Continuous Mining of Trona Ore

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ABSTRACT

The mining of trona ore with a milling drum type continuous miner was first accomplished with a Jeffrey 120H HELIMINER at Texas Gulf Sulphur Company, Green River, Wyoming in 1971. The HELIMINER was a continuous miner developed for underground coal mining that was modified for application in mining trona ore. The HELIMINER had the power, weight and machine balance necessary to cut trona with a fixed drum milling cutter head.

The factors that were considered in designing a machine to cut trona ore involved the physical characteristics of the ore, the machine design parameters and the design of the cutting elements. The physical characteristics of the material with respect to its compressive strength, crystalline structure and overburden pressure determine the amount of energy needed to cut it from the ore seam. The mining machine then must be designed to be able to supply the energy and forge in the right relationship to the cutting elements to efficiently cut the ore. The efficiency of cutting trona ore is also related to the cutting element design, type of cutting bit and cutting bit tip geometry. The design of the cutting drum required testing several types of bits and bit tip configurations to find the combination that gave the best productivity for the lowest cost per ton. The machine must not only be able to mine the trona ore, but it must mine it more economically than other methods. The HELIMINER with the fixed milling cutter drum is performing satisfactorily on a productivity and cost per ton basis, which is in the final analysis the criteria upon which the success of a mining machine must be judged.

INTRODUCTION

The application of Continuous Miners using the milling-type cutting principle in mining trona ore had been tried several times in the past 15 years with little or no success, so that in 1969, the boring machine was the only continuous miner being used in the trona mines. The milling-type continuous miners available before 1969 were the oscillating head type that apparently did not have the weight or horsepower needed to successfully apply that cutting principle to the mining of trona. This paper will treat the subject of the continuous mining of Trona ore mainly from the engineering and machine design aspects rather than discussing mining plan development and geological details of the ore deposit.

The Texas Gulf Sulphur Company had a new mine-development project underway in 1969 to explore the economic feasibility of opening a new trona operation near Green River, Wyoming. The Green River area has one of the few known deposits of trona ore in the world and there are three producing mines located there. The Texas Gulf Sulphur Company was interested in exploring the application of a different type of mining machine in their new mine rather than use the under cutter and loading machines or the boring type continuous miner that was then being used. They approached Jeffrey Mining Machinery Co. (Jeffrey) to discuss a cooperative development project to try the new Jeffrey 120H HELIMINER in mining their trona seam. The tender roof conditions and the overlying oil shale made undercutting and blasting unattractive so they thought that using a continuous miner was a better approach. The drum-type continuous miner has several advantages over the boring type machine in that it is more compact and maneuverable. It has higher tramming speeds, an operator's station within the confines of the machine frame, and the flexibility for positioning the cutting drum to mine seams over a considerable height range. Jeffrey had developed a cutting drum for the HELIMINER that would cut an arched contour in the roof line similar to a boring-machine contour for application in mining coal. Texas Gulf Engineers felt if they could get a drum type continuous miner to cut an arched top it would make the machine more attractive for their mining application and roof control problem.

DESCRIPTION OF HELIMINER

The Jeffrey model 120H HELIMINER used in mining trona is a drum-type continuous coal mining machine that has been modified for application in mining trona. The 120H is a 46 inch high machine with 9" ground clearance, 32'–9" long and a 10 foot reach. The cutting head is fixed 10'–10" width with carbide tipped point attack bits on 1" or 1–1/4" spacing laced in a two flight helical pattern 180° apart. The cutting drum has a diameter of 34-3/4 inches across the bit tips and rotates at 81 RPM giving a bit tip speed of 765 FPM. The material is cut from the face in a repeated cyclic manner. The cycle is started with the cutting drum positioned at the roof line and then the machine is trammed forward forcing the cutting bits into the face a distance of 28 to 30 inches. The cutting drum is then brought down to the floor line under force of hydraulic cylinders. Next the machine is reverse trammed 6 to 8 inches to remove a circular arc of material caused by the circular cutting drum in the bottom. The last step in the cycle returns the cutting drum to the roof line ready to repeat the process. The four steps in the cycle are designated the *sump, shear-down, cut-out* and *reposition* and are typical of the drum-type continuous miner.

The 120H HELIMINER is a roller-mounted crawler-driven machine with four basic structural components consisting of a main frame, gathering-head frame, intermediate and discharge conveyor, and cutter-head frame. These components are weldments fabricated from low alloy steel plate and serve as mounting bases for the mechanical, hydraulic and electrical components of the machine. The 120H HELIMINER is an electromechanical machine that utilizes a two electric motor design. This means that two 300 HP electric motors driving mechanical gear cases through hydraulically actuated disc clutches supply the power for all the operating functions. The power is transmitted through mechanical drives from both ends of the electric motors for the basic machine functions of driving the cutting head, the material gathering and loading system, the tramming system and the hydraulic system.

The hydraulic system is a low pressure system with operating pressures under 1500 PSI and 125 gallon capacity. It supplies hydraulic oil to the wet-disc clutches that control the power output from the mechanical drives for the 3 main machine operating functions of cutting the material, gathering and loading the cut material and tramming the machine. The control and positioning of the components that perform the operating functions are performed with hydraulic cylinders by actuation of hydraulic control valves in the operator's station. The hydraulic oil and pressure is supplied by three gear type pumps whose outputs are associated with operating the disc clutches, the hydraulic cylinders and the auxiliary hydraulic systems. The low operating pressures and use of gear type pumps make the hydraulic system compatible for using fire resistant hydraulic fluid in the 120H HELIMINER.

The cutting drum is driven from the front end of both electrical motors through identical disc clutches and gear trains. The solid drum-type cutting head with the bits arranged in a helical pattern around the periphery of the drum is the innovative step in the design of continuous mining machines that was developed first by Jeffrey and resulted in the creation of the 120H HELIMINER. The fixed-drum helical cutting principle is one of the factors in successful application of the HELIMINER for use in mining other non-coal materials like trona and iron ore. By driving the cutting drum with both electric motors, it is possible to supply the 400 to 600 horsepower required to mine trona productively with the HELIMINER. Design of the cutting drum will be discussed in more detail later on in the paper. The cutting-drum drive-gear case is mounted on the front of a frame structure which pivots on main supports attached to the machine main frame and it is positioned for the cutting operation by two hydraulic cylinders. The gathering and loading of the cut material is done with an arm-type head which moves the material onto a single strand, (T)-flight swivel-roller chain for discharge into a haulage unit. The arms and chain are driven through two disc-clutch actuated gear-drive trains from each electric motor. The conveyor chain is footshaft driven at 415 FPM and 30 inches wide which gives a maximum loading rate of about 21 tons per minute. The gathering-head frame and conveyor discharge are located and pivot about the same support members on the machine main frame as the cutting drum. The gathering head and discharge conveyor are positioned vertically with hydraulic cylinders. The discharge conveyor can also be positioned horizontally 45° in either direction from the machine center line to align it with the haulage unit when turning corners.

The 120H HELIMINER has two mechanical tramming-speed ranges and a variable hydraulic sump-tramming system. The power for the high speed mechanical tram comes from the rear output-shaft on the R. H. electric motor through the highspeed disc clutch to the R. H. and L. H. tram-gear train to drive the crawler chains at 120 FPM. The power for the intermediate tram speed comes from the rear output-shaft of the L.H. electric motor through the intermediate speed disc clutch to the L.H. and R.H. tram gear train to drive the crawler chains at 63 FPM. The sump-tram power comes from a piston-type hydraulic motor with the oil supply volume variably controlled to give from 7 to 14 FPM speed. The hydraulic motor drives through the L.H. disc-tram clutch through the L.H. and R.H. tram gear train to drive the crawler chains. The hydraulic sump tram power is used for moving the machine into the face during the mining cycle and the higher speed mechanical tram speeds are used when moving the machine from place to place or cleaning up cut material from the bottom.

The electrical system on the HELIMINER is simple for a continuous miner because of the two electric motor designs. The system has the ability to handle alternating current (AC) voltages in the standard NEMA designations from 460 to 4160. The machines built for mining trona have been either 995 or 4160 Volt AC. The HELIMINERs for use in trona were the first 4160 Volt drum-type machines, the others being boring-type machines. The main components of the electrical system are the main circuit breaker, size 5 vacuum-type contactors, a constant voltage transformer for the control circuit and the two motors. The motors are water cooled and rated at 300 horsepower at 1175 RPM continuous duty. But they are capable of producing in excess of 500 horsepower each before rotor stall. The electrical system is normally de-energized by throwing the main circuit breaker at the operator's station but in the event of an emergency, it can be de-energized by throwing the control circuit breaker on the L.H. side of the machine.

DISCUSSION OF CUTTING THEORY

It is important to explore some of the factors that determine how well a continuous miner will cut a particular material. There are three areas that must be considered in designing and developing a continuous miner. The first are those factors related to the mining machine design parameters:

1. The length, width and height dimensions that determine the geometric relationships between the major machine components.
2. The weight of the machine which along with the geometry of the major machine components determine the location of the center of gravity of the machine and thus its balance or inherent stability.
3. The amount of horsepower or torque being supplied to the cutting drum.
4. The amount of force the machine can apply to the cutting drum.
5. The cutting principle utilized, fixed drum cutter.

Next are the factors related to the design of the cutting elements:

1. Style of the cutting tool.
2. The geometry between the cutting tool and surface of the material being cut.
3. The material the cutting tool is manufactured from.
4. The speed the cutting tool attacks the material being cut.
5. The horizontal spacing of the cutting tools on the drum.
6. The radial or angular spacing of the cutting tools on the drum.
7. The wear characteristics of the cutting tools.

The third is the characteristics of the material:

1. Type of crystal structure.
2. The hardness of the material.
3. The material abrasiveness.
4. Is the material in the seam homogeneous.
5. The compressive strength of the material.
6. Pressure on seam from over burden or cover.

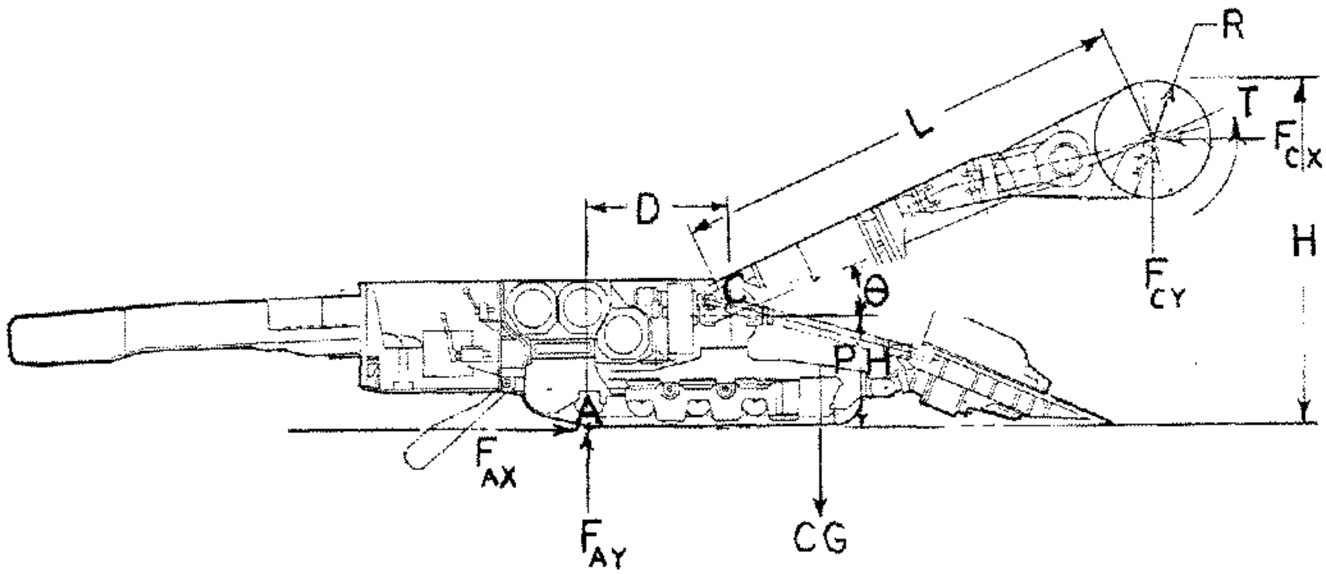
There are other factors besides those listed in the three areas that are factors that must be considered but those listed are the most important ones. The HELIMINER has the right combination of weight, horsepower and the fixed-drum milling-type cutting principle to give the cutting drum the stability, torque, and penetration force needed to mine trona ore.

The machine design parameters shown in Table I determine the stability of the miner during the cutting cycle. The weight of the machine and the location of the center of gravity in relationship to the main pivot of the cutting drum permit the HELIMINER to develop a sump-cutting force of 29,000# and a down cut force of 45,000# to the bits for penetration. These cutting forces are counteracted by the reaction forces at the back of the crawler or stabilizer jack so that the cutter drum has a stable platform from which to work. If the down-cutting force is too small in respect to the torque force being applied to the bits, then the machine will climb the face instead of penetrating the material.

The correct machine parameters must be combined with good cutting-drum design for the characteristics of the material being mined. The cutting bits must have the right tip material, tip-cutting surface geometry, penetration rate and peripheral speed or machine vibration, short bit life and low productivity result. The physical characteristics of the material are important factors in the design of the cutting drum. The type of cutting bits used and the spacing of the bits on the drum are a concern with the hardness of the material, its structure and strength. The abrasive characteristics of the material being cut will affect the type of material used in the cutting bit and its rate of wear which is an important economic cost factor in mining.

DISCUSSION OF THE DESIGN OF THE HELIMINER CUTTING DRUM

The cutting of trona with a fixed-drum milling-type continuous miner is a lot like the action of a machine tool



MINER STABILITY VARIABLES

D = Distance in inches from main pivot to point A.	PH = Height main pivot point above groundline.
L = Length of moment arm of cutting drum.	CG = Location of center of gravity of machine.
R = Cutting bit radius in inches.	F_{AY} = Force in Y direction at point A.
T = Cutting bit torque in lbs.	F_{AX} = Force in X direction at point A.
H = Ore seam height inches.	F_{CX} = Cutting force in X direction.
θ = Angle cutting drum moment arm rotates thru.	F_{CY} = Cutting force in Y direction.

TABLE I.

such as a milling machine cutting steel. The cutting tool geometry, speed and feed rate has to match the steel being machined if the optimum of performance of metal removal, finish and tool life is desired. The main considerations in evaluating whether a machine application will be successful once it is determined it will cut the material is whether it does the job in an economical manner. The two economic considerations are machine repair costs and cutting tool costs. The design of the cutting drum is an important factor in keeping both of these at a minimum level. The main parameters in the design of cutting drums were listed earlier but they need to be discussed as they apply to cutting trona ore.

Trona ore is a hard, tough material when compared to coal. One can see by looking at Table II where trona fits into the list of material that can be mined successfully with the HELIMINER. Most of them are being mined today and all will be mined in the future. When adaptation of a HELIMINER to cut trona was begun, there was very little experience available in cutting material other than coal, and Jeffrey engineers had to educate themselves

COMPARISON OF COMPRESSIVE
STRENGTH OF MATERIALS

ROCK TYPE COAL	COMPRESSIVE STRENGTH LBS/IN^2	COMPRESSIVE STRENGTH KG/CM^2
Pittsburgh No. 6	2500-3500	175-246
Gypsum	4700	330
French Siliceous Iron Ore	5000	351
Michigan Iron Ore	6000-8000	422-562
Mine "A" Trona Ore	8000	562
Mine "B" Trona Ore	9500	668
Kepler Mine Sand Rock	8500-13000	597-914

TABLE II.

about cutting trona. Although Jeffrey had made cutting machines for potash and salt, a continuous miner is quite different from a cutting machine. The trona ore seam that was being attempted was homogeneous, with a very compact crystalline grain structure so that the material does not fracture or break into large pieces. Jeffrey engineers visited the mine site to inspect the trona seam and discuss the approaches to cutting the material with experienced mining engineers and cutting-bit application engineers. The bit-application engineers and the mining company built a small test cutting drum that could be adapted to a cutting machine to run cutting tests to determine cutting-bit spacing and style for the initial design. It was determined a 5/8 X 1 1/4 rectangular cutting bit with a "Cabin Tip" on 1" spacing would be used for the initial design. The cutting drum would cut 15'–6" wide and have a tip-to-tip diameter of 36–3/4".

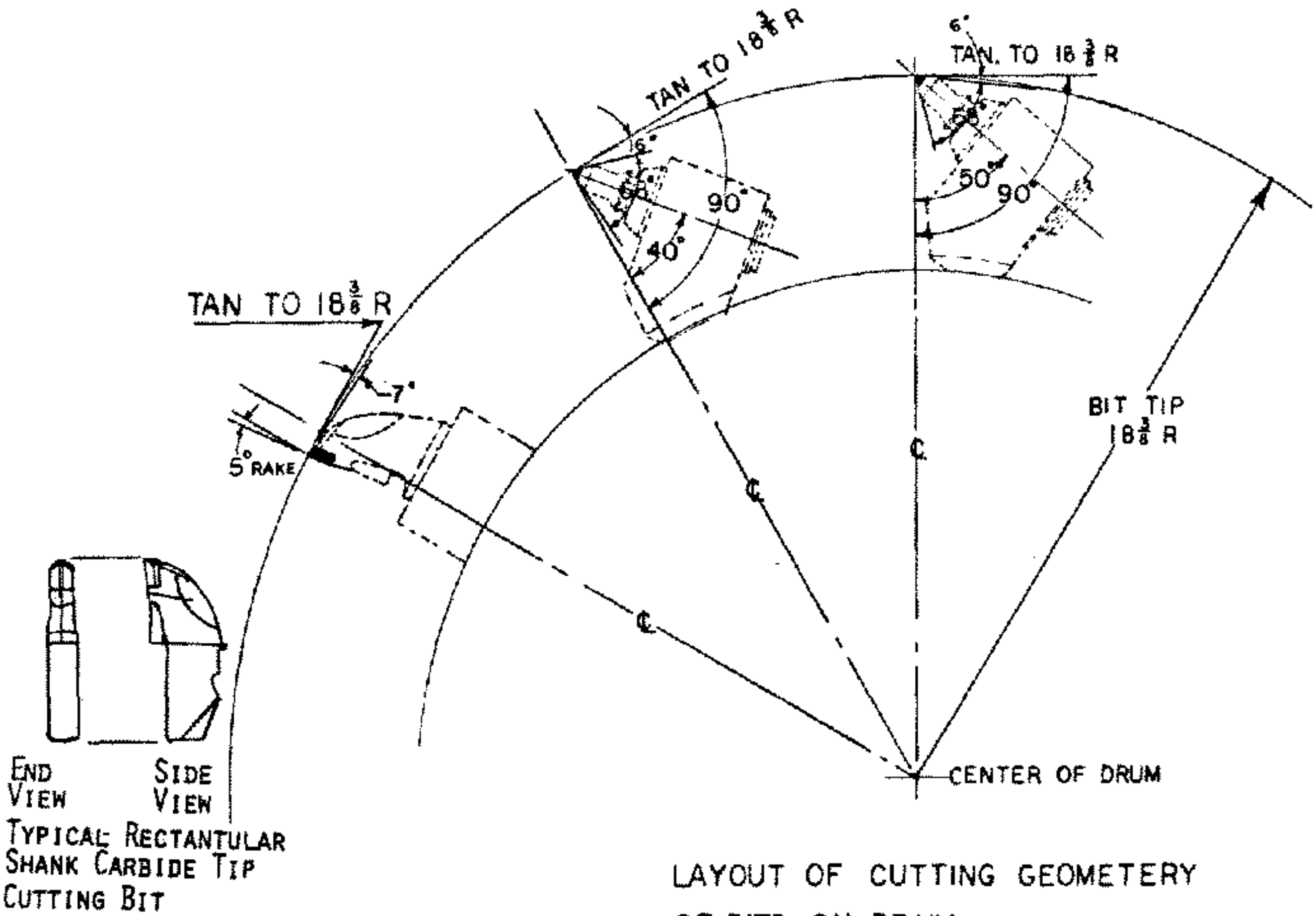
The important element in the design of a cutting drum is to have the correct balance between bit spacing, radial location and the cutting pressure per bit so good penetration, smooth vibration-free cutting and minimum bit tip breakage result. Lack of penetration can be caused by not cutting away all the material so that coring occurs and power is consumed due to rubbing the cutting tools and mounting blocks against the face. The bit-tip geometry is also a factor in low penetration. The coring of material is one of the big problems that occurs when trying to mine trona ore with a continuous miner because it is hard and tough and doesn't fracture away from the face. Another problem is cutting-bit tip breakage caused by overloading the cutting bit owing to high cutting forces caused by vibration, insufficient number of bits or incorrect bit-tip geometry. One of the former reasons for not using continuous miners to cut trona has been the high cost of cutting bits due to breakage. The design of the helical fixed-cutting drum on the HELIMINER is such that the bits are located radially around the drum in a helical spiral to provide balanced loading and smooth progression into the material which in turn controls vibration and equalizes bit-tip loading. It was felt that this design for the cutting drum would achieve the desired results in mining trona economically with the HELIMINER.

DISCUSSION OF THE DESIGN CHANGES IN THE HELIMINER IN ADAPTING IT DURING FIELD TESTING TO SUCCESSFULLY MINE TRONA

The main differences in machine specifications between a coal machine and a trona machine are the cutting drum and electrical components. The first trona HELIMINER was the first 1,000 Volt machine and the 2nd trona HELIMINER was the first 4,160 Volt machine. This meant that Jeffrey electrical engineers and designers had to make the electric motor design for 1,000 Volts and develop the electrical control components to go with them. The 1,000 and 4,160 Volt electrical systems have been very successful and are responsible for increasing the usable horsepower of the two electric motors from the nominal 300 HP to 350 to 400 HP range each. Most of the field design developments were involved with cutting drum and cutting bits. The initial cutting-drum and cutting-bit design did not give the desired penetration or life for economical machine operation. Table III shows three different design changes in the cutting drum and bits. The tip wear, breakage and penetration rate on the HELIMINER were not economical. The carbide-tipped cutting bits of the rectangular cabin type must wear at a rate that permits three or more resharpenings if they are to be used economically. The penetration rate would drop off rather fast after starting with a sharp bit and would degrade even faster after the first resharpening and tip breakage was excessive. It was decided to try a rectangle bit of modified tip geometry to improve the machine and cost performance. These were evaluated by testing and time studies and found to be unsatisfactory.

The decision was made to design a new cutting drum using small point-attack or plumb-bob type bits with sleeved bit holders. The carbide-tipped point-attack bit is the only type used on fixed drum miners in coal but they were not being used on boring machines in trona. The same bit spacing and helical pattern were retained on the new cutting drum because these parameters appeared satisfactory. The bit-tip geometry for the first trial head as shown on Chart III has a 50° attack angle which is the standard for coal. The penetration rate and bit-tip breakage were good in the initial test run but as the carbide tip wore, it became flat and the machine stopped penetrating. The situation was analyzed and it was decided that if a sharp point could be maintained on the carbide-bit tip, penetration would not decrease. The way to keep the bit tip sharp would be to let it wear to a sharper point by changing the bit attack angle to 40° as shown in Chart III. The cutting drum was modified to accomplish this objective and tests verified the desired results were accomplished. Additional testing on the cutting drum were conducted to try to optimize penetration and bit wear by varying the rotational speed of the drum from 81 to 60 RPM and 81 to 99 RPM. The penetration rate decreased at the 60 RPM and bit wear increased at 99 RPM so it was decided the 81 RPM was the best speed for the cutting drum.

Several other changes were made in the machine, as the trial progressed, to correct problems that developed with increased machine usage. The input-bevel gears in the cutting-drum drive-gear case broke owing to excessive tooth wear caused by the 50% higher horsepower used in cutting trona compared to coal. The problem was cor-



LAYOUT OF CUTTING GEOMETERY
OF BITS ON DRUM

TABLE III.

rected by making the pinion out of stronger material. Trona ore is heavier than coal so that the gathering and loading chain-drive clutch was being overloaded when one drive was used. Consequently, a second drive was added to the L.H. side to double the torque available for driving these components. There were other minor changes to improve the machine but they are not of significant importance to discuss them in this presentation.

PRODUCTIVITY OF THE 120H HELIMINER IN MINING TRONA ORE

The productivity of a mining machine can be expressed several ways, depending upon what performance parameters are emphasized. In Chart IV the performance data shown for the HELIMINER is based on measured valves from tests and time studies except for two of the horsepower figures for trona and iron ore which were based on the auger-clutch, operating hydraulic pressure. The valves for two major coal seams are shown to help form a basis of comparison and to indicate how much more difficult it is to mine trona. The competitive climate in the trona industry is such that the production data shown for the two seams are relative values and not necessarily the actual production rates that would be true today.

COMPARISON OF HELIMINER PERFORMANCE DATA

COAL SEAM	SEAM HEIGHT INCHES	AUGER DRUM WIDTH FT. AND INS.	AVERAGE HORSE POWER	SUMP RATE IN./MIN.	PRODUCTION RATE TONS/MIN.
ILLINOIS No. 5	80	15-6	465	70	9.4
PITTSBURGH No. 6	83	13-0	444	90	8.6
FRENCH IRON ORE	132	10-10	480	20	4.0
TRONA ORE SEAM "A"	102	15-6	600	30	4.3
TRONA ORE SEAM "B"	102	15-6	640	35	4.2

TABLE IV.

The data was obtained from studies made during the test and development stage of the application of the HELIMINER and many improvements have been made in the production situation. The production rate shown was determined by measuring the amount of material discharged into the haulage vehicle divided by the machine-operating time for several shifts of mining. Another productivity indicator used is the mining rate of the machine. This is a better indicator of the production capability of the miner but is not the criteria on which costs and economic decisions are based. The production rate as expressed in terms of output and material reflects the efficiency of the complete mining system. The room and pillar system of mining was being used with shuttle car haulage and the miner would run only about 25% of the available time. Average mining rates of 8 to 9 tons per minute were measured on the HELIMINER in both applications which compares to the 12 to 16 tons per minute in coal. The trona ore in mine "B" has a coarse-grained structure and well defined planes on which it fractures. This has permitted the use of 1–1/4 inch bit spacing on the cutting drum which should result in improving the mining rate and machine productivity.

The best indicator to Jeffrey as a manufacturer of mining machines that the HELIMINER has been successful in mining trona is that our customers are buying machines. Jeffrey has HELIMINERs working in two of the three producing mines with additional machines on order. Jeffrey has also been successful in establishing the HELIMINER as a successful machine in the iron ore and potash mines in Europe with orders for delivery for several 120HR models this year. In closing it appears that the drum-type continuous miner is a success in mining trona ore.