MENG541 Advanced Thermodynamics

Example: Exergy Analysis of Storage-Type Domestic Water Heater*

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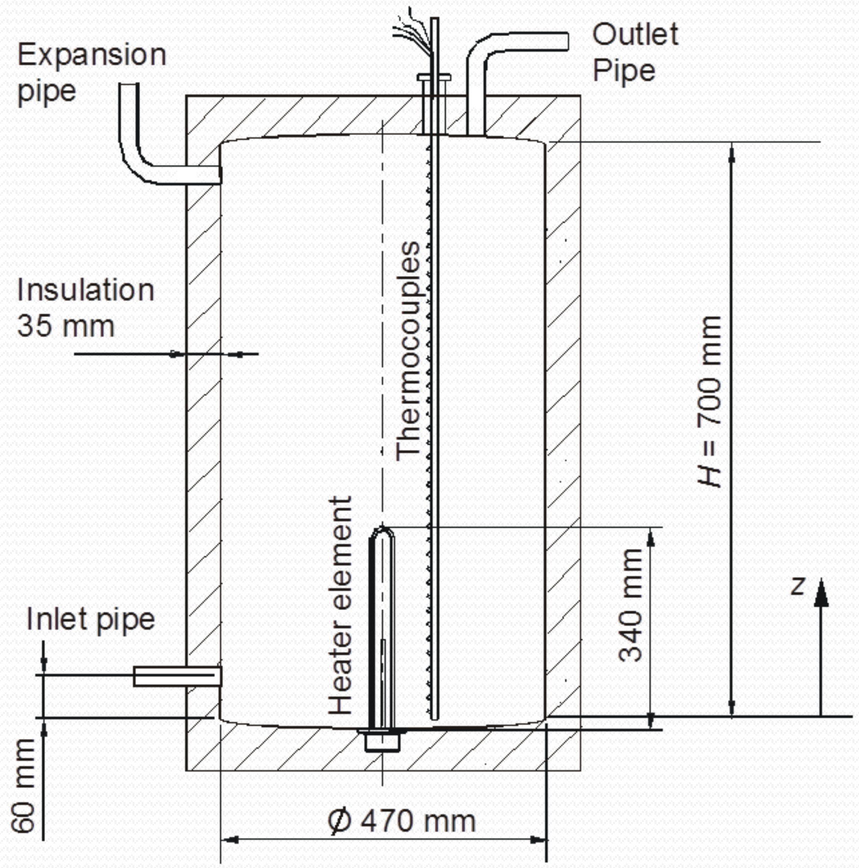
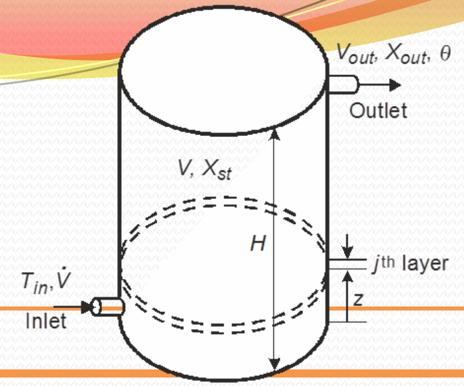
*Source: U. Atikol and L. Aldabbagh, Energy-the International Journal, Vol. 83 (2015)

Storage-Type Domestic Water-Heater

Understanding the system:



Performance Parameters



Definition	Energy and Exergy Equtions
Energy contained in water leaving the storage tank	$E_{out}(t) = \int_0^t \rho \dot{V} C_p (T_{out}(t) - T_{in}) dt$
Initial energy stored in the tank (*j* represents each of the horizontal layers)	$E_{st}(t=0) = \sum_{j=1}^{35} (\rho V C_p)_j (T_j - T_{in})$
Exergy contained in water leaving the storage tank	$X_{out}(t) = \int_0^t (\rho \dot{V})_{out} \left[(h_{out} - h_0) - T_0 (s_{out} - s_0) \right] dt$
Initial exergy stored in the tank (*j* represents each of the horizontal layers)	$X_{st}(t=0) = \sum_{j=1}^{35} \left\{ (\rho V)_j \left[(u_j - u_0) - T_0 (s_j - s_0) \right] \right\}$
Discharging energy efficiency for EWHs	$\eta_I = \frac{E_{out}(t = t @ T = 40^\circ C)}{E_{st}(t=0)}$
Discharging exergy efficiency	$\eta_{II} = \frac{X_{out}(t)}{X_{st}(t=0)}$
Dimensionless temperature of water in the tank	$T^* = \frac{T(z,t) - T_{in}}{T_{max} - T_{in}}$

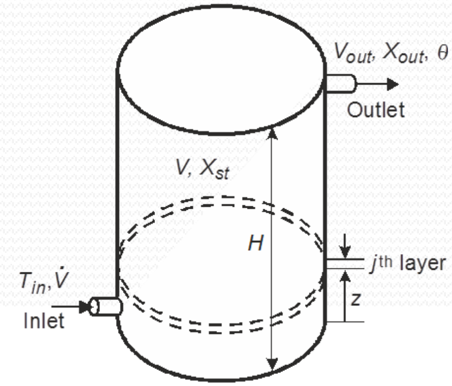
Specific exergy of flowing fluid, ψ

Specific exergy of non-flowing fluid, ϕ

Dimensionless stored exergy

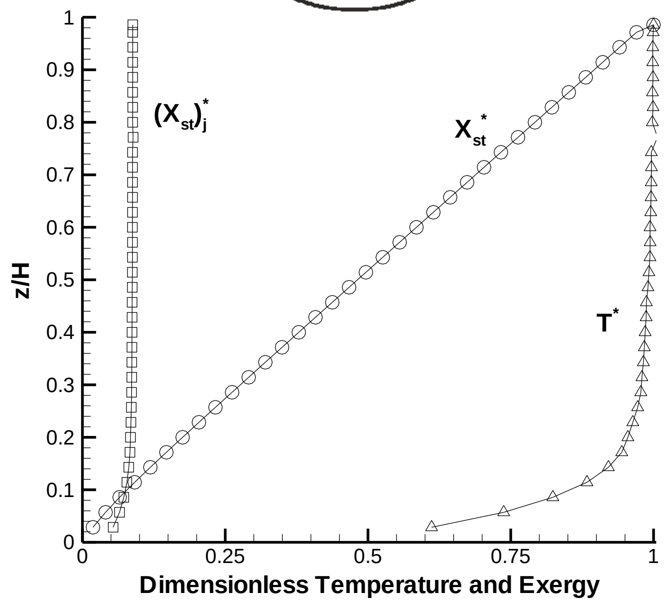
dimensionless stored exergy accumulation as the number of layers is increased from the bottom to the top of the cylinder :

$$X_{st}^{*} = \frac{\sum_{j=1}^{n} \left\{ (\rho V)_j \left[(u_j - u_{0)}) - T_0 (s_j - s_0) \right] \right\}}{X_{st}}$$



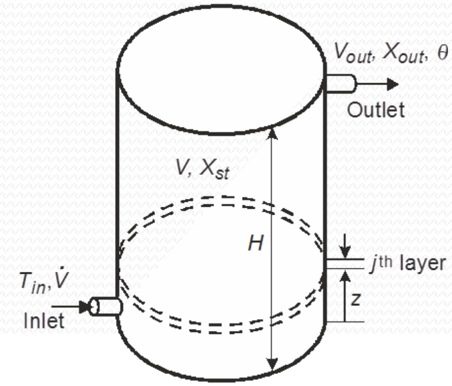
dimensionless stored exergy for each layer :

$$(X_{st})_j^{*} = \frac{(X_{st})_j}{(X_{st})_{j=35}}$$

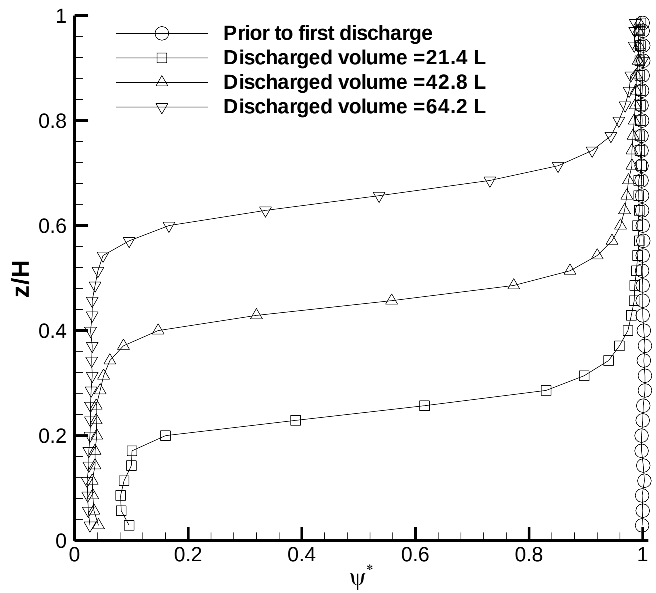


Dimensionless specific exergy

In order to follow the exergetic changes in each layer during discharging with respect to the initial conditions recorded just prior to discharging, dimensionless specific exergy may be introduced as follows:



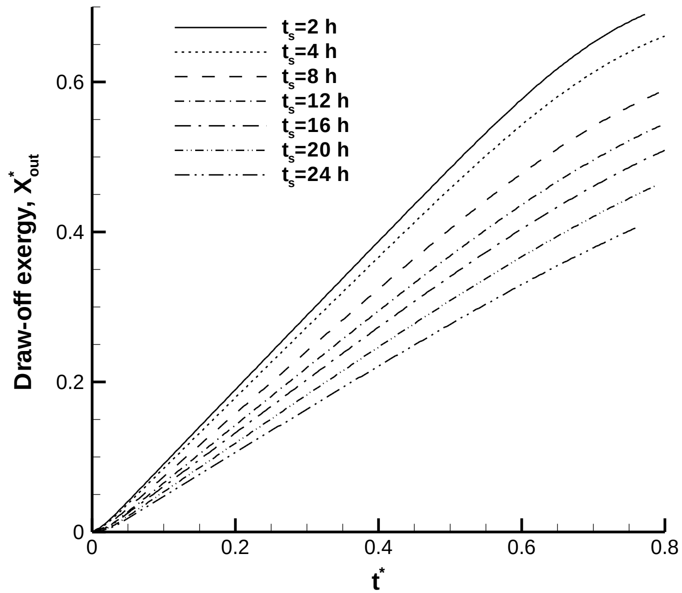
$$\psi^* = \frac{\psi_j(z,t)}{\phi_j(z,t)} = \frac{\left[(h_{out} - h_o) - T_o(s_{out} - s_o)\right]_j}{\left[(u_j - u_o) - T_o(s_j - s_o)\right]}$$



Useful Exergy, X_{out}, During Discharging

defined as the exergy extracted during the discharging process (or processes), which is continued until the minimum usable temperature (40°C) is attained. In dimensionless form:

$$X^*_{out} = \frac{X_{out}(t)}{X_{st}(t=0)}$$

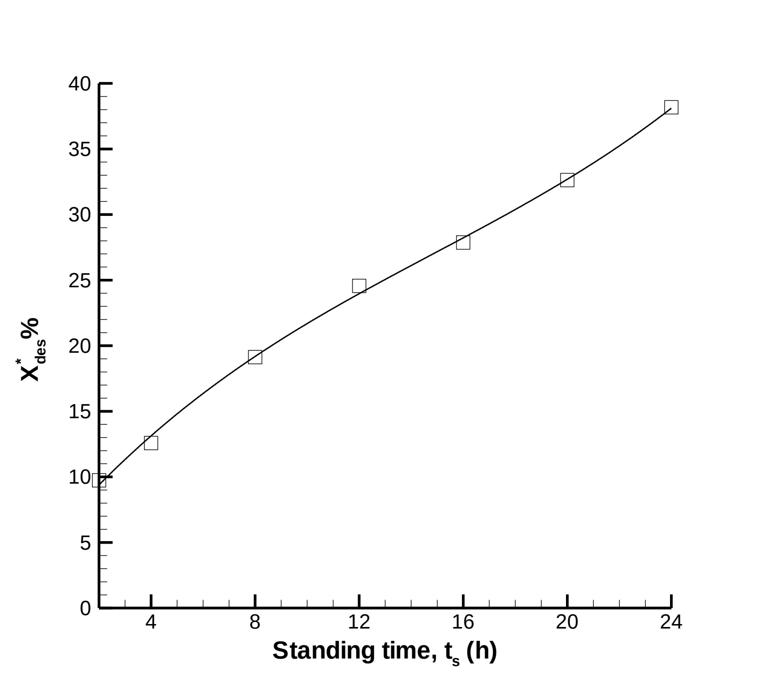


Useful exergy obtained during the second discharging at 5 L/min for different standing times in the case of 21.4 L of pre-drawn hot water.

Dimensionless Exergy Distruction

$$X_{des}(t) = X_{st}(t=0) - X_{out}(t)$$

$$X^{*}_{des} = \frac{X_{st}(t=0) - X_{out}(t)}{X_{st}(t=0)}$$



Total dimensionless exergy destruction as a function of different standing times for the case of 21.4 L pre-drawn hot water.

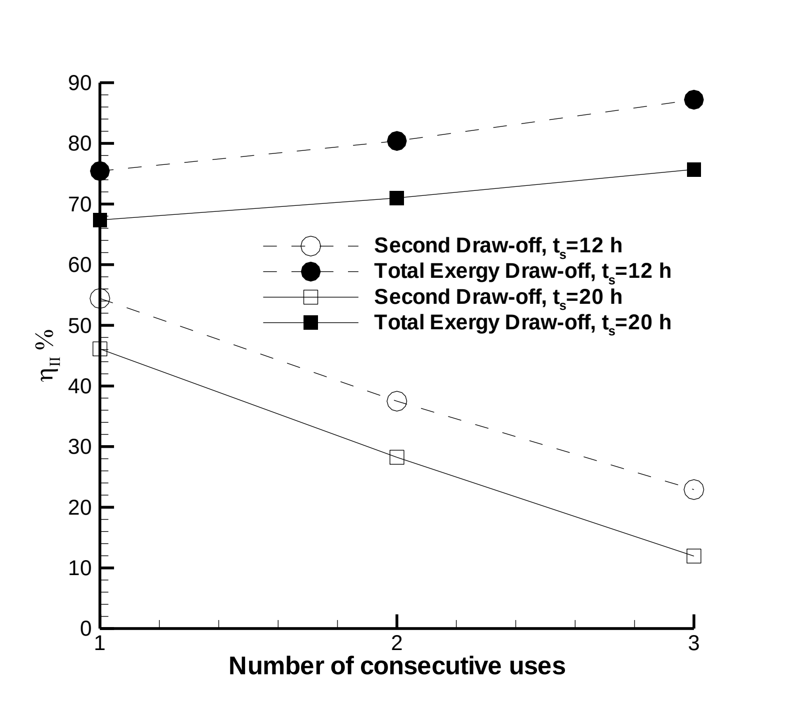
Discharging Exergy Efficiency

$$\eta_{II} = \frac{X_{out}(t)}{X_{st}(t=0)}$$

$$X_{des}(t) = X_{st}(t=0) - X_{out}(t)$$

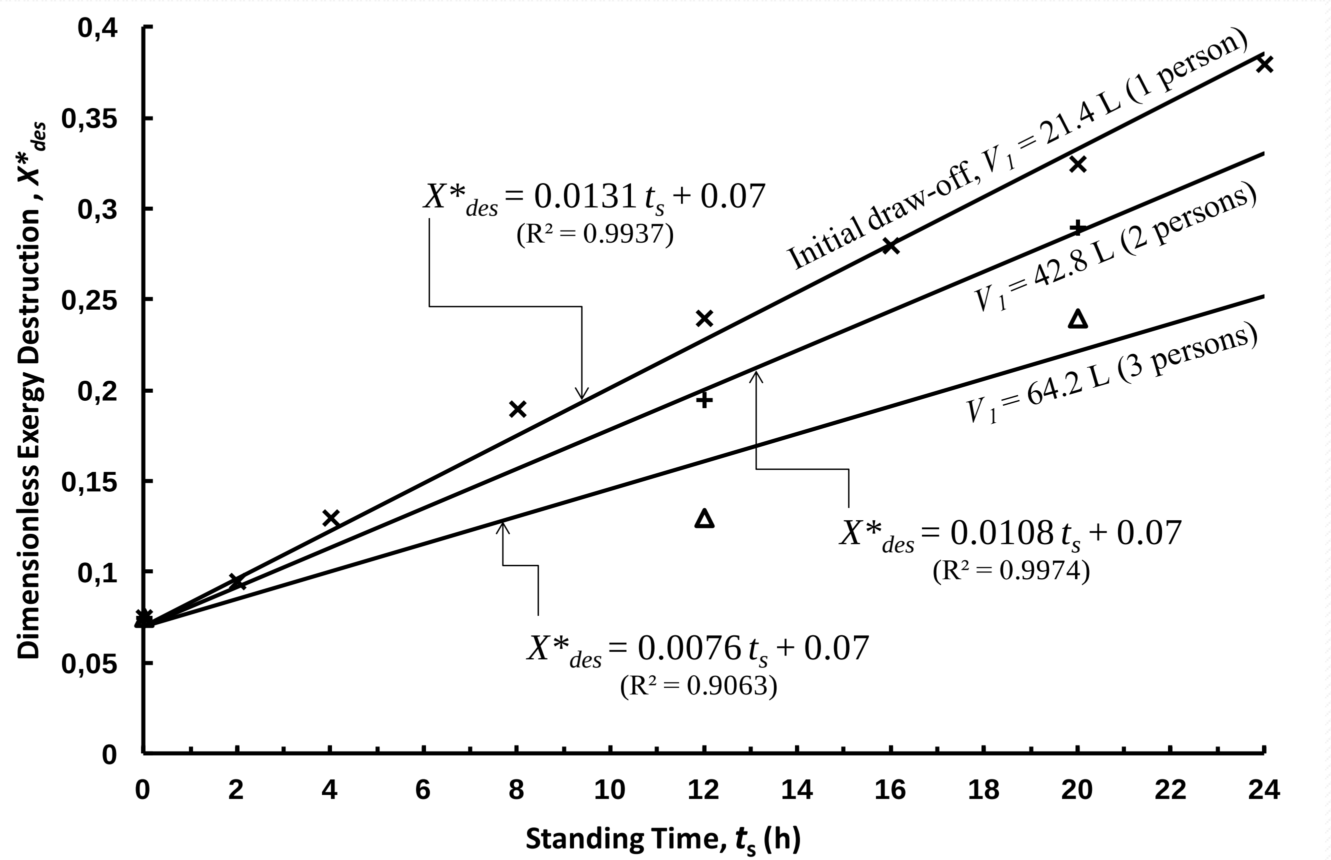
$$X^*_{des} = \frac{X_{st}(t=0) - X_{out}(t)}{X_{st}(t=0)}$$

$$\eta_{II} = 1 - X^*_{des}$$



Discharging exergy efficiency as a function of initial users.

Exergy Destruction for Different Standing Times



Total dimensionless exergy destruction for the period starting from the first discharge and including the standing time and the final discharge with temperatures above 40°C. Linear trend lines are fitted through the experimental results

Cost of Exergy Destruction

The cost of exergy destruction can be expressed as follows:

$$C_{Xdes} = C_{Xst} - C_{Xout}$$

Money paid for the electricity for heating the water until it reaches the required temperature, therefore:

$$C_{Xst} = X_{st} \times c_{el} = \dot{W}_{el} \times \Delta t_{el} \times c_{el}$$

electricity tariff

$$C_{Xout} = X_{out} \times c_{el}$$
$$= \underbrace{X_{st}(\mathrm{a} + \mathrm{b}\, t_s)}_{\text{Deduced fom experimental findings (see previous figure)}} \times c_{el}$$

$$C_{Xdes} = X_{st} c_{el} - X_{out} c_{el}$$
$$= X_{st} c_{el} (1 - \mathrm{a} - \mathrm{b}\, t_s)$$