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压缩式热泵系统㶲效率定义方法初探

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摘　要: 对压缩式热泵系统㶲效率的定义式进行了分析, 指出了该定义式在实际应用过程中存在的一些不足。即当低温热源为环境时, 此定义式合理, 否则即使热泵系统内部可逆, 系统㶲效率仍不为 1, 文中对产生这一问题的原因进行了分析。以热泵系统的㶲平衡方程为依据, 参照㶲效率定义方法及㶲效率的基本特征, 对压缩式热泵的系统㶲效率进行了重新定义。通过对两个不违背㶲效率定义特征的表达式的对比分析, 确定了热泵系统合理的㶲效率表达式。最后说明, 在压缩式制冷系统中当高温热源不为环境时, 㶲效率定义也存在同样缺陷, 改进方法与本文类似。

关　键　词: 㶲效率; 定义方法; 分析; 表达式; 热泵

中图分类号: TK11　　文献标识码: A

1　前　言

㶲作为表征能量中可转换部分的状态量引入了热力学后, 有关㶲及㶲分析的研究逐渐深入, 除在理论上取得了一些重要成果外, "三环节"过程能量分析模型及"三箱"系统㶲分析方法等在实际分析中也得到了广泛应用。目前, 已从单纯对实际循环或过程的㶲分析, 转向了更深层次的对热经济学、寂态热力学、㶲传递、非平衡热力学及过程能量集成等问题的研究[1]。

然而, 在一些实际分析过程中, 有些㶲分析模型或定义也存在着一些不足, 尚需要进一步完善。对热泵系统的㶲分析来说, 文献[2～3] 对热泵系统㶲效率的定义不够完善, 文献[4] 对此做了探讨, 并提出了一些改进建议, 但仍存在一些不足。为此, 本文在借鉴已有成果的基础上, 对热泵的㶲效率进行了合理定义。

2　㶲效率定义方法及㶲效率特征

为探讨方便起见, 先对㶲效率的定义方法和㶲效率特征作一简介。

2.1　㶲效率定义方法

如图 1, 对有 j 股㶲流流入和 k 股㶲流流出的系统[2,5], 㶲平衡方程为:

$$\sum_j E_j^+ - \sum_k E_k^- = E_{\mathrm{irr}} \tag{1}$$

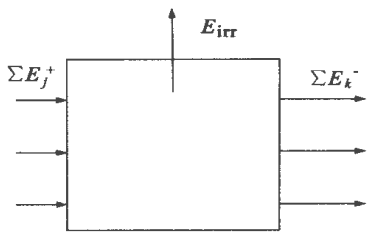

图 1　系统图

根据㶲效率的一般表达式, 有:

$$\eta_{ex} = \frac{\text{收益的㶲}}{\text{消耗的㶲}} = \frac{E_{gn}}{E_{cs}} = 1 - \frac{E_{irr}}{E_{cs}} \tag{2}$$

式中: E_{gn}、E_{cs} 分别为 E_j^+ 和 E_k^- 的线性组合, 即:

$$E_{gn} = \sum_j \alpha_j E_j^+ + \sum_k b_k E_k^- \tag{3}$$

$$E_{cs} = \sum_j c_j E_j^+ + \sum_k d_k E_k^- \tag{4}$$

不同的㶲效率意义, 其区别就在于系数 a_j、c_j、b_k、d_k 的数值不同[2], 这些系数取值为:

$$a_j,\ c_j,\ b_k,\ d_k = \begin{cases} +1 \\ 0 \\ -1 \end{cases} \tag{5}$$

文献[2] 对式(5) 中的系数取值进行了研究, 得到如下结论:

$$a_j = c_j - 1,\ b_k = d_k + 1 \tag{6}$$

各系数取值应遵循式(6)。

实际问题的㶲效率定义, 可有 $j \times k$ 个不同的形式, 哪一种最合适还要根据具体情况来确定。

2.2　㶲效率特征

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由式(2)可得㶲效率的基本特征：

(1) 系统内部可逆时，$E_{irr}=0$，则 $\eta_{ex}=1$；

(2) E_{irr} 越大，则 η_{ex} 越小；

(3) 当 $E_{irr}=E_{cs}$，则 $\eta_{ex}=0$。

由以上可知，$0\leq\eta_{ex}\leq1$。

3　压缩式热泵㶲效率定义存在缺陷

压缩式热泵工作过程中的能量分布如图 2 所示[4]。

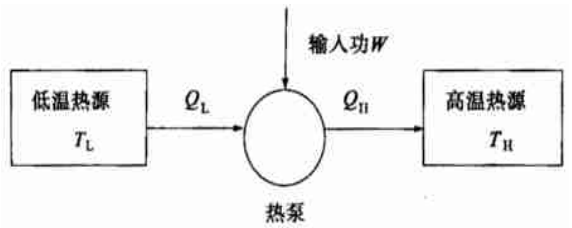

图 2　热泵能量分布原理图

文献[2～3]中均将㶲效率定义为

$$\eta_{ex}=\frac{E_{xQ_H}}{W} \tag{7}$$

式中：E_{xQ_H} 表示输出热量 Q_H 的㶲值。

根据㶲效率基本特征的第 1 条，当系统内部可逆($E_{irr}=0$)时，$\eta_{ex}=1$。但根据㶲效率式(7)，即使热泵系统内部可逆($E_{irr}=0$)时，η_{ex} 有 3 种可能：

$$\eta_{ex}=\begin{cases}<1\\=1\\>1\end{cases} \tag{8}$$

文献[2～3]在进行定义时作了备注，即低温热源温度为环境温度。此时热泵系统内部可逆，$\eta_{ex}=1$。但当低温热源温度不为环境温度时，未作说明。对热泵而言，在用于余热回收时，低温热源均高于环境温度，按如上定义，此时即使热泵内部可逆，但 $\eta_{ex}>1$[4]；反之 $\eta_{ex}<1$。文献[4]对此进行了一些分析，但仍不全面。

对图 2 所示的热泵系统，其㶲平衡方程为：

$$E_{xQ_L}+W=E_{xQh}+E_{irr} \tag{9}$$

当系统可逆时时，$E_{irr}=0$，则：

$$E_{xQ_L}+W=E_{xQ_h} \tag{10}$$

显然，当低温热源为环境温度时，$E_{xQ_L}=0$，$W=E_{xQ_h}$，$\eta_{ex}=1$，式(7)定义合理。但当低温热源不为环境温度时，$E_{xQ_L}\neq0$，$W\neq E_{xQ_h}$，$\eta_{ex}\neq1$，式(7)定义不合理。

4　压缩式热泵㶲效率定义的合理形式

根据前述㶲效率定义方法及㶲效率的基本特征，对压缩式热泵㶲效率的定义作一探讨。

对压缩式热泵而言，当低温热源高于或低于环境温度时，系统输入㶲项，除耗功 W 外，还包括低温热源㶲 E_{xQ_L}。

当低温热源㶲 E_{xQ_L} 位于分母上时，压缩式热泵㶲效率可定义为：

$$\eta_{ex}=\frac{E_{xQ_H}}{W+E_{xQ_L}} \tag{11}$$

可以验证，式(11)满足㶲效率定义的 3 个特征。文献[3]在压缩式热泵装置的㶲分析计算实例中(低温热源温度不等于环境温度)，采用的公式和式(11)相似。

当低温热源㶲 E_{xQ_L} 位于分子上时，压缩式热泵㶲效率可定义为：

$$\eta_{ex}=\frac{E_{xQ_H}-E_{xQ_L}}{W} \tag{12}$$

同样，式(12)也满足㶲效率定义的 3 个特征。

对于式(11)和式(12)，当低温热源为环境温度时，低温热源㶲 $E_{xQ_L}=0$，与原定义式(7)相同。

是采用式(11)还是式(12)作为压缩式热泵的㶲效率定义式，需要作一些讨论。为此可将式(11)和式(12)与一些流体机械(如泵类、压缩机及鼓风机等)和产热设备(锅炉)的㶲效率表达式作一些类比，进而进行选择。

一般流体机械㶲效率可表示为：

$$\eta_{ex}=\frac{E_{xhout}-E_{xhin}}{W_{in}} \tag{13}$$

式中：E_{xhin}、E_{xhout} — 分别为流体带入、带出㶲；

W_{in} — 设备耗功。

锅炉等产热设备㶲效率可表示为：

$$\eta_{ex}=\frac{E_{xpout}-E_{xpin}}{E_{xf}} \tag{14}$$

式中：E_{xpin}、E_{xpout} — 分别为被加热介质带入、带出㶲；

E_{xf} — 供给燃料㶲。

把式(11)、式(12)与式(13)、式(14)相比较，可以发现式(12)与式(13)和式(14)有相似的形式。因此笔者认为式(12)定义更合理一些。

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壳管式海水换热器污垢状况的㶲评价方法研究

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摘　要: 分析了壳管式海水换热器管程结垢后换热强度及流动压降变化对换热器㶲损失的影响, 提出了一种利用㶲损失系数评价换热器污垢状况的方法。该方法比通过检测污垢热阻评价换热器污垢状况的方法更全面, 更简捷。

关　键　词: 换热器; 㶲损失; 污垢

中图分类号: TK172　　文献标识码: A

1　前　言

目前常用的换热器污垢监测的方法有热学法和非传热量监测法两大类。热学法中使用最多的是污垢热阻法, 它是通过清洁状态和污染状态下换热器总传热系数的变化来间接测量污垢热阻的。这种检测方法忽略了两个因素, 一是污垢层的增厚会导致管程流通截面积的减少, 在流体流量不变的条件下引起流速的增加; 二是污垢的积累会破坏流动的粘性底层, 增大局部换热系数, 减少管内对流换热热阻, 因而可能出现负的污垢热阻, 此时一定要通过压降来修正。非传热量污垢监测法(如直接称重法、压降测量法、放射线技术等)往往都只能检测污垢层的厚度或重量, 但同样厚度或重量的污垢层由于其化学成份不同, 传热能力不同, 因而都不能明确指出结垢对换热器传热性能及运行动力消耗的影响。

换热器管内结垢后会引起换热强度和流动压降的变化, 这两方面的变化都会引起换热器㶲损失的增大, 因而可根据结垢后换热器的㶲损失的变化来评价其结垢程度。本文引热力学中的㶲分析方法探讨一种新的换热器管侧污垢状况的评价方法。

2　评价模型的建立

在壳管式换热器中, 㶲损失主要包括以下几方面: 管内流体与管内壁之间的温差换热引起的㶲损失 ΔE_1; 管内污垢层的温差导热引起的㶲损失 ΔE_2; 换热管内外壁之间的温差导热引起的㶲损失 ΔE_3; 换热管外侧污垢层的温差导热引起的㶲损失 ΔE_4; 换热管束外壁与壳程流体间的温差换热引起的㶲损失 ΔE_5; 管内流体流动压降引起的㶲损失 ΔE_6; 管外流体流动压降引起的㶲损失 ΔE_7。随换热管内污垢的积累, 会引起管径的减小, 当管程流体流量不变时, 流体流速增大, 由计算分析可知[3], 当换热器负

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5　结　论

通过对压缩式热泵系统㶲效率定义式的分析, 指出了其存在的缺陷, 即仅当低温热源温度为环境温度时, 该定义式成立, 否则不成立。以热泵系统的㶲平衡方程为依据, 参照㶲效率定义方法及㶲效率的基本特征, 对压缩式热泵的系统㶲效率进行了重新定义。综合分析后认为, 式(12)是较为合理的㶲效率定义式。值得注意的是, 在压缩式制冷系统中当高温热源不是周围环境时, 㶲效率定义也存在同样问题, 改进方法与本文类似。

参考文献:

[1]　华　贲, 过增元, 马重芳. 高效节能的关键科学问题[J]. 华北电力大学学报, 2000(增刊): 6－7.
[2]　杨东华. 㶲分析和能级分析[M]. 北京: 科学技术出版社, 1986.
[3]　朱明善. 能量系统的㶲分析[M]. 北京: 清华大学出版社, 1988.
[4]　张永贵. 热泵定义的拓展及其㶲效率表达式的改进[J]. 暖通空调, 2002(1): 99－100.
[5]　BAEHR H D. Zur definition exergetischer wirkungsgrade eine systematische untersuchung[J]. **BWK**, 1968, **20**(5): 197.

(辉　编辑)

船用齿轮设计技术的发展趋势＝**Development Tendency of Marine Gear Design Technology** [刊, 汉] / WANG Shi-an, TIAN Guang, YOU Ke-quan, et al (Naval Representative Office Stationed at No. 703 Research Institute, Harbin, China, Post Code: 150036) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(6). — 547 ~551

The outstanding features of a marine high-capacity gear transmission device are high speed, heavy load and low noise. Through a description of the main types of marine gear transmission units and an analysis of their uses it can be shown that the technology of marine gear transmission devices are developing in the direction of attaining high-load capacity, high reliability, low noise, variegated transmission forms and miniaturization. After a discussion of the hot-spot problems of gear design technology both at home and abroad the authors expound some key issues concerning marine gear technology in China. They include the design technology of multi-engine, multi-shaft combined crossover transmission units and high-power density ones, comprehensive control techniques for vibration and noise reduction and the dynamic design of innovative transmission elements and components. **Key words**: marine gear unit, power transmission layout, design technology

基于能级概念的㶲经济学计价策略＝**Exergoeconomic Cost Valuation Strategy Based on an Energy-level Concept** [刊, 汉] / SUN Jia-ning, CHEN Qing-lin, YI Qing-hua, et al (Education Ministry Key Laboratory on Intensified Heat Transfer & Process Energy Conservation under the South China University of Science & Technology, Guangzhou, China, Post Code: 510640) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(6). — 552 ~555, 596

A correct and rational cost valuation of exergy flows and the determination of the process of cost formation and variation during a fuel-to-product exergy flow transformation constitute one of the key issues for the realization of exergoeconomic analysis and optimization of an energy system. A concept of energy level is introduced into the system of thermoeconomic cost valuation with the supplied energy flows being split according to their energy levels. On the basis of the principle of close energy levels and maximum energy supply, the problem of matching the energy extraction and supply has been solved. Moreover, the authors have come up with a cost valuation strategy of exergy flows based on the above-mentioned principle. This strategy is aimed at decreasing the number of unknown variables involved in the calculation process. An explanation is also given of the introduction of an additional equation in the presence of a multi-product exergy flow. Finally, with a typical heat and electricity cogeneration system serving as an example described is the application of the method of exergy-flow cost valuation in the optimization of exergoeconomic analysis. **Key words**: exergoeconomics, energy system, energy level, cogeneration of process heat and electrical power

压缩式热泵系统㶲效率定义方法初探＝**Preliminary Exploratory Study of a Method for Defining the Exergy Efficiency of a Compression-type Heat Pump System** [刊, 汉] / MA Yi-tai, WANG Zhi-guo, ZHA Shi-tong (Thermal Energy Research Institute under the Tianjin University, Tianjin, China, Post Code: 300072) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(6). — 556 ~557

After an analysis of the method for defining the exergy efficiency of a compression-type heat pump some deficiencies of such a definition during its practical use are pointed out. This means that in an environment of low-temperature heat source the definition under discussion has been found to be rational. Otherwise, even with an endo-reversible heat pump system the exergy efficiency of the system will still not be "unity". The cause which gives rise to such a problem is analyzed. By adopting the exergy balance equation or the heat pump system as a basis and referring to the basic characteristics of exergy efficiency and its definition method the exergy efficiency of a compression-type heat pump is defined once again. Through a contrast analysis of two expressions not contradictory to the exergy-efficiency definition characteristics determined is a rational expression of the exergy efficiency for the heat pump system. In conclusion, it is noted that in the absence of an environment of high-temperature heat source for a compression-type refrigeration system the same defect may

emerge with regard to the definition of the exergy efficiency. In such a case a similar method for coping with the defect can be put into use. **Key words**: exergy efficiency, definition method, analysis, mathematical expression, heat pump

壳管式海水换热器污垢状况的㶲评价方法研究＝**An Investigation of the Method for Evaluating the Exergy Loss Relating to a Shell-and-tube Seawater Heat Exchanger Fouling Condition** [刊, 汉] / JIANG Zhu-xing, LIU Xiao-hong (Guangzhou High Technical School of Navigation, Guangzhou, China, Post Code: 510725) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(6). — 558 ~ 560

An analysis is given of the impact, which the fouling of a shell-and-tube seawater heat exchanger at the tube side and the resulting changes in heat transfer intensity and flow pressure drop will have on the exergy loss of the heat exchanger. A method is proposed to evaluate heat exchanger fouling condition by making use of the exergy loss factor. This method has been found to be more comprehensive and straightforward for evaluating heat exchanger fouling than the one based on heat resistance detection and measurement. **Key words**: heat exchanger, exergy loss, fouling

城市污泥和煤混燃特性的热重分析法研究＝**A Study of the Characteristics of Mixed Burning of Municipal Sewage Sludge and Coal by a Thermogravimetric Method** [刊, 汉] / GU Li-feng, CHEN Xiao-ping, ZHAO Chang-sui, et al (Education Ministry Key Laboratory on Clean Coal Power Generation and Combustion Technology under the Southeastern University, Nanjing, China, Post Code: 210096) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(6). — 561 ~ 563

A thermogravimetric method is employed to study such parameters as ignition temperature, activation energy and comprehensive combustion characteristics in connection with the burning of municipal sewage sludge and coal as well as their blends. The result of the study indicate that as compared with the case of burning only coal the combustion of blends has resulted in an enhanced activation energy with a lowering of the ignition temperature and a reduction of comprehensive combustion performance. During the blend burning process the municipal sewage sludge and coal have basically maintained their respective devolatilization characteristics with the coal burning exhibiting a more conspicuous behavior in this respect. **Key words**: municipal sewage sludge, coal, mixed combustion of sewage sludge and coal, thermogravimetric method

余热多级动力回收系统及其优化＝**Waste Heat Multi-stage Recovery System and It Optimization** [刊, 汉] / LIU Ye-kui, WANG Li, YAN Wen-jun, et al (College of Environmental and Chemical Engineering under the Xi' an Jiaotong University, Xi' an, China, Post Code: 710049) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(6). — 564 ~ 567, 576

Taking into account the commonly seen phenomenon of incomplete recovery of waste heat from reactors a multi-stage system of reaction heat recovery is proposed based on a single-stage system of waste heat recovery. With the net power output serving as an objective function an optimization of the multi-stage recovery system was conducted. It can be demonstrated that the multi-stage system of waste heat recovery is markedly superior as compared to the single-stage one in terms of heat recovery efficiency. **Key words**: heat recovery, waste heat, optimization, multiple stage, model

离心叶轮内三维湍流流场的数值分析＝**Numerical Analysis of a Three-dimensional Turbulent Flow Field in a Centrifugal Impeller** [刊, 汉] / TAN Da-zhi, YUAN Xin (Department of Thermal Engineering, Tsinghua University, Beijing, China, Post Code: 100084) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(6). — 568 ~ 571

Through the use of a LU-SGS-GE implicit scheme and an improved version of high-order MUSCL TVD scheme and by solving for a full three-dimensional compressible Reynolds time-averaged Navier-Stokes equation and low Reynolds number q-ω dual equation turbulent flow model calculated is the complicated three-dimensional flow in the impeller passage of a centrifugal compressor. The results of the calculation are in good agreement with those obtained by tests. This shows that