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直接蓄冰系统蓄冷过程动态模型研究

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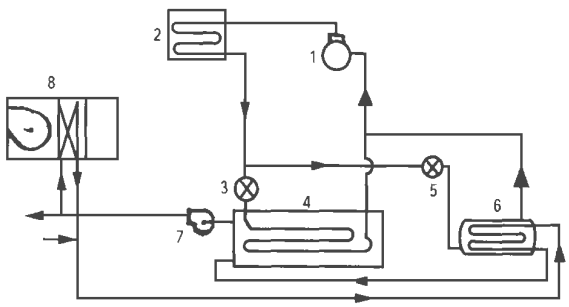
[摘要]　分析了直接蓄冰系统的动态特性,建立了相应的物理模型,并利用该模型得出了蓄冰半径及蓄冷率随时间的变化规律,模型预测值与实测值吻合较好。该模型可为直接蓄冰系统的设计及优化提供理论依据。

关键词　空调蓄冷　直接蓄冰系统　动态特性
中图分类号　TB612

1　前言

直接蓄冰系统是空调蓄冷工程中常用的一种方式,与间接蓄冰系统相比,其结构紧凑、投资省、换热效率高,省去了二次载冷剂侧的换热,并且可与空调机组构成一体,如图 1 所示为直接蓄冰系统工作原理图。低谷时,机组进行蓄冰贮冷;高峰时,机组溶冰供冷,这样可使空调机组在高峰时段不开或少开。



1－压缩机　2－冷凝器　3－夜间蓄冰用膨胀阀
4－蓄冰槽　5－白天空调用膨胀阀　6－蒸发器
7－循环泵　8－风机盘管空调器

图 1　直接蓄冰系统工作原理图

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式(6)的关系式变化。St_{TP} 与来流水流量关系不大,而主要与截面含气率 α 有关,St_{TP} 与 α 的关系可近似用直线表示,该直线的斜率与来流方向、涡街发生体形状、大小等有关。

(2)气液两相混合物中含气量太多将破坏涡街,使旋涡的形成和脱落受到影响,与单相流相比,气液两相流更不易形成稳定的涡街。

(3)应用式(6)的关系式,根据测得的涡街频率,可将涡街发生体用作测量两相流流量与组分的测量元件。

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(复　编)

直接蓄冰系统是由沉浸在充满水的贮槽中的金属管作为蓄冷介质和制冷剂间的换热表面。在蓄冰充冷时，制冷剂在管内循环，吸收贮槽中水的热量，直至管外形成冰层。直接蓄冰是一个动态变化过程，随着蓄冰时间的增加，其冰层不断加厚，而管外冰层增厚将影响其换热效率和蓄冰量。为了搞清其变化规律，文中将就其动态特性作一探讨。

2　直接蓄冰动态模型建立

蓄冰运行时，制冷剂在管内流过，与管外的冰或水进行热交换，其传热经历三个过程：

(1)通过可变厚度冰层的导热；

(2)通过管壁的导热；

(3)管壁与管内制冷剂间的对流换热。

为分析方便起见，在对直接蓄冰过程建立模型前需作如下假设：

(1)传热管外壁与固液两相界面之间为同心圆环，可按纯导热计算冰环的传热；

(2)在贮槽内水开始结冰时，水几乎被充分冷却，即槽内水的温度近似于水的冰点。

(3)由于管的长度相对于管径较大，因此可认为轴向导热很小，这时可将多维问题简化为一维(径向)问题。

2.1　蓄冰半径 r 随蓄冰时间 t 的变化关系

(1)蓄冷量 Q_i

$$Q_i = h_f \cdot \frac{dm_i}{dt} \tag{1}$$

式中：Q_i —蓄冷量，kW；

h_f —冰的融解潜热，kJ/kg；

m_i —蓄冰量，kg；

t —蓄冰时间，s。

(2)蓄冰量 m_i

$$m_i = \pi (r^2 - r_0^2) \cdot L \cdot \rho \tag{2}$$

式中：r —冰层外径，m；

r_0 —管外径，m；

L —管长度，m；

ρ —冰密度，kg/m^3。

(3)冰外径 r 与蓄冰时间 t 的关系

由式(1)、(2)得：

$$\frac{dr}{dt} = \frac{Q_i}{2\pi r L \rho h_f} \tag{3}$$

(4)管内制冷剂与管外冰之间的换热量 Q_e

$$Q_e = K \cdot A \cdot \Delta t = K \cdot A \cdot (t_f - t_e) \tag{4}$$

式中：Q_e —管内制冷剂与冰层间的换热量，W；

A —传热面积，m^2；

K —传热系数，W/(m^2·K)；

Δt —传热温差，℃；

t_f —水的冰点，℃；

t_e —制冷剂蒸发温度，℃。

其中：
$$A = 2\pi r L \tag{5}$$

$$K = \frac{1}{\frac{r}{r_i}\frac{1}{h_i} + \frac{r}{k_P}\ln\frac{r_0}{r_i} + \frac{r}{k_i}\ln\frac{r}{r_0}} \tag{6}$$

式中：r_i —管内径，m；

h_i —管内对流换热系数，W/(m^2·K)；

k_p —管壁导热系数，W/(m·K)；

k_i —冰的导热系数，W/(m·K)

由式(4)、(5)、(6)得：

$$Q_e = \frac{2\pi L (t_f - t_e)}{\frac{1}{r_i}\frac{1}{h_i} + \frac{1}{k_P}\ln\frac{r_0}{r_i} + \frac{1}{k_i}\ln\frac{r}{r_0}} \tag{7}$$

由能量平衡关系得：

$$Q_i = Q_e \tag{8}$$

将式(7)、(8)代入式(3)：

$$\frac{dr}{dt} = \frac{(t_f - t_e)}{\rho h_f \left(\frac{r}{r_i}\frac{1}{h_i} + \frac{r}{k_P}\ln\frac{r_0}{r_i} + \frac{r}{k_i}\ln\frac{r}{r_0}\right)} \tag{9}$$

积分式(9)，并有 $t = 0$ 时，$r = r_0$：

$$t = c_1 (r^2 - r_0^2)^2 + c_2 (r^2 \ln r - r_0^2 \ln r_0) \tag{10}$$

式中：c_1、c_2 —常数。

$$c_1 = \frac{\rho h_f}{(t_f - t_e)}\left[\frac{1}{2h_i r_i} + \frac{\ln r_0}{2k_p} - \frac{\ln r_0}{2k_i} - \frac{\ln r_i}{2k_p} - \frac{1}{4k_i}\right]$$

$$c_2 = \frac{\rho h_f}{2k_i (t_f - t_e)}$$

2.2　蓄冷率 ε 确定

蓄冷率 ε 被定义为实际蓄冷量与最大可能的蓄冷量之比。最大可能蓄冷量只有在管内制冷剂出口温度等于水的冰点(0 ℃)时才能达到。

$$\varepsilon = Q / Q_{max} \tag{11}$$

式中：ε —蓄冷率；

Q —实际蓄冷量，W；

Q_{max} —最大蓄冷量，W。

$$Q_{max} = (mc)_{min} \cdot (T_f - T_{ri}) \tag{12}$$

式中：$(mc)_{min}$ —最小热容，(kJ/℃)，它等于制冷剂热容，即 $(mc)_{min} = (mc)_r$；

T_{ri} —制冷剂进蓄冰盘管温度，℃；

T_f —水的冰点，0 ℃。

$$Q=(mc)_r\cdot(T_{ro}-T_{ri}) \tag{13}$$

式中：$(mc)_r$—制冷剂热容，kJ/ ℃；

T_{ro}—制冷剂出蓄冰盘管温度，℃。

$$\varepsilon=\frac{(mc)_r\cdot(T_{io}-T_{ri})}{(mc)_{min}\cdot(T_f-T_{ri})} \tag{14}$$

上式可简化为：$\varepsilon=1-T_{ro}/T_{ri}$ (15)

上式中进入蓄冰盘管的制冷剂温度 T_{ri} 受蓄冰用热力膨胀阀调节控制，它也就等于蓄冰盘管内的制冷剂蒸发温度 T_e（一般选取 $T_e=-5$ ℃）；制冷剂出蓄冰盘管的温度 T_{io} 受其过热度 Δt 限制，一般热力膨胀阀的调节热度为 2 ℃~4 ℃，则有：

$$T_{ii}=T_e \tag{16}$$

$$T_{io}=T_{ri}+\Delta t=T_e+\Delta t \tag{17}$$

则蓄冷率 ε 可表示为：

$$\varepsilon=1-\frac{T_e+\Delta t}{T_e}=-\frac{\Delta t}{T_e} \tag{18}$$

当 $T_e=-5$ ℃、$\Delta t=3$ ℃时，则有：ε=60%。

3 模型分析

利用该模型分析了某直接蓄冰系统。如图 2 所示为其蓄冰半径 r 随蓄冰时间 t 的变化规律。该模型预测值与其实测值能较好地吻合。在蓄冰初期，冰层厚度增长较快，随着冰层厚度加大，其冰层增长速度减慢，到了蓄冰后期，其冰层厚度变化很小，也即达到了额定蓄冷量。这主要是由于随着冰层厚度的增加，其传热热阻急剧增大，影响了蓄冰过程的传热。

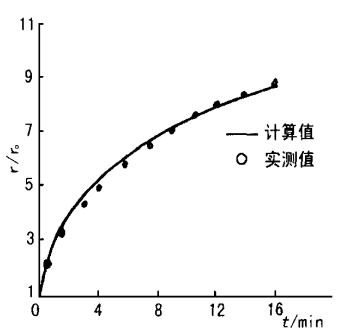

图 2 蓄冰半径 r 随蓄冰时间 t 的变化规律

利用该模型可得到蓄冰厚度，在已知管长的情况下，就可得出总的蓄冰量，即总的蓄冰量。这为直接蓄冰系统的设计提供了理论根据。

从式(18)的蓄冷率表达式可以看出：蓄冷率 ε 随蓄冰盘管内制冷剂过热度 Δt 变化。Δt 选取过小时，蓄冷率 ε 较低，但蓄冰盘管长度也可相应减小；相反，若 Δt 选取过大，虽然蓄冷率 ε 可提高，但蓄冰盘管的长度须增大，即蓄冰槽的体积要相应增大。具体选取时应从技术经济的角度综合考虑。一般情况下，在 $T_e=-5$ ℃时，可选取 $\Delta t=3$ ℃，相应的其蓄冷率为 60%。

另外，值得一提的是在设计直接蓄冰空调系统时，应分别设置空调用膨胀阀和蓄冰用膨胀阀，两者不可共用，如图 1 所示。因为空调用的膨胀阀调节的蒸发温度是+5 ℃左右，而蓄冰用的膨胀阀调节的蒸发温度是−5 ℃左右，两者的调节工况不一样。

从以上动态模型分析得知：蓄冰厚度并不是随时间线性增加，即蓄冰时间不是越长越好，到了某一极限时间后，蓄冰厚度基本上无变化，这时应停止蓄冰。

4 结论

通过前面的分析讨论，可得出如下几点结论：

(1)过去对直接蓄冰系统的动态特性了解得较少，都是按静态特性来设计蓄冷系统，与实际过程相距甚远。现通过其蓄冷过程动态特性的研究，了解了其蓄冷过程的变化规律，这将对空调蓄冷工程的设计具有很好地指导意义。

(2)为直接蓄冰系统的运行、控制提供了物理模型。

(3)利用该模型可以仿真、优化整个蓄冷系统，使整个系统性能达到最佳。

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（辉 编）

热经济学的辉煌发展＝**Impressive Developments in Thermoeconomics**〔刊，中〕/Cheng Weiliang，Wang Jiaxuan（North China Electrical Power University）//Journal of Engineering for Thermal Energy & Power. —1999，14（2）. —79～82

A new approach in energy—saving theory and technology，i. e.，thermoeconomics，is expounded in this paper. In narrating its origin，evolution，intended uses and applications，the authors give a brief description of its currently emerging variegated patterns. Thermoeconomics can be viewed as a product，resulting from a combination of thermodynamic analysis and economic factors. In the light of the grim situation of environmental protection on a global scale the authors have made an in-depth study of the thermoeconomics，discovering the existence of an impassable chasm. The latter finds its expression in the absence to date of a method for solving the biomass entropy. Without such a method for solving the biomass entropy it is virtually impossible to secure a solution for the biomass exergy，let alone a method for solving an ecosystem balance. The first half of this paper mainly describes the thermoeconomics while the remaining half focuses on some tentative efforts for solving biomass exergy without resorting to a determination for the biomass entropy. **Key words**：thermoeconomics，ecosystem，information roundup

煤中碱金属及其在燃烧中的行为＝**Various Forms of Alkali Metal in Coal and Its Behavior During Coal Combustion**〔刊，中〕/Zhang Jun，Han Chunli，Liu Kunlei，et al（Southeastern University）//Journal of Engineering for Thermal Energy & Power. —1999，14（2）. —83～85

A summarizing was conducted of the forms of alkali metal in coal，and its release and reaction during coal combustion studied. With the existing issues in current research being pinpointed the authors emphasize the necessity for their in-depth research in the future. **Key words**：coal，alkali metal，release，reaction

钙基脱硫剂掺加粉煤灰在 450℃～850℃下的脱硫研究＝**A Study on the Effect of Desulphurization of Calcium Sorbent by the Adding of Pulverized-coal Ash**〔刊，中〕/Pang Yajun（Beijing Electrical Power College），Xu Xuchang（Qinghua University）//Journal of Engineering for Thermal Energy & Power. —1999，14（2）. —86～88

By mixing pulverized-coal ash with caustic lime in a drop-tube furnace tests were conducted for enhancing SO_2 removal rate. The test results show that the mixing of caustic lime with the pulverized-coal can result in an enhancement of the SO_2 removal rate and the calcium utilization rate of the calcium-based sorbent. This effect is dependent on the reaction temperature. An optimum effect can be achieved when the reaction temperature ranges from 550℃ to 700℃. Also studied was the effect of the mixing mode of pulverized-coal ash with the caustic lime on the SO_2 removal rate and the calcium utilization rate of the calcium-based sorbent. **Key words**：drop-tube furnace，caustic lime，pulverized-coal ash，desulphurization，reaction temperature，mixing mode

垂直向上气液两向流中 T 形柱体两相斯托拉赫数的研究＝**A Study of T-shaped Cylinder Gas-liquid Two-phase Strouhal Number in a Vertically Upward Gas-liquid Two-phase Flow**〔刊，中〕/Li Yongguang（Shanghai Electrical Power Institute），Lin Zonghu（Xi' an Jiaotong University）//Journal of Engineering for Thermal Energy & Power. —1999，14（2）. —89～91

Tested and studied in this paper is the variation relationship of gas-liquid two-phase Strouhal number when a gas-liquid two-phase vortex street occurs for two types of T-shaped cylinder in a vertically upward gas-liquid flow. On the basis of a huge quantity of measured data obtained is a universal relation of the gas-liquid Strouhal number for the above-cited case. The study results indicate that the gas-liquid two-phase Strouhal number under the two-phase operating conditions is a variable. The magnitude of this variable depends on such factors as the incident flow void fraction，vortex street generating body shape，characteristic dimensions and the incident flow direction，etc. On the basis of the measured two-phase vortex street frequency and by the use of the above-mentioned relation the vortex street generating body may serve as an element for measuring the two-phase flow rate and components. **Key words**：gas-liquid mixture，Karman vortex，Strouhal Number，column

直接蓄冰系统蓄冷过程动态模型研究＝**A Study of the cold storage Process Dynamic model for an Ice Direct**

Storage System〔刊, 中〕/Fang Guiyin (China National University of Science & Technology)//Journal of Engineering for Thermal Energy & Power. —1999, 14 (2). —92~94

The dynamic characteristics of an ice direct storage system is analyzed with a relevant physical model being set up. With the help of this model obtained is the variation of the ice storage radius and cold storage rate with time. The model forecast values agree relatively well with the measured ones. This model can be used for providing a theoretical basis for the design and optimization of ice direct storage systems. **Key words**: air conditioning cold storage, ice direct storage system, dynamic characteristics

异抗坏血酸稳定亚硫酸盐的制备及其贮存稳定性研究=**Preparation of Isoascorbic Acid Stabilized Sulfite and a Study of Its Storage Stability**〔刊, 中〕/Xiong Rongchun, Wei Gang, Zhang Xiaodong (Beijing Chemical Engineering University)//Journal of Engineering for Thermal Energy & Power. —1999, 14 (2). —95~98

The inhibition of isoascorbic acid on sulfite automatic oxidation was studied by way of oxygen removal and air oxidation tests. The investigation results show that Cu2+ as a radical chain reaction initiator can accelerate the reaction of sulfite with oxygen. The isoascorbic acid as a radical absorbent can inhibit the reaction by removing the free radical produced in the sulfite oxidation process. Water pH value, hardness and alkalinity do not exercise any influence on the reaction. The test results provide an important evidence for the free radical chain mechanism of sulfite oxidation and also an effective method for preventing sulfite failure during its storage. **Key words**: sulfite, isoascorbic acid, free radical chain reaction, initiator, absorbent

富氧膜技术及其装置试验研究=**An Experimental Study of Oxygen—rich Membrane Technology and Related Equipment**〔刊, 中〕/Lin Xiangdong, Chen Xinghai, Huang Fei (Harbin 703 Research Institute)//Journal of Engineering for Thermal Energy & Power. —1999, 14 (1). —99~101

Based on the performance testing of an oxygen—rich membrane device the authors give a comprehensive review concerning the effect of oxygen—rich concentration and oxygen—rich air production rate under various operating regimes on the oxygen—rich membrane device performance and operating conditions (pressure ratio, air supply rate and operating temperature). Discussed are some problems during the practical application of such devices. In addition, an analytical study is conducted of the merit of combustion supporting effect of oxygen—rich air from the combustion technology viewpoint. **Key words**: membrane method of oxygen enrichment, device, performance test, combustion technology

多压凝汽器在 200MW 汽轮机组中的应用=**The Use of a Multi—pressure Condenser in a 200 MW Steam Turbine Unit**〔刊, 中〕/Ding Xuejun, Feng Huiwen (Central China University of Science & Technology), Hu Pingfang (Wuhan Municipal Construction Institute)//Journal of Engineering for Thermal Energy & Power. —1999, 14 (2). —102~105

Described in this paper are the specific features of a multi—pressure condenser and its energy—saving fundamentals. An analysis is given of the application prospects of such condensers in 200 MW units. A triple—pressure condenser has been designed with its energy—saving effectiveness calculated. In addition, the authors also discussed the possibility of modification of a condenser to triple—pressure for a 200 MW unit currently in operation. It is shown that the use of triple—pressure condensers in a region with a high water temperature or in the case of a cooling tower being employed can lead to an enhanced economical operation of the power plants. **Key words**: multiple—pressure condenser, steam turbine, economy

管内强化对流换热的热力经济性分析=**Thermodynamic Performance Analysis of In—tube Intensified Convection Heat Transfer**〔刊, 中〕/Wu Huiying (Shanghai Jiaotong University), Shu Fang (Nanjing Architectural Engineering Institute)//Journal of Engineering for Thermal Energy & Power. —1999, 14 (2). —106~107

In the light of the simultaneous increase of in—tube heat transfer and resistance the authors on the basis of Webb's index performed an evaluation of the complex thermodynamic performance of heat transfer and flow re-