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Status of Industrial Waste Heat and Heat Trading Practice among District Heating Companies in Korea

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Abstract
Waste heat from industrial sectors of Korea is statistically investigated to assess the potential of energy recovery. The quantities of unused heat ejected by factories are collected through a national wide survey with the aid of a government organization. The data a processed to delineate key statistical features. We found that chemical plants are responsible for more than half of the waste heat generation. Metal processing produces the second largest portion (about 30%). A great majority (83%) of the waste heat is ejected in the form of flue or exhaust gas. The temperature range of the waste heat is analyzed to assess the potential for applicable technologies. We also surveyed the amount of steam trading among neighboring factories and found that that there are virtually no relations between the steam price and quality (or state). The implication is that steam trading occurs mostly through arbitrary contract without meticulous technological or economic considerations. The current steam trading practice leaves ample potentials for improvement and gives hints to policy makers on the future direction of energy policy. The states (pressure and temperature) of the traded steam are sorted to estimate the exergy destructions associated with the accompanying throttling processes that are required to adjust the pressures of the supplier and receiver sides. A thermodynamic analysis on useful energy destruction during the trading processes is included to provide quantitative technological information.

Keywords: industry waste heat in Korea, recovery potential, steam trading, industrial district heating

INTRODUCTION

As an industrialized country, industry sector consumed almost 60% (115 Mtoe) of total (194 Mtoe) energy in 2012[1]. Building and commerce sector (19.2%) and transportation sector (19.1%) share about the same consumption and the remaining portion (less than 4%) is used by the public sector. Unfortunately, we imported 253 Mtoe of oil and gas in the same year, and the imported portion of the energy supply constitutes 96.5% of the total supply. This unusually high dependence on overseas oil and gas has been posing lingering threats to the healthy growth and development of economy for a long time, and we have every good reason to do our best efforts to save energy. As seen in Figure 1 steady growth in energy consumption by industry section is evident.

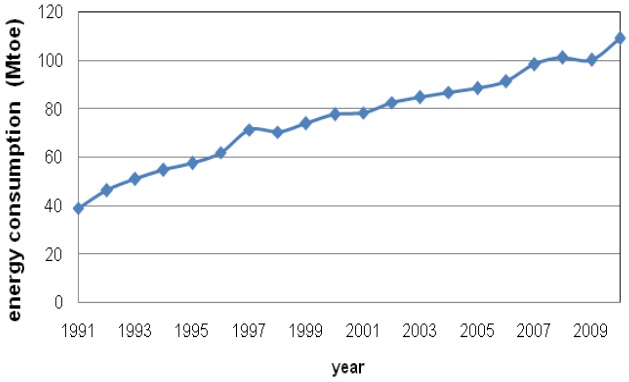

Figure 1: Growth of energy consumption by industry.

As industry is one of the major consumers of energy, industry energy has been a popular research topic for researcher from many countries for a long time. Limiting our attention only to most recently development, we still can find numerous publications: Saidur and Mekhilef [2] studied energy use and savings for Malaysian rubber industry, Hong et al [3] analyzed energy flow in pulp and paper industry, and estimated energy saving potential in Taiwanese textile industry [4]. Heat recovery is a popular topic among researchers. For example, Seck et al [5] developed a detailed model to study heat recovery with heat pumps for French food and drink industry and Ammar et el[6] investigated low grade thermal energy sources for UK process industry. Rich sources of information for other industry energy related topics are also available including CO_2 and greenhouse gas reduction [7-9], efficiency and conservation[10-14] and operation strategy[15-17].

In this study, we will try to present the general statistical characteristics of industry energy consumption in Korea and try to estimate the potentials for recovery. The first step to find where we should focus our attention would be to recognize which sectors of the industry section consume most energy. Figure 2 shows the distribution of energy consumption by industry sectors for 2010. We can easily expect that petro-chemical and metal industry would consume most energy considering the fact that our country has strong production industry. The two sectors are responsible for 78% of total energy consumption by industry as a whole.

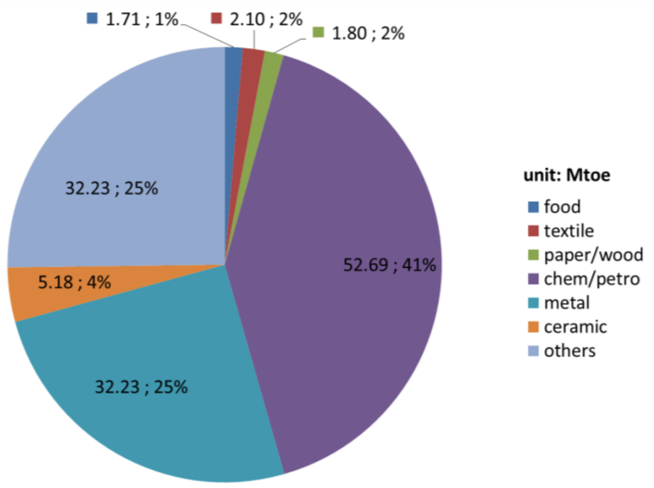

Figure 2: Industry energy consumption by sectors in Korea

To estimate the potential for the waste energy recovery from the industry, we will present related statistics obtained through a survey with the aid of a government agency. Another area of interest is to find the current situation of district heating business practices because we have more than 20 such companies. We will I investigate the amounts of energy exchange through steam trading among companies. To evaluate the soundness of steam trading, the relation between the steam quality and price will be investigated along with the exergy destruction associate the energy exchange.

STATUS OF WASTE ENERGY BY INDUSTRY

Estimation of waste heat quantity

As a government corporation responsible for the management of the national energy, Korea Energy Management Corporation (KEMCO) collected data by surveying the factories all around the country of Korea. They got a reply from about two-thirds of the factories, and the quantity of energy consumed by the replied factories is 77.7 Mtoe. The reply contained the estimations on how much energy is actually used their processes and how much wasted. Based on the data, we estimated the amount of waste energy, and the results are summarized Table 1. The combined waste energy (or the recovery potential) for our nation reaches about 11.7% of all the energy consumed by industry. Comparing with 9.63% for Japan, this number is about 20% higher.

Figure 3 shows the relative importance of each sector of industry in waste heat recovery. The general trend is similar to Figure 2. About 75% of the total estimated heat recovery is from the leading two sectors: petro-chemical and metal industry. As heavy and chemical industries are the principal stream of Korean industry dominance by the two sections is no surprise.

Table 1: Estimated waste process heat

Industry	Energy purchase (A) (TOE)	Recovery potential (B) (TOE)	Ratio B / A
Food	1,612,000	157,766	0.097
Textile	3,504,000	612,752	0.174
paper/wood	2,226,000	153,744	0.069
chem/petro	36,227,000	4,414,425	0.121
metal	21,926,000	2,985,623	0.136
ceramic	5,637,000	87,375	0.016
Others	6,658,000	757,444	0.114
Sum	77,790,000	9,169,129	0.117

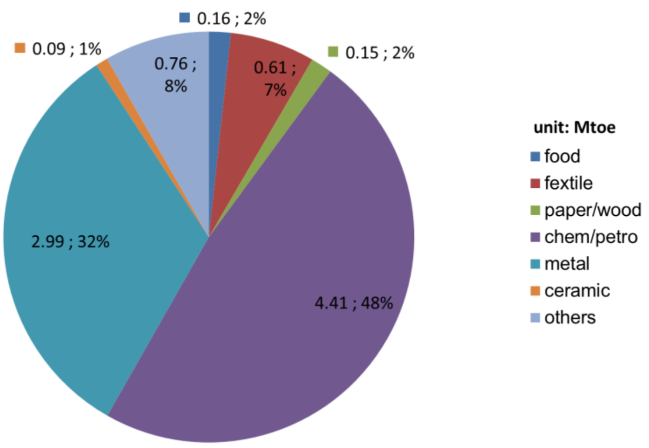

Figure 3: Recovery potential by industry sectors

When it comes to designing utilization facilities factors such as the forms of waste energy and the temperature ranges are important. In Figure 4, the compositions of the waste energy forms are presented. Most of the waste energy is exhausted in the form of hot gas.

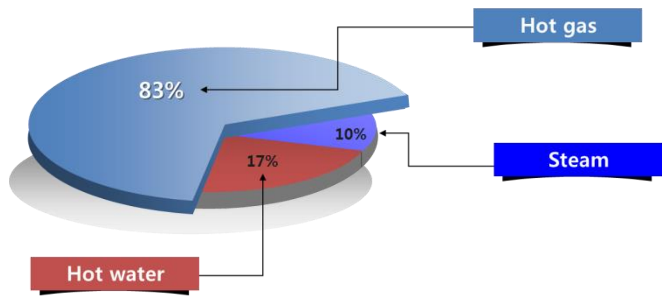

Figure 4: Distribution of forms of waste energy [18].

Figure 5 shows the temperature distribution for wasted hot gas. From the technological point of view, the ranges are high enough to build heat exchangers for space heating and hot-water supply. Depending on the characteristics of processes exhausted gas may be utilized for subsequent processes. Most of the wasted heat also can easily be used as heat sources for absorption chillers or adsorption chillers during summer seasons.

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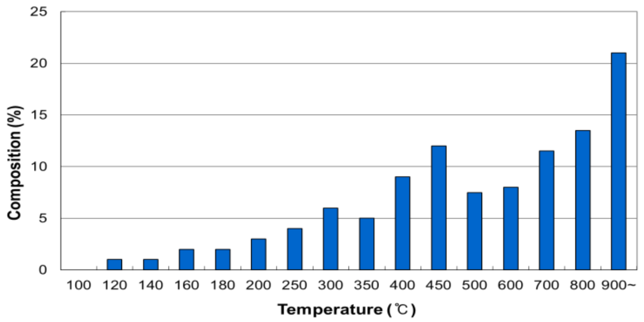

Figure 5: Temperature ranges for wasted hot gas [18].

Figure 6 shows the temperature range for wasted hot water. Here, the temperatures are relatively low and only direct use as a heat source for space heating is advisable. During summer, hot water may drive single-effect absorption chillers or multiple effect ones with added heat from other sources such as gas-fired heaters.

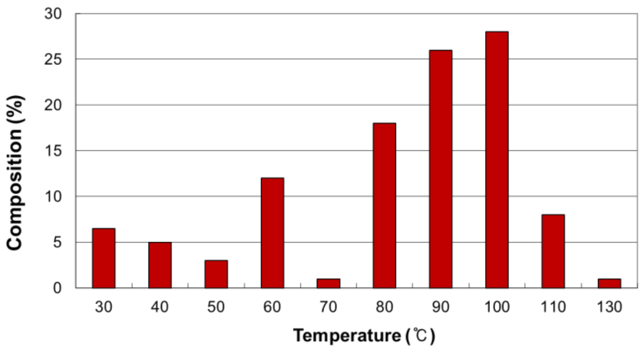

Figure 6: Temperature ranges for hot water [18].

Figure 7 shows the temperature distribution for wasted hot steam. This time, we can see a great potential for recovering and reusing including power generation. With modern technologies such as organic Rankine cycle [19, 20, 21], a large portion of the wasted heat by hot gas can be easily exploited. With this high temperature, recovered heat can also be reused in wide variety of processes if we develop an efficient heat exchanging or trading systems.

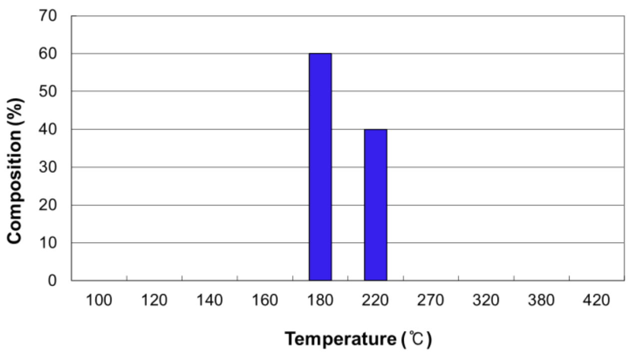

Figure 7: Temperature ranges for wasted steam [18].

INDUSTRIAL DISTRICT HEATING

District heating business in Korea

There are two categories of district heating business in Korea depending on where the energy is supplied: residential/commercial and industrial area. In this paper, the focus is on only the industrial district heating. Figure 8 shows the growth of the number of district heating companies. Up to 2007 there were about 20 companies and the number started to increase from 2007. As of 2010, there are 27 district heating companies in business. Figure 9 shows the total annual sales of energy by all companies. It can be observed that the size of the sales resembles the trend of the number of companies.

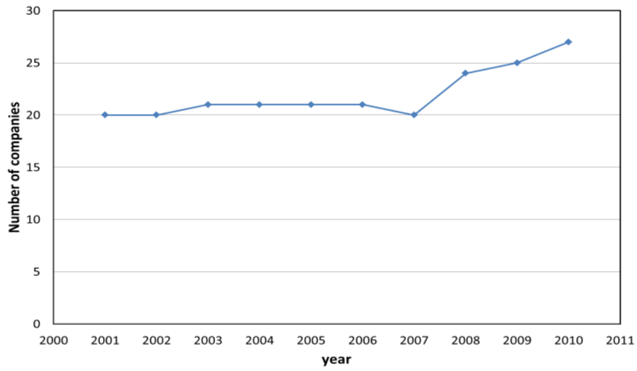

Figure 8: Number of district companies.

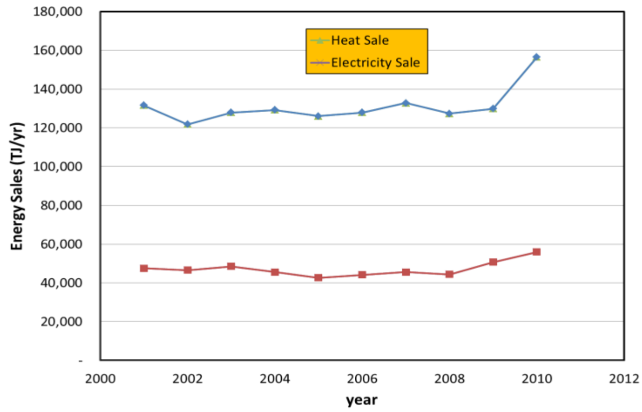

Figure 9: Total sales of energy.

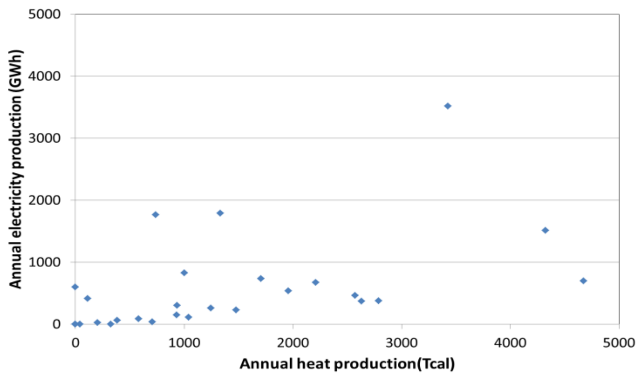

Figure 10: Energy production profile.

Figure 10 presents the annul heat and electricity production profiles. Each data point in the figure represents the energy production by the 27 individual companies. There is a large variation in the size of company and the energy production. Figures 11 and 12 show the details of how the electricity and heat energy are produced by each surveyed company.

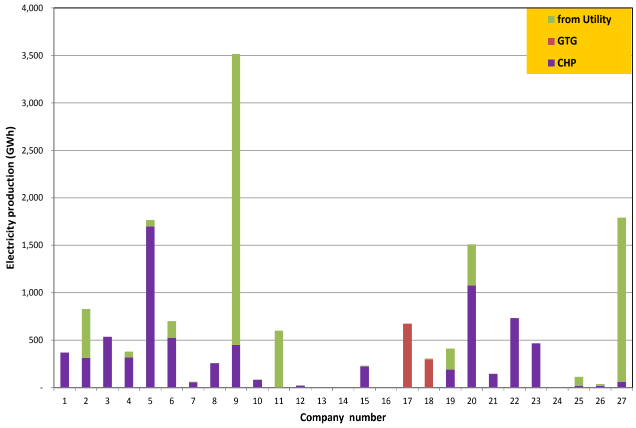

Figure 11: Electricity production profile.

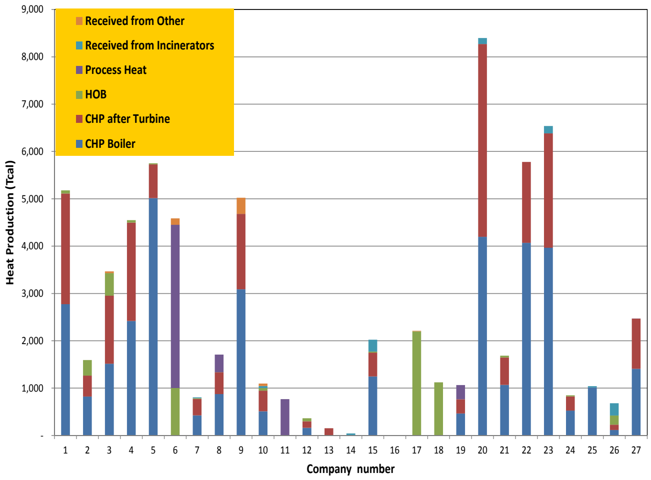

Figure 12: Heat production profile.

Steam trading profile

One of our primary interests is to find if there are any consistent trends in the trading price. For this purpose, we investigated how much energy is traded at what states. We used temperature and pressure as the two required thermodynamic properties to designate a state. Our survey results are plotted in Figure 13 as a bubble chart. The size of the bubble represents the relative amounts of the energy trading. The temperature varies from about 100ºC to 500 ºC while pressure varies over the range of 5 to 55 bars. As expected, the last manufacturing process that followed by the heat ejection of as a waste determines the states of steam, and they are strongly dependent on the products and processes.

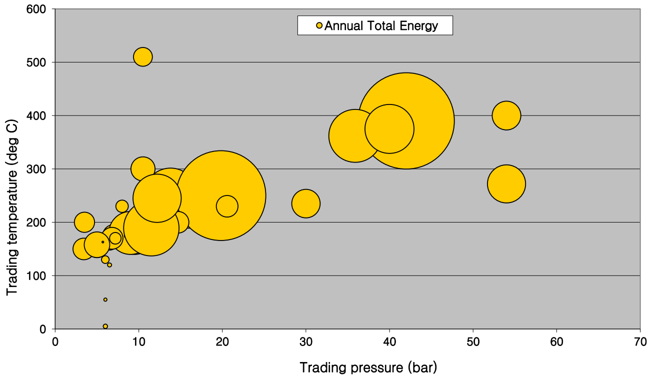

Figure 13: Heat trading states and relative quantities.

Loss associated with throttling process in steam trading

We found that throttling processes are widely used to match steam pressures of the supplying and receiving sides. A thermodynamic analysis is performed to assess potential loss of work and the adequateness of price of steam trading based on energy value from a point of physics. Referring to Figure 14, steam is extracted at state 1, which depends on the associated processes. Then the pressure is adjusted to the value specified by the buyer side. Usually, this process can be represented as a throttling process because no heat or work is transferred during the process. Enthalpy is preserved in accordance to the first law of thermodynamics for a steady state open system [22]. The final state is marked as state 2 in the figure.

One of the widely adopted techniques to estimate the size of the destruction of useful energy is using the concept of exergy. We use the similar concept here with a slight modification to make our point easier to understand. Our approach is to simply estimate the work production by a steam turbine when the extracted steam expands to a specified pressure. Usually, it is assumed to expand to a dead state of the environment when exergy analysis is performed. Applying the first law of thermodynamics the work production is

$$w_t = h_{inlet} - h_{exit} \tag{1}$$

where w_t is work production per unit mass of working fluid and h_{exit} and h_{inlet} are enthalpy values of the fluid. In the figure, steam with higher values of entropy (a point located on the right side of the *T-s* diagram) will produce less work when expanded to the same terminal pressure. This can be explained as flows: The inlet enthalpy is assumed to be the same because a throttling process is adopted for pressure matching. According to Eqn (1), the work production is larger when the exit enthalpy value is smaller. The Gibbs equation (or the Tds equation), $Tds = dh - vdP$, tells us that enthalpy will increase ($dh > 0$) as entropy increases ($ds > 0$) along a constant pressure line ($dP = 0$). This means that the enthalpy value for the exit is higher when entropy is smaller when pressure remains the same, In other words, the point located on the right side in Figure 14 will have larger values of enthalpy and produce less work than the point on the left. Quantitatively speaking the shaded area surrounded by the four points a-b-4-3-a in the figure represents the lost work during the throttling process of 1-2.

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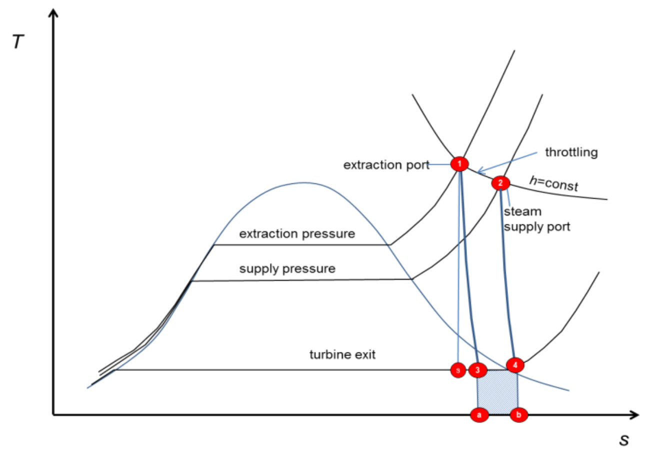

Figure 14: T-s diagram for a steam extraction process.

Steam trading price

From a purely physical point of view, the value of the traded steam should be determined by the thermodynamic state alone because work producing potential is fixed by Eqn (1). We investigated the relation between the price and thermodynamic property values. Enthalpy is the primary variable in assessing the value of steam from the first law of thermodynamics. We plotted the trading price versus enthalpy values for the steam at the trading states. We used REFPROP 8.0 [23] in our thermodynamic calculations.

Figure 15 shows the relation between enthalpy of the steam and trading price. To our surprise, there is almost no relation between the two parameters. This means that the power production or heat delivery potential of the traded steam in not a primary variable as far as steam price is concerned. Although we did not ask specifically to the companies, it is evident that steam trading occurred based on opportunistic variables such as ease of transportation or mutual trust between the trading parties.

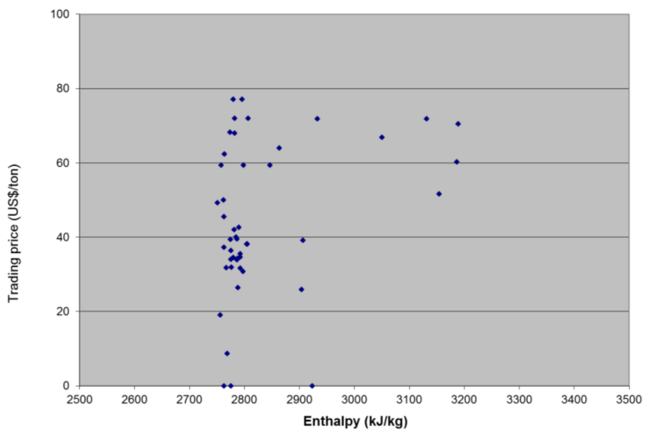

Figure 15: Relation between enthalpy and price.

**A exchange rate of 1100 KRW/US$ is applied through this study*

Similar trend is observed when we plotted the price-temperature relation because temperature is the primary property that determines the value of enthalpy.

One of the issues during the power crisis we experienced during the late months of 2012 was that there was almost no spontaneous electricity production by the district heating company, even from the companies specifically designated for power production. Those companies had excuses that if they produce electricity and sell it, their income would be less than the income by selling steam itself (as a form of thermal energy). We studied this case by investigating the steam trading price in relation to electricity selling by power production. For a consistent comparison, we assumed that.

- at point 3 in Figure 14, the turbine exit pressure is fixed at 0.005 MPa and quality is 0.9.
- and the turbine isentropic efficiency is 90%.

With these assumptions, state 1 in Figure 14 is determined once the inlet pressure is specified. Then we can calculate the power production per unit mass with Eqn (1). In Figure 16, actual steam trade price and expected income by selling electricity (produced by the imaginary processes mentioned above) are plotted together. Here we made four electricity selling scenarios at 70, 90, 110, and 180 cents per kWh. Actually, the electricity selling price in Korea is lower than the lowest value of 70 cents/kWh in the figure.

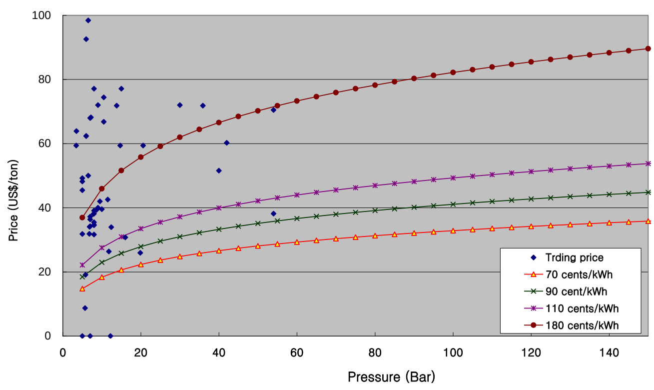

Figure 16: Steam trading price versus pressure.

It is evident from the figure that the actual stream trading is far more lucrative than producing electricity. This is a baffling result to the government because this strongly signifies that the electricity price is very low in relation with the price of thermal energy. There has been a continual argument regarding the adequateness of the electricity price in Korea. The result from this study clearly (and quantitatively) shows that Korea needs adjustment in relative energy prices for more rational consumption of energy for the interest of public in general. The authors believe that social parameters such as price should properly reflect the values of natural resources estimated from a point of law of nature. As our experience and common sense suggest, any artificial or excessive bending of natural tendency by the name of policy will inevitably invite certain backfire when the direction is against the natural tendency of nature. At the center of the natural tendency are the laws of nature, the 1st and 2nd laws of thermodynamics.

CONCLUSIONS

In this paper, we presented energy consumption characteristics industry section of Korea. We also presented district heating business profiles and steam trading market prices. Through this study, we can find the following points that are important in understanding the current status and future planning of district heating in Korea.

- Industry waste heat originates from two major sectors: petro-chemical and metal industry. We need to focus our management plan on the two sectors.
- Hot gas is the dominant form of waste. This is good news in the sense that we have a great potential for recovery due to high temperature. Treating toxic exhaustion must be considered together.
- District heating business in Korea is not neatly organized as yet. The size and the amount of traded energy vary substantially among companies. A well-structured management plan from the administration side (government) can increase the effectiveness of the business significantly.
- There are no rational rules for pricing traded steam. The physical quality of steam is not the primary parameter that determines the price. This is not healthy from the market order point of view, and we may need a guideline for pricing steam.
- The ratio of electricity price to that of heat is very low, and this is one of the main obstacles that hinder healthy function of autonomous market. Our government needs to improve the ratio to the level of global average. A badly distorted price system inevitably destroys the natural order of the market. There is not much room for good practice once the market is severely distorted.

NOMENCLATURE

Abbreviation

KEMCO	Korea Energy Management Corporation
Mtoe	Million tons of oil equivalents (41.9 PJ)
KRW	Korean Won 1,100 KRW=1 US$

Symbols

h	specific enthalpy (kJ/kg)
P	Pressure (bar)
T	temperature (ºC)

Subscript

i	turbine inlet

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