

# 天然气脱氮工艺综述

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**摘 要** 高含氮天然气不仅热值低、在集输过程中能耗大, 而且不能直接用作某些化工原料和天然气汽车燃料。脱除其中的氮气, 是提高天然气综合利用价值的重要途径。介绍国外 3 种主要的天然气脱氮工艺: 深冷脱氮工艺、溶剂吸收工艺及变压吸附工艺的原理、工艺流程及工艺特点。指出深冷脱氮工艺具有处理量大、氮气脱除率高、技术成熟可靠等优点, 应为我国优先发展的天然气脱氮工艺。

**主题词** 天然气 脱氮 工艺流程 低温分离 溶液吸收 气体吸附

天然气作为优质、干净的燃料和重要的化工原料, 其应用越来越引起人们的重视, 加快天然气工业的发展, 已成为当今世界的趋势<sup>[1]</sup>。国内外很多含油气盆地产出的天然气中含有大量的氮气, 这些氮气含量过高的天然气不仅热值低、在集输过程中能耗大, 而且不能直接用作天然气汽车 (NGV) 燃料和某些化工原料。因此, 天然气脱氮是合理和充分利用天然气的重要条件。现介绍国外主要的 3 种天然气脱氮工艺, 并结合国内具体情况, 探讨如何发展我国天然气脱氮工业。

## 1 深冷脱氮工艺

深冷脱氮工艺是将具有一定压力的天然气经多次节流降温后部分液化或全部液化, 再根据氮气与甲烷的相对挥发度不同, 用精馏的方法脱除氮气。工艺过程包括原料气预处理、深冷脱氮 (CNR) 及产品气 (脱氮天然气) 压缩等部分。其中原料气预处理的目的是将原料气中的  $\text{CO}_2$ 、 $\text{H}_2\text{O}$  等杂质脱除, 以防止在深冷温度下固化或者生成水合物, 造成堵塞事故; 产品气压缩部分是将产品气压缩到管输或要求的压力后送出装置, 两者均属常规工艺, 因此重点介绍 CNR 部分。

### (1) 工艺流程

从原料气性质、脱氮目的及设备费用等因素综

合考虑, 深冷脱氮可分为单塔、双塔和三塔流程。单塔流程简单、一次性投资低, 但分离效率低、操作弹性差, 一般很少采用; 三塔流程仅用于原料气中重烃含量高或氮气含量低的场合, 目前普遍采用的是双塔流程。

典型双塔流程深冷脱氮工艺流程如图 1 所示<sup>[4]</sup>。

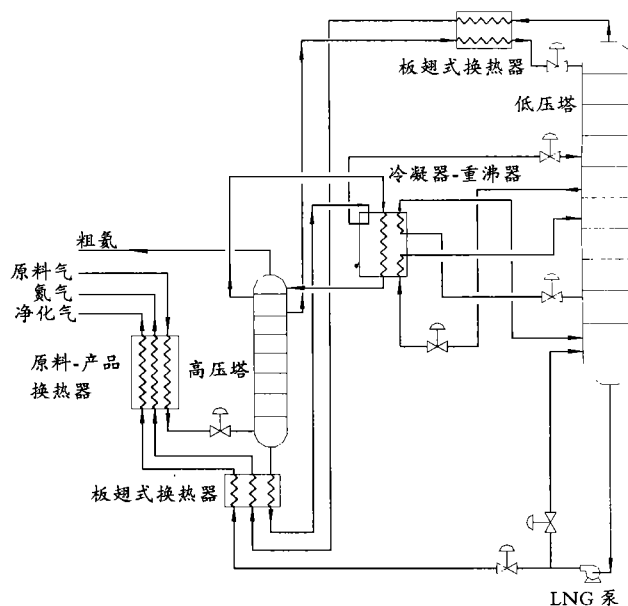


图1 典型双塔流程深冷脱氮工艺流程

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少量的凝析液后进入操作压力为 2.7 MPa 的溶剂吸收塔下部。在塔内,原料气自塔底上行,与同样被冷却到 $-26^{\circ}\text{C}$ 、由塔顶下行的溶剂进行多次气、液接触,使得甲烷等烃类不断被溶剂选择性吸收而由气相转移到液相。这样,当原料气离开塔顶时,就成了含甲烷很少的氮气物流。

离开吸收塔塔底的富溶剂采用逐级闪蒸的方式再生,闪蒸共分 4 级,逐级将 2.7 MPa 的富溶剂闪蒸到 0.14 MPa。由于在吸收甲烷的同时,溶剂中不可避免地吸收了少量氮气组分,因此,为提高天然气的脱氮率和产品质量,将第一级闪蒸罐闪蒸出的氮含量较高的气体压缩后再循环至吸收塔内进行二次吸收,而 2~4 级闪蒸气经压缩、换热、丙烷致冷及分离出所携带的溶剂后,作为产品送出装置。为充分利用各级闪蒸气所具有的不同压力级,降低设备投资和能耗,1~4 级闪蒸气共用一台 4 级压缩机进行压缩。

再生的贫溶剂从第四级闪蒸罐流出,经泵升压和丙烷致冷后,返回吸收塔顶部进行循环利用。

## (2) 工艺特点

①溶剂吸收工艺的关键在于确定性能优良的溶剂,所选择的溶剂必须对烃类溶解度大、选择性好、沸点较高、无腐蚀性、性能稳定。Mehra 溶剂为含部分  $\text{C}_5^+$  天然气液 (NGL) 轻组分的物理溶剂<sup>[4,8]</sup>,其回收  $\text{C}_2^+$  或  $\text{C}_3^+$  组分的回收率比常规吸收油法高 60%~80%。

②操作压力对装置影响较大。如某装置操作压力由 2.7 MPa 增加到 4.3 MPa 时,单位时间内处理量增加近一倍。

③与深冷脱氮法比较,溶剂回收法操作条件温和,不需脱除  $\text{CO}_2$ ,大部分设备和管道的材质为碳素钢;操作弹性大,当进料条件发生变化时,可通过调节溶剂循环量等措施,使脱氮率和甲烷回收率保持不变;开停工时间较短。但该方法溶剂循环量大,设备尺寸大,且需要丙烷致冷系统,设备较多,流程较复杂,难以回收工业用纯甲烷。

## 3 变压吸附工艺

变压吸附 (PSA) 工艺利用吸附剂对天然气中各组分的吸附能力随压力的不同而有差异的特性达到分离目的。为保证工艺过程的连续性,变压吸附工艺一般采用多塔流程。

### (1) 工艺流程

在除掉所携带的油、水等能严重减弱分子筛等吸附剂吸附容量的液相介质后,含氮天然气进入吸附床层进行分离操作,过程一般包括 3 个阶段:

①吸附:甲烷等碳氢化合物在较高压力下被吸附剂选择吸附,氮气等弱吸附组分作为流出相从吸附床层的出口流出。

②解吸再生:根据吸附组分的特点,选择降压、抽真空、产品冲洗和置换等方法使吸附剂解吸再生。

③升压:吸附剂再生完成后,用氮气等弱吸附组分对吸附床层进行逐步加压,使之达到吸附压力值,完成下一次吸附的准备工作。

UOP 公司采用 PSA 技术成功地开发出 NITREX 天然气脱氮工艺<sup>[6]</sup>,工艺流程见图 3。该工艺在常温下操作,不需外部冷却和加热吸附床层,并采用高效吸附剂和废气回收技术,碳氢化合物的回收率可达到 95%。根据原料气处理量、氮气含量以及产品气的规格及压缩要求等,每立方米净化天然气的净化成本一般在 0.02~0.03 美元。目前已有装置投产,处理量为  $6.5 \times 10^4 \text{ m}^3/\text{d}$ ,可将含氮天然气中的氮气含量由 30% 脱至 5%。

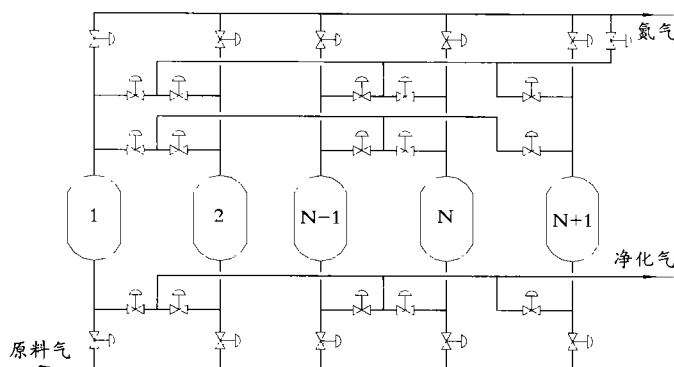


图3 NITREX 天然气脱氮工艺流程

### (2) 工艺特点

①一般在常温和不高的压力下操作,设备简单。床层再生时不需要加热源,再生容易,可以连续操作。

②吸附剂的寿命长,对原料气的质量要求不高,装置操作容易,操作弹性大,在进料气组成和处理量波动时,很容易适应。

③启动快,可以随时停机,易实现无人操作。

④装置运行时,阀门等频繁运作部件多,易发生故障点比较多,要求阀门、控制仪表等具有长期运行的可靠性和稳定性。

⑤由于甲烷与氮气的吸附性能接近,现有的吸附剂的平衡选择性系数较低,造成产品气的回收率较低。

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腐蚀层外,还应进行全站库内部的区域阴极保护,阴极保护工程应与主体工程同时设计、同时施工,并在埋入土壤 6 个月内投入运行,严防腐蚀破坏造成事故。

#### 4 有效使用消防投资

《原油和天然气工程设计防火规范》GB 50183-93 的“消防设施”一章对油气站库消防设施的设置作了详尽的规定,油品从甲类到丙类,储罐从最小到最大,设置什么消防设施都作了全面规定,对于一、二级油气站库,根据第 7.2.1 条第三款的规定还需建消防站,例如黄岛油库就建有相当规模的消防站。但事实上,真正的大火都不是靠自身的消防设施所扑灭,例如大庆北二

地下站、黄岛油库、南京炼厂的大火都是依靠外部的消防力量所扑灭。根据上述规定和中国石油天然气集团公司的概预算指标测算,用于油气站库消防设施的工程投资,约占站库总投资的 15%~25%,这笔投资虽不能说是浪费,但至少未能发挥出很好的经济效益,尤其对中小油气站库。要不要搞大而全、小而全的消防设施早有争议,且一些油气管道的中间站常会遇到干旱、沙漠、永冻的地域条件,在这些地区根本就无法按规范建设消防设施。据悉,西方国家的防火规范均是推荐性的,油气站库要不要建消防设施由业主自定,但企业财产保险条件不同。如果我国也实行

企业财产保险制,将现在用于消防设施的投资转为企业财产保险基金,一是能使资金变活;二是给油气站库设计创造了很大的灵活性;三是能为国家节约大量土地;四是能提高防火安全度。

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#### 4 结论与建议

在上述 3 种天然气脱氮工艺中,溶剂吸收工艺实质上为低温油吸收工艺,溶剂的操作温度一般要控制在-30℃左右,需要比较复杂的致冷系统,设备较多,流程复杂。该工艺的关键在于选择适当的溶剂,溶剂性能的优劣直接决定着吸收操作是否可行有效。

变压吸附法工艺过程简单、适应性强、能耗低,已在空气分离、氢气提纯等方面获得成功应用<sup>[5,7]</sup>。但用于天然气脱氮时,存在吸附选择性低、吸附容量有限、甲烷回收率低等缺点。

从当前情况看,深冷脱氮工艺具有处理量大、回收率高、氮气脱除率高等优点,而且不存在诸如吸附剂制造、溶剂配方等专有或专利技术,是目前国外最普遍采用的脱氮工艺。我国已有较成熟的深冷装置设计、制造经验,大中型空分装置已遍及全国各地,加上 LNG 工业在我国的发展,这些都为我国发展天然气脱氮工业提供了必要的技术保证。从我国实际情况及立足于国内技术的观点看,深冷脱氮工艺应为我国优先发展的天然气脱氮工艺。

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# ABSTRACTS

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## 1 Giving Prominence to Benefit in Refinery Construction Management

Du Jianrong

China National Petroleum (Group) Corporation, after restructuring, has turned into PetroChina Company Ltd., which has set forth five new higher requirements for investment policy and management of construction projects, such as the change of an enterprise's responsibilities, the change of standard for evaluating an enterprise, requirement on return of rate for invested projects, examination on experiences of an enterprise and that an enterprise is supposed to be restrained by indexes. To meet all the said requirements, production objectives and business indexes, refineries have to gain benefit from earlier stage of project construction, engineering management and from management.

## 13 Gas Turbines Used in Natural Gas Pipelines

Chen Rengui et al.

Gas turbines become the only choice in large size gas pipelines for their outstanding characteristics. In this paper, the writer analyzes in detail the fact that the pressure drop and the length do not show lineal relation and also analyzes the inertia of a gas pipeline, main characteristics of compressors with gas as the fuel, the characteristics and performance of gas turbines with single or separate shafts and based on many a theory and practice, the writer calls the readers' close attention on the following: selection of gas turbines, air cleanness and atmospheric influence to gas turbine operation, design of fuel gas system, allocation of station control and DCS systems, etc.

## 18 Process of Natural Gas Denitrification

Liu Chengjun et al.

Natural gas with high nitrogen content has such disadvantages as low heat value and high-energy consumption while being transmitted and is impossible to be directly used as chemical feedstock or fuel of NGVs. Removing nitrogen from natural gas is an important measure to enhance its comprehensive applicability. Introduced in this paper are three kinds of denitrification processes used outside of China (with their principles, diagrams and characteristics given): cryogenic separation, solvent absorption and PSA which shall be preferential in China for their advantages like high processing quantity, high denitrification efficiency with both proven and reliable techniques.

## 21 Telecommunication of Gas Pipelines in and outside of China

Zhang Tianwei et al.

Telecommunication system is major part of a gas pipeline project and is the key facility for pipeline safety, reliability, economy as well as optimal operation. Introduced in detail in this paper is the technical conditions of the telecommunication systems used in some of the major gas pipeline systems at home and abroad and the main telecommunication methods of the trunk lines of the pipeline systems in and outside of China with comparison and evaluation given. Suggestions on how to develop telecommunication for China's gas pipeline systems are also mentioned.

## 24 Architectural Principle Used in Plot Plan Design for Petrochemical Plants

Zhang Lihong

In the design of a plot plan for a chemical plant, it is necessary to meet the requirements like process, fire protection distance as well as environmental protection. Discussed in this paper is how to make use of architectural theory in plot plan design in order to get rid of conventional design methods in plot planning, architecture space environmental design, vertical arrangement, road design, pipeline routing and forestation planning, etc so as to perform the civil and environmental design from three dimensional angles.

## 30 Dynamic Optimization Decision Model for Chemical Mixing Stations

Wang Xingfeng et al.

In order to solve the new problem -- locating of chemical mixing stations, during the three phases of oil production, a dynamic distribution model has been set up by means of the network-flow planning method. Based on the time given for starting production in certain blocks with the transit station distribution as the reference, the model is designed to optimally decide the number of the chemical mixing stations, size, location and their service scope with a method of calculating large scale combination and optimization worked out. To check the scientific performance and efficiency of the said model, the writer has, taking an oil field with polymer as its fuel for example, performed the numerical value calculation and comparison with manually planned one. The latter is found in line with the model, which can help planning personnel with real optimal allocation.

## 35 Safety and Fire Protection in Oil/Gas Stations and Tank Farms

Cheng Zuliang et al.

In oil & gas safety and fire protection codes, too large fire protection distances are required for most of the oil and gas stations and tank farms and the distance between stations and tank farms are also bigger than necessary and without adequate safety precautions; the investment put in fire protection has not played its role as expected. Methods of solving the above mentioned problems are given as follows: 1. Shorten properly the fire protection distances; 2. Shorten properly the distances between stations and tank farms; 3. Four measures of strengthening safety of pipelines and tanks are set forth in this paper; 4. Turn fire-fighting investment to estate insurance.

## 38 Economic Index for Shutting down Oil/Gas Wells with Low Production Rate

Yang Jiali

In increasing an enterprise's economic benefit, shutting down oil and gas wells of low production rates is considered to be of a necessary measure, which can lower the average unit cost and increase the enterprise's economic benefit. Three methods are given of calculating economic indexes: margin costing, increment financial benefit index setting and industrial cost convert rating. By means of which, the calculated economic parameters can be taken as the economic limit for shutting down low production wells.

## 40 SCADA System Used in Changqing Gas Fields

Sun Zhipeng et al.

The SCADA installed in Changqing gas fields is the first control system used in China's natural gas industry. This paper shows you the application of the said system used in natural gas production, exploration and management and particularly gives description on the system structure, size, configuration, function and characteristics followed by general analysis on the economic and social benefits of this system, which is a successful example for automation systems in the field of natural gas exploration and application.