Thermal Energy Storage in Biomass Heating Plants

Dimensioning and controlling of wood-fired heating plants with a heat storage

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- Potential estimation
  - Methods
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Growing share of automated wood furnaces

- Automated furnaces
- Central heating (incl. automated furnaces < 50 kW)
- Single room systems
Problem I: Fossil backup boilers

Total fossil fuel share for an optimized operation 12 %
1  Boiler power under 20% of the rated power 5 %
2  Unfavorable controlling 7 %
3  Commissioning and decommissioning 6 %
=  Total fossil fuel share 30 %
Problem II: Pollutant emission

PM 2.5

- Wood furnaces < 70kW: 16%
- Wood furnaces > 70kW: 16%
- Remaining furnaces: 2%
- Industrial processes: 22%
- Agriculture: 13%
- Households: 13%
- Traffic: 18%

[Müller Beat, LRV-Revision 2018 und Anpassungen zu Messempfehlungen, 15. Holzenergiesymposium]
Goals of this project...

... are to develop the theoretical foundation for the dimensioning and controlling of automated wood boilers with an integrated heat storage in order to reduce fossil fuel shares and air pollution.
Challenge

Heat demand [%]

00:00 06:00 12:00 18:00 00:00

- Winter
- Autumn / Spring
- Summer
- Min. furnace heat
- Max. furnace heat
Challenge

Summer

Spring / Autumn

Charging
Discharging
Heat consumption
Min. funrace heat
Challenge

Summer

Spring / Autumn

- Charging
- Discharging
- Heat consumption
- Funrace heat
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Is a year-around monovalent wood heating plant with storage even possible?

- Analysis based on the heat balance in the storage

\[
Q_S(t + 1) = Q_S(t) + \left( \dot{Q}_K(t) - \dot{Q}_V(t) \right) \cdot \Delta t
\]

- Simplified controlling system decides whether system is in standby-mode or runs at minimal load.

- Assumption:
  - Unlimited system dynamics
  - The full range of initial conditions (at 00:00 a.m.) are considered
Year-around use of monovalent wood heating plants with a storage tank

Theoretical minimal daily starts

- Heating network A, winter
- Heating network B, winter
- Heating network A, transition time
- Heating network B, transition time
- Heating network A, summer
- Heating network B, summer

Storage size [h]
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Modelling structure
Modelling procedure

Start

Heat balance in the distribution system (pipes)

Temperature profile in the storage tank

Storage level estimation

Boiler output controlling

Time increment
\[ t = t + 1 \]

Heat balance in the storage tank

Stop
Heat balance in the distribution system

- Wood boiler
- Heat control
- Furnace control
- Heat storage
- Distribution control
- District heating

Symbols:
- $T_{VL}$
- $T_1$
- $T_n$
- $T_{RL}$
- $Q_{K, soll}$
Heat balance in the distribution system

\[ \dot{Q}_{\text{V,eff}}(t + 1) = \dot{Q}_V(t + 1) \]

\[ \dot{Q}_{\text{V,eff}}(t + 1) = \dot{Q}_V(t + 1) + \dot{Q}_{\text{V,eff}}(t) - \dot{Q}_K(t) \]

\( \dot{Q}_K \)  Boiler heat output
\( \dot{Q}_V \)  Heat demand
\( \dot{Q}_{\text{V,eff}} \)  Effective heat demand
Stored heat in the storage tank

Wood boiler

Heat control

Furnace control

Heat storage

Distribution control

District heating

Wood boiler

Heat control

Furnace control

Heat storage

Distribution control

District heating

Wood boiler

Heat control

Furnace control

Heat storage

Distribution control

District heating

Wood boiler

Heat control

Furnace control

Heat storage

Distribution control

District heating
Heat balance in the storage tank

\[
\frac{dQ_S}{dt} = \dot{Q}_K - \dot{Q}_{V,\text{eff}}
\]

\[
Q_S(t) = Q_S(t = 0) + \left[ \sum_{\tau=0}^{t} \left( \dot{Q}_K(\tau) - \dot{Q}_{V,\text{eff}}(\tau) \right) \right] \cdot \Delta t
\]

\[
0 \leq Q_S(t) \leq Q_{S,\text{max}}
\]

- \(Q_S\): Stored heat
- \(Q_{S,\text{max}}\): Storage capacity
- \(\dot{Q}_V\): Heat demand
- \(\dot{Q}_{V,\text{eff}}\): Effective heat demand
Temperature profile in the storage tank

\[ \delta_h \] Hot storage layer
\[ \delta_s \] Thermocline
\[ \delta_k \] Cold storage layer
\[ h_s \] Storage height
\[ T_{hot} \] Hot temperature
\[ T_{cold} \] Cold temperature
Boiler output controlling

Wood boiler

Heat control

Furnace control

Heat storage

Distribution control

District heating

T_{VL}

Q_{K,soll}

T_1

T_i

T_n

T_{RL}
Simplified control concept
Simulation results for a winter day (large storage)

Heat demand, Furnace heat, Heat from storage, Max. furnace heat

Storage level [%]

Storage temperatures [°C]

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Simulation results for a winter day (small storage)
Simulation results for a winter day (small storage)
Simulation results for a transition day (large storage)
Simulation results for a transition day (small storage)
Simulation results for a summer day (large storage)
Simulation results for a summer day (small storage)
Conclusion

- The implementation of heat storages in wood-fired heating plants enables a year-around operation without or with a minimized fossil fuel share.
- A wise choice of controlling parameters is needed to guarantee a steady operation of the wood boilers output.
- The number of daily starts at low demand days can be reduced by the implementation of storage tanks in wood-fired heating plants.
- The operation mode in the transition time shows the highest potential of improvement by the implementation of heat storages.
Outlook

- Further validation of the simulation is needed.
- Modelling of wood boiler cascade systems
- Modelling of bivalent systems to minimize the fossil fuel share
- Implementation of different controlling concepts
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