The Joint Graduate School of Energy and Environment

King Mongkut's Institute of Technology North Bangkok

Phranakhon Rajabhat University

7th International Symposium of High Temperature Air Combustion and Gasification (HiTAACG 2008)

HiTACG for Sustainable Bioenergy Development

In conjunction with
2nd National Conference on Biomass
and Waste Gasification for Power Generation

January 13-16, 2008, Phuket, Thailand

PROGRAM OF SYMPOSIUM

Jointly Hosted By

The Waste Incineration Research Center
King Mongkut's Institute of Technology North Bangkok

Fuels, Combustion and Emission Control Research Group
The Joint Graduate School of Energy and Environment

Sustainable Energy Research Centre
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HiTACG2008

PROCEEDINGS

7th International Symposium of High Temperature Air Combustion and Gasification (HiTACG 2008)

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Home

Introduction

Committee

Plenary

Presentation

PROCEEDINGS

This is the **PROCEEDINGS** of The 7th **International Symposium of High Temperature Air Combustion and Gasification (HiTACG2008)** in conjunction with The 2nd **Biomass and Waste Gasification for Power Generation Conference**, organized by ***The Waste Incineration Research Centre (WIRC)*** *of* **King Mongkut's Institute of Technology North Bangkok (WIRC)** with **The Joint Graduate School of Energy and Environment (JGSEE)** of **King Mongkut's** *University Technology Thonburi* and **Sustainable Energy Research Centre** of **Pranakorn Rajabhat University**, during January 13 - 16, 2008 @ Phuket, Thailand.

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LEMBAR PENGESAHAN

Judul : The Influence of Power Loss Coefficient and Others Factors to The Primary Energy Saving of a Cogeneration Power Plant in Thailand

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Introduction

PROCEEDINGS

7th International Symposium of High Temperature Air Combustion and Gasification (HiTACG 2008)

in conjunction with

2nd National Biomass and Waste Gasification for Power Generation

INTRODUCTION

- Following the very successful six symposia in Japan, Taiwan, Italy and Germany, this international symposium will *provide a forum for exchange of information* on the latest developments in high temperature air combustion and gasification technology worldwide. Specifically it will be most beneficial to combustion scientists and engineers, fuel technologists, environmental engineers and engineers and scientists engaged in the design and development of power equipment and for information exchange on the potential use of high temperature air combustion and gasification technology. The focus of the 7th HiTACG Symposium will be to provide information on latest developments and commercial application of this technology.

- The symposium will be beneficial to researchers and engineers from academia, industry, research labs and government working in the energy and environmental area worldwide, in particular from Asia, Europe and USA.

- **High Temperature Air Combustion** concerns a process technology, that allows substantial advantages in energy and quality and in reduced noxious emissions. The preceding Symposium have been in Japan and other countries; the forthcoming 7th edition will be in the Phuket, the heaven island, and are hosted jointly by King Mongkut's Institute of Technology North Bangkok, The Joint Graduate School of Energy and Environment and Phranakhon Rajabhat University , an association of many members in the domain of combustion application.

- No breaking new discovery comparable to the original, conceptual introduction of flameless or high air temperature or mild technologies has been produced after the last symposium. However, practical, successful applications in several industries have gone farther ahead and much progress has been made. At the same time academic and R&TD works have further investigated fundamental aspects and improved the computational skill quite a bit. The ancient prophesy on the prospective cost increase of primary energy seems close by: every petrol fill up reminds us that it will be more and more convenient to invest in saving technologies no matter what initial efforts are required for new advanced plants. HiTACG is certainly part of the answer.

- **The symposium is the best** opportunity to update the state of the art and to **meet qualified participants** (well in excess of hundred), coming from many countries (more than 10 nations) and from next door, in the number-1 country, as far as plant / process engineering is concerned.

- The 7th International Symposium of High Temperature Air Combustion and Gasification (HiTACG 2008) will be held in conjunction with the 2nd National Conference on Biomass and Waste Gasification for Power Generation which was organized the first conference on November 24th, 2006. The area of conference will expand to cover the application of High Temperature Air Combustion and Gasification for Sustainable Bioenergy Development. Consequently, the theme of symposium will be

"HiTACG for Sustainable Bioenergy Development"

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Committee

PROCEEDINGS

7th International Symposium of High Temperature Air Combustion and Gasification (HiTACG 2008)

in conjunction with

2nd National Biomass and Waste Gasification for Power Generation

Home
Introduction
Committee
Plenary
Presentation

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Home

Presentation

PROCEEDINGS

7th International Symposium of High Temperature Air Combustion and Gasification (HiTACG 2008)

in conjunction with

2nd National Biomass and Waste Gasification for Power Generation

PRESENTATION SESSION

Reference No.	Full Paper Title	Autho
HiTACG_104	R&D ON HIGH TEMPERATURE STEAM GASIFICATION PROCESS OF SOLID WASTES	Kentaro Umeki, Tomoal Kunio Yoshikawa
HiTACG_105	COMBUSTION KINETICS AND REACTIVITY OF CHAR FOR COCONUT SHELL PYROLYSIS	Tsamba, Alberto J., Yar Blasiak Woldzimierz
HiTACG_106	PERFORMANCE DEMONSTRATION OF A GASIFCATION AND POWER GENERATION FACILITY FOR CHICKEN MANURE BY A LONG-TERM CONTINUOUS OPERATION	Tsutomu Hara, Hiroaki Shiihara, Takuma Naka Yoshikawa
HiTACG_107	PERFORMANCE ANALYSIS OF BIOMASS GASIFICATION PROCESS BASED ON THERMODYNAMIC EQUILIBRIUM MODEL	Woranuch Jangsawang
HiTACG_108	SELECTION OF GASIFICATION AGENTS FOR HYDROGEN RICH GAS PRODUCTION FROM BIOMASS GASIFICATION FOR APPLY IN FUEL CELL APPLICATIONS	Rajesh S Kempegowda, and S.Assabumrungrat
HiTACG_109	HIGH TEMPERATURE DESULFURIZATION TO UPGRADE BIOGAS FOR UTILIZATION IN FUEL CELLS	Rajesh S. Kempegowda Laosiripojana
HiTACG_110	SUSTAINABLE BIOMASS ENERGY IN THAILAND FIRST RESULTS FOR SUGAR INDUSTRY AND BIOFUELS	Werner Siemers
HiTACG_111	GASIFICATION OF BIO-SLUDGE IN SUPERCRITICAL WATER STREAM	Anatoli Vostrikov, Oxar Andrey Shishkin, Dmitry Sokol
HiTACG_112	SUPERCRITICAL WATER CONVERSION OF COAL AT CONTINUOUS SUPPLY OF COAL-WATER SLURRY	Oksana Fedyaeva, Anat Dmitry Dubov and Mikh

HITACG_113	APPLICATION OF MECHANICALLY ACTIVATED FINE COALS IN POWER ENGINEERING	Alekseenko C.B., Burdu V.I., Motorin A.V and Y
HITACG_114	NUMERICAL STUDY ON THE SPRAY COMBUSTION IN HIGH TEMPERATURE AIR COMBUSTION	M.R. Baig Mohammadi, A. Mardani
HITACG_115	ENTRAINED-FLOW GASIFICATION OF BIOMASS-BASED SLURRY - INVESTIGATIONS ON ATOMIZATION AND FUEL CONVERSION	Thomas Kolb and Nikol Santo and Emmanouil F
HITACG_116	HIGH EFFICIENCY TAR REMOVAL FROM BIOMASS PYROLYSIS GAS BY REFORMING AND ADSORPTION	Thana Phuphuakrat, Hi Tomoaki Namioka and I
HITACG_117	THE ROLE OF HYDROGEN ADDITION ON THE STRUCTURE AND STABILITY OF HYDROCARBON FLAMES IN A JHC BURNER	Paul R. Medwell, Peter Bassam B. Dally
HITACG_118	COMPARTMENTED FLUIDIZED BED GASIFIER FOR SYNGAS AND POWER GENERATION USING BIOMASS	V.S. Chok, S.K. Wee, A. and H.M. Yan
HITACG_119	EXPERIMENTAL AND COMPUTATIONAL STUDY OF COMPARTMENTED FLUIDIZED BED GASIFIER (CFBG)	S.K. Wee, V.S. Chok, A. and H.M. Yan
HITACG_120	FABRICATION OF HYDROGEN-SELECTIVE THIN PALLADIUM MEMBRANE ON A POROUS YSZ TUBE VIA ELECTROLESS PLATING	Mettaya Kitiwan, Yoshit Toshishige M. Suzuki
HITACG_122	OPPORTUNITIES FOR PRODUCTION OF BIO-DIESEL FROM ALGAE	Khanh Qaung Tran and
HITACG_124	EXPERIMENTAL INVESTIGATION OF A PARALLEL JET MILD COMBUSTION BURNER SYSTEM	Grorge Szego, Bassam Graham J. Nathan
HITACG_126	INVESTIGATING THE POTENTIAL OF ELECTRICITY GENERATION FROM MUNICIPAL SOLID WASTE	Dinesh Surroop, Yang V Wlodzmierz Blasiak and
HITACG_127	FEASIBILITY STUDY ON THERMAL TREATMENT OF MUNICIPAL SOLID WASTE IN NONTHABURI PROVINCE, THAILAND	P. Chuttrakul, T.Ginsbe M. Norasignh
HITACG_128	COMBUSTION CHARACTERISTICS OF FLUIDIZED BED COMBUSTION USING PALM SHELL FUEL	Rosyida Permatasari, M Mohd. Ja'afar and Moh
HITACG_129	COMPLETE WASTE RECYCLING TECHNOLOGY BY CONVERTING TO SYNTHESIS GAS AND SLAG	Hyup-Hee Lee, Ji Eun L Jae Hoi Gu, Su Hyun Ki and Yong-Chil Seo
HITACG_131	DEVELOPMENT OF WASTE PYROLYSIS AND GASIFICATION SYSTEM: PYROLYSIS CHARACTERISTICS OF WASTES IN A LOW-TEMPERATURE PYROLYZER	Ju Won Park, Sang Shi Won Yang
HITACG_132	HIGH TEMPERATURE AGENT GASIFICATION OF MISCANTUS PELLETS	Christian Sacchet, Anna Swiderski, Weihong Yar Blasiak

HITACG_133	ADVANCED DIAGNOSTICS OF FLAME/FLOW STRUCTURE IN LEAN PREMIXED COMBUSTION CHAMBERS	Sergey V. Alekseenko, Yury S. Kozorezov, Dmi and Sergey I. Shtork
HITACG_134	HEAT TRANSFER AND HETEROGENEOUS CHEMICAL REACTIONS CAUSED IN THE PYROLYSIS OF WOODY BIOMASS	Ken-ichiro Tanoue, Tat Tatsuo Nishimura, Miki Ken-ichi Sasauchi
HITACG_135	EXPERIMENTAL CHARACTERISATION OF BIOMASS PARTICLES COMBUSTION UNDER MICROWAVE ENERGY	*ADEYEMI Waheed and*
HITACG_137	SAMPLING AND ANALYSIS OF TAR FROM BIOMASS GASIFICATION IN BUBBLING FLUIDISED-BED REACTOR	Sommas Kaewluan and Pipatmanomai
HITACG_138	DEVELOPMENT OF SMALL-SCALE GASIFIER FOR WOODY BIOMASS	Miki Taniguchi, Kenichi Chuiju, Yusuke Ito and
HITACG_139	DEVELOPMENT OF A DOWNDRAFT ENTRAINED FLOW TYPE GASIFIER FOR BIOMASS	Futoshi Akasaka, Tomo Kunio Yoshikawa
HITACG_140	FLAME EMISSION SPECTROSCOPY IN A CONVENTIONAL AND A HTAC BURNER OPERATING IN A PILOT SCALE FURNACE	Thangam Parameswara Richard Lacelle, Abdel I Wong
HITACG_142	PRODUCT YIELDS AND KINETIC PARAMETERS OF BIOMASS STEAM GASIFICATION IN A DROP-TUBE/ FIXED-BED REACTOR	Janewit Wannapeera ar Pipatmanomai
HITACG_143	APPLICATION OF FLAMELESS OXIDATION IN GLASS MELTING FURNACES GLASFLOX TM	Anne Giese, Uwe Konol and Klaus Görner
HITACG_144	THE INFLUENCE OF POWER LOSS COEFFICIENT AND OTHER FACTORS TO THE PRIMARY ENERGY SAVING OF A COGENERATION POWER PLANT IN THAILAND	Harmen Burhanuddin, C and Dusan Gvozdenac
HITACG_145	DEVELOPMENT OF A STRATIFIED DOWNDRAFT GASIFIER FOR SMALL SCALE COMBINED HEAT AND POWER GENERATION PURPOSES	Wirachai Soontornrangs Utistham and Sophon P
HITACG_148	IMPROVEMENT OF DEWATERABILITY OF SEWAGE SLUDGE BY HYDROTHERMAL TREATMENT	Ryosuke Yamane, Yosh Tomoaki Namioka and
HITACG_149	NUMERICAL SIMULATIONS OF GAS RECIRCULATION FOR CDC COMBUSTOR	Vaibhav K. Arghode an
HITACG_150	MODELING OF CHEMICAL-LOOPING COMBUSTION IN A BUBBLING FLUIDIZED BED	*Sung Real Son, Kang S* Sang Done Kim and Ho
HITACG_151	CARS AND HEAT FLUX MEASUREMENTS IN HTAC AND CONVENTIONAL INDUSTRIAL-SCALE BURNERS	P. M. Hughes, R. J. Lac Legere, D. Percy, J. Wo Parameswaran and P. C
HITACG_152	FLAMELESS OXIDATION IN GAS FIRED RADIANT TUBES	Joachim G. Wünning
HITACG_154	OPERATING EXPERIENCE OF THE SECOND GENERATION CHEMICAL-LOOPING COMBUSTOR	Ho-Jung Ryu, Chang-Ke and Moon-Hee Park

THE INFLUENCE OF POWER LOSS COEFFICIENT AND OTHER FACTORS TO THE PRIMARY ENERGY SAVING OF A COGENERATION POWER PLANT IN THAILAND

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Abstract: ***For CHP plants which include fully or partially condensing steam turbine, electrical/mechanical electricity generation will decline as steam extraction increases for a given fuel energy consumption, hence there needs a balance between increasing heat energy recovery and reducing electrical/mechanical energy output assuming a constant fuel energy input. Through a daily energy supply data over a year in one of the cogeneration power plants in Thailand, the influence of power loss coefficient to Primary Energy Saving (PES) or efficiency is analyzed. Power loss coefficient used in the calculations was defined as per the basic theory of power loss coefficient in CHP Manual by EU Parliament and CHP Methodology by UNFCCC. Calculation of saving of primary energy according using cogeneration system follows the EU Manual; setting of CHP overall efficiency must be same with overall efficiency of power plant. Power loss coefficient just makes senses for calculation of power generated by CHP mode. Variations of the reference values for the calculation of the PES are shown as the reference values (RV) of both electrical and heat efficiency have a very big influence on the PES criteria. Other factors, like "credits" for distributed generation and the influence of the ambient temperature on the RV are shown as well.***

Key Words: CHP, PES, Reference Value, Power loss coefficient

1. INTRODUCTION

Cogeneration power plants produce electricity, heat and other types of target energy simultaneously within single energy plant and are also called Combined Heat and Power (CHP) plants. The simultaneous production of more than one form of useful energy within single energy plant is normally saves, the so called Primary Energy Saving (PES), in addition it can improve the power plant efficiency and so it becomes more economical and can minimize environmental impact of a power plant. As CHP can contribute to PES, the recent revision of the IPP (independent power producer) and the SPP (small power producer) program in Thailand by EPPO and the MoE's criteria based on PES was included to promote Cogeneration and CHP in Thailand. While applying the PES criteria, several problems may occur and it is necessary to define several parameters and factors to ensure that the intention of PES through CHP is realized. This paper describes some aspects to be considered when using the PES approach to promote CHP in Thailand.

The extraction of heat from an existing power plant results in a loss of electricity generation, i.e. the project activity resulted in a substitution of power generation by heat generation, with a substitution factor defined as *power loss coefficient* β. This substitution may result in less electricity generation in the existing plant and/or increasing the fuel combustion in the existing power plant in order to compensate for the losses of electricity due to the extraction of heat.

In practice, both effects may take place at the same time, for example, the lower electricity generation due to the extraction of heat may partly – but not fully – be compensated by operating the plant at higher load factor. This paper present the influence of power loss coefficient to primary energy saving.

Another parameter that has implication to the PES is efficiency reference value for separate production of heat and electricity which is described as how much the influence of this parameter to the PES is shown in this paper as well.

2. CONCEPT OF PRIMARY ENERGY SAVING

The concept of Primary Energy Saving (PES) as criterion for evaluation of energy system (in this case cogeneration one) is based on comparison of efficiencies of electricity and heat generation for cogeneration and conventional energy system where electricity and heat are generated independently.

Definitions and implementation conditions of the criteria have been changed and complemented in time. Its need several improvements of the PES concept for practical application later.

Unambiguous advantages of cogeneration technologies in increasing energy efficiency compared to conventional systems and expecting their contribution in electrical energy generation on national level request obvious and real government support of each country. The CHP EU Directive has to be assumed only as initial document which are determines the directions how the local regulations have to be developed [1].

CHP Manual [2] is a guidance for calculation and evaluation of power, heat, and fuel in CHP mode of the existing and new cogeneration energy systems. Because EU governments just give incentive to amount of power that is generated in CHP mode, therefore the estimation of real potential in energy savings in comparison to the conventional energy systems, the EU manual needs a little correction. This manual was used to evaluate one of the SPP in Thailand and the result is presented in this paper. Figure 1 show the schematic diagram of the SPP plant. There are three gas turbines (GT) with three heat recovery steam generator (HRSG) and one steam turbine (ST) in one block. The values shown in figure 1 are an average daily data in a year.

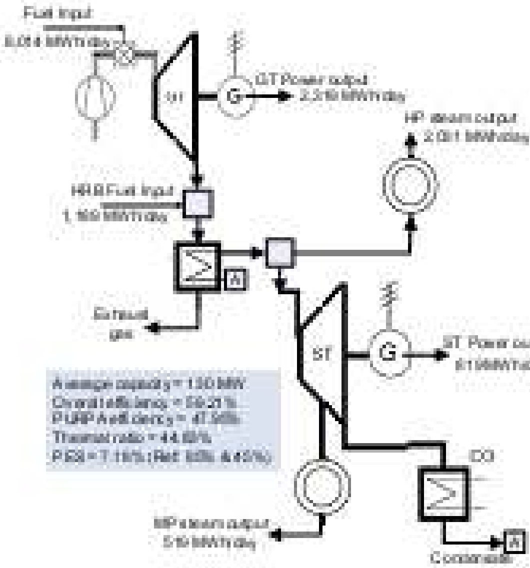

Figure 1 Schematic diagram of the SPP cogeneration power plant

To determine the PES, EU Directive annex III [3] can be used. The formula is given in equation 1.

$$PES = 1 - \frac{1}{\frac{CHP\ H\eta}{Ref\ H\eta} + \frac{CHP\ E\eta}{Ref\ E\eta}} \quad (1)$$

Based on the methodology from the CHP Manual, PES of the plant can be calculated. The results are shown in Table 1 for two overall efficiencies (η_{all}), two reference values of electrical efficiency (Ref Eη) and reference values of heat efficiency (Ref Hη), and two power loss coefficient (β) in average annual data. If overall efficiency is lower than 80%, PES just depends on the reference value of electrical and heat efficiency, but if overall efficiency is same or more than 80%, PES depends on both references values of electrical and heat efficiency and power loss coefficient. Figure 2 and Figure 3 show the sensitivity of PES to overall efficiencies that lower than 80% (actual overall efficiency) and to overall efficiencies that we assume equal to 80% respectively.

Table 1 PES for difference reference values and difference power loss coefficient

PES	CHP η_{all} = 59.21%		CHP η_{all} = 80%	
	β = 0.156	β = 0.185	β = 0.156	β = 0.185
Ref 1: Eη = 41.53% Hη =83.72%	12.98%	12.98%	25.97%	25.38%
Ref 2: Eη = 45% Hη =85%	7.18%	7.18%	21.98%	21.42%

PES ref 1 mean, PES is calculated by using the reference value of electrical and heat efficiency which is 41.53% and 83.72% respectively. PES ref 2 mean, PES is calculated with the use of reference value of electrical and heat efficiency which is 45% and 85% respectively. Negative values of the primary energy saving mean that, the CHP system consumes more fuels than the separated conventional power and heating system. Therefore optimal operation mode must be set to get benefit from cogeneration plant according to primary energy saving.

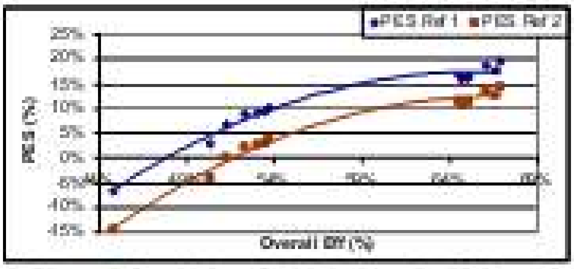

Figure 2 Sensitivity of PES to overall efficiency for CHP η_{all} = 59.21%.

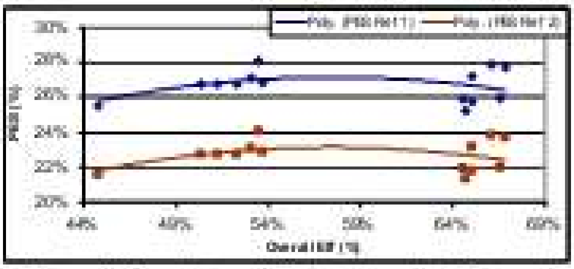

Figure 3 Sensitivity of PES to overall efficiency for CHP η_{all} = 80%.

From Figure 2, PES of the overall efficiencies is lower than 80%. The trend shows that the PES increases at higher overall efficiency. Figure 3 shows that PES of the overall efficiencies that we assume equal to 80% is not different according to the increasing of actual overall efficiencies. If we set the overall efficiencies equal to 80%, it means that all of the electrical power is in the CHP mode. Figure 4 shows sensitivity of PES and percentage of decreasing CHP power for different setting of overall efficiencies.

Therefore, CHP Manual by EU Parliament can be used to calculate both primary energy saving and electrical power in CHP mode of the cogeneration power plant. If incentive is given to IPP/SPP that use cogeneration power plant based on the achievement of PES which is more than 10%. It is suggested to use overall efficiencies equal to 80%. Therefore, it is better to give incentive according to electricity power generated in CHP mode.

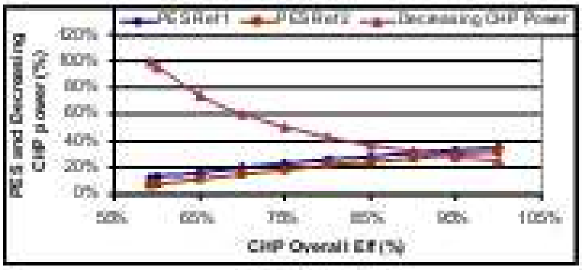

Figure 4 Sensitivity of PES and percentage of decreasing CHP power to CHP overall efficiency.

3. SENSITIVITY OF POWER LOSS COEFFICIENT (β)

The basic concept of power loss coefficient (beta, β) is a loss of power according to extract some steam in cogeneration power plant. The electrical/ mechanical power loss is typical for extraction-condensing or extraction-backpressure steam turbines. It is caused by extracting the working fluid (steam or exhaust gas) from the turbine (expander) for generation of useful heat energy. Be aware of the fact that steam extraction from heat recovery steam generators combines cycles which cause an electrical/mechanical power loss, even though the steam turbine is a back-pressure turbine [2].

In the CHP Manual by EU Parliament, the electrical/mechanical power loss coefficient (β) is the balance between increasing heat energy recovery (ΔH) and reducing electrical/mechanical energy (ΔE) of CHP plants with power loss in a reporting period, as given in equation 2.

$$\beta = -\frac{\Delta E}{\Delta H} \qquad (2)$$

All efficiencies that used to determine β should be in the maximum load of power plant, i.e. in the maximum thermal fuel firing capacity or in the capacity that close to the maximum thermal fuel firing capacity in the same fuel energy input (F) condition, so equation 2 can be rewrote to be equation 3.

$$\beta = -\frac{\frac{E_{max}}{F} - \frac{E_{min}}{F}}{\frac{H_{min}}{F} - \frac{H_{max}}{F}} \qquad (3)$$

Where, E_{max} and E_{min} are the unit of energy of electricity generation in the maximum and minimum conditions. H_{max} and H_{min} are the unit of energy of heat in the maximum and minimum conditions respectively. And F is the unit of energy of fuel input.

The electrical energy is generated in the maximum condition when no heat is extracted. On contrary, it is generated in the minimum condition when heat is extracted in the maximum condition. Therefore equation 3 can be rearranged to equation 4.

$$\beta = \frac{\eta_{el,without\ extr} - \eta_{el,maximum\ extr}}{\eta_{th,maximum\ extr}} \qquad (4)$$

In annual operation, we do not have a situation of electricity generation in the maximum condition with no heat extraction. So, in this paper we try to use both of the equations and make comparison for those. Figure 5 show the sensitivity of beta according to the power capacity and figure 6 shows the sensitivity of PES according to the beta.

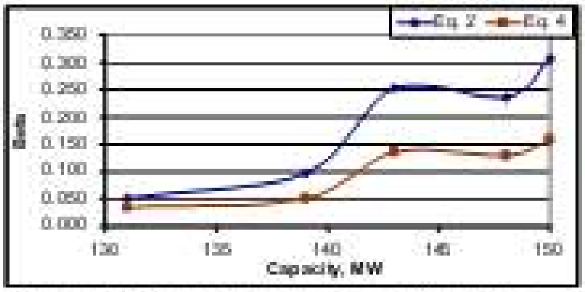

Figure 5 Sensitivity of power loss coefficient to electricity capacity generation.

Characteristic of power loss coefficient curve is the same for both two approaches, so we can say that in principle those equations are the same. The quantity of equation 4 is less than equation 2 because equation 4 is built for maximum power generation in no heat extraction. Beta for generating capacity is less than 140 MW, i.e. below 0.1, because for this condition, the trend of efficiency of plant is low because the operation is not in full load condition.

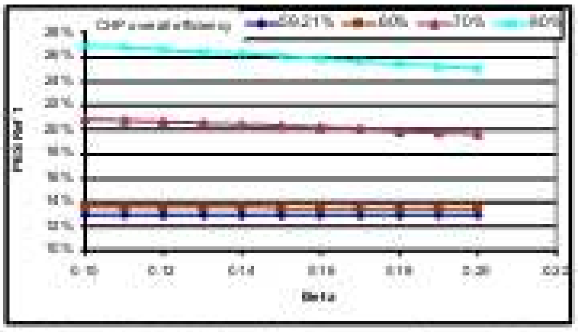

Figure 6 Sensitivity of PES to power loss coefficient

Figure 6 shows that PES does not depend on power loss coefficient, if CHP overall efficiency is set same with actual overall efficiency. But we set CHP overall efficiency higher than actual overall efficiency, PES will decrease according to the increasing of power loss coefficient. Therefore, beta just makes sense for calculation of power in CHP mode.

4. SENSITIVITY OF REFERENCE VALUE

The setting of efficiency reference values for separate production and the resulting qualification of CHP installations as high-efficiency have important implications for the future of CHP. Because the efficiency reference values has high influence to PES or electricity that generated by CHP mode.

The reference values have to be established and monitored by national support mechanisms. These values have to be supportive of CHP, but this effect will be reduced or may even turn negative if the regulatory body defines excessively strict efficiency reference values.

Harmonized efficiency reference values for separate production of heat in EU [4] (these values are based on NCV and standard conditions of 15 °C ambient temperature, 1.013 bar, 60% relative humidity) are shown in Table 2. Harmonized efficiency reference values for separate production of electricity are presented in the Table 3. In this table, the reference values for separate production of heat are based on net calorific value and standard ISO conditions (15 °C ambient temperature, 1,013 bar, 60 % relative humidity) too.

Table 2 Efficiency reference value (%) for separate production of heat (EU)

Type of Fuel	Steam /hot water	Direct use of exhaust gases
Hard coal/coke	88	80
Wood fuels	86	78
Agriculture biomass	80	72
Oil (gas oil + residual fuel oil), LPG	89	81
Biofuels	89	81
Natural gas	90	82
Biogas	70	62

Table 3 Efficiency reference value (%) for separate production of electricity (EU)

Year of construction: / Type of fuel:	1996 and before	2006-2011
Hard coal/coke	39.7	44.2
Wood fuels	25.0	33.0
Agriculture biomass	20.0	25.0
Oil (gas oil + residual fuel oil), LPG	39.7	44.2
Biofuels	39.7	44.2
Natural gas	50.0	52.5
Biogas	39.7	42.0

In Thailand is used reference value around 5% less than EU for natural gas fuel and coal category. The following reference values are usedin Thailand (Table 4):

Table 4 Reference value used in Thailand

Fuel Category	Ref η_E	Ref η_H
Natural Gas	45%	85%
Coal	40%	80%

There is no single "exact" or "correct" definition of efficiency reference values for the separate generation of heat and power for the purpose of the CHP Directive. Because of the complexity and constantly changing generation park on the one hand and the nature of electricity and heat markets on the other hand, it is impossible to say which generation, and thus which primary energy consumption and CO_2 emissions, a specific CHP plant is replacing. But, reference efficiency of separate production of electricity and heat is prescribed or has to be prescribed by national authorities.

As key criteria for determining reference values, the following aspects should be taken into account for the definition of efficiency reference values for separate production [5]:

a. Harmonization
b. Fuel neutrality
c. Best available technology in real-life conditions
d. Year of construction
e. Substitution principle
f. Operational efficiencies under real life conditions
g. Climate conditions, and
h. Avoided grid losses

Generally accepted efficiency reference value for separate production of heat based on net calorific value in Thailand is 85%. The EU Commission Decision [4] assumes that this general value is for standard ISO conditions (15 °C, 1.013 bar, 60% relative humidity). Correction factors related to the average climatic situation assume to reduce this value for 0.1% points efficiency loss for every degree above 15 °C.

Mean annual ambient temperature in Thailand can be assumed as 27.8 °C (76.6% relative humidity).
Correction factor:

$$(27.8 - 15) \cdot 0.1\% = 1.28\% \quad (5)$$

And reference value is:

$$Ref\ Q\eta = 85 - 1.28 = 83.72\% \quad (6)$$

Reference value for separate production of electricity and natural gas as fuel is in Thailand is 45% and does not depend on age of the plant.

In the analyzed case, the percentage of electricity delivered to the grid is approximately 60%$_e$ (contracted with local distribution company) of 150MW$_e$ (installed capacity), i.e. 90 MW$_e$. In this case, the mentioned EU decision offers correction factors 0.965 for electricity exported to the grid (50 – 100 kV) and 0.860 for electricity consumed on-site (0.4 kV).

The reference value is as follows:

$$Ref\ E\eta = 45\% \cdot (0.860 \cdot 0.4 + 0.965 \cdot 0.6) = 41.53\%$$

This correction factor for avoiding grid losses for the application of harmonized efficiency reference value for separate production of electricity is according to the mentioned decision.

The sensitivity of PES on changing independent variables (four efficiencies) is presented in the Figure 7 and Figure 8. It is obvious that slight changes of independent variables cause significant variable of PES. It requires really careful definition and calculation of four independent variables. Independent variables are reference efficiency of independent heat and power production and efficiency of heat and power production in the CHP system. The result changes in the overall PES.

Figure 8 shows suggested reference values of natural gas based systems in Thailand. The cogeneration efficiencies must be at least 40% for heat if the electrical efficiency is only 26% and in the other case if the electrical efficiency is 34%, then the heat efficiency can only be 25% to achieve a 10% PES. In all other cases the PES will be below 10%.

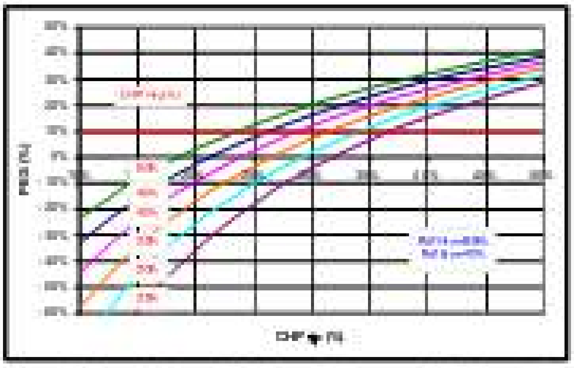

Figure 7 Sensitivity of PES to CHP η_H and CHP η_E (Ref η_H = 85%; Ref η_E = 45%)

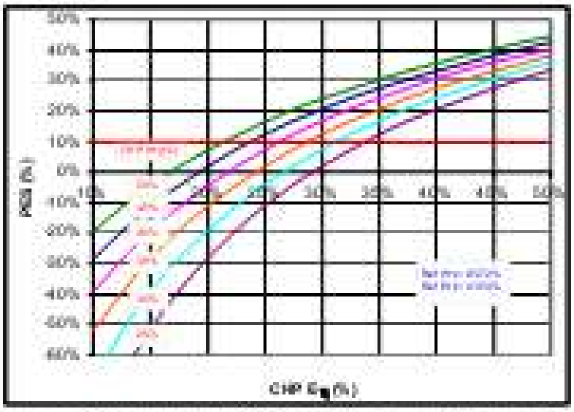

Figure 8 Sensitivity of PES to CHP η_H and CHP η_E (Ref η_H = 83.72%; Ref η_E = 41.53%)

The Directive does not designate explicitly reference efficiencies of separate production of electricity and heat in conventional plants. However, many countries have adopted efficiency reference values for new separate production. These values are used for the computation of PES (Article III, Directive) and are not particularly quoted in this article but some countries have accepted them. Before final values are adopted in Thailand, it is suggested to look into and analyze their impact on final outcome, as it is exceptionally great.

5. CONCLUSION

In calculation, PES of cogeneration power plant EU Directive and CHP Manual by EU Parliament can be used. But, the Directive has to be assumed as only the initial document which determines the directions how the local regulations have to be developed. It is important to define CHP boundary, reference value and power loss coefficient before calculate PES. If incentive is given for IPP/SPP that use cogeneration power plant according to PES achievement more than 10%, it is suggested to use overall efficiencies equal to 80%. But, it is better to give incentive according to electricity power that generated in CHP mode. In the case study, overall efficiency of average annual daily data is 59.21%.

Determination of the power loss coefficients by measurement involves some on-site measurements. All efficiencies used for the determination of β should be determined at plant operation with maximum load. Formula in CHP Methodology by UNFCCC and in CHP Manual by EU Parliament can be used. But it is to be remembered that UNFCCC formula, for electrical and thermal efficiency, is got from maximum heat extraction and from no heat extraction conditions.

The Directive did not designate explicitly reference efficiencies of separate production of electricity and heat in conventional plants. However, many countries have adopted efficiency reference values for new separate production. Before final values are adopted, it is suggested to look into and analyze their impact on final outcome, as it is exceptionally great. Climate situations and losses in transmission and distribution in grid are suggested to look before reference values are used.

6. REFERENCES

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