Off-Line Heat Transfer Systems

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1. Introduction

To realize a smart community, the effort to improve energy use of heat and electric power in a regional community has become increasingly important. For the interchange of energy between users, a smart community has no choice but to limit a service area of heat and power within a range of a few kilometer because heat energy exhibits a greater transfer loss than electric energy.

We applied the off-line heat transfer system using trucks that transport heat energy from a facility having enough heat energy (referred to as the “heat source”) to a facility having insufficient heat energy (the “demand”) and demonstrated the capability of heat interchange system in the medium-range of 10km radius area assuming city use. In particular, we have constructed a Community Energy Management System (“CEMS”) that optimizes waste heat transfer from heat sources to effective demands and verified the efficacy of CEMS.

This document describes the principle and the verification result of off-line heat transfer system.

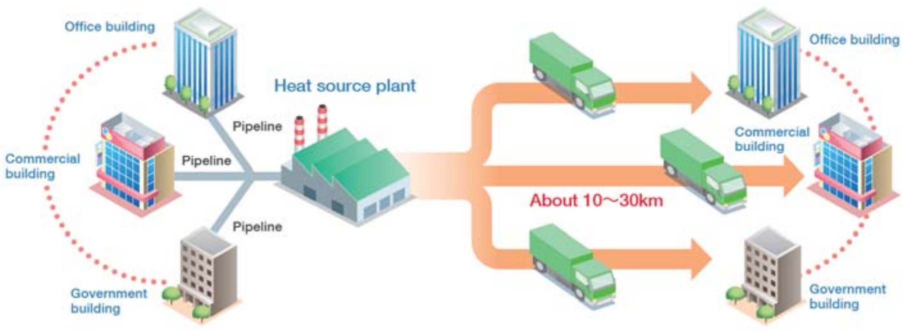


Fig.1: Model of off-line heat transfer system

2. Principle of hear transfer

Here, the principle of heat transfer is explained.

Heat storage units are installed in heat source facilities such as waste disposal plants that exhaust excess heat as steam. Also, heat release units are installed in users’ facilities such as factories, hospitals and bath-houses that have more heat demands than electricity.

A heat storage unit recovers excess heat of a waste disposal plant by heat exchange through oil and stores heat by transferring it from the heated oil to cassettes on a truck. A cassette is filled with Erythritol of melting-point temperature 121℃. It stores heat by latent heat storage method. The latent heat method enables to increase storage capacity by changing the phase of Erythritol from solid at normal temperature to liquid heated by oil of higher-temperature than 130℃. The heat stored in the liquid Erythritol by the latent heat method is released through the reverse process flow in a heat release unit. The recovered heat is utilized for heating water supply to hot-water storage tanks at users’ facilities.

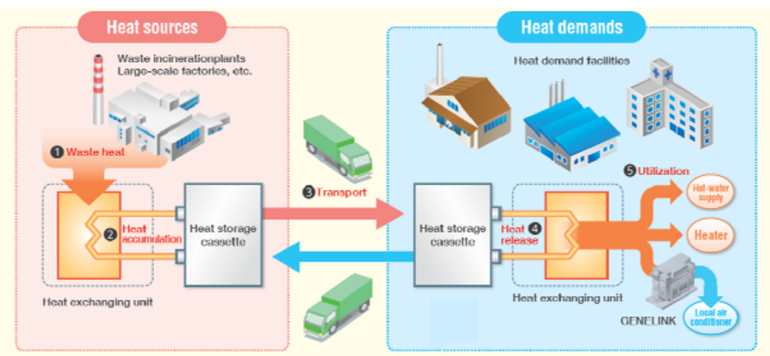


Fig.2: Principle of off-line heat transfer

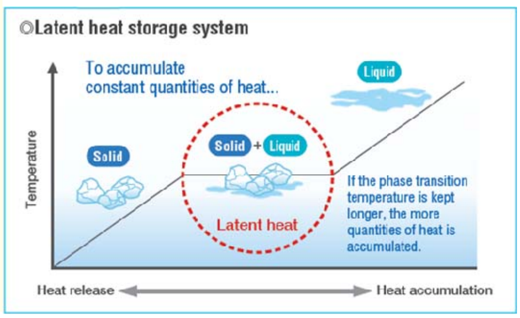


Fig.3: Latent heat storage system

3. Verification of CEMS

We demonstrated the optimum transport of heat from multiple heat sources to multiple demands by CEMS.

A plan for CEMS is made according to steam flow ventilated from a heat source; time of heat extraction from steam; amount of heat received by a heat release unit and the time it takes; traffic situation of trucks.

The parameters to be considered at applying CEMS are;

We calculated the efficacy of CEMS according to the result of CO_2 emission reduction at users' facilities.

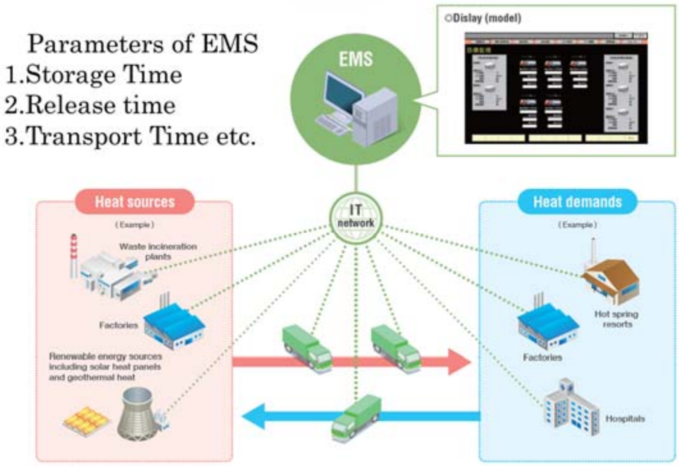


Fig.4: Model of CEMS

4. Test field

Test field of CEMS demonstration was assumed to be an urban area where various heat demands existed. We evaluated the efficacy of CEMS by utilizing waste heat of disposal plant 'X' as a heat source. Two heat storage units were installed in this plant.

Heat release units were installed at site A (a large bath-house), B (a factory) and C (a plant for district heating/cooling) as demands. Heat transferred to these demands was used for heating water supply of hot-water storage tanks at A, for heating water supply of boilers at B and for heating water supply of the district heating/cooling plant at C.

In consideration of heat loss during transportation by trucks, these facilities of demands are located within the range of 10km from X; in increasing order of distance, A, B, and C. The amount of heat is 900MJ for a single transportation.

Fig.5: Test field

Picture1: Heat release unit

	Amount	Specs	
Heat Storage Unit	2	Source Time Pressure of steam Temperature of steam	0.8NPaG Steam(150kg/h) 5hours 1.0MPaG 250℃
Heat Release Unit	3	Use Amount Control	Hot water 0.9GJ(over 8hours) Remote
Casset	5	Storage Substance Amount Weight Dimension	Latent heat storage system Erythritol(m.p.121℃) 0.9GJ 3.9t 1.3m×2.1m×H1.5m

Table1:Specifications of equipment

5. Preconditions

For evaluation, we selected three types of demands, A, B and C that have different usages of heat energy each other. A is the nearest demand from X and has the smallest objective equipment for reducing fuel consumption. B is the second nearest demand from X and has a boiler as the objective equipment larger than A. C is the farthest demand and has the largest objective equipment used for heating water supply of district heating/cooling.

If objective equipment has high efficiency of fuel consumption reduction, the efficacy of waste heat transfer is estimated to be low. On the other hand, if it has low efficiency, the efficacy of waste heat transfer is estimated to be high. Therefore, it can be said that the most positive effect of heat transfer is obtained in A, and the second B, the last C.

To emphasize these features of each demand and to evaluate the efficacy of CEMS, we changed the objective equipment of each demand and arranged the time range for receiving heat in order of A, B and C. The changed preconditions are indicated in red in Table 2.

	Time for transfer	Time of demand	Energy saving	Instrument of demand site	Example
A	Short	Short	High	Boiler (85% efficiency by Bunker A)	Bath-house
B	Middle	Middle	Middle	Boiler (90% efficiency by city gas)	Hospital
C	Long	Long	Low	Absorption refrigerating machine (100% efficiency by city gas)	Factory

Table 2: Features of each demand

The specific conditions for the heat source and demands are described below.

The heat source can accumulate heat for average 150MJ per an hour and completed full accumulation of 900MJ in 6 hours.

The truck admission of X is controlled by limiting the time to access the heat source. However, the limitation is only applied to the time of truck admission so that the accumulation of heat can be started at night.

Regarding the demands, the actual data of transfer time by trucks and the required time for heat release are used for limiting the time for receiving heat.

The time for receiving heat is limited to 9:00–16:00 at A that is expected to show the highest energy-saving effect. No limitation of time is set for the other two demands.

The calculated values of CO_2 emission reduction are 81.5g/MJ for A, 56.6g/MJ for B and 50.9g/MJ for C according to the condition in Table 2.

Heat	Instant Storage	Supply Demand	Time
Unit	150MJ	9 to 18	6h

Site	ReduceCO2	Demand Time	Transfer Time	Release Time
A	81.5g/MJ	9 to 16	25min	6~7h
B	56.6g/MJ	9 to 30	30min	6h
C	50.9g/MJ	9 to 30	35min	6h~7h

Table 3: Conditions for the heat source and demands

6. Test contents

To estimate the efficacy of CEMS in various conditions, we made up 11 model cases of off-line heat transfer.

Heat transfer schedule is determined according to the "operating time" when heat is available to store/release and the "amount of instantaneous heat" at storage/supply that defines how long it takes to store/release for a truck. Therefore, the schedule can be changed by correcting the parameters of "operating time" and "amount of instantaneous heat."

In verification process, we confirmed that the heat transfer schedule was changed by increasing/decreasing the operating time and the amount of instantaneous heat for heat storage unit without changing the parameter of heat release unit (Test 2, 6 and 7).

Also, we confirmed that that the heat transfer schedule was changed by increasing/decreasing the operating time and the amount of instantaneous heat for heat release unit without changing the parameter of heat storage unit. For this case we tested for 6 different kinds of parameters because the schedule would vary depending on whether the time was changed continuously or intermittently on heat release unit side (Test 3, 4, 8, 9, 10 and 11). Additionally, we verified the case of heavy traffic that caused a change in truck behavior (Test 5).

A total of 11 cases were tested. Test 1-5 were performed with using actual equipment because CEMS was expected to have a positive effect on these cases. Test 6-11 were performed only in simulation.

By the combination of these 11 model cases, all possible conditions for the heat source and demands were feasible.

Store Heat Unit

Ordinary	Business hours		Amount of instant heat	
	Plus	Minus	Plus	Minus
①	②	⑥	—	⑦

Release Heat Unit

Ordinary	Business hours				Amount of instant heat			Jam
	Plus		Minus		Plus	Minus		
	sereies	Inter mittent	sereies	Inter mittent		sereies	Inter mittent	
①	③	⑧	⑨	④	—	⑩	⑪	⑤

Red：Include real machine Blue: only simulation

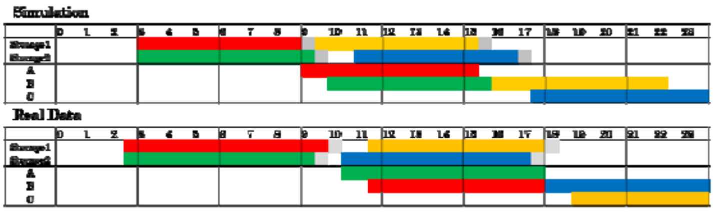
Table 4: Test patterns

7. Test result

Here, the test results of three model cases are explained. Test 1 was performed in a normal condition. Test 2 was performed in an assumed condition that the operating time of heat source was extended. Test 3 was performed in an assumed condition that the operating time of demand was extended.

[Test 1] Operation in a normal condition

In a normal condition, the heat storage unit has capability to charge heat for 4 trucks in a day. The times of heat transfer to A, B and C were arranged respectively once, twice and once in a day. Then, we obtained a large amount of discharge in A (1002MJ) and B (1283MJ). The CO_2 emission reduction resulted in 240.9kg in a day. Table 4 shows the actual results of scheduled heat discharge and the CO_2 emission reduction.



Heat discharge and Reduced CO2

	Heat Discharge at AM	Heat Discharge at PM	Reduced CO2 at AM	Reduced CO2 at PM
Storage1	-	-	-	-
Storage2	-	-	-	-
A	1002		61.7	0.0
B	606	1283	96.4	72.9
C		394	0.0	30.2

Total of reduced CO2
240.9kg

Table 5: The result of Test 1

[Test 2] Extended operating time of heat source

We tested in the condition that the time of truck admission to X was extended. The exit time was put off from 18:00 to 24:00 so that the transfer time was increased. The test showed that this condition provided higher energy-saving effect than a normal condition. The times of heat transfer to A, B and C were arranged respectively once, 3 times and once in a day. The last truck was allowed to transfer heat to B that showed the second higher effect of heat transfer.

If CEMS was not applied, the extended time wouldn't effect on the heat transfer schedule and the time of heat transfer would be the same as in a normal condition.

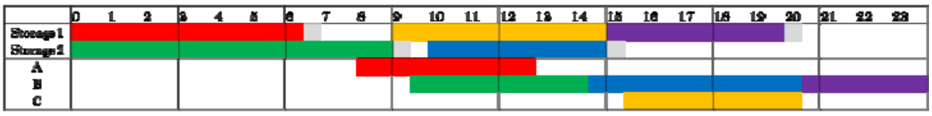
Therefore, in Test 2, it can be said that the heat discharge of 1057MJ by the last truck to B was the efficacy of CEMS. The actual CO_2 emission reduction was calculated to be 254.2kg and the efficacy of CEMS was estimated at 59.8kg.

Heat	Instant Storage	Supply Demand	Time
Unit	150MJ	9 to 24	6h

Table 6: The changed condition for Test 2

Without CEMS

With CEMS



Heat discharge and Reduced CO2

	Without CEMS				With CEMS			
	Heat Discharge at AM	Heat Discharge at PM	Reduced CO2 at AM	Reduced CO2 at PM	Heat Discharge at AM	Heat Discharge at PM	Reduced CO2 at AM	Reduced CO2 at PM
Storage1	-	-	-	-	-	-	-	-
Storage2	-	-	-	-	-	-	-	-
A	664		54.1	0.0	664		54.1	0.0
B	909	1027	51.4	33.1	909	(1027+1057)	51.4	118.0
C		602	0.0	30.6		602	0.0	30.6

	With CEMS	Without CEMS	Effect of CEMS
Reduced CO2(kg)	254.2	194.3	59.8

Table 7: The result of Test 2

[Test 3] Extended operating time of demand (continuously)

We tested that the possibility for increasing heat transfer times when the demand was increased at user's site.

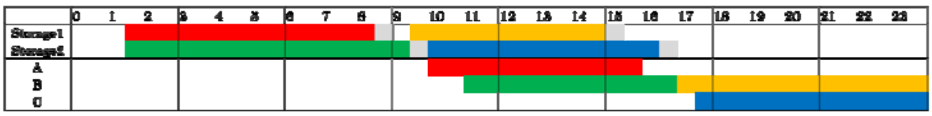
The operating time of A that showed the highest effect of heat transfer was changed to 9:00-30:00 from 9:00-16:00 instead of allowing the extra heat transfer to C that showed the lowest effect.

The actual operation of heat transfer, including twice for A and twice for B, resulted in 260.8kg of CO_2 emission reduction. If CEMS was not applied, the extended time wouldn't effect on the heat transfer schedule and the time of heat transfer would be the same as in a normal condition. In Test 3, the CO_2 emission reduction by CEMS was obtained as 31.2kg from the difference between the actual result of A (in PM) and the simulation result of C (in AM).

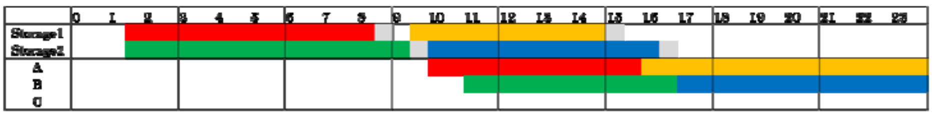
Site	ReduceCO2	Demand Time	Transfer Time	Release Time
A	81.5g/MJ	9 to 30	25min	6～7h
B	56.6g/MJ	9 to 30	30min	6h
C	50.9g/MJ	9 to 30	35min	6h～7h

Table 8: The changed condition for Test 3

Without CEMS



With CEMS



Heat discharge and Reduced CO2

	Without CEMS				With CEMS			
	Heat Discharge at AM	Heat Discharge at PM	Reduced CO2 at AM	Reduced CO2 at PM	Heat Discharge at AM	Heat Discharge at PM	Reduced CO2 at AM	Reduced CO2 at PM
Storage1	-	-	-	-	-	-	-	-
Storage2	-	-	-	-	-	-	-	-
A	665		54.2	0.0	665	1019	54.2	83.0
B	941	1242	53.3	70.3	941	1242	53.3	70.3
C		1019	0.0	51.9			0.0	0.0

	With CEMS	Without CEMS	Effect of CEMS
Reduced CO2(kg)	260.8	229.6	31.2

Table 9: The result of Test 3

Other results of comparative verification for Test 4-11 with/without CEMS are omitted to make the paper short.

8. Consideration

In these verifications, we calculated the CO_2 emission reduction for a year based on the preconditions.

[Preconditions]

- The operation of heat transfer system is implemented for 5 business days in a week through a year (excluding holidays)
- The operation in a normal condition is implemented for 2 days in a week.
- The operation in changed condition is implemented for 3 days in a week
- Regarding the operation in a changed condition, the averaged result of Test 2-11 is assumed to be the result of CO_2 emission reduction per a day.

Based on these preconditions above, the calculated result of CO2 emission reduction in a year was 57.4t. 7.5t of this result was derived by the effect of CEMS.

	week	year
Total reduced CO2	1.1t	58.6t
Effect of CEMS	0.2t	7.7t

Table 10: Annual CO2 emission reduction

9. Conclusion

We demonstrated the heat transfer system in a medium-size regional community in an effort to expanding the area of heat utilization network. First, we defined the basic conditions. Then we implemented the operation of heat transfer system in various assumed situations with using actual equipment or in simulation.

The tests we done resulted in 57.4t of CO_2 emission reduction for a year, and 7.5t of this result was derived by the effect of CEMS.

We have concluded that the effectiveness of off-line heat transfer system was established.

[End]