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Thermodynamic Analysis of Steady-State Flow Processes

Many processes consist of a number of steps, and lost-work calculations are then made for each step separately.]

$$\dot{W}_{\text{lost}} = T_\sigma \dot{S}_{G,\text{total}}$$

Summing over the steps of a process gives

$$\sum \dot{W}_{\text{lost}} = T_\sigma \sum \dot{S}_{G,\text{total}}$$

Dividing the former equation by the latter yields

$$\frac{\dot{W}_{\text{lost}}}{\sum \dot{W}_{\text{lost}}} = \frac{\dot{S}_{G,\text{total}}}{\sum \dot{S}_{G,\text{total}}}$$

Thus an analysis of the lost work, made by calculation of the fraction that each individual lost-work term represents of the total lost work, is the same as an analysis of the rate of entropy generation, made by expressing each individual entropy-generation term as a fraction of the sum of all entropy-generation terms.

An alternative to the lost-work or entropy-generation analysis is a work analysis.

$$\sum \dot{W}_{\text{lost}} = \dot{W}_s - \dot{W}_{\text{ideal}}$$

For a work-requiring process, all of these work quantities are positive and $\dot{W}_s > \dot{W}_{\text{ideal}}$. We therefore write the preceding equation as

$$\boxed{\dot{W}_s = \dot{W}_{\text{ideal}} + \sum \dot{W}_{\text{lost}}}$$

A work analysis then expresses each of the individual work terms in the summation on the right as a fraction of $\dot{W}_s$.

For a work producing process, $\dot{W}_s$ and $\dot{W}_{\text{ideal}}$ are negative, and $\left|\dot{W}_{\text{ideal}}\right| > \left|\dot{W}_s\right|$.

$$\boxed{\left|\dot{W}_{\text{ideal}}\right| = \left|\dot{W}_s\right| + \sum \dot{W}_{\text{lost}}}$$

A work analysis here expresses each of the individual work terms on the right as a fraction of $\left|\dot{W}_{\text{ideal}}\right|$. A work analysis cannot be carried out in the case where a process is so inefficient that W_{ideal} is negative, indicating that the process should produce work, but $\dot{W}_S$ is positive, indicating that the process in fact requires work. A lost-work or entropy-generation analysis is always possible.

Methane is liquefied in a simple Linde system, as shown in Fig. The methane enters the compressor at 1bar and 300 K, and after compression to 60 bar is cooled back to 300 K. The product is saturated liquid methane at 1 bar. The unliquefied methane, also at 1 bar, is returned through a heat exchanger where it is heated to 295 K by the high-pressure methane. A heat leak into the heat exchanger of 5 kJ is assumed for each kilogram of methane entering the compressor. Heat leaks to the other parts of the liquefier are assumed negligible. Make a thermodynamic analysis of the process for a surroundings temperature of T_σ=300 K.

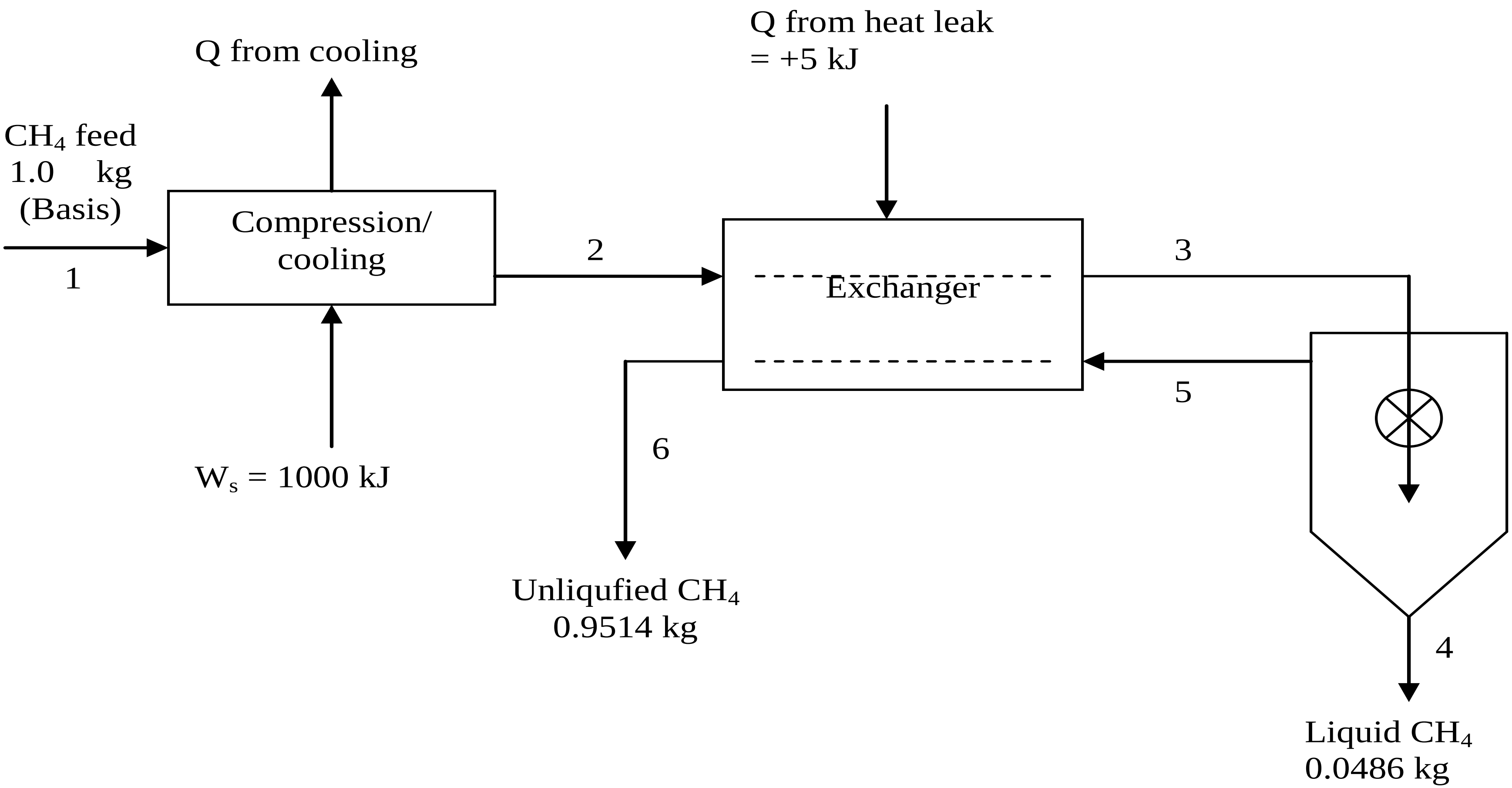

Figure : Linde liquefaction system

Work analysis, based on Eq. $\dot{W}_S = \dot{W}_{ideal} + \sum \dot{W}_{lost}$

	kWkg^{-1}	Percent of $\dot{W}_S$
$\dot{W}_{lideal}$	53.8	5.4(=η_t)
$\dot{W}_{lost}$ (compression/cooling)	378.8	37.9
$\dot{W}_{lost}$ (exchanger)	116.4	11.6
$\dot{W}_{lost}$ (throttle)	451.0	45.1
$\dot{W}_S$	1000.0	100.0

The largest loss occurs in the throttling step. Elimination of this highly irreversible process in favour of a turbine results in a considerable increase in efficiency.

From the standpoint of energy conservation, the thermodynamic efficiency of a process should be as high as possible, and the entropy generation or lost work as low as possible.

The final design depends largely on economic considerations, and the cost of energy is important factor.

The thermodynamic analysis of a specific process shows the locations of the major inefficiencies, and hence the pieces of equipment or steps in the process that could be altered or replaced to advantage.

However, this sort of analysis gives no hint as to the nature of the changes that might be made. It merely shows that the present design is wasteful of energy and that there is room for improvement.

One function of chemical engineers is to try to devise a better process and to use ingenuity to keep operating costs, as well as capital expenditures, low. Each newly devised process may, of course, be analysed to determine what improvement has been made.