

# 白音华三号露天矿3-1煤层直接液化可行性评价

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**摘要:**为了研究内蒙古白音华煤田褐煤直接液化可行性与煤岩显微组分、煤质参数之间的关系,对三号露天矿3-1煤层煤样进行了采样测试与分析,结合前人对于褐煤直接液化相关的煤岩组分和煤质指标研究成果,探究了煤岩惰质组含量、灰分、挥发分、H/C原子比对褐煤直接液化的影响。研究结果表明:低惰质组含量、低灰分、高挥发分、高H/C原子比的褐煤有利于直接液化;3-1煤层煤岩显微组分中惰质组含量较低,小于8.70%,煤质参数中精煤灰分大部分小于10%,挥发分大于35%,H/C原子比大部分大于0.75。综合分析,3-1煤层褐煤各项参数符合直接液化指标要求,可作为较理想的直接液化原料煤。

**关键词:**煤直接液化;褐煤液化;白音华煤田;煤岩组分

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## Feasibility evaluation on direct liquefaction of No.3-1 coal seam from No.3 Open-pit Mine in Baiyinhua Coalfield

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**Abstract:**In order to research the relationship between the direct liquefaction feasibility of lignite in Baiyinhua Coalfield and coal macerals and coal quality parameters, the samples were collected and tested from No. 3-1 coal seam in No.3 Open-pit Mine. In combination with the former researchers' results of coal macerals and coal quality indexes, this paper discussed the effects of inertinite content, ash, volatile content and H/C ratio on direct liquefaction. The results showed that the low inertinite content, low ash content, high volatile content, and high H/C atomic ratio of lignite were favorable for direct liquefaction. The No.3-1 coal seam had a lower content of inertinite, which was less than 8.70%, most of coal ash content of clean coal was less than 10%, volatile matter content was greater than 35%,most H/C atomic ratio was greater than 0.75. Based on the comprehensive analysis, all parameters of No.3-1 coal seam met the requirements of direct liquefaction index and could be used as an ideal direct liquefaction raw material.

**Key words:**coal direct liquefaction;lignite liquefaction;Baiyinhua Coalfield;coal macerals

## 0 引言

煤炭是我国的主体能源和重要工业原料,2015年国家能源局下发《煤炭清洁高效利用行动计划(2015—2020年)》(国能煤炭〔2015〕141号)确定稳步推进现代煤化工产业发展为“十三五”期间煤炭清洁高效利用重点工作之一。煤的分级转化、多元利用是实现煤洁净、高效转化的有效途径<sup>[1-3]</sup>。

煤炭直接液化作为一种清洁的转化利用方式,自1913年诞生以来,如何对不同地区、不同煤种的液化性能进行准确评价一直是关注的热点<sup>[4]</sup>。

褐煤是一种变质程度较低的煤,其具有良好的液化活性,是一种适宜煤炭直接液化的煤种<sup>[5]</sup>。我国褐煤约占煤炭总储量的12.7%<sup>[6]</sup>,但由于褐煤含水量高,热值低,不适宜直接燃烧或长途运输,因此对褐煤采用就地直接液化,不但可提高煤

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炭资源的利用效率,将褐煤转化为高价值的产品(如汽油、柴油等),也可减少褐煤直接燃烧造成的污染<sup>[7-9]</sup>。

褐煤作为液化原料煤,其直接液化过程是比较复杂的化学反应,受很多因素影响。针对褐煤直接液化可行性评价,朱晓苏<sup>[10]</sup>先后对我国各地的气煤、长焰煤和褐煤等煤种进行了液化特性试验研究,最终优选出14种液化特性最好的煤种,其中5种为褐煤。罗星云<sup>[11]</sup>以国内外先进的煤炭直接液化工艺对煤质的要求为依据,全面系统地分析了云南褐煤的液化性能;舒歌平等<sup>[12]</sup>从煤阶、煤岩组成及煤中矿物质等方面研究了褐煤液化特性,认为褐煤是一种优质的液化用煤。

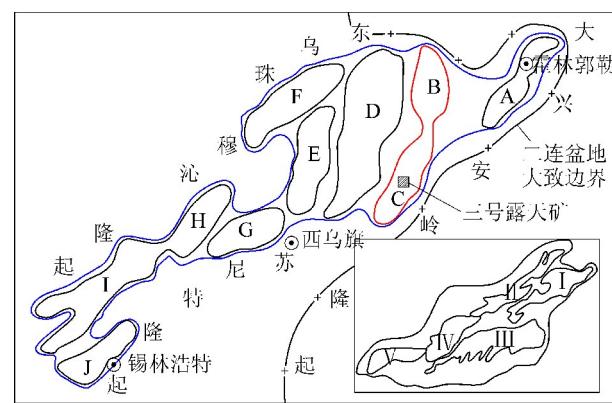
前人对一些地区褐煤直接液化可行性进行了评价,但对内蒙古地区褐煤直接液化性能研究则相对较少。笔者以内蒙古白音华三号露天矿3-1煤层为例,通过对煤样进行测试分析,着重从煤岩组分和煤质特征来探讨该煤层褐煤直接液化的可行性,为该地区褐煤直接液化提供科学依据。

## 1 白音华煤田地质概况

### 1.1 构造特征

白音华煤田位于内蒙古自治区锡林郭勒盟西乌旗境内,是大兴安岭以西储煤盆地之一,位于二连坳陷(亦称二连盆地群)东端乌尼特坳陷带中<sup>[13-14]</sup>(图

1)。北东~北北东向长条状展布,区内构造较简单,呈向斜盆状。



I—乌尼特坳陷; II—马尼特坳陷; III—腾格尔坳陷;  
IV—乌兰察布坳陷; V—川井坳陷  
A—霍林郭勒断陷; B—迪彦庙断陷; C—巴彦花断陷; D—高力罕断陷;  
E—阿拉达布斯断陷; F—包尔果吉断陷; G—布日敦断陷;  
H—包尔果吉南断陷; I—朝克乌拉断陷; J—吉尔嘎朗图断陷  
图1 乌尼特坳陷构造单元划分(据文献[14]修改)

Fig.1 Wunite depression tectonic unit division  
(modified by No.14 Literature)

### 1.2 地层特征

白音华煤田为隐伏煤田,外围有石炭系浅变质岩和侏罗系火山岩出露,其地层分区属天山兴安地层区—兴安分区—西乌旗小区。白音华煤田三号露天矿发育的地层自上而下有第四系、新近系、白垩系、侏罗系等(表1)。

表1 白音华三号露天矿地层基本信息

Table 1 Coalfield stratigraphic of No.3 Open-pit Mine of Baiyinhua Coalfield

地层	厚度/m	岩性特征
第四系(Q)	0.20~46.80	褐黄色砂土、浅灰色细砂、棕红色亚砂土和少量浅黄色亚黏土
新近系(N <sub>2</sub> )	0~80.61	褐黄色黏土或砂质黏土,底部含灰白~灰黄色砂砾层
	>260.00	灰色巨厚层状粉砂岩、粉砂质泥岩,偶夹细砂岩等薄层
白垩系下统白音华组(K <sub>1</sub> b)	第三段 <412.14 第二段 2.86~221.75 第一段 66.06~125.19	深灰色粉砂岩、泥岩、各粒级砂岩与煤层互层;含3个煤组,为本区唯一含煤段 以灰~深灰色巨厚层状细粉砂岩为主,夹细砂岩薄层 以灰白、灰绿色砂砾岩与粗粒砂岩互层为主,夹深灰色细颗粒砂岩
侏罗系—兴安岭群(J <sub>3</sub> xh)	224.16	灰白色流纹岩、凝灰砾岩,绿灰色铝土岩(厚11.25 m),白灰、灰绿色细砾岩及粗中细砂岩

### 1.3 含煤特征

三号露天矿的含煤地层为白垩系下统白音华组第三段(K<sub>1</sub>b<sup>3</sup>),含3个煤组,11个煤层(由上到下编号为1上、1中、1下、1-1、1-2、2-1上、2-1中、2-1下、3-1、3-2、3-3煤层)。3-1煤层全区发育,赋存深度32.10~372.40 m,平均168.23 m。煤层厚度0.85~39.84 m,平均18.31 m,煤类属褐煤。

## 2 煤岩显微组分与液化性能

褐煤直接液化性能与煤中显微组分的种类、含量和结构密切相关,不同显微组分之间液化特性存在较大差异<sup>[15-16]</sup>。在3大显微组分组中:惰质组属于非活性显微组分,在通常的液化反应条件下难于液化;而腐植组和稳定组统称为活性组分,煤岩中活

性组分含量决定着液化产物和转化率,其含量越高越有利于直接液化。

PARKASH等<sup>[17]</sup>选取美国2种褐煤(Texas和North Dakota)进行液化试验对比研究,结果表明腐植组和稳定组与转化率有着较好的正相关关系。李永伦等<sup>[18]</sup>研究了5种不同惰质组含量的上海煤的液化性能,结果表明:惰质组含量越高,煤的转化率和油收率越低。

表2 白音华三号露天矿3-1煤层煤岩显微组分含量

Table 2 Micromacerals content of No.3-1 coal seam from No.3 Open-pit Mine in Baiyinhua Coalfield

有机显微组分+矿物组分质量分数/%							最大镜质组反射率 $R_{o,max}/\%$
腐植组	惰质组	稳定组	黏土组	硫化物组	碳酸盐组	氧化物组	
78.65~82.10	2.21~8.70	1.15~1.40	0.40~15.7	0~0.30	1.90~7.40	—	0.364~0.385

原煤炭科学研究院北京煤化学研究所通过对全国各地的气煤、长焰煤和褐煤等煤种进行了液化特性试验研究,确定了煤炭直接液化优选煤种的必要条件是:(腐植组+稳定组)含量>23.86+100.06  $R_{o,max}$ <sup>[10]</sup>。

GB/T 23251—2009《煤化工用煤技术导则》中要求直接液化原料煤惰质组含量<35.00%;GB/T 23810—2009《直接液化用原料煤技术条件》要求直接液化原料煤中惰质组含量<45.00%。通过对3-1煤层样品测试分析研究,其煤岩组分含量完全符合以上条件,可以作为直接液化的优选原料煤。

### 3 煤质参数与液化性能

前人大量的研究成果表明,煤质对褐煤直接液化有着直接的影响,低灰分、高挥发分、高H/C原子比有利于褐煤直接液化。

#### 3.1 灰分对液化性能的影响

褐煤直接液化过程中,煤中灰分(主要是煤中的无机组分)的高低对煤的液化率与转化率无明显影响,但对煤转化终端产品的质量和系统的正常操作有着直接影响,会给液化进程带来诸多不便,因此

笔者对3-1煤层4个褐煤煤样进行了显微煤岩组分测试,结果表明:3-1煤层有机显微组分变化不大,腐植组质量分数为78.65%~82.10%;惰质组质量分数分为2.21%~8.70%;稳定组含量较少,质量分数一般在1.15%~1.40%。无机显微组分以黏土岩为主,质量分数一般在0.40%~15.7%,硫化物组、碳酸盐组含量较少,不含氧化物组(表2)。

表2 白音华三号露天矿3-1煤层煤岩显微组分含量

Table 2 Micromacerals content of No.3-1 coal seam from No.3 Open-pit Mine in Baiyinhua Coalfield

煤中的无机组分越低越有利于煤炭直接液化<sup>[19~20]</sup>。

对3-1煤层65个褐煤煤样进行了煤质测试分析,其原煤灰分在9.79~27.64%,平均19.61%;精煤灰分为7.01~10.66%,平均8.84%(图2,表3)。

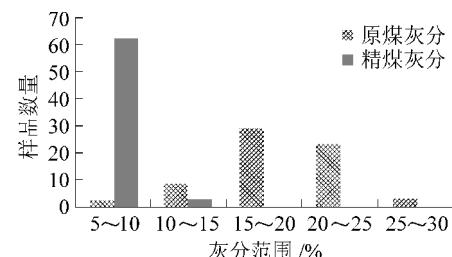


图2 3-1煤层煤样灰分分布

Fig.2 Coal samples ash distribution of No.3-1 coal seam

罗星云<sup>[11]</sup>通过对云南褐煤直接液化可行性研究分析,认为加氢液化的原料煤灰分应小于10%。《煤化工用煤技术导则》中要求直接液化原料煤中灰分  $A_d < 10.00\%$ ;《直接液化用原料煤技术条件》将灰分定为小于12.00%。通过对3-1煤层煤样分析测试,其精煤灰分均小于12.00%(图3),因此3-1煤层通过分选后可作为直接液化原料煤。

表3 白音华三号露天矿3-1煤层煤质分析结果

Table 3 Testing data of coal quality of No.3-1 coal seam from No.3 Open-pit Mine in Baiyinhua Coalfield

项目	工业分析/%			元素分析/%	
	$A_d$	$V_{daf}$	$w(C)_{daf}$	$w(H)_{daf}$	$w(O)_{daf}$
原煤	9.79~27.64	39.96~48.81	66.73~75.29	4.33~5.61	17.17~26.40
精煤	7.01~10.66	39.82~47.30	66.99~76.70	3.98~5.16	16.66~27.06

#### 3.2 挥发分对液化性能的影响

挥发分是煤有机质在高温下热解析出的气态产物,包括煤气和焦油蒸汽。一般来说,煤中挥发分越

高,其越易于液化。司胜利等<sup>[21]</sup>研究了我国西部低煤阶煤的液化性能,结果表明:煤的挥发分与液化性能表现出良好的线性关系。

本次对3-1煤层65个褐煤煤样(测试6个,收集59个)进行了煤质测试分析,其原煤挥发分在39.96~48.81%,平均46.07%;精煤挥发分在39.82~47.30%,平均44.16%(表3)。

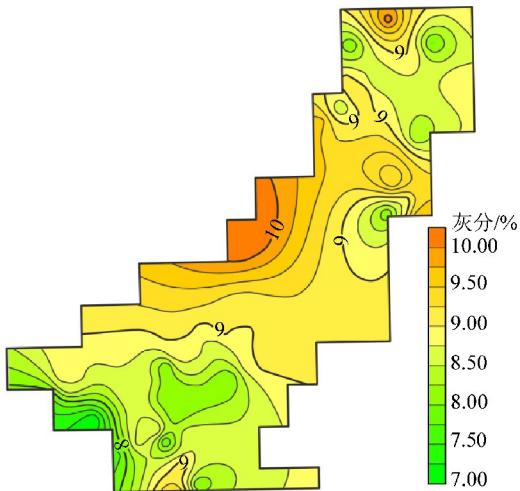


图3 3-1煤层精煤灰分等值线

Fig.3 Clean coal ash content isogram of No.3-1 coal seam

舒歌平等<sup>[12]</sup>和贺永德<sup>[22]</sup>研究认为直接液化用煤煤种挥发分应大于35%。《煤化工用煤技术导则》和《直接液化用原料煤技术条件》中均要求直接液化原料煤中挥发分 $V_{daf} > 35\%$ 。通过样品测试分析研究,三号露天矿3-1煤层原煤和精煤挥发分均大于35%(表3、图4),由此可见,3-1煤层挥发分符合直接液化用煤要求。

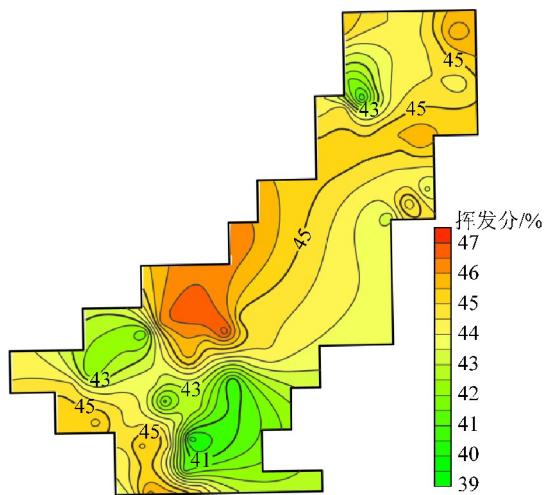


图4 3-1煤层挥发分等值线

Fig.4 Volatile content isogram of No.3-1 coal seam

### 3.3 氢碳原子比对液化性能的影响

一般认为,煤中氢碳原子比(H/C)对煤直接液化有着重大的影响。谢崇禹<sup>[23]</sup>和凌开成等<sup>[24]</sup>通过对煤液化试验研究,得出煤中H/C比与煤的转化率有着良

好的相关性,H/C比越高,转化率越大。

本次对3-1煤层63个褐煤煤样(测试4个,收集59个)进行煤质测试分析,其碳含量在66.73~75.29%,平均71.74%;氢含量在4.33~5.61%,平均4.91%;氧含量在17.17~26.40%,平均21.19%;H/C在0.72~0.93,O/C在0.17~0.30(表3)。

针对褐煤直接液化,朱晓苏<sup>[10]</sup>和罗星云<sup>[11]</sup>研究发现,一般碳含量不应低于65%,H/C大于0.75,O/C在0.06~0.26。《直接液化用原料煤技术条件》中要求直接液化原料煤中H/C>0.75。本次63个煤样中有50个煤样落在该矩形区域内(图5),占样品总数的79.36%,说明3-1煤层H/C原子比和O/C原子比表现出了良好的液化性能。

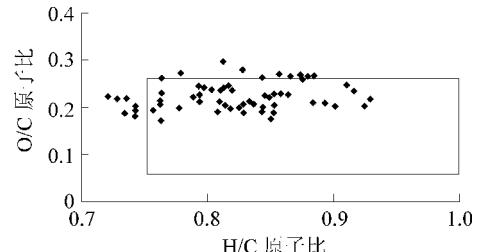


图5 3-1煤层煤样H/C原子比和O/C原子比关系

Fig.5 Relationship between H/C atomic ratio and O/C atomic ratio of No.3-1 coal seam

## 4 直接液化用煤评价结果

笔者以采样化验和资料收集为基础,分析白音华煤田三号露天矿3-1煤层褐煤的液化性能,主要侧重于煤岩显微组分(惰质组含量)和煤质(灰分、挥发分、H/C原子比等)2个方面6项参考指标研究,对以上关键参数进行综合分析和信息叠加,优选出3-1煤层符合直接液化用煤有利区(图6)。面积约35.33 km<sup>2</sup>(占全区总面积76.82%),估算直接液化用煤资源量约48 945万t。

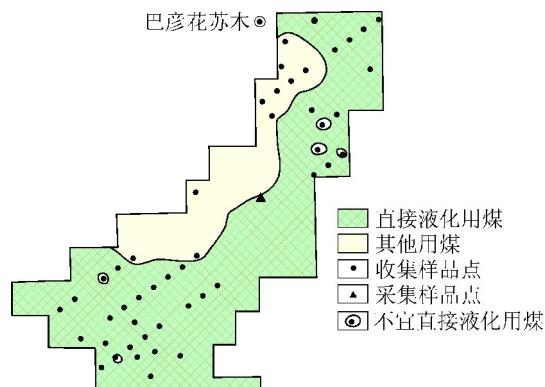


图6 3-1煤层直接液化有利区

Fig.6 Favorable area of direct liquefaction of No.3-1 coal seam

## 5 结 论

1) 褐煤中惰质组分难于液化,3-1煤层煤岩显微组分中惰质组含量较低(2.21%~8.70%),完全符合直接液化原料煤惰质组含量要求范围。

2) 一般而言,低灰分、高挥发分、高H/C原子比有利于褐煤直接液化。3-1煤层精煤灰分大部分小于10%,挥发分大于35%,H/C原子比大部分大于0.75,符合褐煤直接液化对煤质参数的指标要求。

3) 从3-1煤层煤岩显微组分和煤质参数2个方面出发,对该煤层直接液化用煤进行了评价,其可作为较理想的直接液化原料煤,圈定有利区面积约35.33 km<sup>2</sup>,资源量约48 945万t。

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