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Humidified air injection for zeolite boiler
in thermochemical energy storage and transport system utilizing unused heat from sugar mill

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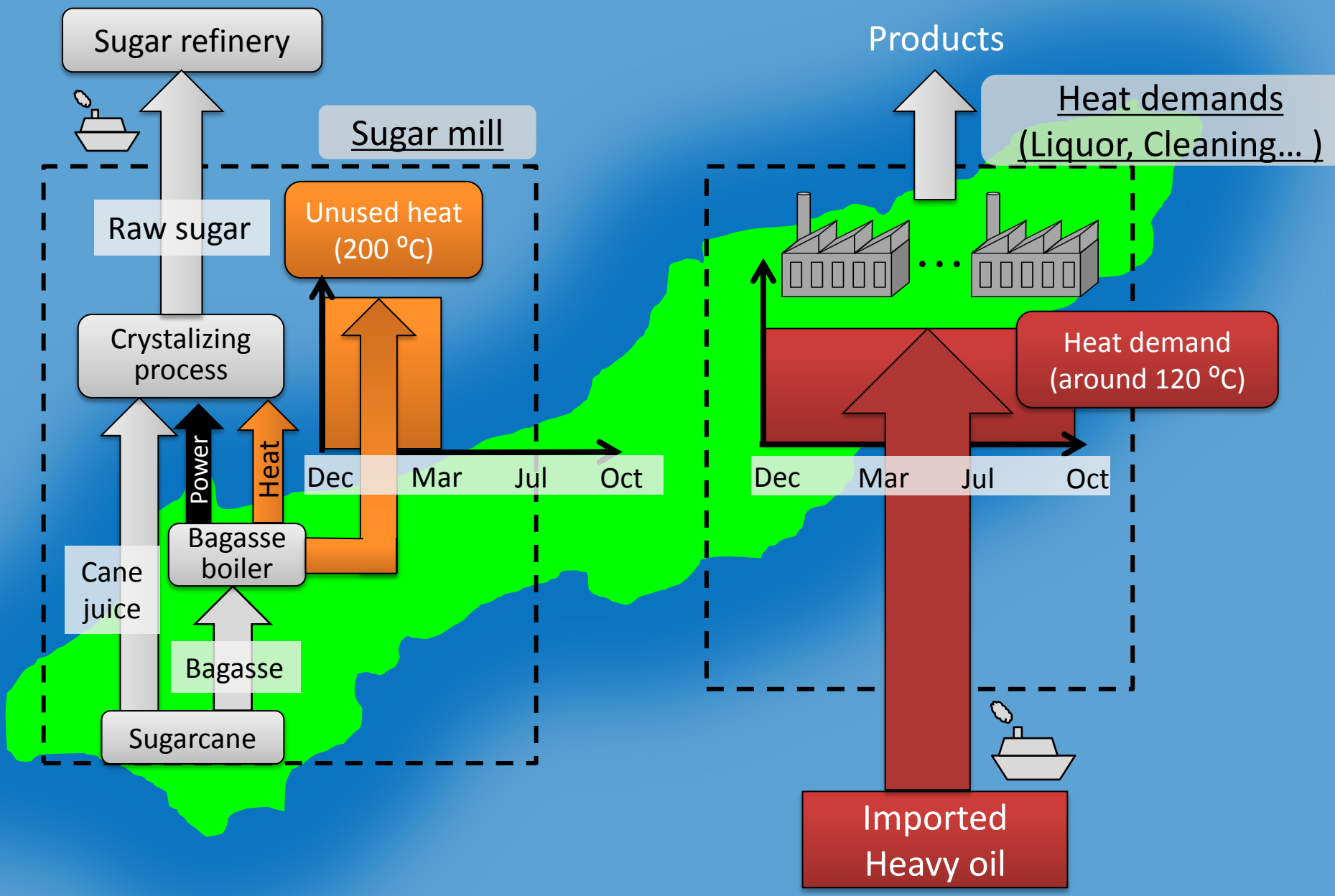
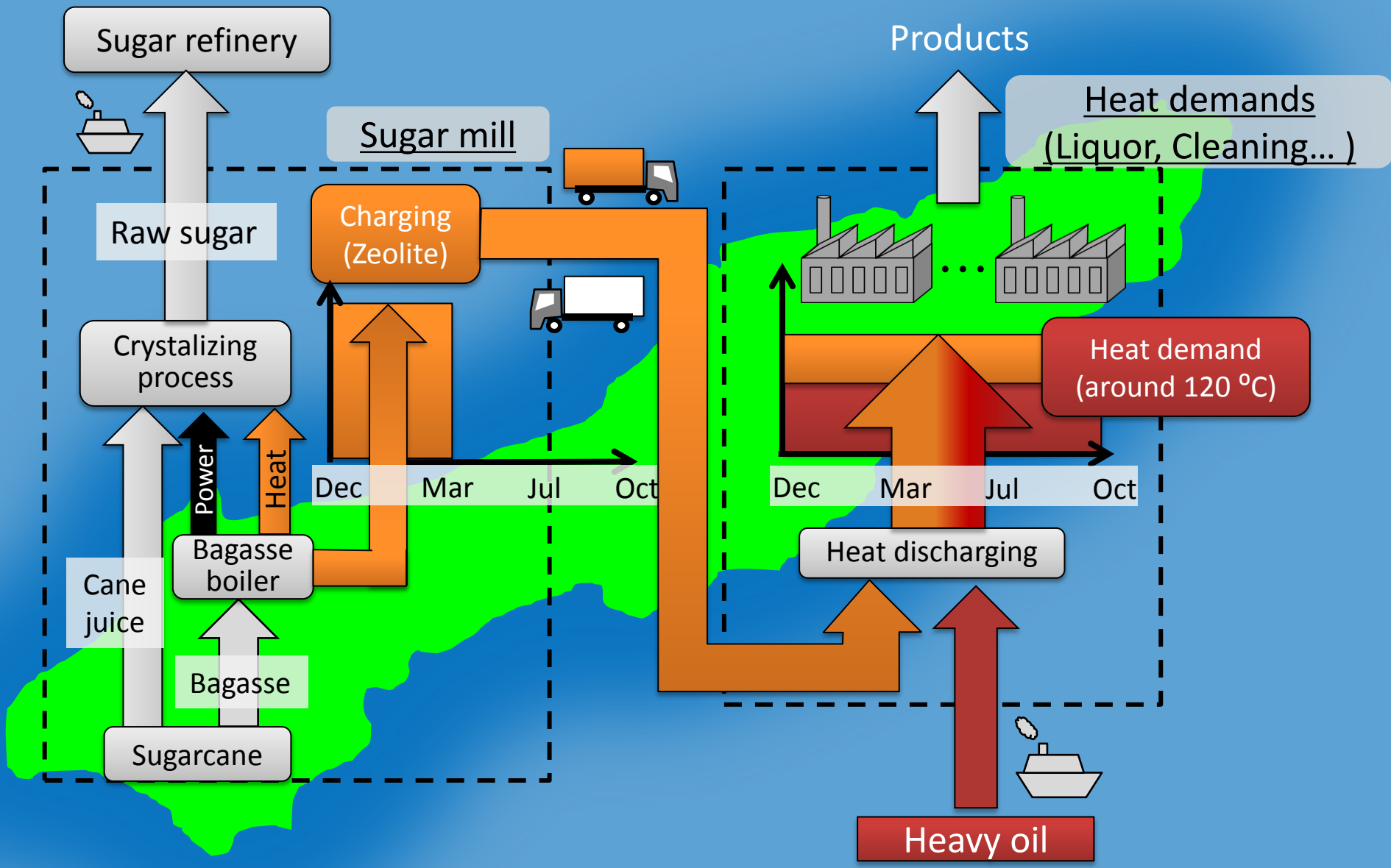
Spatial & Seasonal heat mismatch



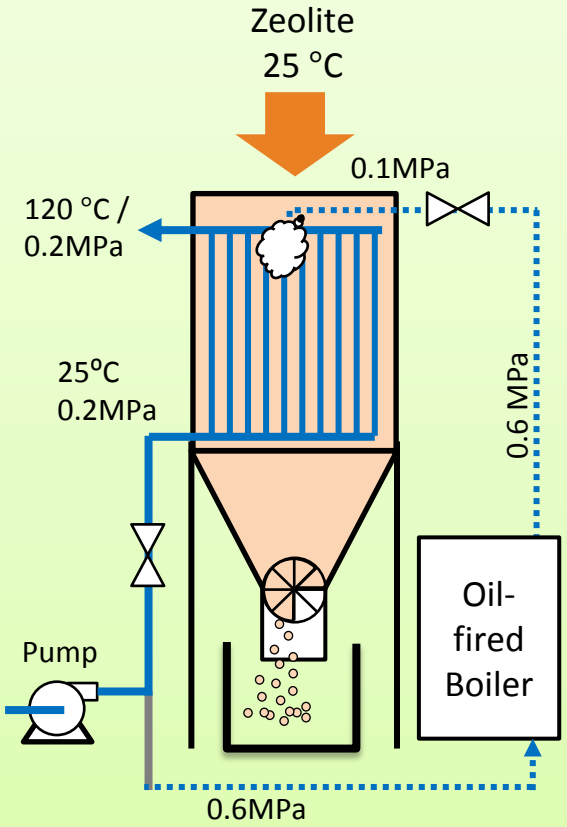
Thermochemical energy storage & transport system



Overview of the system

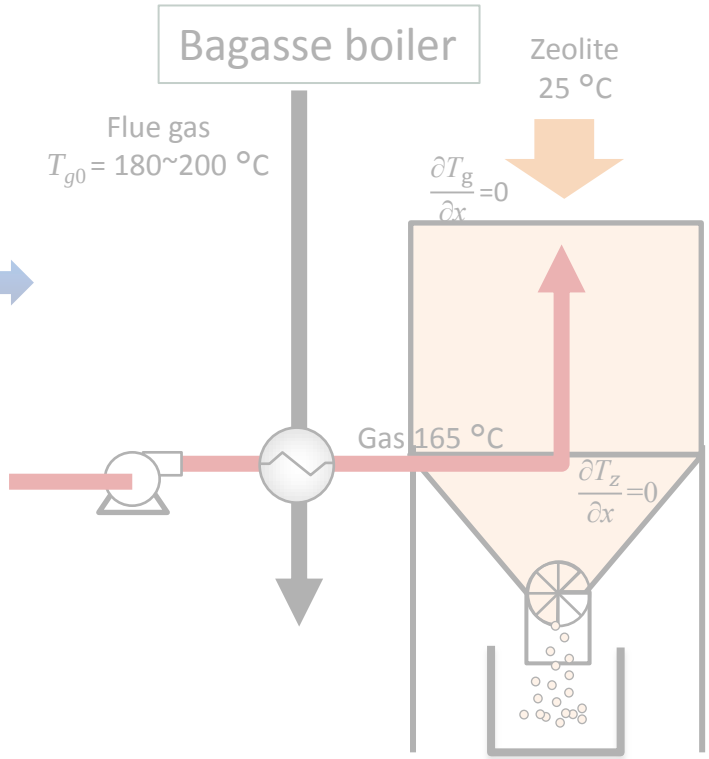
Zeolite boiler (Discharging)

- Moving bed
- Indirect heat exchange



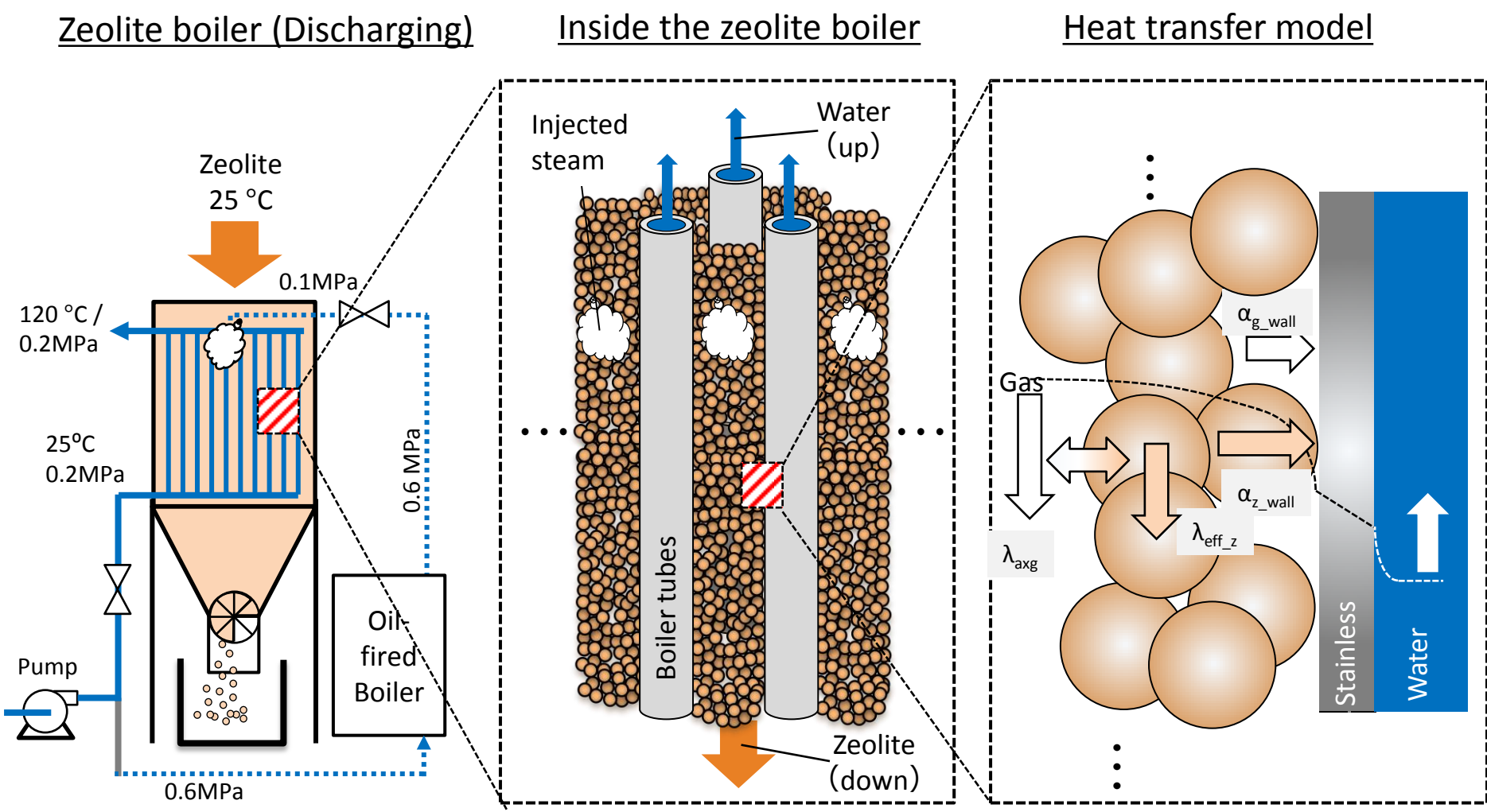
Heat charger (Charging)

- Moving bed
- Counter current heat exchange

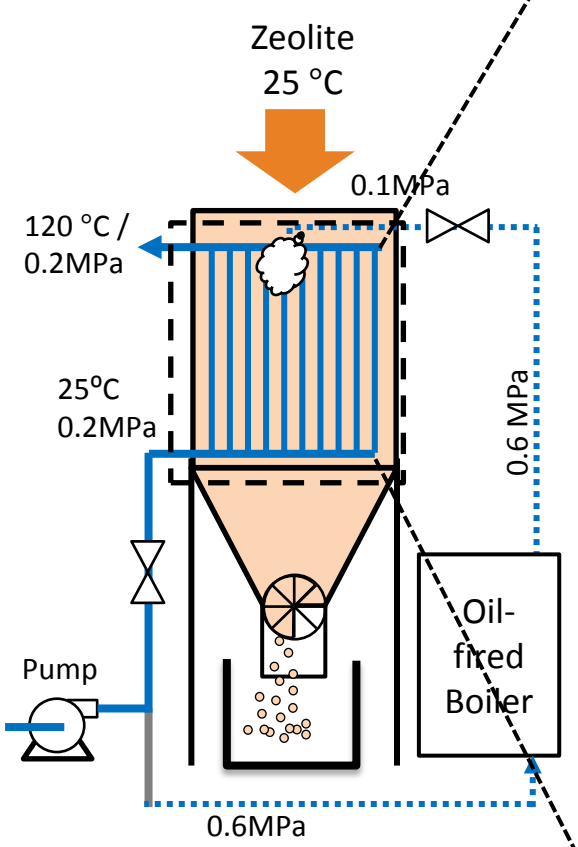


✓ Improve the fossil fuel conservation of the existed boiler

Moving bed and indirect heat exchanging in zeolite boiler



Governing equations of zeolite boiler



Heat balance

- Zeolite

$$\frac{\partial}{\partial x}\left(\rho_{zeo} u_{zeo} c_{pzeo} T_{zeo}\right) = \frac{\partial}{\partial x}\lambda_{ax\_zeo}\frac{\partial T_z}{\partial x} - \alpha_{zw}\sigma_{zw}(T_{zeo} - T_w) - \alpha_{gz}\sigma_{gz}(T_{zeo} - T_g) +$$

- Gas

$$\frac{\partial}{\partial x}\left(\rho_g u_g c_{pg} T_g\right) = \frac{\partial}{\partial x}\lambda_{axg}\frac{\partial T_g}{\partial x} - \alpha_{gw}\sigma_{gw}(T_g - T_w) + \alpha_{gz}\sigma_{gz}(T_{zeo} - T_g)$$

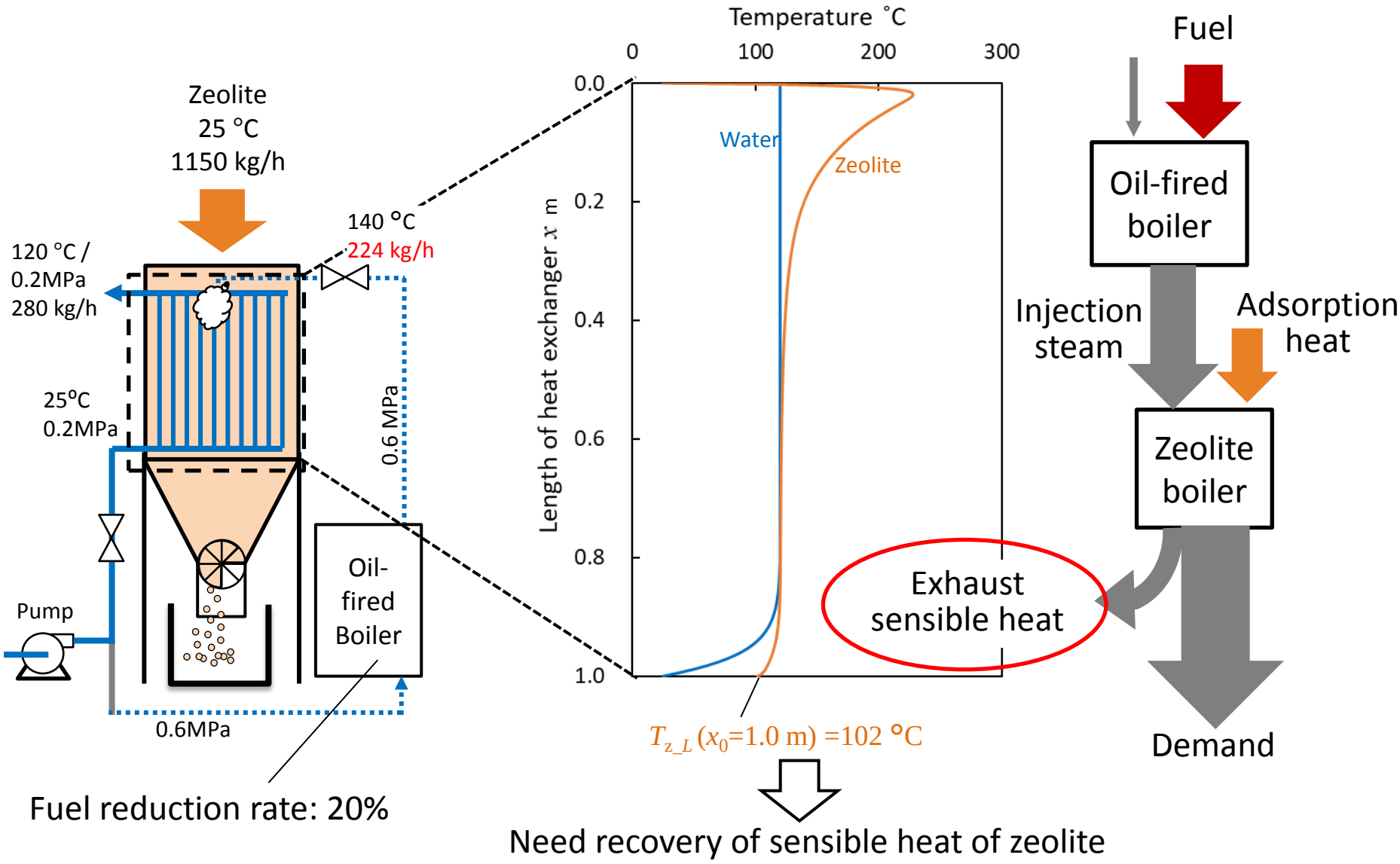
- Water

$$\frac{\partial}{\partial x}(-\rho_w u_w h_w) = \alpha_{zw}\sigma_{zw}(T_{zeo} - T_w) + \alpha_{gw}\sigma_{gw}(T_g - T_w)$$

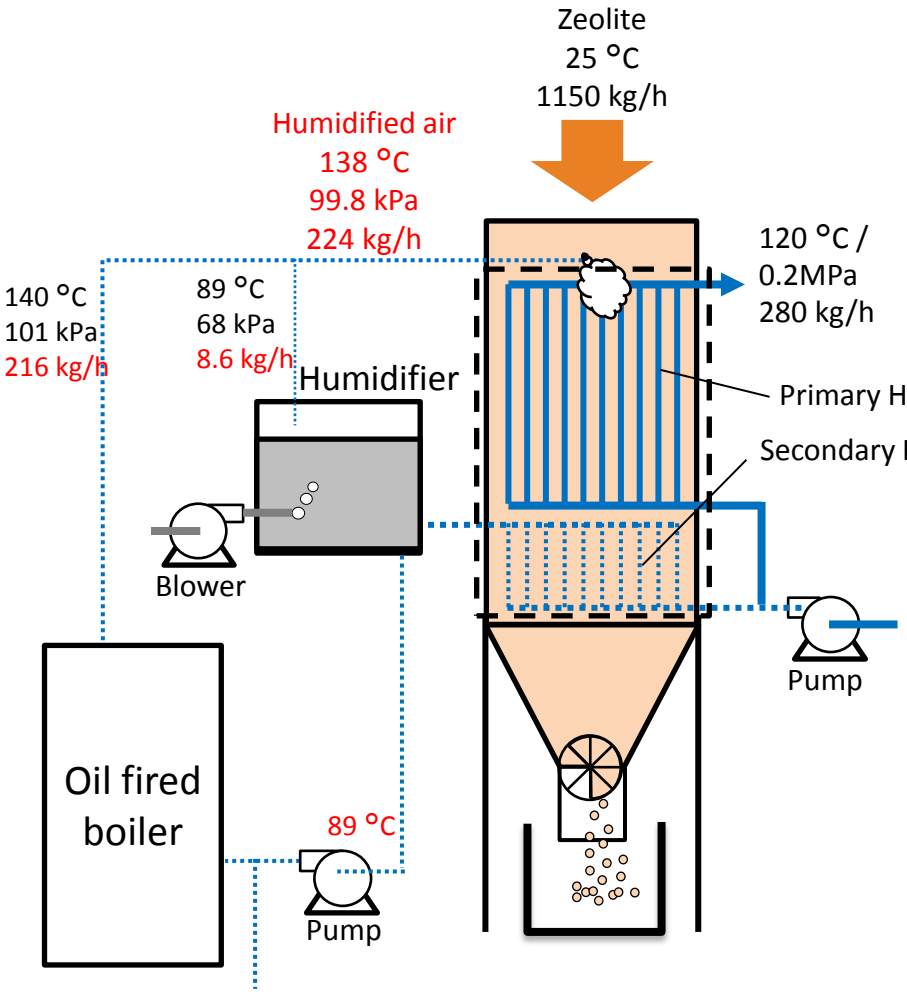
Steam conservation

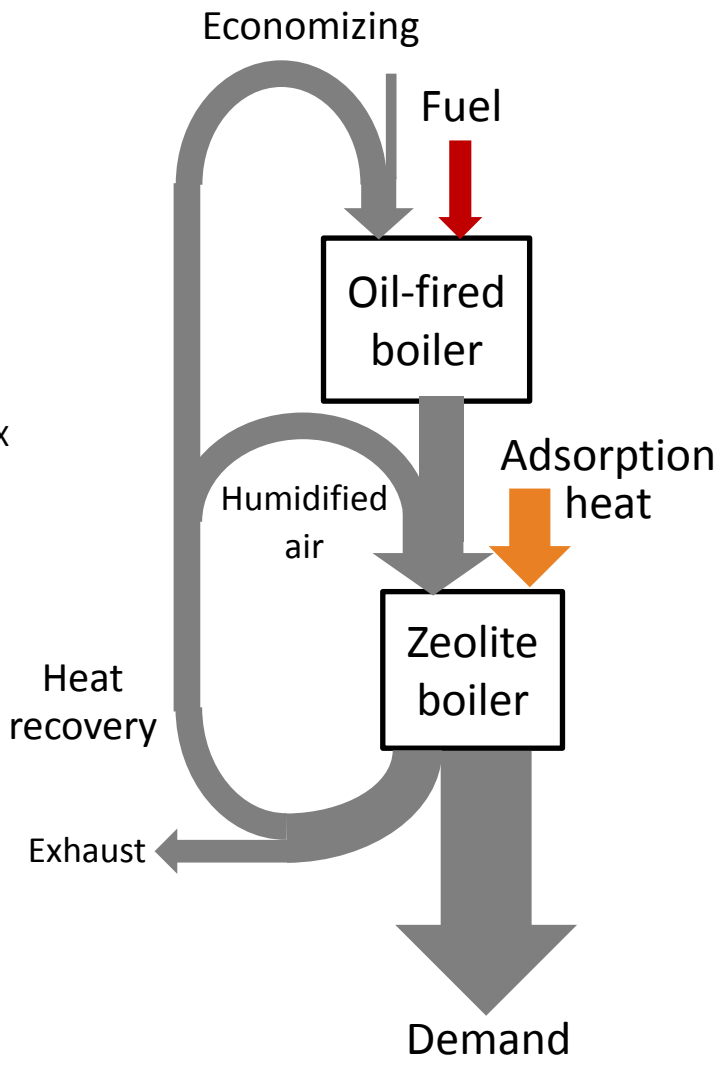
$$\frac{\partial}{\partial x}(\rho_s u_g) = -\rho_{z0} r \qquad r = k_{LDF}(q_{eq} - q)$$

Performance prediction of “Normal process”

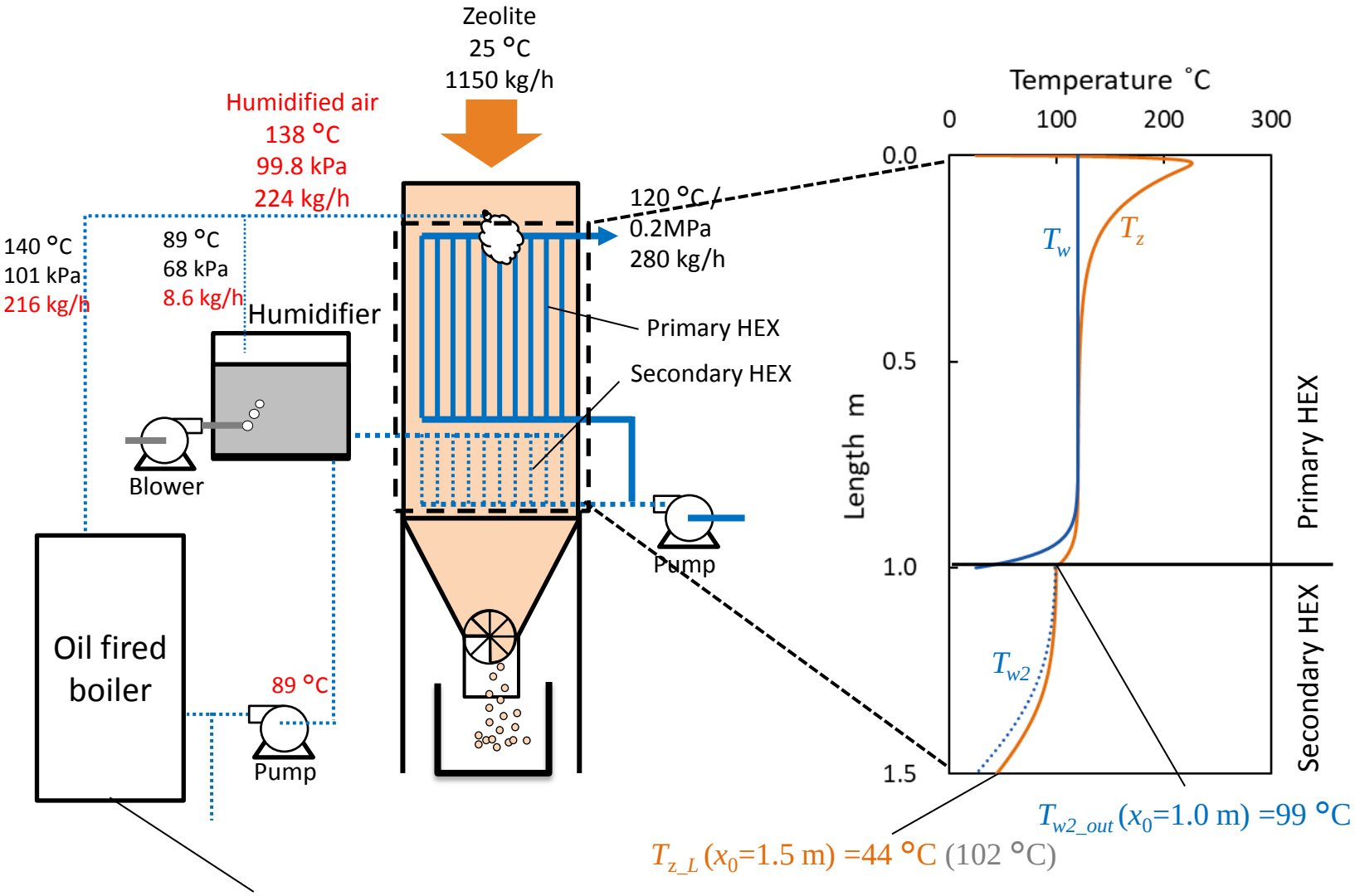


Applying Humidified injection & Economizing process



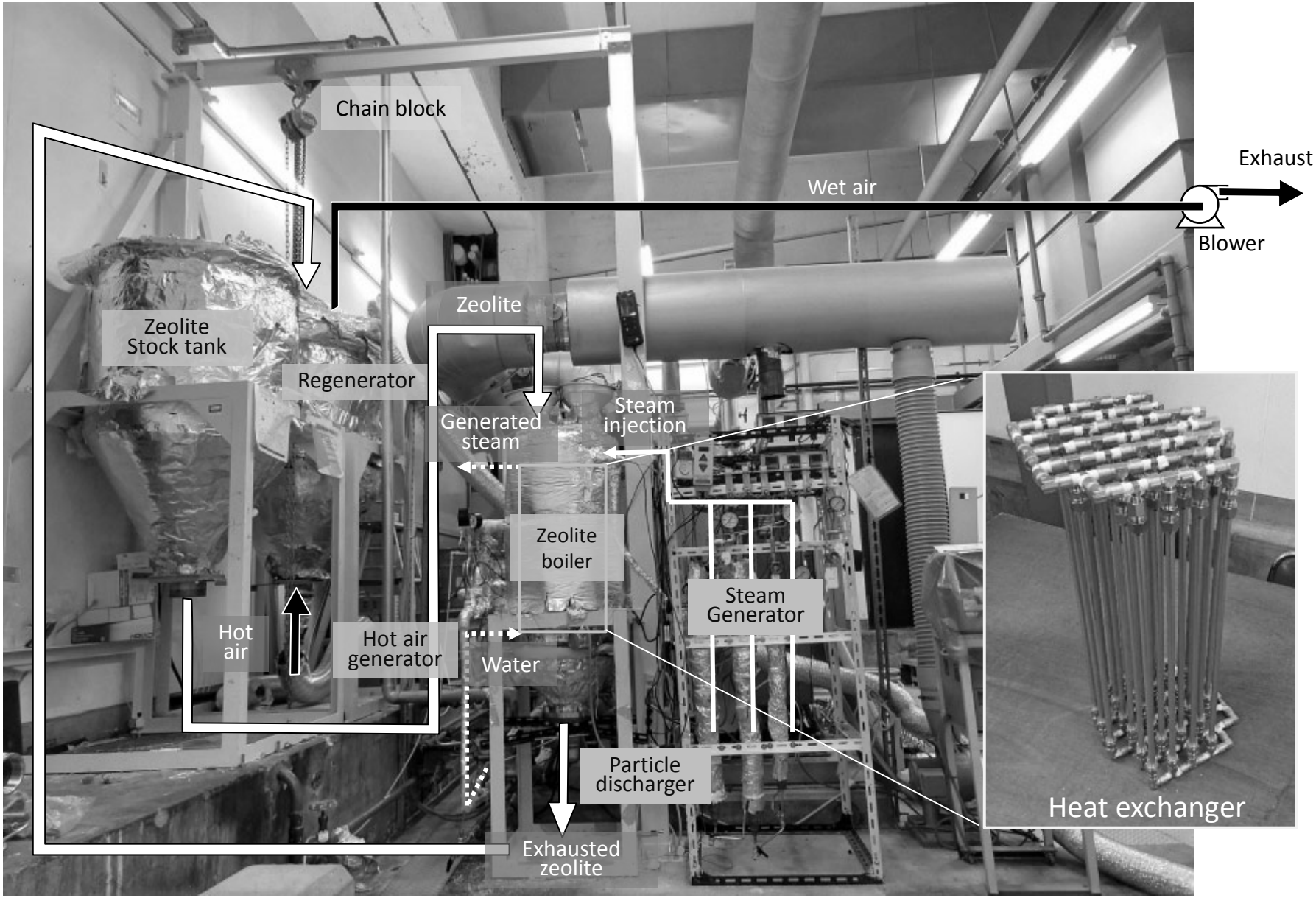


Improving fuel reduction rate by adding secondary HEX

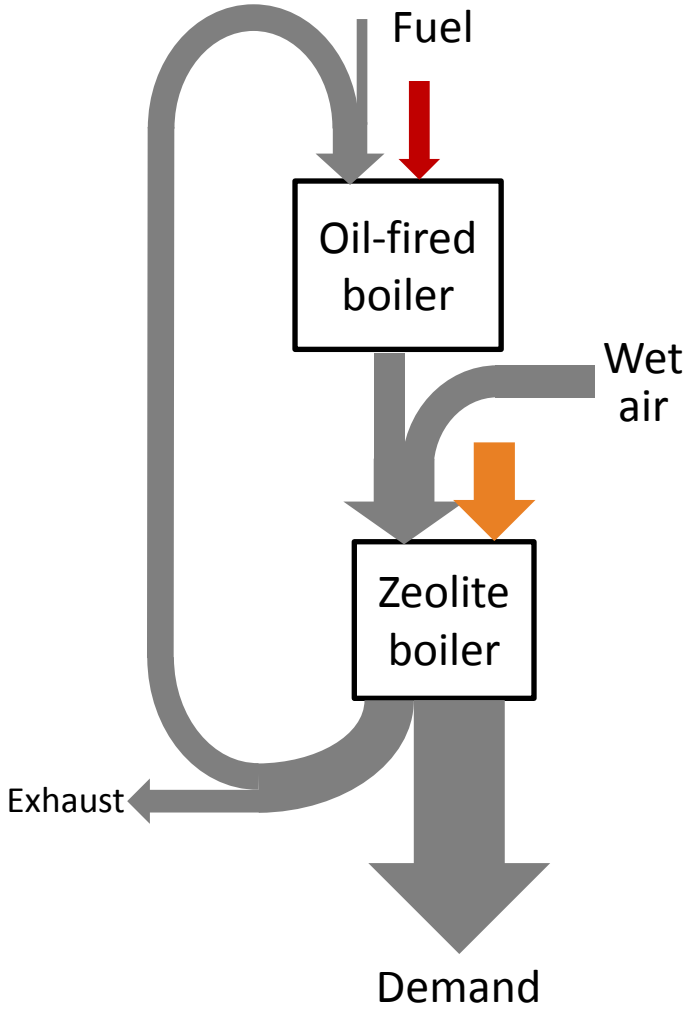


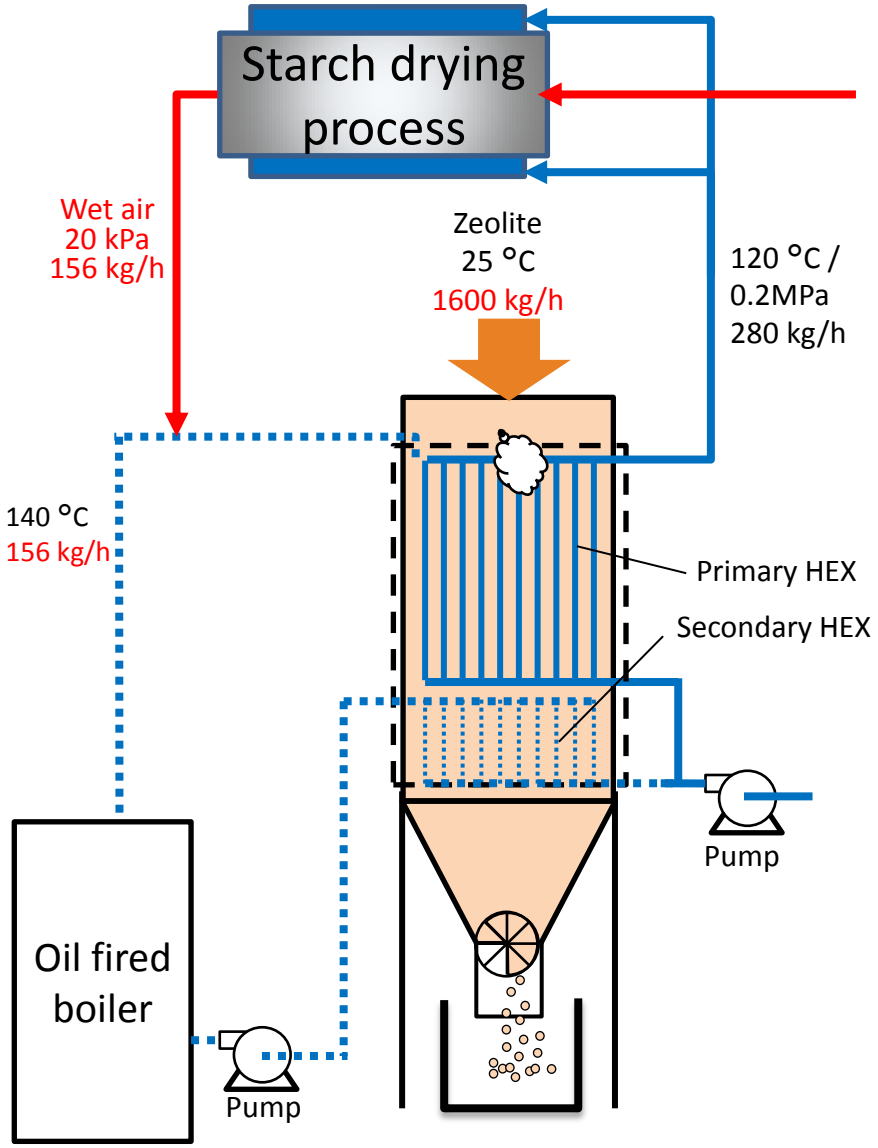
Fuel reduction rate: 31% (Normal process: 20%)

Future work 1: Zeolite Boiler test



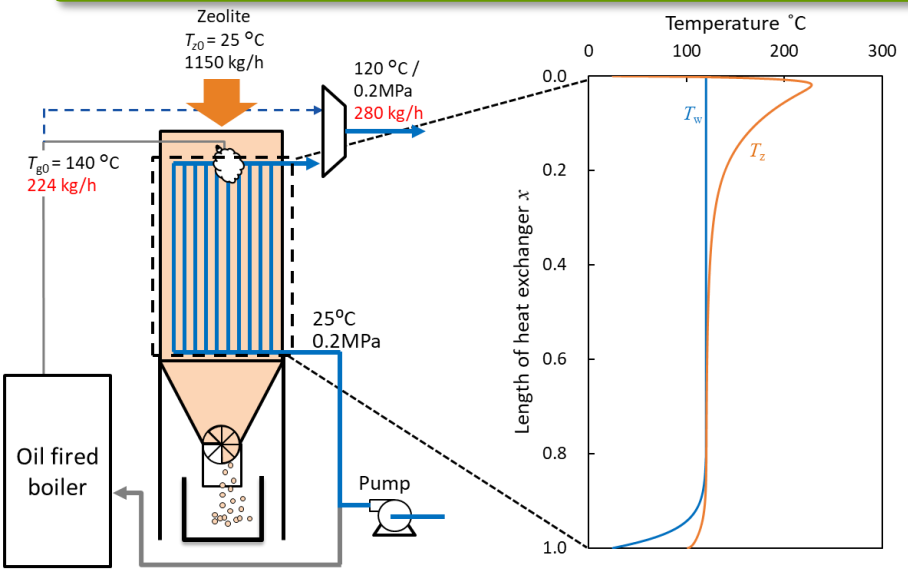
Future work 2:Wet air injection from the drying process





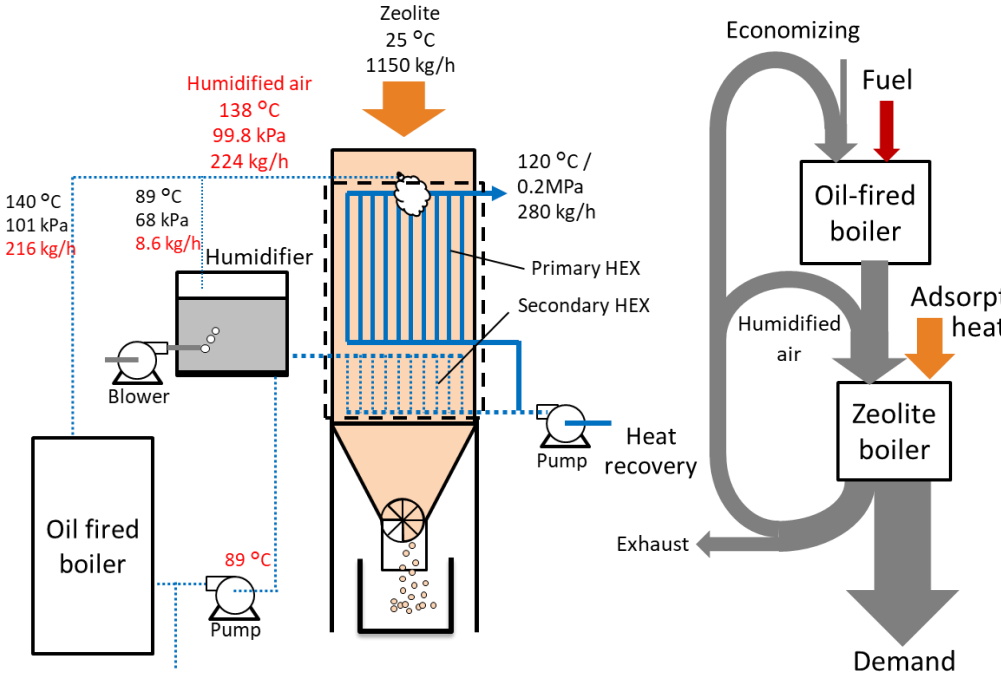
Fuel reduction rate: 50% (Normal process: 20%)

Conclusions



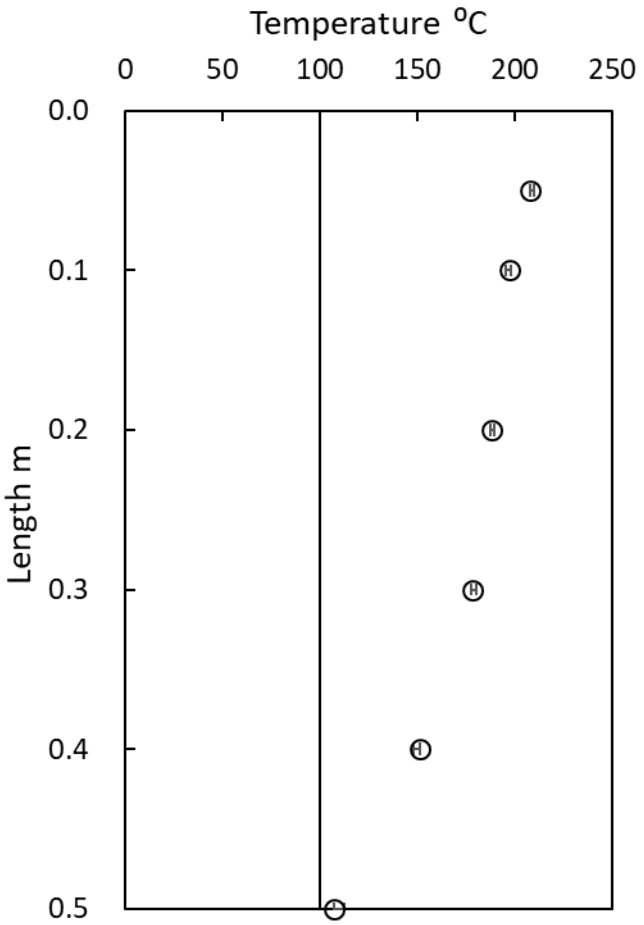
- ✓ "Zeolite Boiler" as a steam generator
  - Moving bed & indirect HEX
  - Quasi-2D modelling
- ✓ Fuel reduction by "Zeolite boiler"
  - 280 kg/h steam generate
  - 20% fuel reduction rate

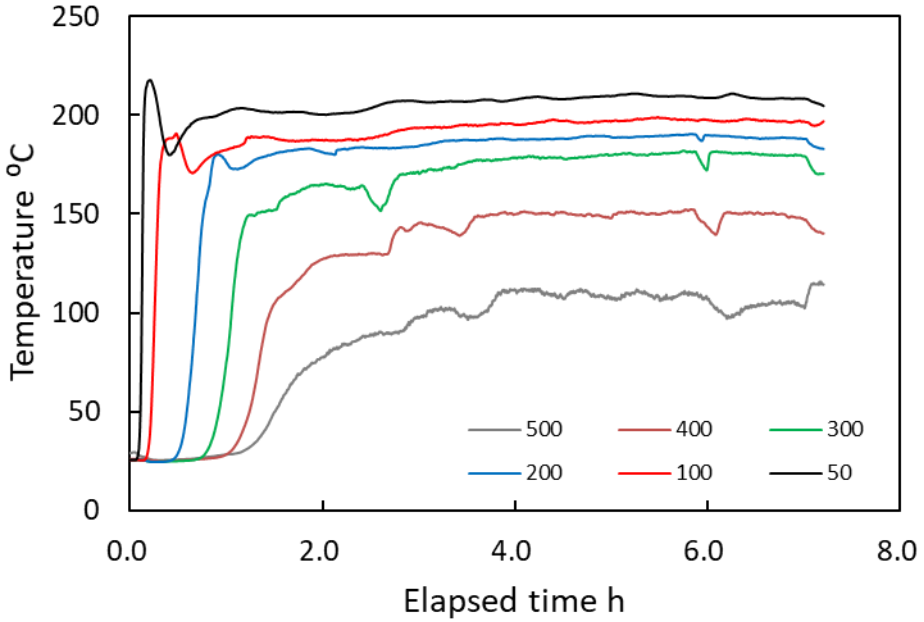
- ✓ Humidified injection and economizing process
  - Exhausted sensible heat recovery
  - 8.6 kg/h of water vapor can be generated
  - 31% fuel reduction

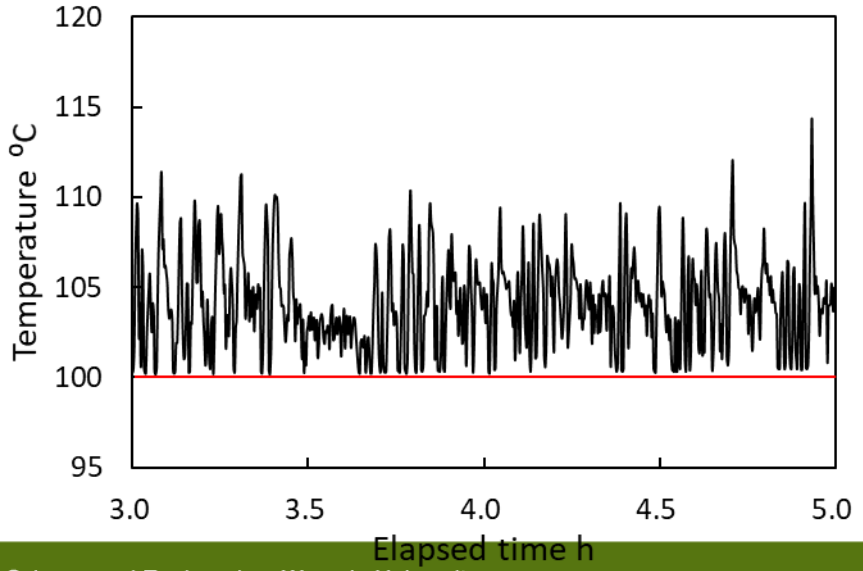


Appendix

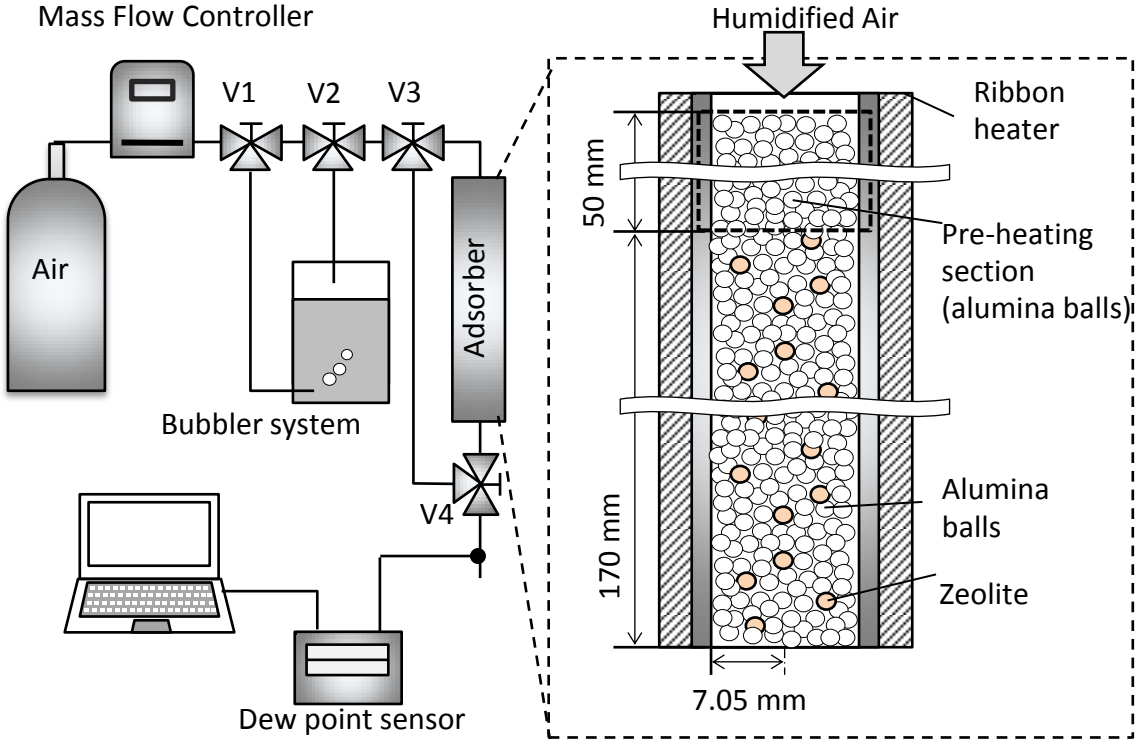
Experimental data

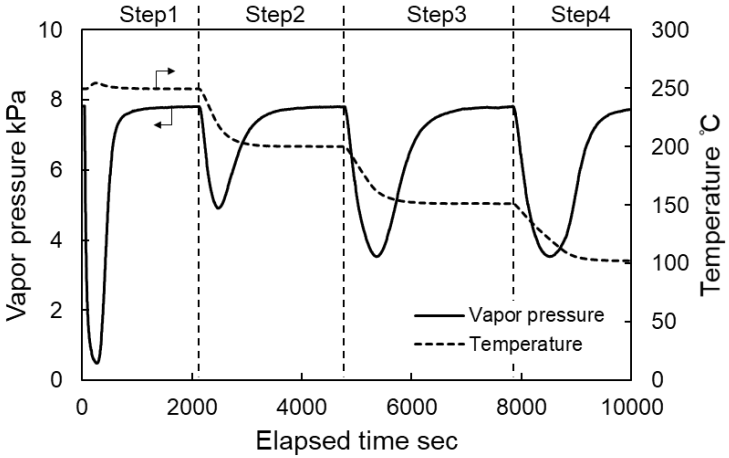


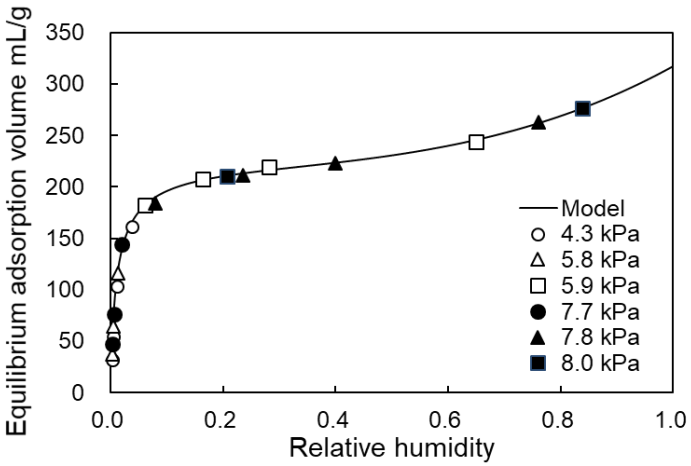




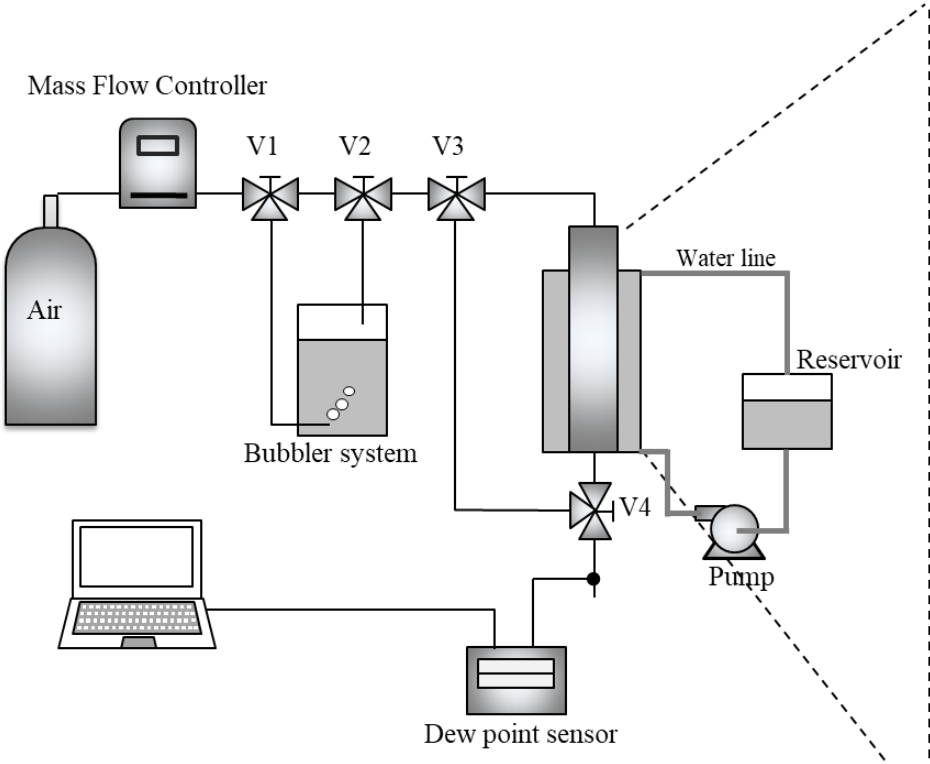
Diluted fixed bed test to obtain adsorption equilibria

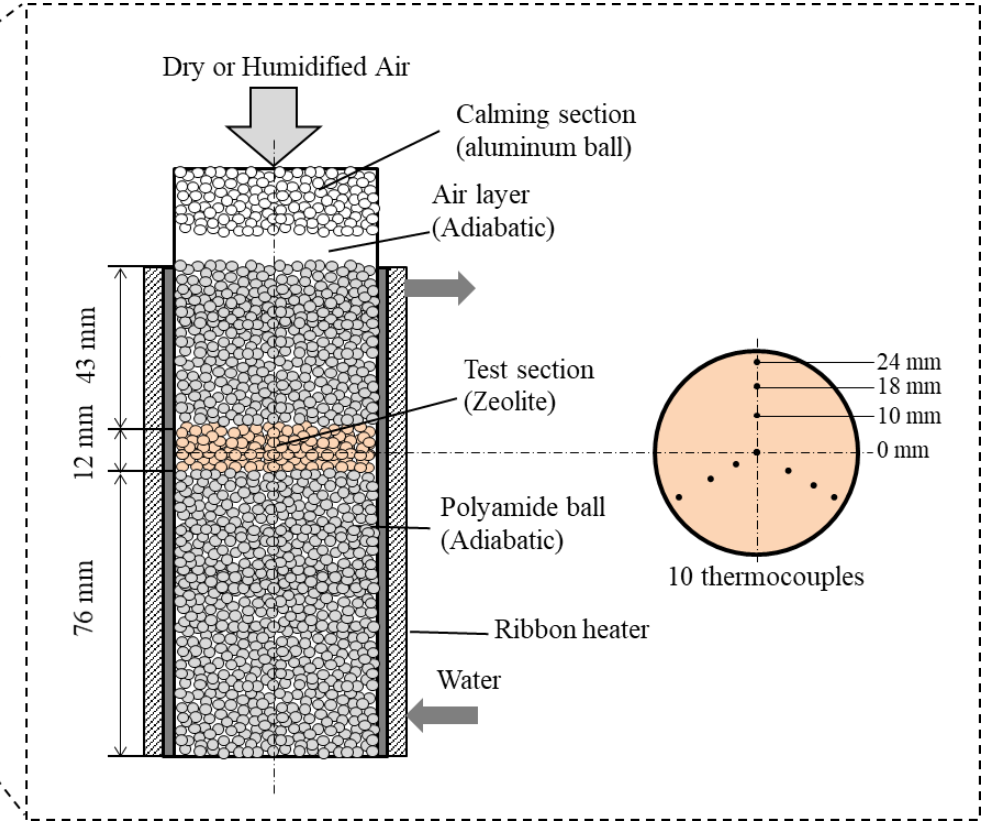




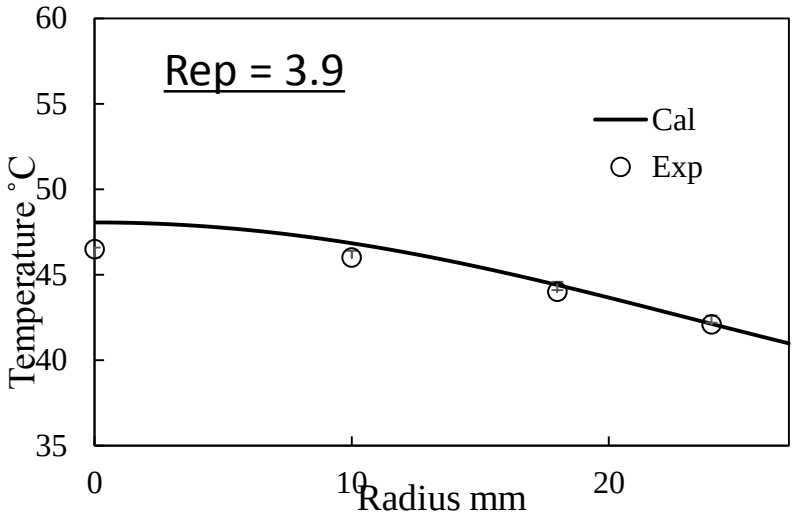


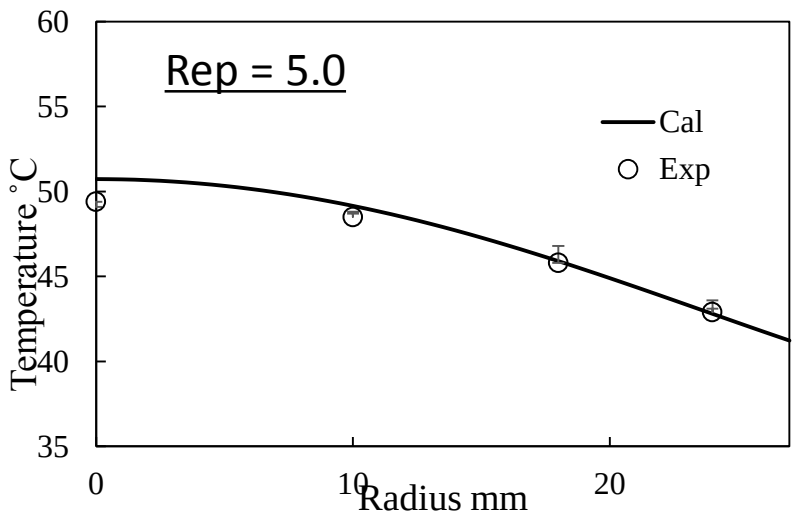
Experimental setup for heat transfer measurement

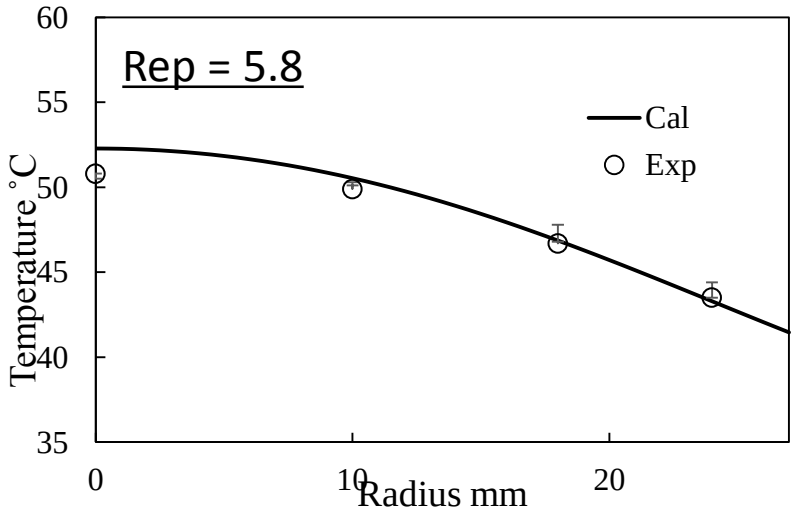




Validation under steady state condition



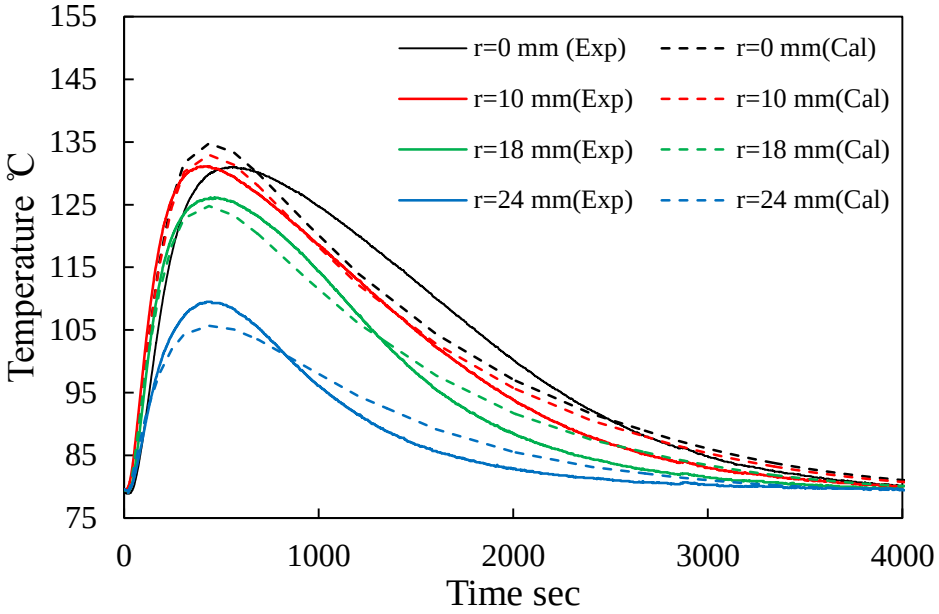




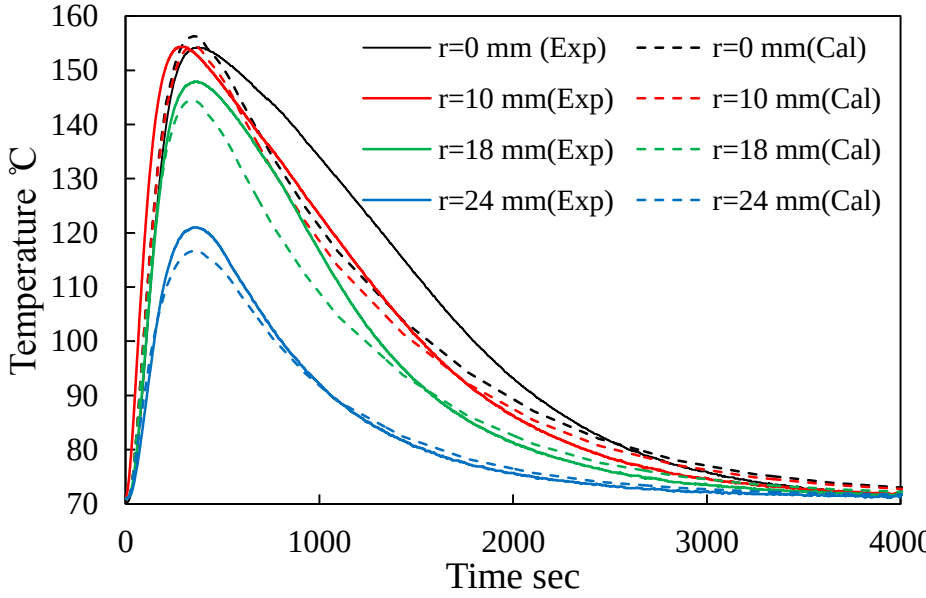
- ✓ Check that the reported heat transfer model has good agreement to the experimental result under the steady state condition
- → How about unsteady state with adsorption ?

Validation under unsteady state condition

ps = 4.2 kPa

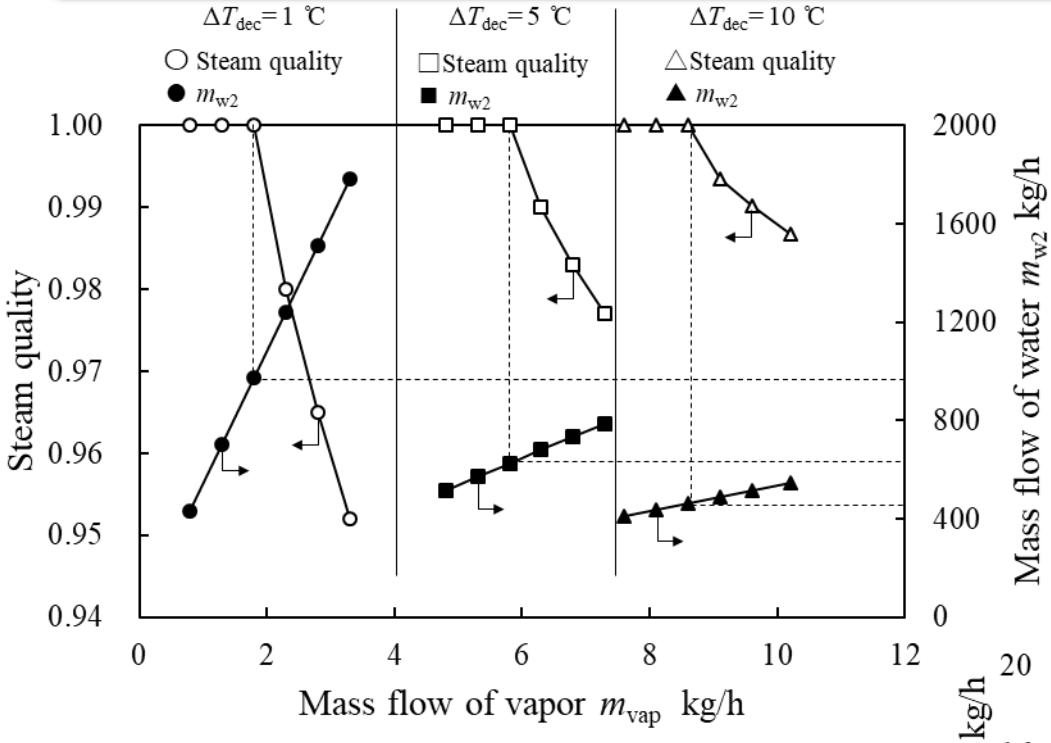


ps = 7.4 kPa



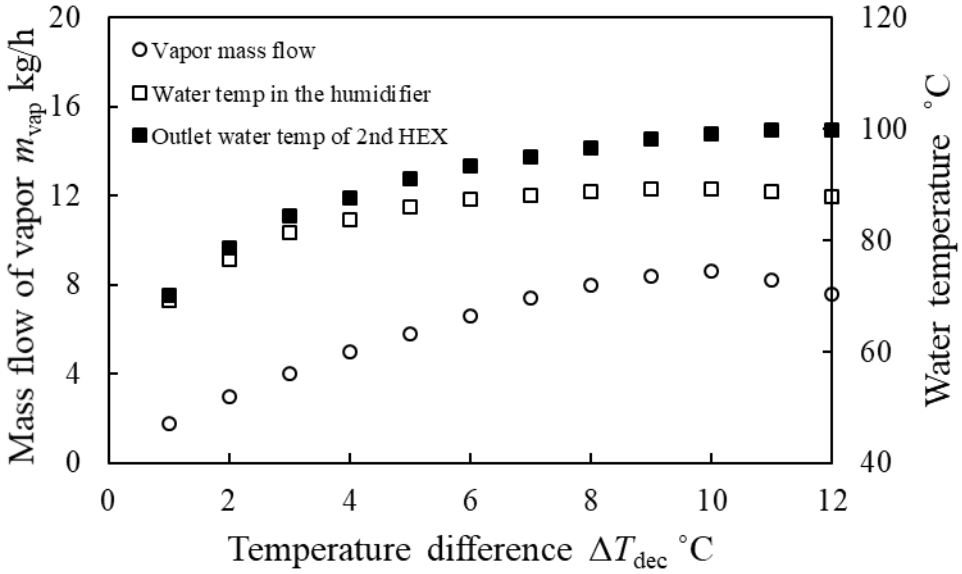
✓ Approximate good agreement to experimental data

Parametric study of humidified air injection & economizing process

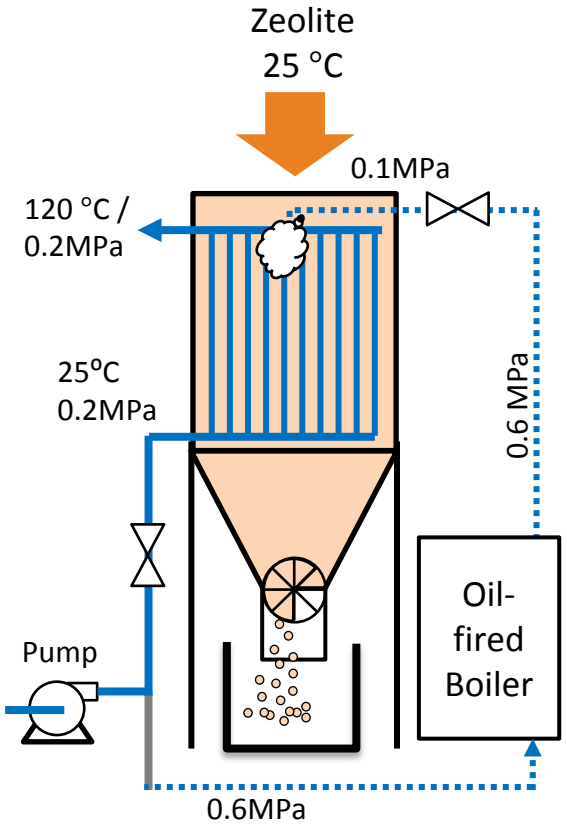


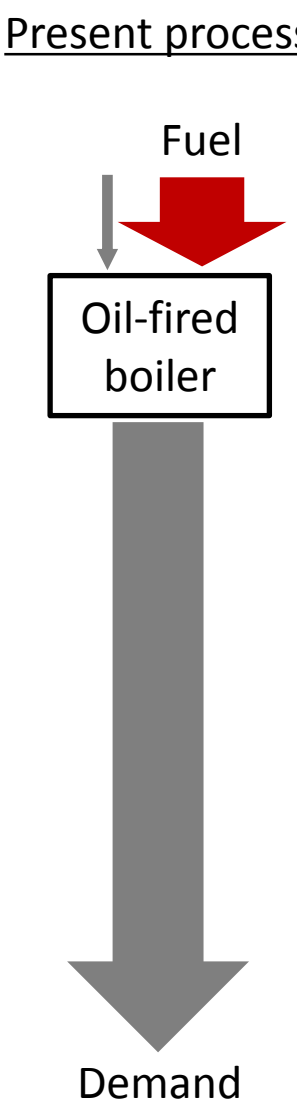
1. Determining ΔT_{dec}
2. m_{vap} is calculated by following equation
   $m_{w2} c_{pw2} \Delta T_{dec} = m_{vap} \Delta L$
3. the maximum value of m_{vap} is determined to obtain dry saturated steam
4. Correspondingly the m_{w2} is also determined.

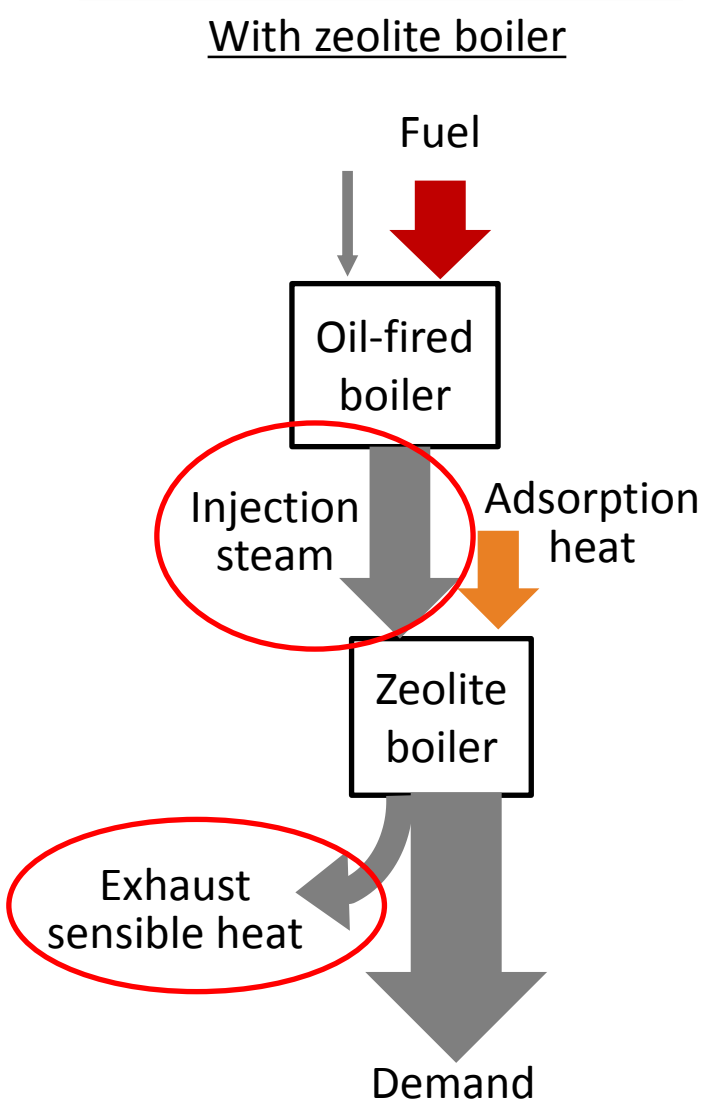
- ↗ ΔT_{dec}
  - ↗ $T_{\mathrm{w2\_out}}$(limited below 100 °C)
  - ↘decreasing m_{w2}.
  - ↗ the water temperature of humidifier
    - ↗ vapor pressure of humidified air
    - ↗ mass flow rate of vapor



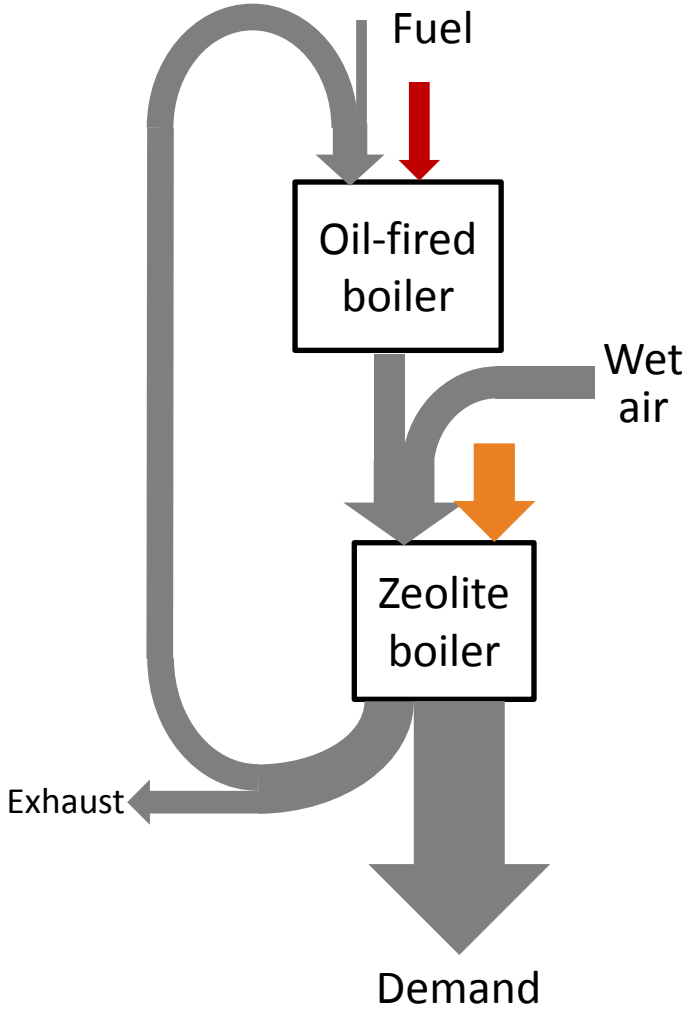
Overview of the system

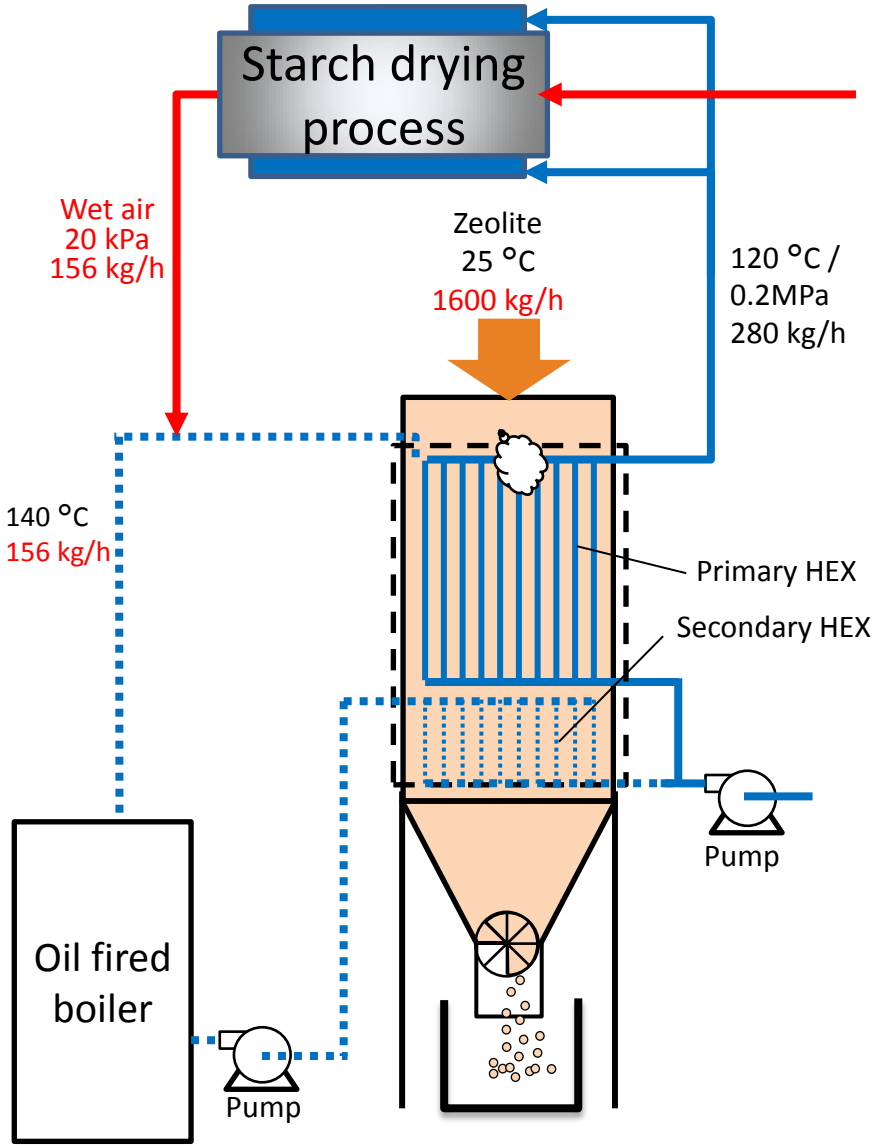






Wet air injection from the drying process





Fuel reduction rate: 50% (Normal process: 20%)

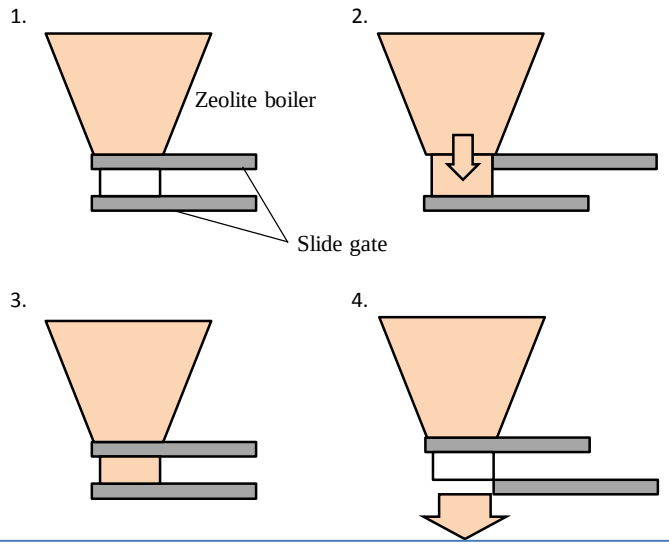
Economic analysis

	Normal process	Humidified injection & economizing	Wet air injection
Total heat supply	30 MWh/y	50 MWh/y	78 MWh/y
LCOE	517 €/MWh	324 €/MWh	243 €/MWh
Revenue	3100 €/y	5177 €/y	8039 €/y
OPEX total	2351 €/y	2597 €/y	3813 €/y
Profit	849 €/y	2580 €/y	4267 €/y

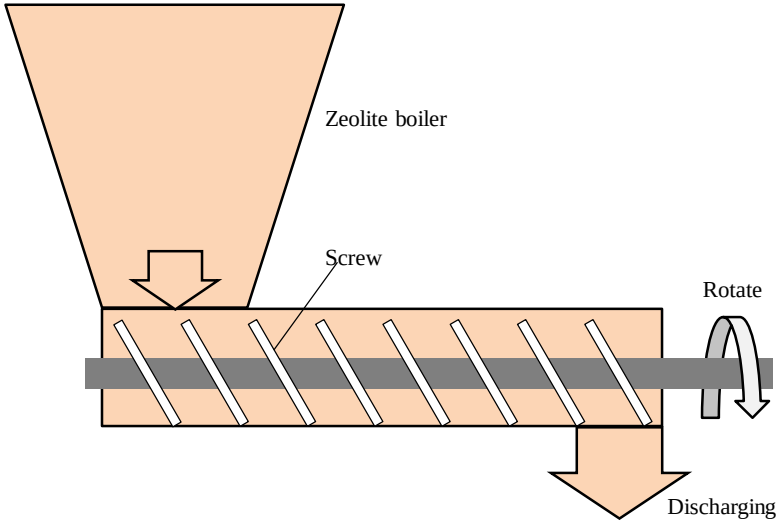
- ✓ High LCOE due to low total heat supply
  - Need governmental funding support
  - Increase total heat supply (Maximum: approx. 400 MWh/y)

Conventional discharger types

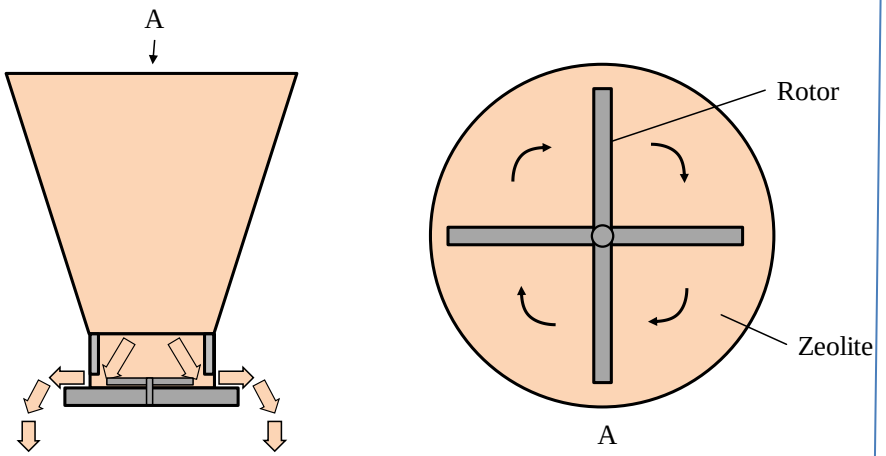
Shutter valve



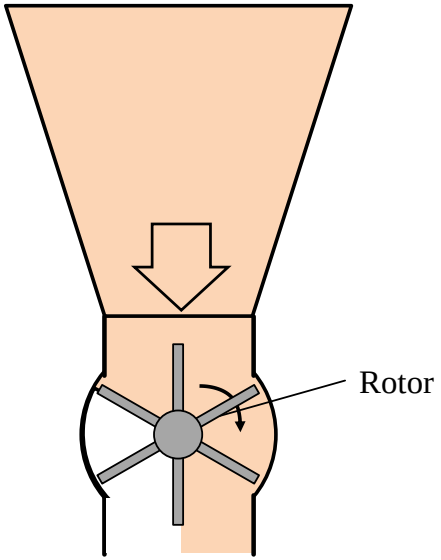
Screw



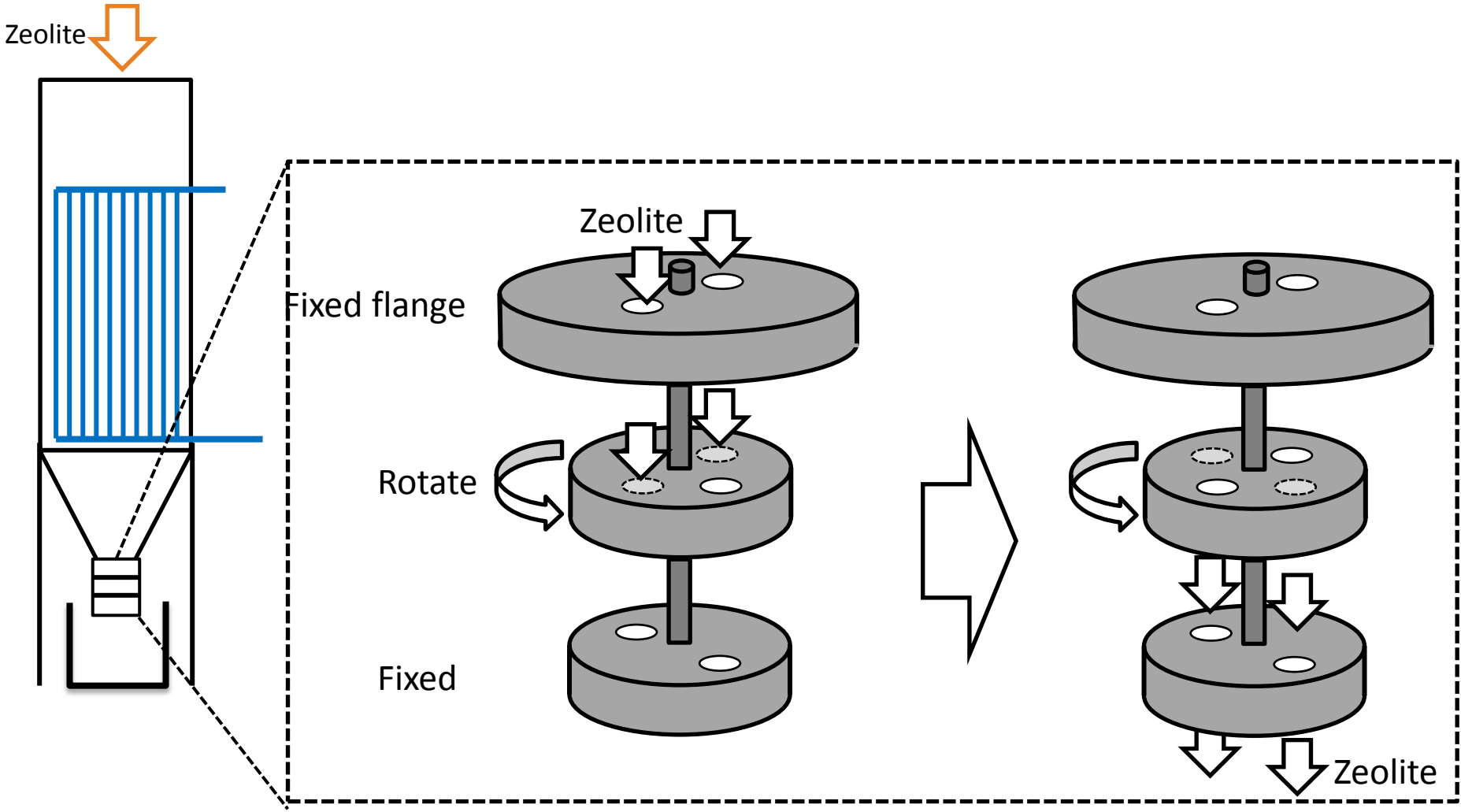
Table



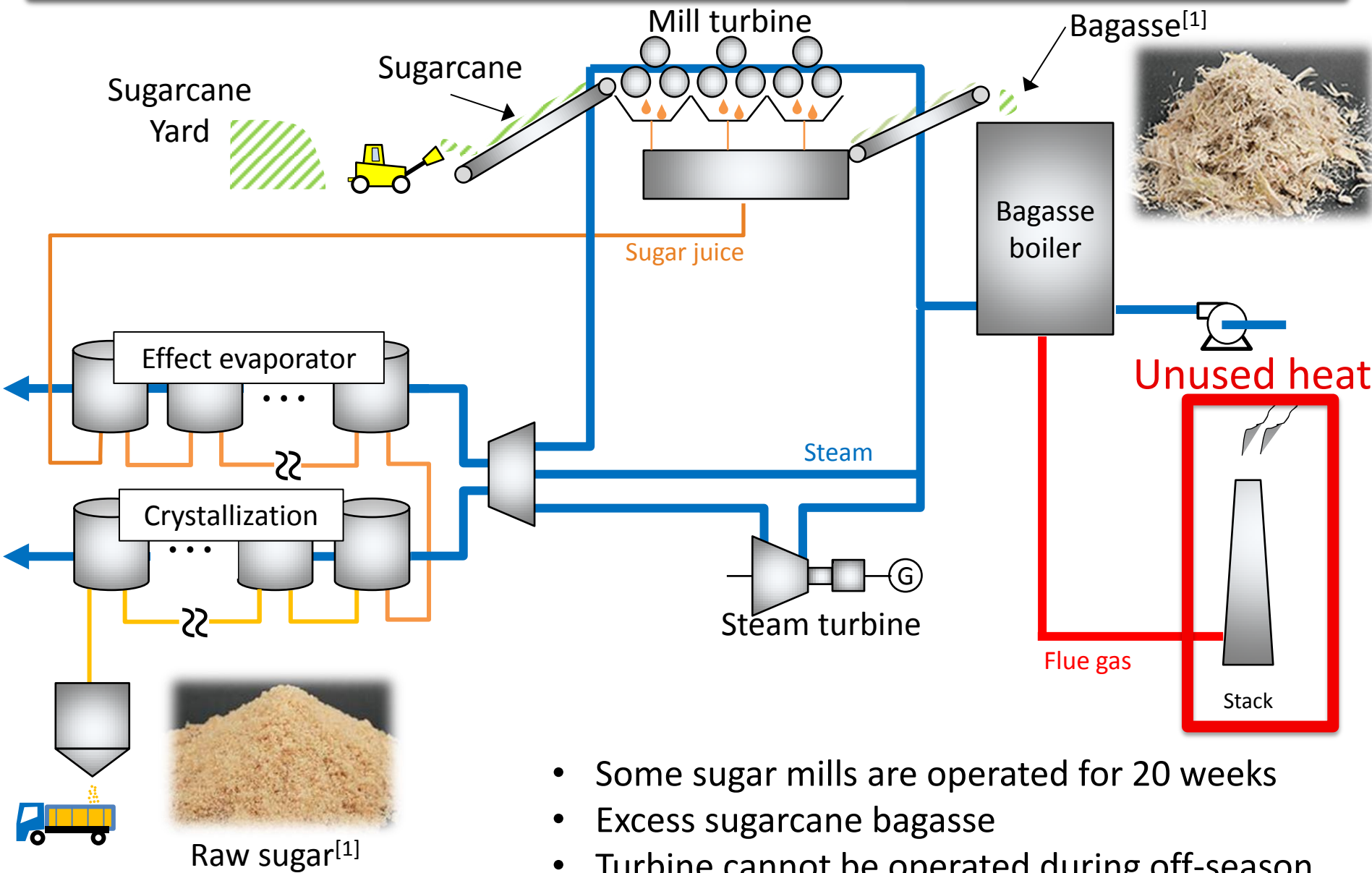
Rotary



Our discharger



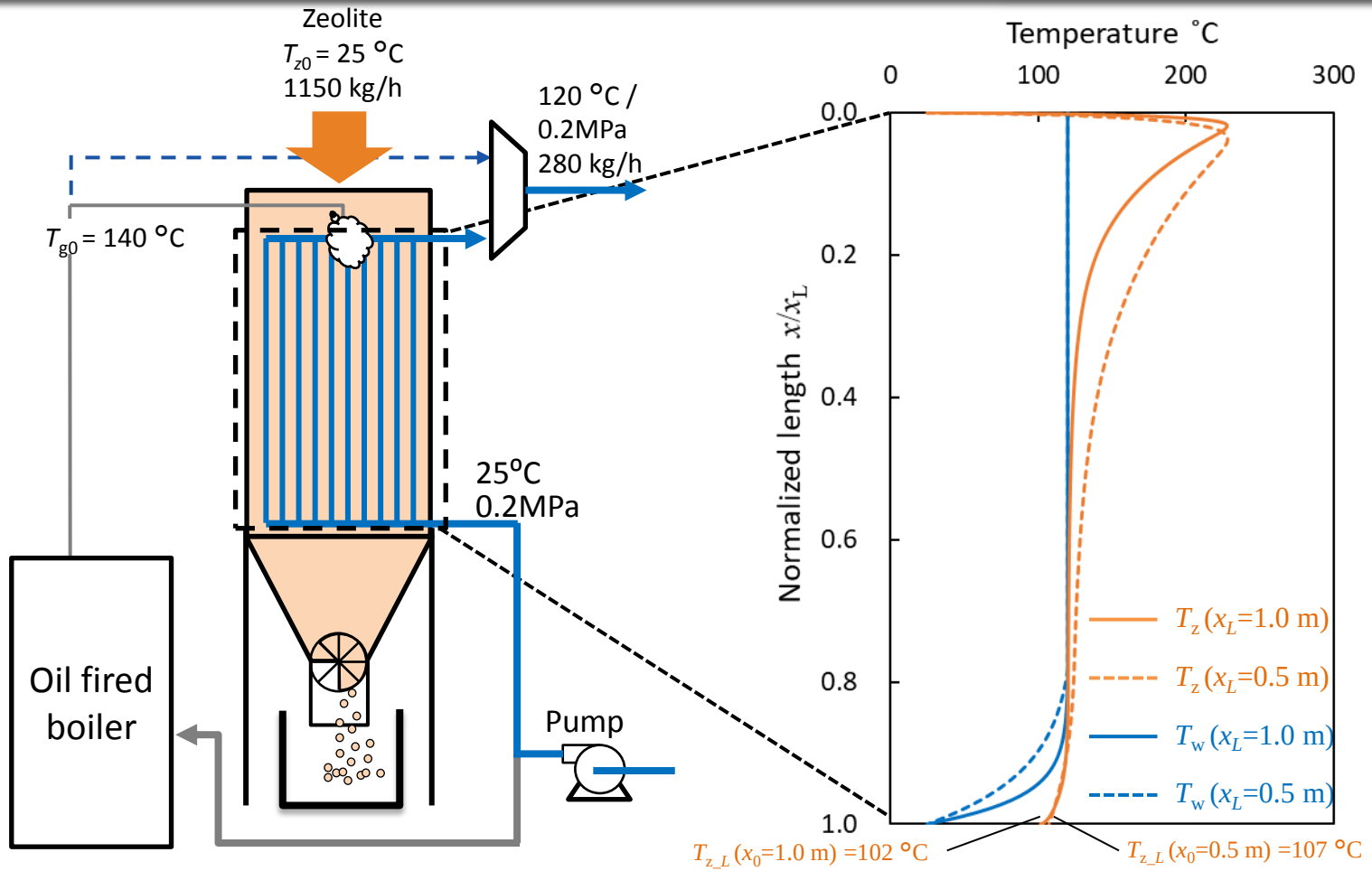
Unused heat from sugar cane bagasse



- Some sugar mills are operated for 20 weeks
- Excess sugarcane bagasse
- Turbine cannot be operated during off-season

[1]http://www.shinko-sugar.co.jp/zero_emission02.html

Performance prediction of “Normal process”



Length m	Zeolite kg/h	Exhausted T_z C	q_{eq_out} kg/kg
0.5 m	1200	107	0.239
1.0 m	1150	102	0.244
1.5 m	1150	102	0.244

Island: Tanegashima（種子島）

Bagasse[1]

Raw sugar[1]

Sugar mill

Sugarcane

Sugar refinery

[1]http://www.shinko-sugar.co.jp/zero_emission02.html

Heat charger