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Output and Availability Factors of Bucket Wheel Excavators under Actual Mining Conditions

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Summary

The author defines the term "theoretical output" [bm³/h] as basic value for the assessment of the short and long time effective output [bm³/h] of bucket wheel excavators.

Approximately 40 bucket wheel excavators operating in overburden on four continents, are analyzed on the basis of outputs actually obtained in performance tests and long term operation.

Efficiency and availability are determined for all these machines.

Finally, a comparison is made with so-called "mobile equipment" i.e., shovels and draglines.

1. Introduction

Such terms as "theoretical output", "effective output", "daily output" and "average output" are generally quoted without appropriate and realistic consideration of the particular mining conditions and the time factor. The output for the equipment is often estimated too optimistically. This applies especially to new equipment.

Information published on the subject matter is often vague and inaccurate.

Theoretical output calculations for bucket wheel excavators (BWEs), based on well established formulae, are of course necessary and are of value in determining the average output of the equipment. Such calculations have, however, no resemblance to actual "real life" operating factors.

In the following an analysis of the output, operating factors and availability of 40 bucket wheel excavators is presented without priority to size and location of the machines.

All of the BWEs were taken into service between 1960 and 1980 and are still operating. They are excavating unconsolidated and cemented soils.

The machines work in four different continents and their output reflects:

- type of material excavated
- mine management
- climatic conditions and other environmental forces
- various material handling systems.

2. Theoretical Output

The starting point for the determination of the output of a BWE is the "theoretical output", where:

a)
$$Q_{th} = I_N \times s \times 60$$

Q_{th} = theoretical output in loose m³/hour
s = bucket discharges per minute
I_N = nominal bucket capacity in m³
I_N = usually given as the volume of the bucket plus 50 % of the volume of the ringspace, the space forming part of the bucket but being located within the wheel body. The ringspace has usually a volume of 50 % of the actual bucket.

Therefore, I_N is usually given as:
Bucket volume $1.0 + 0.5 \times 0.5 = 1.25$ of the actual bucket volume. For all excavators considered here, this interpretation of "I_N" is used.

The term "bucket volume" is sometimes considered without the volume of the cutting edge or cutting lip, but often manufacturers include this volume in "I_N". In some instances, where cutting teeth are used, even the volume delineated by the teeth is included in the bucket volume. Due to the question of bucket volume definition a better determination of Q_{th} would be:

b)
$$Q_{th} = H \times V_s \times t_m \times f \times 60$$

where:

H = height of slice in metres
V_s = slewing velocity in the deepest cut at a slew angle φ = 0 measured in metre per minute
t_m = maximum depth of cut taken by the bucket in metres
f = swell factor.

The product of $V_s \times t$ stays constant as long as the depth of cut 't', which decreases with increasing slew angle φ, can be compensated for by increased slew speed 'V_s' (Fig. 1).

Experience has shown that V_{max}, the maximum slew speed, should not exceed 30 m/min for kinetic reasons — forces encountered at slew reversal and impact forces when hitting obstacles.

The function $\frac{1}{\cos\varphi}$ drops drastically between $\varphi = 60°$ and $\varphi = 90°$. It is not economical to increase the slew speed to compensate for an angle greater than 60°.

c) Determination of the theoretical output of a BWE, using the installed conveyor capacity, or the diameter of the bucket wheel, is inaccurate.
(± 30 % variation).

Lumpsize, stickiness of the material and free-cutting conditions of the wheel are only three of many reasons rendering such formulae useless.

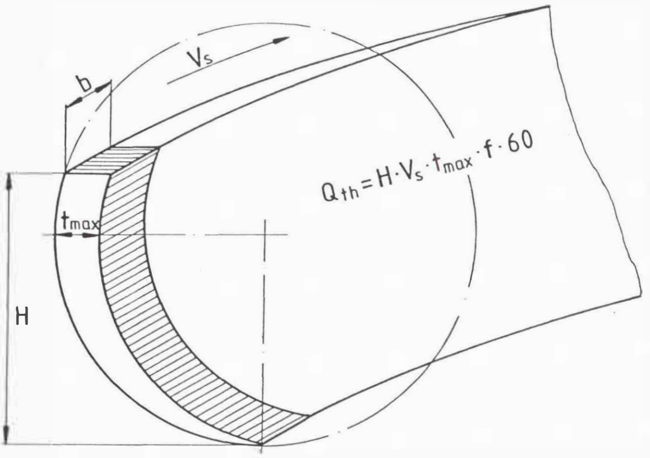


Fig. 1

d) To have a basis for comparison of the output of the excavators, the following approach is taken:

Since all mine planning is done in bank m³, the Q_{th} defined in 1a) and 1b) as loose m³ must be changed by the swell factor 'f' to bank m³ (bm³). This factor varies between 1.2 in loose sands to 1.7 in cemented materials.

$$Q_{th}\,[\text{bm}^3/\text{h}] = \frac{Q_{th}\,[\text{loose m}^3/\text{h}]}{f}$$

This definition will be compared to the effective output Q_{ff} expressed in bank m³.

e) The output efficiency factor is therefore derived as

$$\eta\, L_{eff} = \frac{Q_{eff}\,[\text{bm}^3/\text{h}]}{Q_{th}\,[\text{bm}^3/\text{h}]}$$

This factor varies with the timespan of the observation period. Depending on the time period, the factor may or may not account for the following:

η Soil — Influence of the soil to be excavated (hardness, lumpsize, cementation, consolidation, stickiness).

η Mining — Deviation from the optimum operating conditions, such as height of mining face, width of block excavated, trimming of the mine floor.

η Maint. — Type of maintenance, such as availability of parts and labour, maintenance of sharp teeth and cutting edges etc.

η Oper. — Operator efficiency: Ability of the operator to run at maximum capacity and optimum cut configuration.

η_{T_t} — Time losses due to raising and lowering of the boom, slew reversal and travelling time of the excavator.

η_R — Restriction caused by the transportation system behind the BWE, such as capacity limitation of the conveyor system, stacker or storage bin, or extraction plant.

The efficiency factor of a BWE mining system can be expressed as:

$$\eta\, L_{eff.} = \eta\,\text{soil} \times \eta\,\text{mining} \times \eta\,\text{maint.} \times \eta\,\text{oper.} \times \eta_{T_t} \times \eta_R$$

assuming that the time factor is considered in the foregoing factors.

η_{T_t} alone can be approximated mathematically. The time losses are dependent on the block dimensions to be excavated, such as height, width, number of terraces, slope angles of the highwall and the excavation face as well as the dimensions and capabilities of the excavator — such as boom length, wheel diameter, bucket size, slew speed, hoist speed, travel speed. η_{T_t} is calculated as follows:

$$\eta_{T_t} = \frac{t_b}{t_b + t_o}$$

where

t_b = actual excavating time
t_o = lost time due to hoisting and travelling, as well as slew reversal.

3. Test Output and Test Output Efficiency Factor

To demonstrate the capability of a BWE or a whole mining system, it has become customary to conduct a performance test. The mining company and the manufacturer enter into a contract. The performance test becomes an important part of the commercial undertaking. If the test output is achieved, the manufacturer will not have to pay penalties for non-performance or even take back the equipment if a certain minimum output is not achieved. Performance tests were conducted for periods ranging between eight and 1,000 hours.

In addition to the actual test operating time, certain allowances must be made for maintenance and service of the machine. The test is therefore usually conducted over a predetermined calendar period. A reduction of time is granted for delays caused by the mining company. The delays caused by the mining company seem to increase disproportionally with increasing test period times.

The value of a test over a long test period becomes therefore questionable. Tests are costly for the mining company and the manufacturer and require a good deal of management, planning and personnel.

Test periods normally ranging between eight and 150 hours, and in rare instances up to 500 hours, appear appropriate and indicate to the expert the capability of the BWE.

The test efficiency factor — η_L test — of an excavator depends on the length of the test period, the cutting resistance of the soil and the block dimensions excavated.

Table 1: Performance test results

Continent	Type SchRs	Material	Eff. Test Time [h]	Average Output in bank m³/h Q_{eff}	Test Output Efficiency Factor η_L Test	Theoretical Machine Factor η_{T_t}
Europe	$\frac{4000}{20}$ x 50	overburden > 50 % clay $f = 1.5$	144.5	3,395	0.70	0.97
	$\frac{4500}{12-14}$ x 41	sandy overburden $f = 1.3$	95	5,227	0.77	0.88
	$\frac{700}{9.4}$ x 29	overburden with clay content $f = 1.4$	179	1,500	0.83	0.92
	$\frac{1900}{5}$ x 30	overburden $f = 1.3$	60.5	3,318	0.86	0.87
	$\frac{270}{7}$ x 13	overburden $f = 1.3$	5.25	526	0.92	0.90
	$\frac{250}{7}$ x 13	overburden with clay content $f = 1.4$	48	475	0.88	0.85
	$\frac{1500}{6}$ x 31	overburden with high clay content $f = 1.55$	430	2,725	0.77	0.88
	$\frac{900}{6}$ x 25	sandy overburden $f = 1.3$	88	2,358	0.75	0.85
America	$\frac{1000}{1.5}$ x 26	tar sand $f = 1.39$	122	2,730	0.68	0.80
	$\frac{2450}{1.5}$ x 18	overburden $f = 1.39$	133	4,050	0.72	0.67
Africa	$\frac{560}{1}$ x 12.5	sand $f = 1.25$	410	1,770	0.70	0.67
	$\frac{350}{5}$ x 12.8	overburden $f = 1.3$	195	893	0.92	0.79
	$\frac{350}{5}$ x 12.8	overburden $f = 1.3$	164.5	920	0.95	0.79
	$\frac{150}{0.5}$ x 10.5	phosphate with calcium layers $f = 1.4$	69	358	0.85	0.86
	$\frac{2300}{1.5}$ x 12.5	overburden with high clay content $f = 1.5$	83	3,471	0.61	0.66
Asia	$\frac{2000}{1}$ x 12	sand $f = 1.3$	280	4,887	0.72	0.57
	$\frac{250}{1}$ x 12.5	weathered granite and clay $f = 1.55$	15	594	0.72	0.75
	$\frac{630}{1.2}$ x 15	weathered granite and clay $f = 1.5-1.7$	9	1,051	0.58	0.72
	$\frac{1500}{2}$ x 26	pre-blasted sand stone $f = 1.45$	8	3,550	0.76	0.81
	$\frac{1500}{2}$ x 26	pre-blasted sand stone $f = 1.45$	1000	2,515	0.53	0.81

3.1 Short Performance Tests

Short performance tests of between five and 70 hours resulted in an average η_L test of 0.79 for 9 study cases, that is 79% of the theoretical output expressed in bank m³ were achieved.

Only one BWE deviates to η_L test = 0.58 over a 15-hour test period. The cutting force required for the test material consisting of clay and weathered granite was 110 N/cm².

The test outputs indicate that the installed bucket wheel power, as calculated on the basis of lab test results, is sufficient for the actual field conditions.

The reasons for a high test efficiency factor can be recognized as:

- Low wear and few plug-ups for the digging head and the conveyors.
- High concentration and efficiency of the operator and the maintenance personnel.
- Constant supervision and positive influence by the manufacturer's representative.
- Few interruptions due to delays caused by the mining company.
- Availability of auxiliary equipment for mine floor clean-up etc.
- With BWEs having short booms, the hoisting, travelling and slewing required to start a new terrace, are quite often done simultaneously while productivity is maintained. This technique leads in cases to the elimination of the factor η_{T_t}.
- In one case, the nominal bucket capacity is exceeded by a factor of 1.3 over short periods of time.
- Continental influences are negligible (rain, temperature, management).
- Influence of downstream delays is minimal (conveyor system — full bin etc.).

3.2 Long Performance Tests

Long performance tests over periods of 70 to 1,000 hours result in an average output efficiency factor of η_L test = 0.71 for 15 machines surveyed.

The lowest value is η_L test = 0.53 for three machines in Asia, tested over a 1,000 hour-period.

The highest value is η_L test = 0.95.

For the long test periods the influence of weather factors and operational restraints result in a reduction of the efficiency factor η_L test compared to the short test periods. Significant is that in both cases the long-term efficiency factors for the normal mining operation sinks below the test period factor.

Interesting is that for nine out of 24 test results the factor η_L test is approximately equal or higher than the theoretical factor η_{T_t} which reflects only the operating losses due to hoisting and walking etc.

Only ten excavators show an influence of η_{T_t} on the effective total efficiency factor η_L. These machines have bucket wheel booms in the range of 30 to 62 m and cannot be operated in an unorthodox way.

4. Long-term Output Efficiency Factor η_L for Mining Operations

After the performance test, the BWE operates under normal mining conditions.

It is unavoidable that unfavourable influences encountered during the performance test only in a limited way, or not at all, start to have a greater influence.

- A greater variety of soil types may have to be excavated.
- Selective mining may be required.
- Rocks must be removed by special excavating techniques.
- Auxiliary equipment is not used for pit floor clean-up and is left to the BWE.
- The block height changes to unfavourable conditions.
- Worn-out bucket teeth are not changed when required.
- The excavator is not operated at full motor load.
- Operation continues under unfavourable conditions. (Frost, rain etc.).
- The operator does not work in a concentrated way but operates routinely and in a more relaxed fashion.
- Under-dimensioned mine conveyor systems lead the operator to operate at lower rates to avoid conveyor trip-outs.

It appear that after a period of one to three years the yearly output stabilizes, if mining conditions do not change substantially. Q_{eff} in bank m³/hour stays reasonably constant.

While a mine with experienced personnel may reach a constant effective output only after two or three years of operation, it can be observed that an improvement at least of the output is evident, even in mines with inexperienced personnel after the first year of operation; although the final Q_{eff} is not reached until a later date.

Optimum conditions for favourable efficiency factors η_L exist in central European mines.

40 years of experience with bucket wheel excavators, the tool of the German open-pit mines, sand and clay overburden, favourable climatic conditions and well organized maintenance and operating crews result in long-term output efficiency factors η_L = 0.60—0.85.

The survey shows that 12 BWEs of all sizes, working in three German lignite pits, have a factor η_L = 0.69 over 29 total bucket wheel operating years.

One large German open-pit shows an efficiency factor of η_L = 0.76 for 95 BWE operating years for machines of the 60,000 to 200,000 bank m³ per day class.

The same open-pit shows a factor η_L = 0.85 over a 12-month period during 1976/1977 for one of the 200,000 bank m³ machines. 13% of the BWE production was coal and during 20% of the 4,400 yearly operating hours the machine was cutting below track level.

The open-pit, where the three largest BWEs of the world with a machine weight of 13,000 t are working, records a η_L = 0.8 after initial opening-up cuts were completed. This mine expects to have the three machines of the 240,000 bank m³ class operating at a η_L = 0.85 in the near future.

One especially good efficiency factor is recorded for the first BWE with an output of 100,000 bank m³. This machine was designed in 1951, started to operate in 1955 and worked in several pits, excavating mainly overburden. Over a period of 25 years, this machine excavated 469 million bank m³ with an efficiency factor $\eta_L = 0.857$. The machine is in first class mechanical condition due to good maintenance practices and will shortly be loading a conveyor system. Previously it had been used to load rail cars.

The efficiency factors of 24 BWEs surveyed in other areas of the world are much lower. The machines removing overburden for mines located on other continents have a $\eta_L = 0.45$ over 115 BWE operating years.

7 BWEs working in Africa in sandy soils have a factor $\eta_L = 0.58$ for 26 BWE operating years. This may be a result of the good digging conditions and the extensive experience with BWEs in these mines.

The machines working in North and South America have to battle with adverse climatic conditions. In South America five months of rainy season, and in Canada four months of very cold temperatures, may have an influence on the efficiency factor $\eta_L = 0.45$.

The machines working in Asia have encountered the hardest digging conditions (Fig. 2).

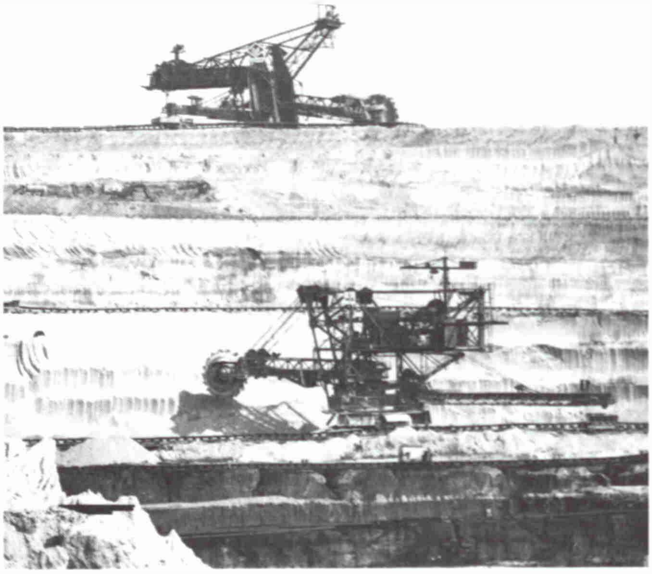


Fig. 2: Bucket Wheel Excavator SchRs $\frac{1500}{2}$ x 26 (top) and SchRs $\frac{700}{3}$ x 20 operating in Cudalore sandstone in South Asia.

Blasted sandstone with a swell factor of 1.45 and weathered granite with a swell of 1.7 combine with adverse weather conditions during the long rainy season. This may have an influence on the resultant factor $\eta_L = 0.4$. This factor may even be considered excellent when taking into account these adverse conditions.

The foregoing does not imply that certain efficiency factors are resultant from operations on certain continents, such as Asia $\eta_L = 0.4$, America $\eta_L = 0.45$, Africa $\eta_L = 0.58$ and Central Europe $\eta_L = 0.69$.

It rather indicates that hard digging conditions and climatic influences result in $\eta_L = 0.4$ over a very long period and $\eta_L = 0.5$ over a short survey period (Fig. 3).

Easy digging conditions result even under tropic, subtropic and arctic conditions in efficiency factors $\eta_L = 0.45$—0.65.

Optimum conditions in Europe result in efficiency factors $\eta_L = 0.6$—0.85. Over short periods of time (1—5 years), the factors are even $\eta_L = 0.75$—0.85 (Fig. 4).

5. Formulae in Literature

General formulae for calculation of effective output hardly ever meet reality.

— DIN 22266 shows the following formula for effective output of BWEs:

$$Q_{eff.}\,(\text{bm}^3/\text{h}) = \frac{0.8}{f} \times Q_{th}$$

— The recommended value for f (swell factor) is 1.3

— The combination of an efficiency factor of 0.8 as well as a swell factor of 1.3 are rarely experienced in mines and, when applicable, then only during short performance periods and under optimal conditions.

— Fully automatic BWEs are supposed to result in:

$$Q_{eff.}\,(\text{bm}^3/\text{h}) = \frac{0.96}{f} \times Q_{th}$$

Under the best conditions such results may be possible for a short performance test but not for long-term average mining conditions.

— If a BWE works in material of different hardness, the output is supposed to vary with the square of the cutting resistance of the material k, expressed in [N/cm].

$$\left(\frac{Q_{eff\,1}}{Q_{eff\,2}}\right) \cong \left(\frac{k_{l_2}}{k_{l_1}}\right)^2.$$

This statement might also be at best true for short time periods of an hour or a day only.

— Another formula states that:

$$Q_{eff}\,[\text{bm}^3/\text{h}] = \frac{Q_{th}\,[\text{loose m}^3\text{h}]}{f\,(1 + t_e/t_b)}$$

where t_e = the sum of all delays and
t_b = the actual digging time
f = the swell factor.

Experience shows that reference to operating and delay times alone does not give a realistic estimate of BWE output.

— Operating factors resulting from machine dimensions may be calculated or approximated reasonably well. The influence of human factors, climatic and mining conditions, in relation to the digging machine, cannot be determined mathematically. One must unfortunately rely on experience for these factors.

— The relationship of performance test output and long-range output is to be calculated by:

$$\frac{\eta_L\ \text{test}}{\eta_L\ \text{long-term}} = 1.2 \text{ to } 1.6$$

This, of course, is dependent on the length of test and the number of years of BWE experience. It is relatively independent of the varying digging conditions, changing climatic conditions or management influences.

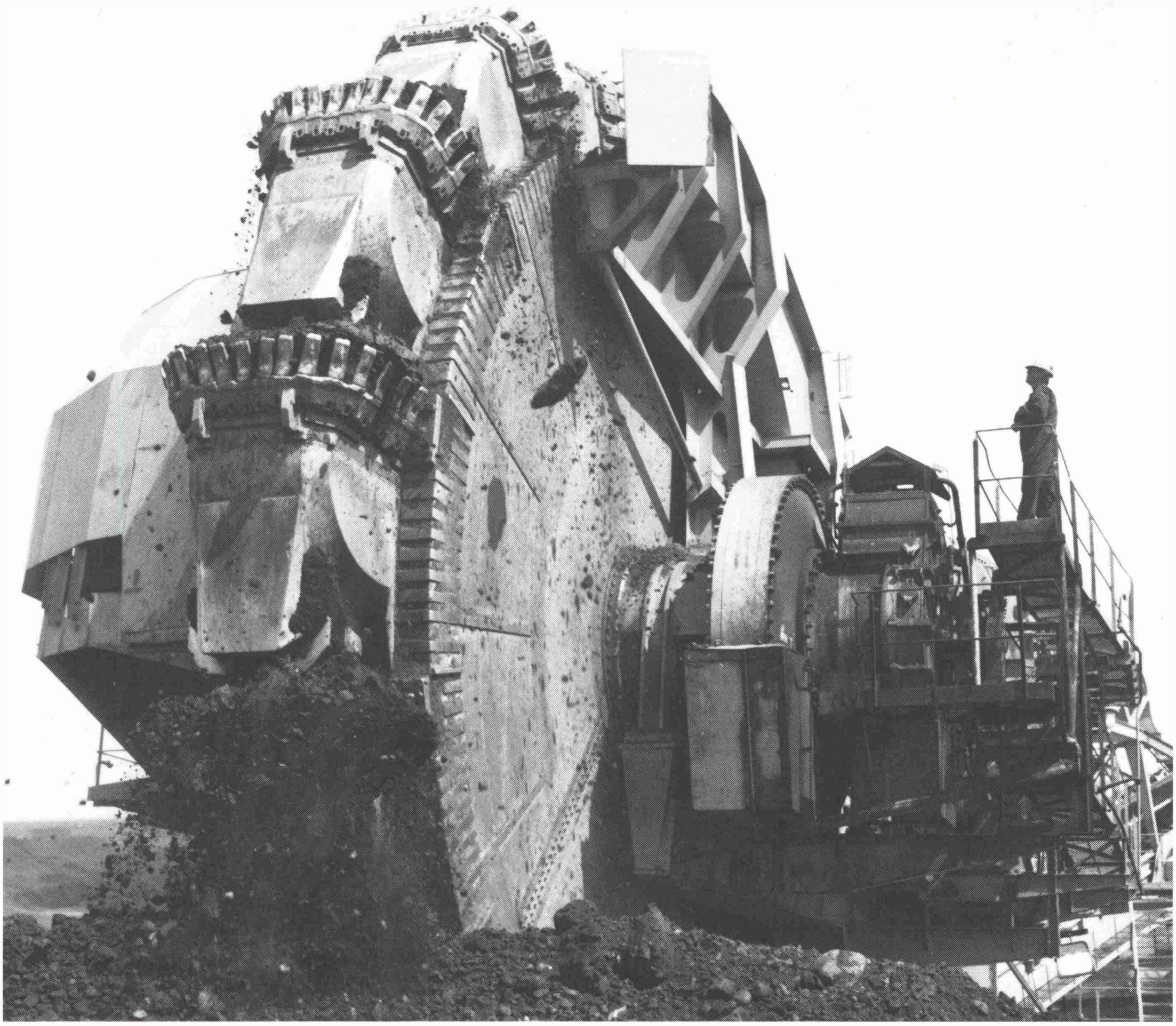
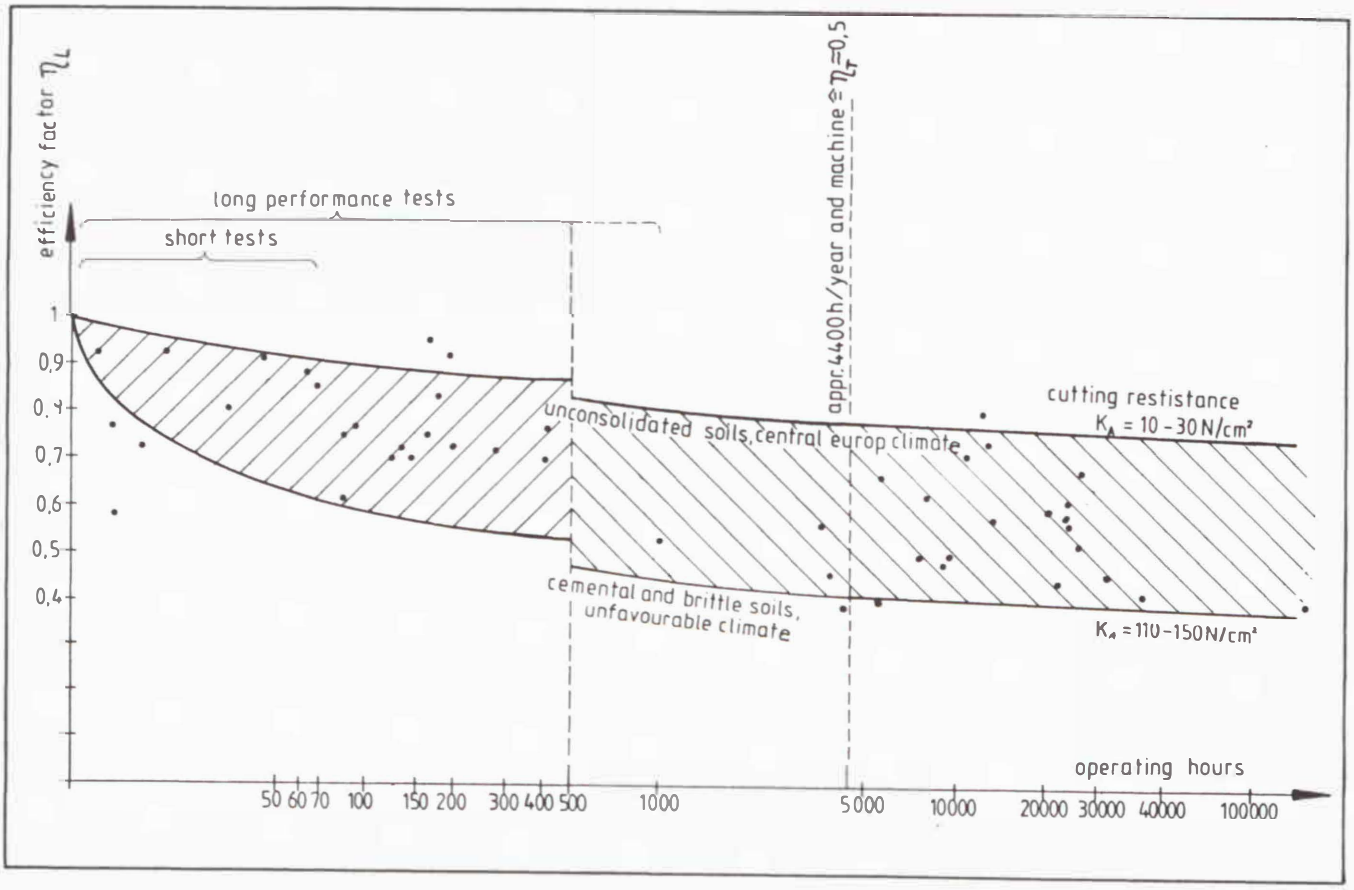


Fig. 3: Bucket Wheel Excavator SchRs $\frac{2450}{1.5}$ x 18 in overburden above the tar sand fields in Canada.

Fig. 4: The first "Giant Bucket Wheel Excavator" SchRs $\frac{3600}{5}$ x 48 with a daily output of 100,000 bm³; put into operation in 1955.

Table 2: Effective operating time

		Open Pit X		**Open Pit Y**
Calendar time		8,760 h		8,760 h
./. statutory holidays	5 days:	120 h	10 days:	240 h
./. expected weather delays	4 days:	96 h	10 days:	240 h
./. general overhaul	3 weeks:	504 h	3 weeks:	504 h
./. operational delays — equipment moves conveyor moves, bin full etc.	10 days:	240 h	12 days:	288 h
	325 days:	7800 h	312 days:	7488 h
./. lost time due to 2 shift instead of 3 shift operation		—		2496 h
./. daily preventative maintenance	3 h/day:	975 h	2 h/day:	624 h
scheduled operating time		6,825 h		4,368 h
./. unscheduled downtime approx. 15 % of scheduled operating time		1,025 h		658 h
Effective operating time T_{eff}		5,800 h		3,710 h



— Almost every BWE can repeat the performance test output; even after many years of operation.

The long-term output efficiency factor η_L does not indicate primarily the capability of the machine, but rather indicates how the machine is applied and what positive or negative influences are experienced under real-life operating conditions (Fig. 2).

6. Operating Time Factor

This factor is calculated as follows:

$$T_{eff} = T_{cal} - T_R - T_{PM} - T_D$$

Where:

T_{eff} = Effective operating time
T_{cal} = Calendar time
T_R = Time at rest (Sundays etc.)
T_{PM} = Preventative maintenance
T_D = Unscheduled down time.

T_R — Can be planned reasonably well, as it constitutes operating policies as to work times or rest times during legal holdidays and expected down time due to adverse weather conditions.

T_{PM} — Can also be planned considering the total mining operation including associated extraction plant, power plant or other plant connected with the particular mining system.

The preventative maintenance is usually carried out during one shift per week or two hours per day — or both. A one to three week outage per year is usually planned for the overall inspection of the machine or a major overhaul. Usually, conveyor moves are planned during the latter outage, or a move of the stacker or BWE from one working area to another may take place during the extended outage.

T_D — includes all down time exceeding several minutes caused by electrical, mechanical or operational problems, as well as plug-ups of the conveyor system, pit wall instability etc.

T_{eff} — is the actual operating (digging) time. It often includes down time of several seconds or minutes that are not registered as down time. Such short outages may be caused by overload trips of the BWE motor, slew motor, conveyor.

In addition it includes lowering, hoisting, travelling, also short discussions of the operators during changes of positions. Since the bucket wheel is rotating in an idling mode during such operational changes, the time is registered as digging time.

The effective operating time T_{eff} and the unscheduled down time T_D make up the operation time.

The operation time factor is

$$\eta_{T1} = \frac{T_{eff}}{T_{eff} + T_D}$$

$T_R + T_{PM}$ is the planned idle time

The planned idle time factor results from the differences between calendar time and operation time and is expressed as:

$$\eta_{T2} = \frac{T_{eff} + T_D}{T_{cal}}$$

Calendar time is taken as 8,760 hours/year.

η_T, the overall time factor is $\eta_T = \eta_{T1} \times \eta_{T2}$

$$\eta_T = \frac{T_{eff}}{T_{eff} + T_D} \times \frac{T_{eff} + T_D}{T_{cal}} = \frac{T_{eff}}{T_{cal}}$$

This says that the time factor of a BWE coupled with a mining system is governed by two time definitions.

T_{eff} = effective digging time per year
T_{cal} = calendar time = 8,760 h/year

The calender time is well defined. The digging time varies between 3,000 and 6,000 hours per year depending on governing conditions in various open pits.

Two examples will show what effective digging times can be achieved (Table 2).

The overall factor for pit "X" is

$$\eta_T = \frac{5{,}800}{8{,}760} = 0.66$$

Time factor η_T for pit "Y" is

$$\eta_T = \frac{3{,}710}{8{,}760} = 0.42$$

Mines overseas usually work three shifts per day for seven days per week so that worldwide time factors of

$\eta_T \approx 0.5 = 4{,}380$ hours are achieved.

German mines, with years of bucket wheel experience, do not achieve average time factors much better than that.

A BWE system — under Japanese management — achieved a time factor of 0.68 over a period of four years. The time factor for two bucket wheels was $0.71 \triangleq 6{,}240$ hours in this mine in Singapore for one particular year.

The assessment of the time factor in terms of calendar time gives a definite term of reference. It must, however, be considered in the light of influence such as climatic conditions, legal holidays etc. governing a BWE application.

In North America the term "availability" of a mining system is used. The "mechanical availability" is sometimes expressed in terms of effective or actual digging time and unscheduled down time

$$\eta_{T1} = \frac{T_{eff}}{T_{eff} + T_D}$$

resulting in time factors of approx. 0.85. Sometimes it is expressed in terms of effective digging time and repair regardless of repair time being scheduled or unscheduled.

Such interpretation of mechanical availability results in factors much lower than 0.85.

Table 3: Long-term efficiency factors

Continent	Machine Type	Overburden Material Excavated	Climate	No. of Machines	Operating Years	Time Efficiency Factor η_T	Output Efficiency Factor η_L
Europe	**SchRs**						
Central Europe	$\frac{4500}{12-14}$ x 41	sandy overburden f = 1.3—(1.4)	continental	1	5	0.54	0.62
Central Europe	$\frac{4500}{12}$ x 44	sandy overburden f = 1.3—(1.4)	continental	1	5	0.6	0.68
Central Europe	$\frac{6300}{9-17}$ x 51	sandy overburden f = 1.3—(1.4)	continental	3	3	0.48	0.8
Central Europe	$\frac{6300}{9-17}$ x 51	sandy overburden f = 1.3—(1.4)	continental	1	1	0.51	0.85
Central Europe	$\frac{700}{9.4}$ x 29	with high clay content f = 1.4	continental	1	3	0.47	0.72
Central Europe	$\frac{450}{10}$ x 20	with high clay content f = 1.4	continental	1	3	0.52	0.62—0.83
Central Europe	$\frac{200}{7}$ x 12	with high clay content f = 1.4	continental	1	4	0.37	0.74
Central Europe	$\frac{250}{7}$ x 13	with high clay content f = 1.4	continental	2	2	0.46	0.62
Central Europe	$\frac{300}{4.5}$ x 14	with high clay content f = 1.4	continental	1	3	0.5	0.58
	Average for η_T and η_L			12	29	0.5	0.69
East Europe	$\frac{4600}{2.5}$ x 30	clayey sand f = 1.25—(1.4)	continental, partly cold winters	1	2	0.47	0.79
East Europe	$\frac{4600}{14}$ x 50	clayey sand f = 1.25—(1.4)	continental, partly cold winters	1	2	0.41	0.56
	Average for η_T and η_L			2	4	0.44	0.68
Africa	**SchRs**						
South Africa	$\frac{400}{0.6}$ x 11	Sand f = 1.3	tropical	1	6	0.45	0.59
East Africa	$\frac{2300}{1.5}$ x 12.5	high clay content f = 1.5	subtropical	1	2	0.44	0.50
West Africa	$\frac{560}{1}$ x 12.5	sandy overburden f = 1.25	tropical	1	6	0.49	0.53
West Africa	$\frac{350}{5}$ x 12.3	sandy overburden f = 1.25	subtropical	2	2	0.59	0.72
West Africa	$\frac{350}{1}$ x 14	high clay content f = 1.4	subtropical	1	5	0.54	0.57
West Africa	$\frac{560}{1}$ x 12.5	sandy overburden f = 1.25	tropical	1	5	0.48	0.60
	Average for η_T and η_L			7	26	0.49	0.58

Continent	Machine	Type	Overburden Material Excavated	Climate	No. of Machines	Operating Years	Time Efficiency Factor η_T	Output Efficiency Factor η_L
America	**SchRs**							
North America	$\frac{1000}{1.5}$	x 26	tar sand $f = 1.4$	continental partly arctic	2	12	0.41	0.42
South America	$\frac{200}{2}$	x 19	sand with clay content $f = 1.3$	subtropical	1	1	0.65	0.5—0.84
South America	$\frac{250}{2}$	x 19	sand with clay content $f = 1.3$	subtropical	1	2	0.53	0.43—0.55
South America	$\frac{150}{0.5}$	x 10.5	sand with clay content $f = 1.3$	subtropical	1	1	0.63	0.37—0.43
South America	$\frac{600}{2}$	x 20	sand with clay content $f = 1.3$	subtropical	1	1	0.43	0.4—0.53
South America	$\frac{400}{2}$	x 15	swampy clay $f = 1.4$	subtropical	1	1	0.50	0.35—0.43
South America	$\frac{400}{3}$	x 20	swampy clay $f = 1.4$	subtropical	1	2	0.55	0.5
	Average for η_T and η_L				8	20	0.46	0.45

Continent	Machine	Type	Overburden Material Excavated	Climate	No. of Machines	Operating Years	Time Efficiency Factor η_T	Output Efficiency Factor η_L
Asia	**SchRs**							
South Asia	$\frac{1500}{2}$	x 26	pre-blasted sand-stone $f = 1.45$	subtropical	3	7	0.53	0.46
South Asia	$\frac{700}{3}$	x 20	pre-blasted sand-stone $f = 1.45$	subtropical	4	58	0.50	0.39
South East Asia	$\frac{630}{1.2}$	x 15	weathered granite $f = 1.5—1.7$	subtropical	2	4	0.68	0.48
	Average for η_T and η_L				9	69	0.51	0.40

The mining system coupled to the BWE has the greatest influence on the time factor. Every component of the system has an influence on the availability of the other components. The bucket wheel could be delivering directly to a conveyor bridge for a direct overcasting operation or could be coupled to an conventional around-the-pit-system with bucket wheel, beltwagon, face conveyor, connecting conveyor, dump conveyor, tripper and stacker.

As long as the components following the BWE are designed for appropriate maximum output, the BWE time factor is affected to a greater degree than the output factor Q_{eff}.

The system should be designed so that:

Q_{max_1} bucket wheel $<$ Q_{max_2} bucket wheel conveyor $<$ Q_{max_3} mine conveyors $<$ Q_{max_4} dump equipment conveyors.

An appropriate design factor for these components could be recommended as follows:

$Q_{max_2} \cong 1.2$ to $1.25 \times Q_{max_1}$
$Q_{max_3} \cong 1.1 \times Q_{max_2}$
$Q_{max_4} \cong 1.05 \times Q_{max_3}$

7. Comparison of Mining Systems

The time factors $\eta_T \cong 0.5$ and effective output factors $\eta_L = 0.4$ to 0.85 may not look too attractive to the uninitiated observer.

However, when one considers the terms of reference, that is, "calendar time" and "theoretical output", the picture looks much more attractive. The term "theoretical output" for mobile equipment and shovels is usually never calculated and would result in factors η_L of surprisingly low magnitude.

Comparisons of mobile equipment application (shovels and trucks or dozers and scrapers) with bucket wheel application (BWE, conveyors and stacker) or comparison of dragline versus bucket wheels and conveyor bridges (cross-pit conveyors), show that the bucket wheel systems are often more economical.

Due to the limited reach of draglines and stripping shovels, double handling is often required. More than half the operating time for such equipment consists of swing time and not excavating time.

BWE systems show generally better economics in soils with a cutting resistance of 1,500 (to 2,000) N/cm or 150 (to 200) N/cm².

A well-known North American manufacturer of draglines and shovels, who has also built a limited number of BWEs, published a paper in 1980 (Ref. No. 6) regarding removal of deep overburden. The economics on a comparable basis are quoted as follows:

Long boomed dragline	—	83 ¢/bank cu.yd.
Shovel and cross-pit conveyor	—	85 ¢/bank cu.yd.
Dragline and cross-pit conveyor	—	73 ¢/bank cu.yd.
BWE and cross-pit conveyor	—	68 ¢/bank cu.yd.

This comparison includes operating and capital costs for loosening, excavating and transporting materials on a comparable basis. The economics are greatly influenced by the output and time efficiency factors.

References

[1] Rasper, L., "Der Schaufelradbagger als Gewinnungsgerät", Trans Tech Publications Clausthal, 1973; "The Bucket Wheel Excavator — Development, Design, Application" Trans Tech Publications, Clausthal, 1975

[2] Krumrey, A., "Schaufelradbagger für feste Erdstoffe", Deutsche Hebe- und Fördertechnik (1981), No. 10

[3] Lubrich, W., "Zur Beurteilung von Geräten über den Zeit- und Lastgrad in Tagebausystemen".

[4] Henning, D., "Erste Betriebserfahrung beim Aufschluß des Tagebaus Hambach", BRAUNKOHLE, (1981) No. 7

[5] Schönfeld, G., "Der Tagebau Fortuna von 1955 bis 1990", BRAUNKOHLE, (1977), No. 9

[6] Learmont, T., Chare, H.B., "Area stripping productivity solutions in deep overburden", Australian Coal Miner, (1980) June

[7] Durst, W., "Der Schaufelradbagger"(unpublished)

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