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AUTOMATION AND REMOTE CONTROL OF CONTINUOUS MINING SYSTEMS FOR SURFACE MINING OF OIL SANDS

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ABSTRACT

A variety of mining equipment is used in the surface mining of oil sand. This includes bucketwheel excavators, belt conveyors, feeder-breakers, hydraulic and electric shovels, and off-highway trucks. This paper examines the existing mining schemes and equipment used. Peculiarities of oil sand surface mining and their influence on equipment selection, utilization, and other mining schemes are described. Recent developments undertaken to improve mine productivity are also dealt with together with some notes on proposed measures to obtain further gains in productivity. These gains, the authors demonstrate, can only be achieved by introduction and acceptance of the available and upcoming technology of equipment remote control and automation.

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AUTOMATISATION ET CONTRÔLE À DISTANCE DES SYSTÈMES PERMANENTS D'EXPLOITATION MINIÈRE POUR L'EXPLOITATION À CIEL OUVERT DES SABLES BITUMINEUX

par

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RÉSUMÉ

Une variété d'équipements miniers est utilisée dans l'exploitation à ciel ouvert des sables bitumineux. Ceci inclue des roues à augets, des excavateurs, des convoyeurs à bande, des interrupteurs d'alimentation, des pelles hydrauliques et électriques et des camions hors-routes. Cet article examine les plans et les équipements d'exploitation minière en usage. Les particularités causées par l'exploitation en surface des sables bitumineux et leurs influences sur la sélection de cet équipement et son utilisation, ainsi que d'autres plans d'exploitation minière sont décrits. Les récents développemnts entrepris pour améliorer la productivité minière sont également traités, autant que certains commentaires proposés pour obtenir un gain accru de la productivité. Tel que démontré par les auteurs, ces mêmes gains ne peuvent être obtenus que par l'introduction et l'acceptation de ces équipements de contrôle à distance et d'automatisation actuellement ou bientôt disponibles.

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Abstract. A variety of mining equipment is used in the surface mining of oil sand. This includes bucketwheel excavators, belt conveyors, feeder-breakers, hydraulic and electric shovels, and off-highway trucks. This paper examines the existing mining schemes and equipment used. Peculiarities of oil sand surface mining and their influence on equipment selection, utilization, and other mining schemes are described. Recent developments undertaken to improve mine productivity are also dealt with together with some notes on proposed measures to obtain further gains in productivity. These gains, the authors demonstrate, can only be achieved by introduction and acceptance of the available and upcoming technology of equipment remote control and automation.

Introduction

Canada, Venezuela, the United States, Europe and the U.S.S.R. all have major oil sand deposits. Canada leads all other countries in its development of oil sands and is recognized as a forerunner in the oil sand recovery technology. The first successful commercial plant here was that of Great Canadian Oil Sands Ltd. (now Suncor Inc.), which began operation in 1967. The second plant, the Syncrude Canada Ltd., came on stream in 1978. The combined production capacity of these two plants is 32,000 m3 (200,000 bbl) of synthetic crude oil per day. Both of these plants are located north of the City of Fort McMurray, in the province of Alberta.

At the time of writing, due to the depressed oil prices, the work on the development of new oil sand projects is on hold, as are the expansion plans of the existing plants. Nonetheless, the oil sands represent a major energy source of the future. The operation of the two existing plants has provided valuable experience in the mining and processing of oil sand that would prove valuable in increasing efficiency, economy and cost competitiveness of the next generation of oil sand projects.

Mining Schemes

The oil sand which constitutes the orebody at Suncor and Syncrude mine sites is contained within the McMurray Formation (see Figure 1). The average thickness of the bitumen saturated beds is 30 m, with the actual thickness varying from less than 5 m to over 85 m. Bitumen concentrations average 11% to 2% by weight, but range from less than % to 18%. Ore grading a minimum of 6% is considered economic in the present day technical and financial regime. Ore averaging less than 6% is called 'lean' and is usually discarded with the waste materials.

The mineral matter in the oil sand is 95% to 98% uniform white quartz sand. The remainder is essentially clay with minute quantities of mica, rutile, zircon, tourmaline and pyrite. An average sample of oil sand has the following particle size and distribution:

10% finer than 0.1 mm
90% finer than 0.2 mm
95% to 98% finer than 0.8 mm

The oil sand is extremely abrasive causing wear on cutting elements of mining equipment, crawlers, bearings, seals and other moving parts. Oil sand exposed to summer temperatures becomes a soft, sticky mixture of sand and bitumen. Under freezing conditions, oil sand becomes extremely hard. Due to poor trafficability, which varies with moisture and bitument content, mining equipment with very low ground pressure is required.

Production of synthetic crude oil from oil sand involves four basic operations: overburden removal, oil sand mining, extraction of bitumen from oil sand and upgrading the bitumen. The complete process is shown in Figure 2. In the extraction plant, the bitumen and the sand are separated by hot water treatment. The clean sand in the form of tailings is then delivered to the tailings disposal area. The bitumen is diluted with naphta to reduce its viscosity and passed through centrifuges to remove remaining water and solids. The naphta is then separated out by distillation, leaving the very thick, tar-like bitumen. This bitumen is fed into cokers, where it is used to produce coke, sour gas, naphta and gas oil. The coke is stockpiled for future use. The naphta and gas oil are hydrotreated to remove sulphur and nitrogen and then shipped down the pipeline as synthetic crude oil. Gases from the cokers are hydrotreated and desulphurized, and used to fuel the boilers in the utility plant. The utility plant is capable of providing steam, electric power and process water for the entire mining, processing and upgrading facilities.

Mining at Syncrude Canada, Ltd.

Mining begins with land clearing and removal of overburden by conventional methods. The hydraulic and electric shovels as well as front-end loaders are used, loading 170 t off-highway trucks. The oil sand is excavated by four draglines, equipped with 60 m3 buckets and 110 m long booms. These mine a single bench highwall, height of which varies from 40 m to 60 m. The highwall slope angles vary from 45 to 50 degrees. The feed grade oil sand is windrowed on the dragline bench, adjacent to the draglines. Waste material encountered in the dragline cuts is rejected into mined-out pit. The windrowed oil sand is reclaimed by four bucketwheel reclaimers, each with a 12.5 m diameter wheel. The reclaimers load face conveyors equipped with 1.8 m (72 in.) wide belts moving at 4.5 m/sec. (14.8 ft./sec.) These shiftable face conveyors are 2,300 m long and are powered by 3,725 KW drives. The face conveyors discharge on to similar collector conveyors, which in turn, discharge on to radial stackers. The stackers place the oil sand on a 240,000 t stockpile over the extraction plant draw points.

The Syncrude mine area extends 4.2 km in the north-south direction. It is 7.5 km wide and approximately 60 m deep. It is divided into four 2,300 m long quadrants, each quadrant equipped with a dragline, a nominal 7,000 t/h bucketwheel reclaimer and a conveyor system for oil sand mining. The face conveyors are shifted every two mine cuts. The time required for these moves varies from 4 to 14 days, depending on the complexity of the move.

Mining at Suncor, Inc.

Like Syncrude, the overburden is excavated by conventional mining equipment. A fleet of front-end loaders and hydraulic shovels are used, and up until recently, the 170 t electric trucks. The last were replaced with 85 t mechanical drive trucks, which have proven to be better able to cope with poor trafficability and high rolling resistance faced in this mine. The overburden is used to construct tailings impoundments, which is a seasonal activity conducted during the summer months only. Frozen overburden excavated in winter cannot be compacted and is therefore stockpiled in waste dumps.

Unlike the Syncrude mine, Suncor uses bucketwheel excavators for the direct excavation of oil sand. The three bucketwheel excavators that mine ore make two cuts with a total width of 97.5 m in 20 m to 25 m high benches between subsequent face conveyor shifts. Excavators of the SchRs 1100/1.5-27 type are used, what denotes a crawler mounted bucketwheel excavator with a slewable structure. The nominal bucket capacity is 1,100 l, maximum digging depth below the crawler level is 1.5 m and the maximum bench height is 27 m. The bucket wheel has ten buckets, and a theoretical excavating capacity of 3,600 m3/h of loose material. The service weight of these machines is 1,660 t, and the height above the crawlers is 18 m.

Use of bucketwheel excavators requires that all of the oil sand is drilled and blasted prior to mining. Blasting is a seasonal activity, that is carried out during the summer months when the oil sand is not frozen. Rippers and sheep's foot rollers are used to seal the surface after blasting to prevent frost from forming during the winter months, during which the temperature often drops to -40^{o} C. Blasting also breaks up the hard shale and sandstone inclusions in the oil sand, and shatters the bench material making it easier to dig by the bucketwheel excavators.

The ore mined by the bucketwheel excavators is conveyed via a slewable discharge boom conveyor on to a mobile transfer conveyor (called a belt wagon), which in turn, transfers it into a travelling hopper straddling the face belt conveyor. Type BRs 1800/(28 + 32) - 15.5 belt wagons are used, what denotes a 1,800 mm belt conveyor on a 28 m long receiving boom and on the 32 m long discharge boom, and a discharge height of up to 15.5 m.

The travelling hopper car is rail mounted. The rails are attached to the steel support sleepers of the conveyor, and run its entire length. A travelling cable car, that carries the trailing power cable to supply power to the belt wagon and the bucketwheel excavator, is coupled to the travelling hopper and moves with it along the conveyor rails.

Technological Enhancements

It must be recognized that oil sand surface mining plants are truly mega-projects in terms of capital investment and volume of material handled. Typical plant that produces 19,000 m3 (125,000 bbl) of synthetic oil per day requires handling of some 270,000 tonnes of oil sand per day (assuming 11% ore grade), and almost as much as waste. Most of raw oil sand is a waste, so after bitumen extraction, it must be handled again in the form of waste for final disposal. Excavation and disposal of such enormous quantities of materials can best be accomplished with the aid of continuous surface mining systems.

Over the years, the oil sands industry has become proficient in large volume excavation, handling and disposal of ore and waste. It was possible by development of new operating procedures along with modifications and enhancements to equipment and to standard operating practices. Apart from large volume material handling, these permit to efficiently deal with the peculiarities of the operations - the properties of oil sand and overburden, extremities of weather, and remoteness of major equipment and part suppliers.

The impact of these enhancements has been to make the whole mining system more reliable, efficient and productive, thus leading to productivity levels required to make the synthetic crude oil price competitive with that of conventional oil. At present, it appears that further meaningful gains can only be obtained by application of innovative mining and material handling concepts. These are briefly discussed below.

Bucketwheel Excavators

Bucketwheel excavator is the prime excavation unit in a continuous surface mining system. Its production rate depends on many design parameters, as well as the nature of the material to be excavated and the method of working a face. The number, shape and size of buckets, design of the digging wheel together with its diameter and rotational speed, length of the load boom together with its slew and hoisting speeds, excavator travel speed and maneuverability are the most important design parameters which influence the production rate and efficiency of mining. The diggability, hardness, uniformity, plasticity, stickiness and moisture content relate to the properties of material to be excavated, whereas the design of cuts, geometry of the face (in particular its height, width and slope angles) relate to the method of excavation.

The multitude of factors influencing the bucketwheel productivity makes its manual control, used so far, relatively inefficient. Production loss is faced as a result of underutilization of excavator potential and frequent production peaks which cannot be handled by belt conveyors of the system. Automation of the digging process appears to be an answer to these problems, as it may permit to:

1. Ensure a steady output volume stream permitting full utilization of belt conveyor system capacity.

2. Reduce the operational downtime by preventing production peaks of the excavator and resultant stoppages of system conveyors.

3. Prevent operating errors by excavator operators.

4. Monitor the functionality of all peripheral equipment thus ensuring the quicker localization of faults in case of their malfunction.

A number of suitable microprocessor based bucketwheel automation systems became recently available. One of these, proposed by Krupp, is shown in Figure 3. It consists of a central control unit (CCU), located in the operator's cabin, to which video display monitor, text display (a printer) and a fault printer are connected. The CCU communicates with the peripheral modules located on the superstructure, undercarriage and the loading unit. In total, seven peripheral modules are proposed, of which two (Number 4 and 7 on Figure 3) are equipped with independent microprocessors. They relieve the central unit by evaluating their measured volumes independently.

After entering the several parameters which describe the block to be mined, the CCU computes the block geometry, and checks if all of the input data is within the limits imposed by the excavator design. Automatic excavator operation is then activated, with all the parameters (direction and speed of hoisting, slewing and crawler movements) selected and controlled by the CCU. The required excavator rate can be set from 0% to 100%, with the slew speed being the control factor.

Semi-automatic operation is also possible, with manual hoisting and slewing movements as well as forward and reverse crawler movement, and with the excavator boom kept within the specific limits of the mined block.

Experience with similar systems implemented elsewhere indicate that an increase of average production rate up to 20% is possible by automation of the bucketwheel operation, together with substantial increase of the working time of the whole mining system of which the excavator is a part of.

Belt Conveyors

Belt conveyors provide an economical method of transporting large volumes of materials in mining. Whereas a bucketwheel excavator is a continuous excavation unit, a belt conveyor serves as a continuous transportation unit forming an integral part of the continuous mining system. While many types of belt conveyors are available, the oil sand mining industry, as described, uses shiftable and stationary belt conveyors for ore transport only.

Continuous nature of conveyor work makes this equipment easily adaptable to automation and remote control. Partial automation and full remote control of conveyor systems is already in place, and depends on automatic control of the system start-up and interlocking of conveyor flights within the system. Automatic, instantaneous start-up of all conveyors within the system shortens the whole mining system downtime substantially. The interlocking of all conveyor system components prevents damage to the system if one of the downstream components fail. Accessories to any conveyor automation system are the TV monitors permitting one operator to visually control the material flow along the whole system, the load measuring devices which permit adjustments of either the bucketwheel excavator output , or the conveyor speed, and a number of other monitors and sensors which provide information on irregularities of the system operation.

While no totally automated conveyor system works in oil sand mines at present, its introduction is foreseen in the future, most likely in connection with the automated bucketwheel operation. The CCL unit described above can be easily expanded to provide the conveyor system control in addition to that of the excavator.

Other Equipment

Other mining equipment used by the oil sands industry is more difficult to automate or to remotely control due to the discontinuous nature of its work. However, some initial steps in this direction were undertaken, indicating possible future developments. In particular, the performance monitoring systems were introduced on large draglines mining the oil sand, and the truck dispatch system for the overburden removal fleet in one operation is being installed.

The microprocessor based dragline performance monitoring system (Figure 4) provides the operator with accurate and reliable real time performance data, the information which may be used to quickly respond to changing operating conditions, thus improve equipment productivity. It is also seen as a first module of a future mine management system, which will assist mine management in making the decisions which most affect the mine efficiency and performance.

The truck dispatch system, while increasing the utilization and productivity of a truck fleet at present, has a potential of becoming one of the modules of an integrated truck management system. Such a system will likely also include truck weighing and the maintenance management, permitting optimization of the truck fleet utilization.

General Discussion

It must be recognized, that oil sand operations have long lead times from the moment the project is conceived to the time a plant actually starts producing synthetic crude - almost a decade passes. Thus some of the features which are considered innovative at the beginning of a project tend to become proven and reliable at the project start-up. Retrofitting is not always easy.

The technical advances ofthe last few years and those pursued recently, clearly demonstrate that a new microprocessor based technology is now available for application to the continuous surface mining systems. It is particular suitable for large volume surface mining operations such as these in Canadian oil sand mines. Adoption of this technology will bring higher efficiency and reliability to the entire operation. Excavation and transportation equipment will be provided with sensing devices to monitor both its performance and possible malfunctioning on one hand and quality of ore on the other. The entire material flow from the time when a machine is scheduled to excavate ore to the time the extracted bitumen leaves the process plant will be synchronized by automation and remotely controlled, with a continuous information feedback to the excavator operator.

Individual pieces of equipment will have on-board microprocessors to analyze, display and alert on activities of this equipment, providing a real time information. Several of such units can be coupled via VHF radio links (and the like) to a command centre, a complete mine management system, in which individual signals will be processed and analyzed, information stored and decisions made.

The greatest challenge facing the oil sands surface mining industry lies in its practice of overburden handling. Trucks, while flexible, are highly expensive to operate and maintain. Automatic Truck Dispatch Systems which have recently become available, must still be considered under development. While an improvement to the present practice of manual dispatch, these systems are no match in performance to the automated continuous mining systems. Automatic truck control to eliminate truck drivers, although tried, is not available.

One reason the trucks are employed in oil sand mining is their flexibility, an asset in construction of tailings impoundments. The impoundment material, either overburden or lean oil sand, may be easily delivered where required. Spread in thin layers, it readily dries and can be compacted to meet the impoundment construction requirements. It is believed that stacker discharged impoundment material will be more difficult to control resulting in its inadequate strength.

While problems such as these are recognized, it is believed that a variety of dumping modes can be employed with the use of stackers, making the resulting impoundment of sufficient quality for safe tailings containment. This aspect requires further detailed investigations. Stackers, if used in connection with bucketwheel excavators and conveyors already in place, will lead to a truly continuous mining system amenable to automation resulting in substantial cost reductions.

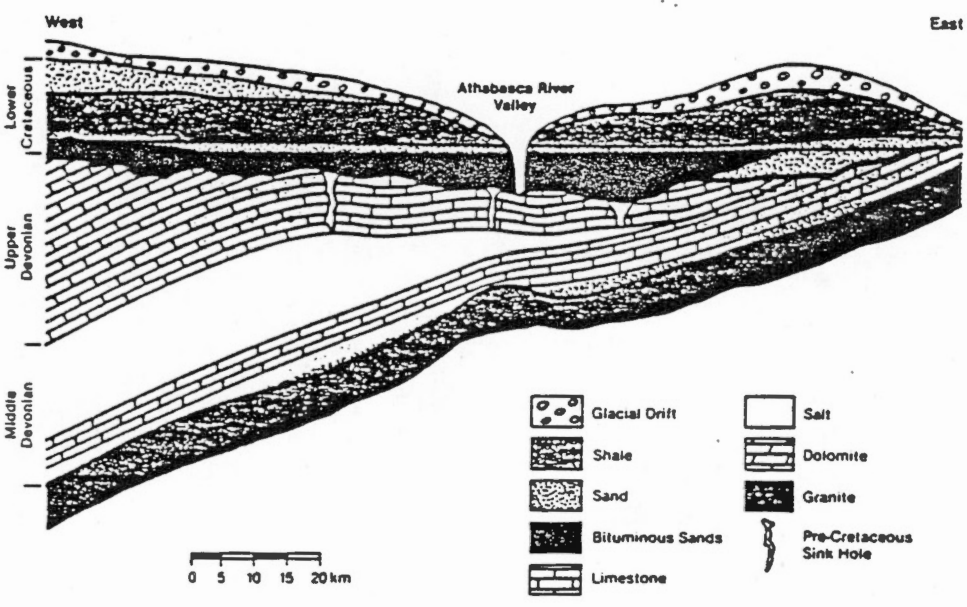

Figure 1. Simplified geological profile of Athabasca Oil Sands deposit

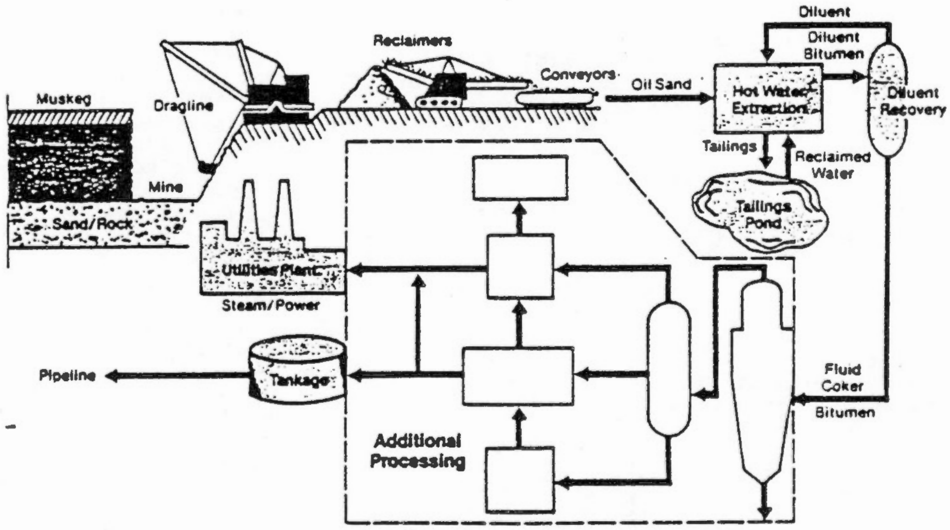

Figure 2. Simplified scheme of synthetic crude oil production from oil sands

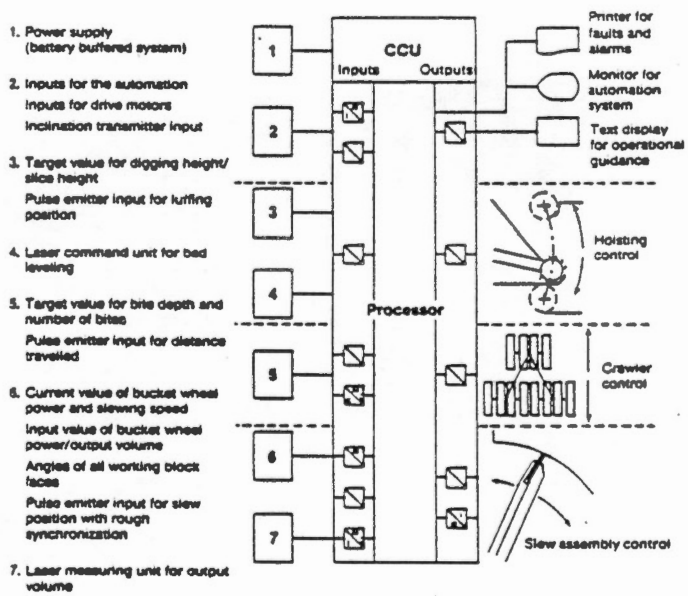

Figure 3. Krupp bucketwheel excavator automation system.

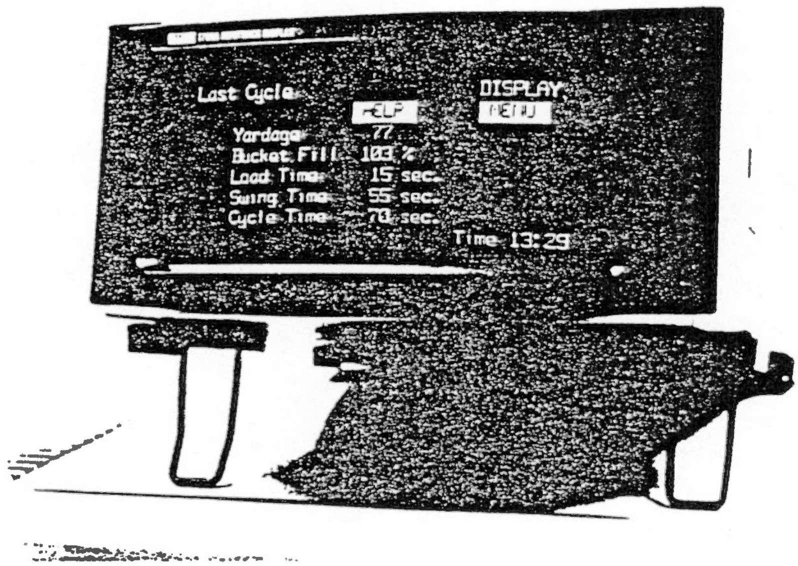

Figure 4. Display unit of a dragline performance monitoring module.