

寒区太阳能—土壤源热泵系统太阳能保证率的确定

余延顺, 廉乐明

(哈尔滨工业大学 建筑热能工程系, 黑龙江 哈尔滨 150090)

摘要: 在寒冷地区以太阳能、土壤源作为热泵的低位热源对节约能源、保护环境、开发利用新能源和可再生能源具有重大的意义。文中首次提出了土壤源热泵系统在不同的运停比下的土壤温度场恢复率, 并以此作为指标, 衡量土壤源热泵在各种不同运停比下土壤温度场的恢复程度, 确定土壤源热泵的最佳运停比及太阳能保证率, 从而确定太阳能集热装置的容量。

关键词: 寒冷地区; 太阳能—土壤源热泵; 太阳能保证率; 土壤温度场恢复率

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1 引言

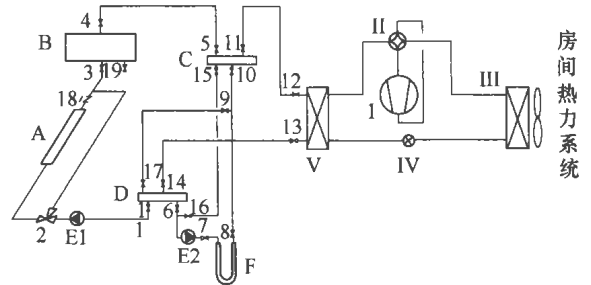
针对寒冷地区的气候特点, 从节约能源、保护环境、开发利用新能源和可再生能源的角度出发, 并以太阳能为主热源, 土壤源为辅助热源, 提出以太阳能、土壤热作为热泵的低位热源的思想, 定义太阳能保证率为所利用的太阳能与采暖负荷的比值。为合理的确定太阳能保证率的大小及配置各装置的容量, 采用控制容积法对土壤源热泵系统在各种不同的运停比下垂直 U 型管二维轴对称温度场进行了模拟, 并以土壤温度场的恢复率为指标, 来确定土壤源热泵系统的最佳运停比及太阳能保证率, 从而确定集热装置的容量^[1]。

2 土壤温度场的数学模型

结合太阳能—土壤源热泵系统的功能特点, 提出如下的原理图, 如图 1 所示。

2.1 土壤源热泵连续运行时的温度场分布

土壤源热泵连续运行时的温度场分布采用 NWWA (National Water Well Association) 模型, 该模型是建立在 Kelvin 线热源理论的基础上, 是一种常用的地下埋管换热器的计算方法^[2]



A—太阳能集热器; B—贮热水箱; C、D—分(集)水器; E1, E2—循环水泵; F—地下埋管换热器; I—压缩机; II—四通换向阀; III—冷凝(蒸发)器; IV—节流阀; V—蒸发(冷凝)器; 1, 3~18—截止阀; 2—三通阀; 19—止回阀
图 1 太阳能—土壤源热泵系统原理图

$$t(r, \tau) - t_{\infty} = \frac{q}{4\pi\lambda_s} \int_{\frac{r^2}{4\alpha\tau}}^{\infty} \frac{e^{-s}}{S} ds \quad (1)$$

式中: $t(r, \tau)$ — τ 时刻半径为 r 处土壤的温度, $^{\circ}\text{C}$; t_{∞} —土壤的原始温度, $^{\circ}\text{C}$; q —埋管的热流率, W/m 。

2.2 热泵停止运行时土壤温度场的恢复

土壤温度恢复过程是指热泵停止运行后的温度自然恢复过程。在建立其温度恢复过程的数学模型时作如下假设^[1]:

(1) 假设土壤、埋管为均质且各向同性的固体, 各材料物性参数为常数; (2) 认为垂直埋管周围土壤温度场为二维非稳态导热; (3) 忽略由于土壤中水分迁移而引起的热迁移; (4) 在土壤深度 13 m 以下, 土壤温度恒温。

由于地下埋管是轴对称的, 因此轴坐标下的数学模型为:

$$\frac{\partial}{\partial \tau} = \alpha \left[\frac{\partial^2}{\partial y^2} + \frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial}{\partial r} \right) \right] \quad (2)$$

$$0 \leq y \leq 50, 0 \leq r \leq 1.0$$

$$\frac{\partial (y, r, \tau)}{\partial r} \Big|_{r=0} = 0 \quad (3)$$

$$t(y, r, \tau) |_{r=1.0} = \text{const} \quad (4)$$

$$t(y, r, \tau) |_{r=0} = \text{const} \quad (5)$$

$$t(y, r, \tau) |_{y=50.0} = \text{const} \quad (6)$$

$$-\lambda_s \frac{\partial t}{\partial y} |_{y=0} = \alpha_0 Q - F + \alpha_w (t_a - t(y, r, \tau))$$

$$|_{y=0} \quad (7)$$

式中: Q —太阳总辐射量, W/m^2 ; α_0 —土壤表面对太阳总辐射的吸收率; F —土壤表面的有效辐射量, W/m^2 ; α_w —土壤表面对流换热系数, $W/(m^2 \cdot ^\circ C)$ 。

由于式(7)中土壤表面的有效辐射量的大小与表面温度、气温、云量、气压、透明度等因素有关, 计算比较困难^[3]。因此计算时采用式(8)替换式(7):

$$-\lambda_s \frac{\partial t}{\partial y} |_{y=0} = \alpha'_w (t_a - t(y, r, \tau)) |_{y=0} \quad (8)$$

式中: α'_w —考虑了辐射的总对流换热系数, $W/(m^2 \cdot ^\circ C)$; $\alpha'_w = 23.3 W/(m^2 \cdot ^\circ C)$; t_a —室外综合温度, $^\circ C$ 。

2.3 太阳能保证率及土壤温度场恢复率

太阳能保证率定义为在采暖期太阳能提供的有效热量与建筑物热负荷的比值。即:

$$f = \frac{\text{太阳能提供有效热量}}{\text{建筑物热负荷}}$$

土壤温度场恢复率为:

$$eff = \frac{\text{计算时刻土壤温度}}{\text{土壤原始温度}}$$

3 模拟结果及分析

3.1 土壤源热泵连续运行时土壤温度场分布

以哈尔滨一月份为例, 对土壤源热泵连续运行时的土壤温度场分布模拟结果如图2~图6所示。

从图2~图6可以看出, 在土壤源热泵连续运行过程中, 近盘管即在距盘管0.35 m的半径范围内土壤的温度变化很大, 在距盘管0.35 m以外的区域, 土壤的温度变化趋势比较平缓, 而且随着半径的

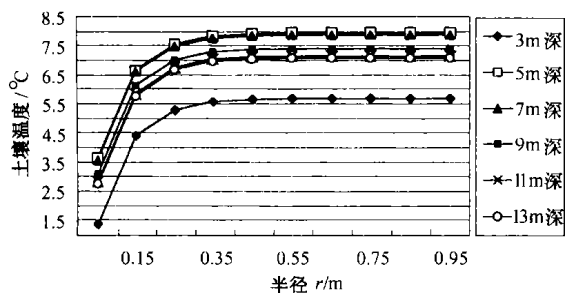


图2 热泵连续运行8 h的土壤温度场分布

增大逐渐接近该层土壤的初始温度。随着运行时间的延长, 在相同深度不同半径之间的温差有逐渐增

大的趋势, 如运行8 h在深度为3 m处, 半径0.05 m和半径0.15 m之间的温差为3.0 $^\circ C$; 运行36 h后温差为3.4 $^\circ C$ 。但从整个运行过程来看, 变化的幅度是很缓慢的。

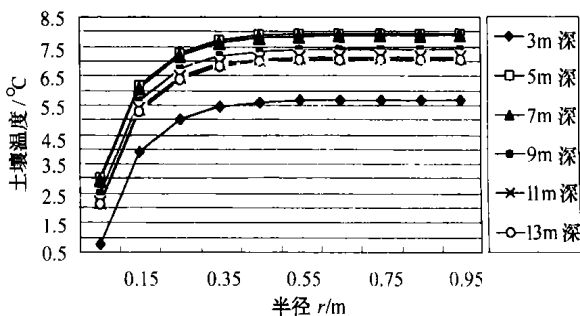


图3 热泵连续运行12 h的土壤温度场分布

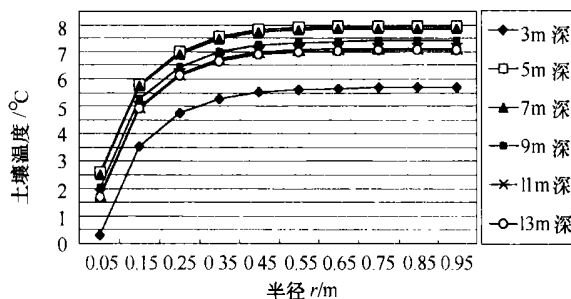


图4 热泵连续运行16 h的土壤温度场分布

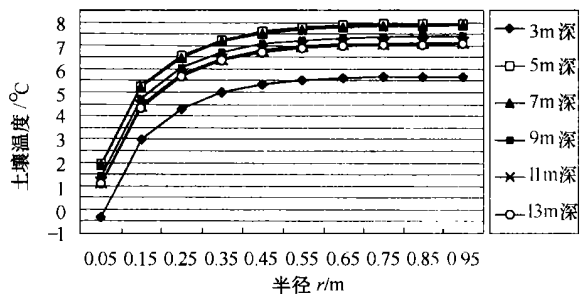


图5 热泵连续运行24 h的土壤温度场分布

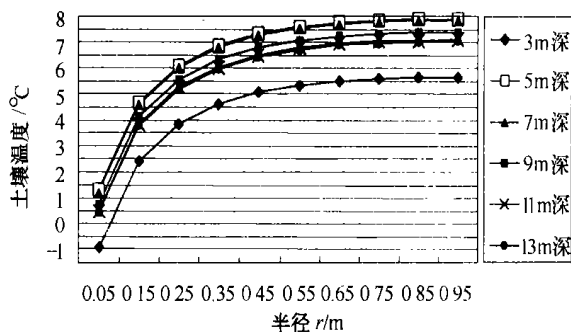


图6 热泵连续运行36 h的土壤温度场分布

3.2 土壤温度恢复时的温度场分布

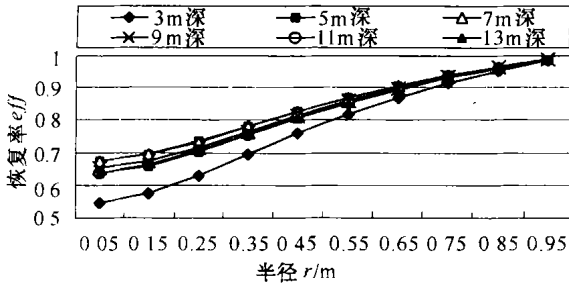


图 7 热泵 8 h 运行, 16 h 恢复的温度场恢复率

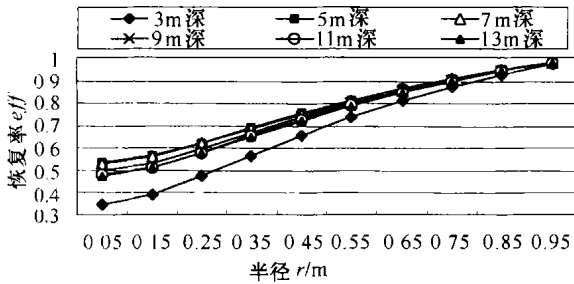


图 8 热泵 10 h 运行, 14 h 恢复的温度场恢复率

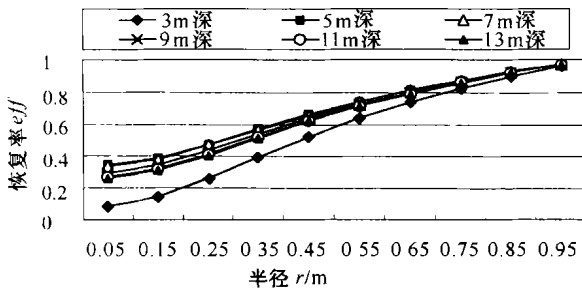


图 9 热泵 12 h 运行, 12 h 恢复的温度场恢复率

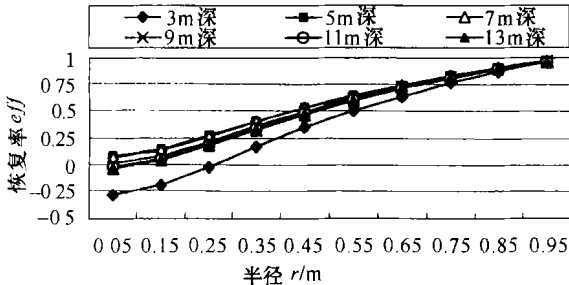


图 10 热泵 14 h 运行, 10 h 恢复的温度场恢复率

通过以上建立的数学模型, 采用控制容积法对哈尔滨地区一月份 30 个运行周期土壤温度恢复时的温度场分布进行了模拟, 模拟结果如图 7 ~ 图 10 所示。

从图 7 ~ 图 10 可以看出, 在土壤源热泵运行 30 个周期内, 土壤温度场的恢复状况与土壤源热泵的

运行时间分配比例有很大的关系, 即与土壤源热泵运行停比有关。在热泵 8 h 运行, 16 h 恢复的运行工况下, 近盘管土壤温度场在不同深度的恢复率达 55% ~ 75% 左右; 在 10 h 运行, 14 h 恢复的运行工况下, 近盘管土壤温度场在不同深度的恢复率为 35% ~ 55%; 而在 14 h 运行, 10 h 恢复的运行工况下, 在近盘管处, 土壤的温度场几乎得不到恢复, 致使土壤温度达到零度下值, 这对土壤源热泵的运行效率是很不利的。因此从以上模拟计算的结果分析可知, 土壤源热泵的运行时间为 8 ~ 12 h 为宜, 即在以 24 h 为周期内土壤源热泵单独运行的时间分配比例控制在 33% ~ 50% 左右是比较有利的, 在这种运行时间分析比例下, 系统运行 30 周期土壤温度场恢复状况较好, 在近盘管处恢复率可达 20% ~ 70%。当土壤源热泵的运行时间低于 8 h, 土壤温度的恢复率自然较高, 但同时必然会造成太阳能集热装置庞大, 使系统的初投资增加。这对整个系统的经济性是不利的。因此在确定最佳的土壤源热泵单独运行的时间分配比例后, 便可以确定太阳能保证率及集热装置的容量。所以通过以上的模拟分析, 从系统能量的利用效率及经济性的角度考虑, 太阳能保证率选择为 $f = 50\% \sim 70\%$ 为宜。

4 结论

本文通过控制容积法, 模拟了系统在 30 个运行周期内, 在不同的运停比下, 土壤温度场的分布情况及土壤温度场的恢复率。由此得出结论: 在太阳能—土壤源热泵系统中, 土壤源热泵在以一天为周期的运行时间分配比例为 33% ~ 50% 左右为宜, 并以此反推, 推算出哈尔滨地区最佳的太阳能保证率为 50% ~ 70% 左右, 以此作为确定太阳能集热器集热面积的依据。

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(渠 源 编辑)

speed-measuring pump with a floating type seal construction and reliable conclusions obtained. All the above has provided a theoretical and experimental basis for the improvement of an overspeed protection device for a main steam turbine. **Key words:** main steam turbine over-speed protection, speed-measuring pump, seal, test

寒区太阳能—土壤源热泵系统太阳能保证率的确定 = **Determination of the Solar Energy Assurance Factor of a Solar Energy - Ground Soil-source Heat Pump System in Frigid Regions** [刊, 汉] / YU Yan-shun, LIAN Le-ming (Department of Architectural Thermal Energy Engineering, Harbin Institute of Technology, Harbin, China, Post Code: 150090) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(4): 393 ~ 395

In frigid regions the use of solar energy and ground soil-source heat as a low-level heat source of heat pumps is of great significance from the perspective of environmental protection and the development and utilization of new and renewable energy sources. The authors have for the first time put forward the concept of ground-soil temperature restoration rate of the ground soil-source heat pump system under different ratios of operation/shutdown. With the above-cited restoration rate serving as an index the restoration degree of ground soil temperature field is evaluated of the ground soil-source heat pump under various operation/shutdown ratios. On this basis, the optimum operation/shutdown ratio of the said heat pump and solar energy assurance factor were identified, and thereby the capacity of solar energy heat-collection device was determined. **Key words:** frigid region, solar energy - ground soil-source heat pump, solar energy assurance factor, ground soil temperature restoration rate

大型火电站高压加热器可靠性增长模型验证及预测 = **Verification of a Reliability Enhancement Model and its Prediction for High-pressure Heaters at a Large-sized Thermal Power Plant** [刊, 汉] / CAO Xian-chang, ZHONG Zhi-qiang, JIANG An-zhong (Department of Energy Sources, Shanghai Jiaotong University, Shanghai, China, Post Code: 200240), SHI Jin-yuan (Shanghai Power Equipment Design and Research Institute, Shanghai, China, Post Code: 200240) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(4). // Journal of Engineering for Thermal Energy & Power. — 2002, 17(4): 396 ~ 398

A reliability enhancement model is proposed for high-pressure heaters at a large-sized thermal power plant along with a detailed discussion of the model parameter estimation and fitting inspection. According to the statistics data of Electric Power Reliability Management Center the model fully conforms with the reliability-enhancement change tendency of high-pressure heaters under statistical evaluation. The results of analysis also indicate that the reliability of the heaters has been gradually enhanced through the introduction of such measures as eradication of defects in product design and fabrication, enhancement of personnel quality, improvement of operational level, production facilities and operating conditions. **Key words:** high-pressure heaters, reliability, growth model, prediction

移动—流化型组合阀工作特性的研究 = **A Study Concerning the Test of the Operating Characteristics of a Shifting-fluidized type of Combination Valve and Its Model** [刊, 汉] / ZHANG Jing-yuan (Power Engineering Department, Taiyuan Electric Power High Technical School, Taiyuan, China, Post Code: 030013), YE Gui-zhen (Guangdong Provincial Electric Power Test Research Institute, Guangzhou, China, Post Code: 510006) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(4): 399 ~ 401, 413

A shifting-fluidized type of combination valve is a kind of novel non-mechanical valve for transporting solid-particle raw materials. The key technique affecting its operating characteristics involves the provision of a sort of slackening air at the bottom of the shifting bed. The present paper mainly focuses on an experimental investigation regarding the provision of the slackening air device and a mathematical model for calculating raw material flow rate. **Key words:** valve, slackening air, non-Newton fluid

获取知识的一种新方法——粗糙集(Rough Set) = **“Rough Set” as a New Method of Machine Self-learning** [刊, 汉] / DONG Cai-feng, WANG Tian-yu (Aerospace Institute under the Harbin Institute of Technology, Harbin, China, Post Code: 150001) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(4): 402 ~ 404

A difficult issue encountered during the diagnosis of rotating machine failures consists in the acquisition of diagnostic