天然气热值的计量与控制

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摘　要　天然气热值计量是比体积和质量计量更为科学和公平的计量方式。实现热值计量首先必须准确测定热值, 天然气热值的测定方法有: 按其化学组成和各组分浓度进行计算的间接计算法, 使用气体量热计和在线式热值自动测试仪等。在线式热值自动测试仪为连续测定系统, 能对天然气的热值变化及时作出反应, 特别适合用于商品燃气的热值调节, 保证供气的热值恒定。并以日本横河电机公司 CM6G 型燃气热量计为例, 介绍了热值在线自动测试仪的工作原理和基本组成框图。同时, 还介绍了带"反馈"控制的热值自动调节系统框图。最后提到了比单纯"反馈"系统更为快速、灵敏、准确控制热值的"前馈"加"反馈"的复合控制系统。

主题词　天然气　热值　流量测量　自动控制

热值是指单位质量或体积的燃料完全燃烧产生的发热量。

燃料按热值计价可以体现优质优价, 促进能源部门提高产品质量和提高经济效益。对用户来说, 热值的合格和稳定可对生产、生活带来很多好处。

由于天然气成分比较稳定, 国外普遍以热值为计价依据。为提高我国的能源管理水平, 与国际接轨, 也应该推行以热值为计价单位。

发热量大小与燃烧状况和测试条件有关, 由于燃料的组分十分复杂, 在不同的燃烧条件下化学反应有所不同, 例如燃料中的硫, 在空气中燃烧时生成 SO_2, 但在过氧燃烧时则生成 SO_3, SO_3 溶于烟气中的水蒸气, 生成硫酸(H_2SO_4), 这些都是放热反应。但不同的燃烧状况, 燃料的发热量是不同的。

此外, 燃料发热量还与测试条件有关。例如燃烧后的烟气在高温下排出, 则烟气将带走一部分热量。但若将烟气中的热量也加以收集利用, 把烟气温度冷却至室温后排出, 则其中的水蒸气(由燃料中液态水蒸发及由燃烧化学反应生成的水蒸气两部分构成) 将冷凝而放出气化热, 使测得的发热量增加。因此, 讨论燃料的热值(发热量) 必须说明其测定条件及方法。

天然气热值的测定方法

气体燃料的热值是指在标准状态下(0℃, 1.013 × 10^5Pa), 1 m^3 容积的可燃气体完全燃烧所释放的热量, 常用单位为 kJ/m^3、MJ/m^3, 测算气体燃料热值的方法有两种: 间接计算法和直接测定法。

1. 间接计算法

可燃气体的热值取决于其化学成分。如果能通过物理或化学的分离分析方法识别其化学成分, 并准确测定各组分的浓度, 则可由各组分的热值, 通过公式准确计算得出该混合气体的热值。例如其低位热值可用下式计算:

$$H_l = \sum \frac{G_i}{100} H_{li}$$

式中: H_l 为可燃气体的低位热值, kJ/m^3;

H_{li} 为第 i 种组分的低位热值, kJ/m^3;

G_i 为第 i 种组分的体积浓度(体积百分比)。

2. 直接测定法

用气体量热计可直接测定气体燃料的热值, 常用的气体量热计为水流型量热计, 又叫容克式量热计。其工作的原理是: 将气体燃料连续地通过量热计, 使其完全燃烧, 燃烧所释放出来的热量被逆流而过的水流连续吸收, 根据燃烧掉的气体燃料的容积,

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以及在此气体燃烧时间内通过的水量和进、出水的温度差, 就可以计算出气体燃料的高位热值:

$$H_h = \frac{CW(t_o - t_i}{V}$$

式中: H_h 为量热计实测的气体燃料高位热值, kJ/m³;

C 为水的比热, J/g;

W 为燃烧时间内通过量热计的冷却水质量, g;

t_i 为水的进口温度, ℃;

t_o 为水的出口温度, ℃;

V 为燃烧掉的燃料气体容积(标准状态下), m³。

供气中的热值自动测量与调节

1. 在线式热值自动测试仪的工作原理

水流式量热计有几个缺点: ①燃气的热值变化时, 量热计的反应很慢; ②测试操作是手动的, 间断的, 不能直接用于自动控制, 下面介绍连续工作的热值在线自动测定仪的工作原理。

图 1 是日本横河电机公司的 CM6G 型燃气热量计的组成方框图, 主要由: ①空气稳压部分; ②燃气稳压部分; ③压差检测部分, 包括孔板流量检测及差压变送器; ④喷嘴燃烧及热值检测部分; ⑤密度计; ⑥运算器共六部分组成, 其基本工作原理是将稳压后的试样气体燃料在燃烧室内燃烧, 使用空气作为热量吸收媒体, 检测其燃烧温度, 同时用孔板和差压变送器检测试样燃气流量和空气流量, 并用密度计测出试样燃气的密度, 经智能仪表进行密度、温度、压力补偿后, 直接以数字方式给出试样燃气的热值。

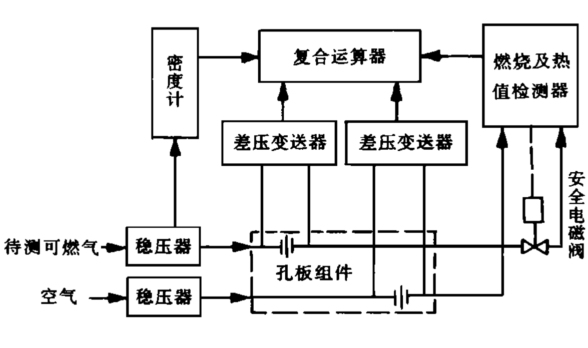

图 1　自动热量计的组成方框图

Fig. 1. Block diagram of automatic heat meter composition.

测试时, 干燥的清洁助燃空气先经一次减压稳压器减压至 0.2 MPa, 再经第二次精密减压阀减压至 0.02 MPa, 再在空气预热槽中将空气温度控制在 40℃左右, 用节流阀设定孔板流量计上的压差在 500 Pa 左右。

试样燃气先从管道上的取样点用升压泵升压至 6 kPa 左右, 再经洗涤瓶洗净, 过滤器滤去杂物, 除湿器除去水分, 稳压器稳压后, 用节流阀设定孔板流量计的读数在 10 L/min 左右。

以上孔板流量计的孔板安装在恒温槽内, 该恒温槽的温度由无接点比例控制方式工作的温度调节器保持在 50 ℃左右, 以保证测量精度。

仪器的燃烧及热值检测部分由燃烧装置、热电偶温度测量电路以及点火及保安系统构成。正常燃烧时, 试样燃气在燃烧器内的喷嘴上燃烧, 空气由空气入口进入, 该空气被分流成 1 次、2 次、3 次空气; 其中 1 次空气先与试样燃气混合, 再由 2 次空气使其充分燃烧, 燃烧后产生的热量由 3 次空气快速搅拌均匀, 以便温度检测器准确测量。测量排气温度的热电偶输出 0~ 20 mV 信号, 经放大成 1~ 5VDC 的标准信号后送往运算器。当燃烧器熄火或发生其他故障时, 仪器会发出报警信号。

量热计的量程可由已知热值的标准样气标定。燃气的热值与燃烧器内的燃烧温度有线性关系。

量热计内的运算器是内藏计算机的智能仪表, 它输入燃气和空气的流量差压信号、燃气的密度信号, 以及燃烧室温度即发热量检测信号, 运算器可对燃气流量进行密度和温度、压力补偿运算, 并自动计算得出燃气的热值。其测量精度在低热值时为 ±1.5%, 在高热值时为±1.0%, 响应的纯滞后时间约 10 s, 惯性时间约 40 s。

这种量热计的优点是取掉了容克式量热计的水路系统, 热工结构简单, 而且是自动测量, 连续工作, 测量燃烧室气体温度比测量进出水温度响应速度快, 测量精度也高。但价格相当昂贵。

2. 热值闭环自动调节系统的构成

为保证供气质量, 可在供气过程中使用热值自动调节系统, 保证供气的热值恒定。

热值自动调节系统的工作原理是连续地测定供气的热值, 当测得值与要求值有偏差时, 自动改变几种可燃气的混合比例, 使热值符合要求。也就是说, 自动调节仪表应该不断监视混合后的结果, 并与期望值进行比较, 然后按偏差修正混合比例。这种反馈是自动调节的基本工作特征, 热值调节是一种典

型的自动调节系统。图 2 是最简单的热值调节系统方框图。

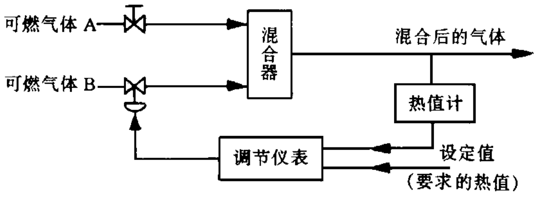

图 2　热值自动调节系统框图

Fig. 2. Block diagram of heating value automatic adjustment system.

图 2 中如果可燃气 A 为高热值的可燃气体(例如天然气), 其热值高于混合后可燃气体要求的热值。为调整热值, 采用热值较低的可燃气 B(例如水煤气, 发生炉煤气等) 与之混合。调节过程是不断检测混合气体的热值, 将其与设定热值进行比较, 根据其偏差值的大小, 按比例、积分、微分(简称 P、I、D) 算法进行自动调节, 改变管道 B 上的调节阀开度, 改变 A、B 两种燃气的混合比例, 使混合气的热值符合要求。

在这个自动调节系统中, 引起混合气热值波动的扰动因素主要有下面几种: ①可燃气体 A 的流量波动; ②可燃气体 B 的流量波动; ③A 的热值变化; ④B 的热值变化。对这些扰动, 图 2 的简单自动调节系统往往表现出动作迟缓, 不能及时克服干扰。这是因为热值计的测定过程有几十秒的滞后, 混合器后面如果有贮罐, 则惯性更大, 因此这种单纯的"反馈"控制原则很难迅速奏效。为此, 实际上采用的热值调节系统要比图 2 的结构复杂得多, 通常要采取前馈与反馈结合的复合控制原则。例如当可燃气体 A 或 B 由于自身的压力和流量波动时, 用流量或压力测控仪表直接检测干扰来源, 并立即修正混合比例。

除采取前馈与反馈结合的复合控制方法外, 热值自动调节系统中还常采用串级控制以及其他一些复杂控制算法, 以保证热值控制的快速、灵敏、准确。

(审稿人　高级工程师　王协琴
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渡 3 井大井眼中途测试成功喜获工业气流

四川石油管理局川东钻探公司渡 3 井于 1996 年 10 月 4 日开钻, Ø339. 7 mm 表层套管下至井深 287 m 固井后, 用 Ø311. 2 mm 钻头钻至井深 2 419. 07 m, 钻至自流井组, 井段 2 325~ 2 345 m 发生溢流, 电测解释为气层。为此, 四川石油管理局勘探公司决定采用 HST 地层测试器进行中途测试, 以求得地层压力、流体产量、流体性质等各项地质资料。

该井井身结构跟以往的中途测试井有所不同, 具有一定的特殊性及复杂性: ①全井只下了 287 m 表层套管, 其余全是 Ø311. 2 mm 大井径裸眼井段, 而且封隔器坐封井段岩性为砂岩, 这必然会影响封隔器在测试过程中的封隔质量以及给测试后的解封造成了客观的困难; ②从井深 287~ 2 419. 07 m 长达 2 132. 07 m 的裸眼井段, 岩层多为易垮塌的泥岩和页岩, 在原钻井过程中出现上部井段多处井漏、下部井段溢流"又漏又喷"的复杂情况。被迫采用桥接泥浆堵漏以恢复正常钻进, 而桥接泥浆堵漏的井段又是中途测试的大忌。由于复杂的地质情况, 地层垮塌、掩埋井下工具和测试管串以及压差卡钻等事故容易出现在中途测试过程中; ③封隔器在 311. 2 mm 大井径、岩层为砂岩的井眼中坐封测试, 这在川东地区尚属首例。

为了保证测试安全并能快速、成功地求得各项地质资料, 现场施工人员经公司批准, 制订出七条相应的安全技术措施: ①钻井液中加入防卡剂 20 m^3, 以减小摩阻系数, 防止压差及粘附卡钻; ②支撑尾管全部采用 Ø177. 8 mm 钻铤; ③井下用 2 只反循环阀, 一只为机械式启动, 一只为液压式启动, 安装距离相隔 100 m, 防止接在同一井段以免造成井壁垮塌掩埋; ④在封隔器上部安装 2 只正反扣安全接头, 若工具被卡后, 才能安全倒扣起出上部钻具; ⑤做好测试后工具及管串遇卡的准备工作, 详细计算好钻具的抗拉强度, 若遇卡后能尽快在裸眼内解卡; ⑥按中途测试及井控技术要求, 在施工期间, 井队干部与现场施工技术负责人须跟班监督把关; ⑦为保证测试工作有条不紊地进行, 现场测试时成立钻台操作、地质资料、外围警备及应急救护四个组。

现场技术措施及人员组织落实后, 1997 年 4 月 6 日~ 8 日, 仅用 4 d 完成通井、下测试工具、开井测试、压井解封和起钻 5 道工序。获得井口测试产量 1. 51 × $10^4 m^3/d$ 的工业气流, 取全、取准了包括地层压力、气产量、流体性质在内的一切地质资料。

此次中途测试取得一定的成果和经验, 获得了良好的经济效益, 开创了川东地区大井径、大段裸眼、喷漏共存等复杂地层测试成功的先例。取全、取准的地质资料为以后渡口河构造勘探、开发各项工作的开展提供了可靠依据。整个测试时间仅 4 d, 较下油管中途测试节约时间约 20 d, 节约测试总成本约 80 万元, 直接经济效益显著。

(四川石油管理局川东钻探公司　张安先　张明云)

merits and demerits of the instruments are introduced.

Subject Headings: Natural gas, Flow measuring, Detection, System.

He Mingxuan, senior engineer, graduated in Xi' an Communications University in electrification of industry. He has published several papers, and is engaged in researches on electricity, auto-control meters design and natural gas flow gauging study. Add: (610017) No. 28, Xiaoguanmiao Houjie, Chengdu. Tel: (028) 6747700.

He Mingxuan *(Design Institute of Sichuan Petroleum Administration, Huang Mingchang:* **COMPUTING METHOD OF NATURAL GAS FLOW MEASURING, NGI** 17(4), 1997: 63~ 65

ABSTRACT: Non-on-line real-time computing method and on-line real-time automatic computing method adapting to on-the-spot flowing measuring computation are proposed out to simplify overelaborate manual calculation and avoid mistakes. The fractional computation programmed with unsophisticated program calculator and the pragram computation with programmed order are used by the former and flow rate computer with programmed order is used by the latter. Non-on-linereal-time fractional computation is restricted by the values of K_ε, C', K_0, K_R etc., relevant coefficients at concrete measuring points. Program computation is interchargeable but not convenient for plenty of parameters. On-line real-time automatic computation can overcome the defect caused by the non-on-line real-time computation and omit the manual flow rate calculation.

Subject Headings: Natural gas, Flow measuring, Computing method, Computer program.

Huang Mingchang *(Design Institute of Sichuan Petroleum Administration:* **ON-THE-SPOT INSPECTION METHOD OF NATURAL GAS ORIFICE METER, NGI** 17(4), 1997: 66~ 69

ABSTRACT: The on-the-spot inspection of natural gas orifice meter is adopting the transitivity calibration method taking Venturi nozzle as calibration scale. The straightness and circularity of the orifice and survey tube need to be geometrically inspected in the periodicity maitenance course of restrciction devices at measuring station. The principle, technlolgical process, inspecting equation of on-the-spot inspection orifile meter, the inspecting method of systematically arbitrating orifice meter, as well as the necessary geometric inspection contents of calibration orifice and surved tube in field condition, the tools and operation methods are introduced.

Subject Headings: Natural gas, Orifice meter, Field testing, Inspecting, Analytical method.

Wang Yudong *(Xi' an Petroleum Institute, Wang Huaixiao:* **NECESSITY AND POSSIBILITY OF ADOPTING CALORICITY TO GAGE COMMERCIAL GAS IN CHINA, NGI** 17(4), 1997: 69~ 70

ABSTRACT: As a fuel, the main commercial value of natural gas is its inclusive caloricity. The gas price dispute caused by gaging volume can be eliminated by gaging caloricity. The on-line determination of natural gas caloricity can be accomplished by caloricity indirect calculating and direct determining. The gas flow computer system, made in Beker Co. U. S. A, used at the gate station in south suburb of Beijing, and its on-line full components gas chromatograph spectrometer with microcomputer processor which can on-line analyse the gas full components and gage the caloricity flow by linking up the flow computer is introduced.

Subject Headings: Natural gas, Fuel, Caloricity, Gaging, Possibility.

Wang Yudong, professor, graduated from Beijing Petroleum Institute in 1958; he is long engaged in oil-gas processing design, researching and teaching. Add: (710065) Xi' an, Shanxi.

Shi Ren *(Xi' an Communications University, Li Ling:* **THE CALORICITY GAGING AND CONTROLLING OF NATURAL GAS, NGI** 17(4), 1997: 71~ 73

ABSTRACT: Natural gas caloricity gaging is more scientific and impartial than volume gaging and mass gaging. The indirect gaging in accordance with gas components and each component concentration and the direct gaging with gas heat meterand on-line caloricity automatic tester are common methods. The on-line caloricity automatic tester is a continuous detecting system being able to timely reflect gas caloricity change, especially suit to the caloricity adjustment of commerial fuel gas and ensure caloricity of gas service constant. Taking CM6G type of fuel gas heat meter made in YOKOGAWA Electric Machinary Co., Japan as example, the working principle and basic block diagram of caloricity on-line automatic tester and that of caloricity automatic adjustment system with "backfeed" control are introduced. The composite control system with "prefeed" and "backfeed" which controls caloricity more sensitive, accurate and faster than the one just with "backfeed" is involved.

Subject Headings: Natural gas, Caloricity, Flow measuring, Automatic control.

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Guo Xuming *(Design Institute of Sichuan Petroleum Administration, Tang Haiping, Luo Zhenwei, Sun Yusheng, Hao Yuewu, Chen Junqian:* **NATURAL GAS FLOW STANDARD UNIT BY QUALITY-TIME METHOD, NGI** 17(4) 1997: 74~ 77

ABSTRACT: Natural gas flow standard unit should be built up so as to set up a national and perfect dynamic retrogressive system of natural gas flow value and enhance the accuracy of on-the-spot gaging natural gas. The quality-time method gas flow standard unit developed by Sichuan Petroleum Administration and China Test Technique Institute, including the measurement principle, the composition and measurement system and the total uncertainty analysis and estimation of the unit is introduced. According to analysis and estimation, total uncertainty measured with the unit is less than 0. 1% which is the expected index. The check result of critical flow nozzle shows that the repeatability relative error band mesasured with the nozzle is within 0. 1%, which can meet the requirements of standard unit.

Subject Headings: Quality, Time, Method, Natural gas measuring, Standard, Equipment, Analytical method.

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Yang Zifu *(Chuanzhong Oil-Gas Exploration and Development Company:* **THE DEVELOPMENT OF CORIOLIS FORCE QUALITY FLOWMETER AND ITS APPLICATION TO CNG GAGING, NGI** 17(4), 1997: 78~ 80

ABSTRACT: The gas-entraining course of CNG gas-entraining station is of the characteristics of change pressure and change flow. It is difficult for common flow gaging method to meet the requirement of high accuracy. If importing from overseas, the high price is hard to be received by users. So, the MFM-1 quality flowmeter by Coriolis principle is developed by Chuanzhong Oil-Gas Company of Sichuan Petroleum Administration and China Test Technique Institute. Consisting of sensor and converter, the flowmeter can directly measure CNG quality flow without being influenced by temperature, pressure and flow change. A good utilization result is obtained at the CNG gas-entraining stations in Nanchong and Suining.

Subject Headings: Quality flowmeter, Research, Compressed natural gas, Gaging, Application.

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