设备及管道绝热设计允许最大散热损失量的研究

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摘要 《设备及管道绝热技术通则》(GB/T 4272)是保障我国工业设备及管道工况运行和节能降耗的重要基础性国家标准，已发布实施40余年，现行版本为2008版，被国内60余项国家标准规范、行业标准所引用。标准中给出的常年和季节工况运行最大允许散热损失量是石化、电力、冶金等行业进行设备及管道绝热设计时的重要基础参数，也是绝热工程施工、验收及绝热效果测试评价的重要依据。该标准被列入2022年国家双碳标准专项计划，已于2024年1月顺利通过审查会。本文详细介绍了GB/T 4272修订工作中对最大散热损失量的研究和分析，阐述了最大允许散热损失量的修订方案的确定依据和过程。

关键词 设备及管道；绝热工程；散热损失量
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为配合双碳战略顺利实现，国家标准委等11部门发布《碳达峰碳中和标准体系建设指南》(以下简称《指南》)。《指南》要求到2025年，制修订不少于1000项国家标准和行业标准(包括外文版本)，并显著提升与国际标准的一致性程度。在此背景下，《设备及管道绝热技术通则》(GB/T 4272)被列入了“2022碳达峰碳中和国家标准专项计划”，2024年初完成报批。该标准的修订，通过进一步降低工业能耗来达到减少碳排放量的目标。

近几年，我国绝热材料发展迅速，质量不断提升，导热系数小、耐温性好的绝热材料的出现，为我国绝热节能水平的提升奠定了基础。允许最大散热损失量作为绝热设计和验收中最重要的指标值，是本次GB/T 4272修订工作的重点。本文介绍了修订中对国内外标准、规范中最大散热损失量要求的对比，分析了散热损失量的影响因素，探讨了采用经济厚度法进行绝热设计的可行性。通过上述分析和研究，结合国内实际工程情况，确定了允许最大散热损失量的修订方案。

1 国内外允许最大散热损失量要求比对

GB/T 4272中的允许最大散热损失量于1984年版首次提出，也是国内首个提出该指标值的标准，2008版进行了修订。国内其他设计标准、规范和电力、石油化工等行业标准的最大散热损失量要求均来自或直接引用了GB/T 4272。

据不完全统计，国外标准中明确给出了允许最大散热损失量要求的有俄罗斯标准СП 61.13330.2012(СНиП 41-03-2003)《设备和管道的隔热设计》[1]、日本标准JIS A9501：2019《保温保冷工程施工规范》[2]和英国标准BS 5422：2009《工作温度范围为-40℃～700℃的管道、储罐、容器、管道系统和设备用绝热材料的规定方法》[3]。其中，JIS A9501中给出四种绝热材料不同介质温度、不同管径及平面的常年运行和季节运行工况下的经济厚度值和允许最大散热损失量。СП 61.13330.2012中，按不同使用场合给出了11个工况条件下的允许最大散热损失量，还给出了各种条件下的修正系数。BS 5422仅包括273mm以内管径的指标值，与我国对比性不强。

为了便于对比，以平面计算为例，按相同条件计算了介质温度为100℃～600℃的允许最大散热损失量和绝热层外表面温度控制水平，对比如图

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1、图2所示。可以看出，我国的控制水平均较国外宽松许多。

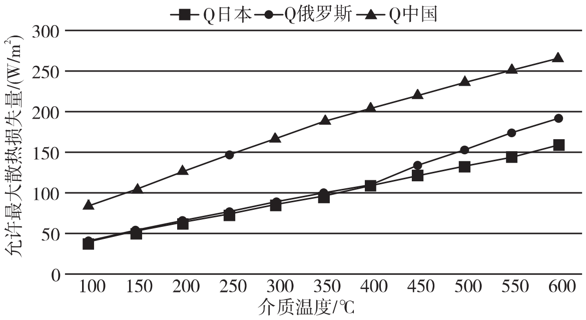

图1 国内外允许最大散热损失量控制水平对比

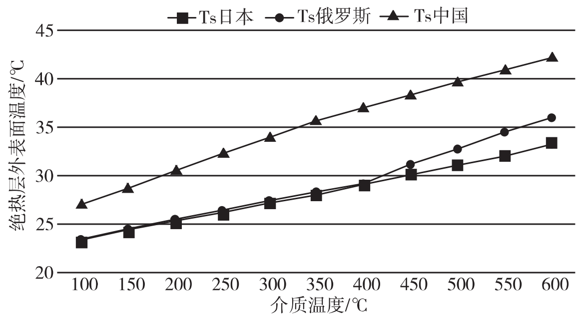

图2 国内外绝热层外表面温度要求对比

2 散热损失量的影响因素研究

2.1 绝热层厚度

绝热层厚度是散热损失量最直接的影响因素。厚度越大，散热损失量越小，绝热节能效果越好。但在实际工程中，绝热层厚度要考虑工程用地(如管廊)大小、材料用量、施工费用等因素影响，在节能带来的经济收益与总投资的平衡中选取综合经济性最佳的厚度。

2.2 换热系数

换热系数是绝热层厚度计算时的一个重要参数，其受项目所在地气候条件影响较大。假设使用岩棉板作为绝热材料，从调研的27个项目中，选取不同换热系数计算绝热层厚度和散热损失量，发现换热系数的影响随介质温度的升高而降低，但总体影响较小，变化量不超过5%。

2.3 环境温度和绝热层外表面温度

我国各地气候条件不同，环境温度差异较大，根据我国年平均温度的统计数据[4]，最冷为-1℃，最热为24.1℃。假设其他设计条件相同，分别计算了上述两个环境温度下的绝热层厚度和散热损失量，如图3、图4所示。对比可以发现，环境温度对二者的影响主要集中在中低温区，整体而言，影响较小。

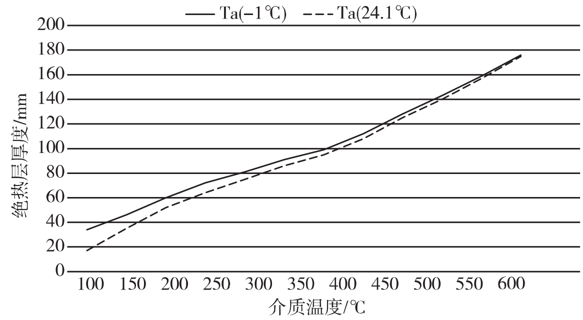

图3 不同环境温度下绝热层厚度的对比

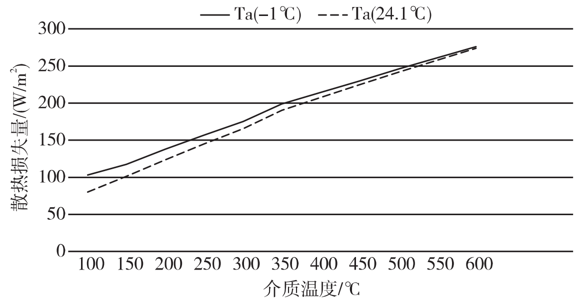

图4 不同环境温度下散热损失量的对比

绝热层外表面温度也可以体现绝热效果，当绝热层外表面温度与环境温度接近时，散热量损失较小。国内外均提出了外表面温度要求，随着介质温度的升高，允许最大散热损失量要求与表面温度控制要求逐渐接近，但允许最大散热损失量要求整体严于表面温度控制要求，国内要求的对比如图5所示。在俄罗斯标准СП 61.13330.2012中，虽然分段提出了表面温度控制要求，但也可以发现上述趋势，如图6所示。因此，以允许最大散热损失量作为控制绝热层厚度设计的最低要求是更严格的。

当散热损失量相同时，绝热层外表面温度将随着环境温度的升高而升高。但不同环境温度下，绝热层外表面温度与环境温度的差值基本不变，如图7所示。

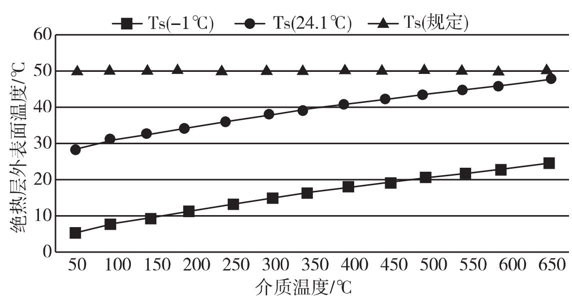

图5 计算出的绝热层外表面温度和表面温度控制要求的对比图(中国)

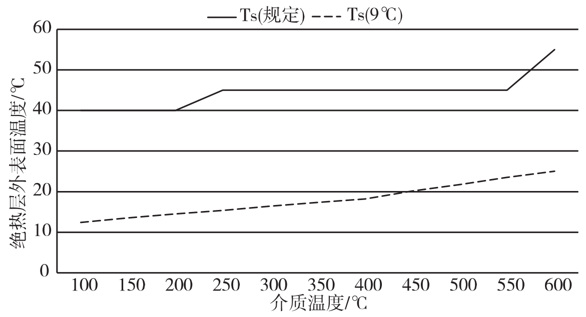

图6 计算出的绝热层外表面温度和表面温度控制要求的对比图（俄罗斯）

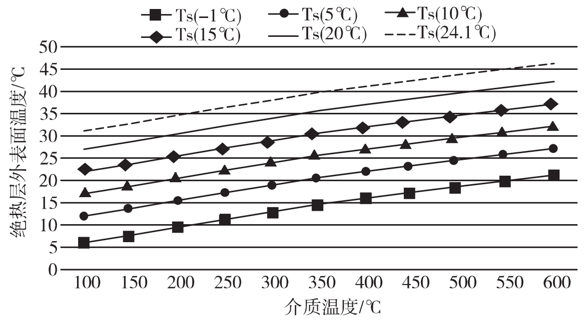

图7 相同散热损失量下绝热结构外表面温度与环境温度的关系

故根据绝热层外表面温度计算公式，当换热系数一致时，允许最大散热损失量与绝热层外表面温度及环境温度的差值同增同减。

2.4 其他因素

俄罗斯标准分别提出了室内、室外的允许最大散热损失量要求，如图8所示。在450℃以下时，室外与室内控制水平相差不大，在450℃以上时，室外的最大散热损失量要求较室内宽松。因我国未区分室内、室外两种情况，故在高温段可以参考俄罗斯控制水平稍微放宽。

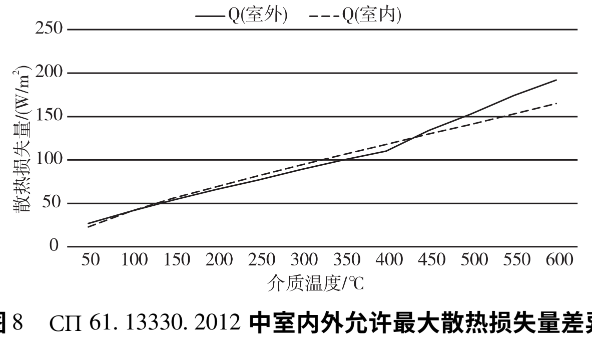

图8 CП 61.13330.2012 中室内外允许最大散热损失量差异

国外标准中，还给出了不同管径下的允许最大散热损失量。本次研究分别计算了相同设计条件下DN1000、DN1400、DN1600三种管径的绝热厚度，并与平面厚度进行比较。发现按平面计算方法得出的保温厚度要大于按圆筒计算方法得出的保温厚度，温度越高、差异加大。故GB/T 4272中仅给出平面的允许最大散热损失量是可行的、安全的。

3 国内外工程项目对比

3.1 国内外项目控制水平对比

为了与标准更好地进行对比，委托石油、化工、电力等16家国内主要设计单位，选择我国不同省市近五年的项目，按项目设计厚度推算各温度段的允许最大散热损失量，对比情况见图9。目前项目的实际控制水平均严于标准指标值。

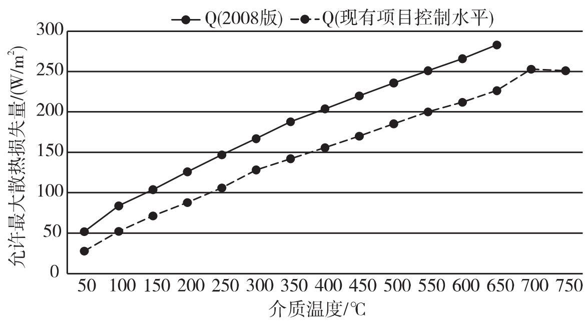

图9 目前项目实际控制水平与标准指标值的对比

对沙特阿拉伯、越南、泰国等8个国家的26个项目进行绝热设计资料的分析研究，由于大部分项目资料直接给出该项目的最小绝热厚度使用表，虽然有允许最大散热损失量要求，但由于缺乏环境等条件无法进行换算与对比，只能作为参考。

3.2 国内项目运行情况

对国内18个省市的67个不同类型的绝热项目进行绝热效果测试，发现其中使用年限超过5年的项目的绝热结构破坏较多、破坏程度较大，实测散热损失量均超过标准要求。

4 现阶段采用经济厚度法进行绝热设计的可行性分析

由于我国绝热材料种类、品牌、地区等因素对材料价格的影响较大，施工价格的波动也较大。且现行2008版标准中，允许最大散热损失量指标值较宽松，较薄绝热厚度即可满足标准要求，使得工程中对绝热部分的投入减少，引发低价竞标的现象，致使保温结构造价难以统一计算口径。我国能源价格也“因省而异”，电、煤、天然气、蒸汽等能源的价格也相差较大。例如，电价与实际用电量有关，且与各地不同的补贴或优惠政策有关。在工程中，热价还随行业的不同而不同。若涉及能源的再利用，则导致核算出的热价偏低。故标准无法给

出一个统一的、行业认可的计算口径，经济厚度法缺失必要的计算条件。

5　允许最大散热损失量的修订方案研究

综上所述，由于日本、俄罗斯目前热损量的控制水平较我国严格很多，为了调整后的指标值既能实现节能降耗的目标，又具有经济性和可行性，经对比日本、俄罗斯目前的控制水平，结合我国项目实际控制情况，反复调整后确定了常年运行工况的允许最大散热损失值修订方案见表1。因国内项目的介质温度多处于中低温区范围，修订方案对中低温区的允许最大散热损失量要求严于高温区，以提高节能水平。

表1　常年运行工况的允许最大散热损失值修订方案

设备、管道及其附件外表面温度/K(℃)	允许最大散热损失值(W/m²)
323(50)	39
373(100)	56
423(150)	71
473(200)	86
523(250)	101
573(300)	116
623(350)	131
673(400)	145
723(450)	160
773(500)	174
823(550)	190
873(600)	209
923(650)	229
973(700)	249
1023(750)	268
1073(800)	286
1123(850)	303

季节运行工况允许最大散热损失值，仍按2008版季节与常年运行的指标值的比例进行调整，见表2。

表2　季节运行工况允许最大散热损失值

设备、管道及其附件外表面温度/K(℃)	允许最大散热损失值(W/m²)
323(50)	78
373(100)	98
423(150)	125
473(200)	151
523(250)	173
573(300)	189

修订后的常年运行工况下的允许最大散热损失量与日、俄和目前项目控制水平的对比见图10。

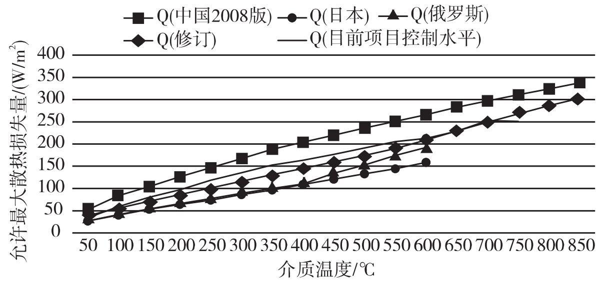

图10　常年运行工况下允许最大散热损失量对比

6　结语

本文详细阐述了GB/T 4272修订中，围绕允许最大散热损失量展开的各项调研及分析研究。通过分析研究，在遵循“经济厚度”的原则下，在保障修订后绝热厚度变化量合理、经济、可行的前提下，按照逐步提升向国际先进水平靠拢与分段控制满足国内实际情况的思路，提出允许最大散热损失量的修订方案。

允许最大散热损失量是GB/T 4272的核心部分，也是最为重要的内容，对我国设备及管道绝热工程的节能降耗有重要的作用。在我国当前的碳排放中，工业占比约70%，在工业碳排放中，约50%是由高温热能损耗造成的。GB/T 4272的修订贯彻综合考虑经济与节能双目标的原则，最终确定的修订方案中的允许最大散热损失量的提升幅度可能接近25%，这将使得我国设备和管道每平方米节能约25%，进而将间接减少源头能源消耗，为碳减排作出贡献。

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ABSTRACTS

Research on Waste Liquid Recovery Process of Hydrogenation Unit of 2-PH Plant

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The production process of hydroformylation of butene to 2-PH (2-propylheptanol) includes a two-step saturated hydrofining process, in which a large amount of continuous waste liquid is discharged from the front and rear distillation towers. In this paper, the feasibility of reusing the waste liquid discharged from the hydrofining unit of 2-PH plant by adding a vacuum distillation system is studied in order to recover most of the effective components in the waste liquid and increase the 2-PH yield. The results show that over 90% of 2-PH in the waste liquid can be recovered through vacuum distillation, and the recovered liquid can be pressurized and returned to the original hydrofining unit for further hydrogenation or separate hydrogenation to obtain qualified products. At the same time, simulation analysis is conducted based on Aspen Plus software, and investment cost estimation and preliminary economic calculation are completed, which can provide reference for the treatment of similar waste liquids in domestic 2-PH plants.

Key words 2-PH; waste liquid; vacuum distillation; simulation analysis

Application of RCO in Treatment of Regenerated Waste Gas from Natural Gas Deacidification Unit

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VOCs can cause an increase in the concentration of ozone and PM2. 5 in the atmosphere, and national and local standards have put forward requirements for the emission concentration and removal efficiency of VOCs. The deacidification unit of a certain oil and gas treatment plant adopts an activated MDEA one-stage absorption regeneration process, and the content of VOCs in the regenerated waste gas exceeds local environmental requirements, which makes it impossible to discharge directly. The unit applies RCO process technology to reduce the VOCs content in the regenerated waste gas to below 80mg/Nm3, so as to meet the local requirements for direct discharge to atmosphere. The RCO method is suitable for the treatment of low concentration VOCs, with the advantages of low NOx pollutant generation, small equipment volume and high VOCs treatment efficiency. However, in the design, it is necessary to fully consider production fluctuations and the accuracy of component concentrations to ensure that the RCO facilities after put into production can adapt to actual production needs.

Key words natural gas deacidification; VOCs; RCO

Study on the Treatment of Scale Formation of Polysilicon High-salt Wastewater

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Aiming at the problem of serious scaling of heat exchanger in polysilicon high-salt wastewater evaporation system, the composition of scaling was analyzed. The results showed that the main component of scaling was calcium sulfate and a small part was calcium silicate. Process analysis showed that sulfate mainly came from the reverse osmosis concentrated water of the water reuse device, and calcium silicate came from the silica produced by the acid gas washing. The main reason was that the liquid flow rate in the evaporator heating system pipe was too slow and the evaporator did not set up automatic sewage discharge. Based on this, the following means were adopted in this study for process optimization and equipment optimization: the reverse osmosis effluent was added with the addition of hard equipment to separate and remove sulfate, the acid water was added with flocculant and the mechanical filtration was strengthened to remove silica, and the sulfate and silica in the incoming water were reduced to 100mg/L and 50mg/L, which would not cause scaling of the heater; the flow rate in the heater tube was increased from 1. 5-1. 7m/s to 2. 5m/s, and the evaporator was added with automatic sewage discharge equipment. Starting from the water source and the improvement and optimization of the equipment, the scaling cycle of the heater was effectively prolonged, and the system could run smoothly for a long period.

Key words high-salt wastewater; scale formation; sulfate radical; silicon dioxide

Research on the Maximum Heat Dissipation Allowance in Insulation Design for Equipment and Pipes

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GB/T 4272 " General Principles for Thermal Insulation Technique of Equipment and Pipes" is a crucial foundational national standard for ensuring the operation and energy conservation of industrial equipment and pipeline conditions in China. Having been implemented for over 40 years, the current version dates back to 2008 and has been referenced by more than 60 domestic national standards and industry norms. The maximum allowable heat dissipation under normal and seasonal operating conditions, as specified in the standard, serves as a significant parameter for insulation design in industries such as petrochemicals, power, and metallurgy. It also plays a vital role in the construction, acceptance, and insulation effectiveness testing and evaluation of insulation projects. This standard has been included in the 2022 National Dual Carbon Standards Special Plan and successfully passed the review meeting in January 2024. This paper provides a detailed presentation of the research and analysis conducted during the revision of GB/T 4272, focusing on the determination basis and process for the revision of the maximum allowable heat dissipation.

Key words equipment and pipes; insulation engineering; heat loss

Structural Analysis and Design of Blind Holes in Thick Walled Containers

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This article discusses insufficiency of the radiation intensity of the fourth type of radiation level meter after the enlargement of the coal powder feeding tank, under the background that equipment gradually becomes larger due to pulverized coal gasification. By analyzing the reasons for this, the blind hole structure design is carried out. Then, using Ansys 15. 0 analysis software to establish a model calculation, a detailed comparison of the local stress of the cylinder body under different parameters of the blind hole (aperture, bottom thickness, and reinforcement section or not) is conducted to explore the patterns and find the best combination of blind hole parameters (hole diameter φ30mm, depth 50mm, retaining reinforced pipe). Also conduct stress analysis and path assessment to fully meet the stress requirements. By utilizing the blind hole structure, the problems of material level meters in large-scale equipment can be solved, saving equipment costs. Exploring a method for local thinning of large pressure bearing thick walled equipment.

Key words blind hole; stress analysis; material level meters; pulverized coal gasification

Dynamic Studies of the Pressure-swing Distillation for Separating Acetonitrile-water Azeotrope System

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Based on the steady-state process of the pressure-swing distillation for separating the acetonitrile-water azeotrope, a dynamic model of pressure swing distillation was established, and its different dynamic schemes were explored. The results showed that whether the control structure of the proportional control module of both the return flow and the distillate flow, or the control structure of return flow and the input flow, the product purity appeared divergent oscillation. The stability time of the temperature control structure is shorter than that of the composition-temperature control structure, but the water purity can only be maintained around 99. 88wt%. The proportional control module of the reboiler heat duty of atmospheric column and feed flow can adjust the steam flowrate of atmospheric column in time. The composition controller can monitor the product purity online. The composition-temperature control structure has stronger anti-disturbance ability.

Key words pressure-swing distillation; acetonitrile-water; dynamic characteristics

Design and Simulation Analysis of W1 Anti-vibration Clamp in HG/T21629

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The W1 disc spring anti-vibration clamp in HG/T21629 is widely used for supporting pipelines with vibration risks. In the actual static stress analysis, designers generally model such supports in CAESARII as a combination of Y and guided restraints without gaps. This combination only considers the friction of pipeline and medium weight, ignoring the influence of preload of disc spring, which will have a significant impact on the calculation results. This article mainly focuses on this issue and discusses how to accurately simulate the W1 type disc spring anti-vibration clamp using the translational double acting bilinear restraints in CAESARII. It is recommended to select preload according to dynamic loads, the applicable range of disc spring, and the friction coefficient. The design specification should include requirements for installation to ensure the accuracy of preload. In the example simulation, two methods are used to calculate the preload friction force and no preload friction force. By comparing their load and displacement, it is recommended to use the W1 type disc spring anti-vibration clamp. It should be noted that the axial friction force generated by thermal expansion of the pipeline on the support should be considered as the structural design load.

Key words anti-vibration; clamp; preload friction