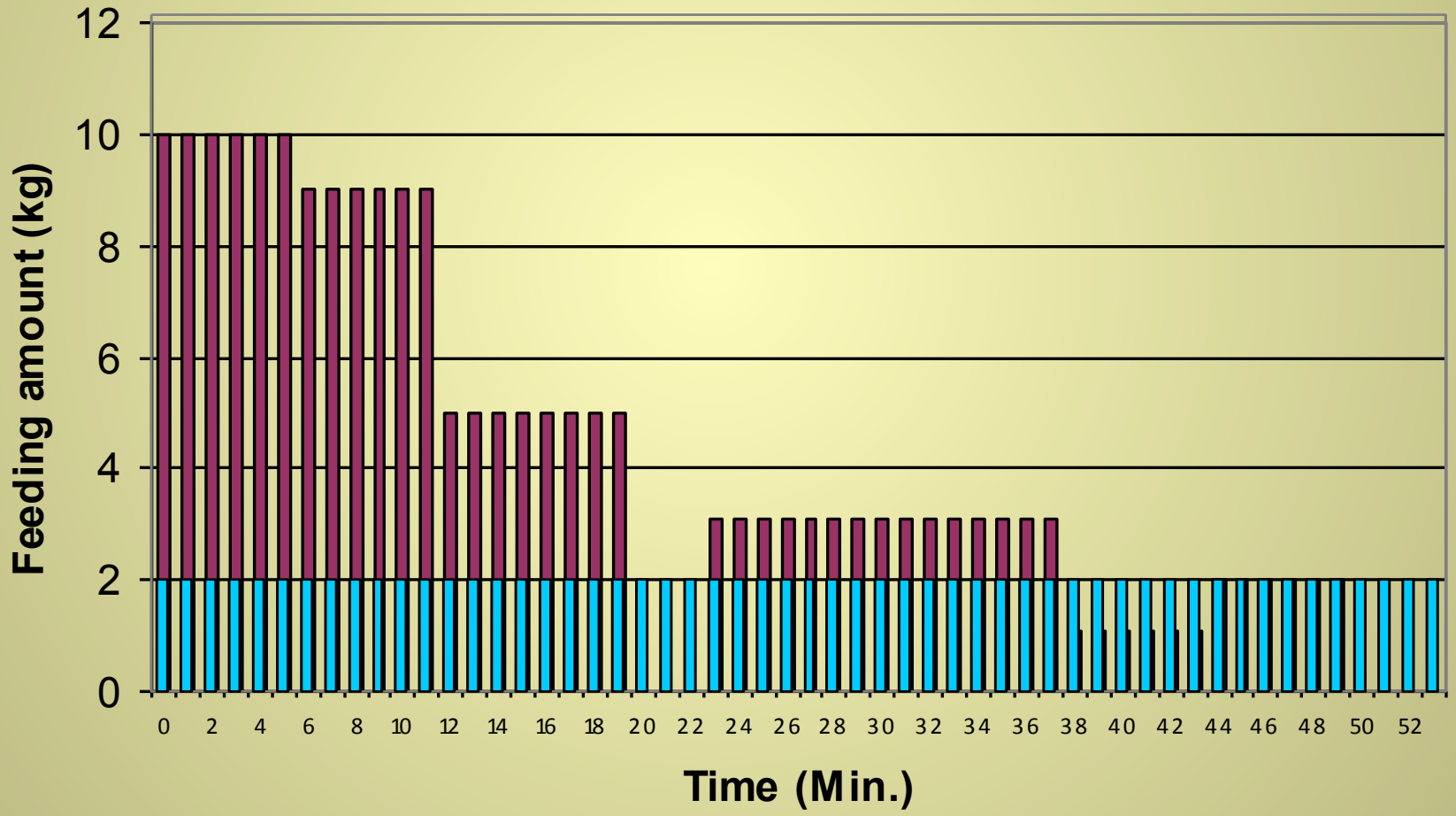
Exergy balance



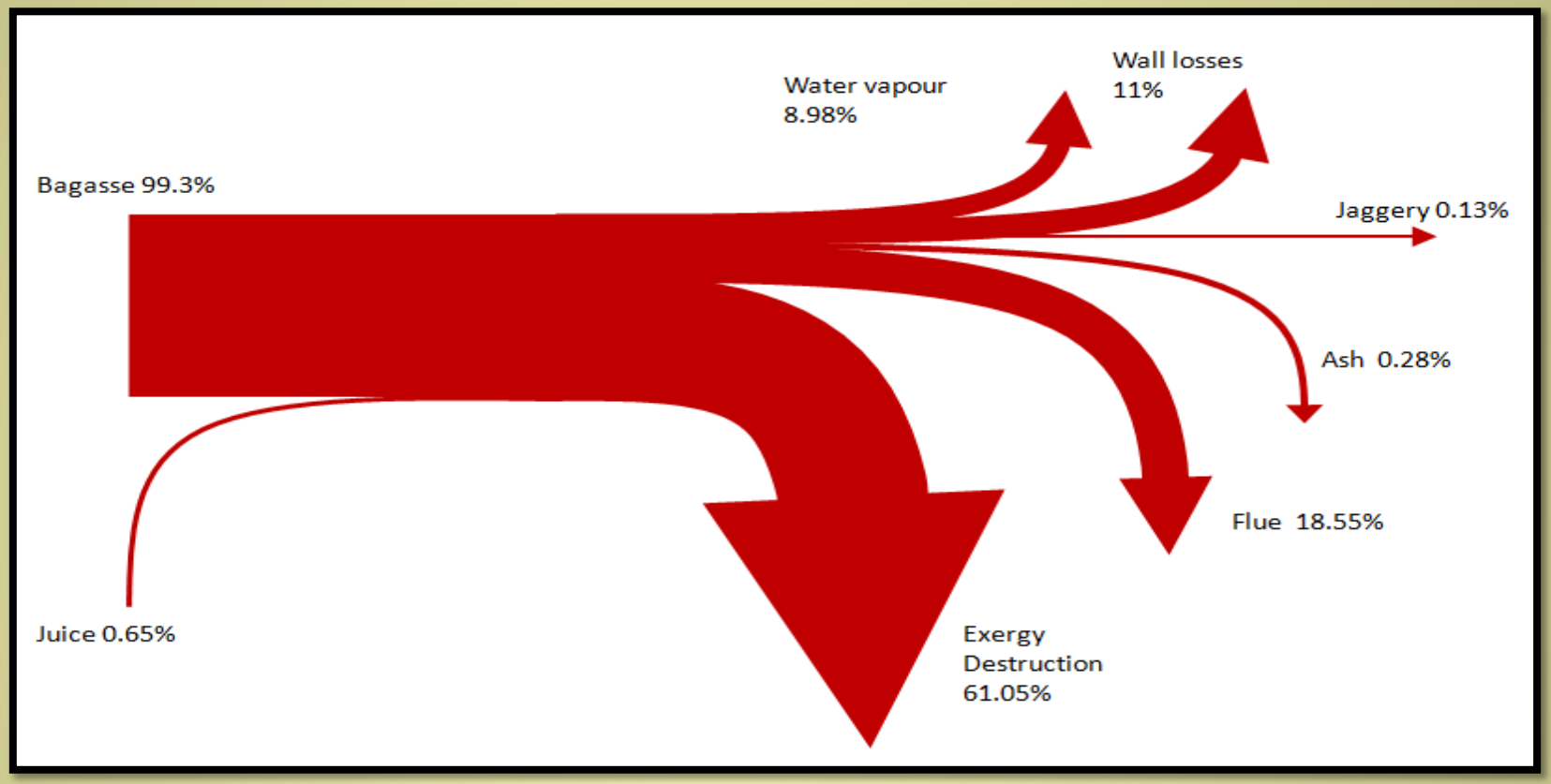
Proposed Modification

- Made fuel firing rate uniform
- Checked oxygen at every 4 minute interval
- Adjusted fuel firing to maintain oxygen rate at 5 to 6 % oxygen with 0 ppm CO
- Fuel rate input modified
- The fuel was stopped at the end of 55 min.
- Process time is increased by 5 min.
- Smoke observed was pale gray

Fuel Feeding Rate



Improved process exergy balance

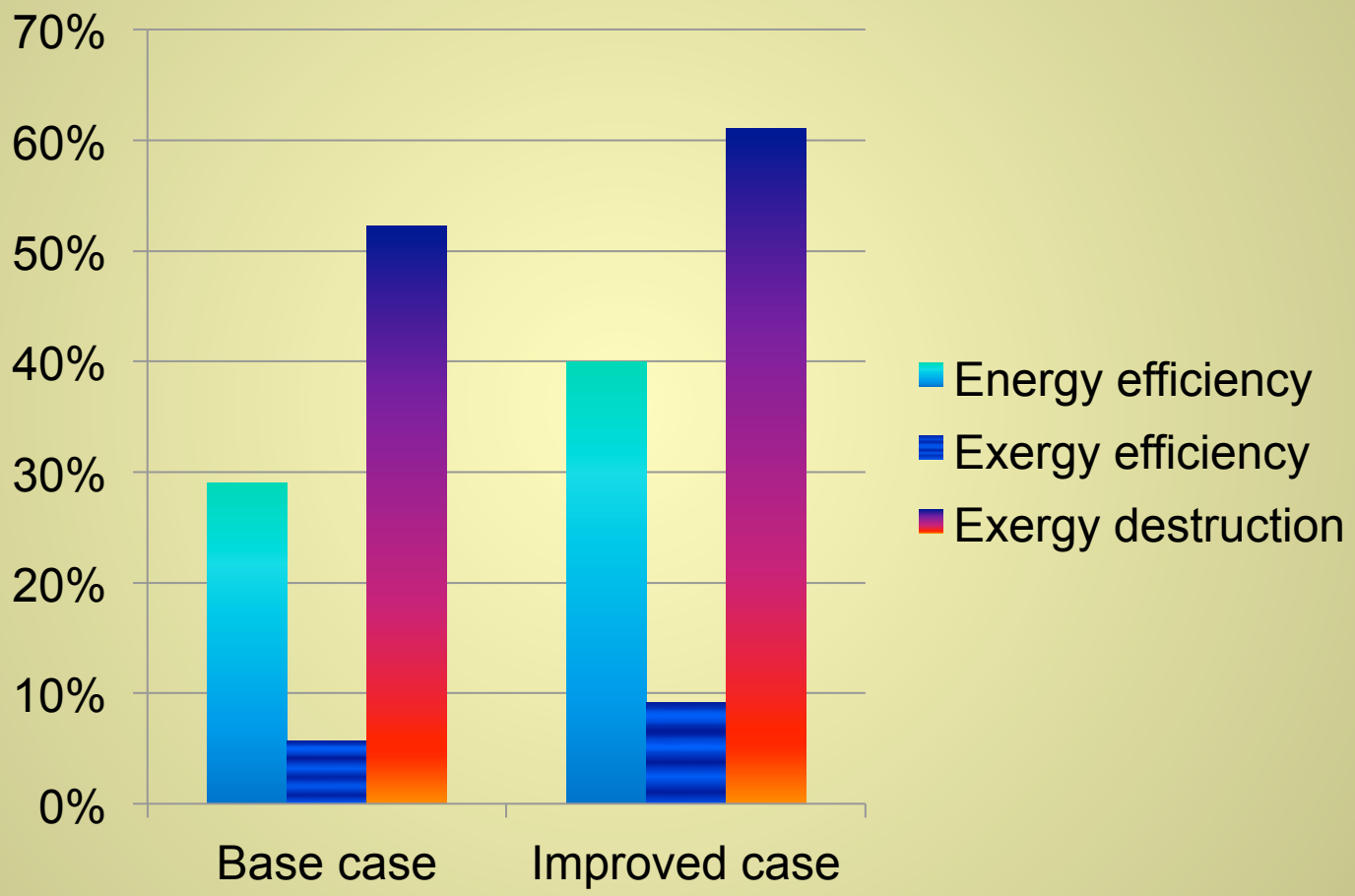


(1) More productive exergy out (water vapour + jaggery)
(2) Lesser wall losses and flue
(3) But increased exergy destruction

Results Comparison

Performance Comparison		
	Base case Operation	Altered Operation
Energy efficiency	29%	40%
Exergy efficiency	5.66%	9.12%
Exergy Destruction	52.23%	61.05%
Exhaust flue gas	30.01%	18.55%

Results



- Efficiency increases but destruction also increases

Insights…

- If a **secondary process** is integrated, the minimum beneficial efficiency increase is of 9%
- How much **extra data** required for exergy balance?
- **Complexity** of calculations: Careful assumptions necessary to simplify analysis.
- Resource accounting and sustainability