A TECHNICAL AND ECONOMIC EVALUATION OF SULPHUR BASEPAD RECOVERY AND RECLAMATION[1]

by
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Abstract. Sulphur block basepad recovery has been ongoing in Alberta since the early 1980's. A variety of techniques that rely on various degrees of off-site disposal have been used extensively. Recovery techniques range from extensive use of landfills for disposal of sulphur contaminated material to attempts to neutralize and reclaim the material on site. The problems and costs of site reclamation vary depending on site location, conditions, and basepad recovery techniques. While the location and condition of the sites are fixed variables, choices of recovery techniques can influence the success of reclamation programs. This paper reviews the techniques used for recovery and reclamation to date, investigates the problems and costs associated with each and provides case history information from work undertaken by Mobil Oil Canada.

Introduction

Hydrocarbons extracted from a reservoir that has a significant amount of hydrogen sulphide are referred to as sour oil and sour gas. Alberta produces 95% of Canada's elemental sulphur by converting the hydrogen sulphide present in sour oil and gas to elemental sulphur through a controlled oxidative method called the Claus Process (Hyne 1977).

The majority of sour gas plants built in the 1950's to early 1970's stored elemental sulphur by pouring molten sulphur into a large block. The block was poured on top of a basepad, that was also formed from molten sulphur. Many of these basepads were poured directly onto soil, with minimal ground preparation.

There are approximately 105 basepads at 34 locations in western Canada (Hyne and Schwalm 1983). The total area of the basepads is estimated to be 100 hectares. Since 1980 few, if any, new basepads have been established. Therefore, most basepads and associated blocks have been in place for at least ten years. As a result of increased sulphur sales and declining hydrocarbon reserves in older sour oil and gas fields, sulphur blocks are being depleted.

Once a sulphur block has been recovered, the basepad remains. Approximately 10% of the total sulphur inventory in Alberta is comprised of basepad material. The removal of the basepad can be an expensive aspect of sulphur block clean-up depending on the thickness of the sulphur:soil interface and the degree of mixing

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that has taken place. The extent of basepad clean-up operations will dictate how much sulphur will remain as a contaminant in the underlying soil.

Once basepad clean-up is completed and the sulphur-contaminated soils are exposed, sulphur oxidation and resulting soil acidification will occur if the soil is left untreated. Former basepads must be neutralized and plant owners must satisfy regulatory authorities that the sites will not pose environmental hazards. Alberta Environment has implemented a program whereby all former industrial sites must be reclaimed. The site must be restored sufficiently to safely accommodate future land use activities. In addition contaminants may not remain in quantities that could migrate offsite, affect the quality of adjacent land, or pose an environmental threat. Clean-up requirements are ensured under a number of pieces of legislation including the Hazardous Chemicals Act, the Land Use Act, the Planning Act and the Clean Water Act.

Overview of Recovery and Disposal Options

The objectives of a basepad clean-up are two-fold. One is to remove as much pure sulphur as possible so that the product can be marketed. The second objective is to minimize the degree of soil:sulphur mixing that generates contaminated soil that must either be disposed of or reclaimed. A review of basepad recovery systems is presented in Schwalm et al (1985).

Two main approaches have been used in the clean-up process. The first approach which has been used in the majority of cases is to remelt and recover pure sulphur from as much of the basepad as possible. This procedure requires that extreme care be exercised by the operator to avoid excessive mixing of the soil:sulphur interface. To attain marketing specifications, relatively pure sulphur is blended in the melter with contaminated materials from the soil: sulphur interface.

The end result of this process is sulphur-crete; a concrete-like material. The sulphur-crete and contaminated soil which generally contains at least 30% sulphur has traditionally been disposed of in a landfill.

Using the remelt procedure, 5,000 - 10,000 tonnes of material may require disposal. Depending on the volume of wastes and the proximity of the site to a landfill that will accept sulphur-contaminated wastes, disposal costs would average about $35/tonne for a total cost in the range of $150,000 to $350,000.

Depending on the initial site preparation and the amount of contaminated material removed, final soil sulphur concentrations generally range from about 5-20% sulphur prior to initiating reclamation.

A second approach has recently been commercially developed by Husky Oil Operations Ltd. that employs a cold mining flotation process. This system is capable of removing higher amounts of sulphur from contaminated soil than most remelt operations can achieve (D. White pers. comm.).

The facility is designed to process material that contains 80% sulphur and 20% contaminants (including soil). Highly contaminated materials such as those removed from the soil:sulphur interface are blended with pure sulphur to provide a high enough overall sulphur concentration to achieve efficient recovery. The use of this process, therefore, requires preplanning as the entire basepad must be processed rather than just the sulphur-contaminated soil.

The tailings from the process are estimated to contain sulphur concentrations of approximately 8-10%. This material is considered suitable for landfarming. Therefore, this method allows recovery of maximum levels of sulphur and does not rely heavily on landfilling of wastes.

Processing costs are $50/tonne plus trucking charges. Assuming an average trucking rate of $15/tonne and an average weight of 30,275 tonnes of material for processing, costs would be approximately $1.97 million. This would correspond to sending a basepad of approximately 30 cm thickness and an associated 15 cm depth of contaminated soil over a 3.2 ha area.

Assuming a bulk density of 2.0 g/cm^3 there would be approximately 21,475 tonnes of sulphur. Assuming that one acre of soil taken to a depth of 15 cm weighs 1100 tonnes, this combination of basepad and soil would be approximately 70%, by weight, sulphur and 30% contaminant.

Revenue is generated from the sale of the pure sulphur that is recovered. Assuming a recovery rate of 98% and a selling price of approximately $80/tonne for sulphur, approximately $1.68 million revenue would be generated. Actual disposal costs would therefore be approximately $284,000.

A cost comparison can be estimated if a remelt operation was used for recovery of a similar basepad, assuming a recovery rate of 80% and a processing fee of $39/tonne. Processing costs would be $1.18 million and the revenue generated from the sale of pure sulphur would be $1.37 million. Subtracting disposal costs of approximately $250,000 would mean that the cost of recovering the basepad would be approximately $55,000.

An advantage of using the remelting process is that the plant owner keeps a greater proportion of the revenue generated from the sulphur sales. A disadvantage is that disposal of large amounts of sulphur in the form of sulphur-crete and sulphur-contaminated soil to a landfill is required.

A disadvantage of the cold mining process is the greater loss of income to the plant owners from the sale of pure sulphur. The major advantage of the second method is the reduced percentage of sulphur in the tailings and the reduced volume of tailings requiring disposal.

Overview of the Reclamation Process

When basepad sites were levelled prior to construction the topsoil was usually stripped and molten sulphur poured directly onto the subsoil. Over the years the stripped topsoil was often used for other purposes, leaving a subsoil surface to be reclaimed when basepad recovery is complete.

The focus of a reclamation program on former basepad sites becomes two-fold then, firstly neutralizing the potential acidity and secondly, restoring a subsoil to a quality capable of sustaining vegetative cover.

The first objective is to neutralize acidity generated by the biological and chemical oxidation of elemental sulphur into sulphuric acid. The degree to which the soil will become acidified will depend on the amount of elemental sulphur and calcium carbonate present, the extent and rate of sulphur oxidation, and the specific nature of the soil.

The second objective is to improve the organic carbon content and structure of the subsoil so that it can support plant growth. This can be accomplished by adding organic matter in the form of animal manure and/or straw. Additionally, the sites can be seeded with plants that can be ploughed down as green manure. Establishing plant growth also helps to improve soil tilth through the penetration of roots into the soil, thus improving soil aeration and moisture penetration conditions.

It is well documented that acidified soils can be reclaimed by amending the soil with calcium carbonate. There are several methods available to determine the amount of limestone required to neutralize an acidic soil.

The principal method used in Alberta is based on accounting for the total acidity generated if all the sulphur present in the soil was oxidized. On the basis of molecular weight and stoichiometry, calcium carbonate is required in a ratio of three parts for every part of total sulphur detected in the soil. Therefore a soil that contained 20% sulphur, by weight would require a calcium carbonate application of 60%, by weight, to the soil.

A fundamental factor influencing the extent of basepad clean-up and future reclamation success is the amount of sulphur that can be left on-site. Because of the large amounts of calcium carbonate required to neutralize all of the acidity that could be generated from the oxidation process and the varied sulphur particle sizes left in the soil, there has been a tendency to remove as much sulphur as possible from the basepads.

There is conflicting data about the amount of sulphur that can remain in the soil while still achieving effective reclamation. Results from one greenhouse experiment indicated that reclamation of soils containing more that 4% sulphur was difficult if limestone was added in a 3:1 ratio (Leggett and Parkinson 1988). Roberts and Komadowski (1988) concluded that lack of reclamation success noted from the first year of their field study was due to the physical presence of the limestone in the soil.

Results from two other studies have indicated that soils containing as much as 10% sulphur (Nyborg 1982) and 11% sulphur (D.McCoy pers. comm.) can be limed in a 3:1 ratio and still be reclaimed. At present, there is a general consensus that reclamation of soils containing upwards of 20% sulphur would require both intensive effort and represent a long term project.

From the reclamation programs that have been undertaken to date, it is apparent that reclaiming a site that contains an average sulphur concentration of less that 5% will take at least three years and more likely five to seven years. Therefore operators are recognizing the merits of initiating liming programs immediately following basepad recovery. Prompt reclamation while the plant is still generating revenue allows the plant owners to spread the costs over a number of years prior to decommissioning.

An example of a unique approach to reclamation used at one plant site in Alberta was to leave the sulphur-contaminated soil on site once the remelting operation was completed. It was estimated that the soil contained approximately 25-30% sulphur (R. Cursons pers. comm.). Limestone was applied in a 3:1 ratio and incorporated into the soil. A 15-30 cm cover of topsoil was then spread over the entire site and the area was seeded.

To date, growth has been established over much of the site. The advantage of this approach was that the sulphur-contaminated material has been retained on-site reducing the costly step of removal to landfill. The disadvantage of this approach is that it will be difficult to place additional limestone, if required, within the zone generating the acidity.

Mobil Case Histories

Mobil Oil Canada is in the process of reclaiming former sulphur basepad sites at three facilities; Lone Pine Creek, Wimborne, and Harmattan. In all three cases, basepad recovery was carried out using an on-site remelter.

Remelting operations were initiated at the Lone Pine Creek facility in 1985, at Wimborne in 1986, and at Harmattan in 1988. The amount of material requiring disposal, the disposal costs and the average soil sulphur concentrations for each basepad once clean-up was completed are presented in Table 1.

Reclamation activities were initiated in 1987 at both Lone Pine Creek and Wimborne facilities and in 1988 at the Harmattan facility. Table 2 provides a summary of the amendments that were applied and the reclamation costs. In all cases, reclamation programs were developed based on results of soil sampling programs carried out at each site.

Table 3 provides a summary of selected soil chemical parameters measured at fixed locations at all three sites. The increase in soil pH between 1987 and 1988 at both Lone Pine Creek and Wimborne facilities was due to liming programs. The drop in soil pH in 1989 at Lone Pine Creek indicates that re-acidification had occurred.

In September 1988, the average soil pH of nine bare spots was 3.9. Powdered limestone was applied to these areas in November 1988 at rates of 44-80 tonnes/ha, depending on results from lime requirement tests. Despite this limestone application, the average pH of the same nine bare spots in May 1989 had dropped to 3.5.

Six plots, each measuring 18.3m x 44.2m, were established in 1987 on a portion of the Lone Pine Creek site to assess procedures, materials and equipment used in the reclamation program for applicability at other Mobil basepad sites. The use of two types of limestone, powdered and pelletized, was evaluated as was the merit of adding partially decomposed straw to improve soil tilth. Details of this field experiment are outlined in Leggett et al (1988).

Based on soil chemical analyses and above-ground biomass measurements, it was concluded that for flat, relatively dry sites with good access for large vehicles, powdered limestone provided effective neutralization that was four times less expensive than pelletized limestone. The combination of powdered limestone and straw were the most effective, cost efficient amendments for

Table 1 Amount of Sulphur-contaminated Material requiring Disposal, Associated Costs and Levels of Sulphur remaining in soil at three Mobil Oil Canada facilities.

Site	Amount of Material Requiring Disposal (tonnes)	Disposal Costs ($)	Average Levels of Total Sulphur Remaining in Soil
Lone Pine Creek	7,750	150,000	2%
Wimborne	12,260	325,000	7%
Harmattan	13,100	400,000	2%

Table 2 Reclamation Steps Undertaken at Former Sulphur Basepad Sites of three Mobil Oil Canada facilities.

Year	Area(ha)	Amount of Limestone Applied (tonnes)	Amount and Type of Organic Matter Applied	Type of Seed Used	Annual Cost($)	Annual Cost/ha ($)
Lone Pine Creek						
1987	3.4	363	----	Barley & yellow sweet clover	23,690	6,967
1988	3.4	103	8 round bales of yellow sweet clover	Barley & yellow sweet clover	18,000	5,294
Wimborne						
1987	3.2	437	----	Fall rye & yellow sweet clover	15,000	4,687
1988	3.2	68	330 tonnes of manure and straw	----	11,000	3,448
Harmattan						
1988	3.4	145	----	----	10,625	3,125

Table 3 Summary of Selected Soil Chemical Parameters at three Mobil Oil Canada former sulphur basepad sites. Data are expressed as mean values ± standard deviations.

Site	pH			Electrical Conductivity (dS/m)			Total Sulphur (%)		
	1987	1988	1989	1987	1988	1989	1987	1988	1989
Lone Pine Creek (n=9)	4.5±2.1	5.9±1.8	5.3±1.4	7.3±3.3	7.7±7.7	7.1±2.8	0.5±0.5	1.7±1.6	N/A
Wimborne North Pad (n=23)	3.9±1.9	5.6±1.6	N/A	13.5±7.2	7.8±2.5	N/A	6.5±9.2	5.1±6.9	N/A
Wimborne South Pad (n=15)	5.7±1.8	6.6±1.2	N/A	10.2±3.7	7.6±1.6	N/A	7.8±4.7	4.8±4.1	N/A
Harmattan N.E. Pad (n=4)	N/A	7.7±0.3	N/A	N/A	5.8±0.7	N/A	N/A	2.5±1.2	N/A
Harmattan N.W. Pad (n=3)	N/A	7.7±0.5	N/A	N/A	5.8±0.8	N/A	N/A	1.4±1.5	N/A
Harmattan S.W. Pad (n=3)	N/A	7.3±0.3	N/A	N/A	5.7±0.3	N/A	N/A	1.5±1.5	N/A

* N/A not available.

sites similar to Lone Pine Creek. The combination of straw and powdered limestone was approximately 2.5 times less expensive than the use of pelletized limestone alone. Equipment used to apply both the limestone and straw were effective, but numerous passes were required to add the desired quantity of both powdered and pelletized limestone.

Good growth was achieved at Lone Pine Creek in 1987, although there were some bare spots that appeared again in 1988. Sampling the bare spots in 1988 and 1989 revealed that the soil was both acidic and contained high levels of soluble salts. The bare spots were re-limed in 1988 and again in 1989 prior to seeding the site.

The 1989 seed mixture selected for all three basepad sites included plants that have a tolerance for either high salt levels or low soil pH values so as to maximize germination and growth potential. Six row barley was seeded in one direction. A forage mixture composed of alsike clover, alfalfa, tall wheatgrass and brome grass was then seeded in a diagonal direction. Timothy grass was substituted for brome grass at Harmattan.

Fall rye and yellow sweet clover were seeded in the fall of 1987 at Wimborne. Seed germination and plant growth were poor, but it is thought that these results were partly due to seeding methods and the weather. The site was too wet in 1988 to work on it during the summer. The site was re-limed in the fall of 1988, based on results from the 1988 spring soil sampling program. Manure and straw were also applied in the fall of 1988. This site was seeded in June, 1989.

Reclamation work was initiated late in the fall of 1988 at Harmattan with the application of powdered calcium carbonate. The site was then cultivated, rock-picked and seeded in June of 1989.

Preliminary results indicate that barley growth will be quite good at all three sites. None of the forage mixture had germinated at the time of preparing this paper. Bare spots are still appearing at Lone Pine Creek site which is not a surprise given the high electrical conductivity values (15-25 dS/m) recorded on some of the bare spots.

A primary objective for 1989 was to seed the sites as early as possible so that it would be feasible to re-seed the bare spots in mid-summer following further reclamation treatments. Seeding these sites provides the opportunity to use growth as an indicator of areas where further work is required. Soil sampling of the individual bare spots allows the rehabilitation programs to be specifically tailored to the problem areas.

The approach taken by Mobil has been to initially apply limestone in a 3:1 ratio based on the average sulphur level over the entire basepad. Areas known to be more highly contaminated receive additional limestone. The basepads are then seeded and growth is monitored. Once the bare spots become evident, additional soil sampling is carried out. Amendments are applied to the bare spots as necessary and the areas are re-seeded.

A number of observations have been noted as a result of the work carried out on these three basepads. The first of these is that the sulphur levels across sites are highly variable. Although the average levels for each site are quite low, the range of values is very wide. The average sulphur value at Wimborne is 7% while the range is from 0.5-29%. Without sampling on a very small scale grid, it is difficult to accurately determine sulphur levels throughout each basepad.

The second observation is that some site preparation work is generally required as part of the reclamation program. This can include rock-picking and some landscaping in order to improve site drainage. It is important that acidic materials not be buried during landscaping. It is most efficient to leave the sulphur-contaminated soil on the surface where limestone can be easily mixed with it. This allows the opportunity to neutralize areas that re-acidify over the years.

The next observation is that the areas that are re-acidifying and not supporting plant growth at Lone Pine Creek exist where sulphur-contaminated piles of material, remelt pits or equipment were located during the basepad recovery operation.

The final observation is that the methods used for seeding are crucial to the success of the program. Attempts to broadcast the seed have not been highly successful at both Lone Pine Creek and Wimborne. All sites are now seeded with a seed drill. Because of the relatively small size of the sites and the even smaller size of the bare spots, farm equipment that is eight feet wide is being used. This should also allow cultivation and seeding of the bare spots without disturbing the rest of the basepad areas that are supporting growth.

Conclusions

Sulphur blocks and associated basepads will likely no longer exist in the near future as producers have chosen alternative methods for sulphur storage. Technologies and methodologies required to recover basepads and reclaim the underlying soil will only be utilized for the next ten years. Despite this short term and finite requirement, proper clean-up and reclamation programs are essential to preventing future environmental problems that could result from poor practices now.

Each basepad project must be individually evaluated when chosing recovery options. Although the cold mining flotation process is capable of removing higher amounts of sulphur from contaminated materials than most remelt operations can achieve, tailings are produced which require further treatment and/or disposal. Depending on the final concentration of sulphur in the tailings, some disposal to a landfill may be required. As the entire basepad must be sent to the facility in order for recovery to be economic, large volumes of material must be trucked.

Based on the fictitious examples outlined in this paper, it is more costly to send material to the Husky Oil facility than to remelt the basepad on-site. However, the remelting operation generates waste that contains relatively high levels of sulphur. Landfilling of this waste could create a long-term liability for the plant owners if acidic materials leached from the waste.

Remelting operations would be more environmentally acceptable and economically attractive if the sulphur levels in the tailings could be reduced. According to Schwalm et al (1985), this may be feasible through the use of a pre-conditioning process that would improve the separation of fine particles from the sulphur. Hopefully such improvements in technology can be brought on-stream quickly.

Reclamation of former basepad sites containing low amounts of sulphur (less than 5%) should be fairly straightforward. Because of the variability of sulphur levels in the soil, repeated liming and seeding operations will likely be required. The major issues in reclaiming these types of basepad sites are the logistics of accomplishing the required work and ensuring that the site is monitored and actively worked until successful reclamation is achieved.

At present, there are a couple of different approaches proposed for reclaiming soils that have in excess of 5% sulphur. Although it is not clear how much sulphur can be left in a soil and limed in a 3:1 ratio, it is understood that reclamation of soil heavily contaminated with sulphur requires a long-term commitment.

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