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Comparative environmental assessment of methanol production technologies: A cradle-to-gate life cycle analysis

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ABSTRACT

The surge in methanol demand as a fuel source, coupled with global resource competition, necessitates innovative routes for bulk chemical production, including methanol. China, a prominent methanol producer and consumer, drives industry expansion, raising substantial environmental concerns. This article compares the state-of-the-art "liquid sunlight" methanol production technology with traditional pathways through a cradle-to-gate life cycle assessment. The research analyzed ten environmental impact categories and two endpoint categories. It revealed that the coal gasification to methanol has the most severe comprehensive environmental impact, which is 2.0–3.6 times that of the other four routes. For these five technological routes, 73% to 81% of the impact is on ecosystem damage, followed by 10% to 12% on human health damage. This research find that adopting 100% clean energy electricity can reduces of 79.6%, 64.4%, 81.4%, and 81.0% in cumulative impacts for coal gasification/coal coking/natural gas/biomass to methanol by sensitivity analysis and electricity optimization. In the CO_2 capture route, the potential reduction achieved 54.9% by electricity optimization, while the impact can be lowered by 85.2% when optimizing both steam and electricity. To ensure competitiveness, CO_2 capture to methanol route must be combined with clean electricity resources. In summary, modifying technology or optimizing clean electric power can advance the methanol industry towards sustainable goals.

1. Introduction

In the 1950s, China's methanol industry emerged, undergoing accelerated technological upgrading and transformation to become a major producer. Methanol, known as "clean coal," "cheap oil," "mobile electricity," and "liquid hydrogen," finds extensive application across industries, from chemicals to energy[1]. G.A. Olah's[2] proposition of the "Methanol economy" anticipates its heightened prominence in the coming years, potentially ushering in a new fuel era. Currently, global methanol demand has doubled in the past decade, reaching 107 million tons[3]. With a 99.47 million-ton production capacity in 2022—an 8.84% increase from the previous year—China leads the world methanol industry in terms of new production capacity. In the same year, China's methanol production reached 8.306 million tons, marking a 6.27% year-on-year rise[4]. Methanol demand is still rising, propelled by consistent domestic economic growth and quicker developments in the chemical, electronics, and automotive industries.[5]. Data indicates a notable surge in methanol consumption in China, reaching 7.808 million tons in apparent consumption in 2021, a 5.96% increase from the previous year [6]. This trend intensified in 2022, with apparent methanol consumption hitting 90 million tons, reflecting a 15.26% year-on-year rise[7] Methanol, a vital chemical raw material, primarily serves downstream industries like olefins and acetic acid[3]. In 2021, methanol to olefins accounted for 50.59% of demand, followed by methanol fuel at 15.66% [8]. Diverse technologies presently produce methanol from fossil fuels such as natural gas, coal, crude oil, and biomass[9]. In China, the resource distribution - "more coal, less oil, and less gas"[4,10] has historically favored the coal-to-olefins route (58% in 2017), with coal-to-gas (17%) and natural gas-to-methanol (14%) following suit[11]. Methanol production, characterized by high energy intensity, often

Abbreviations: CGTM, Coal Gasification to Methanol; COTM, Coal Coking to Methanol; BOTM, Biomass to Methanol; NGTM, Natural Gas to Methanol; CCTM, CO_2 Capture to Methanol; ADP, abiotic depletion potential; AFFDP, fossil fuel depletion potential; ODP, ozone depletion potential; HTP, human toxicity potential; PCOP, photochemical oxidation potential; TETP, terrestrial ecotoxicity potential; EP, eutrophication potential.; AP, acidification potential; MAETP, marine aquatic ecotoxicity potential; FAETP, freshwater aquatic ecotoxicity potential; GWP, global warming potential 100 years; LCA, Life Cycle Assessment; LCI, Life Cycle Inventory.

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Abstract: The surge in methanol demand as a fuel source, coupled with global resource competition, necessitates innovative routes for bulk chemical production, including methanol. China, a prominent methanol producer and consumer, drives industry expansion, raising substantial environmental concerns. This article compares the stateof-the-art "liquid sunlight" methanol production technology with traditional pathways through a cradle-to-gate life cycle assessment. The research analyzed ten environmental impact categories and two endpoint categories. It revealed that the coal gasification to methanol has the most severe comprehensive environmental impact, which is 2.0-3.6 times that of the other four routes. For these five technological routes, 73% to 81% of the impact is on ecosystem damage, followed by 10% to 12% on human health damage. This research find that adopting 100% clean energy electricity can reduces of 79.6%, 64.4%, 81.4%, and 81.0% in cumulative impacts for coal gasification/coal coking/natural gas/biomass to methanol by sensitivity analysis and electricity optimization. In the CO2 capture route, the potential reduction achieved 54.9% by electricity optimization, while the impact can be lowered by 85.2% when optimizing both steam and electricity. To ensure competitiveness, CO2 capture to methanol route must be combined with clean electricity resources. In summary, modifying technology or optimizing clean electric power can advance the methanol industry towards sustainable goals.

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第 2 篇 SCI 2 区 top (共 6 篇)

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Methanol-based fuel boiler: Design, process, emission, energy consumption, and techno-economic analysis

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ABSTRACT

Methanol-based alternative energy sources are critical to maintaining energy security, reducing the need for oil imports, and safeguarding the environment in China. However, the use of methanol-based fuels in the field of thermal combustion has not been thoroughly investigated. Therefore, an evaluation of the costs, emissions, and usage of methanol boilers is necessary. The study finds that methanol heaters and air source heat pumps have comparable annual cost values. Methanol heating furnaces emit the least amount of NOx and produce no SO_2. After the refurbishment, the boiler's emissions and energy consumption have significantly decreased upon conversion of coal-fired steam boilers to methanol-based fuel hot water boilers. Nevertheless, the economy has also somewhat declined. Additionally, 5499 tce (standard coal) less energy will be used during the heating season, and 1.8 million CNY less will be spent on dust removal and desulfurization. Unfortunately, the economic benefits of methanol are only apparent when the cost of methanol fuel is less than 1900 CNY/t. The research presented in this paper provides an essential technological foundation for the development of methanol-fueled fuel burners and for the renovation of small and medium-sized coal-fired boilers.

1. Introduction

1.1. Background

The two biggest issues facing China's energy sector currently are climate change and environmental pollution, with one of the primary causes of environmental pollution being coal-fired boiler heating [1,2]. China started requiring coal-fired boilers with a capacity of less than 35 t/h to be phased out and shut down in 2015 [3]. The coal-fired boilers with a capacity of more than 35 t/h will be upgraded to meet the national and provincial energy efficiency standards and pollutant emission requirements [4].

In China, 750 million tons of coal were used annually for coal-fired power generation, industrial boilers, and other kilns in 2018. Of this, 2.6 tons of CO_2, 8.5 kg of SO_2, and 7.4 kg of NOx were produced for every ton of coal burned in industrial boilers [5]. In addition to wasting energy, this is now the primary contributor to air pollution and the greenhouse impact. Fig. 1 shows more fuel kinds. Namely, coal, crude oil, and natural gas emit more CO_2 and major pollutants (NO_x, SO_x, PM), whereas liquid sunlight fuels, such as methanol or hydrogen, emit less, with methanol emitting only 45 CO_2, 34 NOx, and none other pollutants. Methanol is undoubtedly simple to store and move over the globe. Methanol-based fuel has a promising future as a sustainable substitute energy source for industrial boilers that burn coal [6–8].

In 1990, Nobel laureate George A. Olah proposed the concept of methanol economy, replacing fossil resources with renewable methanol [9,10]. Furthermore, methanol-based gasoline has been around since the early 1970s. Methanol-based gasoline has entered

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Abstract: Methanol -based alternative energy sources are critical to maintaining energy security, reducing the need for oil imports, and safeguarding the environment in China. However, the use of methanol -based fuels in the field of thermal combustion has not been thoroughly investigated. Therefore, an evaluation of the costs, emissions, and usage of methanol boilers is necessary. The study finds that methanol heaters and air source heat pumps have comparable annual cost values. Methanol heating furnaces emit the least amount of NOx and produce no SO2. After the refurbishment, the boiler's emissions and energy consumption have significantly decreased upon conversion of coal-fired steam boilers to methanol -based fuel hot water boilers. Nevertheless, the economy has also somewhat declined. Additionally, 5499 tce (standard coal) less energy will be used during the heating season, and 1.8 million CNY less will be spent on dust removal and desulfurization. Unfortunately, the economic benefits of methanol are only apparent when the cost of methanol fuel is less than 1900 CNY/t. The research presented in this paper provides an essential technological foundation for the development of methanol -fueled fuel burners and for the renovation of small and medium-sized coal-fired boilers.

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Numerical analysis of the effect of swirl angle and fuel equivalence ratio on the methanol combustion characteristics in a swirl burner

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ABSTRACT

The outstanding advantages of methanol such as low pollutant emissions of nitrogen oxides (NOx) and carbon monoxide (CO) make it a promising clean-burning fuel. Despite, the latent heat of vaporization of methanol is 3.70 times that of gasoline, the low heating value of methanol is one of the most critical barriers to its effective utilization in industrial applications. Thus, the methanol burner needs to be effectively designed to determine the desired combustion characteristics and the optimal design of this type of clean burner. Hence, this study presents a computational fluid dynamic analysis on the combustion characteristics of a methanol swirling burner with two layers of swirling blades. A particular focus of this study is emphasized on the effects of different swirling blade angles (45°+45°, 60°+60°, and 45°+60°) and various equivalence ratios (0.5, 0.75, 1.0, 1.25, and 1.75) on the combustion characteristics and pollutants formation of the swirl burner. The velocity and temperature profiles, combustion characteristics, and concentrations of major combustion species are analyzed in detail. The results show that the blade angle arrangement of 45°+ 60° exhibits the best combustion characteristics in comparison with the other blade angle arrangements. It is also found that the BA_3 with an equivalent ratio in the range of 1.0–1.25 shows the best performance in the emissions of NOx and CO compared with other combinations of swirling blade arrangements and equivalence ratios. More specifically, the optimal equivalence ratio ranges from 1.0 to 1.25 at which the NOx and CO emissions are measured to be 27.0 and 11.0 mg/m^3, respectively.

1. Introduction

The increase in the usage of coal, as a source of energy, contributed to 33% of Particulate Matter (PM), 27% of SOx emissions, and 9% NOx emissions in China, as shown in Fig. 1. Therefore, China's air pollution control action plan issued by the Chinese State Council urged to reduce the use of coal boilers and search for new energy boilers, environmentally friendly sources, and energy-efficient (Lu et al., 2020; Geng et al., 2019). At present, natural gas is still expensive and the needed infrastructure is not well established in China (Lin et al., 2010; Chaudry et al., 2014). At present, rapid progress in sustainable eco-friendly technologies is the main trait of modern clean industrial applications (Zayed et al., 2020, 2019; Zhao et al., 2021). Methanol has been regarded as an effective renewable gaseous fuel because it is widely available as a product of coal gasification and can be easily transported at ambient temperature and pressure. Methanol has been widely used in the power field, such as internal combustion engines, marine engines, and gas turbines, etc (Verhelst et al., 2019a; Dierickx et al., 2021). Moreover, methanol has been used as an additive in gasoline to reduce soot and particulates for decades (Wei et al., 2009; Esarte et al., 2012). Recently, methanol is also used as a clean alternative fuel in industrial boilers for manufacturing, food production, agriculture warming, pharmaceutical production process, and medical sanitation (Ran et al., 2014; Dalena et al., 2018; Olah, 2013). The usage of methanol as fuel has reached 193 million barrels in 2016, a more than 5-fold increase since 2006. Methanol consumption is expected to continuously increase at an annual growth rate exceeding 12%, reaching 713 million barrels (97million metric tons) in 2022 (Shih et al., 2018). Moreover, the methanol boilers show superior emission benefits of a 75% reduction of total emissions in terms of PM, and SOx, and NOx

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Abstract: The outstanding advantages of methanol such as low pollutant emissions of nitrogen oxides (NOx) and carbon monoxide (CO) make it a promising clean-burning fuel. Despite, the latent heat of vaporization of methanol is 3.70 times that of gasoline, the low heating value of methanol is one of the most critical barriers to its effective utilization in industrial applications. Thus, the methanol burner needs to be effectively designed to determine the desired combustion characteristics and the optimal design of this type of clean burner. Hence, this study presents a computational fluid dynamic analysis on the combustion character-istics of a methanol swirling burner with two layers of swirling blades. A particular focus of this study is emphasized on the effects of different swirling blade angles (45 degrees+45 degrees, 60 degrees+60 degrees, and 45 degrees+60 degrees) and various equivalence ratios (0.5, 0.75, 1.0, 1.25, and 1.75) on the combustion characteristics and pollutants formation of the swirl burner. The velocity and temperature profiles, combustion characteristics, and concentrations of major combustion species are analyzed in detail. The results show that the blade angle arrangement of 45 degrees+ 60 degrees exhibits the best combustion characteristics in comparison with the other blade angle arrange-ments. It is also found that the BA3 with an equivalent ratio in the range of 1.0-1.25 shows the best performance in the emissions of NOx and CO compared with other combinations of swirling blade arrangements and equivalence ratios. More specifically, the optimal equivalence ratio ranges from 1.0 to 1.25 at which the NOx and CO emissions are measured to be 27.0 and 11.0 mg/m(3), respectively .

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Study on optimization characteristics of methanol combustion cooker based on porous media

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ABSTRACT

This research initially presents an internal structure optimization technique through numerical investigation with the intention of addressing the issues of unstable and poorly adjustable combustion flame of porous media methanol furnace. The entire premixed combustion technology and the flue gas waste heat evaporation technology are then combined in a combustion technology that is based on this stove structure. As a result, this resolves substantially the issues with methanol stove tempering, misfire, and uneven temperature. The fully premixed methanol cooker was eventually created and put into wide production. According to the findings, the flow rate was between 0.25 and 0.7 m/s before the cooker structural improvement and around 0.45 m/s after. More crucially, by eliminating the low temperature zone of approximately 300 °C and raising the temperature to about 500 °C, the temperature field at the cooker's exit porous medium was much improved. Additionally, the methanol cooker in the typical diffusion combustion mode was outperformed by the full premixed combustion technology and flue gas waste heat evaporation technology in this trial in terms of complete fuel combustion with no pollutant emissions. The study's findings indicate that the cooker's overall thermal efficiency is 68.2%, which has clear financial benefits.

1. Introduction

Compared with the traditional cooking fuels LPG and natural gas, methanol fuel is favored by the cooking industry because of its green, clean, safe and efficient, convenient transportation and other advantage [1]. At present, methanol stoves are mostly designed and applied independently by enterprises, and diffusion combustion mode is adopted [2]. The flame combustion in this way is stable and easy to control, but it is inevitable that the fuel combustion is insufficient, resulting in the thermal efficiency of less than 50% and the high content of polluting gases in the combustion products [3,4].

At present, domestic enterprises and institutions have conducted extensive research on the technological innovation and application expansion of methanol fuel [5], but there are few studies on it as stove fuel. The combustion of methanol fuel focuses on clean heating, and the burner design is one of the research emphases [6]. In order to solve the problems of high starting temperature, slow speed and low safety factor of methanol fuel burner, Jin et al. [7] optimized the design of 30 kW methanol fuel atmospheric burner. When the air temperature is 293K, the necessary incident temperature of theoretical methanol steam is only 473 K, the combustion efficiency can reach 98%, and the maximum temperature can reach 2300 K, ensuring the rapid and safe start of the burner. Ran et al. [8] proposed a new ejector burner to solve the problem of poor adaptive air distribution capacity of existing methanol burners. The

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Abstract: This research initially presents an internal structure optimization technique through numerical investigation with the intention of addressing the issues of unstable and poorly adjustable combustion flame of porous media methanol furnace. The entire premixed combustion technology and the flue gas waste heat evaporation technology are then combined in a combustion technology that is based on this stove structure. As a result, this resolves substantially the issues with methanol stove tempering, misfire, and uneven temperature. The fully premixed methanol cooker was eventually created and put into wide production. According to the findings, the flow rate was between 0.25 and 0.7 m/s before the cooker structural improvement and around 0.45 m/s after. More crucially, by eliminating the low temperature zone of approximately 300 degrees C and raising the temperature to about 500 degrees C, the temperature field at the cooker's exit porous medium was much improved. Additionally, the methanol cooker in the typical diffusion combustion mode was outperformed by the full premixed combustion technology and flue gas waste heat evaporation technology in this trial in terms of complete fuel combustion with no pollutant emissions. The study's findings indicate that the cooker's overall thermal efficiency is 68.2%, which has clear financial benefits.

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Article

Heat-Transfer Characteristics of Liquid Sodium in a Solar Receiver Tube with a Nonuniform Heat Flux

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Abstract: This paper presents a numerical simulation on the heat transfer of liquid sodium in a solar receiver tube, as the liquid sodium is a promising heat-transfer candidate for the next generation solar-power-tower (SPT) system. A comparison between three mediums—solar salt, Hitec and liquid sodium—is presented under uniform and nonuniform heat-flux configurations. We studied the effects of mass flow rate (Q_m), inlet temperature (T_{in}), and maximum heat flux ($q_{o\max}$), on the average heat-transfer coefficient (h) and the friction coefficient (f) of the three mediums. The results show that the h of liquid sodium is about 2.5 to 5 times than other two molten salts when T_{in} is varying from 550 to 800 K, Q_m is 1.0 kg/s, and $q_{o\max}$ is 0.1 MW/m^2. For maximum heat fluxes from 0.1 to 0.3 MW/m^2, the h of liquid sodium is always an order of magnitude larger than that of Hitec and Solar-Salt (S-S), while maintaining a small friction coefficient.

Keywords: solar-power tower; liquid sodium; solar salt; Hitec; heat flux

1. Introduction

Compared to the parabolic trough, Fresnel and dish collectors, the solar-power-tower (SPT) plant has the remarkable advantages, such as lower electricity cost, large-scale power generation and higher efficient thermodynamic cycles [1–3]. The SPT is equipped with a large number of heliostats on the ground, each with a tracking mechanism that accurately reflects the reflection of sunlight onto the receiver at the top of a tall tower. The concentrating magnification on the receiver can exceed 1000 times. One typical arrangement of the SPT receivers is the external tubular receiver designed for Solar Two project, in which only half of the surface of the tube is exposed to solar irradiation. This may bring about many problems, such as aggravating the plastic deformation of the receiver tube, facilitating degradation of the selective absorptive coating and decreasing the allowable solar heat flux [4,5]. Since the nonuniform solar heat flux tends to cause the temperature inhomogeneity of the heat-transfer fluid

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Abstract: This paper presents a numerical simulation on the heat transfer of liquid sodium in a solar receiver tube, as the liquid sodium is a promising heat-transfer candidate for the next generation solar-power-tower (SPT) system. A comparison between three mediumssolar salt, Hitec and liquid sodium is presented under uniform and nonuniform heat-flux configurations. We studied the effects of mass flow rate (Q(m)), inlet temperature (T-in), and maximum heat flux (q(omax)), on the average heat-transfer coefficient (h) and the friction coefficient (f) of the three mediums. The results show that the h of liquid sodium is about 2.5 to 5 times than other two molten salts when T-in is varying from 550 to 800 K, Q(m) is 1.0 kg/s, and q(omax) is 0.1 MW/m(2). For maximum heat fluxes from 0.1 to 0.3 MW/m(2), the h of liquid sodium is always an order of magnitude larger than that of Hitec and Solar-Salt (S-S), while maintaining a small friction coefficient.

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塔式太阳能集热器HTF温度均化特性研究及评价

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摘 要: 以太阳能发电站中集热器中的传热介质(HTF)为研究对象,并对其进行量化评价。采用数值模拟的方法研究3种介质在集热器内的流动和传热特性,流体介质假定为各向同性的均匀介质,液相处于局部热平衡状态,对集热管的轴向切平面和周向截面的温度分布进行分析和定量评价。结果表明,液态钠作为塔式太阳能集热管的传热介质时管壁及管内的温度分布更均匀,在流动和传热方面有比S-S或HITEC更适合作为传热介质的潜力。

关键词: 塔式太阳能热发电; 太阳能集热管; 传热特性; 液态金属; 熔盐流动传热介质

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0 引 言

塔式太阳能热发电系统(solar power tower,SPT)具有规模大、热循环效率高等优点[1-3],但非均匀的太阳能热通量会导致管内温度分布不均,并且传热管的热应力属性需要更宽的工作温度区间[4]。硝酸盐是常用的流动传热介质(heat transfer fluid,HTF),熔融盐(S-S,60% $NaNO_3$ 和 40% KNO_3,质量分数)和三元熔融盐 HITEC(53% KNO_3 + 40% $NaNO_2$+7% $NaNO_3$,质量分数),这 2 种硝酸盐混合物在温度仅为 873 K 时分解,如果采用液态钠作为传热流体,可提供大于 1 MW/m^2 的入射峰值热流密度通量,研究表明,液态金属对于 SPT 的应用具有很大的吸引力[5-6]。

Amy 等[7]解决了 1300 K 以上液态金属的收集、运输和储存问题;De Angelis 等[8]使用液态金属作为传热流体,效率达 90%;Boerema 等[3]比较了液态钠和 HITEC 作为传热介质的特征,前者可使吸收面积减少 57%,效率提高 1.1%;Pacio 等[9-10]总结了液态金属在太阳能发电厂中作为 HTF 的最新技术;Matsubara 等[11]研究普朗特数在 0.025~5.000 之间的湍流通道内沿翼展的热传递;文献[12-13]着重于对热流密度的非均匀性进行相关的热、机械和水动力分析,揭示了固体壁的热场和热应力情况[14];液态金属的实验研究涉及到复杂且成本高的系统和安全问题,因此数值模拟是一种有效的研究方法[15-16]。

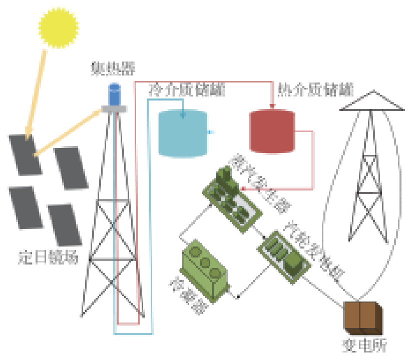
本文对非均匀热流条件下液态钠及传统熔融盐介质的传热特性进行数值计算分析,研究对比 3 种传热介质的传热特性,对其作用于传热管并改善传热性能进行分析和量化评价。

1 数值模型

1.1 物理模型

本文的研究背景是塔式太阳能热发电系统(图 1a),位于塔顶的吸热器是圆柱形且流体在集热管内呈蛇形串联流动,因此本文只研究和评价单根集热管的传热性能,单根吸热管的物理模型如图 1b 所示。

在建立物理模型的基础上研究沿轴向(z)、周向(θ)和径向(r)3 个方向的集热管共轭传热问题,区域热源的热传递包含 3 个正交分量,具体模型见图 2,几何模型的外径 R 为 20 mm,管长为 $100R$,本文研究讨论给定热边界条件下集热管的传热性能并定量评价三者的差异性。



a. 系统结构

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