落地原油对芦苇湿地生态工程净化系统影响

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摘要 以芦苇湿地为介质净化石油开采过程中落于地面的原油，研究了中试条件下芦苇湿地的净化效果及落地原油对土壤和芦苇介质的影响。结果表明：芦苇湿地对不同施入剂量的落地原油都有较好的净化率，在试验运行期内，芦苇湿地对矿物油的净化率高达 88% ～96%。落地原油对土壤的污染基本局限于表层，对深层土壤的污染趋势并不明显，一般 40～60cm 土层的矿物油含量已接近或低于对照区表层土的背景值；落地原油对芦苇生长指标的影响表现出两面性，一方面抑制芦苇的叶龄指数和株高生长量，另一方面又能刺激芦苇的长粗、增加芦苇的生物量；落地原油对纤维素、木质素、戊糖、纤维素宽及纤维素长宽比等芦苇品质指标的影响很小，一些指标甚至优于对照区。

关键词 落地原油；芦苇湿地；生态工程；植物修复

Impact of Ground Crude Oil on the Ecological Engineering Purification System of Reed Wetland

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Abstract: Contamination of ground crude oils is international concern. Conventional technologies including physio-chemical treatments are expensive with regard to their consumption of chemicals or energy. Wetland systems can serve as attractive alternatives to conventional treatment processes by advantage of low capital costs, low energy consumption, and low maintenance requirements. However, in China, this method is only at the laboratory level. Currently, no research has been published related to reed wetlands to treat ground crude oils.

Two key questions that were investigated were as follows:

(1) Determining effectiveness of reed wetlands nearby Shuguan oil refinery plant in Liaohe Oilfield.

(2) Determining influences of ground crude oils on reed wetland system.

The study site is located in the Liaohe Oilfield, the northeast of China. The reed wetland consisted of four reed beds and a control bed with parallel arrangement, 6m length and 5m in width, with a surface area of 30m^2. A central 10m thick, 0.5m high soil partitions divided each reed bed. The wetland was walled with dimensions: 0.7m top wide, 2.1m bottom wide and 1m high.

Reed bed 1# was dosed with ground crude oils (with 30% mineral oil concentration) 0.2 kg/m^2, i. e., mineral oil concentrations in the surface soil (0～20cm deep) was 240mg/kg soil; reed bed 2# with 2 kg/m^2, 2400mg/kg; reed bed 3# with 6kg/m^2, 7200mg/kg; reed bed 4# with 18kg/m^2, 21600mg/kg; the control bed with no ground crude oils.

Both experiments were operated seven months annual. The soil samples were collected and analyzed for pH, salt, organics, total nitrogen (TN) and total phosphorus (TP) according to the standard method.

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As measured, the ground crude oils had litter effect on pH value in the surface soil (0～20cm deep). The TN and TP concentrations were slightly lower in the reed beds than in the control bed. The salt concentration was strongly lower in the reed beds than in the control bed.

In reed bed 3#, the pH value and salt concentration in deeper soil were higher than in the upper soil, whereas TN, TP, organics concentration had the converse law, indicating that the wetland soils in the presence of ground crude oils were in conformity with the normal soil distraction principle, and the ground crude oils had litter effect on physiochemical property of soil.

In order to evaluate the ground crude oils movement in soil, the soil profile sample in reed bed 3# were analyzed. The results showed that in experiments, the mineral oil concentrations in the surface soil (0～20cm deep) were different strongly, while in the deep soil (20～80cm deep), they were equivalent. The mean removal efficiencies of reed beds on mineral oil in reed bed 3# were 88%, 96%.

The results showed that within 0.2～18kg ground crude oil/m^2 soil dosed into reed wetland, it would inhibit the initial reed germination. After Day 40, the ground crude oils had litter impact on the final reed germination. During the experiments there did not appear to be a trend of number of leaves. Mineral oils in ground crude oils had different impact on reed height during the experiments and the reed height increased with increasing ground crude oils level. At experiment Ⅰ, reed biomass in reed bed 4# was 2.5 times higher than in the control bed. At final harvest, biomass of plant was 346g/m^2 higher in the reed bed 1# than in the control bed, suggesting that biomass of plant in reed beds was higher than in the control bed. The result also suggested that the ground crude oils had litter effect on reed quality indices such as cellulose, pentose, and lignin.

The reed wetland located in the Liaohe Oilfield was used to purify ground crude oils. The results obtained showed that large amounts of pollutants especially mineral oil in the ground crude oils could be removed. The removal efficiencies of reed wetland increased with increasing the ground crude oil level. The mineral oil concentration in the deep soil (40～80cm deep) of reed bed was lower than in the surface soil of the control bed. The results suggested that the ground crude oils had little impact on number of leaves, while the reed height increased with increasing ground crude oils level. The ground crude oils had litter impact on reed quality indices. Some reed quality indices in reed beds were superior to those of the control bed.

Key words: ground crude oil; reed wetland; ecological engineering; phytoremediation
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石油开采过程中散失的原油落于地面,会造成开采地的点源污染,致使土壤的理化性质发生改变,植被遭受破坏。对于这种污染,国外多采用物理化学和生物处理相结合的方法进行生态工程综合整治,改变污染区土壤的性质恢复植被[1]。而我国还在采用物理化学法处理落地原油,生物处理技术尚处于试验研究阶段,而且这些研究多采用微生物处理[2～4],尚未见利用芦苇湿地净化落地原油的报道。鉴于我国的大部分油田都位于湿地资源丰富的湖沼或近海地区,从保护和利用油田所在地芦苇湿地资源的角度出发,选取辽河油田某采油厂附近的芦苇湿地为净化介质,净化原油开采和集输过程中落于地面的原油,研究芦苇湿地净化落地原油的可行性。同时,深入探讨了落地原油对芦苇湿地净化系统的影响。

1 材料与方法

1.1 试验方案设计

该项试验共进行 3 年,分别在第 1 年和第 2 年的 4 月 1 日将落地原油施入芦苇湿地 0～10cm 土壤中,模仿原油散失的状态观测落地原油迁移降解及处理介质的变化情况。芦苇床 1# 每次施入落地原油 0.2kg/m^2,0～20cm 土壤中矿物油浓度 240mg/kg;芦苇床 2# 每次施入落地原油 2kg/m^2,0～20cm 土壤中矿物油浓度 2400mg/kg;芦苇床 3# 每次施入落地原油 6kg/m^2,0～20cm 土壤中矿物油浓度 7200mg/kg,芦苇床 4# 每次施入落地原油 18kg/m^2,0～20cm 土壤中矿物油浓度 21600mg/kg;内外两个对照区不施落地

原油。试验区内的每个小芦苇床长 6m,宽 5m,单区面积 30m^2 ;各芦苇床之间以 10m 宽的土坝相隔离,坝高 0.5m。试验区全封闭,四周设围坝,坝高 1m,坝顶宽 0.7m,坝底宽 2.1m。

芦苇床浇灌上游河水,每年灌水 7 个月,期间试验区的水面始终与对照区保持一致,这样既可促进芦苇的生长,又使实验区内外的湿地处于相同的试验环境之下。本文报道了第 1 年(试验Ⅰ)和第 3 年(试验Ⅱ)的实验结果。

1.2　样品的采集与分析

每年 11 月采集土壤样品,对表层土混合样和不同剖面层中的矿物油含量以及土壤理化指标 :pH 值、盐分、有机质、氮和磷等进行分析测试。对土壤样品的采集和分析采用标准方法[5]。

在每个芦苇床中随机选取 30～60 株芦苇,根据试验需要调查芦苇的发芽率、叶龄指数、株高生长量和生物量(105℃烘干恒重)等指标。对成熟芦苇品质指标 :纤维素、木质素、戊糖、纤维长和纤维宽的分析测试采用标准方法[6]。

2　结果与讨论

2.1　落地原油在土壤中的降解与迁移

从表 1、表 2 可以看出,落地原油的施入对不同试验区 0～20cm 土壤 pH 值的影响没有明显的规律性 ;盐分含量随着落地原油施入量的增加而减少 ;土壤的营养指标 :总氮、总磷和有机质随着时间的推移而逐渐减少。

表 1　试验Ⅰ土壤理化性质变化 (%)

Table 1　Dynamic change of physico-chemical property of soil (Experiment Ⅰ)

项目 Index	1#	2#	3#	4#	外对照 Control
pH	8.27	8.11	8.37	8.14	8.14
盐分 Salt	0.17	0.09	0.09	0.09	0.28
总磷 Total phosphorus	0.08	0.06	0.06	0.07	0.07
总氮 Total nitrogen	0.11	0.14	0.15	0.04	0.17
有机质 Organics	5.12	4.01	3.88	3.62	3.69

表 2　试验Ⅱ土壤理化性质变化(%)

Table 2　Dynamic change of physico-chemical property of soil (Experiment Ⅱ)

项目 Index	1#	2#	3#	4#	外对照 Control
pH	8.05	8.28	8.05	8.09	7.91
盐分 Salt	0.15	0.13	0.10	0.09	0.18
总磷 Total phosphorus	0.05	0.04	0.05	0.06	0.06
总氮 Total nitrogen	0.09	0.10	0.13	0.14	0.15
有机质 Organics	2.27	2.15	2.21	2.35	2.59

由表 3 和表 4 可知, 3# 芦苇床土壤理化指标的变化趋势非常明显,即 :土壤的 pH 值和盐分下层高于上层 ;土壤的营养指标,总氮、总磷和有机质的则表现为上层明显高于下层。这表明,施入落地原油的湿地土壤完全符合正常土壤的指标分配规律,落地原油对湿地土壤理化性质的影响很小。

表 3　试验Ⅰ3# 小区土壤剖面理化性质(%)

Table 3　Physico-chemical property of soil profiles in reed bed 3# (Experiment Ⅰ)

项目 Index	0～20cm	20～40cm	40～60cm	60～80cm	外对照 Control 0～20cm
pH	8.37	8.50	8.37	8.51	8.14
盐分 Salt	0.09	0.13	0.13	0.16	0.28
总磷 Total phosphorus	0.06	0.06	0.06	0.05	0.07
总氮 Total nitrogen	0.05	0.05	0.05	0.04	0.17
有机质 Organics	3.88	1.15	0.83	0.45	3.69

表 4　试验Ⅱ3# 小区土壤剖面理化性质 (%)

Table 4　Physico-chemical property of soil profiles in reed bed 3# (Experiment Ⅱ)

项目 Index	0～20cm	20～40cm	40～60cm	60～80cm	外对照 Control 0～20cm
pH	8.05	8.25	8.14	8.17	7.91
盐分 Salt	0.10	0.17	0.14	0.17	0.18
总磷 Total phosphorus	0.05	0.05	0.05	0.05	0.06
总氮 Total nitrogen	0.13	0.08	0.06	0.06	0.15
有机质 Organics	2.21	2.58	1.25	0.92	2.59

试验Ⅰ0～20cm 土层中矿物油的残留量分别为 130mg/kg(1#),150mg/kg(2#),983mg/kg(3#)和 1550mg/kg(4#),对照区的矿物油含量为 52mg/kg,该层土壤中矿物油的实际残留量为施入量的 4% ～32%。表明,0～20cm 土层中矿物油的残留量随着落地原油污染土壤施入量的增加而增大,施入量的增加

大大加速了矿物油的降解。经过芦苇的两个收获季节后，试验Ⅱ 4＃芦苇床 0～20cm 土层中矿物油残留量只有 214mg/kg，还不到试验Ⅰ的1/7。这表明，随着时间的推移，矿物油的残留量逐年递减。

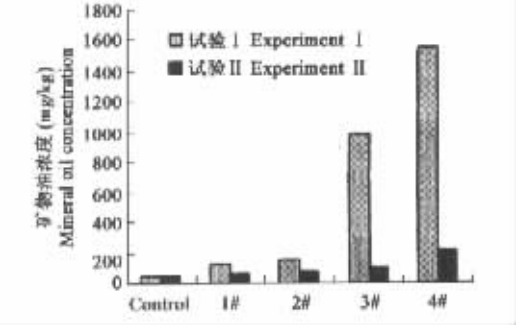

图 1 芦苇湿地表层土壤(0～20cm)中矿物油变化

Fig. 1 Dynamic change of mineral oil concentration in reed wetland surface soil(0～20cm)

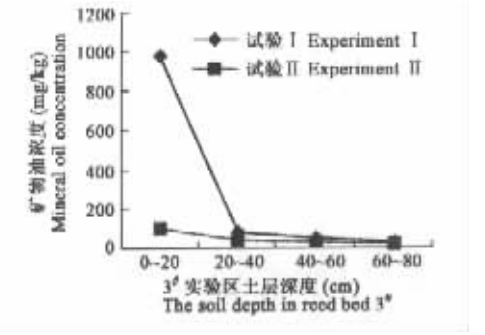

图 2 3＃芦菁床矿物油在不同土层中的分配

Fig. 2 Mineral ooil concentration in soil profile of reed bed＃3

实验过程中除定期进水外，未采取任何强化措施，使得芦苇湿地尽可能保持自然状态。因此，芦苇湿地对矿物油的净化效果直接反映芦苇湿地系统的自恢复能力。3＃芦苇床 0～80cm 剖面土壤中矿物油的残留量呈成倍递减的趋势。试验Ⅰ3＃芦苇床 0～80cm 剖面湿地土壤中矿物油的残留量为 285mg/kg，相应的降解率为 88%。这表明，经过 7 个月的净化，大部分矿物油已经从湿地土壤中被去除。经过试验Ⅰ的驯化和芦苇的 2 个收获期后，试验Ⅱ 3＃芦苇床 0～80cm 剖面湿地土壤中矿物油的残留量只有试验Ⅰ的 1/6，去除率已高达 96%。

2.2 落地原油对芦苇的影响

2.2.1 落地原油对芦苇发芽率的影响 为了能够深入研究落地原油对芦苇生长指标的影响，在试验Ⅱ中增加了落地原油对芦苇发芽率影响的实验。从图 3 可以看出，随着时间的推移，芦苇的发芽过程受到明显的抑制，但芦苇的最终发芽率没有明显差异。内对照区由于受外界地面水水质水温变化的影响较小，发芽时间较早。外对照区在芦苇发芽的最初 20d 显著受地面水水质水温变化的影响较大，从而延迟了芦苇的发芽时间，当水质水温稳定后其发芽率迅速增加，4 月 25 日的发芽率已经高于其它芦苇床。结果表明，只要将施入量控制在一定范围内，落地原油只对芦苇的发芽过程起抑制作用，对芦苇的最终发芽率影响很小。

2.2.2 落地原油对芦苇叶龄指数的影响 叶龄指数是植物生长指标的重要参数，叶龄指数的大小代表植物体光合及蒸腾作用的相对强弱，即新陈代谢的快慢。叶龄指数越大，说明植物的生长越旺盛[7]。从图 4 可以看出，芦苇叶龄指数的变化趋势不明显。这表明，落地原油的施入并没有减弱芦苇光合作用和蒸腾作用的强度，芦苇具有较强的抵抗矿物油等污染物胁迫的能力。

2.2.3 落地原油对芦苇株高、生物量的影响 试验Ⅰ的结果表明，芦苇的株高随着落地原油施入剂量的增加而增加，3＃和 4＃芦苇床的株高明显高于对照区。试验Ⅱ芦苇的株高均受到不同程度抑制。

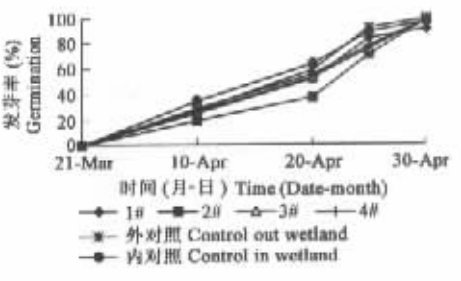

图 3 芦苇发芽率随时间变化曲线

Fig. 3 Dynamic change of germination percentage with time

从图 6 可以看出，试验Ⅰ和试验Ⅱ成熟芦苇生物量的变化规律有所不同。试验Ⅰ施入落地原油的芦苇床成熟芦苇的生物量明显高于对照区，而且落地原油

施入量越大芦苇的生物量越大，这是矿物油刺激芦苇长粗的结果。试验Ⅱ的 1＃和 4＃芦苇床的生物量明显高于对照区，而 2＃和 3＃芦苇床的生物量低于对照区。试验Ⅰ4＃芦苇床的生物量为 1333g/m^2，是其控制床芦苇生物量的 2.5 倍，生物量最小的＃1 芦苇床单位面积芦苇的生物量也高出控制床 346g/m^2；试验Ⅱ 4＃芦苇床成熟芦苇的生物量为 700g/m^2，生物量最小的 3＃芦苇床单位面积芦苇的生物量只有 483 g/m^2。

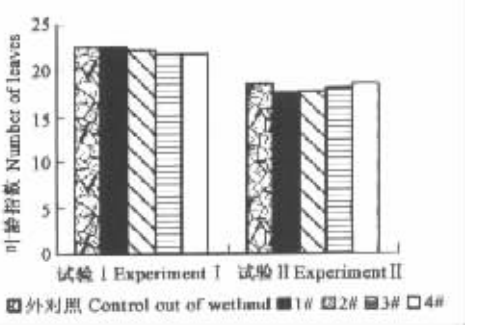

图 4　落地原油对芦苇叶龄指数的影响

Fig.4　Impact of ground crude oils on number of leaves

2.2.4　落地原油对芦苇品质的影响　一般芦苇品质的正常值为：纤维素 38％～42％，测试值越高品质越优；木质素在 18％～19％之间，测试值越低品质越优；其它指标以戊糖在 16％～19％之间，纤维素长宽比 1.0～1.2，纤维素宽 10～14μm 为优。芦苇产品质量的好坏，直接影响到芦苇的使用价值和销售价格。为此，对芦苇的品质进行了分析测试，结果列于表 5。

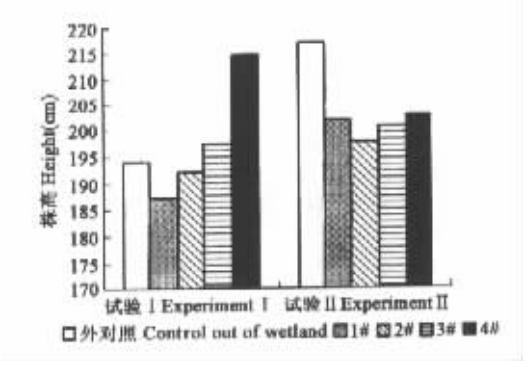

图 5　落地原油对芦苇株高的影响

Fig.5　Impact of ground crude oils on reed height

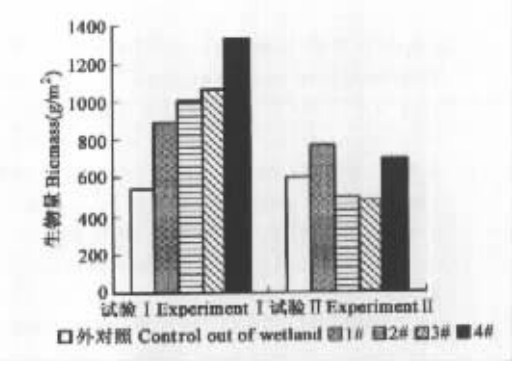

图 6　落地原油对芦苇生物量的影响

Fig.6　Impact of ground crude oils on reed biomass

表 5　试验Ⅱ成熟芦苇品质指标

Table 5　Analysis results of mature reed quality

项目 Indicator	1＃	2＃	3＃	4＃	外对照 Control	正常值 Normal values
纤维素(％)Cellulose	36.35	36.32	36.54	41.69	38.92	38.0～42.0
木质素(％)Lignose	18.67	18.32	19.37	19.00	19.37	18.0～19.0
戊糖(％)Pentose	17.00	17.50	17.20	17.00	17.00	16.0～19.0
纤维长宽比 Length/Width of cellulose	1.31	1.25	1.20	1.34	1.27	1.0～1.2
纤维宽(μm) Width of cellulose	13.60	13.20	11.40	11.00	13.60	10.0～14.0

表 5 的结果表明，落地原油施入量相对较小的 1＃、2＃、3＃芦苇床成熟芦苇中纤维素所占百分率低于正常值所在区间，而落地原油施入量较大的 4＃芦苇床成熟芦苇中纤维素所占百分率既优于其它芦苇床。除 3＃芦苇床外，其它施入落地原油的芦苇床中成熟芦苇的木质素所占百分率均在正常值范围内，且优于对照区；3＃芦苇床成熟芦苇的木质素所占百分率与对照区相同。各芦苇床成熟芦苇的戊糖所占百分率都在正常值范围内，其纤维素宽和纤维素长宽比等指标或多或少都受到了落地原油的影响，但与对照区之间无显著差异。从以上结果可以看出，落地原油的施入对芦苇品质的影响很小。

3　结论

采用芦苇湿地净化落地原油是一种尝试,中试规模的研究尚无文献报道。本文的研究结果表明:采用芦苇湿地生态工程净化落地原油是保护油田开发地区土壤环境和湿地自然保护区的有效方法。芦苇湿地对落地原油的净化效果非常显著,对特征污染物矿物油具有很高的去除率,在试验剂量范围内落地原油的施入量越大去除率越高。

落地原油对湿地土壤理化性质无显著影响。矿物油向下迁移对深层土壤的影响一般不会超过 40cm,深层土壤的矿物油含量低于对照区表层土壤的背景值。

Proffitt 和 Diwan 等认为,矿物油抑制植物的生物量、茎高生长量,甚至引起个体死亡[8~10];同时也有学者指出,轻微的油污染不仅不会影响植物的正常生长,而且可以刺激生长[11,12]。本文的研究结果表明,0~20cm土壤中矿物油含量在 240~21600mg/kg 之间时,落地原油对芦苇的发芽率和叶龄指数没有影响,对株高的影响随着落地原油施入量的增加而减小,矿物油含量在 2400~7200mg/kg 之间时抑制芦苇的生物量,施入量较低和较高的芦苇床都可以观察到芦苇生物量增加的现象。

落地原油对芦苇品质的影响很小,还可以改善纤维素和木质素等芦苇的品质指标。收获的芦苇可用于造纸,不进入食物链,既无二次污染又可获得可观的经济效益。

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