ENERGY SAVING POSSIBILITIES IN THE PRODUCTION PROCESSES OF THE CONCRETE INDUSTRY 1

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SYNOPSIS

Energy consumption and the possibility of saving energy in the production process of ready-mixed concrete plants and precast concrete factories manufacturing wall elements were studied in detail. Moreover, special features of beam, column and pile production and conrete product manufacture were discussed from energy saving points of view. The best possible energy saving is achieved with the use of correct aggregate storing and heating techniques and by the selection of a good treatment programme and heat treatment method.
A list of plausible means of saving energy, together with ideas for energy conservation, are introduced as a result of this research.

Key words: energy saving, energy consumption, concrete industry, concrete products.

1. INTRODUCTION

Efforts to save energy gained increasing importance in the mid 1970's as a result of the sharp rise in fuel prices. In 1980, energy consumed by the Finnish concrete industry exceeded 600 QWH and its costs amounted to more than 70 mill. Fmk. The production process is restricted in this project between the following work phases: The raw materials obtainable from the factory - a finished product kept in factory storage.

The research is based on interviews, visits to factories, and in the first place on literature. The subject was viewed particularly from the standpoint of concrete technology.

In the production process, energy is used in the heating of materials, in the heat treatment of products, in the making of fresh concrete, in concreting and transportation operations. Heat treatment often serves as a heating system for production space, which is why its use, limited to the energy consumption of the production process alone,is subject to consideration.

2. ENERGY CONTENT OF CONCRETE

One of the starting points in the consideration of energy saving could well be the energy content of the concrete. The energy content of fresh concrete consists of the energy contained in cement and aggregate as well as the energy involved in transport and mixing /2/. On the basis of studies carried out at the Tampere University of Technology, Finland, the energy content of one cubic metre of concrete can be calculated as follows:

cement	250 to 500 kg/conc.cu.m.	330 to 660 kWh/m^3
aggregate	1750 to 1950 kg/conc.cu.m.	18 to 20 kWh/m^3
manufacture		90 kWh/m^3
Total		440 to 770 kWh/m^3

In comparison with the energy content of cement (about 1.3 kWh/kg) the energy content of reinforcing steels is high (about 8 kWh/kg). For this reason the energy content of reinforced concrete elements rises to a relatively high level:

reinforced concrete elements	800 to 3200 kWh/conc.cu.m.
prestressed concrete elements	700 to 1700 kWh/conc.cu.m.

These figures include heat treatment and transportation, which amounted to approximately 50 kWh/concr.cu.m. and 100 kWh/conc. cu.m. respectively. The main proportion of transport energy is consumed in the conveyance of the finished elements. The proportion required by heat treatment might be, however, greater than e.g. 50 kWh/conc.cu.m.

3. USE OF ENERGY IN FRESH CONCRETE MANUFACTURE

In the energy consumption of the production process the most important phases of energy consumption are the heating of aggegates and the heat treatment of concrete. The energy consumption in the heating of constituents can easily be theoretically calculated starting from the amounts and specific heats (5) of different materials. An example of calculation is given in the case where heating of aggregate is started at -6 °C continuing for 4 months and at +9 °C for the rest of the year. The energy distribution given in Table 1 is obtained when the temperature of a ready concrete mix is +15 °C.

Table 1. Amount of heat Q required for heating the constituents of fresh concrete up to 15 °C.

Constituent to be heated	m kg	Cp kJ/kg°C	a kk/12kk	t_1 °C	t_2 °C	Q MJ/Bm³	Q kWh/Bm³	%
Aggregates in winter (4 months)								
Aggregate -6...15 °C	1870	0.92	4/12	-6	15	12	3.3	35.8
Moisture	65							
heating of ice -6..0 °C	65	2.09	4/12	-6	0	0.3	0.08	0.9
melting of ice 0 °C	65	334.7 1)	4/12	0	0	7.3	2.0	21.8
water 0...15 °C	65	4.18	4/12	0	15	1.4	0.4	4.2
Aggregates in summer (8 months)								
Aggregate 9...15 °C	1870	0.92	8/12	9	15	6.9	1.9	20.6
Moisture 9...15 °C	65	4.18	8/12	9	15	1.1	0.3	3.3
Aggregates in total	1870					29.0	8.0	86.6
Cement	300	0.92	12/12	20	15	-1.4	-0.4	-4.2
Water	140	4.18	12/12	5	15	5.9	1.6	17.6
Total						33.5	9.2	100

1) melting heat of ice 334.7 kJ/kg
$Q \, 0 \, m \cdot Cp \cdot a \, (t_2 - t_1)$,
where
m is fresh concrete
Cp is specific heat
a is annual share
t_1 is initial temperature
t_2 is final temperature.

In this example, the proportion of energy required by aggregate is about 87 %. When the heating efficiency of aggregate is taken into account, which preferably falls below rather than above 50 %, together with the energy required in mixing and transportation, the share of energy consumed in the heating of aggregate may generally be about 80 % in the making of concrete. On the basis of these figures it is evident that examination of the energy needed in the manufacture of fresh concrete is to be focussed on the heating process of aggregate. The amount of energy used for aggregate at an efficiency of 50 % is about 16 kWh/concrete cu.m.. In itself, this amount of energy does not form a large percentage of the price of concrete. On the other hand, by improving heating techniques and heat insulation, great variations of temperature and moisture in aggregate, as well as e.g. disturbances caused by frozen aggregates, can be avoided. This might have as great an effect as that of an actual reduction in the consumption of energy.

Measures by means of which the energy consumption in the manufacture of concrete can be reduced are:

- An improvement in the insulation of underground receiving bins and silos. Most easily corrected defects are found in the deck structures of underground receiving bins. In their design, heat insulation as well as the prevention of damages caused by ice and drifting snow should be taken into consideration.
- The control of steam streams in free steam heating in such a way that the heat does not canalize. The canalized steam streams produce an uneven temperature distribution and great differences in moisture content. Although free steam heating in itself is effective, the difficult control of heating, heat loss due to condensed water, and even the penetration of steam into the surroundings generally reduce the efficiency to such a low level that the use of free steam at new plants can hardly be recommended. The circulation of steam and the regulation of stock corresponding to the degree of filling should improve energy economy.
- Steam and water radiators are more energy-economical by far, but less efficient than free steam heating. As a counterbalance to the lower consumption of energy the investment and maintenance costs are relatively high.
- Electric resistance heating is used primarily for maintaining an even temperature, e.g. in the case of silo walls.
- Energy economy of a hot air blasting method partly depends on the same factors as that of free steam heating. The direction of heat streams can be steered, however, more easily than that of free steam heating, and there is no problem as in the case of the condensed water of free steam. On the other hand, the drying of aggregates, in conjunction with heating, is not advisable from the standpoint of energy economy, which emphasizes the importance of heat distribution. Air circulation improves heat economy and that is just what should be strived for. Although a direct feeding of combustion gases into aggregates would be profitable as far as energy consumption is concerned, a possible incomplete burning will lead to rather a great risk in the field of concrete technology.

When hot air blasting is used in heating the moisture content of aggregates decreases. It is considered as advantageous as far as the making of fresh concrete is concerned, because the water-cement ratio is then closer to the desired one than when moist aggregates are used /1/.

When heating is arranged the flow profile of granular material in a silo has to be taken into account. A moving material then forms an ellipsoid in the silo, the height-width of which is characteristic of each granular material and which remains constant when flow continues from the silo /4/. Heating has to be directed, of course, onto the flowing material.

Since, unlike cements, aggregates do not age in the silo, the formation of a passive, fairly thick motionless aggregate layer that remains on the silo walls and serves as insulation is profitable from the viewpoint of energy economy. The dependence of the height-width ratio of the ellipsoid on the particle size of a granular material is shown in Fig. 1.

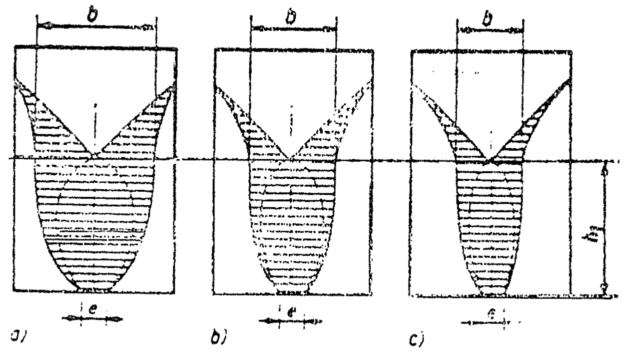

Fig. 1 The dependence of the flow of the granular material from the silo on particle size. The material flows in the hatched area /14, p.27/.
a) large particle size
b) medium particle size
c) small particle size

As shown in Fig. 4 the coarse aggregate fraction pours out of a wider ellipsoid than the fine aggregate fraction. Thus heating of the fine aggregate fraction should be concentrated on a smaller area in the middle of the silo than the coarse aggregate fraction. Moreover, it would be advisable, if only possible, to direct heating more carefully than previously to the middle part of the silo when the degree of filling of the silo decreases.

In principle, in the heating of aggregates energy economy can be improved considerably by two arrangements independent of a heating method. In the first arrangement, an aggregate is used the whole year through and is prevented from freezing by keeping it either in underground storages or in sufficiently large storages above ground in summer, in which case it is relatively easy to keep it almost unfrozen. This procedure requires lots of space above ground. By using unfrozen aggregate all year long the amount of energy needed for the manufacture of concrete can be reduced by about one third. The returns on expenses caused by quarrying the underground storages will take, however, rather a long time. When deciding on the measures, the following should be borne in mind:

1. The case where it is necessary to obtain crushed aggregate by quarrying or where there is a suitable cave in the immediate vicinity of the concrete plant.
2. The case where it is necessary to store aggregates in large amounts, e.g. to make its quality uniform, it is advisable to try keeping the used aggregate temperature above 0 °C.

If the temperature of fresh concrete is raised, the daily heating of silo constructions and the water tank is of great importance. Simultaneously, a loss of heat through the walls of silos and pipes increases. A situation is being approached where it is advisable to heat up materials on a batch-by-batch basis. If aggregates, in particular, cannot be handled when they are not frozen, it should always be profitable, in theory, to heat them up just prior to mixing. In some cases this is also done in conjunction with the making of fresh concrete.

The amount of energy used for making fresh concrete could be reduced by developing a rapid aggregate heating method which, however, would not let it dry. In the case of coarse aggregate it is proposed that the aggregate is moved through a hot water bath. The methods still require a great deal of development. As it appears from the foregoing, it is indeed worth the effort to pay attention to the heating of aggregate. On the other hand, in the mixing operation of fresh concrete it is not advisable to economize. On the contrary, experience has been gained with the method in which, by the effective mixing of cement with water, the cement is made to divide into the mix so well that its amount can be reduced. The energy needed for the making of fresh concrete then increases, but the construction of cement and thus the energy content of concrete decreases. An activator mixer has the same kind of effect as several admixtures in that it divides flocculated cement particles. The rapid abrasion of the fast rotating activator mixer coupled with a great need for maintenance might have prevented the generalization of the procedure.

4. MANUFACTURE OF ELEMENTS

The starting point for slab and panel production is the energy consumption which is good when battery moulds are used and much weaker in the case of horizontal moulds. In the use of battery moulds hydration heat is usually sufficient to raise the temperature of hardened concrete quite distinctly. The situation in the horizontal mould is described by the following example of the energy consumed by the double T slab mould /3/. Heating is carried out using a set of steam pipes, the curing temperature being 60 ^{o}C, and heat treatment takes seven hours. Energy is distributed as stated in Table 2:

Table 2. Energy distribution in a double T slab when heat treated

Energy consumption need	Proportion (%)
Heating of fresh concrete	49
Heating of reinforcement	4
Heating of mould	10
Losses - through base	8
- to sides	5
- in upper surface	14
- in set of pipes	10
Total	100

Compaction does not consume a great deal of total energy. Ordinary vibration energy is about 0.2 to 0.6 kWh/conc.cu.m. /5/. Different vibrators do no differ greatly from one another. When a small vibrator is used more energy is consumed per mix unit than in the case of a large vibrator. When considering the energy consumed in vibration only, the use of plasticizers is not profitable.

The amount of energy consumed in transportation varies, depending on the arrangements of each plant. It is, however, of little importance as far as the total energy consumption is concerned. The proportion used in transportation is usually of the same order of magnitude as that used in vibration, or about 1 % of the total energy consumption.

The best opportunities of saving on energy in the production of elements is to be found in heat treatment. The selection of a proper heat treatment programme can favourably affect the energy consumption. When the stripping time is 16 hours we are near the area where heat treatment is not necessarily needed to achieve the stripping or handling strength. Heat treatment can be compensated by increasing the amount of cement or by decreasing the amount of water with the aid of admixtures. At present it is safer, however, to ensure handling strength by using 45 kWh/concr.cu.m. (12 mk/concr.cu.m.) in extra heating than by adding less than 40 kg/m^3 of cement ($\sim$12 mk/concr. cu.m.). This amount of energy increases the temperature of concrete by about 30 °C at an efficiency of 0.5. If a corresponding extra cost is invested in the use of a plasticizer, an increase in strength may be obtained by means of extra heating.

The energy economy of heat curing could be improved compared with what it is today by controlling heat curing. Control could be based e.g. on the ultrasonic pulse velocity or on the measurement of temperature. In the control based on temperature measurement it would be wise to use the relation between the strength development and the temperature instead of the number of degree-days, for the sum of degree-days clearly underestimates the rate of strength development during the first days. The measurement of the strength development based on ultrasound is made with two sensors situated on different sides of the mould. The equipment follows a change in the velocity of ultrasonic pulses travelling between the sensors and converts it to describe the strength development.

With regard to energy economy the use of battery mould and, wherever necessary, a warm concrete mix is a favourable solution. On the other hand, the use of free steam in horizontal moulds is clearly most unprofitable. Advantageous heating methods seem to consist of electrical and infra red heating as well, although their efficiency is greatly dependent on insulation measures. On the other hand, the stripping times used in our country are so lengthy that the use of proper curing kilns is not usually necessary. The use of unheated kilns has proved, on the other hand, to be very profitable in the production of small discrete products, when e.g. the blocks or roof tiles are cured in insulated kilns by means of hydration heat. In the case of curing, the temperature often exceeds 40 ^{o}C without using extra heating. The same technique could be applied e.g. to pile production, where the amount of energy consumed is relatively large.

5. SUMMARY OF ENERGY CONSERVATION IDEAS AND NEED FOR FURTHER STUDIES

The potential energy conservation and ideas for it in the concrete and prefabricated concrete industries are listed below.

<u>Ready-mixed concrete industry</u>

- heating of aggregate in underground receiving bins is given up and aggregate is heated just before mixing directly with the aid of a hot medium using e.g. air or water, or possibly steam first in a mixer
- snow and ice are prevented from entering into the underground bins
- a stream of hot air in an aggregate silo is directed onto a material stream (onto the middle of the silo) and adjusted to correspond to the degree of filling
- air circulation is arranged in hot air heating
- aggregate is kept for the winter in covered or underground storage or in piles provided with a cover
- fine aggregate is stored dry for the winter, and coarse aggregate, even slightly frozen, is efficiently heated using a direct water heating method.

<u>Panel and slab industries</u>

- all ideas that refer to the ready-mixed industry (the preceding item)
- as many battery moulds as possible are used instead of horizontal moulds
- instead of free steam indirect water, oil or electric heating is used in heat curing
- leakages in the pipes of the medium transferring heat are repaired
- transport from factory to factory is so arranged that the time when the doors are open is minimized
- the overhead travelling crane is replaced by a wagon rail in moving the elements out
- the upper faces of the horizontal moulds are covered with thermal insulation
- an unnecessarily efficient and long heat curing period used for the attainment of the stripping strength is avoided by improving our knowledge of early strengths and by developing a simple and quick testing method for the determination of strength.

<u>Beam, column and pile production</u>

- all ideas that refer to the ready-mixed concrete industry
- free steam curing is replaced by mould heating or by using electrical heating for prestressing steels

- aim in pile production is to have the use of battery mould type equipment and the manufacture that takes place indoors
- an unnecessarily efficient and long heat curing period used for the attainment of the stripping strength is avoided by improving our knowledge of early strengths and by developing a simple and quick testing method for the determination of strength.

Manufacture of concrete products

- all ideas that refer to the ready-mixed concrete industry (above)
- heat curing is carried in continuous heating ovens, in which adequate heat curing is secured by hydration heat
- on using lightweight aggregate as aggregate water and cement are mixed first in a mixer, after which the mortar obtained is mixed with lightweight aggregate
- unnecessarily efficient and long heat curing period for the attainment of the required strength is avoided by improving our knowledge of early strengths and by developing a simple and quick testing method for the determination of strength.

On the basis of this research further studies of the following topics are needed:

- a better knowledge of the early strength of concrete and the development of a non-destructive testing method
- the quantitative determination of the drying of aggregate taking place in hot-air blasting heating
- equipment used for direct water heating of coarse aggregate
- the use of a hot concrete mix
- the optimization of energy consumption in heat curing
- the heat curing instructions for prefabricated concrete and concrete products industries
- the effect of combustion gases on the properties of aggregate for concrete.

LITERATURE

1 Bernzott, E., Grundsätze des Betriebs und der Planung von werken Hochbaukonstruktionen in Skelettbauweise. Berlin, Bauverlag GmbH, 1969. 193 s.

2 Björkholz, D., Betonin ja betonirakentieden energiasisältö. IX Betonipäivät 1981. Helsinki, Suomen Betoniyhdistys ry., 1981. S. 1 - 4

3 Brolich, N. Die beschleunigte Betonhärtung durch Wärmebehandlung, Teil 2. Betonwerk + Fertigteil-Technik 39 (1973) s. 209-213.

4 Kaysser, D., Technologie der industriellen Betonproduktion, Band 1. Berlin, VEB Verlag für Bauwesen, 1967. 215 s.

5 Kaysser, D., Technologie der industriellen Betonproduktion, Band 2. Berlin, VEB Verlag für Bauwesen, 1967. 256 s.