

# 大高差长输供热管线中继泵站设置分析

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**摘要** 目的 研究大高差下长输集中供热干线中继泵站的设置条件,中继泵站在供热干线中的理论设置范围,中继泵站位置对长输供热干线上各种泵扬程的影响. 方法 采用传统的水力计算方法和流体动态模拟分析软件(AFT Fathom10),对山西省阳城电厂拟向晋城市区供热的23 km长距离供热输送管线进行可行性分析,研究在大高差下供热管道内的压降规律. 结果 AFT Fathom模拟得出管线压力曲线,中继泵站的设置条件,得出了满足工况要求的中继泵站设置范围为距供热首站3 785~10 222 m. 系统循环泵扬程为97.7 m,中继泵扬程为54.6~113 m,系统总扬程为210.7 m. AFT Fathom模拟管道压力可知大高程差对管道压力有着明显的影响;水压图分析可以确定系统中各泵的扬程及运行所需总扬程,且所需总扬程保持定值. 结论 设置中继泵站与隔压站相结合的供热工程方案,在大高差下可以同时满足输送干线及城区一级管网的压力等级. 在满足输送需求的水力工况基础上,在中继泵站设置范围内,可现场勘察选出最合适的中继泵站设置位置.

**关键词** 中继泵站;大高差;压力模拟分析;水力工况;水泵扬程

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## The Analysis and Research of Setting Relay – Pump Station in Long – Distance Central Heating Pipeline with Large Height Difference

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**Abstract:** This paper studies the influence of the setting conditions, the theoretical setting range and the location of relay – pump station in long – distance central heating mainline on various pumps lift and their shaft power. The feasibility of the long – distance central heating mainline (23 km) from the Yang Cheng power plant to Jincheng urban district heating in Shanxi Province is studied

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theoretically by using the traditional hydraulic calculation method and the fluid dynamic analysis software (AFT Fathom10). The pipeline pressure curve is obtained by AFT Fathom, and the setting range of relay - pump station satisfying the working condition is 3 785 m ~ 10 220 m from the first heating station. The circulating pump head of the system is 97.7 m, the relay - pump head is 54.6 ~ 113 m, and total pump head of the system is 210.7 m. Simulation of pipe pressure by AFT Fathom shows that high elevation difference has a significant effect on pipe pressure. The head of each pump in the system and the total head required for operation can be determined by hydraulic diagram analysis. And the total head is required to maintain a constant value. The heating engineering scheme which is the combination of the relay - pump station and the pressure isolation station in this project can meet the pressure level of the conveying mainline and the first - level urban pipe network at the same time in the case of large height difference. Within the scope of the theory allows setting can be through the field survey and select the most appropriate relay - pump station setting - up position.

**Key words:** Relay - pump station; large height difference; pressure simulation analysis; hydraulic regime; pump lift

近年来,随着我国集中供热规模不断扩大<sup>[1-2]</sup>,供热能力不足,供热率低下问题逐渐显现.出于城镇环境保护的要求,特别是近些年我国北方地区雾霾问题突出,人们对环境保护更加关注.国家出台清洁供暖<sup>[3-4]</sup>政策,要求各地方开展燃煤锅炉的综合整治,淘汰关停环保、能耗、安全等不达标的燃煤机组和落后燃煤小热电,原有区域锅炉房的供热区域未来将全部通过集中供热的方式获取热量<sup>[5-7]</sup>.在距集中供热热源较远且地势条件复杂的地区,集中供热的长距离输送一般通过在供热干线增设中继加压泵站的方式<sup>[8-11]</sup>,使供热管网的水力工况<sup>[12-14]</sup>和热力工况满足末端各热力站的资用压力,同时还需保证在大高差情况下,长输供热管线到达已有城市一级管网时的压力不超过一级热网的压力等级.此外,若采用增设中继泵站的方案,中继泵站的设置条件及其可设置的位置范围、中继泵站位置与输送管线中各种泵的扬程的关系也需要进行分析<sup>[15-18]</sup>.笔者采用传统的水力计算方法和流体动态模拟<sup>[19-22]</sup>分析软件(AFT Fathom10),对山西省阳城电厂拟向晋城市区供热的23 km长距离供热<sup>[23-24]</sup>输送管线进行可行性分析,探究在大高差下供热管道内的降压规律.从水压图上分析提出设置中继泵站的工

程方案,得出中继泵站的设置条件及其位置设置的理论范围,计算出不同的中继泵站设置位置对各水泵扬程的影响.

## 1 供热管线工程概述

阳城电厂位于山西省晋城市阳城县北留镇,距离晋城市区约22 km.阳城电厂计划供热面积 $3.0 \times 10^7 \text{ m}^2$ ,包括5%的管网损失情况下,供热面积热指标为 $54.5 \text{ W/m}^2$ ,设计热负荷1 635 MW,供热时间为2 904 h/a,总耗热量12 033 432.6 GJ.采用“大温差”技术供、回水温度分别为 $130^\circ\text{C}$ 、 $30^\circ\text{C}$ ,循环流量为14 059 t/h;输送管线长度23.2 km,最高点海拔825 m,位于输送管线中部管道穿越隧道处,电厂首站海拔689.3 m和城区位于低点,海拔768 m,最高点与最低点地形高差约136 m,输送干线静压线标高取846 m,定压值1.57 MPa.供、回水密度为 $933.12 \text{ kg/m}^3$ .输送干线长直管段较多,经计算局部阻力系数取0.2<sup>[25]</sup>.管道绝对粗糙度为0.5 mm.图1为拟建输送干线路由示意图,将各管段以1~14编号.

拟建方案是在管道进入隧道前设置一座中继泵站进行加压,一座隔压泵站在进入城区的一级管网前进行隔压换热,供热方案流程如图2所示.

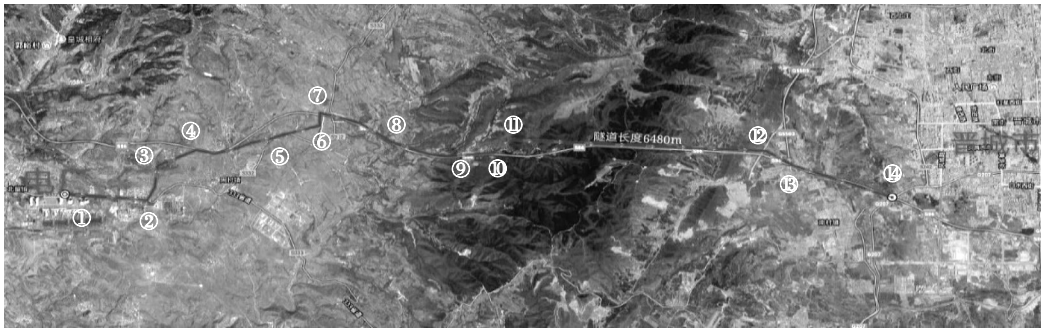


图1 拟建输送干线路由示意图

Fig. 1 Schematic diagram of proposed heating mainline route

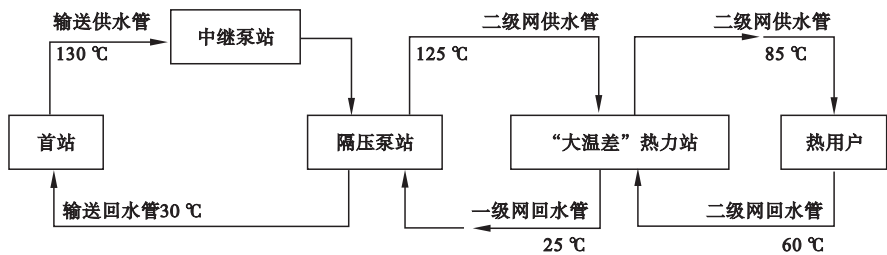


图2 供热方案系统流程图

Fig. 2 Flow chart of the heating system

2 水压图与流体动态模拟软件分析

2.1 水压图分析

2.1.1 定压方式及主要参数

采用变频补水泵定压,定压方式为旁通管定压.输送干线定压方式为旁通管定压.输送干线供水温度为 130 °C,其汽化压力为 172.5 kPa;地面最高点位于牛王山隧道,供热隧道路面高 825 m;安全富裕压头为 33.3 kPa,输送干线静压线标高取 846 m,定

压值 1.57 MPa.经隔压泵站换热后,一级管网供水温度为 125 °C,其汽化压力 101 kPa;市区内最高点 790 m,最低点 706 m,安全富裕压头为 33.3 kPa<sup>[26]</sup>.市区一级管网静压线标高取 804 m,定压值为 0.98 MPa.

2.1.2 不设中继泵站的理论输送干线方案

根据管线沿途地势高程数据和水力计算成果,不设中继泵站方案时,输送干线与城市一级管网水压图如图 3 所示,供回水管线资用压差设置为 147 kPa.

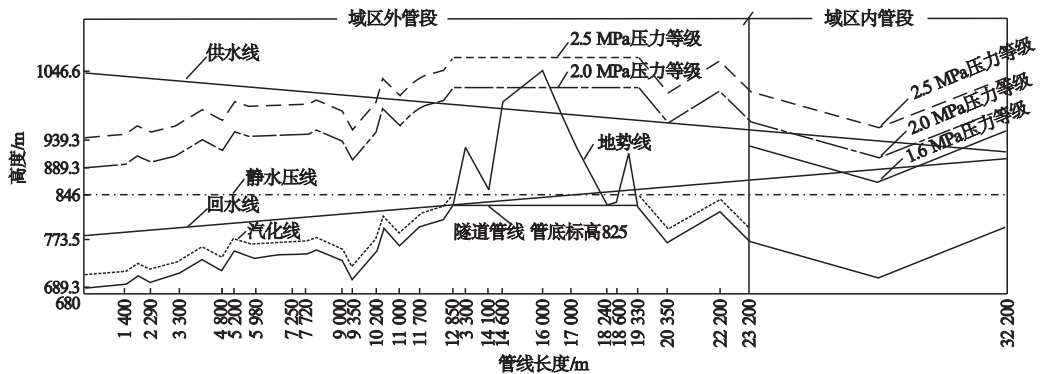


图3 不设中继泵站时输送干线水压图

Fig. 3 Hydraulic pressure diagram of mainline without rely – pump station

不设中继泵站的方案只在供热首站内对管网进行一次加压,从图3可以看出,该方案将导致整个管网处于较高的压力等级,输送干线大部分管段压力超过2.5 MPa,城区内管线压力超过1.6 MPa,首站出口管线的压力更是高达3.66 MPa,这样不仅会造成管网的投资过高,而且运行存在安全隐患。

2.1.3 设置中继泵站的理论输送干线方案

图4为示设置中继泵站的输送干线水压

图,供热首站一级加压时,管道内压力限定为不超过2.5 MPa,管线中部设置一座中继泵站对供水进行二次加压,且加压后管线最大压力未超过2.0 MPa,同时在管线进入市区前设置隔压站,使得管线压力与市区内已有的一级管网压力等级匹配,其最大压力不超过1.6 MPa,运行较为安全.此时中继泵的扬程 $H$ 为90.2 m,首站循环水泵扬程为160.8 m.

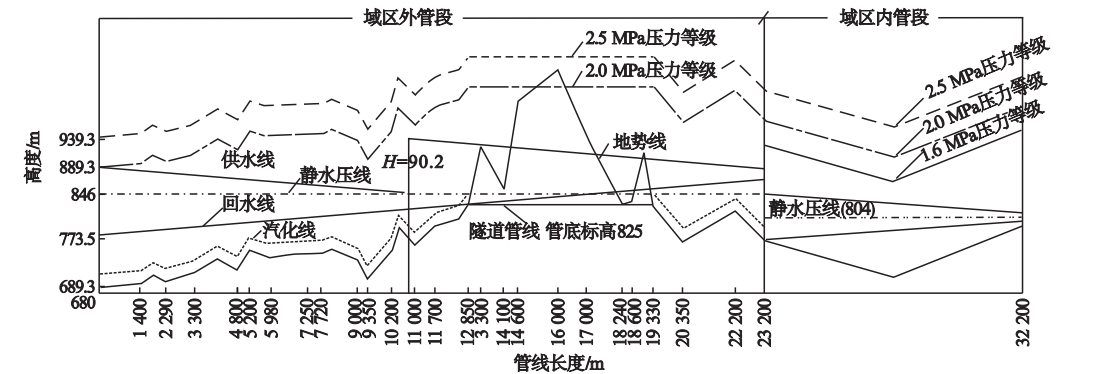


图4 设置中继泵站的输送干线水压图

Fig. 4 Hydraulic pressure diagram of mainline with rely-pump station

2.2 流体动态模拟软件 AFT Fathom 模拟

2.2.1 输送干线模型建立

由于管线距离很长,且管线路由走向变化较多,输送管线以同一方向上管线最大路经分为14段管段(见图5),运用AFT Fathom建立输送干线模型,在AFT Fathom中系

统由管线和连接元件组成,由管线定义每段管道的长度;由连接元件确定每段管段两端的高程,根据实际高程定义每个连接元件的海拔高度,使整个输送系统中的管段、连接元件形成长度与高度的相对关系进行模拟。

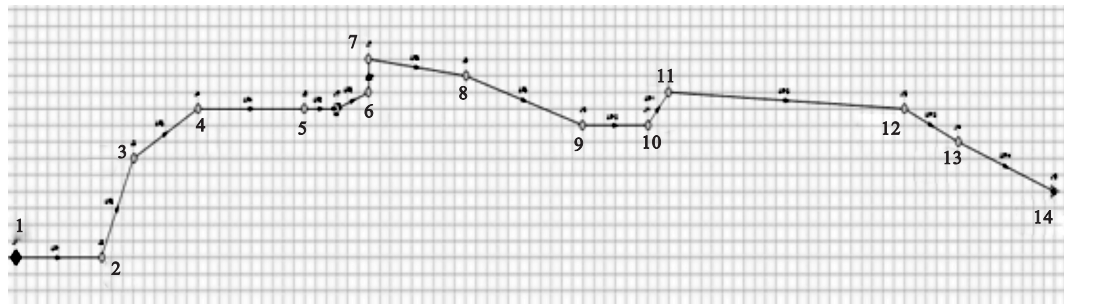


图5 拟建输送干线模拟线路示意图

Fig. 5 Schematic diagram of simulated mainline route

2.2.2 不设中继泵站的模拟输送干线方案

在模拟输送管线中,供水管线的起始端定义为指定压力,且为满足管线承压能力不

大于2.5 MPa.则指定首站最大供水压力设置为2541.14 kPa;管线末端定义为流量出口,模拟中不考虑流量及热量损失.将AFT

Fathom 模拟计算结果进行可视化输出,可以更直观地得到供回水压力、静水压力与沿程管线之间的关系. 其中供水管线模拟计算结果如表 1 和图 6 所示.

表 1 不设中继泵工况下供水管线模拟计算结果

Table 1 Simulation results of water – supply pipeline without Rely – pump station											
管段	体积流量/ ( $\text{m}^3 \cdot \text{h}^{-1}$ )	流速/ ( $\text{m} \cdot \text{s}^{-1}$ )	入口标高/m	出口标高/m	总压损失/kPa	势能增量/kPa	扬程损失/m	入口静压/kPa	出口静压/kPa	入口滞止压力/kPa	出口滞止压力/kPa
1~2	15 067	2.719	689.3	700.0	187.29	97.85	9.78	2 542.8	2 356.1	2 541.14	2 353.86
2~3	15 067	2.719	700.0	713.0	155.69	118.88	4.02	2 355.6	2 200.5	2 353.86	2 198.14
3~4	15 067	2.719	713.0	737.0	253.21	219.47	3.69	2 200.0	1 947.4	2 198.14	1 941.48
4~5	15 067	2.719	737.0	740.0	104.96	27.43	8.48	1 947.0	1 842.7	1 941.48	1 840.05
5~6	15 067	2.719	740.0	746.0	118.76	54.87	6.99	1 842.3	1 724.2	1 840.05	1 721.27
6~7	15 067	2.719	746.0	753.0	72.39	64.01	0.92	1 723.7	1 651.9	1 721.27	1 648.85
7~8	15 067	2.719	753.0	730.0	-165.46	-210.33	4.91	1 651.3	1 817.6	1 648.85	1 814.27
8~9	15 067	2.719	730.0	760.0	357.25	274.34	9.07	1 817.2	1 460.4	1 814.27	1 457.06
9~10	15 067	2.719	760.0	795.0	348.61	320.07	3.12	1 460.1	1 111.9	1 457.06	1 108.48
10~11	15 067	2.719	795.0	825.0	308.84	274.34	3.77	1 111.4	803.1	1 108.48	799.58
11~12	15 067	2.719	825.0	825.0	249.64	0.00	27.30	802.6	553.5	799.58	549.98
12~13	15 067	2.719	825.0	765.0	-509.96	-548.69	4.23	553.5	1 064.5	549.98	1 059.97
13~14	15 067	2.719	765.0	768.0	138.77	27.43	12.17	2 542.8	2 356.1	1 059.97	921.20

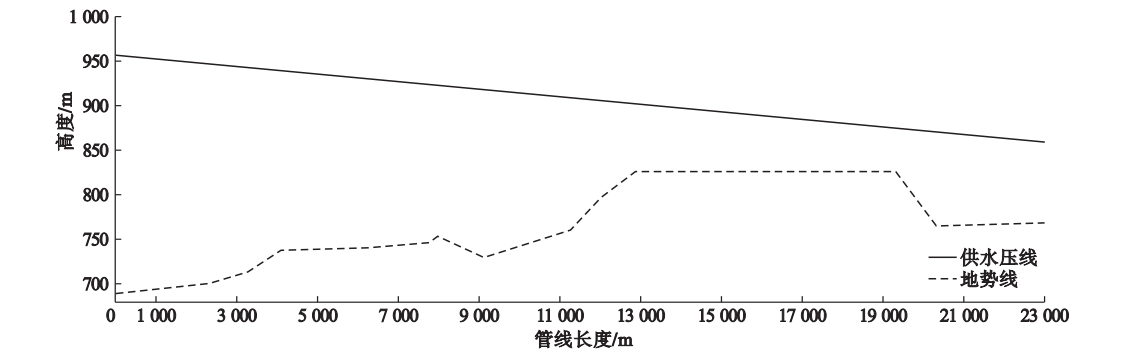


图 6 不设中继泵时供水管水压线

Fig. 6 Hydraulic pressure line of water supply pipe without Rely – pump station

将连接元件海拔标出形成地势标高,表示出每段管道长度与高程. 由表 1 得到,管道 1~2 供水管出口压力为 2 541. 14 kPa,为 2.5 MPa压力等级的临界点,保证了供水压

力在管道安全压力以下.

根据模拟计算结果作出城区外输送段的供回水管水压图(见图 7).

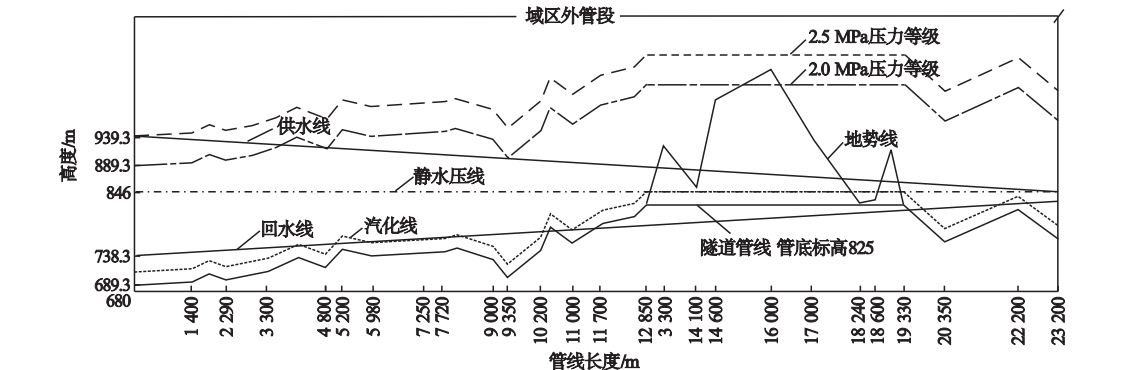


图 7 不设中继泵时模拟计算供回水管线水压图

Fig. 7 Simulated hydraulic pressure diagram of mainline without rely – pump station

从图7可以看出,供水管线压力不足以将热水供到末端.此时需要对供水管线进行二次加压,加压位置可以设置在供水压线与静水压线交点之前的某一位置且加压后的供水到达23 200 m处时,需满足管线末端的资用压力

2.2.3 设置中继泵站的模拟输送干线方案

指定首站最大供水压力设置为2 541.14 kPa;管线末端定义为流量出口,供水管线末端设定条件为压力值2 200.1 kPa,

此时为供水管满足输送水力工况的临界点,且加压点设置在进入隧道前,即管线长度小于11 200,加压后压力不超过2.0 MPa压力等级.模拟不考虑流量及热量损失.从图7可以得出,当在供水管线起点时,2.5 MPa压力等级线与纵坐标的交点值为939.3 m,将供水管出口压力设置低于2.5 MPa,其值2 051.14 kPa,其最低点的设置,保证在静水压线及供水汽化压力线之上,模拟压力结果如表2和图8所示.

表2 设置中继泵工况下供水管线模拟计算结果

Table 2 Simulation results of water – supply pipeline with rely – pump station

管段	体积流量/ (m <sup>3</sup> · h <sup>-1</sup> )	流速/ (m · s <sup>-1</sup> )	入口标高/m	出口标高/m	总压损失/kPa	势能增量/kPa	扬程损失/m	入口静压/kPa	出口静压/kPa	入口滞止压力/kPa	出口滞止压力/kPa
1~2	15 067	2.719	689.3	700.0	186.72	97.91	9.70	2 353.5	2 166.8	2 357.0	2 170.3
2~3	15 067	2.719	700.0	713.0	155.10	118.96	3.95	2 166.3	2 011.3	2 169.8	2 014.7
3~4	15 067	2.719	713.0	737.0	252.68	219.62	3.61	2 010.8	1 758.1	2 014.2	1 761.6
4~5	15 067	2.719	737.0	740.0	104.34	27.45	8.40	1 757.7	1 653.4	1 761.2	1 656.9
5~6	15 067	2.719	740.0	746.0	118.14	54.90	6.91	1 653.1	1 534.9	1 656.5	1 538.4
6~7	15 067	2.719	746.0	753.0	71.74	64.06	0.84	1 534.4	1 462.7	1 537.9	1 466.1
7~8	15 067	2.719	753.0	730.0	-166.26	-210.47	4.83	1 462.0	1 628.3	1 465.5	1 631.8
8~9	15 067	2.719	730.0	760.0	307.89	237.92	7.65	1 627.9	1 320.1	1 631.4	1 887.7
9~10	15 067	2.719	760.0	795.0	348.15	320.28	3.05	1 883.9	1 535.8	1 887.4	1 539.2
10~11	15 067	2.719	795.0	825.0	308.35	274.52	3.70	1 535.3	1 226.9	1 538.7	1 230.4
11~12	15 067	2.719	825.0	825.0	249.12	0.00	27.22	1 226.5	977.4	1 229.9	980.8
12~13	15 067	2.719	825.0	765.0	-510.99	-549.05	4.16	977.4	1 488.3	980.8	1 491.8
13~14	15 067	2.719	765.0	768.0	138.17	27.45	12.10	1 488.3	1 350.2	1 491.8	1 353.6

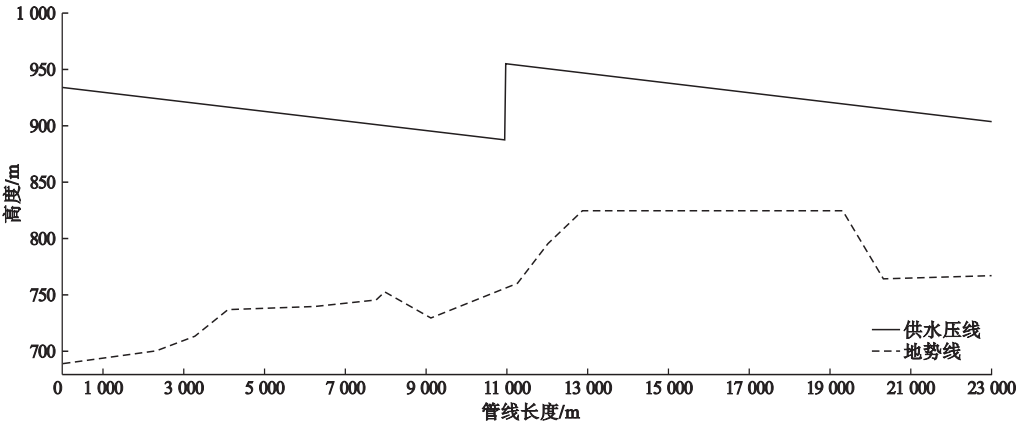


图8 设置中继泵时供水管水压线

Fig. 8 Hydraulic pressure line of water supply pipe with rely-pump station

根据模拟得到的供回水压力,设置中继泵时模拟计算供回水管线水压图如图 9 所示.此时,回水线处于汽化临界点,通过设置

中继泵加压保证中继泵站后的供回水管线压力均在静水压线及汽化线之上,此时中继泵扬程  $H=67\text{ m}$ ,距离供热首站  $10\,920\text{ m}$  处.

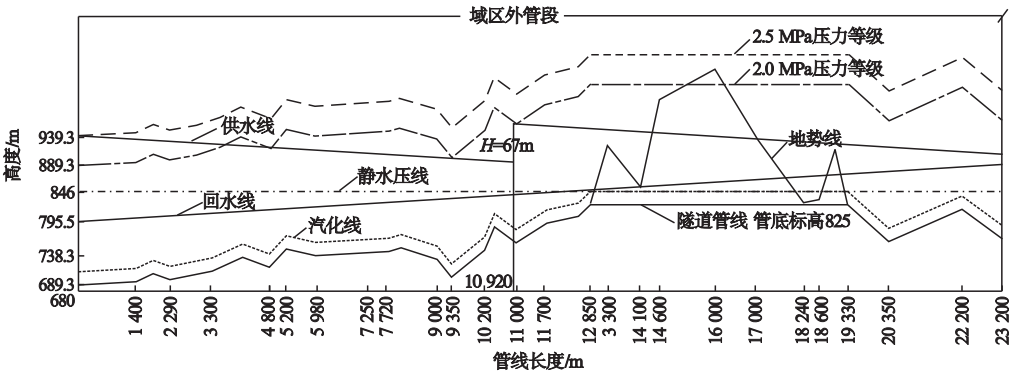


图 9 设置中继泵时模拟计算供回水管线水压图

Fig. 9 Simulated hydraulic pressure diagram of mainline with rely-pump station

### 3 输送干线中继泵站设置位置范围及中继泵扬程

#### 3.1 中继泵站设置距供热首站最近时方案

中继泵站的位置理论上在一定范围内都可以满足“不超压、不汽化、不倒空”的水力工况要求.若要满足热力输送的水力要求,则首先保证回水压线处于地势线最高点之上,考虑一定裕量,即回水压线不低于汽化线的最高点则可以保证回水线不形成倒空;供水压线保持在管道安全压力等级线之下,即供

水不超压;同时供水压线保持在汽化线之上,即供水不汽化.在满足水力工况的条件下,中继泵站距首站最近时输送干线水压图如图 10 所示,此时中继泵站距供热首站可实现的最短距离为  $3\,785\text{ m}$ .此方案为供热首站一级加压,供水到达中继泵站时进行二级加压,当供水到达输送段末端的隔压站时,在隔压站内对输送干线的回水管线进行三级加压,回水线可以满足“不倒空”的水力工况要求.此时中继泵扬程  $H=54.6\text{ m}$ ,首站循环泵扬程为  $97.7\text{ m}$ ,隔压泵站内的加压泵扬程为  $58.5\text{ m}$ .

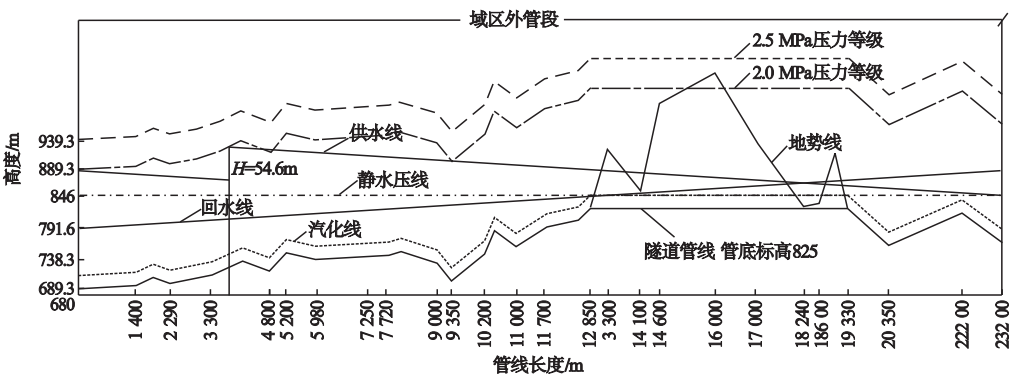


图 10 中继泵站距首站最近时输送干线水压图

Fig. 10 Hydraulic pressure diagram of mainline when relay-pump station is closest to the First Station

#### 3.2 中继泵站设置距供热首站最远时方案

在满足热力输送水力工况的条件下,中继泵站设置距供热首站的最远距离时,为供

水压线与静水压线交点处,此时需要二次加压保证水压可以满足继续热力输送的要求,中继泵站距首站最远设置时输送干线水压图

如图 11 所示,供水线低于 2.0 MPa 压力等级,当供水压线与静水压线交点时,此时设置中继泵站为此条件下最远距离,距供热首站

的距离为 10 222 m. 且保证加压后压力不超出 2.0 MPa 压力等级,此时中继泵加压所需扬程  $H=113\text{ m}$ ,首站循环水泵扬程为 97.7 m.

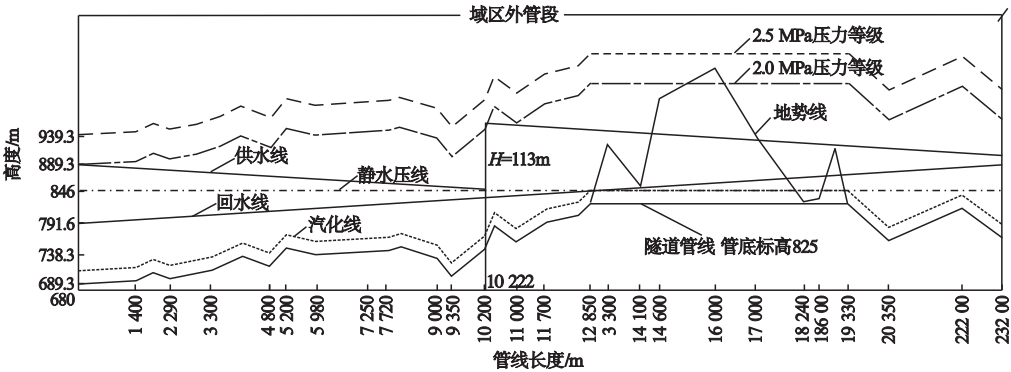


图 11 中继泵站距首站最远设置时输送干线水压图

Fig. 11 Hydraulic pressure diagram of mainline when relay-pump station is furthest to the First Station

4 结 论

(1) 通过 AFT Fathom 模拟得到仿真管线压力曲线,确定了满足工况要求的中继泵站设置范围为距供热首站 3785 ~ 10 222 m. 首站循环泵扬程为 97.7 m, 中继泵扬程为 54.6 ~ 113 m.

(2) 中继泵站与隔压站相结合的供热工程方案,在大高差下可以同时满足输送干线及城区一级管网的压力等级,大高程差对管道压力有着明显的影响.

(3) 同一设计方案中继泵站在输送干线上位置并不影响整个输送干线所需水泵扬程,总扬程保持定值为 210.7 m,在满足热力输送要求的基础上,可以通过现场勘察选出最合适的中继泵站设置位置.

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