

固体氧化物燃料电池与燃气轮机 联合发电系统模拟研究

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摘 要: 固体氧化物燃料电池(SOFC)是一种高效低污染的新型能源。建立了以天然气为燃料的固体氧化物燃料电池和燃气轮机(GT)联合发电系统的计算模型,并对具体系统进行计算。结果表明:SOFC与GT组成的联合发电系统,发电效率可达68%(LHV);加上利用的余热,整个系统的能量利用率可以超过80%。文中还分析了SOFC的工作压力、电流密度等参数对系统性能的影响,提高工作压力,可以增加电池发电量,提高系统的发电效率;而电流密度的增大将使SOFC及整个系统的发电量降低。

关 键 词: 固体氧化物; 燃料电池; 燃气轮机; 联合发电

中图分类号: TM611.3 文献标识码: A

符号表

Q_{dw}^v —应用基低位发热量/kW
 K_{pr} —重整反应平衡常数
 R —通用气体常数(8.3144J/(mol·K))
 X_{H_2} —电池反应中H₂的反应量/kmol·h⁻¹
 n_e —氢氧反应中转移的电子数($n_e = 2$)
 ΔG^0 —标准氢氧反应吉布斯函数变化
 F —法拉第常数($F = 96487C/mol$)
 $h_{m,T}$ —温度T时物质的摩尔焓/kJ·kmol⁻¹
 $h_{m,298}$ —温度298K时的摩尔焓/kJ·kmol⁻¹
 Q_a —空气的物理热焓/kW
 Q_{sm} —散热损失量/kW
 c_p —定压比热容/kJ·(kmolK)⁻¹
 W_{SOFC} —SOFC发电量/kW
 W_{comp} —压缩机耗电/kW
 W_{GT} —GT发电量/kW
 P —压力/MPa
 K_{ps} —置换反应平衡常数
 T —温度/K
 i —电池电流密度/mA·cm⁻²

η_e —系统发电效率/%
 d_{ic} —联接器厚度/cm
 P_0 —标准压力/0.1MPa
 N —摩尔流率/kmol·h⁻¹
 E_{re} —理想可逆电压/V
 E —SOFC电池电压/V
 n —电池个数
 h —总焓/kJ·kmol⁻¹
 η_a —阳极过电位/V
 η_c —阴极过电位/V

A —电池单体面积/cm²
 Δh_f^0 —标准生成焓/kJ·kmol⁻¹
 η_{IR} —欧姆过电位/V
 Q_f —燃料的物理热焓/kW
 Q_{bu} —不完全燃料损失量/kW
 N_p —燃料产物生成量/kmol·h⁻¹
 Q_{fr} —余热回收量/kW
 w_{ic} —联接器宽度/cm

σ_e —电解质阻抗/ Ω_{cm}
 d_e —电解质厚度/cm
 σ_c —阴极阻抗/ Ω_{cm}
 d_c —阴极厚度/cm
 σ_a —阳极阻抗/ Ω_{cm}
 d_a —阳极厚度/cm
 l —电池直径/cm
 σ_{ic} —联接器阻抗/ Ω_{cm}

1 引 言

能源是国民经济重要的物质基础,也是人类赖以生存的基本条件。随着人类经济、社会活动的大规模发展,能源消耗大幅度增长。多年来人们一直在努力寻找既有较高能量利用率又不污染环境的新的能源利用方式。固体氧化物燃料电池(SOFC)工作温度高(800~1000℃)^[1],可以与传统的燃气轮机、蒸汽轮机组成联合循环,提高能量利用率,有非常好的发展前景,已日益受到国内外研究机构的重视。但目前关于SOFC的研究大多集中在电池材料和电池制备等问题上,对于如何充分发挥SOFC的优点和提高能量利用率的研究还不是很广泛。

本文通过对一个采用内部重整的SOFC与GT组成的联合发电系统进行热力分析,建立系统的计算模型,计算分析了系统的各种性能指标;研究了SOFC电压、电流密度等运行参数对系统性能的影响。研究结果对于我国固体氧化物燃料电池的研究开发具有指导和借鉴意义。

2 系统描述

本文研究的是以天然气和空气为原料的固体氧

收稿日期: 2003-11-25

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化物燃料电池, 采用内部重整使甲烷反应成电池所需的氢气, 并利用燃气轮机来有效利用其高温排气。系统组成如图 1 所示。燃料和空气经压缩提高压力并由 GT 的废气加热, 分别送到 SOFC 的阳极和阴极。燃料在进入阳极前与一定量的水蒸气混合, 以便在 SOFC 中进行重整。在阳极室, 甲烷与水蒸气发生重整反应和置换反应, 产生氢气。空气中的氧在空气极/电解质界面被还原, 在空气极和燃料极氧分差的作用下, 通过电解质向燃料极侧移动。在燃料极, 氧离子与氢气发生电化学反应, 生成水, 放出电子。电子通过外电路返回空气极, 形成回路, 产生电能。从燃料电池出来的阳极气体, 包括甲烷、氢气、一氧化碳等与阴极气体一同被送入后燃室进行完全燃烧, 提高气体温度。燃尽的气体进入燃气轮机继续做功, 所做的功一部分用来提供压缩机所需的电功, 剩余部分发电, 与燃料电池所发的电能共同构成系统发电量。燃气轮机排气除了加热燃料、空气和水, 使其达到一定的温度外, 还可以产生热水或蒸汽外供, 进一步利用余热, 提高能量利用率。

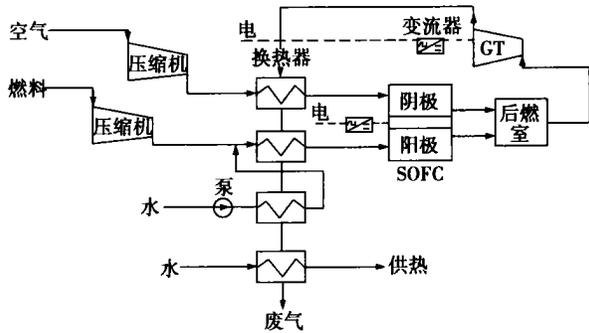


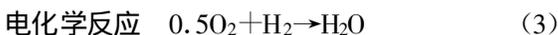
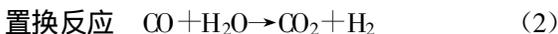
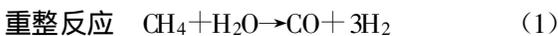
图 1 SOFC 与 GT 联合发电系统流程图

3 计算模型

3.1 SOFC 模型

3.1.1 物质平衡

在 SOFC 阳极, 甲烷发生重整反应, 产生氢气和一氧化碳。一氧化碳与水蒸气发生置换反应, 继续产生一部分氢气, 反应方程为:



对于一定的化学反应, 平衡常数表示平衡时各物质的数量关系是计算平衡组分的重要依据。平衡常数与反应的温度有关。因此, 平衡时阴阳极气体的组成由进入燃料电池的气体成份、摩尔流率以及

反应的温度所决定:

$$K_{\text{pr}} = \frac{P_{\text{CO}} P_{\text{H}_2}^3}{P_{\text{H}_2\text{O}} P_{\text{CH}_4} P_{\text{O}_2}^2} = \frac{N_{\text{CO}} N_{\text{H}_2}^3}{N_{\text{H}_2\text{O}} N_{\text{CH}_4} N^2} \left(\frac{P}{P_0}\right)^2 \quad (4)$$

$$K_{\text{ps}} = \frac{P_{\text{CO}_2} P_{\text{H}_2}}{P_{\text{CO}} P_{\text{H}_2\text{O}}} = \frac{N_{\text{CO}_2} N_{\text{H}_2}}{N_{\text{CO}} N_{\text{H}_2\text{O}}} \quad (5)$$

3.1.2 电流密度

$$i = \frac{X_{\text{H}_2} n_d F}{nA} \quad (6)$$

3.1.3 电池电压

燃料电池理想可逆电压可以由能斯特公式求得^[1], 但理想可逆电池电压不是燃料电池输出的最终电压, 还要减去各种不可逆损失。包括阴、阳极的过电位 η_c 、 η_a 以及由于电解质、电极和联接器阻抗引起的欧姆过电位 η_{IR} ^[6]。

$$E_{\text{re}} = E^0 + \Delta E = -\frac{\Delta G^0}{2F} + 0.316 \frac{RT}{2F} \ln \frac{P_{\text{H}_2} P_{\text{O}_2}^{0.5}}{P_{\text{H}_2\text{O}}} \\ = -\frac{\Delta G_{\text{H}_2\text{O}}^0 - \Delta G_{\text{H}_2}^0 - \frac{1}{2} \Delta G_{\text{O}_2}^0}{2F} + 0.158 \frac{RT}{F} \ln \frac{P_{\text{H}_2} P_{\text{O}_2}^{0.5}}{P_{\text{H}_2\text{O}}} \quad (7)$$

根据实验数据^[6], 可以假定阳极过电位与电流密度无关, 当 SOFC 的工作温度为 1073 K 时, 其值约为 150 mV; 工作温度为 1273 K 时, 其值为 50 mV。阴极过电位的数值可由下式求得^[4]:

$$\eta_c = 0.07i^3 - 0.077i^2 + 0.04i - 0.00003 \quad (8)$$

由电解质、电极和联接器阻抗引起的欧姆过电位 η_{IR} 计算^[4]:

$$\eta_{\text{IR}} = i \sigma_e d_e + i b \sigma_{\text{ic}} \frac{d_{\text{ic}}}{w_{\text{ic}}} \left(\frac{\sigma_c}{d_c} + \frac{i \pi^2 l^2}{8} \frac{\sigma_a}{d_a} \right) \quad (9)$$

于是, 燃料电池最终的电压值为:

$$E = E_{\text{re}} - \eta_{\text{IR}} - \eta_a - \eta_c \quad (10)$$

3.1.4 SOFC 发电量

$$W_{\text{SOFC}} = inAE \quad (11)$$

3.1.5 能量平衡

SOFC 的工作温度可以通过热力学第一定律求得。在 SOFC 中发生的是化学反应, 因此在运用热力学第一定律时, 一方面在计算热力学能变化及焓变时应当把发生变化的化学能包括进去; 另一方面由于在化学反应过程中, 不同的化合物将出现在同一化学反应方程中, 因此, 在能量的分析计算中, 必须采用统一的基准。本文把 SOFC 看作一个整体, 并以化学标准状态(压力 0.1 MPa, 温度 25 °C) 作为计算基准列写能量平衡方程(不计散热损失), 即:

$$\sum_{in} N_i h_i = \sum_{out} N_i h_i + W_{SOFC} \quad (12)$$

$$h = \Delta h_f^0 + h_{m,T} - h_{m,298} \quad (13)$$

假设 SOFC 的工作温度与电池产物的出口温度相同,那么要从能量方程中求出工作温度,必须要先求出 SOFC 的电流密度和电池电压,而电流密度和电池电压又与工作温度相关。因此需经过迭代计算,才能最终求得 SOFC 的工作温度。

3.2 后燃室模型

燃烧温度是燃烧装置运行的重要参数,其值与燃料性质、燃料成份、燃烧过程的完善程度以及燃烧装置的结构完善性有关,可以通过热平衡条件确定。根据热平衡原理,输入后燃室的总热量与消耗的总热量相等,即:

$$Q_{dw}^v + Q_a + Q_f = N_p c_p T_p + Q_{san} + Q_{bu} \quad (14)$$

定义 η_c 为后燃室效率^[2],则 $Q_{dw}^v - Q_{bu} = \eta_c Q_{dw}^v$ 。上式中只有燃烧温度 T_p 是未知的,经过迭代计算,即可求出燃烧产物的温度值。

3.3 系统效率

进入系统的能量,除一部分损失外,其余的转化为 SOFC 和燃气轮机的发电量,还有一部分余热也将被回收利用。定义系统发电效率 η_e 为 SOFC 和燃气轮机的总有效发电量(除去供给压缩机的部分电量)与系统总能量输入(以燃料的应用基低位发热量来计算)之比,即:

$$\eta_e = \frac{W_{SOFC} + W_{GT} - W_{comp}}{Q_{dw}^v} \quad (15)$$

定义系统总能量利用率 η_{total} 为系统总有效发电量与余热回收量和系统总能量输入之比,即:

$$\eta_{total} = \frac{W_{SOFC} + W_{GT} - W_{comp} + Q_{fr}}{Q_{dw}^v} \quad (16)$$

4 计算与分析

4.1 算例

本文的计算中,燃料天然气的摩尔成份为 97% CH₄、1%CO₂ 和 2%N₂,摩尔流率 17.3 kmol/h。空气为 21%O₂ 和 79%N₂,摩尔流率 238 kmol/h。燃料、空气和水进入系统时的参数为 25 °C, 0.1 MPa, 其它系统参数见表 1。

本文使用 Visual Basic 进行热力系统计算。输入系统初始参数,程序调用压缩机、SOFC、后燃室和 GT 等模块,计算出各工作点的工况,从而得到 SOFC 的电流密度、电压、发电量以及系统发电效率、能量

利用率等性能指标(见表 2)。本文中:SOFC 的电流密度为 215.025 mA/cm²,电池电压 0.731 3 V,发电量 2 003.43 kW,占全系统总发电量的 78.64%。系统发电效率为 68.073%,若计入回收的余热,则整个系统的能量利用率 80.881%。而传统发电方式的发电效率只 40%左右^[3]。因此,发展固体氧化物燃料电池与传统发电方式结合的联合发电系统,将是提高能量利用率的一种有效发电方式。

表 1 系统输入参数

SOFC 参数	燃料利用率/%	83	入口空气温度/K	963
	入口燃料温度/K	803	单体面积/cm ²	260
	电池个数/个	50 000	电池压损/%	5
	阳极厚度/cm	0.01	阴极厚度/cm	0.15
	电解质厚度/cm	0.015	联接器厚度/cm	0.015
	联接器宽度/cm	0.3	电池直径/cm	1.9
其它参数	各部分质量损失/%	1	压缩机压缩比	8
	压缩机绝热效率/%	85	GT 压力比	5
	换热器压损/%	2	蒸汽/碳比	2.2
	后燃室效率/%	99	机械效率/%	99
	后燃室散热损失/%	1	换热器散热损失/%	1
	变流器效率/%	98	后燃室压损/%	5
	废气温度/K	363	GT 绝热效率/%	89

表 2 系统性能指标

燃料侧压缩机功耗/kW	42.95	空气侧压缩机功耗/kW	547.93
SOFC 电流密度/mA·cm ⁻²	215.025	SOFC 电压/V	0.731 3
SOFC 工作温度/K	1 152.9	SOFC 发电量/kW	2 003.43
后燃室温度/K	1 465.37	GT 发电量/kW	1 134.99
余热回收量/kW	479.31	系统发电量/kW	2 547.55
系统发电效率/%	68.077	系统能量利用率/%	80.88
欧姆过电位/V	0.353 2	电池总过电位/V	0.468 9

4.2 SOFC 电流密度对系统性能的影响

图 2 和图 3 所示为当系统其它参数保持不变,仅改变 SOFC 电池个数使电流密度变化时,SOFC 发电量和系统发电效率的变化趋势。SOFC 电流密度增大,电池的阴极过电位和欧姆过电位都将增大,SOFC 的实际电压降低,SOFC 的发电量相应从 2 044.48 kW 减小到 1 691.31 kW。虽然电流密度的增大,会提高电池的工作温度,GT 发电量有所增加,但不足以弥补 SOFC 发电量的减小。因此,整个系统的发电效率将表现出随电流密度的增大而减小的趋势。

4.3 SOFC 电池工作压力对系统性能的影响

通过改变压缩机的压缩比,使 SOFC 工作压力从 0.365 MPa 增大到 0.821 MPa。电池的工作压力增大一方面使得压缩机消耗的电量增多;另一方面经过重整反应和置换反应生成的氢气量增加,则参

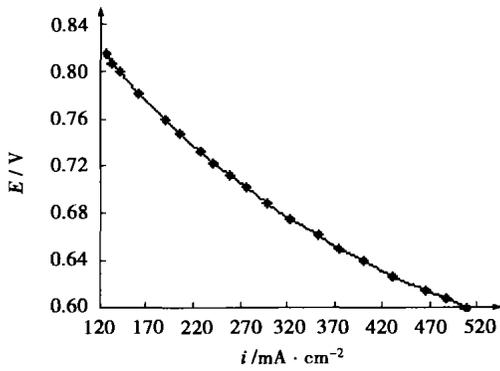


图 2 电流密度对 SOFC 发电量的影响

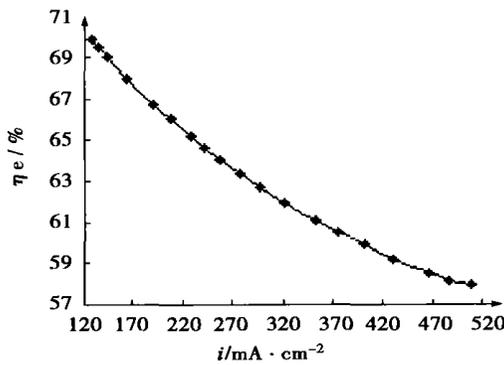


图 3 电流密度对系统发电效率的影响

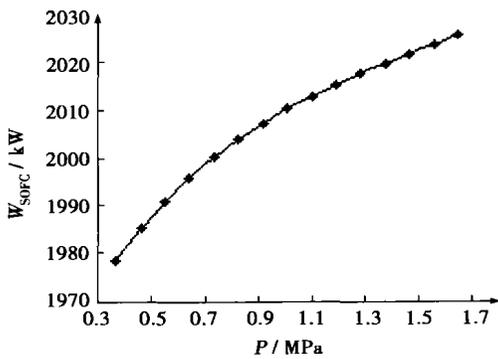


图 4 电池工作压力对 SOFC 发电量的影响

与电池反应的氢气量同步增加。电池电压上升, SOFC 发电量增多, 如图 4 所示。工作压力的提高使 GT 的压力比增大, 发电量增加, 所以系统的发电效率增大。

4.4 蒸汽/碳比对系统性能的影响

为了防止甲烷发生热分解, 生成的固体碳在电池内发生沉积, 破坏电池的性能, 在甲烷进入 SOFC

前需要混合一定比例的蒸汽, 最小的蒸汽/碳比应为 $2.0^{[4]}$ 。图 6 和图 7 分析了蒸汽/碳比从 2 变化到 4 时, 对 SOFC 发电量和系统发电效率的影响。增加蒸汽/碳比, 即增加混合的蒸汽量, 电池中水的分压力增大, 则电池的电压减小, 电池发电量相应减小。但由于蒸汽量的增加, 使得在 GT 中做功的工质量增加, 所以虽然 SOFC 的发电量是减小的, 但整个系统的发电效率仍然呈上升的趋势。

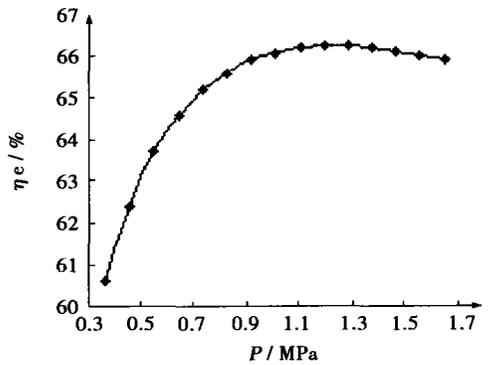


图 5 电池工作压力对系统发电效率的影响

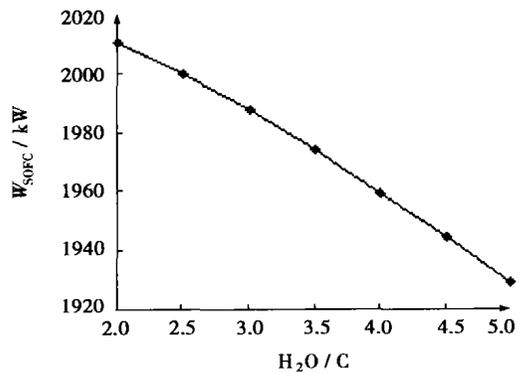


图 6 蒸汽/碳比对 SOFC 发电量的影响

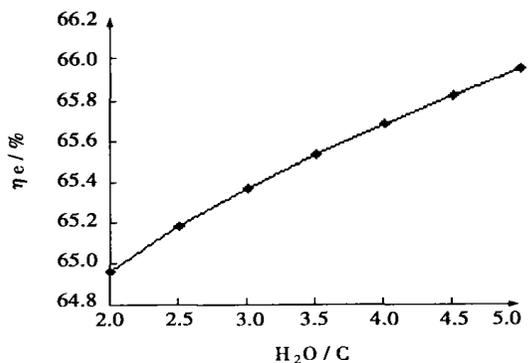


图 7 蒸汽/碳比对系统发电效率的影响

5 结 论

以一个 2 MW 的固体氧化物燃料电池与燃气轮机组成的发电系统为研究对象,建立了系统的计算模型,并利用 Visual Basic 编程计算分析了系统的性能,结论如下:

(1) 以天然气为燃料,空气为阴极气体的 SOFC,当电池工作压力为 0.731 3 MPa,电池电流密度为 215.025 mA/cm² 时,SOFC 的发电量为 2 003.43 kW。如果与压力比为 5 的 GT 组成联合发电系统,则系统总发电量可达 2 547.55 kW,发电效率为 68.073%,整个系统的能量利用率接近 81%,表现出了 SOFC 联合发电系统的优势;

(2) 由于过电位的存在,使 SOFC 的实际电压远远低于理想可逆电池电压的值,不利于提高电池的发电量。本系统中:电池总过电位为 0.468 9 V,其中欧姆过电位为 0.353 2 V,约占电池总过电位的 75%。因此要减小电池的过电位,提高效率,应重点改变电池材料的性能,以减小欧姆过电位;

(3) 减小 SOFC 的电流密度可以增加电池的发电

电量,从而提高系统的发电效率。但这需要增加电池的个数,增加系统投资;

(4) 增大电池的工作电压,可以增加电池的发电量,进而提高系统的发电效率和能量利用率;

(5) 为防止天然气中的甲烷发生热分解,影响电池的性能,应向进入电池的燃料中加入一定比例的蒸汽。蒸汽量增大,SOFC 和系统的发电量都会增加,但换热器的面积需相应加大,并且系统排出的废气量也会增大,因此不能盲目增加蒸汽/碳比。

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根据文献[5]提供的热力系统详细计算方法得到的结果为:

$$\Delta b = -1.393$$

5 结 论

针对二次再热供热机组采用低压缸分缸抽汽供热的特点,利用等效热降理论,经过理论分析与数学推导,得出了该类型机组抽汽等效热降和抽汽效率的计算方法,建立了纯热量和带工质热量局部定量分析的数学模型,以实例计算验证了本文方法的准确性,为二次再热超临界供热机组热力系统的经济性诊断和定量分析计算提供了工具,拓宽了等效热

降理论的应用范围。

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calculated and analyzed by using a numerical method. A comprehensive analysis was performed of the erosion mechanism and features specific to stator and rotor blades on the basis of the impact location and velocity of solid particles on blades, impact angle and blade material erosion-resistance behavior. It is noted that the suction side erosion of the stator blades is caused by the impact of solid particles rebounding from the rotor blades. Furthermore, also analyzed was the influence of the turbine load and the axial clearance between the stator and rotor blades on the number of particles rebounding to stator blades. The results of the analysis indicate that an decrease in axial clearance and a reduction in turbine load has given rise to an increase in the quantity of particles rebounding to the stator blades. **Key words:** solid particle erosion, supercritical steam turbine, reheat stage, numerical analysis.

二次再热超临界供热机组热力系统经济性定量分析方法 = **Economic-quantitative Analysis Method Used for the Thermodynamic System of a Supercritical Heat Supply Unit with a Double Reheat** [刊, 汉] / LI Yang, XING Qin-an, YAN Jun-jie, et al (Energy and Power Engineering Institute under the Xi'an Jiaotong University, Xi'an, China, Post Code: 710049) // Journal of Engineering for Thermal Energy & Power. — 2004, 19(4). — 351 ~ 353, 362. A supercritical heat-supply unit with a double reheat employs steam extraction from a low-pressure turbine cylinder for supplying process heat. On the basis of the above arrangement, a method for calculating equivalent enthalpy drop and steam extraction efficiency for the above unit is obtained by making use of an equivalent thermal-drop theory and performing a theoretical analysis and mathematical deduction. A mathematical model based on an economic-quantitative analysis has been derived for the above-mentioned turbine unit, thereby extending the application range of the equivalent heat-drop theory to heat supply units with a double reheat. By using this model it is possible to effect a convenient, rapid and accurate analysis of the thermodynamic system cost-effectiveness of the above supercritical heat supply unit. **Key words:** double reheat, thermodynamic system, quantitative analysis, heat supply unit.

基于支持向量机的燃气轮机故障诊断 = **Gas Turbine Fault Diagnosis Based on a Support Vector Machine** [刊, 汉] / LUO Ying-feng, ZENG Jin (Mathematics Department, Shanghai Jiaotong University, Shanghai, China, Post Code: 200240) // Journal of Engineering for Thermal Energy & Power. — 2004, 19(4). — 354 ~ 357.

With respect to eight kinds of commonly seen typical faults a fault diagnosis model is set up based on a support vector machine. Specific sample calculations have demonstrated the effectiveness of such a model. A comparison with a neural network method has shown that under the condition of a small quantity of samples the support vector machine-based method is superior to the neural network method in terms of calculation results, generalization ability and efficiency. When a relatively small number of diagnosis samples is involved, the above method may provide a new approach for creating an intelligent system of highly practical value for the condition monitoring and fault diagnosis of gas turbines. **Key words:** gas turbine, support vector machine, fault diagnosis system.

固体氧化物燃料电池与燃气轮机联合发电系统模拟研究 = **Simulation Study of a Combined Power Generation System Incorporating a Solid-oxide Fuel Cell and a Gas Turbine** [刊, 汉] / LU Li-ning, LI Su-fen, SHEN Sheng-qiang (Power Engineering Department, Dalian University of Science & Technology, Dalian, China, Post Code: 116024), LU Li-yu (Inner Mongolia Dalate Power Plant, Baotou, China, Post Code: 014300) // Journal of Engineering for Thermal Energy & Power. — 2004, 19(4). — 358 ~ 362.

A solid-oxide fuel cell (SOFC) is a new type of energy featuring high efficiency and low pollution. A calculation model is set up for a combined power generation system, which comprises a solid-oxide fuel cell with natural gas serving as its fuel and also a gas turbine (GT). The calculation results of the above system indicate that the combined power generation system composed of SOFC and GT can attain a power generation efficiency of 68% (based on low heating value). With the waste heat being put to use the energy utilization rate of the whole system can surpass 80%. The impact of such parameters as SOFC operating pressure and its current density on the system performance was analyzed. An increase in its operating pressure can lead to an increase in cell electricity generation and power generation efficiency of the system. On the other hand, an increase in current density may result in a decrease of electricity generation for both the SOFC and the

whole system. **Key words:** solid oxide, fuel cell, gas turbine, combined power generation.

湿度对HAT循环燃烧室旋流扩散燃烧特性的影响= **The Influence of Humidity on the Swirl Diffusion-combustion Characteristics in a Humid Air Turbine (HAT) Cycle Combustor** [刊, 汉] / ZHOU Jian-guang, ZANG Shu-sheng, WENG Shi-lie (College of Mechanical & Power Engineering under the Shanghai Jiaotong University, Shanghai, China, Post Code: 200030) // Journal of Engineering for Thermal Energy & Power. — 2004, 19(4). — 363 ~ 366, 391.

A turbulent Reynolds stress model and a laminar small flame model are used to study the influence of humidity on combustion characteristics. A numerical simulation was conducted of a methane diffusion-combustion process in the swirler-equipped combustor of a humid air turbine (HAT) cycle gas turbine. The distribution states of temperature profile, velocity field and NO constituent elements in the combustor are compared for four different air humidity values (0, 100, 200, 300 g/kg [DA]) along with an analysis of the influence of humidity on diffusion combustion characteristics in the HAT cycle combustor. It has been found that moisture addition can lead to a reduction in combustor temperature, a more uniform distribution of temperature and a drastic lowering of NO concentration in the combustor as well as a reduction in the length of a return flow zone. **Key words:** combustor, diffusion combustion, humid air combustion, simulation of combustion.

燃料稀释对富氧空气/甲烷扩散火焰中氮氧化物生成的影响= **Impact of Fuel Dilution on the Formation of NO_x in an Oxygen-rich air/Methane Diffusion Flame** [刊, 汉] / ZHAO Dai-qing, FENG Yao-xun, LIU Qing-cai (Guangzhou Institute of Energy Conversion under the Chinese Academy of Sciences, Guangzhou, China, Post Code: 510070), H Yamashita (Department of Mechanical Informatics & Systems, Graduate School of Engineering, under the Nagoya University, Nagoya, Japan, Post Code: 464-8603) // Journal of Engineering for Thermal Energy & Power. — 2004, 19(4). — 367 ~ 371, 420.

The present study is aimed at revealing the NO_x formation mechanism in an oxygen-rich combustion process. NO_x suppression mechanism is also investigated with the oxygen-rich flame characteristics being taken account of. With a counter-flow diffusion flame serving as an object of research the impact of fuel dilution on the NO_x formation in an oxygen-rich air/methane diffusion flame was studied with the help of a fully developed elementary reaction-dynamics model. The diluent being used is N₂ or CO₂. It is found that with the variation of concentration of dilution constituent elements in fuel there emerged a marked change in flame structure and NO formation mechanism. It is also discovered that with an increase in the concentration of diluent CO₂ the emission index of NO decreases monotonically and the latter index may reach a maximum value when N₂ is used as a diluent. **Key words:** counter-flow diffusion flame, fuel dilution, NO_x, numerical analysis.

脉动供燃料燃烧技术及各参数影响研究= **A Study of Combustion Technology Featuring the Pulsating Feed of Fuel and the Influence Exerted by Various Parameters** [刊, 汉] / ZHAO Hai-liang, LI Yan, YOU Chang-fu, et al (National Key Laboratory of Clean Combustion of Coal under the Tsinghua University, Beijing, China, Post Code: 100084) // Journal of Engineering for Thermal Energy & Power. — 2004, 19(4). — 372 ~ 375, 415.

A jet-flow diffusion flame based on the adoption of a pulsating fuel-feed combustion mode is investigated. By making use of a direct photographing technique the characteristics and variation mechanism of the flame are observed and analyzed under various operating conditions and parameters. They include: fuel-rich combustion-time share, average Reynolds number and pipe connecting conditions, etc. The impact of various parameters and the flame characteristics under resonant operating conditions are also analyzed. It was found that with the fuel-rich combustion-time share in the range of 70% - 90% the flame would assume a more or less regular fuel-rich and fuel-lean alternative structure with a clearer picture being observed during resonant frequencies. At a duty cycle of 70% - 80% the flame has a maximum length and the alternative structure assumes a most regular form. At a still lower duty cycle of fuel-rich combustion-time share there emerged under a resonant frequency a collapsed mixing and turbulent flow at the root of the flame accompanied by a flame