Exergy Meters in District Heating Systems

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4th Generation District Heating Technologies and Systems
What is Exergy

• Exergy is defined as the theoretical maximum work which can be obtained from an energy system.
  – High grade energy (work or electricity)
  – Low grade energy (Heat)

• A simple example:
  – 1 MWh of electricity can give 1 MWh of heat.
  – 1 MWh of heat always gives less than 1 MWh of electricity because of the notion of irreversibility and the concept of entropy.
Exergy Background

• Nicolas Leonard Sadi Carnot in 1824 proposed a theoretical thermodynamic cycle providing an upper limit on the efficiency that any engine can achieve during the conversion of heat into work.

• Josiah Williard Gibbs (1839 – 1903) was accredited with the availability of energy concept by indicating that the environment plays an important part.

• Zoran Randt (1904 – 1972) proposed in 1956 the exergy term that quantifies in a coherent way the quantity and the quality of different forms of energy.
Carnot Factor

The maximum work that can be supplied by a reversible machine only depends on the temperature of the internal energy considered.

The Carnot factor or the maximum efficiency possible for any engine is:

\[ \Theta = 1 - \frac{T_c}{T_h} \]
Heat Exergy

Heat exergy is the maximum work that can be obtained from a heat source by means of a reversible cycle operating between the temperatures $T_i$ of the heat source and $T_a$ of the atmosphere.

$$\dot{E}_q = \Theta \times \dot{Q}_i = \left(1 - \frac{T_a}{T_i}\right) \times \dot{Q}_i$$

$\Theta$: Carnot factor

$\dot{Q}_i$: Heat
The exergy meter would monitor the transformation exergy $\dot{E}_y$ cumulated on the flow leaving a heat exchanger.

$$\dot{E}_y = \dot{Q}^+ * (1 - \frac{T_a}{\hat{T}_{ln\ fluid}})$$

$$\hat{T}_{ln\ fluid} = \frac{T_{out} - T_{in}}{\ln\left(\frac{T_{out}}{T_{in}}\right)}$$

If 10 MWh of cumulated heat is metered from the heat meter, 1.9 MWh of Exergy would instead have been monitored by an exergy meter with an outside temperature of 5°C.

$$\dot{E}_y = 10 \times \left(1 - 278 \times \frac{\ln\left(\frac{353}{333}\right)}{353 - 333}\right) = 1.9 \text{ MWh}$$
Heat Pump Performance

Heating coefficient of performance (COP) – (Heating effectiveness)

\[ \varepsilon_h = \frac{\text{Heat generated}}{\text{Electricity consumption}} > 1 \]

Exergy efficiency (Includes all consumptions and generation)

\[ \eta = \frac{\text{Heat exergy generated}}{\text{Electricity consumption (exergy)}} < 1 \]

Please note that the heat exergy consumed to evaporate the heat pump refrigerant equals zero.
**CHP engines Performance (E-425)**

Overall energy efficiency (HHV)

Part load: \( \varepsilon = 45.6\% + 30.4\% = 76.1\% \)

Full load: \( \varepsilon = 37.6\% + 34.4\% = 72.0\% \)

Exergy efficiency \((T_a = 5^\circ C)\)

Part load: \( \eta = 10.8\% + 32.3\% = 43.2\% \)

Full load: \( \eta = 8.9\% + 36.6\% = 45.5\% \)

1) The overall energy efficiency reduces with an increasing load.
2) The exergy efficiency increases with an increasing load.
Plate heat exchanger and exergy destruction @ $T_a = 20^\circ C$

- 100 kW of heat from the primary flow gives 100 kW of heat on the secondary side.
- $M_p$: 100 kW of heat equals to 14.5 kW of exergy-heat on the primary side.
- $M_s$: 100 kW of heat equals to 6.3 kW of exergy-heat on the secondary side.

$$\dot{E}_y = \dot{Q}^+ * \left(1 - \frac{T_a}{\ln \frac{T_{out}}{T_{in}}}\right)$$

$$\hat{T}_{ln \ fluid} = \frac{T_{out} - T_{in}}{\ln \left(\frac{T_{out}}{T_{in}}\right)}$$

Primary exergy $M_p = 14.5$ kW

Secondary exergy $M_s = 6.3$ kW

Exergy destruction
Useable Heat and Heat Meter Location

ESCo sell useable heat which can vary in quality. To heat a building at 21°C, the DH flow temperature must be above that temperature. However, a space would heat up sooner if the heat is supplied at a higher temperature than 21°C. Hence, heat at 70°C could be more expensive than heat at 21°C.

**Heat meter**: It calculates the heat consumed on the primary side. Thus, it measures the flow rate and the supply and return temperatures of the primary side.
End User

Underfloor heating

\[ T_{sup} = 45^\circ C \]
\[ T_{ret} = 30^\circ C \]

Radiator

\[ T_{sup} = 60^\circ C \]
\[ T_{ret} = 45^\circ C \]
Pimlico District Heating Undertaking
50,000 MWh of heat per year
Open Loop Heat Pump
Sankey Diagram

- Electricity: 17,390 [MWh]
- Supplementary electricity: 1,484 [MWh]
- River pumping: 793 [MWh]
- Network pumps: 691 [MWh]
- Heat pumped: 49,842 [MWh]
- Heat accumulator: 48,937 [MWh]
- Consumers: 47,132 [MWh]
- Heat losses: 905 [MWh]
- Heat losses: 1,806 [MWh]

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Grassman Diagram

Initial Exergy (100%)
18.85 MWh

- Heat pump (92.1%)
- DHN pumping (3.7%)
- River pumping (4.2%)

Exergy destruction (53.1%)

DHN heat exergy losses (1.7%)

Exergy destruction (20.6%)

Consumed heat-exergy
- DHW: 3,233 MWh - (17.1%)
- SH: 1,411 MWh - (7.5%)

Energy Centre  DH network  Substation  Consumer
In Conclusion

Exergy meters would encourage consumers to reduce their heating cost by requiring a lower flow temperature and cooling it further. This would simultaneously improve the performance of a district heating system by:

• Reducing the electricity consumption for Pumping;
• Flattening the heating load;
• Reducing the heat losses in the DH network.
Questions

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