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CONTINUOUS MINING SYSTEMS FOR OIL SANDS MINING

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ABSTRACT: Canada is a forerunner in the development of oil sands mining and processing technology. At present two commercial plants with an aggregate capacity of 32,000 m^3 (200,000 bbls) of syncrude per day are operating in the Athabasca region of northern Alberta. Each of these plants represents billions of dollars of investment in mining and processing facilities. At both plants, high capacity continuous mining equipment is used for material handling. Typically, a plant that produces 19,900 m^3 (125,000 barrels) of synthetic crude oil per day would require the handling of some $54\text{-}58 \times 10^6$ m^3 of pit materials per year.

This paper provides an overview of the equipment and systems used to load and transport ore and overburden in Alberta's oil sands surface mining operations. Continuous mining systems such as bucketwheel excavator/conveyors are used side by side with more conventional equipment e.g., trucks/shovels. Emphasis is on mining schemes and equipment selection for each of these projects. Technological enhancements currently underway and incorporated into the mining systems during the recent past have also been considered.

SYSTÈMES MINIERS EN CONTINU SERVANT À L'EXPLOITATION DES SABLES BITUMINEUX

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Résumé: Le Canada joue un rôle de précurseur dans le développement de méthodes d'exploitation et de techniques de traitement pour les sables bitumineux. Dans la région de l'Athabasca au nord de l'Alberta, deux usines commerciales produisent actuellement un rendement global de 32 000 m^3/jour (200 000 barils/jour) de brut de synthèse. Chacune des usines représente un investissement de plusieurs milliards de dollars répartis dans les installations d'exploitation et de traitement. On utilise aussi dans chacune des usines, un équipement minier en continu d'une grande capacité de production pour effectuer le traitement des matériaux. En règle générale, une usine ayant une capacité de production de 19 900 m^3/jour (125 000 barils/jour) de brut de synthèse devra traiter 54-58x10^6 m^3 de matériaux de fonçage par année.

La présente communication donne un aperçu de l'équipement et des systèmes utilisés pour effectuer le chargement et le transport du minerai et des terrains de couverture dans le cadre de l'exploitation à ciel ouvert des sables bitumineux en Alberta. Des systèmes miniers en continu tel que les excavateurs à godet et les convoyeurs ainsi que de l'équipement classique soit des camions et des pelles sont utilisés côte à côte dans ces exploitations. Enfin, on a attaché de l'importance aux systèmes miniers et au choix de l'équipement utilisés dans le cadre de chacun des deux projets. Les améliorations en cours actuellement au point de vue technologique et que l'on a apportées aux systèmes miniers depuis les dernières années sont aussi examinées.

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1 INTRODUCTION

Canada, Venezuela, the United States, Africa, Europe and the U.S.S.R. all have major oil sands deposits. Canada leads all others in its development of oil sands and is recognized as a forerunner in oil sands recovery technology. Canada's four major oil sands deposits (Athabasca, Cold Lake, Peace River, Wabasca) are all located in the northern half of Alberta covering some 30,000 km^2 and contain approximately 950 billion barrels of bitumen. The Athabasca deposit is among the largest in the world: it contains an estimated 700 billion barrels of bitumen making it at least four time larger than Ghawar, the world's largest conventional oil field in Saudi Arabia. Of Canada's four major deposits, only the Athabasca oil sands are amenable to surface mining operations.

The first successful commercial plant was the Great Canadian Oil Sands Ltd. (now Suncor, Inc.) plant which began operation in 1967. The second commercial plant, the Syncrude Canada Ltd. mining project, came on stream in 1978. The combined capacity of the two plants is approximately 32,000 m^3 (200,000 bbls) of synthetic crude oil per day. Both of these plants are located near 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 at a slow pace, 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 will prove valuable in increasing efficiency, economy and cost competitiveness of the next generation of oil sand projects.

Both operating oil sand plants are in the Athabasca deposit. Figure 1 shows a typical geological profile of this deposit. The average thickness of the bitumen saturated beds is 30m but because of the highly irregular contact between the oil sand stratum and limestone base, actual thickness varies from less than 5m to more than 85m.

Bitumen concentrations average 11 to 12% by weight but range from less than 1 to about 18%. Ore grading a minimum of 6% by weight is considered economic in the present day technical and financial regime. Ore averaging less than 6% is called "lean" and is

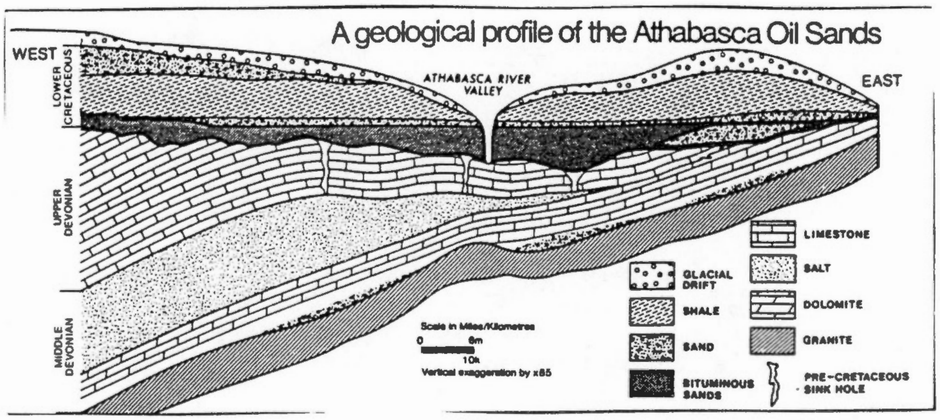

Figure 1 Typical Geological Cross-Section through the Athabasca oil sands Region.

usually stockpiled for future processing when appropriate technology or economics will allow viable extraction of the bitumen.

The sand makes up about 84% of oil sand by weight. Water makes up about 4% by weight and is present in the form of a film which envelops each grain of sand keeping it separate from the oil, Figure 2. This water envelope enables the separation of bitumen and sand by the hot water extraction method; at present this is the only commercial method of extracting bitumen from the oil sands. In it's raw state, bitumen is a semi solid, sticky, black substance which requires chemical processing to make it liquid enough to transport by pipeline.

The mineral matter in the oil sands

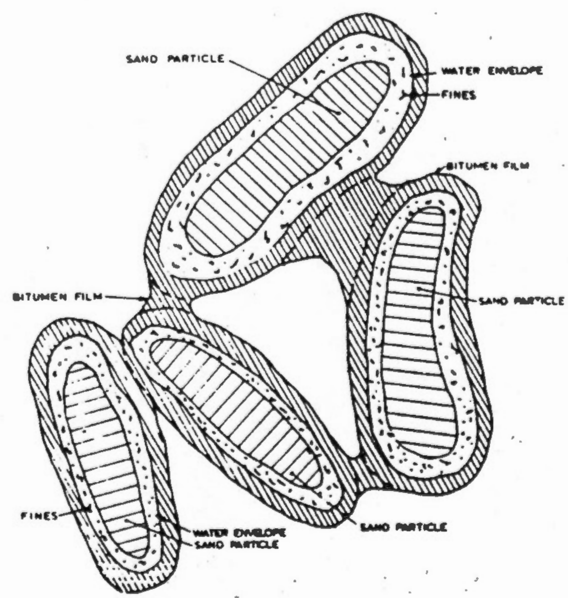

Figure 2 Cross Section of an oil sands sample showing separation of sand and bitumen by water.

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 the sand has the following particle size and distribution:

10% finer than 0.1mm
90% finer than 0.2mm
95-98% finer than 0.4mm

The oil sands are extremely abrasive causing wear on cutting elements of mining equipment, crawlers, bearings, seals and other moving parts. Exposed to summer temperatures oil sands become a soft sticky mixture of sand and oil; under freezing conditions, they become extremely hard.

Trafficability in oil sands varies greatly with moisture and bitumen content. Mining equipment with very low ground pressure in the range of 138kPa and lower is required. Density of in situ oil sands ranges from 1840 to 2160kg/m^3 with average values at 2100 kg/m^3. Loose oil sand weighs from 1360 kg/m^3 to 1600kg/m^3.

2 SCOPE OF OPERATIONS

The hot water separation process, first developed by the Alberta Research Council, has proven very successful in achieving good bitumen recoveries from oil sands averaging a minimum of 6 to 8% of bitumen by weight. One attendant disadvantage of this wet process is that hugh ponds are required to contain the resulting tailings.

Typically for an energy self sufficient operation capable of producing 19,900m^3 (125,000 barrels) or 17,100 tonnes of synthetic crude oil per day, the quantity of oil sands to be mined daily (assuming an average grade of 11%) will be in the order of 270,000 tonnes. This means that 2.2 tonnes of oil sands of 11% bitumen will yield 0.159m^3 (1 barrel) of oil. With an insitu bulk density of 2100kg/m^3, 129,000m^3 of oil sand would be mined daily. Table 1 shows the distribution of materials in tailings disposal for each tonne of oil sand mined.

A plant that produces 19,900m^3 (125,000 barrels) of synthetic crude oil per day will use 270,000 tonnes of oil sands daily and will produce over a typical mine life of 25 years, approximately 3100 x 10^6 cubic metres of tailings. After disposition and sedimentation approximately 1500 x 10^6 cubic metres of clarified water is returned during this period for reuse in the plant. Permanent storage must be found for the remaining 1600 x 10^6 cubic metres of the material. This material is composed of approximately 1200 x 10^6 cubic metres of sand and 400 x 10^6 cubic metres of thickened sludge.

Flow	Mass		Volume	
	kg	lb	m^3	ft^3
In-situ oil sand				
Bitumen	110	240	0·108	3·8
Water	50	110	0·050	1·8
Fines (<0·044 mm) / Sand (>0·044 mm)	840	1850	0·317	11·2
Total	1000	2200	0·475	16·8
Oversize reject*				
Water	10	22	0·010	0·35
Fines / Sand	60	132	0·022	0·78
Total	70	154	0·032	1·13
Extraction process				
Water added	900	1980	0·900	31·8
Bitumen removed	100	220	0·098	3·5
Tailings stream				
Bitumen	10	22	0·010	0·4
Water	940	2073	0·940	33·2
Fines	90	198	0·034	1·2
Sand	690	1521	0·260	9·2
Total	1730	3814	1·244	44·0
Dyke and beach				
Bitumen	3	7	0·003	0·1
Water	206	454	0·206	7·3
Fines	43	95	0·016	0·6
Sand	687	1514	0·259	9·1
Total	939	2070	0·484	17·1
Thin sludge				
Bitumen	7	15	0·007	0·2
Water	734	1618	0·734	25·9
Fines	47	104	0·018	0·6
Sand	3	7	0·001	0·1
Total	791	1744	0·760	26·8
Thick sludge				
Bitumen	7	15	0·007	0·2
Water	121	267	0·121	4·3
Fines	47	104	0·018	0·6
Sand	3	7	0·001	0·1
Total	178	393	0·147	5·2
Reclaim water	613	1352	0·613	21·6

Fines definition is passing no 325 sieve or finer than 0·044 mm

* Bitumen content in oversize reject assumed to be negligible

Table 1 Flow chart for tailings disposal for 1 tonne of oil sands mined.

In addition to mining and handling the oil sands and tailings, the overburden on top of the oil sands must also be mined. The oil sands are overlain by overburden of varying thickness.

The oil sands mining is governed by all the economic rules and indicators applicable to any other surface mining project. The cut off stripping ratios and ore grade are considered in determining the depths of the overburden that can be stripped to make a profit on the oil sands mined. At present, with the existing crude oil prices, overburden depths of up to

50 metres are being economically mined. The stripping ratio (ie., ratio of overburden to oil sand) is roughly one to two, therefore, every tonne of overburden removed should make available two tonnes of oil sands. Thus, for $19,900m^3$ (125,000 barrels) per day plant some 150,000 tonnes of overburden will be mined daily.

It is hoped that this discussion gives some ideas of the complexities involved in planning, scheduling and handling of the large volumes of materials involved in an oil sands plant. Disposal of tailings forms an integral part of all mine planning. Guidelines for tailings disposal call for satisfactory reclamation and maximum possible utilization of the mined out pit to contain tailings.

3 MINING SYSTEMS

Production of synthetic crude oil from oil sands involves four basic operations: overburden removal, mining oil sands, extraction of bitumen from oil sands and upgrading the bitumen. This paper deals with the first two by describing the methods and machines that are used at the existing oil sands plants.

Since climate plays an important role in the selection and application of mining systems, a brief reference at this stage will be appropriate.

The climate of the Athabasca oil sands region is continental. Winter temperatures have been known to drop as low as -52°C. Summer temperatures can rise as high as 36°C, but, on the average fewer than 20 days per year are higher than 27°C. The frost free period averages 69 days with a maximum of 115 frost free days. The average annual precipitation is 43 cm., half of which falls during the growing season. Average annual snowfall is 163 cm. The climate and the very nature of the oil sands e.g., its abrasiveness and extreme hardness in winter require some special provision in its mining.

For example, during winter, frost is a problem. The depth of frost penetration in undisturbed overburden and in situ oil sands can be up to 2-3m after a few months winter exposure and up to 5m after longer periods of time. The temperature of the protected in situ oil sand is relatively constant, summer and winter, at about 4.5°C.

In the autumn, before sub freezing temperatures occur, the in situ oil sand is fluffed up by drilling and blasting to reduce winter frost penetration and make excavation easier. Muskeg, 2 to 10m deep in places forms the uppermost layer of overburden. When wet, it gives swamp like ground conditions and when dry, it resembles peat moss in texture. Muskeg is drained for 2 to 3 years in advance of oil sands mining operation by digging drainage ditches. Often even after this period, it remains a wet and spongy mass and can only be excavated when it is frozen. Muskeg removal is carried out during winter months.

Winter temperatures encountered in the oil sands region require that cold weather steel be used on all major load carrying members in mining machines. Radial tires on the fleet provide larger ground contact area than conventional tires, resulting in lower ground bearing pressure and reduced rolling resistance. Other measures include: heating of gears and transfer points, heating and ventilation of power houses, insulating and heating of switchgear, flamethrowers to heat buckets, cold weather oil and greases, use of special rubber compounds for conveyor belts, spraying of oil on conveyor belts to prevent freezing of oil sands to belts and installation of heated cabs for conveyor operators, etc.

4 MINING OPERATIONS AT SYNCRUDE CANADA LTD.

The Syncrude minesite (Mildred Lake) is located in the northern part of the Athabasca oil sands deposit. It is located 40km northeast of Fort McMurray. Figure 3 shows Syncrude's overall process of synthetic crude oil production from the oil sands.

The process begins with the removal of waste with shovels and other mobile equipment followed by dragline windrowing of oil sand and bucketwheel conveyor system reclaiming of the windrowed oil sands. The mine conveyors deliver oil sands to the extraction plant, where the bitumen and the sand are separated by hot water treatment. The clean sand is then delivered to the tailings area. The bitumen is diluted with naptha to

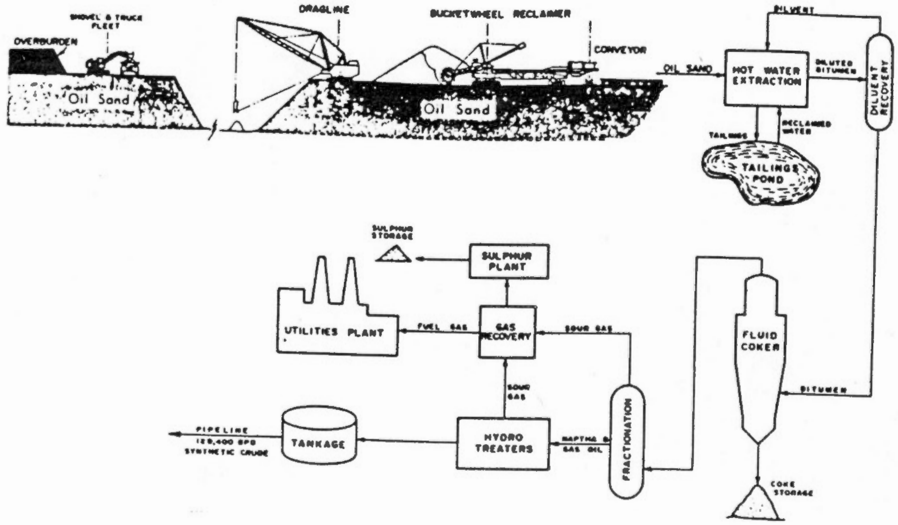

Figure 3 Syncrude's overall process of producing Synthetic crude oil from oil sands.

reduce its viscosity and passed through centrifuges to remove remaining water and fines. The naptha is then separated out by distillation leaving the very thick black tar like bitumen. The bitumen is then fed into fluid cokers where it is cracked to produce coke, sour gas, naptha and gas oil. The coke is stockpiled for future use. The naptha and gas oil are hydrotreated to remove sulphur and nitrogen, then shipped down the pipeline as synthetic crude oil. Gases from the cokers are hydrotreated and desulphurized and used to fire boilers in the utility plant. The utility plant is capable of providing steam, electric power and processed water for the entire mining, extraction and upgrading facilities. It is also tied into the Alberta Power grid system for power stability.

At Syncrude overburden is excavated by conventional mining equipment. Hydraulic and electric shovels as well as front end loaders are used to load 154 tonne (170t) off highway trucks. The oil sand is excavated by four draglines, equipped with $60m^3$ buckets and 100m booms. These mine a single bench highwall, which varies from 40m to 60m. 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 materials encountered in the dragline cuts is rejected into the mined out pit, figure 4. The windrowed oil sand is reclaimed by four bucketwheel reclaimers, each with a 12.5m diameter wheel, figure 5. The reclaimers load face conveyors equipped with 1.8m wide belts moving at 4.5m/sec. These shiftable face conveyors are 2,300m long and are powered by 3,725KW drives. The face conveyors discharge on to similar collector conveyors, which in turn, discharge onto radial stackers. The stackers place the oil sand on a 240,000 tonne stockpile over the extraction plant draw points.

Figure 4 Typical view inside Syncrude mine: dragline excavates oil sands; trucks haul overburden.

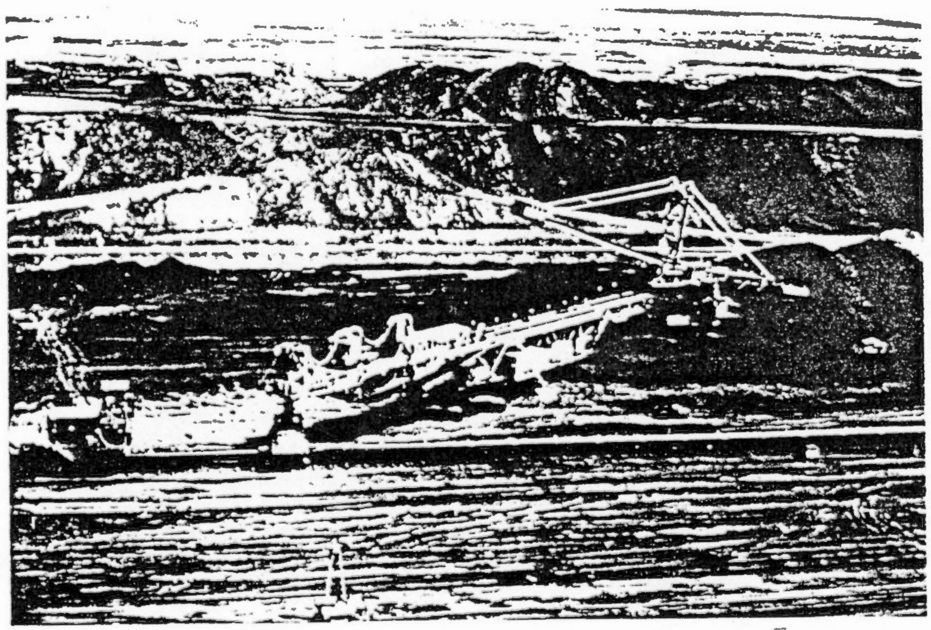

Figure 5 Dragline stockpiled oil sands is reclaimed at Syncrude mine with bucket-wheel reclaimers.

The Syncrude mine is the largest surface mining operation in the world in terms of the volume of materials handled. Its mining area extends 4.2km in the north-south direction. It is 7.5km wide and approximately 60m deep. It is divided into four 2,300 long quadrants, each quadrant equipped with a dragline, a nominal 7,000 tonnes per hour bucketwheel reclaimer and a conveyor system. 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.

The tailings pond at Syncrude is 8km long and 4.8km wide with perimeter dykes extending a total length of 20.9km making it the largest tailings pond in the world. At current production levels, the Syncrude pond receives between 260,000 and 315,000 tonnes per day of slurry.

5 MINING AT SUNCOR, INC.

Suncor mine is the smaller of the two oil sands plants operating in Canada. Production of oil sand is in the range of 36 x 10^6 tonnes per year. This yields a synthetic crude oil output of 7950 to 8750m^3 (50 to 55,000 bbls) per day.

Like Syncrude, the overburden is excavated by conventional mining equipment. A fleet of front end loaders and hydraulic shovels are used to load off highway trucks. Until recently, 154 tonne (170t) electric trucks were used. These were replaced with 77 tonnes (85t) mechanical drive trucks, which have proven to be better able to cope with the poor trafficability and high rolling resistances faced in this mine. The overburden is used to construct tailings impoundments, 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 mining oil sands. At this mine, oil sand varies in thickness from 36m to 61m. It is mined in three benches each about 15m high, figure 6. Each bench is equipped with its own bucketwheel beltwagon and face conveyor. Excavators of the SchRs 1100/1.5-27 type are used which 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 1.5m and the maximum bench height is 27m. The bucketwheel has ten buckets, and a theoretical excavating capacity of 3,600m^3/hr of loose material. The service weight of these machines is 1,660 tonnes, and the height above the crawlers is 18m.

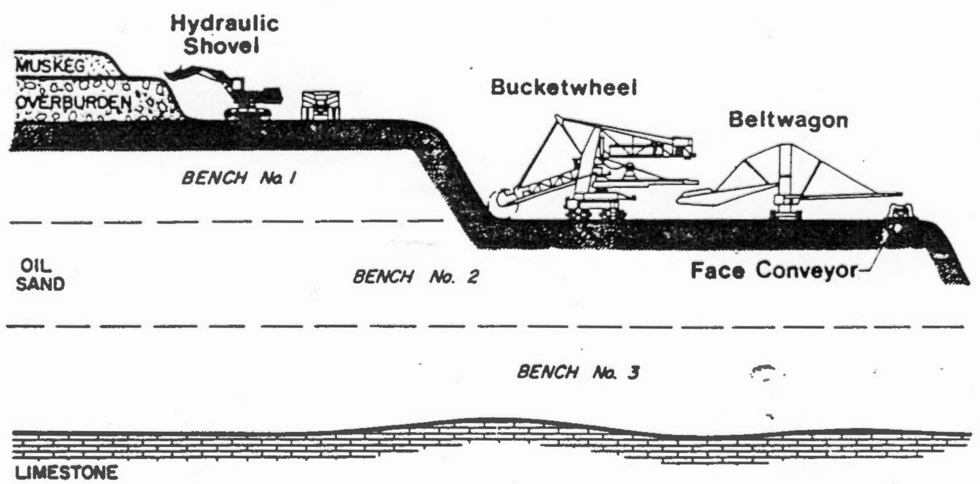

Figure 6 Scheme of pit operations at Suncor mine.

The oil sand 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, which denotes a 1,800 mm belt conveyor on a 28m long receiving boom and a 32m long discharge boom, with a discharge height of up to 15.5m. The mobile conveyor transfers the ore into face conveyors which are 1500mm wide; from face conveyors the ore is discharged onto two main plant feed conveyors each 2100mm wide. Belt speed on all conveyors is 5.2m/s.

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.

Use of bucketwheel excavator requires that all of the oil sand is drilled and blasted prior to mining. 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 excavator. ANFO (94% ammonium nitrate prills with 6% fuel oil) was used as the blasting agent with plastic liners. Suncor has recently introduced Heavy ANFO - which is 60% ANFO and 40% emulsion - to improve safety by eliminating plastic liners (static electricity generated by the handling of plastic liners). Emulsion works as an oxygen inhibitor and is more water resistant. The density of heavy ANFO is 1.2gm/cm^3 vs 0.8gkm/cm^3 for ordinary ANFO.

An auger type machine is used for drilling blast holes. The holes are 460mm in diameter with depth varying between 5 to 14m. The blast hole pattern is usually 12.9 x 14.0m. The bottom 1.5m to 3m of the bench is left unblasted to ensure trafficability on the bench floor. Most of the blasting is carried out during the spring and summer months when the oil sand is not frozen. Rippers and sheep foot rollers are used to seal the surface after blasting to prevent frost from forming during the winter months.

If blasting is required in winter, standard depth blastholes are supplemented with shallow frostholes. Frostholes are usually 15cm in diameter and are drilled by a rotary drill to a depth of 3 to 5 m to break the frosted cap.

6 MEASURES FOR PRODUCTIVITY ENHANCEMENT

High capacity equipment is used for excavation and transportation of overburden ore in the two operating oil sands plants be it either a dragline or a bucketwheel excavator/conveyor system. Each bench or quadrant is equipped with its own independent materials handling system. Nearly twenty years of mining experience is now behind this industry and numerous improvements to all phases of mining practices, achieved one step at a time, have been made. The technology and problems of today's oil sands plants are not the same as they were in the early 1970's. Since then the oil sands excavation and transportation technology has come a long way.

At both oil sands plants state of the art facilities are used. At the same time, considerable effort has been directed towards developing innovative technology, operating techniques and procedures for improving the productivity of existing mining operations. These are described in several papers listed in the bibliography. To give a few examples, special rubber has been developed for belt conveyors to prevent them from cracking in the cold climate when coated with bitumen. Newly developed corrugated rubber covered idlers have proved to be self cleaning and have eliminated the problem of oil sand build up on steel shell idlers. Micro processor based measurement and display systems for bucketwheels and draglines have been introduced providing machine operators a continuous feedback on machine health and performance, figure 7.

Figure 7 Micro-processor based equipment performance monitoring system on a dragline.

Modifications to mobile equipment necessitated by the harsh climate, abrasive nature of the oil sands and high haul road rolling resistances have resulted in greater equipment availabilities and higher productivity. Re-design, changes to the fabrication procedures and use of different grade steels have resulted in a prolonged life for the cutting elements of mining equipment including those used on bucketwheels and draglines. To improve trafficability wider pads were provided for track mounted machines. In addition, to improving haul road design and maintenance, rubber tyred machinery has been equipped with wider radial tires.

The 154 tonne trucks have been modified to adapt the electric drives to oil sands operation so that they switch from parallel to series when hauling with 20% and over rolling resistance. A recent addition to mining schemes has been a feeder breaker, figure 8. These machines are currently employed in an auxiliary production system to supplement oil sand feed to the extraction plant. They are also used to process grizzly reject material containing siltstones and frozen oil sand lumps. Greater use of this type of equipment and high capacity mobile crushers is visualized.

Extensive laboratory and field studies have been carried out with a view to developing specifications for designs, construction and maintenance of stable haulroads, waste dumps, tailings dams, in pit dykes and pit walls. Continuous monitoring for the stability of all geostructures is carried out at both oil sand mines. In some cases, unique instrumentation

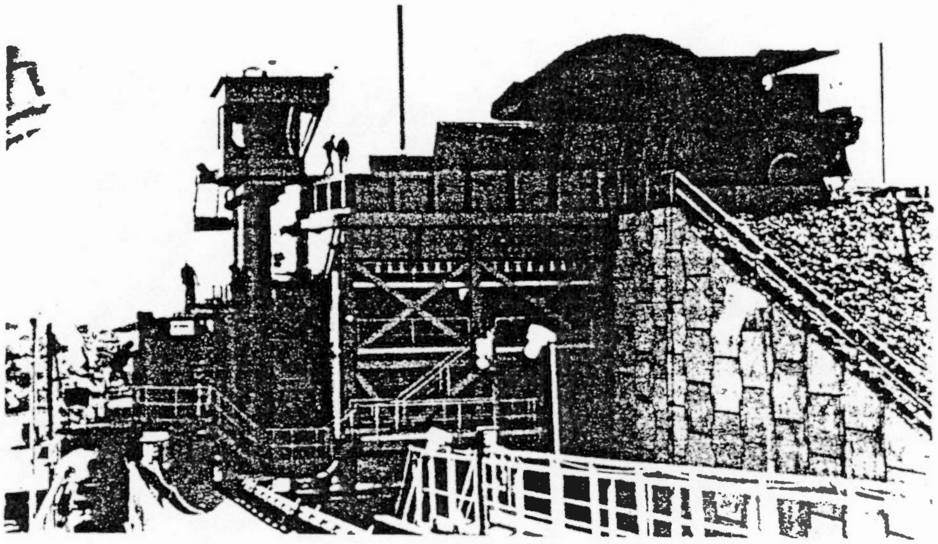

Figure 8 Trucks discharging into the hopper of a feeder-breaker at Syncrude mine.

and procedures have been developed for monitoring the integrity of the bench face. As an example, serious highwall instability at Syncrude mine could result in a catastrophy if a dragline were to fall over due to bench crest failure. In order to ensure safe and efficient dragline operation, Syncrude have established rigorous procedures to identify and monitor potential highwall instability problems and institute remedial stabilization where necessary.

7 CONCLUDING REMARKS

In surface mining, a very large part of capital and operating costs is consumed in the material handling phase of the operation. Oil sands mining is no exception. Efforts are being made in the pit, in the mine design and planning phase to develop alternatives to improve cash flow, by developing programmes to further improve the life, reliability and flexibility of existing equipment and systems to improve their performance. New technology which will reduce material handling costs is also being investigated e.g., high angle conveyors, computerized truck dispatching, hydraulic transportation, dredging, application of stackers and surface miners for selective mining, figure 9. Micro processor based real time data collection and analytical systems are being installed on individual pieces of equipment which can transmit information to a central control station. Application of computers to enable remote control and automate some parts of material handling flowsheet are under examination.

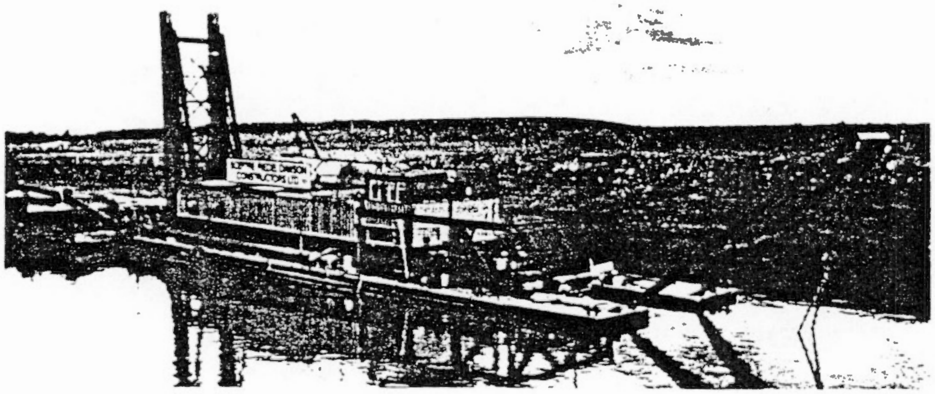

Figure 9 Hydraulic Dredging test of overburden at Syncrude mine.

Canadian oil sands mining has made phenomenal progress during the past decade and has established itself as a technical leader for high volume mining and materials handling of a difficult material in a hostile climate. This has been made possible in a greater part by the application of continuous mining equipment. In spite of this level of achievement, work continues towards further improving the existing technology. Considerable attention is being paid to developing and adapting ;newer excavation and transportation technology some components of which have been mentioned in this paper.

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