International Journal of Heat and Mass Transfer 81 (2015) 167–170

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

Technical Note

Entransy variation associated with work

XueTao Cheng, XinGang Liang *

Key Laboratory for Thermal Science and Power Engineering of Ministry of Education, Department of Engineering Mechanics, Tsinghua University, Beijing 100084, China

ARTICLE INFO

Article history:
Received 13 February 2014
Received in revised form 23 June 2014
Accepted 11 October 2014
Available online 30 October 2014

Keywords:
Entransy
Heat transfer
Heat–work conversion
Work
Analyses

ABSTRACT

The analyses of thermal systems are necessary because of the energy situation. In this paper, two kinds of thermal systems with work, a common heat–work conversion system and a common heat pump system, are analyzed with the entransy theory. The entransy terms and variations for thermal system with heat–work interaction are discussed. The concept of entransy variation associated with work is proposed. The results show that the entransy variation associated with work is directly related to output work and has the same change tendency as that of the work.

1. Introduction

As the energy construction of the world is facing the rigorous situation, so the analyses of thermal systems have received more and more attention because they can increase the energy utilization efficiency in many engineering fields [1–3]. In the past decades, some theories have been developed to analyze thermal systems, such as the entropy generation minimization [3] and the entransy theory [1,2].

The entropy generation minimization has been widely used to analyze heat transfer processes and thermodynamic cycles [3–6]. However, there are different viewpoints for the applicability of this theory to the analyses of thermal systems. In heat transfer, the entropy generation paradox was noted [3]. It was found that the entropy generation minimization does not always lead to the largest effectiveness of heat exchangers [3,5,7]. In thermodynamic cycles, the Gouy–Stodola theorem indicates the linear relationship between the entropy generation and the loss of exergy [8],

$$E_{\mathrm{loss}} = T_0 S_{\mathrm{g}}, \tag{1}$$

where E_{loss} is the exergy loss, S_{g} is the entropy generation, and T_0 is the environment temperature. In Eq. (1), it can be seen that the entropy generation does not directly describes the output work, but the exergy loss [9,10]. When the net exergy flow into the discussed system is fixed, the entropy generation minimization leads to the maximum output work [10]. However, when the net exergy flow into the discussed system is not fixed, smaller entropy generation may not lead to larger output work [8,10]. For instance, the entropy generation of the Carnot cycle is zero because the cycle is reversible. The entropy generation does not change with the change of output work. For some other thermodynamic processes, it was also found that the entropy generation minimization does not always lead to the best system performance [11,12].

On the other hand, the entransy theory has also been used to analyze heat transfer [1,2,7,13–17] and thermodynamic systems [9,12]. The concept of entransy was developed by the analogy between heat conduction and electrical conduction, in which the concept of entransy corresponds to the electrical potential energy in a capacitor [1]. Based on this concept, Guo et al. [1] and Cheng et al. [18] proved that the system entransy always decreases during any practical heat transfer process. The decreased entransy was named entransy dissipation, and describes the irreversibility of heat transfer [18]. The extremum entransy dissipation principle was developed and in recent years applied to optimizing many heat transfer systems [1,2,7,13–17,19–21]. When heat exchangers were analyzed with the entransy theory, no paradox similar to the entropy generation paradox was noticed up to now [7]. In the analyses of thermodynamic cycles, Cheng and Liang [22] proposed the concept of entransy loss, which is the entransy consumed during the thermodynamic processes. Under some conditions, it was found that larger entransy loss leads to larger output power for the discussed systems [9,12,22–26]. In heat pump systems, it was found that the system entransy does not decrease but increase, so the concept of entransy increase was proposed [26]. For the discussed cases, the analyses showed that larger entransy increase leads to larger heat flow into the high temperature heat source [26].

* Corresponding author. Fax: +86 10 62788702.
E-mail addresses: chengxt02@gmail.com (X. Cheng), liangxg@tsinghua.edu.cn (X. Liang).

http://dx.doi.org/10.1016/j.ijheatmasstransfer.2014.10.026
0017-9310/

However, the direct relationship between the work in thermodynamic systems and a parameter in entransy theory has not been established until now. This is the reason why sometimes larger entransy loss does not always lead to larger output power [24]. With the entransy theory, we try to find the parameter which has direct relationship with work in this paper.

2. Entransy variation associated with work in heat–work conversion

A common heat–work conversion system is shown in Fig. 1, where the heat flux, q_{in}, gets into the system, while the heat flux, q_{out}, gets out of the system and into the environment at temperature T_0, and the work W is output. For the system, the energy conservation gives

$$\int q_{in} dA_{in} = \int q_{out} dA_{out} + W, \tag{2}$$

where A_{in} and A_{out} are the areas through which the heat flows gets into and out of the system. From the viewpoint of entransy, the entransy loss can be defined as the difference between the entransy flows into and out of the system, and it is the entransy consumed in the heat–work conversion [9,12,22–25]. Therefore, we have

$$G_{loss} = G_{in} - G_{out} = \int q_{in} T_{in} dA_{in} - \int q_{out} T_0 dA_{out}, \tag{3}$$

where G_{in} and G_{out} are the entransy flows that get into and out of the system, and T_{in} is the temperature of the corresponding area, dA_{in}. Considering Eq. (2) gives

$$\begin{aligned} G_{loss} &= \int q_{in} T_{in} dA_{in} - \int q_{out} T_0 dA_{out} \\ &= \int q_{in} T_{in} dA_{in} - T_0 \left(\int q_{in} dA_{in} - W \right) \\ &= \int q_{in} (T_{in} - T_0) dA_{in} + W T_0. \end{aligned} \tag{4}$$

The heat–work conversion system will turn to be a heat transfer system if there is no work. The entransy loss of the heat transfer system, $G_{loss\text{-}H}$, is to be the entransy dissipation, $G_{dis\text{-}H}$. As shown in Fig. 2, we can get the entransy dissipation based on the energy conservation in this case,

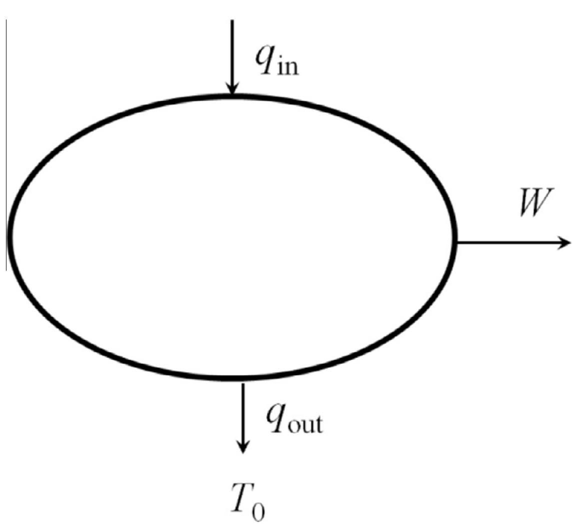

Fig. 1. A common heat–work conversion system.

$$\begin{aligned} G_{dis-H} = G_{loss-H} = G_{in} - G_{out} &= \int q_{in} T_{in} dA_{in} - \int q_{out} T_0 dA_{out} \\ &= \int q_{in} T_{in} dA_{in} - T_0 \int q_{out} dA_{out} \\ &= \int q_{in} T_{in} dA_{in} - T_0 \int q_{in} dA_{in} = \int q_{in} (T_{in} - T_0) dA_{in}. \end{aligned} \tag{5}$$

So, Eq. (4) can be turned into

$$G_{loss} = G_{loss-H} + W T_0. \tag{6}$$

The entransy dissipation is the irreversible entransy loss of the corresponding heat transfer system. Therefore, more entransy is consumed in the heat–work conversion than that in the corresponding heat transfer system. We can see from Fig. 2 that G_{loss} is determined by G_{out} when G_{in} is fixed. Larger G_{out} means less G_{loss}. As G_{out} is

$$G_{out} = \int q_{out} T_0 dA_{out} = T_0 \left(\int q_{in} dA_{in} - W \right). \tag{7}$$

All the heat flow into the system gets into the environment if it is a heat transfer system in which W is 0. G_{out} gets to its maximum value,

$$G_{out-H} = T_0 \int q_{in} dA_{in}, \tag{8}$$

and G_{loss} gets to the minimum value and equals to $G_{loss\text{-}H}$. When there is work output, the heat flow into the environment is less than that in the case without work output and G_{out} is smaller than $G_{out\text{-}H}$. As shown in Fig. 2, we have

$$G_{out-H} - G_{out} = W T_0. \tag{9}$$

Comparing the heat–work conversion system with the corresponding heat transfer system, we can find that part of the entransy flow into the environment in the heat transfer system, WT_0, will not get into the environment any more in the corresponding heat–work conversion system because of the output work. This is the reason why Eq. (6) shows that the entransy loss in the heat–work conversion system is larger than that in the corresponding heat transfer system. Compared with the corresponding heat transfer system, this part of entransy, WT_0, is the entransy variation associated with the output work, W. So, we can define it as the entransy variation associated with work,

$$G_{V-W} = G_{loss} - G_{dis-H} = G_{out-H} - G_{out} = W T_0. \tag{10}$$

Eq. (10) shows that the entransy variation associated with work has the same variation tendency as that of the output work. For the discussed thermodynamic system, we have got the relationship between the work and the entransy variation associated with work. The format is similar to the Gouy–Stodola theorem but they have different meanings. S_g describes exergy loss due to irreversibility, while W is the cause of entransy variation due to work.

Furthermore, Eq. (10) is also different from Eq. (1), because it describes the output work of the system directly.

Especially, we can discuss a system in which the working fluid of the thermodynamic cycle is heated by n streams below. Assume that the heat capacity flow rate and inlet temperature of the ith stream is C_i and $T_{in\text{-}i}$, respectively. The entransy loss induced by dumping the used streams into the environment should be considered [22]. The entransy loss of the system is [22]

$$G_{loss} = \sum_{i=1}^{n} \frac{1}{2} C_i (T_{in-i} - T_0)^2 + W T_0. \tag{11}$$

If there is no output work, the process will be a heat transfer process, and the entransy loss would be the entransy dissipation induced by dumping all the streams into the environment directly. We have