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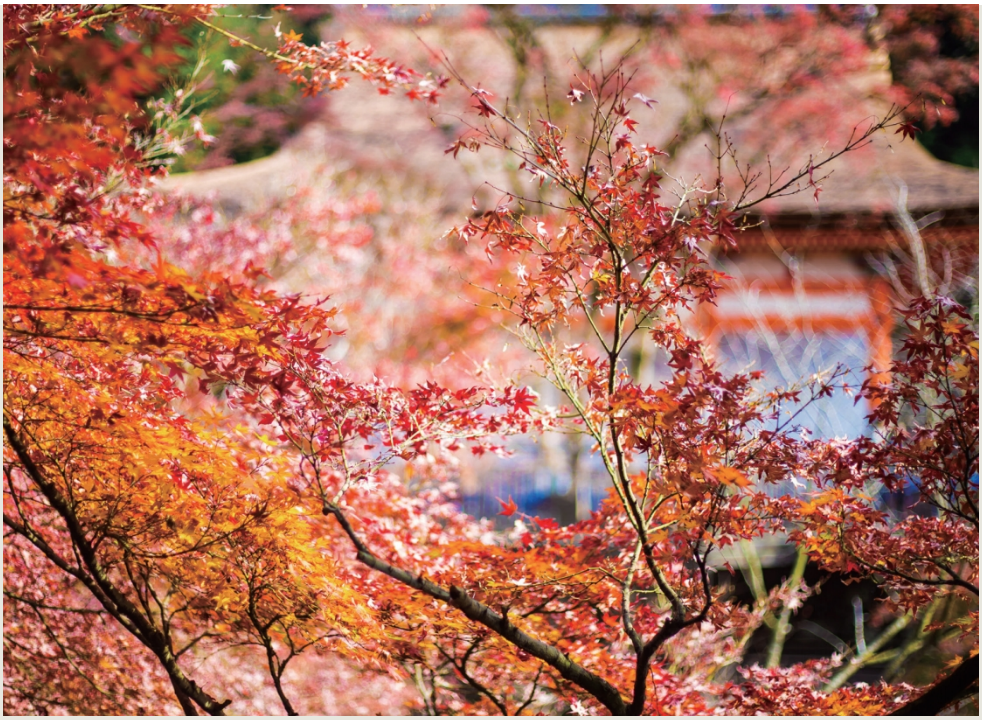

本期焦点
CURRENT FOCUS

把握“双碳”目标，加强生态文明建设，促进实现碳达峰、碳中和，使生态更绿色，能源更经济，环境更宜居。不断促进和提升浅层地热能无燃烧清洁供暖，发展可再生能源热冷一体化。

封面 / 目录图片 供图：王赫

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单井循环系统承压含水层地下水流动的解析解

AN ANALYTICAL SOLUTION OF GROUNDWATER FLOW IN A CONFINED AQUIFER WITH A SINGLE-WELL CIRCULATION SYSTEM

作者：涂坤；武强；Jirka Simunek；陈超凡；朱珂；曾一凡；徐生恒；王洋

摘　要：在本研究中，建立了单井循环系统的一般解析模型，用于分析承压含水层的瞬态降深。利用拉普拉斯余弦变换和傅里叶余弦变换相结合的方法，推导出拉普拉斯域瞬态降深的解析解，并利用 Stehfest 算法对其进行时域数值反演。研究了单井循环系统的瞬态降深特性，以及不同参数对降深的影响，并利用傅里叶余弦变换得到了稳态条件下的解析解。计算结果表明，稳态降深等值线围绕含水层水平中面是对称的，且随距离井轴的距离变化较大。隔断区周围的降深等值线密集，说明该区域的水力梯度较大。通过灵敏度分析评价各参数对水位降深特性的影响，结果表明径向水力传导系数和隔断区长度对降深影响较大，各参数对降深的影响周期各不相同。

1. 引言

在不同类型的地下水热泵系统中，单井循环地下水热泵系统在井结构方面尤其不同于常规地下水热泵系统——例如异井系统或循环单井系统。在一个单井循环系统中 (图 1)，一个钻井被隔断区 (图 1,图 2 中灰色区域) 分为两个部分，它被放置在单个钻井中间，用于阻止注入回水段的回灌水流入抽水段。单井循环系统可以看作是两个非完整井的组合。隔断区下部为抽水井，地下水抽取速率为 Q，隔断区上部为回水井，回水以同样的速率 Q 被注入含水层。

单井循环地下水热泵系统是从 2001 年兴起的一项新技术，自此在中国就被用于向建筑供暖和制冷。在过去的二十年中，这种独特的地下水热泵系统得到了极大的关注，特别是在中国北方地区，并得到了越来越多的应用。尽管该系统已有大量实际工程应用，但有关其理论研究还比较有限。徐生恒等人从系统设计、节能和环保等方面介绍了这一创新技术的发展，以及几项成功的工程实施案例。武强等人从井结构配置、对水文地质和热地质条件的要求、环境影响、监管要求等方面，将单井循环系统与其他常规地下水热泵系统进行了比较。Rybach 介绍了其在中国和其他国家的工程应用，总结了单井循环地下水热泵系统的运行原理。最后，曾一凡等人通过内布拉斯加州的案例研究，详细讨论了该系统的能源效率、成本效益、运行和维护。

单井循环地下水热泵系统的热交换是地下水流动和热量传输耦合结果，特别是对流换热受流体流动的影响。因此，在开始研究单井循环地下水热泵系

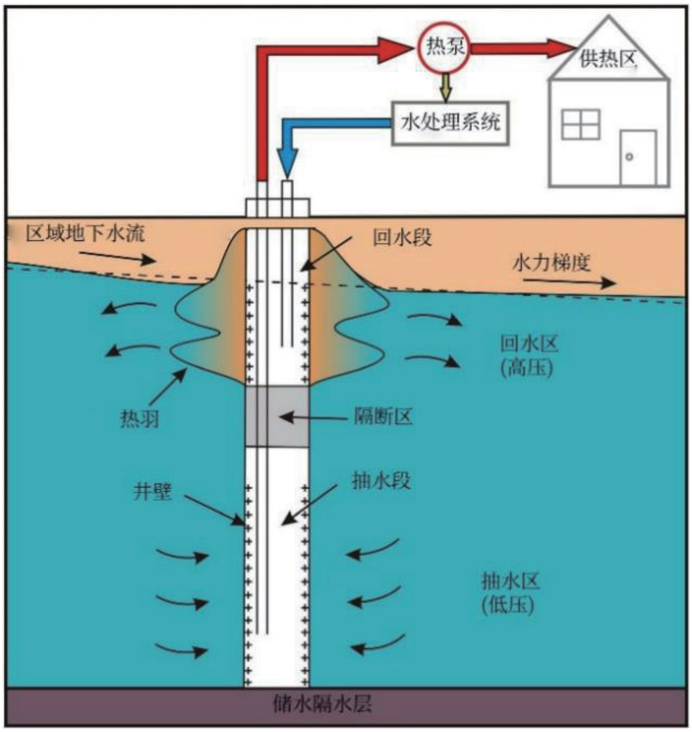


图 1 提取浅层地热能的单井循环系统概述

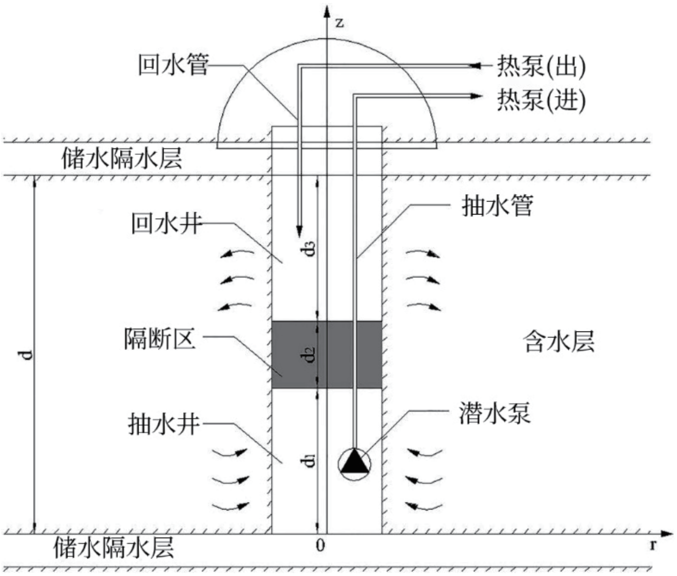


图 2 单井循环系统数学模型示意图

统的热交换之前，对地下水流动的充分了解是尤为重要、必要的一步。迄今为止，对地下水流的研究大多集中在完整井和非完整井上。

关于完整井的降深问题已在许多文献中讨论过。例如，Theis 首先提出描述地下水流向无限承压含水层中完整井的解析解。之后 Papadopulos 和 Cooper 提出了一个数学模型，该模型描述了在井筒半径和井筒储存量影响下承压含水层中的地下水流动。Chen 在已有解的基础上，推导出了一个描述有限承压含水层地下水流动的解析解，该含水层的外边界降深为零。Novakowski 在考虑井筒半径和井筒储存量影响的情况下，得到了复合承压含水层内降深的拉普拉斯域解。随后，Yeh 等人提出了描述两区承压含水层系统段塞流试验水头分布的解析解。Wen 和 Zhan 通过结合幂律函数和线性化过程，提出了一种描述复杂含水层中非达西地下水水流的一般解析模型。Wang 等人提出定流量抽水条件下，沿有限半径井表皮区附近地下水流动的解析解。Lin 等人提出了一种解析模型，该模型描述了由抽水试验引起的有限复合含水层中的地下水渗流，同时考虑了表皮效应和 Robin 边界条件的影响。

部分关于非完整井地下水流动的研究总结列于表 1。Hantush 提出了第一个非完整井的数学模型，他利用拉普拉斯和傅立叶余弦变换推导出了解析解。此后，许多研究人员对非完整井系统进行了研究。例如，Luther 和 Haitjema 研究了非承压含水层中一个或多个非完整井的稳态流。Yang 和 Yeh 提出了在无限大含水层中，由恒水头试验引起的向非完整井流动的地下水的半解析解。考虑到有限厚度的表皮效应，Chiu 等人提出了非完整井的地下水流降深的解析解。Barua 和 Bora 提出了有限承压含水层中抽取非完整井而引起地下水流动的稳态解，该解与外边界恒定水头的条件有关。Ataie - Ashtiani 等人推导出了在无限小井半径和定抽水速率条件下非完整井捕获区的解析解。利用 Izbash 方程和线性化过程，Wen 等人提出了一个近似解析解，可以描述承压含水层中非达西流向非完整井的流动。Feng 和 Wen 考虑了井壁表皮效应的影响，提出向承压含水层中非完整井的非达西流的解析解。表 1 总结并比较了上述可用的解析模型。

表 1 完整井和非完整的解析模型对比

模型	井结构	井径	地下水流	表皮效应	含水层类型
本文	同一井中有 2 个非完整井	0	达西流	否	无限大承压含水层
Theis	完整井	0	达西流	否	无限大承压含水层
Chen	完整井	0	达西流	否	有限承压含水层
Wen	完整井	0/ 有限	非达西流	否	无限大承压含水层
Lin	完整井	有限	达西流	是	有限两区承压含水层
Hantush	非完整井	0	达西流	否	无限大承压含水层
Chiu	非完整井	有限	达西流	是	无限两区承压含水层
Wen	非完整井	0	非达西流	否	无限大承压含水层
Feng	非完整井	有限	非达西流	是	无限两区承压含水层

然而，与上述对完整井或非完整井地下水流动的研究相比，对单井循环系统的特殊井结构的研究相当有限。只有少数学者研究涉及具有单井循环系统的含水层中地下水流动。Sorensen 和 Reffstrup 最早提出了分析一种新型地下水热泵系统的地下水流动和传热的简化数学模型，该系统用同一钻井抽取和回灌地下水。Ni 等人开发描述在越流承压含水层中由单井循环系统引起的地下水流动的数学模型，基于叠加原理，采用 Hantush 导出的非完整井的解析解，Ni 进一步将这两个非完整井的解析解相加，得到相关地下水流动的解析解。虽然利用叠加原理可以方便地得到解析解，但这种方法不可避免地会引入复杂井构函数等问题。Hantush-Jacob 井函数使解析解更加复杂，增加了不稳定性和计算成本。随后，涂坤等人利用分离变量法和拉普拉斯变换推导出了一个封闭形式的稳态解析解，用于研究承压含水层中的地下水流动。但是，他们的解决方案仍然包括复杂的 Hantush-Jacob 井函数和井构函数。因此，为了解决以上问题，本文通过结合拉普拉斯和傅里叶余弦变换，严格推导出基于单井循环系统的控制方程的解析解。

本研究主要目的是开发一个描述承压含水层中地下水流动的通用解析数学模型，该模型适用于的井型结构独特的单井循环系统，该系统集两口非完整井于同一井。利用拉普拉斯余弦变换和傅里叶余弦变换，得到了拉普拉斯域降深的解析解。分析了渗透系数、隔断区长度和其他参数对降深分布的影响，还导出了时域的稳态解，据我们所知，其他研究人员目前还未对此进行相关研究。在灵敏度分析中使用瞬态降深的解析解来研究不同参数对降深的影响，并确定在设计单井循环系统时必须仔细考虑的相关参数。

2. 数学模型

为了研究单井循环系统中的地下水流动，建立如图 2 所示数学模型。对该数学模型作出以下假设：(1) 承压含水层在水平方向上是均质、各向异性、无限大的；(2) 下伏和上覆岩石不透水、均质、各向异性和均厚；(3) 承压含水层中地下水流遵循达西定律；(4) 水头升降引起的地下水的存储和释放是瞬时的；(5) 抽水和回水速率 Q 为常数 (抽水为正，回注为负)；(6) 井径无穷小，可视为 0。

控制方程

基于上述假设，承压含水层中地下水流的方程可以描述为：

$$K_r\left(\frac{\partial^2 s(r,z,t)}{\partial r^2}+\frac{1}{r}\frac{\partial s(r,z,t)}{\partial r}\right)+K_z\frac{\partial^2 s(r,z,t)}{\partial z^2}=S\frac{\partial s(r,z,t)}{\partial t} \quad (1)$$

其中 r 为径向坐标 (L)；t 为时间 (T)；s 为地下水降深 (L)；K_r 和 K_z 分别为径向水力传导系数和垂向传导系数 (LT^{-1})；S 为含水层的比容量 (L^{-1})。

3 结果与讨论

3.1. 解析解验证

通过与 Ni 等人的求解结果比较，验证了推导所得瞬态降深解析解的准确性。他们认为，单井循环系统是由非完整注水井和非完整抽水井共同构成，参考 Hantush 提出的针对非完整注水井的解析解计算方法，Ni. 等基于叠加原理将同一单井循环系统中两个非完整井的解析解相加，推导得出的单井循环系统地下水渗流理论解。这些单井循环系统的解析解 (即方程 7 和 Ni 等人所得解析解) 用于计算具有以下参数的系统的瞬态地下水

降深：Q=60 m^3/h，K_r=0.1m/h，K_z=0.01m/h，S=0.0001m^{-1}，d=40m，d_1=15m, d_2=10m, d_3=15m，r=5m, z=15m。从图 3 可以看出，推导所得新解析解与 Ni 等人的计算结果非常吻合。

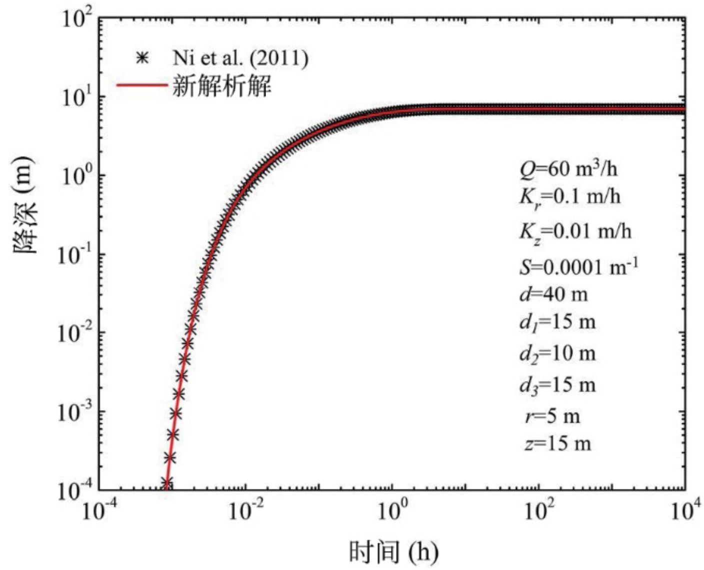


图 3 降深新解析解与 Ni 等人计算结果比较

3.2. 稳态降深

图 4 描绘了单井循环系统稳态降深和稳态流量矢量 (分别为方程 10 和 12) 的等值线。与图 3 相同，该处参数设置为：Q=60 m^3/h，K_r=0.1m/h，K_z=0.01m/h，S=0.0001m^{-1}，d=40m，d_1=15m, d_2=10m, d_3=15m。如图所示，稳态降深的等值线以承压含水层的水平中面呈对称分布，且随着距井轴的距离变化而剧烈变化。隔断区周围水位降深等值线较为密集，说明该区域的水力梯度较大。此外，由于水流对称，承压含水层中平面附近的水位降深的绝对值很小；z=20m 处 (承压含水层中部) 水位降深为 0。

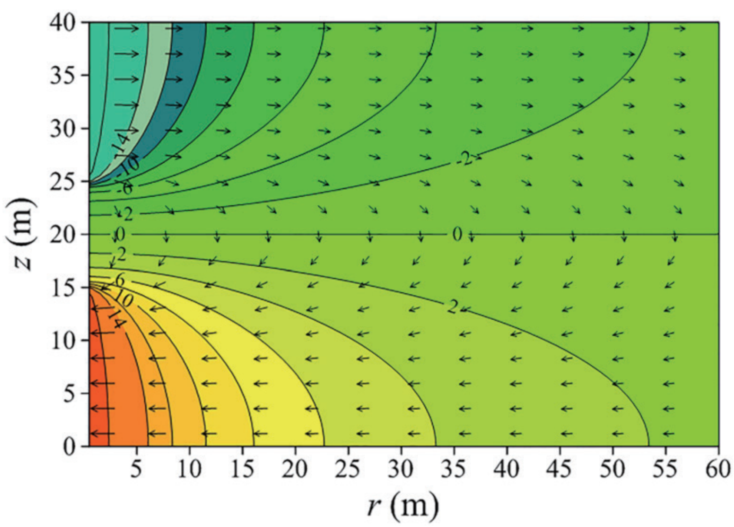


图 4 单井循环系统中稳态水位降深和稳态流量矢量等值线

3.3. 径向水力传导系数

图 5 表示不同径向水力传导系数随时间对水位降深的影响 (K_r=0.01、0.02、0.05 和 0.1 m/h)。其他参数设置同上述示例中相同：Q=60 m^3/h，K_z=0.01m/h，S=0.0001m^{-1}，d=40m，d_1=15m，d_2=10m，d_3=15m，r=5m，z=15m。在运行前期，水位降深幅度随着径向水力传导系数 Kr 的增大显著增大，在运行后期随着 Kr 的增大而逐渐减小。良好的水力传导系数使得地下水在早期抽取 / 注入含水层时反应更快，抽水区降落漏斗区域扩展更快，地下水能得到及时补充。因此，当水力传导系数较大时，运行早期的水位降深量较大。相比之下，在后期，较大水力传导系数引起的降深增加量反倒小于较小水力传导系数。此外，值得注意的是，当径向水力传到系数较大时，降深量收敛至稳态的速度更快。

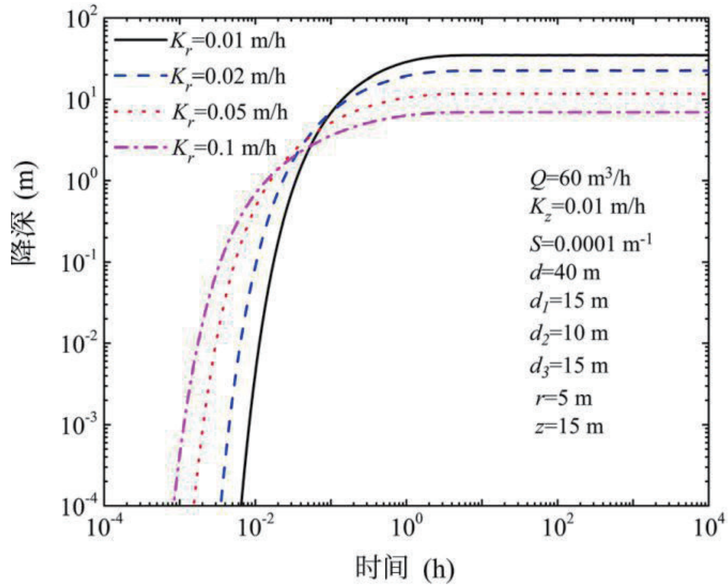
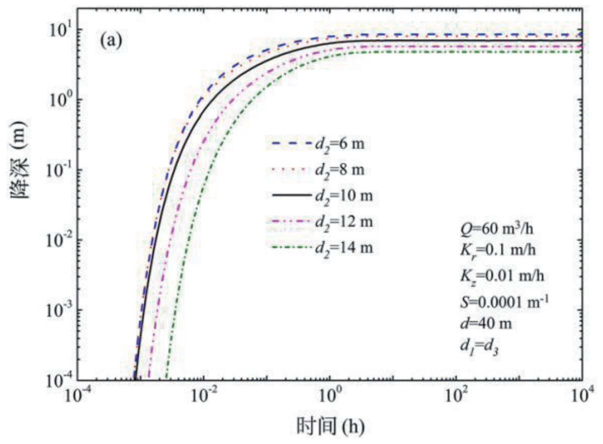


图 5 径向导水率 Kr 对水位降深随时间的影响

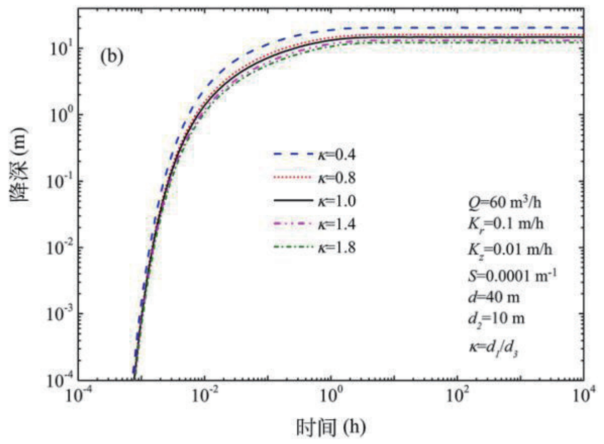
3.4. 隔断区

图 6 为单井循环系统中隔断区长度 d_2 对地下水水位降深的影响。如图 2 所示，隔断区位于承压含水层中部，介于井的抽水段和回水段之间。使用与上节相同参数设置以获得图 6 所示计算结果：Q=60 m^3/h，K_z=0.01m/h，S=0.0001m^{-1}，d=40m，d_1=15m，d_2=10m，r=5m，z=15m。同时，采用不同的隔断区长度 d_2=6m，8m，10m，12m，14m，对 d_1 和 $_3$ 进行相应调整以使 d 保持不变。从图 6a 中可以看出，隔断区长度越短，运行早期的降深越大，而隔断区长度对运行后期的降深影响很小。这是由于隔断区长度减小时，相应抽水段和回水段的长度增大，此时单位井长所需抽水速率和注水速率变小 (总抽水速率 / 注水速率恒定)。因此，较短的隔断区在早期引起的水位降深较大。此外当运行时间超过 1 h 后，降深变化量趋于稳态，降深量变化曲线维持水平平行，这与径向水力传导系数有所不同。图 6a 中，将隔断区长度从 8 m 减小到 6 m 时对降深的影响可忽略不计，两条曲线在图中几乎重合。隔断区长度越大，降深差越大。

抽水段和回水段长度比 对水位降深的影响示于图 6b (K=d_1/d_3，$d_1 \neq d_3$，d 和 d_2 为常数)。由图可知，长度比 越大导致降深越小，相对于较大 值，降深的变化对较小 更为敏感 (从 1.0 至 1.8)。在各运行工况中，降深均逐渐收敛至稳定状态。



a) d_1=d_3



b) 各长度比 =d_1/d_3，d_2 为常数

图 6 隔断区长度 d2 对降深随时间的影响

3.5. 含水层比容量

图 7 说明了不同比容量含水层的降深随时间的变化 (S=0.0001，0.0002，0.0005，0.001m^{-1})，其他参数设置与之前其他工况相同。如图所示，早期降深量随着比容量 S 的增大逐渐减小。相比之下，尽管各工况的含水层比容量不同，但运行后期降深曲线最终都收敛至相同渐近值。在其他条件相同的情况下，比容量大的含水层释放水量更多，因此运行早期的降深随着含水层比容量水平增大而减少。由于含水层释水过程在后期基本完成，所有的降深曲线在运行 10 h 后最终趋近并稳定于相同的渐近值，可以认为在运行后期，含水层比容量对降深的影响不显著。

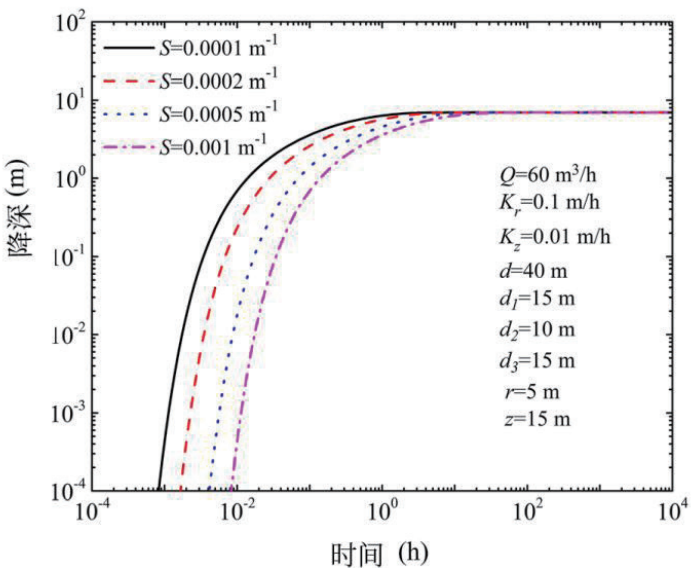


图 7 含水层比容量对水位降深的影响

3.6. 抽水时间

分析不同抽水时间下的降深随距离的变化也是很有趣的 (t=0.1,1,10 h，稳态)，其他参数设置同上。本节使用稳态降深的解析解方程 10 作为参考。从图 8 可以看出，在近井处水位降深仅随时间略有变化，这表明在近非完整井区域，地下水流量迅速达到准稳态。另外，抽水时间为 10 h 的降深曲线与稳态降深曲线几乎重合，这表明单井循环系统的整个渗流场会相对较快的达到稳态。

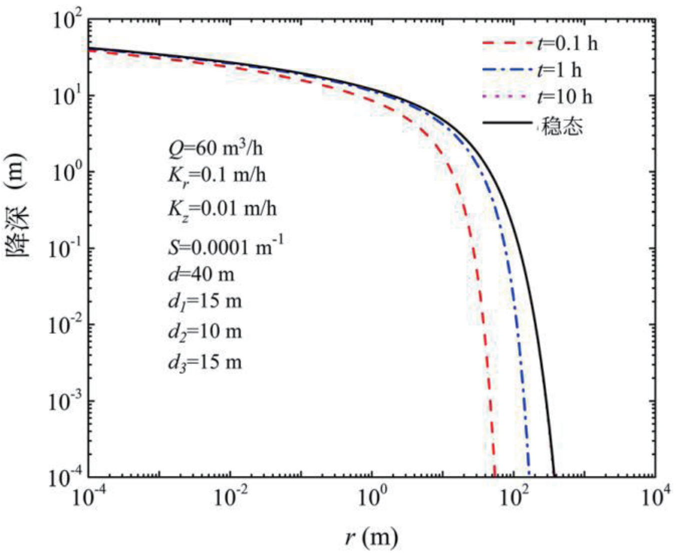


图 8 抽水时间 t 对水位降深随径向距离的影响

4. 结论

本研究建立了一个通用数学解析模型来研究单井循环系统中地下水流动的特征。利用拉普拉斯和傅里叶余弦变换，在初始条件和边界条件下同时求解控制偏微分方程，获得了拉普拉斯域中瞬态降深的解析解，并使用 Stehfest 算法对其进行了数值反演。本文还提出了用于单井循环系统时降深的稳态求解，并分析了不同参数对降深的影响。主要研究结论如下：

(1) 稳态水位降深的等值线围绕含水层的水平中线对称分布，当 d_1=d_3 时，降深随着距井轴的距离剧烈变化。隔断区周围的降深等值线较为密集，说明该区域的水力梯度较大。

(2) 当 d_1=d_3 时，隔断区的长度 d_2 对降深有显著影响。当 $d_1 \neq d_3$，隔断区长度 d_2 为常数时，更大的长度比 (=d_1/d_3) 造成更小的降深，随着 进一步增大，其对降深的影响逐渐不明显。

(3 在单井循环系统中，水位降深的空间分布对径向水力传导系数 K_r 和隔断区长度 d_2 反应敏感，不同参数对水位降深有不同的影响周期。

(4) 水位降深在前期对参数 S, d_2，K_r 和 K_z 不敏感，运行后期对这些参数非常敏感，尤其是对径向水力传导系数 K_r。

第二届中国国际地热产业发展高峰论坛暨产业装备博览会在天津成功召开

SUCCESS OF THE 2nd CHINA INTERNATIONAL GEOTHERMAL INDUSTRY DEVELOPMENT SUMMIT FORUM & INDUSTRIAL EQUIPMENT EXPO IN TIANJIN

编辑：王赫

2021年9月24日至26日，由中国地热与温泉产业技术创新战略联盟、中国煤炭地质总局水文地质局、河北省地热产业协会联合主办的第二届中国国际地热产业发展高峰论坛暨产业装备博览会在天津市社会山国际会议中心隆重召开。此次会议以“双碳目标背景下，产业发展新机遇”为主题，邀请超百余为来自各级政府能源、国土、建设、规划、节能、环保、水利、电力部门；地产商、温泉开发商、休闲养老开发商；地热及地源热泵行业企事业单位；各基建、规划、设计、科研、教学、房地产、建筑节能、物业等企事业单位；热泵技术开发、设计、施工安装，热泵集成企业；地勘、钻井、地热勘察规划、设计、开发、利用单位;地热发电、暖通、中央空调等；温泉服务、管理，温泉服务业人员，温泉旅游规划与设计、温泉旅游中的智能设备研发与应用;高等院校、科研院所;相关投融资机构、新闻媒体、社会团体领导及专家等共计300余人，共同研讨、分享、绘制产业新蓝图。

产业装备博览会参展设备囊括地源热泵技术与设备；水源热泵技术与设备；污水源、余热利用技术与装备；地热发电机组及技术与设备；中深层地热能供暖技术与设备；中低温发电技术；干热岩发电技术与设备；地热+多能互补清洁能源站技术与设备；地热+农业；地热+旅游；地热+养生；地热能+智慧能源；地热钻井设备与材料；地热能发电机供暖配套产品；地（水）源热泵配套产品；清洁供暖及温度测量设备、传感器及温控器等供暖、发电自控系统等。

国务院资深参事、原国家发改委能源局局长徐锭明、中国工程院院士、国家煤矿水害防治工程技术研究中心主任武强、原国土资源部地质环境司副司长李继江、中国地调局水环中心党委书记、俄罗斯外籍院士张发旺、中国科学院地热资源研究中心主任庞忠和、国际地热协会前理事郑克棪、天津市规划和自然资源局副局长张云霞等领导专家出席论坛，《中国地热能》杂志作为联盟及大会的支持媒体参加并出席此次会议。

本次大会在国务院资深参事、中国工程勘察大师、住建部科技委顾问兼部建设环境工程技术中心主任王秉忱的欢迎致词中拉开帷幕。

中国地热与温泉产业技术创新战略联盟理事长刘玉强、河北省地热产业协会会长刘建军、中国煤炭地质总局水文地质局局长、党委书记蒋向明、天津市规划和自然资源局副局长张云霞分别致词。对推进地热、温泉综合开发利用的积极作用给予肯定，对未来的发展提出了建议和期许。随后，武强院士、徐锭明参事、李继江司长等多位领导专家分别就政策解读、地热产业发展、创新技术推介、地热供暖系统应用及温泉产业发展等主题对我国地热能行业的发展及在双碳目标下地热发展机遇与热资源勘查、新技术开发利用等展开了演讲，提出了发展方向指导性意见。

会议期间，参会者结合会议内容及装备博览会中所展示的新设备与新技术共同探讨地热、温泉行业、碳中和及碳达峰现状及未来发展趋势。并随后一同前往中国能建电力产业园对地热资源综合开发利用项目进行了实地考察。

我国地热资源开发利用现状与发展趋势概论

OVERVIEW OF CURRENT SITUATION AND DEVELOPMENT TREND OF GEOTHERMAL RESOURCES DEVELOPMENT AND UTILIZATION IN CHINA

作者：王秉忱（国务院资深参事、中国工程勘察大师、住建部科技委顾问兼部环境工程中心主任
中国地热与温泉产业技术创新战略联盟总顾问、国家地热中心技术委员会名誉主任
《中国地热能》杂志编委会主任）

在京津冀一体化背景下，为落实习近平总书记提出的重大战略部署，解决京津冀三地面临的严重空气污染问题，地热产业有了更大的发展机遇。到2020年，三地的供暖和制冷面积累计达到4.4亿平米，任务艰巨！

由于严重的雾霾目前虽稍有改善，但仍得不到彻底地解决，人民群众意见很大，国际影响也不好，有关各地政府部门也急需找到解决问题的对策。地热能进一步合理开发利用被提到议事日程，直接推动了地热产业的发展和地源热泵技术的推广应用。近年来，深、浅地热能开发利用形势发生了巨大的变化，如：

1. 2014年，为进一步推动地源热泵技术推广，财政部与住建部联合发文，要求对地源热泵应用工程提供资金补贴；国家近期也出台了《可再生能源发展专项资金管理暂行办法》和《节能减排补贴资金管理暂行办法》等政策性文件，鼓励采取节能减排措施，促进行业发展。

2. 2015年10月7日，原国防科工委主任、中国工程院院士丁衡高上将，基于对北京恒有源集团研发的“浅层地热单井循环换热地热能采集技术”的长期跟踪和深入了解，给国务院总理李克强同志写信，提出“关于推荐浅层地热能作为供暖替代能源的有关建议”，具体建议内容如下：

(1) 政府应首选或强制推行浅层地热能作为供暖替代能源，不仅要从节能角度考虑，还要上升到国家能源战略和生态文明建设高度看待；应以能源安全、原创技术、对国际低碳环保的贡献来审视和综合评价，并且协调制定出强制推广该技术的相关政策；

(2) 规范地热能供暖动力电的价格。浅层地热能为建筑物无燃烧供暖的地源热泵环境系统的动力电价，是供暖成本的核心，规范地热能供暖动力电的价格 (不高于居民用电价格) 是该技术可持续推广的关键；

(3) 进一步加快落实，国家发改委对此项技术进行调研后，在 2013 年向丁衡高和王岐山同志呈报的《国家发展改革委关于加快推广单井循环换热地热能系统技术的报告》中要求采取的五项措施：①加大定位力度；②推动产业发展；③实施激励改革；④夯实推广基础；⑤鼓励地方推广。

李克强总理对此建议高度重视，10 月 10 日，他在丁衡高同志的建议上批示：“请肖捷同志（时任总理办公厅主任）阅处”，肖捷主任 10 月 12 日批示：“转请发改委会同国土资源部、环境保护部、住房和城乡建设部、能源局研究，提出意见”。

有关各部委立即行动，同时我也以国务院资深参事的身份给国家发改委徐绍史主任、国土资源部姜大明部长和汪民副部长、环保部陈吉宁部长和住建部陈政高部长写信，表示完全赞成丁衡高主任的建议，请几位领导同志予以高度关注并加以落实。姜大明部长亲自给我写了回信。国家发改委综合各有关部委意见，在组织专家讨论与调研的基础上，于 2015 年 12 月 31 日向李克强总理呈报了《国家发展改革委关于我国浅层地热能开发利用有关情况的报告》，明确提出：应尽快完善支持改革和规范要求，加快推广地源热泵开发利用浅层地能，为建筑提供节能高效的热冷一体化用能服务，有效减少燃煤消耗的结论性意见。李克强总理 1 月 6 日在此报告上批示：“请将有关情况告衡高同志”。

在 2017 年 2 月，由国家发改委环境资源司蒋靖浩处长主持召开会议征求水利部水资源司郭孟卓司长和毕守海处长等领导同志对丁衡高主任的 3 点建议和国家发改委上述报告的意见和建议，我也被邀请参加了征求意见会。

恒有源科技发展集团在 2016 年 1 月 25 日向丁主任呈报了“关于在北京首选和强制推广浅层地热能作为供暖替代能源，走出治雾霾新路子”的报告，丁主任当天即将此报告批转给时任北京市委书记郭金龙同志请他关注此事，郭金龙书记很重视，很快批示给时任北京市长的王安顺同志落实。

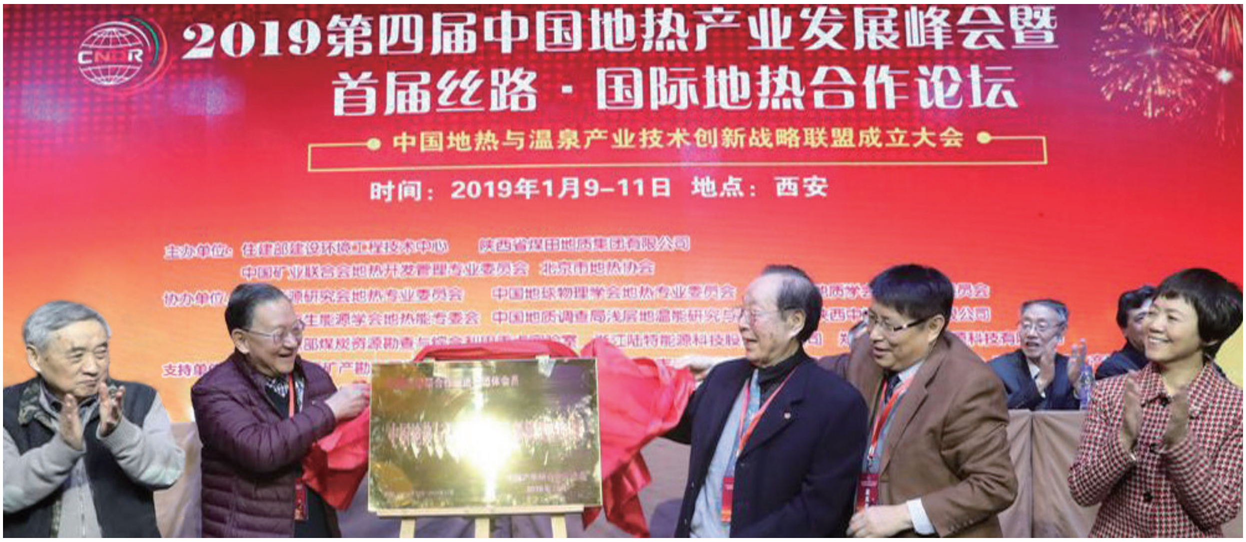
3. 2016 年地热能开发首次被列入“全国经济社会发展总规划”根据已编制完成的《中国“十三五”地热产业发展规划》，到 2020 年，我国地热供暖 / 制冷面积将累计达到 16 亿平方米，加上发电、种植、养殖、洗浴等，地热能可替代标准煤 7210 万吨。为了强化和推动规范地热产业的发展，同时在“一带一路”战略指导下，国家能源局和国家标准化技术委员会于 2016 年 5 月正式组建了能源行业地热能专业标准化技术委员会，着手提出地热领域的国家标准、发展规划和地方标准，这将大大推进中国地热产业发展的科学化和规范化。

4. 2016 年 1 月，由我们住建部建设环境工程技术中心和中国能源环保高新技术产业协会两个单位主办了在江苏省苏州市召开的“浅层地热能开发和地源热泵技术交流大会”，邀请了不少专家学者和业界朋友参加，中国工程院武强院士和中国科学院汪集旸院士等人均在会上做了重要的学术报告。国家地热中心两次召开有关中国地热产业发展的重要会议：一次是在 2016 年 6 月召开的“中国地热产业规划和布局战略研究 (中国工程院重点咨询项目) 的启动会”，有 20 多位院士参加。另一次是在 2016 年 10 月召开的“中国工程科技论坛暨 2016 中国地热国际论坛”，作为应邀参会者，我见证了两次会议对中国地热产业的规划、布局、技术、改革等一系列问题进行的深入研讨。

5. 2017 年 12 月，国家发改委、国土资源部、环保部、住建部、水利部和国家能源局六个部门联合发布了“关于加快浅层地热能开发利用，促进北方采暖地区燃煤减量替代的通知”。这份重要文件指出：在开发利用中，要坚持因地制宜、安全稳定、环境友好、市场主导与政府推动相结合等原则，要统筹推进浅层地热能开发利用，科学规划开发布局，提升运行管理水平，创新开发利用模式，加强政策保障和监督管理，内容全面系统。这份文件充分吸取了有关部门的意见和建议，对进一步推动浅层地热能的开发利用有重要指导意义。

6. 2018 年 5 月，国家地热中心委托中石化集团有关部门和中科院地质与地球物理所，天津大学、上海交大等单位完成了中国工程院咨询项目：“中国地热产业规划和布局战略研究”，其成果包括一份综合报告、五份子课题报告和一份院士建议。我和十几位院士应邀参加此项目成果的评审会，我认为这是关系我国今后地热产业发展的重大咨询研究成果。

7. 2019 年 1 月，由中国产学研合作促进会批准成立了中国地热与温泉产业技术创新联盟，集中了国内开发地热与温泉事业的各有关单位，包括机关、企业及科研院所的大批负责人和行业专家，形成实力很强的专业平台 ，对推进我国地热与温泉产业的发展将会起到重要的指导与推进作用。2019 年 4 月已召开了联盟的第一届理事会，确定了联盟的工作目标和分阶段工作计划，将会进一步掀起我国地热能开发利用的新高潮！



WGC2023，中国地热向世界高光亮相

WGC 2023: CHINA'S GEOTHERMAL ENERGY SHINES TO THE WORLD

作者：郑克棪（中国技术监督情报协会地热产业工作委员会）

世界地热大会由国际地热协会主办，是世界地热领域规模最大、水平最高的盛会。2023 年世界地热大会（WGC2023）将在中国举行，中方组织委员会已在推迟举行的本届 WGC2020+1 大会闭幕式上展示了 WGC2023 的徽标（如图）。次日 2021 年 10 月 28 日，WGC2023 中国组织委员会与国际地热协会的 WGC2023 指导委员会举行了第三次联席会议线下 + 视频会议，筹备组织工作在积极进行中。

1. 历届世界地热大会回眸

国际地热协会（International Geothermal Association，IGA）1989 年成立，自 1995 年起每 5 年举办一次世界地热大会 World Geothermal Congress，简称 WGC，迄今已举办了 6 届。

中国能源研究会地热专业委员会 1998 年加入国际地热协会成为会员，但我们参加了历届世界地热大会。

历届世界地热大会概况

年份	国家	地点	大会主题
1995	意大利	佛罗伦萨	地热能世界范围的利用： 一种本土的环境良性的可再生能资源
2000	日本	别府和盛冈	支持地热能进入 21 世纪
2005	土耳其	安塔利亚	地热能：本土的可再生的绿色选择
2010	印度尼西亚	巴厘	地热：改变世界的能源
2015	澳大利亚	墨尔本	从澳洲新西兰视野正确看地热
2020+1	冰岛	雷克雅未克	奔向源头
2023	中国	北京	（待定）

1995 年世界地热大会在意大利举办，到会 60 多国 1000 余人，会后参观了 1904 年世界上第一个地热发电的拉德瑞罗地热电站，当时发电 545 兆瓦。

2000 年世界地热大会在日本举办，日本是世界第 4 个地热发电的国家，当时排名世界第六。垄断世界地热发电设备生产 70% 的日本三菱、东芝、富士电气公司赞助了大会，支持第三世界代表参会，使到会 1700 余人。大会分两段，分别在南部九州的别府和北部本州的盛冈举行，也参观了两地的地热电站。

2005 年世界地热大会在土耳其举办，到会 83 国 1500 余人，土耳其竭力期望国际帮助来改变其落后状态，果然在大会之后重大转折，使其地热发电迅速跃升为世界第 4 位。

2010 年世界地热大会在印度尼西亚举办，到会 85 国 2500 余人，创最高人数，热情高涨的本国 800 多地热人参会。印度尼西亚是第三世界发展中国家，地热发电起步排在十名之后，但其 2010 年已成世界第三位。参会代表参观了印尼最大的沙拉克地热电站，当时发电 377 兆瓦。

2015 年世界地热大会由澳大利亚联合新西兰联合举

2005 年世界地热大会一角

办，到会 82 国 1600 余人，新西兰是世界第二个地热发电国家，当时地热装机 1005 兆瓦，是进入世界吉瓦级俱乐部的五强之一，澳大利亚地热起步晚，但干热岩 EGS 做成 1 兆瓦发电，是当时亮点。

2020 年世界地热大会在冰岛举办，因全球性疫情影响推迟至 2021 年，仍线上、线下联合举行。冰岛是世界第九个地热发电国家，一直保持在世界排名的八、九位，但冰岛创建了世界首例岩浆钻探，其 IDDP 项目钻遇岩浆，试验注水产出 450℃ 过热干蒸汽 45 千克每秒，单井发电潜力 36 兆瓦，为世界最大产能。

已经举办的 6 届世界地热大会全都宣扬了地热发电的成就，让外国参会者参观他们的地热发电项目，还在大会宣言中以地热发电的能力系数远高于其它可再生能源等优越性而呼吁开发。

2.2023 世界地热大会将在中国举办

世界地热大会今后改为每 3 年举行一次，中国已获得了 2023 年世界地热大会的举办权。在 2019 年申办辩论时，中国以地热直接利用持续 20 年来居世界第一，宣传了地热能除了发电之外，世界上更多更普遍的中低温地热资源可以提供热能为人类社会广泛应用，发挥节能减排的巨大作用，欢迎世界到中国来看看。这一观点终于胜出，中国申办成功！

2020 年世界地热大会因疫情影响推迟一年，刚过去的 10 月 27 日在冰岛雷克雅未克的大会闭幕式上，发布了《雷克雅未克宣言》。这一次的《雷克雅未克宣言》应对全球气候变化和加强能源转型的形势，提出了未来十年全球地热项目可持续增长的原则：可持续地热带来的好处远不止发电，地热项目应该始终为社区、公民和气候带来好处。宣言号召各利益相关者，寻求与其它可再生能源的系统集成效益，为所有人提供清洁、负担得起的能源。

WGC2020+1 雷克雅未克宣言

《雷克雅未克宣言》所包含的与以前不同的韵味，将在 2023 年世界地热大会得以发挥，我们将用中国的实例，向世界充分展示“发电之外”的地热直接利用，这可以更好地实现“为所有人提供清洁、负担得起的能源”。

3. WGC2023 可以期待的中国地热亮相

时间太紧张了。世界地热大会 5 年期缩短为 3 年期，全球 COVID-19 疫情影响又将本届大会推迟了一年，留给下届 2023 世界地热大会只剩下 18 个月的时间了，我们必须加紧准备工作，保障届时的全面高光亮相。

预计出席 2023 年世界地热大会约 3000 人，代表 90 个国家，请他们来看什么？我们能拿出什么展示？

3.1 全面展示中国地热的亮点

既然来到中国，进了我们的家门，我们就可以不受约束地展示我们的各大亮点了。若去其它国家参加世界地热大会，只有论文版贴的展示，一篇论文给你一个版面，不足 2 平方米。但在中国的会场地区，到处可以有我们宣传的位置，拱形门、过道边、围墙上、建筑外立面、条幅、气球……，无数空间，尽可利用，全面展示中国地热的亮点。还有，WGC2023 大会的主题目前尚未敲定，希望集思广益，更多参与，提出最能代表时代和中国特色的响亮地热主题。

3.2 许多世界顶级的案例在中国

中国地热直接利用已独霸世界第一 20 年，我们的案例越做越大，使国外闻所未闻，比如像地源热泵，国外做的项目大到几千平方米，我们早就做出 10 万平方米，几年前有了百万平方米，现在南京市江北新城已经做出了 1600 万平方米！外国人要惊掉下巴了。这些世界顶级的成就，既可作为参观亮点，也能组建会前的培训课程内容，多项培训课题的落实尚在与国际地热协会的协商中。

3.3 世界最大地热直接利用企业排名

过去的世界榜单只有：世界上最大的地热电厂，美国盖瑟尔斯装机容量 1585MW；世界上最大的地热发电设备制造商，日本的三菱、东芝、富士 3 家占了世界总产量的 70% 多，美国的奥玛特占了双工质发电设备的 90% 多……。世界上从来没有对最大的地热供暖项目排名，没有对最大的地源热泵设备生产商排名……，现在，该我们来编制和亮出这类地热直接利用的世界排名表了。

3.4 不宜发电的资源可以用其热

新西兰 1958 年成为世界第二个地热发电国家，新西兰地热发电在世界排名靠前，但 2012 年新西兰第 34 届地热工作会议上，新西兰地热专家就提出了“地热就是瓦特吗？”的发问，意在提倡地热发电之外的热利用，将不能作为发电利用的中低温地热利用起来。然而，专家只是作报告发言了，要真正开展起来还有一系列的事要做。现在很好，《雷克雅未克宣言》提出了地热远不止发电，中国已经做出榜样了，欢迎大家来学习交流。

3.5 热利用的技术和经济门槛低于发电

世界地热的发展进度慢，与地热发电的技术高深、成本投入大有一定关系。为什么地源热泵的发展很快呢，因为地源热泵的技术相对简捷，成本投入也比发电要低，当然温泉洗浴医疗休闲的技术和经济约束条件更宽松，所以，中国地热的产业队伍，最初是温泉休闲业，然后是地源热泵行业，这样就整个把产业队伍壮大起来了。所以这个经验是可供一带一路中，发展中国家朋友们学习的。

3.6 中国地热论文可发挥优势

参加人数最多的世界地热大会是 2010 年在印度尼西亚举办的那届，达 2500 人，其中印尼本国参会 800 余人。第三世界的穷国，普通人要出国去参加个国际会议太难了，但在国内参会就容易得多了。2010 年印尼那届参会人数多，印尼人自己提交的论文也多。这样的方便条件，马上就到中国了，2023 年世界地热大会在中国举办，组织委员会大多是中国人，其中分担论文出版工作的技术委员会也大多是中国专家，这些都是有利条件。中国作者在世界地热大会上发表的论文数，1995 年 10 余篇，后来历届逐增为 20 余篇、30 余篇、50 余篇……，2020 年世界地热大会共发表论文 1931 篇，其中主办国冰岛最多 213 篇；印尼和德国第二、第三多；中国 119 篇居第四，美国 118 篇居第五。所以如同以前的举办国，相信 2023 年中国的论文数一定可以夺冠。

3.7 传统中国文明欢迎世界贵客

中华五千年历史，中国是传统的文明古国，礼仪之邦，中华民族讲求“有朋自远方来，不亦乐乎”，所以外国人乐意来中国，我们也有能力当好东道主。大会为参会嘉宾和他们的陪同准备有社会和文化活动，万里长城、中国京剧、北京烤鸭、丝绸制品等等都是外宾的喜爱，我们可以充分服好务，让外宾们乘兴而归。

3.8 样板项目欢迎外宾参观学习

各届世界地热大会都有会前和会后的参观考察，现在许多项目报名尚在备审之中。我们要拿出最亮点的项目，准备好介绍材料，待中方组委会与国际指导委员会的下次联席会议讨论选定，充实世界的样板，奉献给世界地热同行。

4. 注意克服我们尚存的不足

世界地热大会是中外地热交流的平台，我们展示中国做出榜样的中低温地热直接利用，但我们也有地热发电的掉队和干热岩 EGS 研究的落后，这方面我们要与世界同行多讨论，向世界学习。

4.1 地热发电是弱项

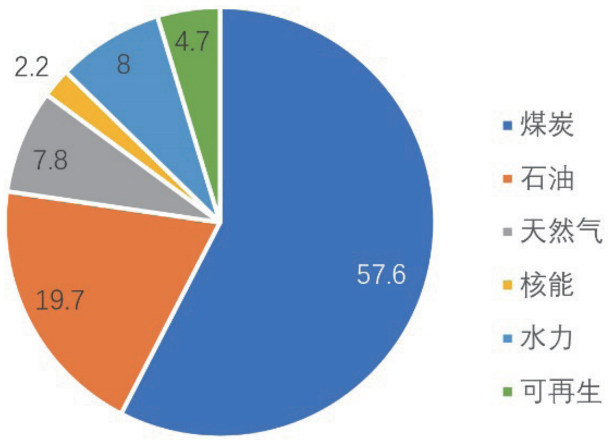
中国首次地热发电成功在 1970 年，是世界第七个地热发电的国家，70 年代低温地热发电和高温地热发电都搞成了。但就是发展太慢，迄今干了 50 年总装机容量不足 45 兆瓦。“十三五”的进步是 2018 年西藏羊易地热电站上网 16 兆瓦，加上几处小试验共新增 18.08 兆瓦，仅实现规划指标的 4%。落后的原因需要探讨，但“十三五”地热发电未得到分文上网电价补贴，而且还让缴纳地热资源税，实属罕见。

4.2 地热教学不可无

国际上对中国纳闷，你们地热直接利用占了 20 年世界第一，但中国的大学居然没有地热专业？ 2020+1 世界地热大会的统计，中国从事地热的专业人年数未排上世界前 5 名。这些明显该是我们的不足。所幸，2021 年秋季学年起，中国地质大学（北京）开设了地热专业，首招了 25 名本科学生。

4.3 为双碳目标做贡献

中国已经确立了减碳目标：2030 年碳达峰，2060 年碳中和。这是非常艰巨的硬目标。2020 年我国消费能源构成中，非化石能源(核能 + 水力 + 可再生能) 占 14.9%(下图)，这与能源转型双碳目标的差距还很大。地热能与其它可再生能源目前只占总能源消费的 4.7%，为双碳目标的实现必须贡献更大的力量。鉴于我国电网接纳风电和太阳能电力波动性和间歇性的能力有限（目前为 15%），能作为基础荷载的地热电力不能偏废（不能仅满足于地热直接利用），目前地热发电的落后面貌须要彻底改变，这需要由国家激励政策的支持。可喜最近杭州锦江集团刚与西藏自治区当雄县签订了羊易地热电站二期项目，将再建 16 兆瓦新机组。



2020 年我国能源消费构成（%）

浅层地热能促双碳

SHALLOW GEOTHERMAL ENERGY ACCELERATES THE ACHIEVEMENT OF THE "DOUBLE CARBON GOALS"

特约记者：马晓芳

节能、高效、无污染 浅层地热能助力国家“双碳”目标

乌飞兔走，又是一年供暖季。在国家碳达峰、碳中和战略背景下，清洁供暖成为今年供暖季的主流声音。与此同时，各行业也围绕“双碳”开始了势如破竹的低碳转型，作为耗能大户的供热行业亦不能例外。但是，供热行业如何为实现“双碳”目标发挥作用？这就需要从国家政策到行业自律各方多管齐下发挥效用。纵观现行多种供暖形式，浅层地热能可再生、高效、无污染的独有特点，成为供热行业助力“双碳”目标的优势选项。因此，需要不断加大浅层地热能行业的科技研发力度，努力提升浅层地热能清洁供暖的占有率，以事实和数据作为有力支撑力促浅层地热能成为供暖替代能源的首选，积极推进新时代供暖能源转型。

2021年是中国共产党成立100周年，也是“十四五”开局之年。面对错综复杂的国内外形势，能源安全风险不容忽视，而全面落实碳达峰、碳中和目标，实现绿色低碳转型的发展任务也十分艰巨。国家能源局发布的《2021年能源工作指导意见》明确指出，要加大清洁取暖工作力度，因地制宜实施清洁取暖改造，建立健全清洁取暖政策体系，确保取暖设施安全稳定运行，实现北方地区清洁取暖率达到70%。

来自地球之下的“热”爱

人们所理解的普遍意义上的清洁取暖、供暖，是指利用天然气、电、地热、生物质、太阳能、工业余热、清洁化燃煤（超低排放）、核能等清洁化能源，通过高效用能系统实现低排放、低能耗的取暖方式，包含以降低污染物排放和能源消耗为目标的取暖、供暖全过程，涉及清洁热源、高效输配管网（热网）、节能建筑（热用户）等环节。

地球内部的高温熔岩将地球岩土孔隙中的水加热，被加热的地下水通过岩石缝隙自然渗出形成温泉。而依靠热泵技术提取地球浅层的热量用于建筑物供暖，这部分低温能量被称为浅层地热能。供暖利用的浅层地热能一般指0~120米深度内储存的温度在25℃以下的低品位可再生热能。作为近20年来被快速开发利用的清洁环保型的新型能源，浅层地热能储量丰富、分布广泛、再生迅速；浅层地热能可在一个使用季节中通过地下局部的暂时降低温度持续不断地输出热能；稳定性好，温度更接近于使人舒适的室温。

数据显示，浅层地热能作为北方供暖的替代能源，每个采暖季，每100万平方米建筑可直接替代散煤约3万吨，减排二氧化碳8万吨，二氧化硫227吨，氮氧化物80吨，烟尘319吨。相较直热式电暖气，可减少耗电量约9×10^4兆瓦时。

实践也证明，浅层地热能作为供暖替代能源，可以实现区域无燃烧、零排放的为建筑物理变化过程供暖，成本低于烧煤，有望成为供暖能源转型的主力，或将引发一场供暖能源革命。

更多人切身感受到地热能优势

《2021年能源工作指导意见》强调，要研究探索南方地区清洁取暖，在长江流域和南方发达地区，鼓励以市场化方式为主，因地制宜发展清洁取暖，培育产品制造和服务企业。研究推进西南高寒地区清洁取暖改造，加大政策支持力度，加强电网、天然气管网等建设。伴随着浅层地热能供暖技术的普级，越来越多的地区开始试点浅层地热能供暖。通过见诸媒体的报道不难看出，在今年供暖季，越来越多的普通民众感受到了浅层地热能供暖带来的惊喜。

地热能产业技术发展的意义重大，近年来，我国大力推动浅层地热能等可再生能源建筑应用取得了明显成效。资料显示，安徽省累计建成浅层地热能建筑应用项目1000多万平方米，浅层地热能为安徽建筑节能减排做出了积极和重要的贡献。

黑龙江省也出台《黑龙江省地热能供暖专项规划》，要求2021年重点示范区中，哈尔滨应至少启动2个示范项目建设。该文件要求通过“黑龙江省建设职业培训与就业服务平台”参加线上地热能供暖专项规划和技术标准培训，促进技术应用。黑龙江各地市要根据相关要求及目标措施制定本地区地热能供暖发展计划，明确年度发展目标，出台相关支持政策，加快示范项目建设。要在集中供热未覆盖区、超低能耗建筑、绿色建筑，以及公用建筑、工业厂房、城镇棚户区改造、保障性住房等房屋建筑工程中，率先打造示范项目，带动本地地热能供暖良性发展。

实现碳中和目标，不仅要求取暖行业热源侧清洁化，还要求企业运用现代化科技手段供热。作为供热领域较早从事浅层地热能供暖的企业，恒有源集团很早就已开始围绕科技运用浅层地热能谋篇布局，通过企业独有的浅层地热能供暖技术，结合自主研发的智慧控制平台，运用物联网和数字化等技术，构建全程可控的数字化热网，这也成为供热企业助力“双碳”目标的重要途径。

深入落实我国碳达峰、碳中和目标要求，需要推动能源生产和消费革命，高质量发展可再生能源，大幅提高非化石能源消费比重，控制化石能源消费总量，着力提高利用效能，持续优化能源结构。地热是一种清洁环保、分布广泛、资源丰富、安全稳定的优质可再生能源，对我国能源结构转型发挥着重要作用。地热供暖产业高质量发展的加速度，逐渐发展成为冬季保供的绿色有

生力量，为城市用能低碳化综合解决方案提供了新选择。目前，恒有源集团正加快产业布局，实现企业效益的同时担负更多社会责任，以实际行动为国家“双碳”目标而努力。

绿水青山就是金山银山，绿色低碳发展理念日益深入人心。对于各行各业来说，实现碳达峰、碳中和是一场持久战，也是一场硬仗。独行者速,众行者远，为碳中和、碳达峰目标的实现，身为清洁能源企业理所应当积极贡献智慧和力量，全面推动首选浅层地热能作为供暖替代能源，全力为习近平主席惦记的亿万百姓暖冷大事而奋斗。

各地用户点赞浅层地热供暖

北京延庆用户：

而在地处京北寒冷地区的北京郊区延庆，随着冬奥会的临近，当地居民对低碳绿色的概念理解也更为深刻，浅层地热能供暖更是受到当地百姓的极大欢迎。当地一位叫侯玉先的90岁老奶奶在用上了浅层地热能供暖后高兴地说，共产党好啊，带她走出解放前的苦日子，生活越来越幸福，日子越来越舒适。老人家常开心地向客人介绍房间的“新玩意儿”——浅层地热能供暖的地能热宝设备，“现在供暖都不用烧火了，又干净又暖和，比烧煤还省，以前做梦也没有想到过上这样的日子啊”。

北京门头沟用户：

在海拔1000米的北京门头沟区禅房村，是北京的第一个农村党支部诞生的地方，新时代的浅层地热能供暖，再一次把党的温暖送到了每家每户。村里的老百姓纷纷表示，现在冬天再也不用搬煤取暖啦，浅层地热供暖又干净有方便，也不用担心煤气中毒了！

北京门头沟用户：

在以前曾是煤矿矿区的北京门头沟龙泉雾村，对浅层地热供暖，村民们的认知经历了从陌生到认可再到称赞的变化过程。村民种乃云说：我10来岁开始砸煤、添火，火最旺的时候屋子才18—19℃，其它的时候也就13—14℃。没想到今年66岁了享受到了这个开始我还不信的取暖方式。曾经的矿区龙泉雾，村民们对浅层地热供暖的认知变化，也成为浅层地热能推广的真实写照。

河北张家口怀来：

在塞外的张家口市怀来县存瑞镇义合堡村，自2016年采用恒有源科技发展集团有限公司单井循环换热地能热宝系统进行煤改清洁能源改造以后，村民们的生活方式有了很大的改变，他们告别黑煤灰、土煤炉，家家窗明几净，在寒冷的冬天里，室内温暖、室外清洁、空气新鲜。就靠浅层地热保证了冬天取暖夏季制冷，村民感叹自己过上了城里人住别墅的生活。

列表：国家促进地热供暖的相关政策措施

1、2017 年 1 月,《地热能开发利用“十三五”规划》

大力推广浅层地热能利用，按照“因地制宜，集约开发，加强监管，注重环保”的方式开发利用浅层地热能。加强我国南方供暖制冷需求强烈地区的浅层地热能开发利用。在重视传统城市区域浅层地热能利用的同时，重视新型城镇地区市场对浅层地热能供暖（制冷）的需求。

2、2017 年 12 月,《北方地区冬季清洁取暖规划（2017-2021 年）》

积极推进水热型（中深层）地热供暖。按照“取热不取水”的原则，采用“采灌均衡、间接换热”或“井下换热”技术，以集中式与分散式相结合的方式推进中深层地热供暖，实现地热资源的可持续开发。大力开发浅层地热能供暖。按照“因地制宜，集约开发，加强监管，注重环保”的方式，加快各类浅层地热能利用技术的推广应用，经济高效替代散煤供暖。

建立健全管理制度和技术标准，维护地热能开发利用市场秩序。制定地热能开发利用管理办法，理顺地热探矿权许可证办理、地热水采矿许可证办理、地热水资源补偿费征收与管理等机制。完善地热行业标准规范，确保地热回灌率100%，依法推行资格认证、规划审查和许可制度。

2021 年，地热供暖面积达到10 亿平方米，其中中深层地热供暖5 亿平方米，浅层地热供暖5 亿平方米（含地源、水源热泵）。

3、2018 年 1 月,《关于加快浅层地热能开发利用促进北方采暖地区燃煤减量替代的通知》

按照“企业为主、政府推动、居民可承受”方针，统筹运用相关政策，支持和规范浅层地热能开发利用，提升居民供暖清洁化水平，改善空气环境质量。

4、2020 年 12 月,《新时代的中国能源发展》白皮书

创新地热能开发利用模式，开展地热能城镇集中供暖，建设地热能高效开发利用示范区。

5、2021 年 1 月,《国家能源局关于因地制宜做好可再生能源供暖工作的通知》

重点推进中深层地热能供暖，按照“以灌定采、采灌均衡、水热均衡”的原则，集中与分散相结合的方式推进中深层地热能供暖。积极开发浅层地热能供暖，经济高效替代散煤供暖，在有条件的地区发展地表水源、土壤源、地下水源供暖制冷等。鼓励利用油田采出水开展地热能供暖、地下水资源与所含矿物质资源综合利用等。

在地热资源禀赋较好的地区可实施地热能供暖重大项目建设和重点项目推广。鼓励开展中深层地热能集中利用示范工作，示范不同地热资源品位的供暖利用模式和应用范围，探索有利于地热能开发利用的新型管理技术和市场运营模式。

6、《2021 年能源工作指导意见》

加大清洁取暖工作力度。因地制宜实施清洁取暖改造，建立健全清洁取暖政策体系，确保取暖设施安全稳定运行，实现北方地区清洁取暖率达到70%。研究探索南方地区清洁取暖，在长江流域和南方发达地区，鼓励以市场化方式为主，因地制宜发展清洁取暖，培育产品制造和服务企业。研究推进西南高寒地区清洁取暖改造，加大政策支持力度，加强电网、天然气管网等建设。

7、2021 年 9 月,《关于促进地热能开发利用的若干意见》

到2025年，各地基本建立起完善规范的地热能开发利用管理流程，全国地热能开发利用信息统计和监测体系基本完善，地热能供暖（制冷）面积比2020年增加50%，在资源条件好的地区建设一批地热能发电示范项目，全国地热能发电装机容量比2020年翻一番；到2035年，地热能供暖（制冷）面积及地热能发电装机容量力争比2025年翻一番。

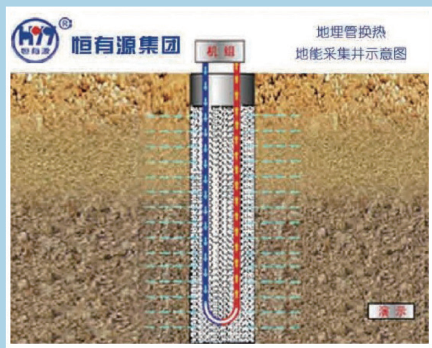
小知识

浅层地热能是怎样供暖的?

地热资源按深度划分为浅层、中深层和深层地热资源。浅层地热深度范围一般为 200 米以浅，包括土壤层及浅层含水层。中深层地热资源一般介于 200 米和 3000 米之间。深层地热资源埋深通常超过 3000 米。地热供暖是利用地热资源，使用换热系统提取地热资源中的热量向用户供暖，可以分为浅层地热能取暖（制冷）模式、水热型地热能取暖模式、中深层地源热泵取暖模式。浅层地热能供暖的原理初听很复杂，分解开来其实很简单。

具体来说，浅层地热能供暖采集方式主要有三种：抽水井 + 回灌井系统、地埋管系统和单井循环换热系统。

抽水井 + 回灌井系统也称为地下水源热泵系统，地埋管与单井循环换热系统也并称为土壤源热泵系统。



地埋管换热示意图

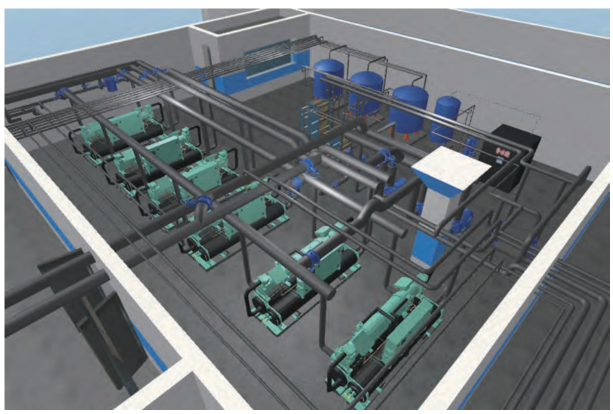
抽水井 + 回灌井系统是以地下水作为低位热源,并利用热泵技术，通过少量的高位电能输入，实现热量由低位能向高位能的转移，从而达到为使用对象供热或供冷的一种系统。该系统，适合于地下水资源丰富，并且当地资源管理部门允许开采利用地下水的场合。

地埋管系统的典型结构是由垂直埋入地下 100 米左右深度的单 U 型或双 U 型换热管组成。换热管内的介质通过管壁与周围的岩土体换热。它的优点是适应多种地质条件，缺点是换热能力差，占地面积大。

恒有源科技发展集团原创的浅层地热能安全、高效、省地、经济的单井循环换热地能采集技术的核心是地下水的同质、同层 100% 回灌。由于井水就地原位回灌，所以既不消耗水也不污染水，没有水的流失，不破坏地下水的自然分布，不会造成潜在的地质灾害等问题。

单井循环换热地能采集与抽水井有本质区别。它是一种封闭的、稳定的地能循环采集系统。从适用性上来讲，单井循环地能采集井可以应用在不同地质进行地能采集。

● 技术应用



地能热泵环境系统与传统燃烧供热产业的区域供热锅炉房相对应，设计供热规模 100 ～ 30000 千瓦，可为 2000 ～ 500000 平方米建筑物供热、制冷并提供生活热水。

恒有源科技发展集团有限公司最新推出的地能热宝系统是针对建筑较为分散的我国北方农村地区和城市的别墅区的分间供暖方案。地能热宝系统是暖保证、冷兼有、生活热水可选配的地能热冷一体化系统。实现了农户“暖保证、冷兼有、生活热水可选配，暖哪间房开哪间，不开也不冻”的继承了中国传统“省着用”的自采暖模式。

太阳能光热 + 空气源热泵携手助力清洁可再生能源供暖

SOLAR THERMAL + AIR-SOURCE HEAT PUMP ASSISTS IN ACHIEVING CLEAN HEATING AND "DOUBLE CARBON GOALS"

特约记者：马晓芳

太阳是地球万千生命的热量之源，人类的诞生和繁衍更是离不开太阳能，比如晒干食物、烘干衣服、制造食盐等。化石燃料日益减少的大背景下，太阳能逐步成为人类可持续发展所仰仗的重要能源，并在中国实现“双碳”目标过程中扮演重要角色。依托自主领先技术，恒有源集团成功聚合太阳能光热和空气源热泵耦合两种技术，打造的全新太阳能

光热 + 空气源热泵耦合清洁供暖产品，利用白天太阳能光热免费和晚上空气源热泵低谷电价供暖费用低的优势，可以大幅度节省供暖运行费用，具有绿色环保、分布广泛等众多特点，为清洁供暖提供了一种全新的低运行成本的解决方案，节能减排，助力 2060 年前实现碳中和。

人类所需能量的绝大部分都直接或间接地来自太阳。植物借助光合作用释放氧气、吸收二氧化碳，然后将太阳能转变成化学能贮存体内。煤炭、石油、天然气等化石燃料等能源的形成也离不开太阳能的作用。中国幅员辽阔，太阳能资源也十分丰富，其中西藏太阳能资源最丰富，最高达 2333kWh/ ㎡（日辐射量 6.4kWh/ ㎡ ）居世界第二位，仅次于撒哈拉大沙漠。

太阳能和空气能是清洁的可再生的能源。太阳能是由太阳内部氢原子发生氢氦聚变释放出巨大核能而产生的，来自太阳的辐射能量。空气能是空气中所蕴含的低品位热能量，借助空气源热泵可以实现从空气中吸收热量提高品位后传到高温物体或环境的作用。恒有源集团开发的太阳能光热 + 空气源热泵耦合清洁可再生能源供暖产品，成功将太阳能和空气能两种清洁能源相结合，形成 1+1 ＞ 2 的联动效果，获得业界好评。

什么是太阳能光热 + 空气源热泵耦合清洁供暖产品系统?

恒有源集团研发的太阳能光热 + 空气源热泵耦合清洁供暖产品系统，主要包括：室外太阳能光热采暖机、室外空气源热泵主机、室内散热器末端、室内循环管路泵阀及云控器等。其工作原理就是，太阳能光热是通过太阳能吸热元件——蓝天管将太阳能转化为满足供热采暖要求的热能。在白天，太阳能光热采暖机充分发挥白天太阳能免费的优势，吸收太阳能转化热能，通过循环系统将热能输送到室内散热器末端，对采暖房间进行持续供热采暖，也可提供生活热水。

空气源热泵供暖是利用其压缩机做功，实现将空气中热能转移到室内采暖房间。根据需要，可使室内房间空气中的热能向室外空气中转移，达到建筑制冷空调的目的。其供给室内房间的热量大部分来自室外自然界中的空气，其得热量是消耗电能的 2 倍以上，它比电采暖运行费用降低 50% 左右。

云控制器联动控制

恒有源集团研发的太阳能光热 + 空气源热泵耦合清洁供暖产品还有一个独特的优势：云控制器联动控制，更智能。系统采用的云控制器可以实现太阳能光热采暖机、空气源热泵主机、散热器末端的自动联动控制运行，同时实时上传耦合系统信息，实现实时监控。通过云控制器实时采集任何需要监控、连接、互动的过程，采集其声、光、热、电、通过 GPRS 网络接入到云平台，并采用大数据分析，实施对用户产品的监控、记录、分析、自学习、报警及后台维护。

因此，采用恒有源太阳能光热 + 空气源热泵耦合清洁供暖系统，不仅节能环保，还能有效节约人力，在疫情防控下更为安全、高效。

常用产品规格

数据统计显示，采用恒有源太阳能光热 + 空气源热泵耦合清洁供暖系统，40-60 平米的供暖面积，仅需一台光热采暖机，末端配置散热器、地板辐射采暖、风机盘管，在 -12℃的环境温度下，可以提供 5.7kW 供热量，系统配电仅需 2.5kW，就能保证供暖、兼有制冷，还能提供 24 小时生活热水。100-120 平米的供暖面积，需要光热采暖机两台，在如上环境下，提供 12kW 供热量，系统配电仅需 5.2kW，就能达到供暖、制冷，24 小时热水的需求。

常用产品规格表

<table>
<tr><th rowspan="2">供暖面积（㎡）</th><th colspan="2">耦合清洁供暖产品配置</th><th colspan="2">供热量</th><th rowspan="2">系统配电（kW）</th><th rowspan="2">功能</th><th rowspan="2">末端配置</th></tr>
<tr><th>光热采暖机</th><th>空气源热泵主机</th><th>环境温度 (°C)</th><th>供热（kW）</th></tr>
<tr><td>40-60</td><td>1 台 LTC-50P</td><td>HYY-NZB8D</td><td>-12</td><td>5.7</td><td>2.5</td><td rowspan="4">供暖、兼有制冷、提供生活热水</td><td rowspan="4">散热器、地板辐射采暖、风机盘管</td></tr>
<tr><td>60-80</td><td>2 台 LTC-40P</td><td>HYY-NZB12D</td><td>-12</td><td>8.7</td><td>3.7</td></tr>
<tr><td>80-100</td><td>2 台 LTC-50P</td><td>HYY-NZB14D</td><td>-12</td><td>9.1</td><td>3.9</td></tr>
<tr><td>100-120</td><td>2 台 LTC-60P</td><td>HYY-NZB18D</td><td>-12</td><td>12</td><td>5.2</td></tr>
</table>

太阳能光热 + 空气源热泵耦合清洁供暖产品系统怎么运行?

白天，太阳能辐照较好时，恒有源太阳能光热 + 空气源热泵耦合清洁供暖产品系统将太阳能转化为热能储存在太阳能储热水罐内，通过控制系统关闭电动阀、关闭空气源热泵机组、循环泵运转，向室内散热器末端供热。

夜晚，太阳能储热水罐余热通过控制系统循环泵向室内散热器末端供热，太阳能供热不足时，打开电动阀，启动空气源热泵机组利用低谷电向室内散热器末端直接供热。

遇到因阴雨雪天气导致太阳能供热不足时，采用空气源热泵机组向室内散热器末端直接供热。

太阳能光热 + 空气源热泵耦合清洁供暖产品系统经济性分析

按照北京供暖电价，加权电价 0.3 元 /kWh 计算，其中峰电 0.4883 元 /kWh，谷电 0.1 元 /kWh。以 60 ㎡供暖面积为例，太阳能光热 + 空气源热泵耦合清洁供暖产品运行电费估算及与其它供暖系统的比较如下表。

常用产品规格表

序号	系统产品类别	供暖配置	系统配电量（kW）	运行电耗（kWh）	电费（元）	备注
1	低环境温度空气源热泵热水机组	3 匹 HYY-NZB8D 空气源热泵热水机组 1 套	2.5	3696	1109	供暖、兼有制冷、提供生活热水
2	电锅炉	6kW 电锅炉	6.2	8500	2550	
3	光热 + 低环境温度空气源热泵热水机组	LTC-50P+3 匹 HYY-NZB8D 空气源热泵热水机组	2.5	2787	356	按空气源热泵系统供暖贡献率为 70%、光热供暖贡献率为 30%，空气源热泵耗电全部为谷电。

4	光热 + 电锅炉	LTC-50P+6kW 电锅炉	6.2	6150	693	按电锅炉供暖贡献率为 70%、光热供暖贡献率为 30%，空气源热泵耗电全部为谷电。

光热 + 空气源热泵耦合清洁供暖系统产品电费最低

光热 + 空气源热泵耦合清洁供暖运行费用较光热 + 电锅炉系统节省电费约 50%。除光热免费之外，夜间的低谷电价也是电费低的主要原因。

最大化利用谷电取暖，降低运行费用

一般太阳能光热 + 供暖系统合理的太阳能集热器面积 / 建筑面积为 1:6-1:8, 整个采暖季太阳能光热采暖的贡献率为 20-40%。通过云控制系统最大化利用谷电取暖，是降低运行费用的一个关键措施。

太阳能热损需要控制，最大化利用太阳能

白天下午时段，由于室外温度较高，光热采暖机内热水温度高，系统停止运行时间较长，导致太阳能热量不能及时输出，致使太阳能的热损增大，热效率降低，应采取措施使太阳能收集热量及时输送到建筑内，或是减少系统热损，提高太阳能贡献率。

系统配电量小，无需进行农村电网增容

对于 60 ㎡左右供暖面积的农户建筑清洁取暖改造，其系统配电仅 3kW，对现有电网冲击小，负荷要求低，可显著地降低改造初投资。

免费提供生活热水

太阳能光热系统冬季采暖，春夏秋三季节可免费提供生活热水，大幅度提高户用太阳能系统的利用效率。

综上，太阳能光热 + 空气源热泵耦合清洁供暖产品尽最大可能利用太阳能免费资源，最大化利用低谷电运行空气源热泵机组，系统运行成本低，大大提高了群众的可接受程度，太阳能光热 + 空气源热泵耦合清洁供暖产品具有极好的推广价值。

百尺竿头更进一步。接下来，恒有源集团将不断加强技术攻关，从太阳能光热和空气源热泵两方面入手，深入提升太阳能光热 + 空气源热泵清洁供暖系统的科技含量，尽早将太阳能光热产品主要部件真空管、光热采暖机、储热水罐按国家标准做检验取得认证报告。其中，涉及的相关标准有 GB/T17049-2005《全玻璃真空太阳集热管》、国家标准 GB/T26975-2011《全玻璃热管真空太阳集热管》、GB/T17581-2007《真空管型太阳能集热器》、GB/T28746-2012《家用太阳能热水系统储水箱技术条件》、GB/T28745-2012《家用太阳能热水系统储水箱试验方法》。

在全球气候变暖的大环境下，共同减碳是人类生存下去的前提。本着大国的责任感和人类命运共同的使命感，中国提出了“双碳”目标。当下，中国大气污染防治任务仍旧艰巨，在此基础上，更需要全面统筹推进城市城区、县城和城乡结合部、农村三类地区的清洁取暖工作。作为供暖行业的一名成员，有责任，也有义务全面贯彻国家决策部署，坚定不移贯彻创新、协调、绿色、开放、共享的发展理念，紧扣新时代我国社会主要矛盾变化，推动能源生产和消费革命、农村生活方式革命，提供更科学、更环保的方式保障广大群众温暖过冬、减少大气污染。作为负责任的科技供暖企业，未来将积极统筹自身技术优势，为加快提高清洁供暖比重，构建绿色、节约、高效、协调、适用的北方地区清洁供暖体系，建设美丽中国做出贡献。

AN ANALYTICAL SOLUTION OF GROUNDWATER FLOW IN A CONFINED AQUIFER WITH A SINGLE-WELL CIRCULATION SYSTEM

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Abstract

In this study, a general analytical model for the single - well circulation system is developed to analyze transient drawdown in a confined aquifer. Utilizing the Laplace and Fourier cosine transforms, the analytical solution of transient drawdown in the Laplace domain is calculated and numerically inverted into the time domain using the Stehfest method. The characteristics of transient drawdown and the effects of different parameters related to the single - well circulation system on drawdown are investigated. Furthermore, the analytical solution under steady - state conditions is obtained using the Fourier cosine transform. The results show that steady drawdown contours are symmetric around a horizontal midplane of an aquifer and vary tremendously with distance from the well axis. The contours of drawdown around the sealed section are dense, meaning that the hydraulic gradient in this area is relatively large. The sensitivity analysis, performed to evaluate the characteristics of drawdown to changes in each parameter, indicates that the radial hydraulic conductivity and the length of the sealed section have a large impact on the drawdown and that each parameter has its influence period on the drawdown.

1.Introduction

Among different types of groundwater heat pump systems, the single-well circulation groundwater heat pump system is different from conventional groundwater heat pump systems, such as the well doublet system (Banks, 2009; Galgaro & Cultrera, 2013) or the standing column well system (Abu-Nada et al., 2008; Deng et al., 2005), especially in terms of the well structure. In a single-well circulation system (Figure 1), a single borehole is divided into two sections by well packers (the gray section in Figures 1 and 2), which are placed in the middle of a single borehole to block injected water in the injection section of the well from flowing to the pumping section of the well. The single-well circulation system can be regarded as a combination of two partially penetrating wells. The lower well is a pumping well, from which groundwater is pumped at Q rate, and the upper well is an injection well for injecting water at the same rate Q.

The single-well circulation groundwater heat pump system is a new technology that emerged in 2001 and since then has been employed to provide heating and cooling for buildings in China (Xu & Rybach, 2003). This unique groundwater heat pump system has gained tremendous interest and has been increasingly used during the last two decades, especially in northern China. Although the system has many practical applications, the theoretical investigation of this system has been relatively limited. Xu and Rybach (2005) presented the development and several successful engineering implementations of this novel and innovative technology in terms of system designs, energy savings, and environmental protection. Wu et al. (2015) compared the single-well circulation system with other conventional groundwater heat pump systems in terms of the well configuration, requirements on hydrogeological and thermal geological conditions, environmental impacts, regulatory requirements, and so forth. Rybach (2015) presented engineering applications in China and other countries and summarized operational principles of the single-well circulation groundwater heat pump system. Finally, Zeng et al. (2017) provided a detailed discussion on energy efficiency, cost-effectiveness, operation, and maintenance of this system using a case study in Nebraska.

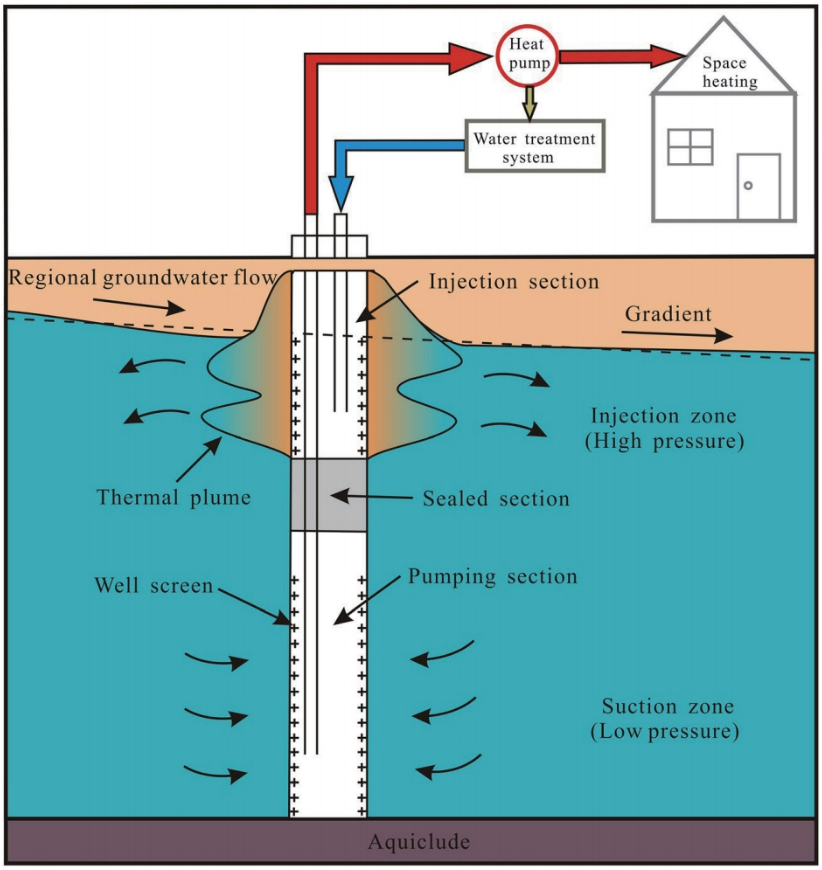

Figure 1. An overview of a single - well circulation system for shallow geothermal energy extraction (Wu et al., 2019).

The heat exchange in a single-well circulation groundwater heat pump system is a result of combined groundwater flow and heat transport. Heat convection, in particular, is influenced by fluid flow. Therefore, a good understanding of groundwater flow is an especially vital and essential step before one can start studying the heat exchange in a single-well circulation groundwater heat pump system. Up to now, most of the research on groundwater flow focused on fully or partially penetrating wells.

The topic of drawdown around a fully penetrating well has been discussed in many works. For instance, Theis (1935) first presented an analytical solution describing groundwater flow toward a fully penetrating well in a confined aquifer of an infinite extent. Later, Papadopulos and Cooper (1967) proposed a mathematical model describing groundwater flow in a confined aquifer while considering the influence of the well radius and wellbore storage. Chen (1984) derived, based on several existing solutions, an analytical solution describing groundwater flow in a finite confined aquifer with a zero-drawdown condition at the exterior boundary. Novakowski (1989) obtained a Laplace domain solution of drawdown in a composite confined aquifer while considering the effects of the well radius and wellbore storage. Subsequently, Yeh et al. (2003) presented an analytical solution describing the head distribution for a slug test in a two-zone-confined aquifer system. Wen and Zhan (2008) proposed a general analytical model describing non-Darcian groundwater flow in a confined aquifer by employing a combination of the power law function and a linearization procedure. Wang et al. (2012) presented an analytical solution describing groundwater flow while considering a constant-flux pumping along a finite radius well in the skin zone. Lin et al. (2016) proposed an analytical model describing groundwater flow in a composite confined aquifer of a finite extent induced by a pumping test while considering

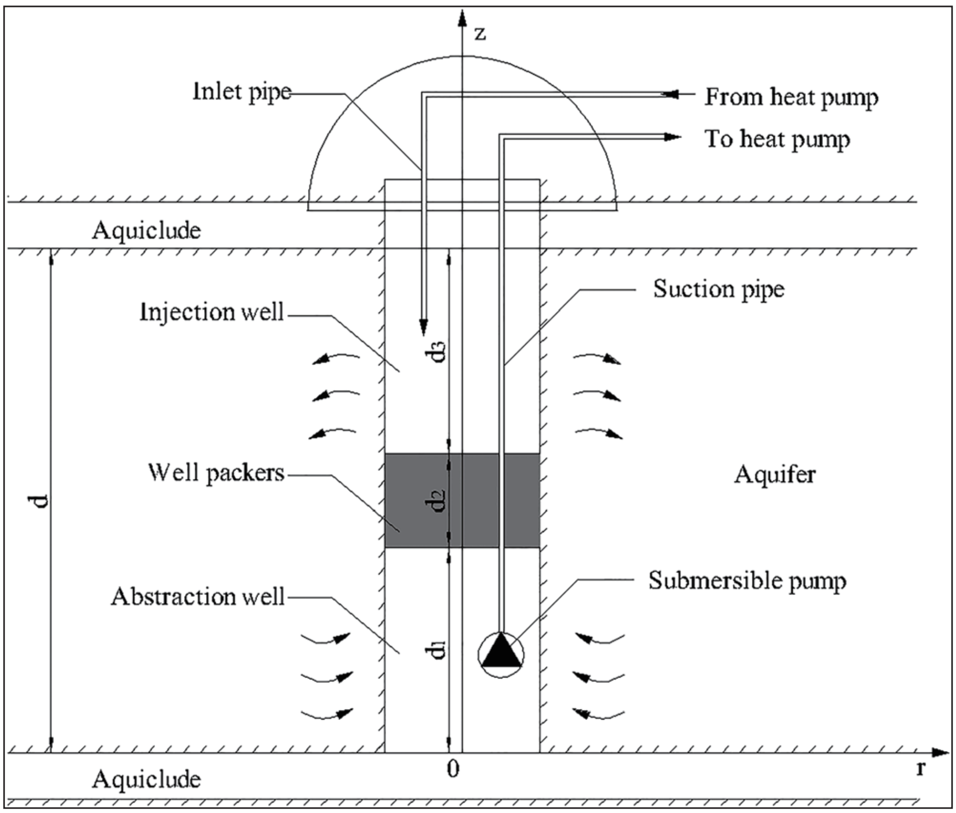

Figure 2. The schematic diagram of a single - well circulation system.

the effect of the well skin and a Robin-type outer boundary.

There have also been a number of literature regarding groundwater flow to a partially penetrating well (Table 1). The first mathematical model for a partially penetrating well was presented by Hantush (1957), who derived an analytical solution by applying the Laplace and Fourier cosine transforms. Since then, partially penetrating well systems have been investigated by many other researchers (e.g., Ataie-Ashtiani et al., 2012; Chang & Chen, 2002; Chang & Yeh, 2009; Chen et al., 2010; Chiu et al., 2007; Yang & Yeh, 2005; Zlotnik et al., 1998). For instance, steady-state flow in unconfined aquifers in one or multiple partially penetrating wells was studied by Luther and Haitjema (1999). Yang and Yeh (2005) presented a semi-analytical solution describing groundwater flow towards partially penetrating wells induced by the constant-head test in an infinite extent aquifer. Taking into account the effect of a finite-thickness skin, Chiu et al. (2007) presented an analytical solution for the drawdown of groundwater flow to a partially penetrating well. Barua and Bora (2010) presented a steady-state solution for groundwater flow induced by

Table 1 Comparison of Analytical Models for Partially and Fully Penetrating Wells

Model	Well structure	Well radius	Groundwater flow	Skin effect	Type of aquifer
This study	Two partially penetrating wells in one wellbore	Zero	Darcian flow	No	A confined aquifer with an infinite areal extent
Theis (1935)	A fully penetrating well	Zero	Darcian flow	No	A confined aquifer with an infinite areal extent
Chen (1984)	A fully penetrating well	Zero	Darcian flow	No	A finite confined aquifer
Wen and Zhan (2008)	A fully penetrating well	Zero/Finite	non - Darcian flow	No	A confined aquifer with an infinite areal extent
Lin et al. (2016)	A fully penetrating well	Finite	Darcian flow	Yes	A two - zone confined aquifer with a finite areal extent
Hantush (1961)	A partially penetrating well	Zero	Darcian flow	No	A confined aquifer with an infinite areal extent
Chiu etal.(2007)	A partially penetratingwell	Finite	Darcian flow	Yes	A two - zone confined aquifer with an infinite areal extent
Wen et al. (2013)	A partially penetrating well	Zero	non - Darcian flow	No	A confined aquifer with an infinite areal extent
Feng and Wen (2016)	A partially penetrating well	Finite	non - Darcian flow	Yes	A two - zone confined aquifer with an infinite areal extent

pumping in a partially penetrating well in a finite confined aquifer associated with the condition of the constant-head at the outer boundary. Ataie-Ashtiani et al. (2012) derived an analytical solution for the capture zone of a partially penetrating well with an infinitesimally small well radius and a fixed pumping rate Q. By employing the Izbash equation and a linearization procedure, Wen et al. (2013) presented an approximate analytical solution, which can describe the non-Darcian flow toward a partially penetrating well in a confined aquifer. Feng and Wen (2016) proposed an analytical model describing non-Darcian flow toward a partially penetrating well in a confined aquifer, which considered the effects of the well skin. Table 1 summarizes and compares the abovementioned analytical models.

However, compared to the studies mentioned above regarding groundwater flow in aquifers with fully or partially penetrating wells, research on particular well structures of a single-well circulation system is quite limited. Only a few studies (Ni et al., 2011; Sorensen & Reffstrup, 1992; Tu et al., 2019) dealing with groundwater flow in an aquifer with a single-well circulation system can be found in the literature. Sorensen and Reffstrup (1992) were the first to present a simplified mathematical model for the analysis of groundwater flow and heat transport for a new type of a groundwater heat pump system, which can extract and inject groundwater with a one-well borehole. *Ni* et al. (2011) developed a mathematical model describing groundwater flow induced by a single-well system in a leaky confined aquifer. Based on the superposition principle and by adopting the analytical solution of a partially penetrating well derived by Hantush (1961), *Ni* et al. (2011) obtained their solution by summing up the analytical solutions for these two partially penetrating wells. Although it is convenient to obtain analytical solutions using the superposition principle, this approach inevitably introduces problems such as complicated well configuration functions. The Hantush and Jacob well function (Hantush, 1961) makes the analytical solution more complicated and increases its instability and computational cost. Subsequently, Tu et al. (2019) derived a closed-form, steady-state analytical solution to investigate groundwater flow in a confined aquifer by employing the separation variable method and the Laplace transform. However, their solution still includes the complicated Hantush and Jacob well function and the well configuration function. Therefore, to overcome the abovementioned problems, we aim at rigorously deriving the analytical solution based on the governing equation for a single-well circulation system by employing a combination of the Laplace and Fourier cosine transforms. The main objective of this work is to develop a general analytical mathematical model describing groundwater flow in a confined aquifer for a single-well circulation system with a unique well structure with two partially penetrating wells in one single wellbore. The analytical solution for drawdown in the Laplace domain is obtained by employing the Laplace and Fourier cosine transforms. The effects of the hydraulic conductivity, the length of the sealed section, and other parameters on the drawdown distribution were analyzed, which to our knowledge have not been investigated by other researchers. The steady-state solution in the time domain is also derived. The analytical solution of transient drawdown is used in the sensitivity analysis to investigate the effects of different parameters on drawdown and to identify which of these parameters must be carefully considered when designing a single-well circulation system.

2.Mathematical Model

In order to investigate groundwater flow in a single-well circulation system, a mathematical model was developed, as shown in Figure 2. The assumptions of this mathematical model are as follows: (1) A confined aquifer is assumed to be homogeneous, anisotropic, and infinite in the horizontal direction; (2) underlying and overlying rocks are considered to be impermeable, homogeneous, anisotropic, and of uniform thickness;(3) groundwater flow in a confined aquifer follows Darcy's law; (4) the storage and release of groundwater due to rising and decreasing hydraulic heads are instantaneous; (5) pumping and injection rates Q (positive for pumping and negative for injection) are constant; and (6) the well radius is infinitesimally small and can be regarded as 0.

2.1.Governing Equation

Base on the above-listed assumptions, the equation describing groundwater flow in a confined aquifer can be written as follows:

$$K_r\left(\frac{\partial^2 s(r,z,t)}{\partial r^2}+\frac{1}{r}\frac{\partial s(r,z,t)}{\partial r}\right)+K_z\frac{\partial^2 s(r,z,t)}{\partial z^2}=S\frac{\partial s(r,z,t)}{\partial t} \quad (1)$$

where r is the radial coordinate (L); t denotes time (T); s is groundwater drawdown (L); K_r and K_z represent the horizontal and vertical hydraulic conductivities, respectively (LT^{-1}); and S refers to the specific storage of an aquifer (L^{-1})

3.Results and Discussion

3.1.Verification of the Analytical Solution

First, the newly derived analytical solution for transient drawdown is ver- ified by comparing its results with the solution of Ni et al. (2011). In their work, a single-well circulation system is regarded as a combination of one partially penetrating well for injection and another one for pumping. The analytical solution for a partially penetrating well was developed by Hantush (1961). Based on the superposition principle, Ni et al. (2011) obtained the analytical solution by summing up the analytical solutions for these two partially penetrating wells in a single-well circulation system. These analytical solutions (i.e., Equation 7 and Ni et al., 2011) for a single-well circulation system are used to calculate transient groundwater drawdown for a system with the following parameters: Q=60 m^3/h, K_r=0.1m/h, K_z=0.01m/h, S=0.0001m^{-1}, d=40m, d_1=15m, d_2=10m, d_3=15m, r=5m, z=15m. Figure 3 shows that the results of the newly derived analytical solution correspond well with the solution presented by Ni et al. (2011).

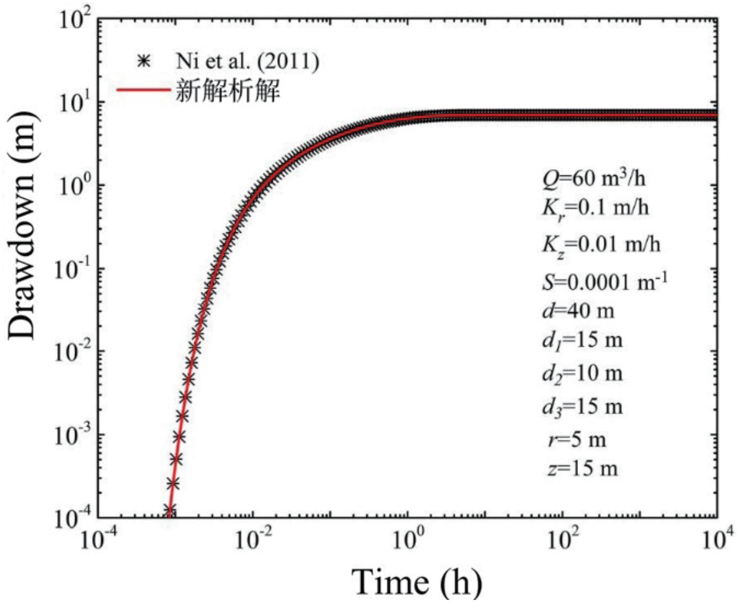

Figure 3.

3.2.Steady-State Drawdown

Figure 4 depicts contours for steady-state drawdown and steady-state flux vectors (Equations 10 and 12, respectively) in a single-well circulation system. The following parameters (the same as in Figure 3) were used in this scenario: Q=60 m^3/h, K_r=0.1m/h, K_z=0.01m/h, S=0.0001m^{-1}, d=40m, d_1=15m, d_2=10m, d_3=15m. It can be clearly observed that contours for steady-state drawdown are sym-metric around a horizontal midplane of a confined aquifer and vary tre- mendously with distance from the well axis. The contours of drawdown around the sealed section are dense, indicating that the hydraulic gradient in this area is relatively large. Additionally, due to flow symmetry, abso- lute values of drawdown are very small around the midplane of a confined aquifer; drawdown is 0 at locations with z=20m (the middle of a con- fined aquifer).

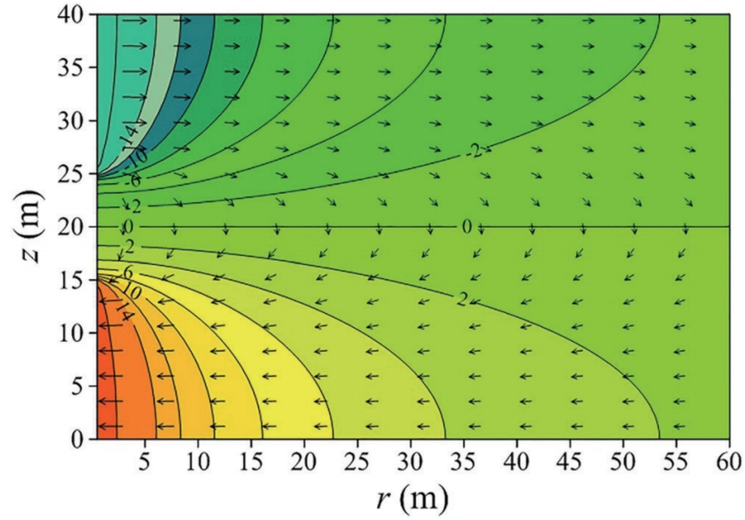

Figure 4. Contours of steady - state drawdown and steady - state fiux vectors in a single - well circulation system.

3.3.Radial Hydraulic Conductivity

Figure 5 shows the effects of different values of the radial hydraulic conductivity (Kr = 0.01, 0.02, 0.05, and 0.1 m/hr) on drawdown over time. Other parameters remain the same as in previous examples; that is, Q=60 m^3/h, K_z=0.01m/h, S=0.0001m^{-1}, d=40m, d_1=15m, d_2=10m, d_3=15m, r=5m, z=15m. It can be seen that drawdown increases with the radial hydraulic conductivity (Kr) at early times, while it decreases as Kr increases at late times. Larger hydraulic conductivities will cause groundwater to react more quickly to the start of water

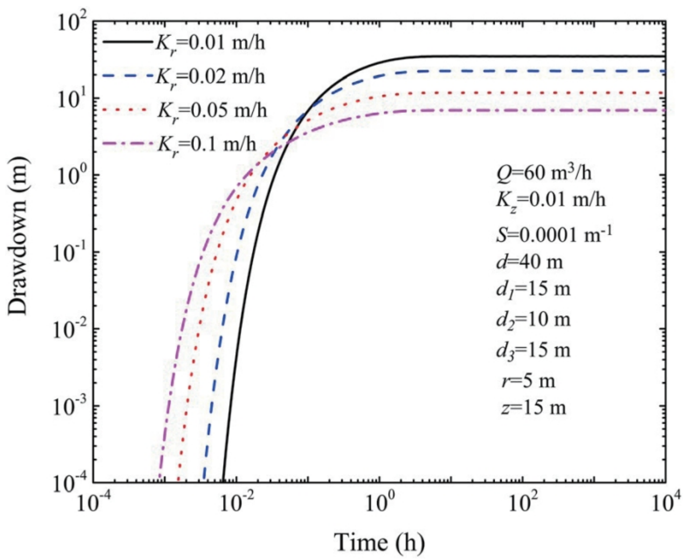

Figure 5. The effect of the radial hydraulic conductivity (K_r) on drawdown over time (for parameters given in the figure).

pumping/injection into the aquifer, with the depression cone in the suction zone spreading faster, while groundwater is replenished in a timely manner. Drawdown is thus larger at early times for larger hydraulic conductivities. In contrast, at late times, an increase in drawdown for larger hydraulic conductivities is not as large as for smaller hydraulic conductivities. Moreover, it is worth noting that drawdown converges toward a steady state more quickly for larger radial hydraulic conductivities, as indicated in Figure 5.

3.4.Sealed Section

Figure 6 shows the impact of the length of the sealed section (d_2) on groundwater drawdown in a single-well circulation system. The sealed section is located in the middle of the confined aquifer and between the pumping and injection sections of the well (see Figure 2). The same parameters as in the previous section are used to obtain results displayed in Figure 6, that is, Q=60 $\mathrm{m^3/h}$, K_z=0.01m/h, S=0.0001$\mathrm{m^{-1}}$, d=40m, d_1=15m, d_2=10m, r=5m, z=15m. Additionally, the following lengths of the sealed section are used: d_2=6m, 8m, 10m, 12m, 14m, while d_1 and d_3 were correspondingly adjusted to keep d constant. One can observe in Figure 6a that shorter lengths of the sealed section result in larger drawdown at early times, while the length of the sealed section has only a little effect on drawdown at late times. This is due to the fact that shorter lengths of the sealed section require longer lengths of the pumping and injection sections, which require smaller pumping and injection rates for a unit well length (note that the total pumping and/or injection rates are kept constant). Thus, shorter lengths of the sealed section produce larger drawdowns at

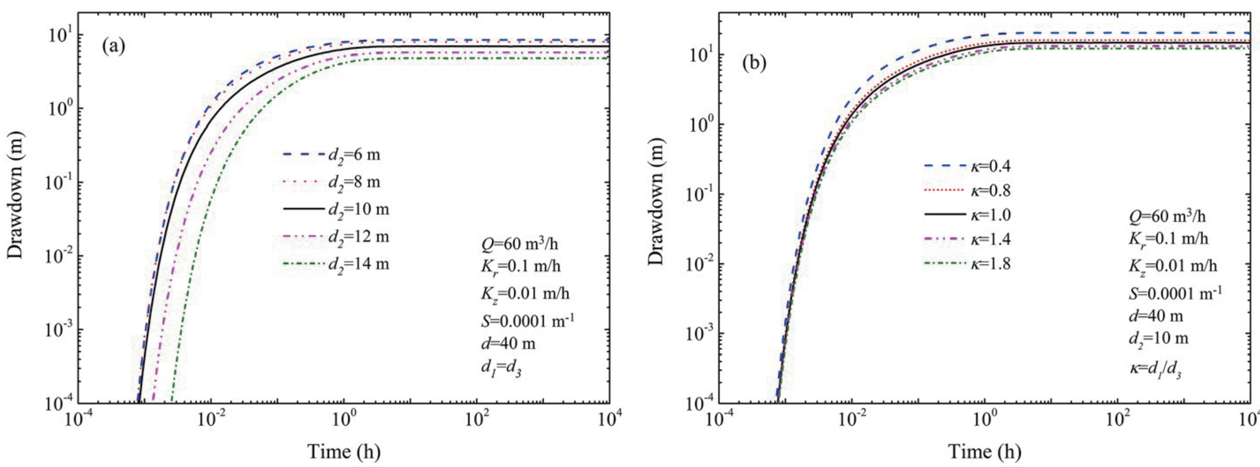

Figure 6. The effect of the length of the sealed section (d_2) when $d_1 = d_3$ (a) and various ratios κ (=d_1/d_3) for a constant d_2 (b) on drawdown over time.

early times. Moreover, drawdowns approach a steady state (i.e., curves are horizontal and parallel) when t > 1 h, which is different from the previous case (the radial hydraulic conductivity). It is worth not- ing that the effect of further decreasing the length of the sealed section from 8 to 6 m on drawdown becomes negligible. Differences between drawdowns are larger for larger lengths of the sealed section (e.g., from 10 to 14 m) than for smaller lengths of the sealed section.

The effect of the ratio κ of the lengths of the pumping and injection sec- tions ($\kappa = d_1/d_3$, for $d_1 \neq d_3$ and constant d and d_2) is shown in Figure 6. As shown in Figure 6, larger K ratios result in smaller draw- downs. Drawdowns converge asymptotically toward a steady state for all scenarios. In addition, it is worth noting that changes in drawdown for smaller K are larger than those for larger κ (from 1.0 to 1.8).

3.5.Aquifer Specific Storage

Figure 7 demonstrates how drawdown changes over time for different values of the aquifer specific storage (S = 0.0001, 0.0002, 0.0005, and 0.001m^{-1}) and for the same other conditions as before, that is,Q=60 m^3/h, K_r=0.1m/h, K_z=0.01m/h, S=0.0001m^{-1}, d=40m, d_1=15m, d_2=10m, and d_3=15m, at r=5m, z=15m. It can be observed that drawdown decreases with an increase in the specific storage (S) at early times. In contrast, all drawdown curves for different values of the specific storage converge asymptotically to the same val-

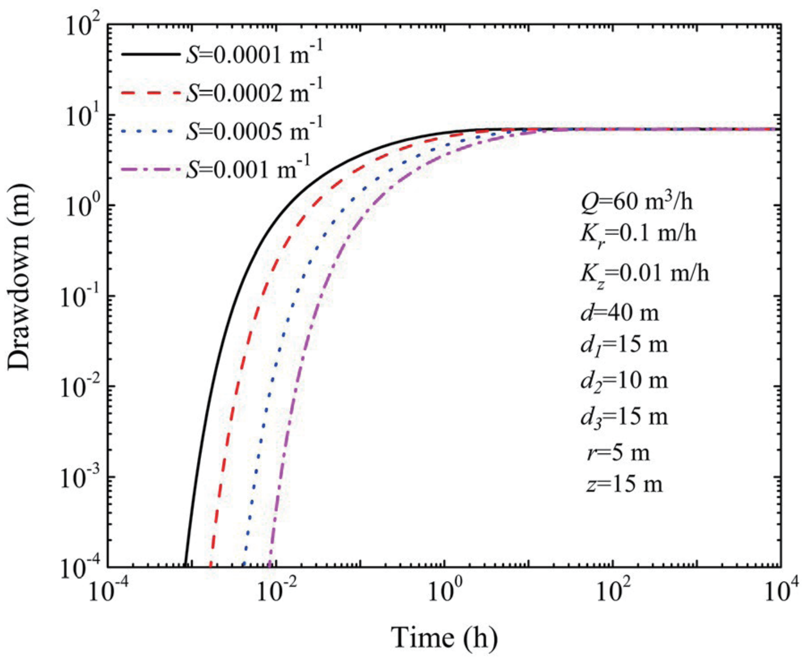

Figure 7. The effect of the aquifer specific storage on drawdown (S) over time.

ue at late times. When other conditions remain the same, an aquifer with large specific storage releases more water than an aquifer with small specific storage. Therefore, as shown in Figure 7, drawdown decreases with the specific storage at early times. Since the process of water release from the aquifer storage is almost complete at late times, all drawdown curves eventually approach the same asymptotic value after about 10 hr of operation and remain stabilized at late times. As a result, the impact of the specific storage on drawdown is insignificant at late times.

3.6.Pumping Time

It is also interesting to analyze how drawdown varies with distance for different pumping times (t = 0.1, 1, and 10h and steady state). The other parameters in this scenario are again the same as before; that is, Q=60 m^3/h, K_r=0.1m/h, K_z=0.01m/h, S=0.0001m^{-1}, d=40m, d_1=15m, d_2=10m, and d_3=15m at r=5m, z=15m. The analytical solution Equation 10 for the steady-state drawdown is utilized as a reference in this section. Figure 8 shows that drawdown changes only slightly with time for relatively small distances from the well, indicating that groundwater flow quickly reaches a quasi-steady state in the area close to partially penetrating wells. Additionally, Figure 8 also shows that the curves for t = 10h and the steady state almost coincide, indicating that the entire flow field in the single-well circulation system reaches steady state relatively quickly.

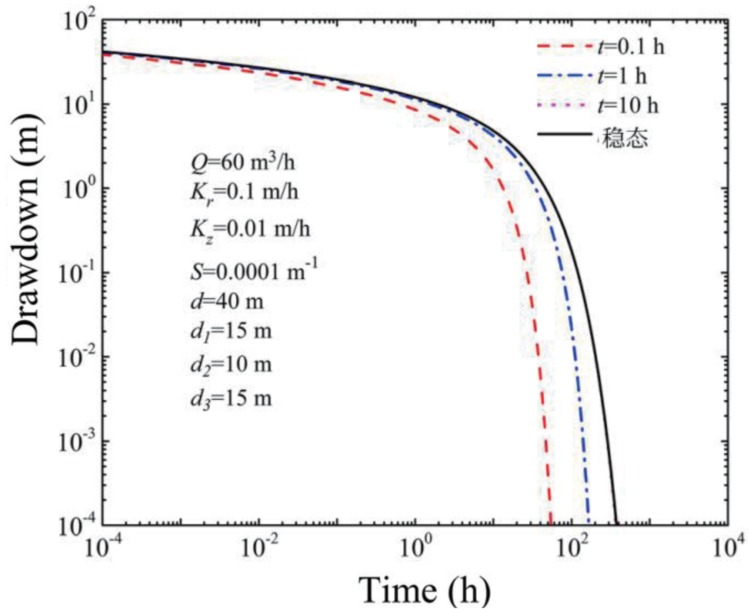

Figure 8.

4.Conclusions

A general analytical mathematical model was developed in this study to investigate the characteristics of groundwater flow in a single-well circulation system. The governing partial differential equation is solved simultaneously with initial and boundary conditions by applying the Laplace and Fourier cosine transforms.

The analytical solution for transient drawdown in the Laplace domain is obtained and then inverted numerically using the Stehfest method. The steady-state solution for drawdown in the time domain for a single-well circulation system is also developed. Additionally, the effects of different parameters on drawdown are also analyzed. The main research conclusions can be drawn as follows:

1.The contours for steady-state drawdown are symmetric around the horizontal midline of the aquifer and vary tremendously with distance from the well axis (in the case of $d_1= d_3$). The drawdown con- tours around the sealed section are dense, indicating that the hydraulic gradient in this area is relatively large.

2.The length of the sealed section d_2 has a significant influence on drawdown in the case of $d_1 = d_3$. In the case of $d \neq d$ and a constant length of the sealed section d , larger ratios of K (K d_1) result in smaller d_3 drawdowns, while changes in drawdown become insignificant for further increases in κ values.

3.The spatial distribution of drawdown in a single-well circulation system is sensitive to the radial hydrau-lic conductivity K_r and the length of the sealed section d_2. Each parameter has its own influence period on drawdown.

4.Drawdown is not sensitive to parameters S, d_2, d_2, and K_z at early times, while it is very sensitive to these parameters at late times, particularly to the radial hydraulic conductivity, d_2.

SUCCESS OF THE 2nd CHINA INTERNATIONAL GEOTHERMAL INDUSTRY DEVELOPMENT SUMMIT FORUM & INDUSTRIAL EQUIPMENT EXPO IN TIANJIN

Written by: He Wang

From September 24th to 26th, 2021, the second China International Geothermal Industry Development Summit Forum and Industrial Equipment Expo, co-sponsored by China's Geothermal and Hot Spring Industry Technology Innovation Strategic Alliance, Hydrogeology Bureau of China, National Administration of Coal Geology, and Geothermal Industry Association of Hebei Province, was grandly held in the Tianjin Shehuishan International Conference Center. With the theme of "New opportunities for industrial development in the context of achieving the goals of carbon dioxide emissions peaking and carbon neutrality," more than 100 attendees from the energy, land, construction, planning, energy conservation, environmental protection, water conservancy sectors, and from all levels of government attended. More than 300 conferees, ranging from real

estate agents, hot spring developers, leisure and elder care center developers were present. Institutions, enterprises, and experts engaged in geothermal and ground source power pump, capital construction and design, scientific research and education, real estate, building energy conservation and property management, geological drilling and exploration, Heating, ventilation, and air conditioning (HVAC), hot spring service and management, investment and financing, news media, social organizations, all jointly participated, discussed, shared and drew a new blueprint for the industry.

Novel technology exhibited at Industrial Equipment Expo included appliances in ground source heat pump, water source heat pump, sewage source and waste heat utilization, geothermal generator sets, medium and deep-level geothermal energy, medium and low-temperature power generation, hot dry rock power generation, geothermal + multi-energy complementary clean energy station, geothermal + agriculture, geothermal + tourism, geothermal + health preservation, geothermal energy + smart energy, and geothermal drilling. Other materials such as supporting products of geothermal energy generator heating, supporting products of groundwater source heat pump, clean heating and temperature measuring equipments, sensors, and temperature controllers, and automatic control systems for heating and power generation were also presented.

Xu Dingming, Senior Advisor to the State Council and former Director of the Energy Bureau of the National Development and Reform Commission, Wu Qiang, academician of the Chinese Academy of Engineering and Director of the National Engineering Technology Research Center of Coal Mine Water Disaster Prevention and Control, Li Jijiang, the former Deputy Director of the Geological Environment Department, the Ministry of Land and Resources, Zhang Fawang, Secretary of CPC of the Water Environment Center of China Geological Survey and Russian foreign academician, Pang Zhonghe, Director of the Research Center for Geothermal Resources, Chinese Academy of Sciences, Zheng Keyan, former Director of International Geothermal Association, Zhang Yunxia, Deputy Director of Tianjin Municipal Bureau of Planning and Natural Resources, were among the leaders and experts who took part in the forum. The magazine China Geothermal Energy participated in the conference as the supporting media of the alliance.

The conference opened with a welcoming speech made by Wang Bingchen, Senior Advisor to the State Council, National Engineering Survey Design Master, consultant of Science and Technology Commission of the Ministry of Housing and Urban-Rural Development, and Director of Environmental Engineering Technology Center of the Ministry of Construction.

Liu Yuqiang, Chairman of China's Geothermal and Hot Spring Industry Technology

Innovation Strategic Alliance, Liu Jianjun, President of Geothermal Industry Association of Hebei Province, Jiang Xiangming, General Director and Secretary of CPC of China National Administration of Coal Geology, and Zhang Yunxia, Deputy Director of Tianjin Municipal Bureau of Planning and Natural Resources delivered speeches respectively, in which the positive role of promoting comprehensive development and utilization of geothermal and hot spring was affirmed, and recommendations and expectations for future development were put forward. Subsequently, Academician Wu Qiang, Counsellor Xu Dingming, Director Li Jijiang and other leaders and experts delivered speeches on the development of China's geothermal energy industry, opportunities of geothermal development, exploration of thermal resources as well as development and utilization of new technologies under the goal of achieving carbon peaking and carbon neutrality in terms of the topics on policy interpretation, geothermal industry development, promotion of innovative technologies, application of the geothermal heating system, development of hot spring industry, etc., and put forward the guiding opinions on the development direction.

During the conference, the participants jointly discussed the current situation and future trends of the geothermal and hot spring industries, carbon neutrality, and carbon peaking based on the conference's content and new equipment and technologies displayed at the equipment expo. Subsequently, they went to the China Energy Construction Power Industrial Park for field investigation of the comprehensive development and utilization project of geothermal resources.

OVERVIEW OF CURRENT SITUATION AND DEVELOPMENT TREND OF GEOTHERMAL RESOURCES DEVELOPMENT AND UTILIZATION IN CHINA

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Honorary Director of Technical Committee of National Geothermal Center
Director of Editorial Committee of 《China Geothermal Energy》 Magazine

In the context of Beijing-Tianjin-Hebei integration, the geothermal industry has a more excellent opportunity for development in order to implement the significant strategic deployment proposed by General Secretary Xi Jinping and to solve the serious air pollution issues faced by the three regions of Beijing, Tianjin, and Hebei. By 2020, the heating and cooling of the Beijing-Tianjin-Hebei areas have reached a total of 440 million square meters, a remarkable accomplishment of a formidable task.

As severe haze has not been completely eradicated, citizens have raised concerns, and this might also bring negative impacts on the country's international image. Hence, relevant government departments need to devise effective countermeasures to resolve this issue. Further development and utilization of geothermal energy have been put on the agenda, which has directly promoted the development of the geothermal industry and the promotion and application of ground source heat pump technology. In recent years, deep and shallow geothermal energy development and utilization has witnessed dramatic changes, for example:

1. In 2014, in order to further enhance the promotion of ground source heat pump technology, the Ministry of Finance and the Ministry of Housing and Urban-Rural Development jointly issued an official document requiring financial subsidies for ground source heat pump application projects; the State has also published policy documents such as Interim Measures for Management of Special Funds for Renewable Energy Development and Interim Measures for Management of Energy Conservation and Emission Reduction Subsidies to encourage the adoption of energy conservation and emission reduction measures and promote the development of the industry.

2. On October 7, 2015, Former Director of the National Defense Commission of Science, Technology and Industry and Academician of Chinese Academy of Engineering, General Ding Henggao, based on long-term tracking and in-depth understanding of the "Shallow Geothermal Single-Well Recirculation Heat Exchange Geothermal Energy Acquisition Technology" developed by Beijing Ever Source Group, wrote a letter to Premier Li Keqiang, proposing "Suggestions on Recommending Shallow Geothermal Energy as an Alternative Energy Source for Heating," and the specific recommendations are as follows.

(1) The government should prefer or enforce the utilization of shallow geothermal energy as an alternative energy source for heating, not only from the perspective of energy conservation, but also from the perspective of national energy strategy and ecological civilization construction; it should review and comprehensively evaluate in terms of energy security, original technology, and contribution to international low-carbon environmental protection, and coordinate the formulation of relevant policies for the mandatory promotion of the technology.

(2) Regulate the price of power electricity for geothermal energy heating. The price of power and electricity for ground source heat pump environmental systems with shallow geothermal energy for combustion-free heating of buildings is the core of heating costs, and regulation of the price of power electricity for geothermal energy heating (not higher than the price of electricity for residential use) is the key to the sustainable promotion of this technology.

(3) Further accelerate the implementation. After investigating this technology, the National Development and Reform Commission submitted a report titled the Report of the National Development and Reform Commission on Accelerating the Promotion of Single-Well Recirculation Heat Exchange Geothermal Energy System Technology to Comrades Ding Henggao and Wang Qishan in 2013: ① Increase positioning efforts; ② Promote industrial development; ③ Implement incentive reform; ④ Consolidate the

foundation of popularization; ⑤ Encourage local promotion.

Premier Li Keqiang attached great importance to this proposal; on October 10, he wrote on Comrade Ding Henggao's suggestions: "Ask Comrade Xiao Jie (then Director of the Premier's Office) to read and deal with this," and Director Xiao Jie then commented on October 12: "Forward to and ask the Development and Reform Commission to study and put forward opinions in conjunction with the Ministry of Land and Resources, the Ministry of Environmental Protection, the Ministry of Housing and Urban-Rural Development, and National Energy Administration."

Relevant ministries and commissions took action immediately, and I also wrote to Director Xu Shaoshi of the National Development and Reform Commission, Minister Jiang Daming and Vice Minister Wang Min of the Ministry of Land and Resources, Minister Chen Jining of the Ministry of Environmental Protection, and Minister Chen Zhenggao of the Ministry of Housing and Urban-Rural Development in my capacity as a senior counselor of the State Council, expressing my full support for Director Ding Henggao's proposal and asking these leading comrades for close attention and implementation. Minister Jiang Daming wrote back to me personally. The National Development and Reform Commission collected the opinions of all relevant ministries and commissions, organized expert discussions and research, and submitted the "Report of the National Development and Reform Commission on the Development and Utilization of Shallow Geothermal Energy in China" to Premier Li Keqiang on December 31, 2015, clearly proposing the concluding recommendations: measures should be taken to support the reform and standardization as soon as possible, accelerate the promotion of ground source heat pump development and utilization of shallow geothermal energy, provide energy-saving and efficient heat and cooling integrated energy services to buildings, and effectively reduce coal consumption. Premier Li Keqiang commented the report on January 6: "Please relay the relevant information to Comrade Ding Henggao."

In February 2017, Jiang Jinghao, Division Chief of the Department of Environmental Resources of the National Development and Reform Commission, hosted a meeting to solicit the opinions and suggestions of Guo Mengzhuo, Chief of the Department of Water Resources of the Ministry of Water Resources, Bi Shouhai, Division Chief, and other leading comrades on the three recommendations of Director Ding Henggao and the report as mentioned earlier at the National Development and Reform Commission.

On January 25, 2016, Ever Source Science & Technology Development Group submitted a report on "Preferred and Compulsory Promotion of Shallow Geothermal

Energy as an Alternative Energy Source for Heating in Beijing and a New Way to Treat Haze” to Director Ding, who forwarded the report to the then Secretary of CPC Beijing Committee, Comrade Guo Jinlong, asking him to pay attention to the matter on the same day, and Secretary Guo Jinlong attached great importance to it and quickly gave instructions to the then Mayor of Beijing, Comrade Wang Anshun, for implementation.

3. In 2016, geothermal energy development was included in the "National Economic and Social Development Master Plan" for the first time, and according to the completed "China's 13th Five-Year Plan for Geothermal Industry Development," by 2020, the total geothermal heating/cooling area in China would reach 1.6 billion square meters, taking into consideration of with power generation, planting, breeding and bathing, geothermal energy can replace 72.1 million tons of standard coal. In order to strengthen, promote and regulate the development of the geothermal industry, under the guidance of the "Belt and Road" initiative, the National Energy Administration and the National Standardization Technical Committee formally established the Geothermal Energy Standardization Technical

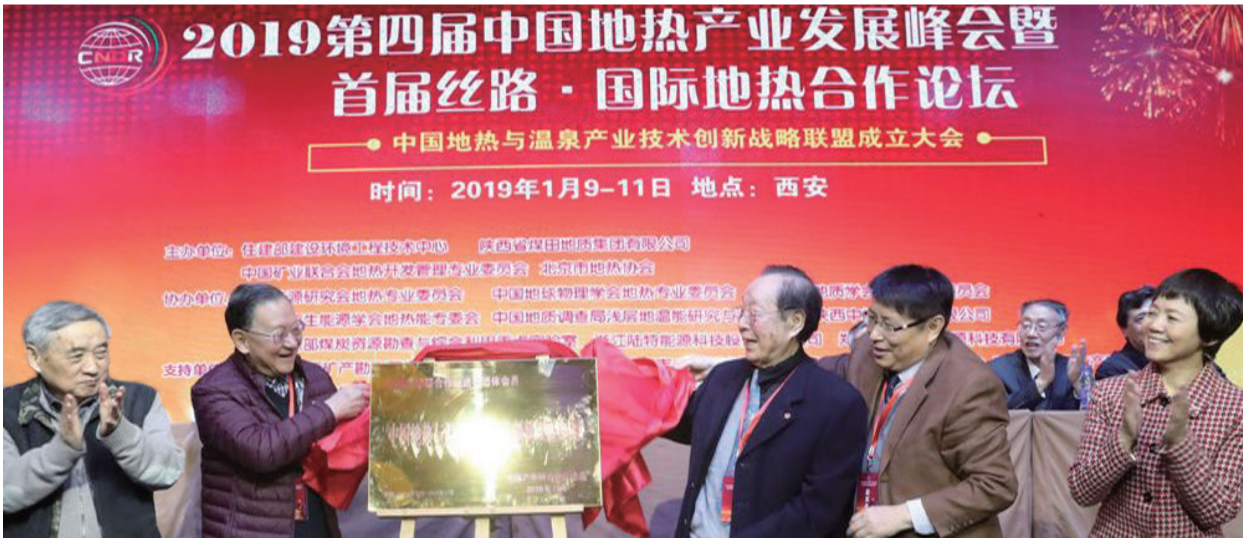
Committee in May 2016 to propose national standards, development plans and local standards in the field of geothermal energy, which would greatly promote scientization and standardization of the development in China's geothermal industry.

4. In January 2016, the "Shallow Geothermal Energy Development and Ground Source Heat Pump Technology Exchange Conference" held in Suzhou, Jiangsu Province and hosted by the Construction Environment Engineering Technology Center of the Ministry of Housing and Urban-Rural Development and China Energy and Environmental Protection High-Tech Industry Association, invited many experts, scholars, and industrial professionals. Academician Wu Qiang of the Chinese Academy of Engineering and Academician Wang Jiyang of the Chinese Academy of Sciences gave important academic reports at the conference. National Geothermal Center has held the important meetings twice about the development of China's geothermal industry, one of which was the "Launch Meeting of the Strategic Study on the Planning and Layout of China's Geothermal Industry (Key Consulting Project of Chinese Academy of Engineering)" held in June 2016, which more than 20 academicians attended, and the other was "China Engineering Science and Technology Forum and China Geothermal International Forum 2016" held in October 2016, which I participated and witnessed as invited, discussed a series of issues such as planning, layout, technology, and reform of China's geothermal industry.

5. In December 2017, six authorities, namely the National Development and Reform Commission, the Ministry of Land and Resources, the Ministry of Environmental Protection, the Ministry of Housing and Urban-Rural Development, the Ministry of Water Resources and the National Energy Administration, jointly issued the "Notice on Accelerating the Development and Utilization of Shallow Geothermal Energy and Promoting the Reduction and Replacement of Fire Coal Consumption in Northern Heating Areas." This critical document points out that in the development and utilization, we should adhere to the principles of localization, safety, stability, environmental friendliness, and a combination of market orientation and government support. We should promote the development and utilization of shallow geothermal energy in an integrated manner, scientifically plan the development and layout, improve the operation and management level, innovate the development and utilization mode, and strengthen policy supervision and management with comprehensive and systematic contents. I believe that this document has fully absorbed the views and suggestions of the relevant authorities and is of crucial guiding significance to further promote the development and utilization of shallow geothermal energy.

6. In May 2018, the National Geothermal Center entrusted relevant departments of Sinopec Group and the Institute of Geology and Geophysics of Chinese Academy of Sciences, Tianjin University, and Shanghai Jiaotong University to complete the consulting project of Chinese Academy of Engineering: "Strategic Research on Planning and Layout of China's Geothermal Industry," the results of which included a comprehensive report, five sub-topic reports and a recommendation by academicians. More than ten academicians and I were invited to participate in the evaluation meeting of the results of this project, and it was an immediate consulting research result related to the future development of the geothermal industry in China.

7. In January 2019, China's Geothermal and Hot Spring Industry Technology Innovation Strategic Alliance was established with the approval of the China Industry-University-Research Institute Collaboration Association. The Alliance brought together a large number of responsible persons and industry experts from all relevant units developing geothermal and hot spring business in China, including organizations, enterprises, and research institutes, which formed a professional platform with strong capabilities, and would play an essential role in guiding and promoting the development of China's geothermal and hot spring industry. In April 2019, the first council of the Alliance was held. The work objectives and phased work plan of the Alliance were determined, which would further set off a new climax of geothermal energy development and utilization in China.



WGC 2023: CHINA'S GEOTHERMAL ENERGY SHINES TO THE WORLD

Written by: Zheng Keyan
Geothermal Industry Working Committee of China Association for Technical Supervision Information

The World Geothermal Congress (WGC), organized by the International Geothermal Association, is the world's largest and highest-level conference in the geothermal industry. World Geothermal Congress 2023 (WGC 2023) will be held in China, and the Chinese Organizing Committee has displayed the WGC 2023 logo (Figure. 1) at the postponed closing ceremony of this year's WGC 2020+1 congress. On the following day of the ceremony, October 28, 2021, the WGC 2023 China Organizing Committee held its third joint offline + video conference with the WGC 2023 Steering Committee of the International Geothermal Association, and preparations for the organization were actively underway.

1. Review of the World Geothermal Congresses' History

The International Geothermal Association (IGA) was first established in 1989, with the World Geothermal Congress (WGC) having been held six times, every five years since 1995.

The Geothermal Professional Committee of China Energy Research Society joined the International Geothermal Association as a member in 1998, and we have participated in all of the World Geothermal Congresses.

In 1995, the World Geothermal Congress was held in Italy, with more than 1000 people from more than 60 countries attending. After the Congress, attendees visited the

Overview of World Geothermal Congresses History

Year	Host country	Location	Theme of Congress
1995	Italy	Florence	Worldwide Use of Geothermal Energy: An Indigenous, Environmentally Sound Renewable Energy Resource
2000	Japan	Beppu and Morioka	Supporting Geothermal Energy into the 21st Century
2005	Turkey	Antalya	Geothermal Energy: An Indigenous, Renewable, Green Option
2010	Indonesia	Bali	Geothermal: The Energy Source that's Changing the World
2015	Australia	Melbourne	Geothermal Energy Right from the Australian and New Zealand Perspective
2020+1	Iceland	Reykjavik	Running to the Source
2023	China	Beijing	(TBD)

Larderello Geothermal Power Plant, the first geothermal power generation in the world established in 1904, which generated 545 MW of electricity at that time.

In 2000, the World Geothermal Congress was held in Japan, the fourth country in the world to generate geothermal power, ranking sixth in the world at that time. Japan's Mitsubishi, Toshiba, and Fuji Electric had monopolized 70% of the production of the world's geothermal power generation equipment, sponsored the congress and supported the participation of third world delegates, ensuring the presence of more than 1,700 attendees. The congress was held in two sections respectively in Beppu in southern Kyushu and Morioka in northern Honshu, and the geothermal power plants in both locations were visited.

In 2005, the World Geothermal Congress was held in Turkey, with more than 1,500 participants from 83 countries. Turkey held great expectations for international aid in transforming its stagnation in geothermal power generation, and indeed, since the congress, a major turnaround was made, as geothermal power generation in the country rapidly jumped to the 4th place in the world.

The World Geothermal Congress 2010 was held in Indonesia, with a record number of more than 2,500 participants from 85 countries in attendance, alongside more than 800 enthusiastic geothermal practitioners from the host country. Indonesia is a

A Glimpse of WGC 2005

third-world developing country, with more than ten countries starting geothermal power generation before it, but it has become the third place in the world in 2010. Delegates had visited the largest geothermal power plant in Indonesia, the 377MW Sokoria Geothermal Power Plant.

World Geothermal Congress 2015 was jointly organized by Australia and New Zealand, with more than 1,600 participants from 82 countries. New Zealand was the second geothermal power generation country in the world, with 1005MW of installed geothermal power at that time, one of the top five countries who entered the world's gigawatt club. Australia started late in geothermal energy, but EGS was used to achieve 1MW of power generation, which was a highlight at that time.

World Geothermal Congress 2020 held in Iceland was postponed to 2021 due to the impact of the global pandemic, but was continued through holding joint online and offline conferences. Iceland was the ninth country in the world to generate geothermal power and has ranked eighth and ninth in the world. Iceland created the world's first magma drilling, and holds the world's largest production capacity in IDDP project magma-encountered drilling, which includes a test injection output of 450℃ superheated dry steam at 45kg per second and a single-well power generation potential of 36 MW.

The six World Geothermal Congresses that have been held so far have all propagated the achievements of geothermal power generation, given foreign participants a tour of novel geothermal power projects, and called for the development of geothermal power generation in the Congress declaration, citing its superiority over other renewable energy sources in terms of its capacity factor.

2. World Geothermal Congress 2023 Will Be Held in China

The World Geothermal Congress will be held every three years in the future, and China has been awarded the right to host the World Geothermal Congress in 2023. During the bidding debate in 2019, China contended that its direct geothermal use had ranked first in the world for 20 years and promoted the idea that in addition to power generation with geothermal energy, increasing prevalence in medium and low-temperature geothermal resources in the world could provide thermal energy for a wide range of applications in human society and play a huge role in energy conservation and emission reduction. China welcomed the world to witness the developments in China, and its bid was finally met with success.

World Geothermal Congress 2020 was postponed for a year due to the impact of the pandemic, and the Reykjavik Declaration was released at the closing ceremony of the Congress in Reykjavik, Iceland, on October 27. The Reykjavik Declaration, in consideration of the situation of global climate change and enhanced energy transition, put forward the principles for sustainable growth of global geothermal projects over the next decade: sustainable geothermal brings benefits far beyond electricity generation, and geothermal projects should consistently deliver benefits to communities, citizens and the climate. The declaration called on stakeholders to seek the benefits of system integration with other

WGC2020+1 Reykjavik Declaration

renewable energy sources to provide clean, affordable energy for all.

The Reykjavik Declaration conveyed a different meaning from before, which will be manifested at World Geothermal Congress 2023, where we will use the examples in China to show the world how direct geothermal use “beyond power generation” can better achieve “clean, affordable energy for all.”

3. WGC 2023 Can Expect the Launch of China's Geothermal Energy

Tempus fugit. The 5-year gap between each World Geothermal Congresses has been shortened to 3 years, and the global COVID-19 pandemic has postponed the congress for another year, leaving only 18 months before the next World Geothermal Congress in 2023, so preparations must be stepped up to guarantee a fully successful launch.

About 3,000 people are expected to attend the World Geothermal Congress 2023, representing 90 countries, and this raises the curious questions of: What shall attendees be invited to see? What can China showcase to the world?

3.1 A Comprehensive Display of China's Geothermal Progress

When attendees arrive in China, they can expect to be shown major progress and developments without restraint. When one attends the World Geothermal Congress in other countries' venues, often, there is only a one-paper-page promotion taking up less than 2 square meters. However, in China's venue, one will see that promotions for the congress is visible throughout countless locations, from archways, aisle sides, fences, building facades, banners to balloons. There will be innumerable spaces to display the highlights of China's geothermal energy fully. As the theme of the WGC 2023 conference has not been finalized yet, we encourage active participation in the brainstorming and proposing of a resounding geothermal theme that best represents China’s unique features of its times.

3.2 China Comprises Many of the Top Examples of World-Class Projects in Geothermal Enery

China's direct geothermal utilization has dominated the world for 20 years, and its growth has been unprecedented. For example, although the largest foreign projects implemented in ground source heat pumps cover several thousand square meters, China has long achieved a cover of more than 100,000 square meters, with projects covering a million square meters completed a few years ago, and the current Jiangbei New City in Nanjing now covering an incredible 16 million square meters. These world-class achievements can not only be used as highlights of the visit, but also form the content of the training program before the congress, and the implementation of a number of training topics are still in consultation with the International Geothermal Association.

3.3 Ranking of the world's Largest Direct Geothermal Utilization Companies

In the past, the world ranking list only contained the world's largest geothermal power plant, created by Geysers Geothermal Field in the U.S. with an installed capacity of 1,585MW, and the world’s largest geothermal power equipment manufacturers, with Japan’s Mitsubishi, Toshiba, and Fuji accounting for more than 70% of the world’s total production and Ormat from the U.S. accounting for more than 90% of the duplex power generation equipment. There has never been a ranking of the largest geothermal heating projects or the largest manufacturers of ground source heat pump equipment. Now, it is China's turn to compile and shine a light on the world in the ranking table for direct geothermal utilization.

3.4 Geothermal Heat Unfitted for Power Generation can also be Utilized

New Zealand became the second country in the world to generate geothermal power in 1958, and continues to rank highly in the world in geothermal power generation. However, at the 34th New Zealand Geothermal Working Conference in 2012, New Zealand geothermal experts raised the question, “Is power watts all that is to geothermal energy?” The intention behind this question was meant to implore the utilizing of geothermal heat for uses beyond power generation, to make full use of the medium and low-temperature geothermal heat resources that could not be used as power generation. Despite the raising of this important question, there remains still a series of tasks to accomplish before this can be truly realized. The Reykjavik Declaration has also proposed the sentiment that geothermal resource is much more than power generation, a positive developmental progress and a novel perspective. China has shown a prime example of how this can be achieved, and others are welcomed to learn and exchange ideas in this path.

3.5 Technical and Economic barriers Involved in Geothermal Utilization are Lower than that of Power Generation

Tepid expansion of geothermal energy has been in part related to the high technology and investment barriers in geothermal power generation. Meanwhile, the rapid growth of ground source heat pumps presents a stark contrast in the speed of its development, and this is because the technology involved is relatively simpler, and the investment is lower than that of power generation. Additionally, China's geothermal energy initially began its implementation in the hot springs leisure industry, where the technical and economic constraints of hot springs, medical and leisure spas are less steep, which allowed the ground source heat pump industry to blossom. Knowledge of this developmental history can serve as a learning experience for developing countries involved in the Belt and Road Initiative to see how geothermal utilization which involves lower technical and economic barriers to entry can bring about mutilpier effect on the development of the whole geothermal industry.

3.6 Chinese Geothermal Research can Play to Their Strengths

The most attended World Geothermal Congress was held in Indonesia in 2010, with 2,500 participants, of which more than 800 were from Indonesia. It is challenging for ordinary people to go abroad to attend an international conference for a developing country in the third world, but it will be much easier to attend the online conference at home. WGC 2010 in Indonesia saw a large number of participants, and many research papers were submitted by Indonesians. Such favorable conditions will also occur in China’s World Geothermal Congress in 2023, where most members of the organizing committee and technical committee responsible for publishing papers will be Chinese. Previously, the number of papers published by Chinese authors at the World

Geothermal Congresses was more than 10 in 1995 and then increased to more than 20, 30, and 50 in each successive congress. In 2020, the World Geothermal Congress published 1931 papers, of which the host country Iceland published the most, at 213. Indonesia and Germany published the second and third most, and China ranked fourth with 119 papers, and the United States ranked the fifth with 118 papers. Just as previous host countries had seen, it is believed that China will secure the title of highest number of papers in WGC 2023.

3.7 As a Cultural and History Hub, China Welcomes Guests from Around the World

China has a 5,000-year history and is a traditional ancient civilization and a country of etiquette. Chinese citizens are always "delighted to host friends from afar." A highlight of the WGC 2023 will be the social and cultural activities for the attendees and their escorts. The Great Wall of China, Chinese Peking Opera, Peking duck, silk products, etc., are all favorites of foreign guests, and they can be expected to be fully served well and return home with great content.

3.8 Guests are Welcomed to Visit and Learn from Model Projects

All World Geothermal Congresses have pre-conference and post-conference visits, and the registration of many projects are still waiting for review. Committee members have to discuss the introduction materials and decide on the most notable projects in the next joint conference of the Chinese Organizing Committee and the International Steering Committee, so as to enrich the world's models and contribute to the global geothermal industry community

4. Overcoming Remaining Deficiencies

The World Geothermal Congress is a platform for the geothermal industry to exchange between China and foreign countries. China has made an example of direct utilization of medium and low-temperature geothermal heat, but we also have fallen behind in geothermal power generation and EGS research. We should discuss more with our world counterparts in this regard and learn from the world.

4.1 Weaknesses in the Developmental Progress of Geothermal Power Generation in China

The first successful geothermal power generation in China was implemented in 1970, making the country the seventh in the world to generate geothermal power, and both low-temperature geothermal power generation and high-temperature geothermal power generation were accomplished in the 1970s. However, development has been tepid, and the total installed capacity still stands at less than 45MW even after 50 years of work in this area. The 13th Five-Year Plan has put forward 16 MW of geothermal power plants connected to the power grid in in Yanyi, Tibet, in 2018, in addition to a number of smaller-scaled experiments which made up a total of 18.08MW, but this was only 4% of the planning target. The reasons for this lag need to be explored, but it is rare that geothermal power generation as outlined in the 13th Five-Year-Plan has not been subsidized in its grid-purchases and industries are paying geothermal resource taxes.

4.2 Geothermal Education is Indispensable

The international community has been curious about why despite ranking first in the world for 20 years in direct geothermal utilization, there is a lack of geothermal majors across Chinese universities. According to the statistics of WGC2020+1, China is not yet ranked among the top 5 countries in the world in terms of the number of geothermal professionals, revealing a shortcoming in this area. Fortunately, starting in the fall 2021 academic year, China University of Geosciences (Beijing) has offered a geothermal program with an initial enrollment of 25 undergraduate students.

4.3 Contributing to Carbon Peaking and Neutrality

China has established bold carbon reduction targets: peak carbon dioxide emissions by 2030 and carbon neutrality by 2060. In 2020, non-fossil energy (nuclear energy + hydropower + renewable energy) accounted for 14.9% of China's energy consumption composition (Figure. 2), which was still far from the dual-carbon goals of energy transformation. Geothermal energy and other renewable energy sources currently account for only 4.7% of total energy consumption and must contribute more to achieving the dual carbon goal. Given the limited ability of China's power grid to handle the volatility and intermittency of wind and solar power (currently 15%), geothermal power, capable of being used as a base load, cannot be disregarded (cannot be just satisfied with direct geothermal utilization), and the current backwardness of geothermal power generation must be completely transformed, which requires the support of national incentive policies. A positive development can be seen in the Hangzhou Jinjiang Group's recent contract for the second phase of the Yangyi Geothermal Power Plant project with Damxung County of the Tibet Autonomous Region to build another 16MW of new units.

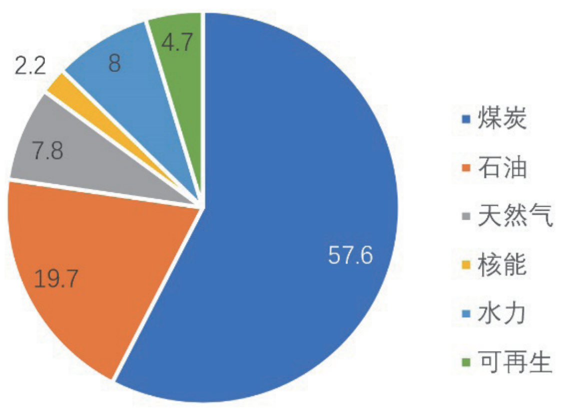


Figure. 2 Composition of Chinese Energy Consumption in 2020 (%)

SHALLOW GEOTHERMAL ENERGY ACCELERATES THE ACHIEVEMENT OF THE "DOUBLE CARBON GOALS"

Written by: Ma Xiaofang

Energy-saving, Efficient and Pollution-free Shallow Geothermal Energy Boosts the Achievement of the National "Double Carbon Goals"

As the weather changes from warm to cold, a new heating season is approaching. Aligning with the dual goals of attaining carbon peaking and carbon neutrality instated by the national government, clean energy heating technology has become the mainstream of this heating season. Under this new direction, various industries have began to rapidly adopt transformative actions, and the high-energy-consumption heating industry is no exception. To realize the "double carbon goals" in the heating industry, a combination of governmental measures and effective industry self-discipline is required. Among diverse methods, shallow geothermal energy stands out as an advantageous option due to its unique characteristics of achieving renewable, efficient, and pollution-free heating. To boost the transformation of heating energy in this new era, it is necessary to continuously strive to increase research and development of science and technology in shallow geothermal energy, increase its market share among clean energy heating, and promote the use of factual data to support its utilization as the prime alternative heating energy choice.

2021 marks the 100th anniversary of the founding of the Communist Party of China and the first year of the 14th Five-Year-

Plan. In dealing with complex matters both domestically and abroad, energy security must be taken into consideration. Meanwhile, the comprehensive implementation of the double carbon goals and realizing green and low-carbon transformation are also formidable tasks. The Guiding Opinions on Energy Work in 2021 issued by the National Energy Administration clearly specifies the necessity of stepping up clean energy heating, implementing transformations in clean energy heating according to local conditions, establishing robust clean energy heating policy systems, ensuring safe and stable operations of heating facilities, and achieving a 70% rate of clean energy heating across Northern China.

Heat from the Earth's Interiors

Clean energy heating is widely acknowledged to be a method which causes low emission and low energy consumption, commonly involving natural gas, electricity, geothermal, biomass, solar, industrial waste, clean coal combustion (ultra-low emission), and nuclear energy heating sources, with efficient systems to realize reduction of pollutant emission and energy consumption, providing warmth and heating through efficient heat transmission to distribution pipe networks (heating network), energy-efficient buildings (heat users), and beyond.

High-temperature lava within the earth's interior heats up water in the pores of the earth's rock and soil, and this heated groundwater naturally seeps out through the rocks' cracks to form hot springs. Heat extracted from the shallow layer of the earth using heat pumping technology is called shallow geothermal energy, and it is used as the heating supply for buildings. This type of heating generally utilizes low-grade renewable heat energy at temperatures below 25℃ , stored 0~120 meters deep within the earth. As a novel clean and environmental-friendly energy that has been rapidly developed and utilized in the recent 20 years, shallow geothermal energy is characterized by its abundant reserve, wide distribution, and rapid regeneration. Shallow geothermal energy can continuously produce heat energy by temporarily lowering the temperature of underground localized areas during heating season, withholding superior stability and providing individuals with a comfortable warmth close to room temperature.

Data has shown that, as an alternative energy source for heating in northern regions, the shallow layer geothermal energy can directly replace about 30,000 tons of bulk coal, reduce carbon dioxide emissions by 80,000 tons, sulfur dioxide by 227 tons, nitrogen oxides by 80 tons and soot by 319 tons per 1 million square meters of buildings per heating season. Compared to the direct-heating electric heater, it can reduce the power consumption by about 9×10^4 MWh.

Practical applications has also indicated that, as an alternative energy source for heating, shallow layer geothermal energy can realize regional combustion-free, zero-emission physical heating for buildings at a lower cost than burning coal. It is expected to become the main force of heating energy transformation and will trigger a heating energy revolution in the future.

A Greater Acceptance of Geothermal Energy among Users

The Guiding Opinions on Energy Work in 2021 emphasizes the necessity of exploring the application of clean energy heating technology in southern China, encouraging market-oriented development of clean energy heating according to local conditions, and cultivatng product manufacturing and service enterprises in the Yangtze River Basin amongst other developed areas in southern China. Research and promotion of clean energy heating transformations in the southwest alpine region, strengthening policy support, and consolidating the construction of power grid and natural gas pipeline network have also been outlined. With the popularization of shallow geothermal energy heating technology, more and more areas began to conduct experiments in shallow layer geothermal energy heating. Media reports have also indicated that, in this new heating season, increasing number of residents are beginning to be pleasantly surprised by the effects of shallow geothermal energy.

The development of geothermal energy industry technology is of great significance. In recent years, China has made great efforts to promote the application of shallow geothermal energy and other renewable energy in buildings, achieving remarkable results. According to data, more than 10 million square meters of shallow geothermal energy building applications have been built in Anhui Province, making positive and significant contributions to buildings' energy conservation and emission reduction in this region.

Heilongjiang Province has also issued the Specialized Planning for Geothermal Heating in Heilongjiang Province, which required Harbin to begin at least two demonstration projects in its critical demonstration areas in 2021. This document required participation in online geothermal heating special planning and technical standard training through "Building Vocational Training and Employment Service Platform in Heilongjiang Province" to promote the application of technology. All cities in Heilongjiang Province should also formulate development plans for geothermal heating in their districts according to relevant requirements and target measures, make clear the annual development goals, introduce relevant support policies, and speed up the construction of demonstration projects. Building demonstration projects in uncovered areas of central heating, ultra-low energy consumption buildings, green buildings, public buildings, industrial plants, urban shantytown renovation, affordable housing, and other housing construction projects are also necessary to reap the benefits of proper development of local geothermal heating.

To achieve carbon neutrality, it is imperative to not only ensure heat sources of heating industry are clean, but also require that enterprises adopt modern scientific and technological means for heat supply. As one of the earliest enterprises engaged in shallow geothermal heating, Ever Source Science and Technology Development Group Co., Ltd. has long begun formulating the practical applications surrounding this technology. Through the enterprise's unique shallow geothermal heating technologies, combined with its self-developed intelligent control platform, and utilization of the Internet of Things (IoT) and digitalization, Ever Source Science and Technology Development Group Co., Ltd. has paved an unprecedented path for heating enterprises in assisting the achievement of the "double carbon goals."

To thoroughly implement China's goals of carbon peaking and carbon neutrality, it is necessary to revolutionize energy production and consumption, develop high-quality renewable energy, increase the proportion of non-fossil energy consumption, control total consumption of fossil energy, improve utilization efficiency and continuously optimizate energy structures. Geothermal energy is clean, environmental-friendly, widely distributed, abundant, safe, and stable, high-quality, and renewable, playing an essential role in China's energy structural transformation. With accelerated exceptional development, the geothermal heating industry has gradually developed into a green and effective force to ensure heating supply during winters, providing a new option for the comprehensive solution of low-carbon energy consumption in urban areas. At present, Ever Source Science and Technology Development Group Co., Ltd. is accelerating the industrial layout, taking on more social responsibilities while realizing enterprise benefits, and striving for the national "double carbon goals" with practical actions.

Clear waters and lush mountains are invaluable natural resources of a country, and the idea of green and low-carbon development has been gradually embedded in people's minds. The goal of attaining carbon peaking and carbon neutrality is a protracted and tough battle, and is one which requires cooperation to achieve sustained progress. Clean energy enterprises should actively contribute their wisdom and strength and commit to promoting the application of shallow geothermal energy as an alternative energy for heating. It should effectively address the winter heating concerns of the hundreds of millions of citizens who are cherished and kept in mind by President Xi Jinping.

Shallow Geothermal Heating Attaining Wider Support Across the Country

User from Yanqing, Beijing:

As the Winter Olympics approaches, local residents in Yanqing, a suburb located in the colder northern region of Beijing, have a deeper insight into the concept of low-carbon living significantly promoted by shallow geothermal heating. Hou Yuxian, a local 90-year-old, sang praises after using shallow geothermal heating, proclaiming "I really appreciate the Communist Party. It takes me out of the bitter days before liberation and helps me live a happier and more comfortable life." Hou frequently boasts about her apartment's geothermal heating equipment to guests, saying, "Now there is no need to burn fire for heating. This equipment is clean and warm, and costs less money than burning coal. I never dreamed of living such a life before."

User from Mentougou, Beijing:

Chanfang Village of Mentougou District is located at an altitude of 1,000 meters at where Beijing's first rural party branch first emerged. This village uses the shallow geothermal energy heating technology in every household. Residents in the village have unanimously expressed joy over the convenience of no longer having to tediously move coal around for heat or concerns over poisonous emissions during cold winters.

User from Mentougou, Beijing:

In Longquanwu Village, Mentougou, Beijing, a former coal mining region, the villagers changed their attitude towards shallow geothermal heating, adjusting from feelings of unfamiliarity to now recognizing and praising its many benefits. Resident Chong Naiyun described "When I was 10 years old, I began to smash coal and add fire to heat the house, and temperatures were 18-19℃ at peak, and 13-14℃ during other times. I never dreamed I could enjoy this fantastic heating technology at the age of 66 this year." Considering this was a former mining area, the transformation of the villagers' attitudes and knowledge about shallow geothermal heating reflects an accurate picture of the advantages of this method.

Huailai County, Zhangjiakou, Hebei:

Beyond the Great Wall, in Yihebao Village, located in Cunrui Town, Huailai County of Zhangjiakou City, ever since Ever Source Science and Technology Development Group Co., Ltd. implemented the coal-to-clean energy transformation utilizing geothermal energy and thermal treasure system of single-well circulation heat exchange in 2016, significant changes have occured in the villagers' lifestyle. Villagers bid farewell to the black coal ash and dusty coal stoves and now their windows are bright and clean. During the cold winter, they can enjoy living in their homes at comfortable temperatures with clean and fresh air. Shallow geothermal energy has allowed them to experience warm winters and cool summers, where villagers have likened their lifestyles to living in an urban villa.

List: Relevant Policies and Measures of the State to Promote Geothermal Heating

1. January 2017, the Thirteenth Five-Year Plan for Geothermal Energy Development and Utilization

Vigorously promote the utilization of shallow layer geothermal energy, and develop and utilize shallow layer geothermal energy by the principles of "develop intensively according to local conditions, strengthen supervision with focus on environmental protection." Strengthen the development and utilization of shallow layer geothermal energy in areas with strong demand for heating and refrigeration in southern China. While paying attention to the utilization of shallow layer geothermal energy in traditional urban areas, also pay attention to the demands of new urban areas for shallow layer geothermal energy heating (cooling).

2. December 2017, the Clean Energy Heating Plan for Winter in Northern China (2017-2021).

Actively advance hydrothermal (middle and deep layers) geothermal heating. According to the principle of "taking heat without taking water," and by using the technology of "balanced mining and irrigation, indirect heat exchange" or "heat exchange under the shaft," promote the middle and deep layer geothermal heating in a centralized and decentralized way, so as to realize the sustainable development of geothermal resources. Vigorously develop shallow layer geothermal energy for heating. In alignment with the method of "develop intensively according to local conditions, strengthen supervision with focus on environmental protection," we must speed up the popularization and application of various shallow layer geothermal energy utilization technologies, and replace bulk coal heating economically and efficiently.

Establish and improve the management system and technical standards and maintain geothermal energy development and utilization market order. Formulate management measures for geothermal energy development and utilization, and straighten out the mechanisms of geothermal exploration license, geothermal water mining license, and geothermal water resource compensation fee levying and management. Improve the geothermal industry standards, ensure the geothermal recharge rate of 100%, and implement the qualification certification, planning review, and licensing system in accordance with existing laws and regulations.

In 2021, the geothermal heating area shall reach 1 billion square meters, including 500 million square meters of geothermal heating in middle and deep layers and 500 million square meters of geothermal heating in shallow layers (including ground source and water source heat pump in electric heating).

3. January 2018, Notice on Accelerating the Development and Utilization of Shallow Layer Geothermal Energy to Promote the Reduction and Replacement of Coal Burning in Northern Heating Areas

In alignment with the principle of "enterprise-oriented, government-driven, affordable for residents," make holistic use of relevant policies, support and standardize the development and utilization of shallow layer geothermal energy, improve the cleaning level of residents' heating and enhance the air quality in the environment.

4. December 2020, the white paper Energy in China's New Era

Innovate the geothermal energy development and utilization mode, carry out geothermal energy central heating in cities and towns, and build a demonstration area for efficient geothermal energy development and utilization.

5. January 2021, the Notice of the National Energy Administration on Doing a Good Job of Renewable Energy Heating according to Local Conditions

Focus on promoting middle and deep layer geothermal energy heating, and promote geothermal energy heating in the middle and deep layers by combining centralization and decentralization according to the principle of "fixed mining by irrigation, balanced mining and irrigation, and balanced water and heat." Actively develop shallow layer geothermal energy heating to economically and efficiently replace bulk coal heating and develop surface water sources, soil sources, and underground water source heating and refrigeration in areas where conditions permit. Encourage the use of oilfield-produced water to carry out geothermal heating, comprehensive utilization of groundwater resources and mineral resources, .etc.

Implement major geothermal heating projects and promote critical projects implemented in areas with sufficient geothermal resources. Encourage the demonstration of centralized utilization of geothermal energy in the middle and deep layers, demonstrate the heating utilization modes and application scope of different geothermal resources, and explore new management technologies and market operation modes that are beneficial to the development and utilization of geothermal energy.

6. Guiding Opinions on Energy Work in 2021

Intensify the clean energy heating work, implement clean energy heating transformation according to local conditions, establish and improve the clean energy heating policy system, ensure the safe and stable operation of heating facilities, and achieve 70% clean energy heating rate in Northern China. Explore the application of clean energy heating technology in southern China, and encourage the market-oriented development of clean energy heating according to local conditions and cultivation of product manufacturing and service enterprises in the Yangtze River Basin and developed areas in southern China. Study and promote the clean energy heating transformation in the southwest alpine region, strengthen policy support, and consolidate the construction of power grid and natural gas pipeline network .etc.

7. September 2021, Several Opinions on Promoting the Development and Utilization of Geothermal Energy

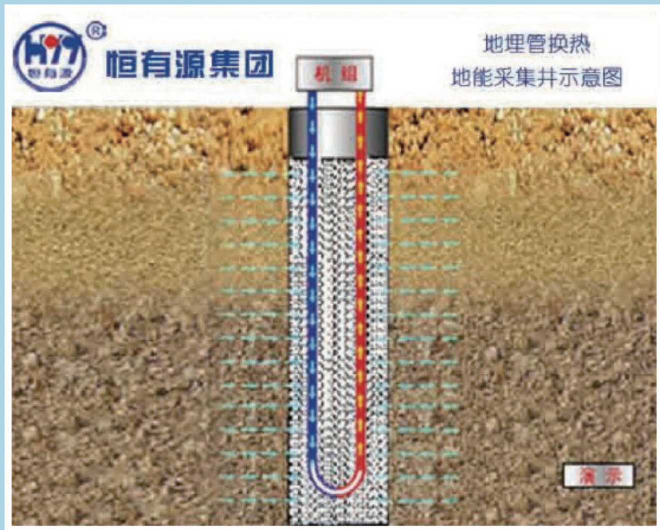
By 2025, a sound and standardized geothermal energy development and utilization management process will be basically established in all regions, with fundamentally sound national geothermal energy development and utilization of information statistics and monitoring system. Geothermal energy heating (cooling) area must increase by 50% compared with 2020. A number of geothermal energy power generation demonstration projects will be built in areas with good resource conditions, and the installed capacity of geothermal energy power generation will double that of 2020. By 2035, the geothermal heating (cooling) area and geothermal power generation installed capacity will be doubled compared with 2025.

Tips:

How does shallow layer geothermal energy heating work?

Geothermal resources are divided into shallow, middle, and deep geothermal resources according to depth. The shallow geothermal depth range is generally 200m and above, including soil and shallow water-bearing layers. The geothermal resources in the middle and deep layers are generally between 200m and 3000m. The buried depth of deep geothermal resources usually exceeds 3000m. Geothermal heating extracts heat from geothermal resources by using a heat exchange system to supply heat for users, which can be divided into shallow layer geothermal energy (cooling) mode, hydrothermal geothermal heating mode, and middle-deep geothermal heat pump heating mode. The shallow geothermal energy principle seems complicated at first sight, but is in actuality straightforward once deconstructed.

Specifically, there are three primary collection methods of shallow layer geothermal energy heating: Pumping well+recharge well system, buried pipe system, and single-well-circulating heat exchange system.



地埋管换热示意图

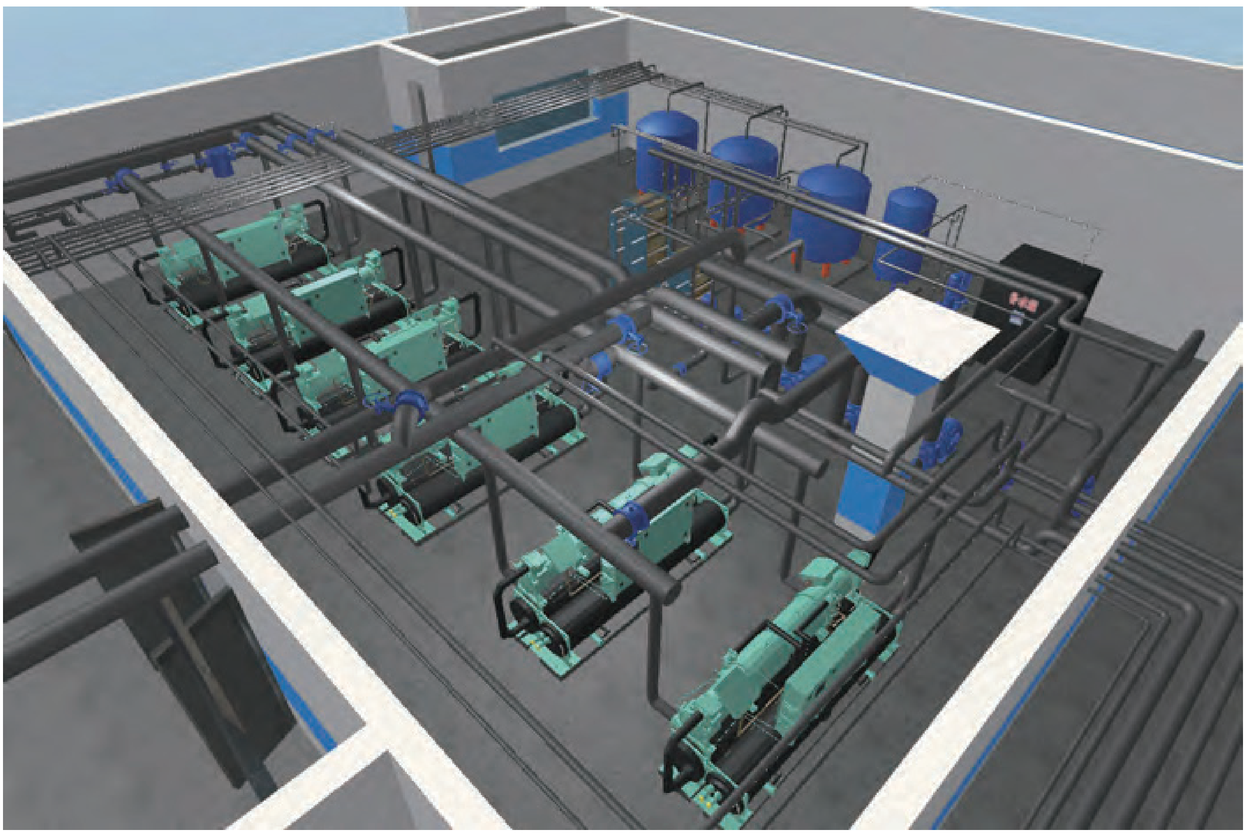
The pumping well+recharging well system is also called the groundwater-source heat pump system, and the ground pipe and single-well-circulating heat exchange system is also called the groudsource heat pump system.

Pumping well+recharging well system is a system that uses groundwater as the low-level heat source and uses heat pump technology to transfer heat from low-level energy to high-level energy through a small amount of high-level electric energy input, so as to realize heating or cooling for users. The system is suitable for abundant groundwater resources, and the local resource management department permits the exploitation and utilization of groundwater.

The underground pipe system is typically composed of single U-shaped or double U-shaped heat exchange tubes buried vertically about 100 meters deep. The medium in the heat exchange pipe exchanges heats with the surrounding rock and soil through the pipe wall. It can adapt to various geological conditions, but its poor heat exchange capacity and ample floor space are also considered as its disadvantages.

The core of the geothermal energy collection technology of single-well- circulation heat exchange of shallow geothermal energy innovated by Ever Source Science and Technology Development Group Co., Ltd., is made up of 100% recharge of homogenous groundwater in the same layer. Because the water in the well is recharged in situ, it will not consume water, pollute water, lose water, destroy the natural distribution of groundwater, or cause potential geological disasters.

There is an essential difference between the collection of single-well-circulating geothermal energy collection wells and pumping wells. Single-well-circulating geothermal energy collection wells are a closed and stable geothermal energy recycling collection system. In terms of appli-

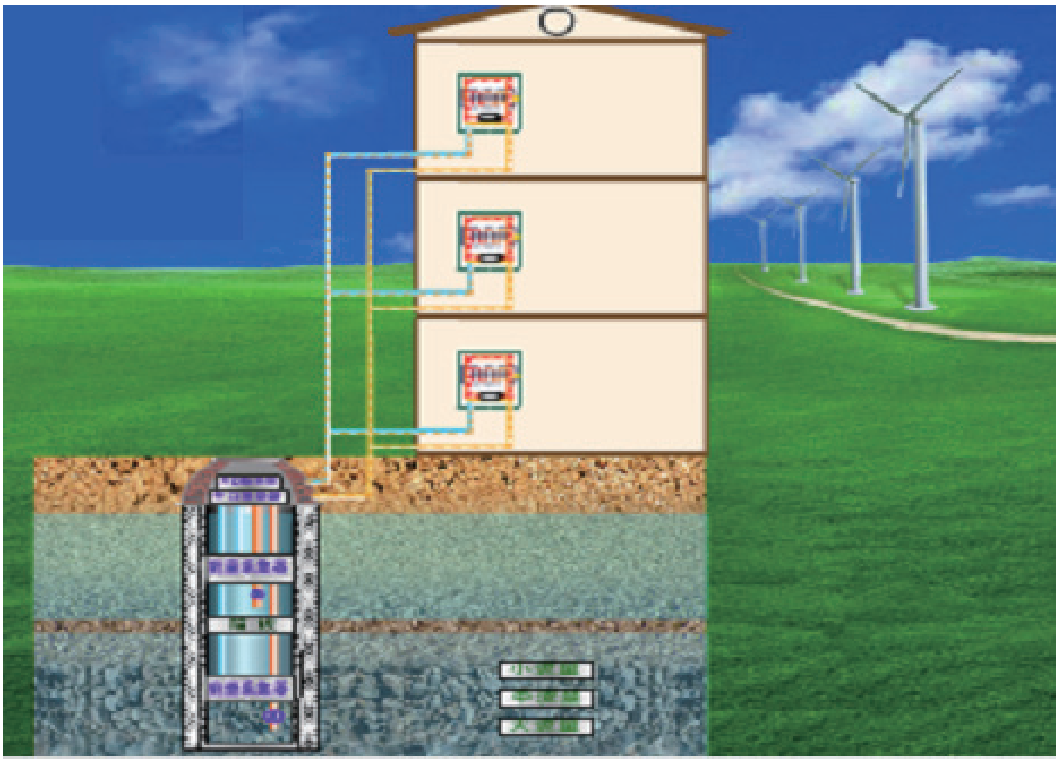


cability, they can be used in different geological conditions for geothermal energy collection.

● Technology Utilizations

The geothermal heat pump environmental system is a heating scheme for individual buildings or buildings with small areas. The system can be regarded as a regional heating boiler room in the traditional combustion heating industry, with a designated heating scale of 100 ~ 30000 kW, which can provide heating, cooling, and localized hot water for buildings up to 2000 ~ 500000 square meters.

The latest geothermal energy heating system introduced by Ever Source Science and Technology Development Group Co., Ltd. is a heating scheme for separate rooms designed for rural areas in northern China where buildings are scattered and there exists villas in the urban area. The geothermal energy heating system is an integrated geothermal energy heating & cooling system that can guarantee heating and cooling simultaneously and with an option of localized hot water. It has realized the self-heating mode with traditional virtue of “economic use” for rural households, which “guarantees heating and cooling, with an option of localized hot water, separate heating supply in each room, where residents will never feel cold even if the heating function is not enabled.”



SOLAR THERMAL + AIR-SOURCE HEAT PUMP ASSISTS IN ACHIEVING CLEAN HEATING AND "DOUBLE CARBON GOALS"

Written by: Ma Xiaofang

The sun is the heat source for millions of lives on earth, and it is vital to the inception and continuation of human beings. This can be seen in how humans use solar energy to dry foods, clothes and make salt. In alignment with the direction of decreasing reliance on fossil fuels, solar energy has gradually become an important energy source for sustainable human development and plays an essential role in the process of achieving the "double carbon goals" in China. Relying on its own leading technology, Ever Source Group is successfully combining solar thermal and air-source heat pump coupled technologies to create a new solar thermal + air-source heat pump coupled clean heating system, taking advantage of free solar thermal heat during the day and low cost of heating with air-source heat pumps during off-peak electricity pricing periods at night, significantly saving on heating operating costs. Comprising the characteristics of eco-friendliness, wide distribution, and many other features, this technology provides a new low-cost solution for clean heating, contributes to energy saving and emission reduction, and helps achieve carbon neutrality by 2060.

Most of the energy required by humans comes directly or indirectly from the sun. Plants release oxygen, absorb carbon dioxide through photosynthesis, and then convert solar energy into chemical energy stored in the body. The formation of fossil fuels such as coal, oil, natural gas, and other energy sources is also dependent on solar energy. China's vast territory is also abundant in solar energy resources, of which Tibet is the richest, with a maximum of 2333kWh/

m2 (6.4kWh/m2 of daily radiation), ranking second in the world, only after the Great Sahara Desert.

Solar energy and air energy are clean and renewable energy sources. Solar energy is generated from the sun's internal hydrogen atoms by hydrogen-helium fusion releasing vast amounts of nuclear energy, which comes from the sun's radiant energy. Air energy is the low-grade thermal energy contained in the air. With the help of air-source heat pumps, heat can be absorbed from the air and transferred to high-temperature objects or the environment with a higher grade. The solar thermal + air-source heat pump coupled clean and renewable heating system developed by Ever Source Group successfully combines two clean energy sources, solar energy and air energy, to form a linkage effect of 1+1>2, which has been well received by the industry.

What is solar thermal + air-source heat pump coupled clean heating product system?

The solar thermal + air-source heat pump coupled clean heating product system developed by Ever Source Group mainly contains; an outdoor solar thermal heating machine, an outdoor air-source heat pump mainframe, an indoor radiator terminal, an indoor circulating pipeline pump valve, and a cloud controller. Its working principle is that solar thermal energy is converted into heat energy through the heat-absorbing "blue sky tubes" to meet heating requirements. During daytime, the solar thermal heating machine takes full advantage of the cost-free and abundant solar energy, absorbing solar energy and converting it into heat energy, and conveys the heat energy to the terminal of indoor radiators through the circulation system to provide continuous heat to rooms and domestic hot water.

Air-source heat pump heating utilizes compressors to realize the transfer of heat energy from the air to the indoor room to be heated. Most of the heat it supplies to the indoor room comes from the air in the outdoor nature, and the heat gain is more than twice as much as the consumption of electric energy, reducing about 50% of the running cost of electric heating. The heat energy in the air of the room indoor can also be transferred to the outdoor air to achieve the purpose of cooling and air conditioning for buildings.

Linkage control by the cloud controller

The solar thermal + air-source heat pump coupled clean heating product developed by Ever Source Group features a unique advantage: linkage control by a digital cloud controller. The cloud controller used in this intelligent system can achieve automatic linkage control operation of solar thermal heating machine, air-source heat pump mainframe, and radiator terminal, while realizing real-time monitoring. Any process that needs to be monitored, connected, and interacted with is collected and uploaded in real-time through the cloud controller to collect its sound, light, heat, electricity. The cloud platform is accessed through the GPRS network, and big data analysis is adopted to implement monitoring, recording, analysis, self-learning, automatic alarming, and back-end maintenance of the user's products.

Therefore, the Ever Source solar thermal + air-source heat pump coupled clean heating system reduces energy consumption, protects the environment, and effectively reduces the need for labor, and this efficiency is particularly beneficial under the current context of the prevention and control of the ongoing pandemic.

Common product specifications

Data and statistics show that with Ever Source solar thermal + air-source heat pump coupled clean heating system, a heating area of 40-60 square meters requires only one solar thermal heating machine with radiators, radiant floor heating, and fan coils at the terminal, which can provide 5.7kW of heat at an ambient temperature of -12 ℃. Only 2.5kW of system power distribution is required to ensure heating, cooling, and provision of 24-hour domestic hot water. For a heating area of 100-120 square meters, two solar thermal heating machines are required, which can provide 12kW of heat in the same environment, and only 5.2kW of system power distribution is needed to achieve heating, cooling, and 24-hour hot water supply.

How does the solar thermal + air-source heat pump coupled clean heating product system operate?

During the daytime, when the solar irradiation is abundant, Ever Source solar thermal + air-source heat pump coupled clean heating product system converts solar energy into heat

Common product specifications

Heating area (㎡)	Configuration of coupled clean heating product		Heat supply		System power distribution (kW)	Functions	Terminal configuration
	Solar Thermalheating machine	Air-source heat pump mainframe	Ambient temperature (℃)	Heat supply (kW)			
40-60	One LTC-50P	HYY-NZB8D	-12	5.7	2.5	Heating, cooling, domestic hot water supply	Radiators, radiant floor heating, fan coils
60-80	Two LTC-40P	HYY-NZB12D	-12	8.7	3.7		
80-100	Two LTC-50P	HYY-NZB14D	-12	9.1	3.9		
100-120	Two LTC-60P	HYY-NZB18D	-12	12	5.2		

energy stored in the solar heat storage water tank, turns off the electric valve through the control system, shuts down the air-source heat pump unit, circulating pump operation, and supplies heat to the terminal of indoor radiators.

At night, the residual heat from the solar heat storage water tank supplies heat to the terminal of indoor radiators through the circulation pump of the control system. When the solar heat supply is insufficient, the electric valve is opened, and the air-source heat pump unit is ignited to supply heat directly to the terminal of indoor radiators using off-peak electricity.

In case of insufficient solar heating due to rainy and snowy weather, the air-source heat pump unit is used to supply heat directly to the terminal of the indoor radiators.

Economic analysis of solar thermal + air-source heat pump coupled clean heating product system

According to Beijing heating electricity prices, the weighted electricity price is 0.3 yuan/kWh, specifically the peak electricity price is 0.4883 yuan/kWh and the off-peak electricity price is 0.1 yuan/kWh. Taking a

Common product specifications

Serial No.	Configuration of coupled clean heating product	Heating configurations	System power distribution (kW)	Electricity consumption for operation (kWh)	Electricity cost (yuan)	Remarks
1	Low ambient temperature air-source heat pump hot water unit	One set of 3HP HYY-NZB8D air-source heat pump hot water unit	2.5	3696	1109	
2	Electric boiler	6kW electric boiler	6.2	8500	2550	
3	Solar thermal + low ambient temperature air-source heat pump hot water unit	LTC-50P+3HP HYY-NZB8D air-source heat pump hot water unit	2.5	2787	356	The contribution rate of heating by air-source heat pump system is 70%, the contribution rate of solar thermal heating is 30%, and the electricity consumption of air-source heat pump is all off-peak electricity.

4	Solar thermal + electric boiler	LTC-50P+6kW electric boiler	6.2	6150	693	The contribution rate of electric boiler heating is 70%, the contribution rate of solar thermal heating is 30%, and the electricity consumption of air-source heat pump is all off-peak electricity.

heating area of 60 m2 as an example, the estimated electricity cost for operation of solar thermal + air-source heat pump coupled clean heating products and comparison with other heating systems are shown in the table below.

Solar thermal + air-source heat pump coupled clean heating system product has the lowest electricity cost

The operation cost of solar thermal + air-source heat pump coupled clean heating saves about 50% of electricity cost compared with solar thermal + electric boiler system. In addition to the free solar thermal, the off-peak electricity price at night is also the main reason for the low electricity cost.

Maximized use of off-peak electricity for heating to reduce operation cost

The reasonable ratio of solar collector area to building area for a general solar thermal + heating system is 1:6-1:8, and the contribution rate of solar thermal heating is 20-40% for the whole heating season. Maximized use of off-peak electricity for heating through a cloud control system is a crucial measure to reducing operating costs.

Solar heat loss needs to be controlled to maximize the use of solar energy

During daytime afternoon hours, due to high outdoor temperatures, high temperatures of hot water in the solar thermal heating machine, and the long stoppage time of the system, solar heat may not be produced in time, resulting in increased solar heat loss and lower thermal efficiency. Measures should be taken to ensure solar-collected heat is delivered to the building in time, and system heat loss should be reduced to increase solar energy contribution.

No need for rural grid capacity increase with small system power distribution

For clean heating renovation in farm buildings that contain a heating area of about 60m2, the system power distribution is only 3kW, which presents a negligibly small impact on the existing power grids alongside low load requirements, making it possible to significantly reduce the initial investment for renovation.

Free domestic hot water

The solar thermal system provides heat in winter and free domestic water-heating supply in spring, summer, and autumn, significantly improving the utilization efficiency of household solar energy systems.

In summary, solar thermal + air-source heat pump coupled clean heating products provides excellent promotional value, with maximized use of free solar energy resource and off-peak electricity to operate air-source heat pump units, reduced system operating costs and wide public acceptance.

Continuous improvement is the key to success. In its next steps, Ever Source Group will continue to strengthen its technical research, beginning in both solar thermal and air-source heat pumps, profoundly enhancing the scientific and technological content of solar thermal + air-source heat pump clean heating system, and testing the main components of solar thermal products, including the vacuum tube, solar thermal heating machine, and heat storage water tank according to national standards to obtain certification reports. Among them, the relevant standards involved are GB/T17049-2005 "All-glass Evacuated Solar Collector Tube", the national standard GB/T26975-2011 "All-glass heat Pipe Evacuated Solar Collector Tube", GB/T17581-2007 "Evacuated Tube Solar Collectors," GB/T28746-2012 "Specification of Storage Tank of Domestic Solar Water Heating System," and GB/T28745-2012 "Test Methods for Storage Tank of Domestic Solar Water Heating Systems."

Under the context of global warming, widespread carbon reduction is required for the survival of mankind. Taking great responsibility in aiding the common destiny of humankind, China has put forward the "double carbon goals." At present, the task of preventing and controlling air pollution in China is still arduous, and on this basis, it is necessary to promote clean heating comprehensively in urban areas, counties and suburban areas, and rural areas. As a member of the heating industry, we have the responsibility and obligation to fully implement the national decision and deployment, unswervingly carry out the core developmental concept of innovation, coordination, greenness, openness, and sharing, closely follow changes in the mainstream Chinese society in the new era, promote the revolution of energy production and consumption and the revolution of the rural lifestyle, and provide a more scientific and environmentally-friendly way to protect the general public to pass the winter warmly while reducing air pollution. As a socially-responsible technological heating enterprise, we will actively coordinate our technical advantages in the future to accelerate the proportion of clean heating, build a green, economical, efficient, coordinated, and applicable clean heating system in northern China areas and contribute to the construction of a scenic China.

敬告读者

TO INFORM THE READER

《中国地热能》是由中国地热能出版社主办，北矿大（南京）新能源环保技术研究院、首都科技发展战略研究院、北京工业对外经贸促进会、北京节能环保促进会浅层地（热）能开发利用专业委员会、中国地热与温泉产业技术创新战略联盟、中国热冷一体化能源研究院协办的科技期刊，双语半年刊。我们的办刊宗旨是为政府制定能源政策提供参考建议；为地能开发企业提供宣传平台；为设计者、大众提供交流空间；推广浅层地热能利用经验，展示应用实例。

我们始终不忘读者的期待，用心用力办好期刊。毫无疑问，优化空气、节能减排、治理雾霾是当前摆在全体中国人民面前一个重大课题，我们期望《中国地热能》这本小小的期刊能够为攻克这一难题贡献微薄之力。

立足长远，着眼当前，在继承中创新，在变革中发展。自创刊以来，期刊一直得到了业内专家学者和广大读者的热情支持，在此致以我们的衷心感谢。大家的关注是我们的追求，大家的支持是我们的动力。让我们携手共进，共同打造《中国地热能》的美好明天。

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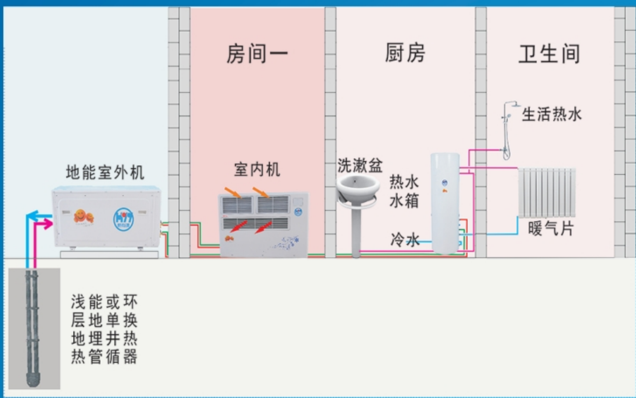

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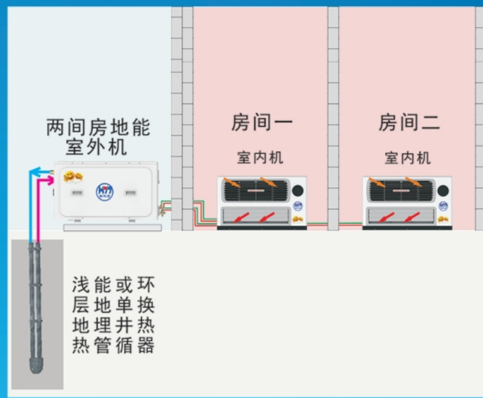

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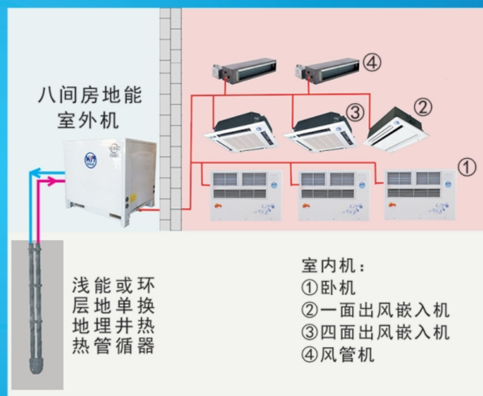

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