NTU method

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The **Number of Transfer Units (NTU) Method** is used to calculate the rate of heat transfer in heat exchangers (especially counter current exchangers) when there is insufficient information to calculate the Log-Mean Temperature Difference (LMTD). In heat exchanger analysis, if the fluid inlet and outlet temperatures are specified or can be determined by simple energy balance, the LMTD method can be used; but when these temperatures are not available **The NTU** or **The Effectiveness** method is used.

To define the effectiveness of a heat exchanger we need to find the maximum possible heat transfer that can be hypothetically achieved in a counter-flow heat exchanger of infinite length. Therefore *one* fluid will experience the maximum possible temperature difference, which is the difference of $T_{h,i} - T_{c,i}$ (The temperature difference between the inlet temperature of the hot stream and the inlet temperature of the cold stream). The method proceeds by calculating the heat capacity rates (i.e. mass flow rate multiplied by specific heat) C_h and C_c for the hot and cold fluids respectively, and denoting the smaller one as C_{min}.

A quantity:

$$q_{max} = C_{min}(T_{h,i} - T_{c,i})$$

is then found,where q_{max} is the maximum heat that could be transferred between the fluids per unit time. C_{min} must be used as it is the fluid with the lowest heat capacity rate that would, in this hypothetical infinite length exchanger, actually undergo the maximum possible temperature change. The other fluid would change temperature more slowly along the heat exchanger length. The method, at this point, is concerned only with the fluid undergoing the maximum temperature change.

The *effectiveness (ϵ)*, is the ratio between the actual heat transfer rate and the maximum possible heat transfer rate:

$$\epsilon = \frac{q}{q_{max}}$$

where:

$$q = C_h(T_{h,i} - T_{h,o}) = C_c(T_{c,o} - T_{c,i})$$

Effectiveness is dimensionless quantity between 0 and 1. If we know ϵ for a particular heat exchanger, and we know the inlet conditions of the two flow streams we can calculate the amount of heat being transferred between the fluids by:

$$q = \epsilon C_{min}(T_{h,i} - T_{c,i})$$

For any heat exchanger it can be shown that:

$$\epsilon = f(NTU, \frac{C_{min}}{C_{max}})$$

For a given geometry, ϵ can be calculated using correlations in terms of the "heat capacity ratio"

$$C_r = \frac{C_{min}}{C_{max}}$$

and the *number of transfer units*, NTU

$$NTU = \frac{UA}{C_{min}}$$

where U is the overall heat transfer coefficient and A is the heat transfer area.

For example, the effectiveness of a parallel flow heat exchanger is calculated with:

$$\epsilon = \frac{1 - \exp[-NTU(1 + C_r)]}{1 + C_r}$$

Or the effectiveness of a counter-current flow heat exchanger is calculated with:

$$\epsilon = \frac{1 - \exp[-NTU(1 - C_r)]}{1 - C_r \exp[-NTU(1 - C_r)]}$$

For $C_r = 1$

$$\epsilon = \frac{NTU}{1 + NTU}$$

Similar effectiveness relationships can be derived for concentric tube heat exchangers and shell and tube heat exchangers. These relationships are differentiated from one another depending on the type of the flow (counter-current, concurrent, or cross flow), the number of passes (in shell and tube exchangers) and whether a flow stream is mixed or unmixed.

Note that the $C_r = 0$ is a special case in which phase change condensation or evaporation is occurring in the heat exchanger. Hence in this special case the heat exchanger behavior is independent of the flow arrangement. Therefore the effectiveness is given by:

$$\epsilon = 1 - \exp[-NTU]$$

References

- F. P. Incropera & D. P. DeWitt 1990 *Fundamentals of Heat and Mass Transfer*, 3rd edition, pp. 658–660. Wiley, New York
- F. P. Incropera, D. P. DeWitt, T. L. Bergman & A. S. Lavine 2006 *Fundamentals of Heat and Mass Transfer* ,6th edition, pp 686–688. John Wiley & Sons US

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