Effect of Order Placement on Energy Efficiency in Ready-mixed Concrete Plants in Japan

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Abstract

Electric energy consumption in ready-mixed concrete plants is not distinctively large for each plant, but not negligible as a whole for their huge production amount. Therefore it is important to seek effective and acceptable ways to improve energy efficiency in concrete production process. In this paper, characteristics of energy consumption are analyzed through direct measurements of electric systems in ready-mixed concrete plants. Production and procurement data are also collected to investigate the effect of shipping/procurement timing and the types of concrete on the efficiency of electric systems. Microscopic dynamism of energy consumption is investigated to find out the ways of improving energy efficiency.

1. Research Background and Objectives

Reduction of Carbon Dioxide (Abbrev. CO₂) is one of the major issues for the sustainable development of construction sector. Some researchers have reported that CO₂ emission related to construction; production of materials, transportation, on-site construction activities etc., amounts up to 30-40% of the Japan’s total emission¹). Cement concrete industries are obviously facing strong criticism because of the dominant ratio to
Many proposals have been made to deal with the issue

1) use of mineral admixtures in concrete (such as fly ash, blast furnace slag),
2) use of precast member (to reduce transportation energy consumption),
3) lengthening the designed duration of materials and members

Most of these proposals implies acceptance of technical trade-offs. For example, use of mineral admixtures likely to increase the carbonation speed of concrete. Use of precast members is tends to increase the cement content. Lengthening the designed duration, in many cases, means “to use better concrete, deeper cover depth”, resulting in the increase of cement content and the amount of concrete used. Therefore, it is not always technically or socially acceptable to introduce these options. If we cling ourselves to the solution by mixture-proportion design of concrete, reduction of production amount of cement or ready-mixed concrete is inevitable, which certainly is not acceptable for the cement-makers and ready-mixed concrete plant managers. In this paper, we will seek for another “more acceptable” solution to reduce CO2 emission focusing on the electric systems of ready-mixed concrete plants in Japan. Firstly, we will introduce an easy-to-use measurement method for trend analysis of electric consumption of ready-mixed concrete plants in Japan. Secondary, availability of production process information and shipping records are investigated to construct the standard procedure to analyze the characteristics of electrical systems. Thirdly, analysis results using the above method are introduced to induce the microscopic dynamism of electric system of the plants. Fourthly, case studies are conducted to estimate the theoretical effect of order placement on the energy efficiency of electric system of ready-mixed concrete plants without the expense of reducing the production amount. Finally, social applicability and possibility of our proposal is investigated and summarized.

2. An Easy-to-use Measurement Method for Electric System

Total electric consumption of the plants is measured and collected by the electric power corporation to charge the fee. Induction type electrical meter is generally used for the measurement in Japan. This type of measurement method is accurate and capable of long time usage without much maintenance. However the method is apparently not suitable for on-site measurement for several reasons. Table 1 shows the comparisons of the two measurement methods. Measurement method for on-site field analysis requires the following conditions;

1) capable of set-up without shutting down the electric systems of the plant,
2) small enough to set-up within cubicle system or switchboard,
3) applicable to three-phase three-wire electric system generally used in Japan,
4) available to collect time-series data on-site (ex. save digital data in memory card)

Our technical survey has revealed that clamp-type electric energy measurement method; which measures the current by clamp and voltage by resistance, fulfills these conditions. Measurement in this paper is conducted under the following conditions; sampling rate=1fps, error margin=± 0.4%, and measurement period two weeks or more per system.

<table>
<thead>
<tr>
<th>Table 1 Comparison of measurement method for electric system</th>
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<tr>
<td></td>
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<tr>
<td>Accuracy</td>
</tr>
<tr>
<td>Equipment size</td>
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<tr>
<td>Easiness to set up on-site</td>
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<tr>
<td>Easiness of data collection</td>
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3. Availability of Process information and shipping/procurement records

In order to construct the standard procedure for trend analysis of electric system in ready-mixed concrete plant, a certain level of uniformly-formatted information about production process and shipping/procurement is required. Interview survey on five plants in Hiroshima Japan is conducted to list up the available information. Survey results are summarized as follows;

- Drawing of cubicle system was available in all plants, though detailed drawings of whole electric systems were not available in any plants. Figure 1 shows a sample of collected drawing.

- Electric system of ready-mixed concrete in Japan is roughly categorized into five processes; mixing process, aggregate-conveyance into plant process, in-plant aggregate conveyance process, in-plant cement conveyance process, waste treatment process, and office. The categorization was common in all five plants. A typical process of ready-mixed concrete plant in Japan and categorization of the electric system is shown in Figure 2.

- Second-by-second shipping record was available in all plant. Some plants stored data only in paper format. Consequently we are forced to input records manually at the moment. However, due to the amendment of Japanese Industrial Standard 5308 in 2010, electronic record is expected to be available after April 2010.
• The shipping records include cement type, amount of fresh concrete, coarse aggregate max size, car number, slump, strength and weighted mass of cement, water, aggregate, admixtures, accompanied by mixture date and time.
• The procurement records were manually summarized by the plant manager and available as daily report in every plant.
• “Mixing process”, as electric consumption source in this paper, mainly consists of mixer, chemical admixture conveyance into mixer, air compressors; which are located at the main building of the plant.
• “Aggregate-conveyance into plant process” cement conveyance process consists of conveyer-belt machinery from outside the plant to aggregate yard or silo.
• “In-plant aggregate conveyance process” mainly consists of conveyer-belt machinery from aggregate yard to aggregate bin in main plant.
• “Cement conveyance process” consists of blower motor to convey cement from silo to main plant.
• “Waste treatment process” includes sludge treatment such as trammel, conveyer-belt, and flocculation tank.

![Figure 1 A Sample drawing of electric system](image-url)
4. Measurement and analysis result

4.1. Result of time-series trend analysis

Time series trends of electric energy consumption on each categorized electric system are shown in Figure 3 - Figure 7. Electric consumption of mixing process, in-plant aggregate conveyance process and cement conveyance process have shown off-peak at noon, which corresponds to the off-peak trend of the construction activity at lunch time. Electric consumption of “aggregate conveyance into plant process” has not shown the off-peak; which corresponds to the irregular order placement of aggregate to crushed-stone plants. Electric consumption was close to zero at night except for the waste treatment process. Since the flocculation tanks are operated on a 24-hour basis, the measurement result is understandable.

Considering the above discussion, the clamp-type measurement method is shown to be effective to analyze microscopic dynamism of electric consumption of ready-mixed concrete plant in Japan.
Figure 3 Electric consumption trend of “mixing process”

Figure 4 Electric consumption trend of “aggregate conveyance into plant process”

Figure 5 Electric consumption trend of “in-plant aggregate conveyance process”

Figure 6 Electric consumption trend of “cement conveyance process”
4.2. Analysis result on specific electric consumption of each system

Relation between production amount of ready-mixed concrete and the electric energy consumption of processes related to material conveyance are shown in Figure 9. Relation between procured weight of aggregate and electric consumption on “aggregate conveyance into plant process” is also shown in Figure 10. Both aggregate and cement conveyance has shown linear correlation with production amount of ready-mixed concrete. Since main consumption source is either conveyance-belt machineries or blowers, strong correlation with the weight of materials is anticipated. Investigation on shipping record has clarified that there was little variation of mixture proportion shipped at plants in suburban area. Therefore, the strong correlation with production amount is also considered reasonable.

Relation between production amount and electric energy consumption of the “waste treatment process” is shown in Figure 11. Little correlation is observed between 2 parameters. Since main consumption source of the process operates 24-hour basis as described above, and other non 24-hour source, such as trammel and conveyer-belt, dominates little ratio in consumption as shown in Figure 7, the result is also considered reasonable.

Relation between the production amount and electric energy consumption of the “mixing process” is shown in Figure 8. According to our interview survey to the plant managers, maintenance activities, such as cleaning of mixer, calibration of load cells, are the source of fluctuation of electric consumption on the day of no shipping. Although regression function is linear, y-intercept of the calculated function (equation 1) clearly has non-zero value. This tendency is important in that, at least theoretically speaking, it indicates the possibility to enhance electric efficiency by controlling the order placement timing of ready-mixed concrete.
Figure 8 Relation between electric consumption of the “mixing process” and production amount of ready-mixed concrete

Figure 9 Relation between electric energy consumption and production amount of ready-mixed concrete; “cement conveyance process” (left) and “in-plant aggregate conveyance process” (right)
Figure 10 Relation between electric energy consumption of “aggregate conveyance into plant process” and procured amount of aggregate

Figure 11 Relation between electric energy consumption of “waste treatment process” and production amount of ready-mixed concrete
5. Case study on effect of order placement of ready-mixed concrete

5.1. Schematic model to enhance electric efficiency of ready-mixed concrete

Figure 12 shows a schematic model to enhance electric efficiency of ready-mixed concrete plant. By concentrating the timing of order placement into specific period of the month, specific electric consumption; which corresponds to the gradient in the right figure, is expected to decrease. In other words, the fact that y-intercept of the electric consumption has non-zero value lead to the theoretical possibility of enhancement in electric efficiency without the expense of decreasing the total amount of ready-mixed concrete shipped. In Japan, operation rate of ready-mixed concrete is considerably low, especially in suburban area. Therefore, the proposal is feasible and realistic on calculation.

5.2. Comparative scenarios of monthly order placement

Comparative study is conducted to numerically estimate the effect of timing of order placements of ready-mixed concrete. The calculation is conducted under the following assumptions. Max production amount of a plant is set at 1008m³ calculated from the mixer capability, 7 hours work, and yearly operation rate=0.8 to exclude the maintenance days. Monthly total production is set at 4652m³ taken from randomly-taken order record of a plant. The figure is set in common for all scenarios. Electric energy consumption for zero-production day is assumed at 86kWh (30% of the y-intercept). The assumption is considered to over-estimate the maintenance frequency. However no practical record is accessible at this point. Electric energy consumption of “mixing process” alone is calculated for simplicity. Regression equation for Figure 8 (Equation 1) is used for calculation.
Table 2 Comparative scenarios

<table>
<thead>
<tr>
<th>Scenario Name</th>
<th>Explanation</th>
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<tbody>
<tr>
<td>Realistic</td>
<td>Order placement randomly taken from real plant record.</td>
</tr>
<tr>
<td>flat</td>
<td>Keeps the same production amount every day.</td>
</tr>
<tr>
<td>100% concentrated</td>
<td>Order placements are concentrated at one day as much as plant’s capability.</td>
</tr>
<tr>
<td>75% concentrated</td>
<td>Order placements are concentrated at one day as much as 75% plant’s capability.</td>
</tr>
<tr>
<td>50% concentrated</td>
<td>Order placements are concentrated at one day as much as 50% plant’s capability.</td>
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\[
E = 0.559 \times p + 281.6 \quad (1)
\]

Where \( E \) (kWh/day) is electric energy consumption and \( p \) (m³/day) is production amount of ready-mixed concrete.

5.3. Result of the comparative analysis

Calculated results of specific electric energy consumption per production are shown in Table 3. All “concentrated” scenarios have shown smaller figure than “realistic” scenario. Since production amount is set at the same figure in all scenarios, the results indicate the possibility to enhance electric efficiency without reducing the production amount. According to our previous survey, some urban plants in Tokyo actually operate at 50% of their capacity. Therefore “50% concentrated” is assumed to be acceptable for workers at plants. “Flat” scenario has shown larger figure than “Realistic”. This is because no maintenance day was set in calculation for “flat” scenario.

Table 3 Results of comparative analysis

<table>
<thead>
<tr>
<th>Scenario Name</th>
<th>Specific Electric consumption (kWh/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Realistic</td>
<td>2.08</td>
</tr>
<tr>
<td>flat</td>
<td>2.38</td>
</tr>
<tr>
<td>100% concentrated</td>
<td>1.31</td>
</tr>
<tr>
<td>75% concentrated</td>
<td>1.40</td>
</tr>
<tr>
<td>50% concentrated</td>
<td>1.52</td>
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</tbody>
</table>
6. Conclusion

This paper is summarized as follows;

• Easy-to-use measurement method for electric systems of ready-mixed concrete plants is proposed. Considering the availability and quality of process information and shipping/procurement record, the method is considered effective for the on-site measurement.

• Trend analysis on electric consumption as well as categorization of the electric system is conducted. The results have shown quantitative characteristics of the system. It is worth mentioning that some process have shown non-zero y-intercept regression function, indicating the possibility to enhance electric efficiency without reducing the production amount.

• Comparative analysis on effect of monthly order placement of ready-mixed concrete is conducted. The results have shown technical possibility of reducing the electric consumption without the expense of reducing the production amount. Since production amount directly connected to the incomes of the plants, proposed scenarios are considered acceptable for plant managers and cement makers.

Acknowledgement

This research is partially supported by The Ministry of Environment, Japan, Global Environment Research Fund (H20-H22, Hc-087, project leader Takafumi Noguchi, The University of Tokyo). Travel expense and participation fee of the conference are supported by The Ministry of Environment (H20-H22, Hc-087) and Electric Technology Research Foundation of Chugoku, foreign voyage fund 2010. Authors also would like to thank for plant managers in Hiroshima-Area Ready-mixed Concrete Association for their cooperation for measurement.

Reference


2) Architectural Institute of Japan: Recommendation for Environmentally Conscious Practice of Reinforced Concrete Buildings, 2008 (In Japanese)