Comparison of various ship-unloading equipment for bulk materials concerning their specific energy consumption per ton

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The worldwide discussion about carbon emissions as a main reason for global warming as well as the economical difficulties of many port operations due to less turnover and high energy costs were the main reasons for the Institute for material handlings, material flow, logistics (fml), Technische Universität München, Germany, to initialise an investigation focusing on the specific energy consumption of various ship-unloading equipment for bulk materials, especially coal.

1 The relevance of hard coal as a primary energy carrier

As Fig. 1 shows, today hard coal is still the most important primary energy carrier after crude oil. If you believe international experts the demand for hard coal will grow much faster than that for oil in the next 20 years, with the effect that the consumption will almost double in the same period.

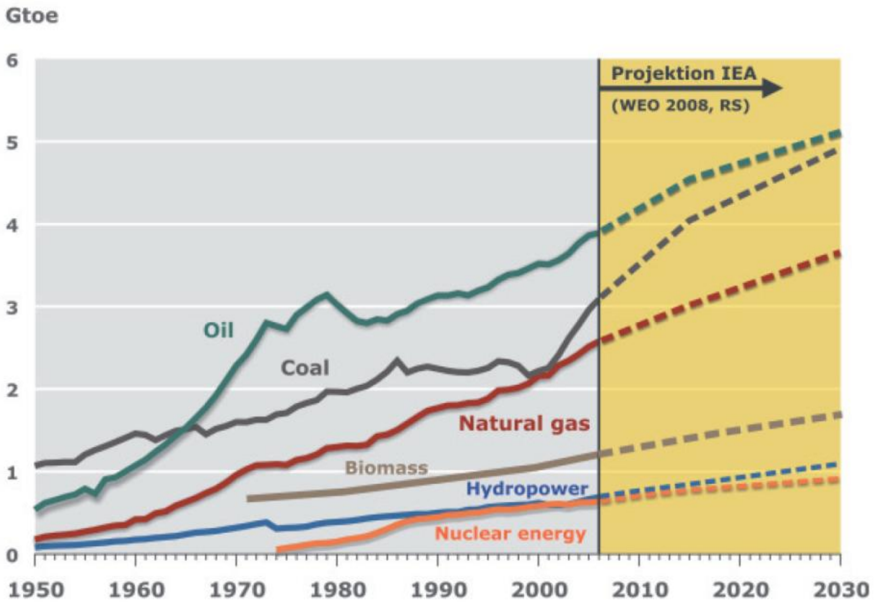

Fig. 1: Development of Primary Energy Consumption Worldwide (cumulative) and Projections of IEA until 2030. (Sources: BP and [1])

The economic performance of the worldwide steel and electricity industry is to an extremely high degree dependent on the extraction and the import of basic commodities like hard coal or iron ore.

If you take Europe, and especially Germany, as an example, where a considerable amount of hard coal is needed for the production of steel and electricity, underground mining is economically unviable everywhere in Europe due to the cheap coal prices on the global market. As a result, many of the local coal mines were closed. Indeed, there are a few mines that survived, supported by German subsidies, but no doubt even these mines will be closed when subsidies end in 2018.

As the European demand for the coal has not seriously decreased in the comparison period, the European Union (EU) is in dire need of imports from coal-producing countries. Fig. 2 shows this correlation using the example of all German non-renewable energy resources.

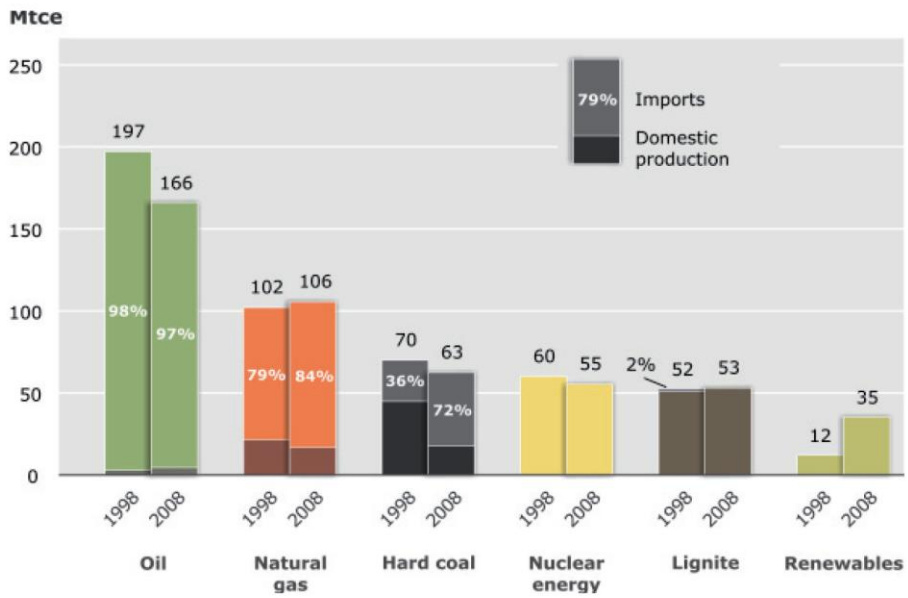

Fig. 2: Energy Consumption and Imports of Germany in 1998 and 2008.[3]

(Sources: AGEB 2009, BGR database)

Global reserves, resources and production

In a worldwide comparison of the energy supply the biggest reserves and resources were shown for hard coal. If you consider consumption, in 2008 coal was the second most important primary energy source after oil, which comprises 29% of demand (hard coal 27%, lignite 2%). In the electricity industry, coal was the most important energy source, comprising 41% of demand [2]. The world coal extraction reached about 6.799 Mt. in 2008, from which the biggest share was hard coal (5.733 Mt., 85%) and the remaining 1.025 Mt. (15%) was lignite.

As every economy tries to improve the security of its energy supplies, the questions are: Will the most important non-renewable energy carriers be able to satisfy the worldwide growing demand? Which ones will be the most reliable in the long run? The answer is given in Fig. 3, which compares the cumulated consumption of the next 20 years with the actual known reserves and resources.

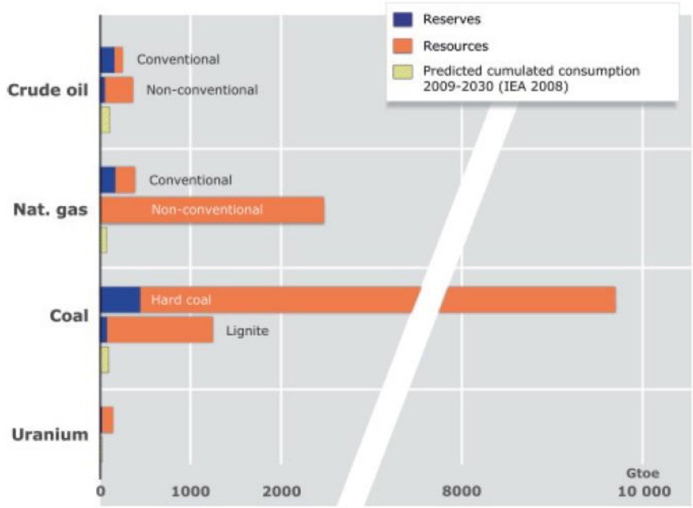

Fig. 3: Worldwide Supply Situation of Non-Renewable Energy Resources in 2008. [3]

Fig. 4 shows the same correlation in even more detail and offers no doubt that, compared to conventional oil, there are still inexhaustible resources of coal that can supply humankind for another 1,000 years with affordable energy.

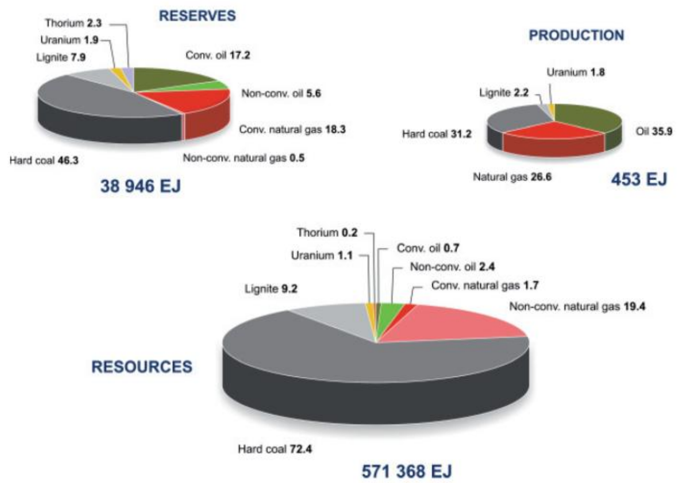

Fig. 4: Annual Production, Reserves and Resources of the Individual Non-Renewable Fuels in 2008. [3]

(Given in per cent of the total)

The regional distribution reserves, resources and the estimated cumulative production of hard coal since 1950 is shown in Fig. 4. North America has the largest remaining hard coal potential, followed by Austral-Asia and the countries of the former Soviet Republic. Regarding hard coal reserves of individual countries, the USA owns the largest volumes in the world (32% of the global share), followed by China (25%), India (11%), Russia (10%), Australia (5%) and Ukraine (4%).

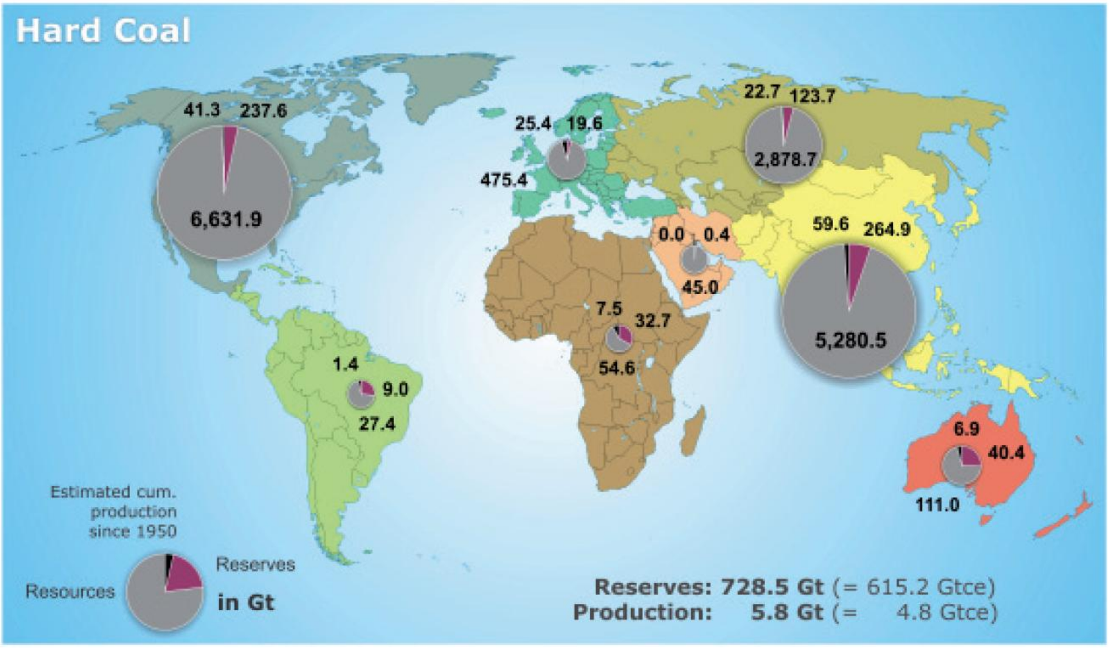

Fig. 4: Distribution of Estimated Ultimate Recovery of Hard Coal in 2008. [3]

Terms of trade

The three biggest producers of hard coal in 2008 were China (with a global share of 45.8%), followed by the USA (17.2%) and India (8.5%). While China and India extended their production by 7%, it increased only by 3% in the United States.

With a total volume of 930 Mt., about 16% of the global hard coal production was actually traded. About 839 Mt. (90%) of the trading volume was handled by ship [2].

Australia dominated the export market with a total volume of 259.8 Mt. (28%) followed by Indonesia with 202.6 Mt. (21.8%) and Russia with 97.9 Mt. (10.5%).

The three largest importers of coal have been Japan, South Korea and Taiwan. In total volume these Asian countries together import 351.7 Mt. (37.8 %) followed by India with 59.8 Mt. (6.4%), Germany with 44 Mt. (4.7 %), Great Britain with 43.9 Mt. (4.7%) and China with 40.8 Mt. (4.4%).

Environmental aspects

If you compare coal with other non–renewable resources, it has the greatest geological availability. Besides other aspects, the deposits are less concentrated on certain regions and therefore the production is spread across many countries and companies. This ensures a cheap availability for decades and for that reason it is quite possible that there will be a continued strong demand for coal, especially for the Asian markets and even worldwide, as Fig. 1 shows.

A frequently discussed issue at the moment are the emissions that occur during the combustion process. Meanwhile, many industrial installations like power plants and steelworks have modern filter techniques available that avoid the emission of combustion residues like sulphur dioxide and ash. Therefore, modern coal-burning plants can reduce emissions and enhance energy efficiency. A remaining problem is that the emission of the greenhouse gas CO^2 can not be reduced so far and unfortunatelycoal is the fossil energy resource with the highest specific level of

CO^2 emissions. Indeed there are experimental plants that can separate carbon dioxide from the flue gas and liquefy it (Carbon Capture and Storage (CSS)) but on the one hand, the process runs at the expense of efficiency and on the other hand, the search for an adequate final storage solution is difficult and antagonizes the residents nearby. Another problem concerning the power generation is the dimension of coal-burning plants. When futurologists describe a smart grid, they are discussing the designs of a network that consists of many different generators and consumers, who supply each other according to their requirements. Therefore it is essential that the generators in the network have a high flexibility and can reduce their output or can even be turned ofwhen windy weather increases the output of wind turbines.

The circumstances mentioned above could create a lower demand for coal in producing electricity than shown in Fig. 1, but at present it is difficult to imagine how the future energy demand of the world can be met without coal.

2 Research project

Although there is less exploitation of resources in European coal mines, the industry consumption is not decreasing. Besides, there are a lot of ongoing projects planned for coal-burning power plants and the turnover of port operations that import coal has been increasing for years. Against the background of rising energy costs and for ecological reasons, the aspect of the specific energy consumption of ship-unloading equipment is becoming more important.

Typical bulk unloading equipment

For the handling of bulk materials like iron-ore or coal, there are two completely different kinds of technologies: the continuous and the discontinuous respectively grab-type way. Fig. 5 shows the different types of ship unloaders classified according to the established technology.

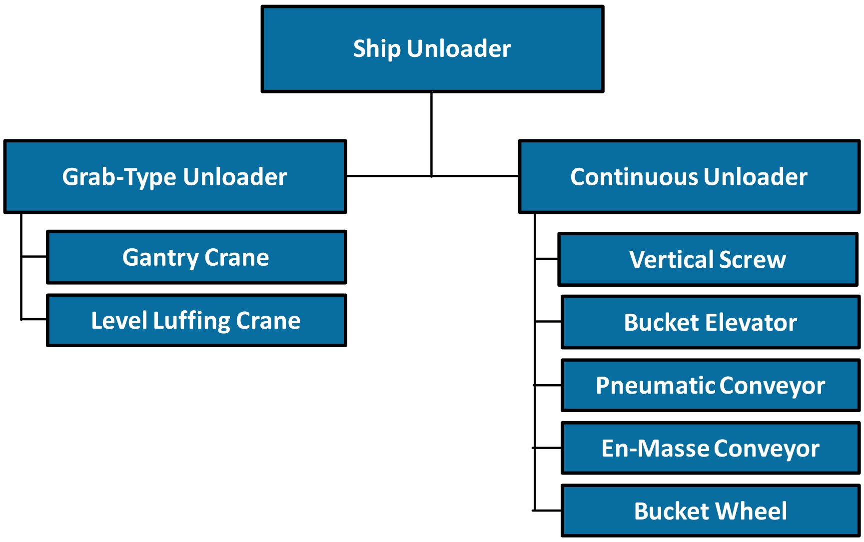

Fig. 5: Classification of different types of ship unloaders.

For the bulk material coal, the following unloading equipment can be found at larger port operations:

- Grab-Type Unloader
- Vertical Screw
- Bucket Elevator

Fig. 6: Gantry Crane, Vertical Screw and Bucket Elevator for unloading coal from seagoing vessels.

Due to the completely different technologies involved, there are various pros and cons to the different unloading systems. Besides the specific energy consumption levels, many different properties have to be considered before investing in a new unloader.

Measurement technique

The aim of the research project was to determine the specific energy consumption of different types of ship unloaders. Many systems have an electricity meter and a belt weigher on board to determine the required values, but to consider the consumption of single driving units, portable power meters are needed.

Two different measuring techniques are adequate to determine the power in AC and DC systems:

The three wattmeter method:

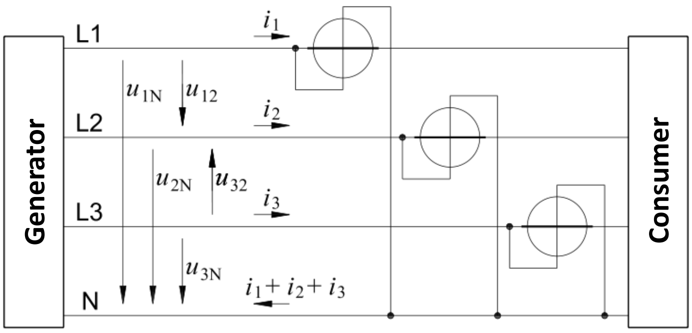

Fig. 7: Three wattmeter method to determine the power consumption in three-phase AC circuits. [4]

With the three wattmeter method, it is quite simple to determine the accurate power consumption as you can measure the real power in each single phase, as shown in Fig. 7, and you will get the instantaneous real power of the system by adding up the values of the single meters. To calculate the total power consumption, you have to add up the measured means of the time slices over the period under consideration, as shown in the following formulas [4].

$$p(t) = u_{1N} \cdot i_1 + u_{2N} \cdot i_2 + u_{3N} \cdot i_3 \quad (1)$$

$$W = \int p(t)dt, \quad (2)$$

The single wattmeter method (single phase):

In three-phase systems, the single wattmeter method only gives correct results with balanced loading of the phases, as for example at driving units, and it is important to know or determine the power factor cos φ, as shown in the following formula.

$$p(t) = 3 \cdot u_1 \cdot i_1 \cdot \cos\varphi \quad (3)$$

Modern measurement equipment combines the described methods in a single meter and is furthermore suitable for measuring in AC and DC systems.

Fig. 8: Power meters to measure the consumption of driving units and whole systems.

In scope of this research project, two different types of power meters were used and can be seen in Fig. 8. On the right side, a fluke 1735 power logger is shown that is suitable for the three wattmeter method. On the right sight is an LEM Analyst 2060 that is suitable for the one wattmeter method. Both meters have a data memory so that values can be logged over a certain period of time.

Measurements at unloading installations

In the following the example of a gantry crane will show the recurring analysis of the unloading devices, especially what values can be measured and what conclusions can be made.

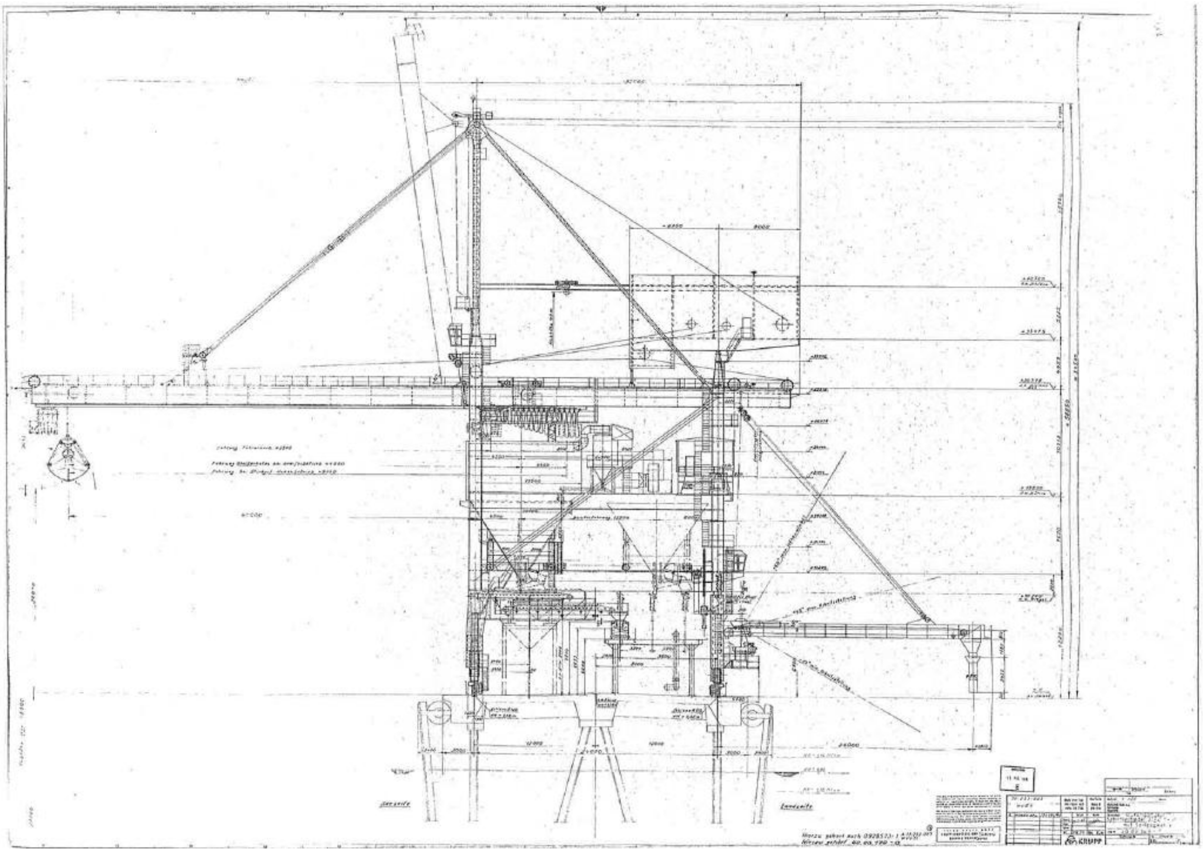

Fig. 9: Detail drawing of a gantry crane.

Fig. 9 shows a detail drawing of the considered crane. The drawing shows the typical installation of a gantry crane with a cable trolley. The main drives with closure, godet and trolley unit are direct current motors. Both drives of the lifting unit have an available power of 490 kW; the trolley drive has 250 kW. Besides these main drives, there are the usual auxiliary consumers like carriage drives, boom lifting drive, lights, etc. The following table shows the key data of the unloading device.

Manufacturer	Krupp
Year of construction	1979
Lifting capacity	35 t
Grab weight	12 t (19 m³)
Lift above pear	ca. 20 m
Horizont. driveway	ca. 25 m
Flow rate max.	ca. 1,200 t/h
Flow rate avg.	ca. 1,000 t/h
Installed power	ca. 1.7 MW
Bulk material	Steam coal
Personnel placement	2+2
Self-weight	ca. 1,000 t

Fig. 10: Technical data of the gantry crane.

Results of the measurement

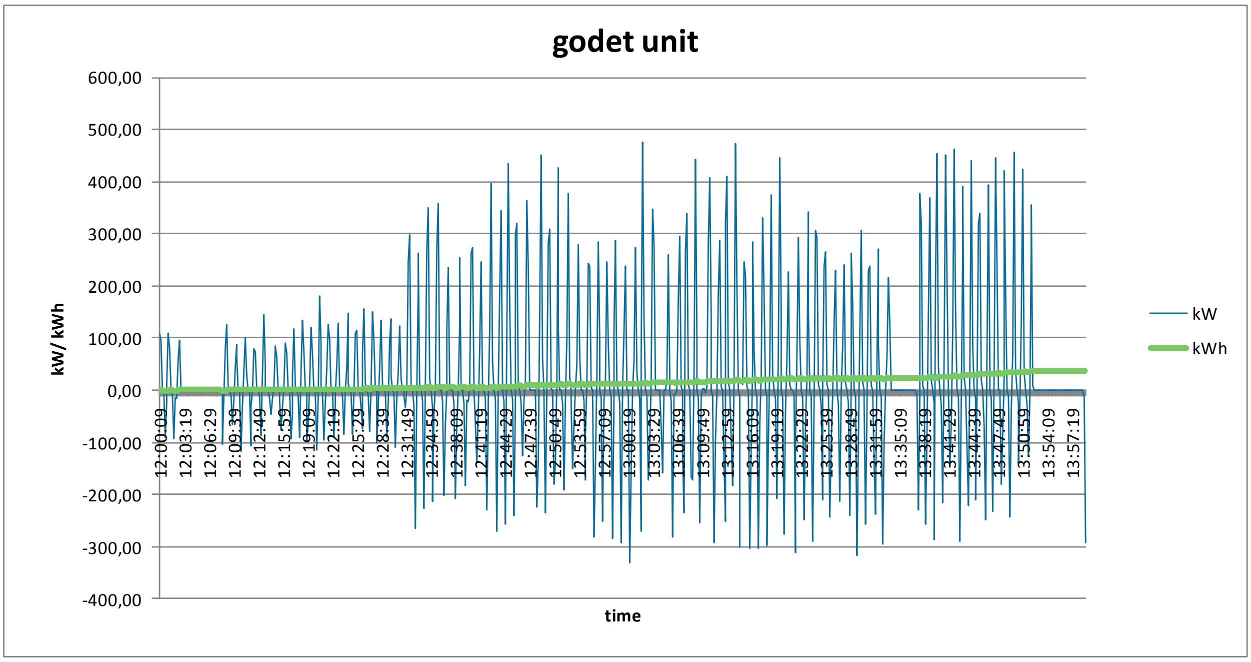

Fig. 11: Power/ power consumption diagram of the godet unit drive.

Fig. 11 shows a diagram of the power and power consumption measurement of the crane's godet unit. You can identify easily different phases of the unloading process. From 12:00 to 12:30, for example, the power level of the unit was reduced because the crane had to clean up the hatch and so the grab was only half-full. After that, the crane changed the hatch and you see amplitudes up to the maximum power of the engine. After a short break at 13:35, the crane driver changed. The negative values occur when the opened grab is lowered into the hatch and the engine is used for dynamic braking. As this installation had no energetic recovery system, the resulting energy was abolished in resistors.

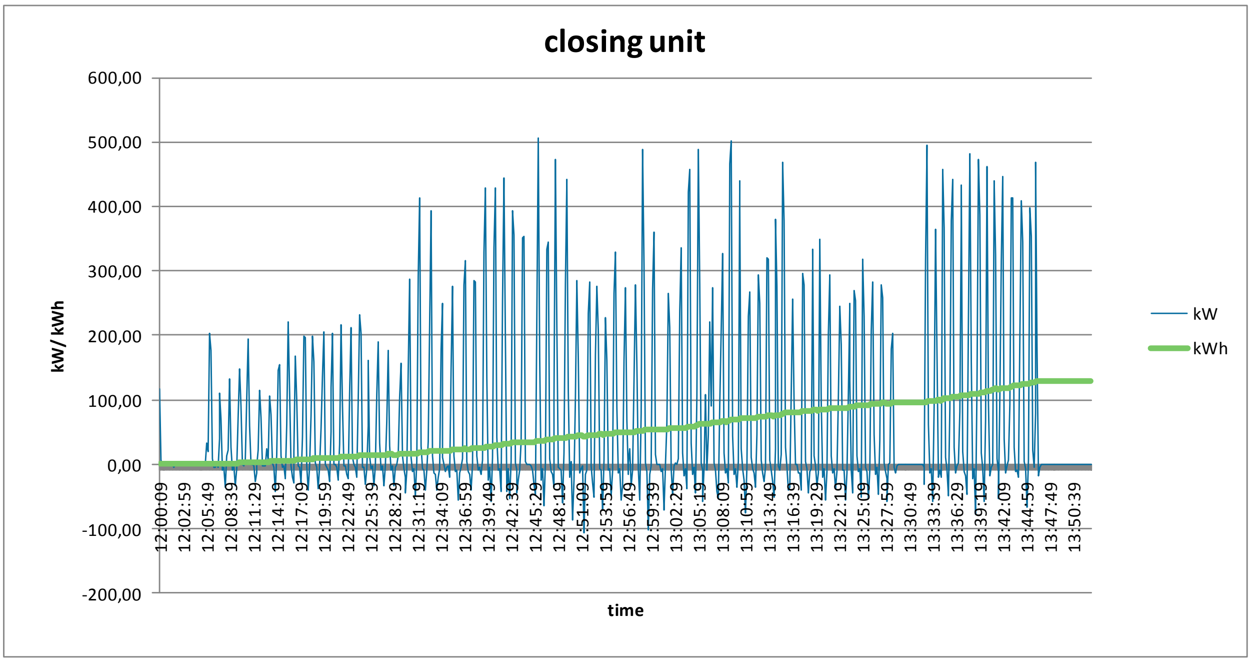

Fig. 12: Power/ power consumption diagram of the closure unit drive.

Fig. 12 shows the power and the power consumption of the cranes closure unit. If you compare the diagram with Fig. 11, you can recognise the same unloading phases. The only difference is that the peaks are slightly higher due to the fact that the applied force of the closure unit has to be higher than that of the godet unit to keep the grab closed. Additionally, the negative values are far lower than with the closure unit, due to the fact that the grab is lowered opened.

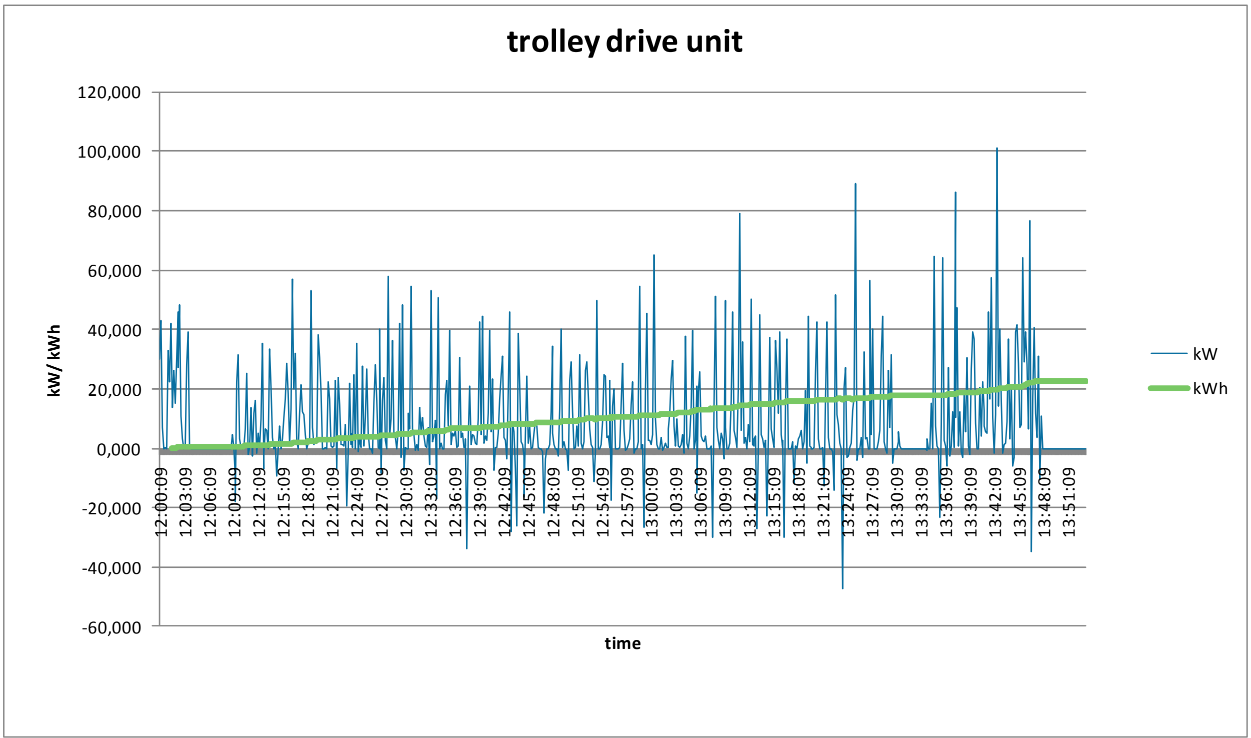

Fig. 13: Power/ power consumption diagram of the trolley drive unit.

Fig. 13 shows the power and the power consumption of the trolley drive unit. The peaks of the power are quite independent of the unloading process phases as the horizontal movement is more or less the same. Only after the change of the driver at about 13:35 are the peaks slightly higher.

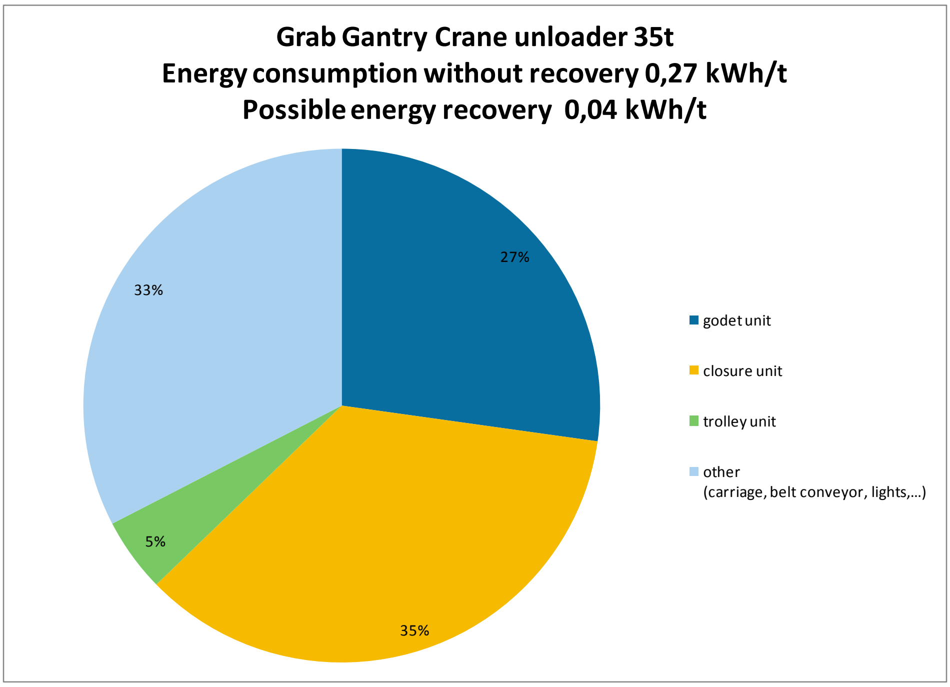

Fig. 14: Breakdown of the power consumption of the grab gantry crane unloader.

Fig. 14 shows the results of the energy consumption check of the crane. The specific consumption is quite low with a value of 0.27 kWh/t and it could be even lower if the operator would invest in an energy recovery system, as the potential energy recovery due to dynamic breaking is 0.04 kWh/t. As expected, the total share of the closure unit is clearly higher than that of the godet unit due to corrections in grabbing the coal and the fact that the cable force has to be higher to keep the grab closed. The share of other types of consumption is, with over 30%, quite high due to many other consumers like, for example, a belt conveyor that pulls the material sideways out of the crane.

3 Summary and conclusions

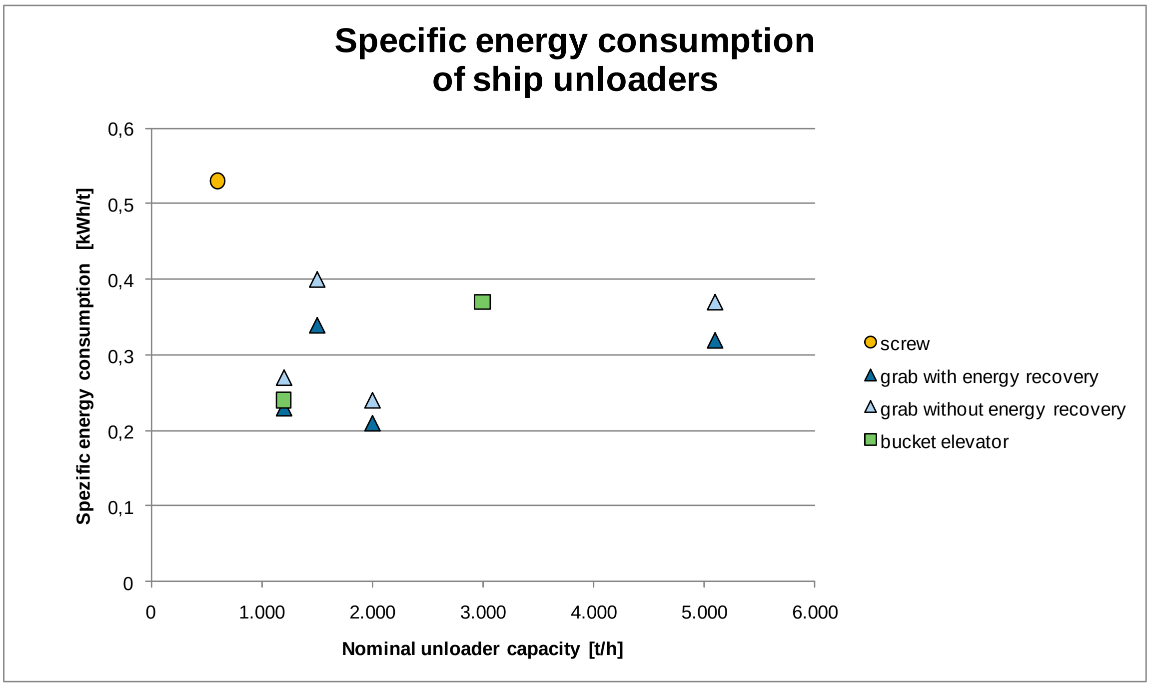

Fig. 15: Comparison of the specific energy consumption of all measured ship unloaders.

Fig. 15 shows a comparison of the specific energy consumption of all ship unloaders that were scope of the survey depending on their nominal capacity.

As a first result it can be said that all measured grab unloaders range from 0.2 to 0.4 kWh/t. Due to the energy-incentive principle of conveying, the only screw unloader in this survey has the highest specific energy consumption. The bucket elevator unloaders lie in the middle. That is amazing, as we expected them to be the most economical.

Overall it has to be said that many factors have a big influence in the valuation of the suitability of a unloading device. For example, the higher the installed capacity of an unloader, the higher the costs for the electrical connection; the higher the weight, the higher the civil costs for the jetty. But especially when the energy consumption is not only a matter of costs, more importance should be attached to it, for example for ecological reasons.

So far the database is too small to give a complete overview, but it is planned to expand the number of measured unloading devices in the future, so that an even more precise conclusion will be possible.

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