KOREA DISTRICT HEATING CORP.

# Performance Analysis on CHP Plant Using Back Pressure Turbine According to Return Temperature Variation

*IDEA 2016(107th Annual Conference & Trade show) – Embracing Change*

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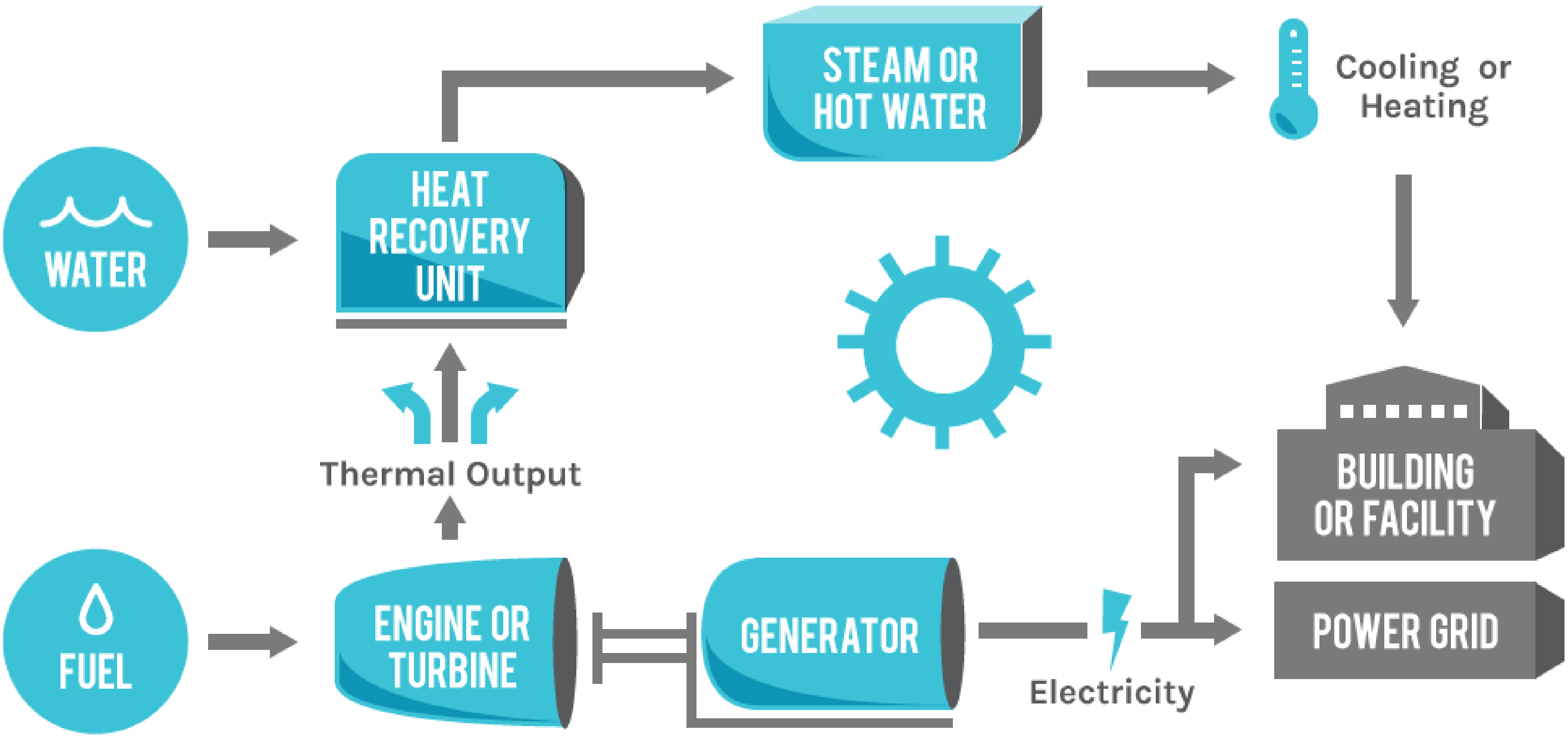
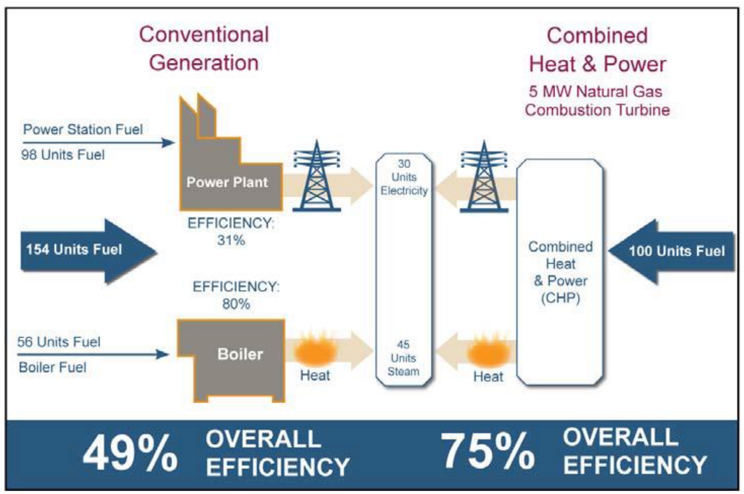
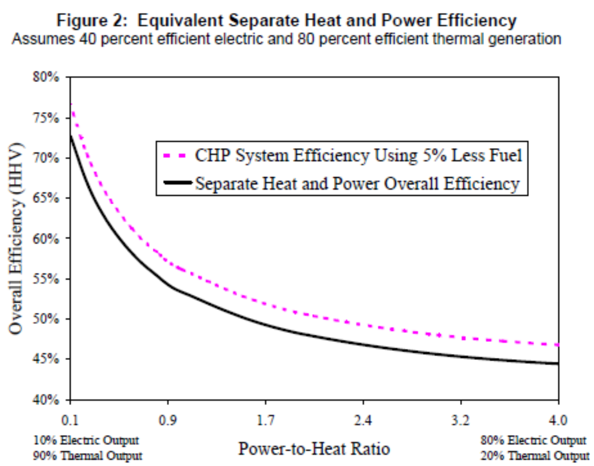
- **Definition of CHP(Combined Heat & Power)**
  - ***One of the Power generation system which can generate electricity and heat***

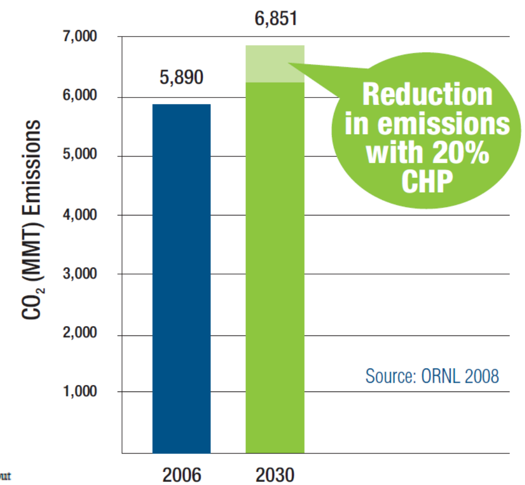



- *Source : http://www.dynamicenergyusa.com/solutions/combined-heat-power/*

- **Combined Heat & Power(CHP) System is one of the solution for using energy more efficiently**
  - **High efficiency and low emissions comparing to conventional Electricity and heat generation**



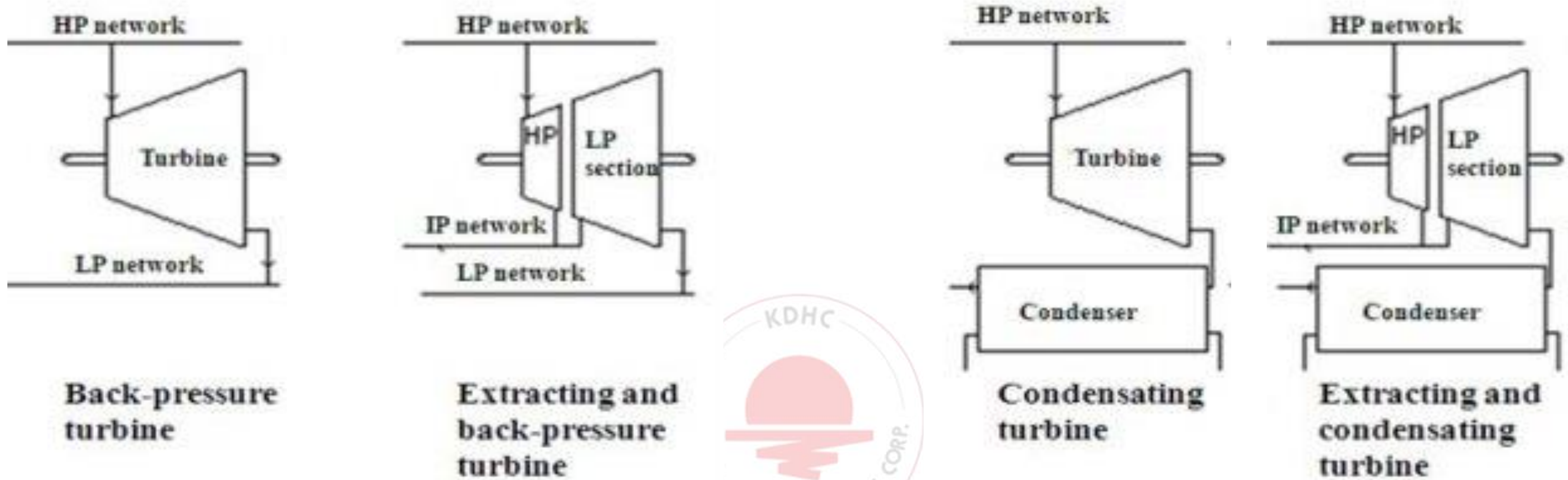




CHP Can Avoid 60 Percent of the Potential Growth in Carbon Dioxide Emissions Between 2006 and 2030

- *Catalog of CHP Technologies, U.S. Environmental protection Agency CHP Partnership, 2008*
- *A decade of progress Combined Heat and Power, U.S. Department of Energy, 2009*

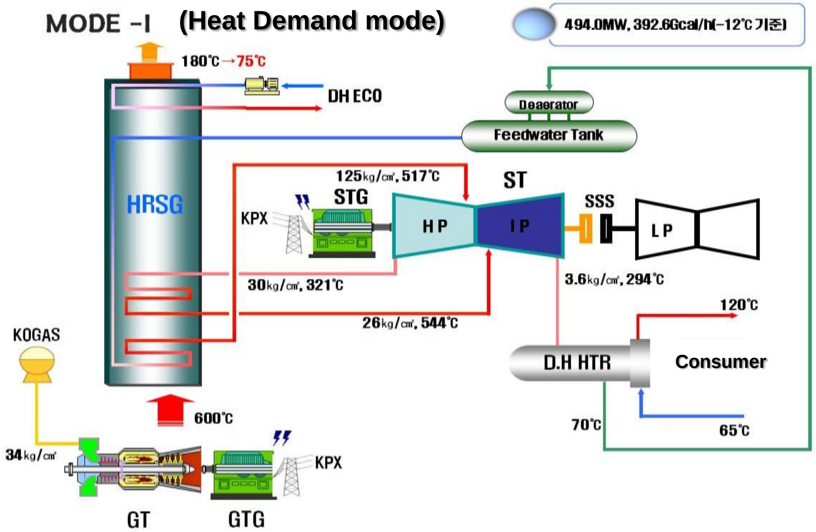
- **Condensing Turbine & Back pressure turbine**

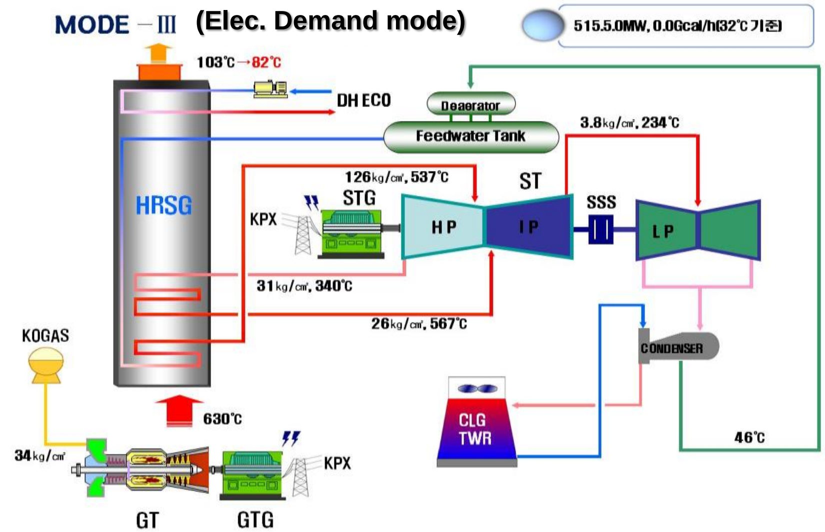


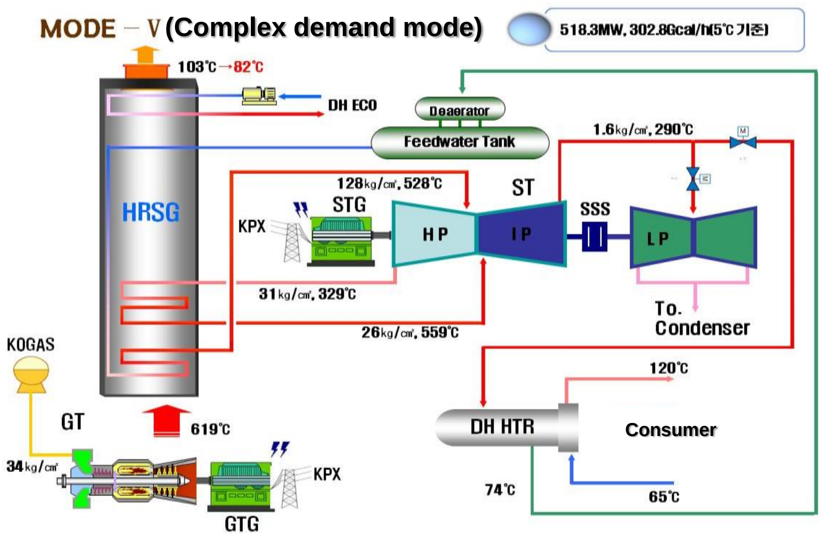

- **Back pressure type**
  - Single(Double) pressure system
  - Narrow range Control Heat & Power ratio
  - More easy control system than Condenser type

- **Condensing type**
  - Multi pressure system
  - Wide range Control Heat & Power ratio(Mode Operation)
  - High initial investment
  - Complex control system
  - Condenser required

## ● Mode Operations

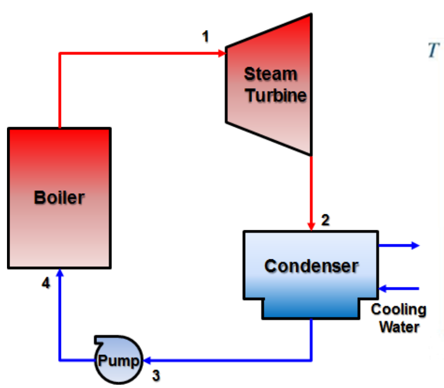


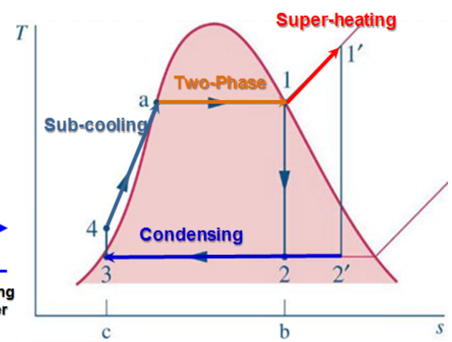



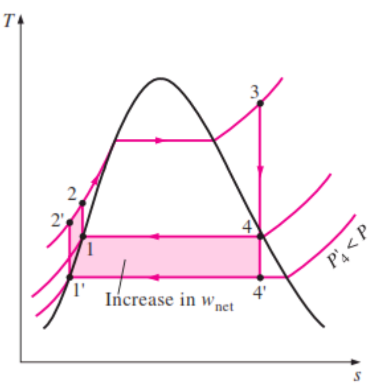




- ***Benefits of Mode Operations***
  - ***Wide range control** of Heat-Electricity ratio*
  - ***Possible to respond** for seasoning heat/electricity demands*
  - ***Possible to maximize revenue***
  - ***Securing Reliability** of Heat & Power generation*

- ***Performance of SRC(Steam Rankine Cycle) may changing depends on the Condenser(District Heater) cooling water temperature variations***
  - ***Condensing pressure varied by cooling water temperature difference***
  - ***Heat drop of turbine inlet and exit are changed when the condensing pressure varied***
  - ***In CHP system, DH return temperature(Consumer's return) replace the cooling water***




***Need to clarify that the end user's heat consuming pattern may influenced to the performance of CHP Plant***

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- ***Modeling Commercial CHP Power Plant (Using commercial program : GateCycle)***

- ***Analyzing CHP performance by DH return temperature variations***

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**System Modeling**

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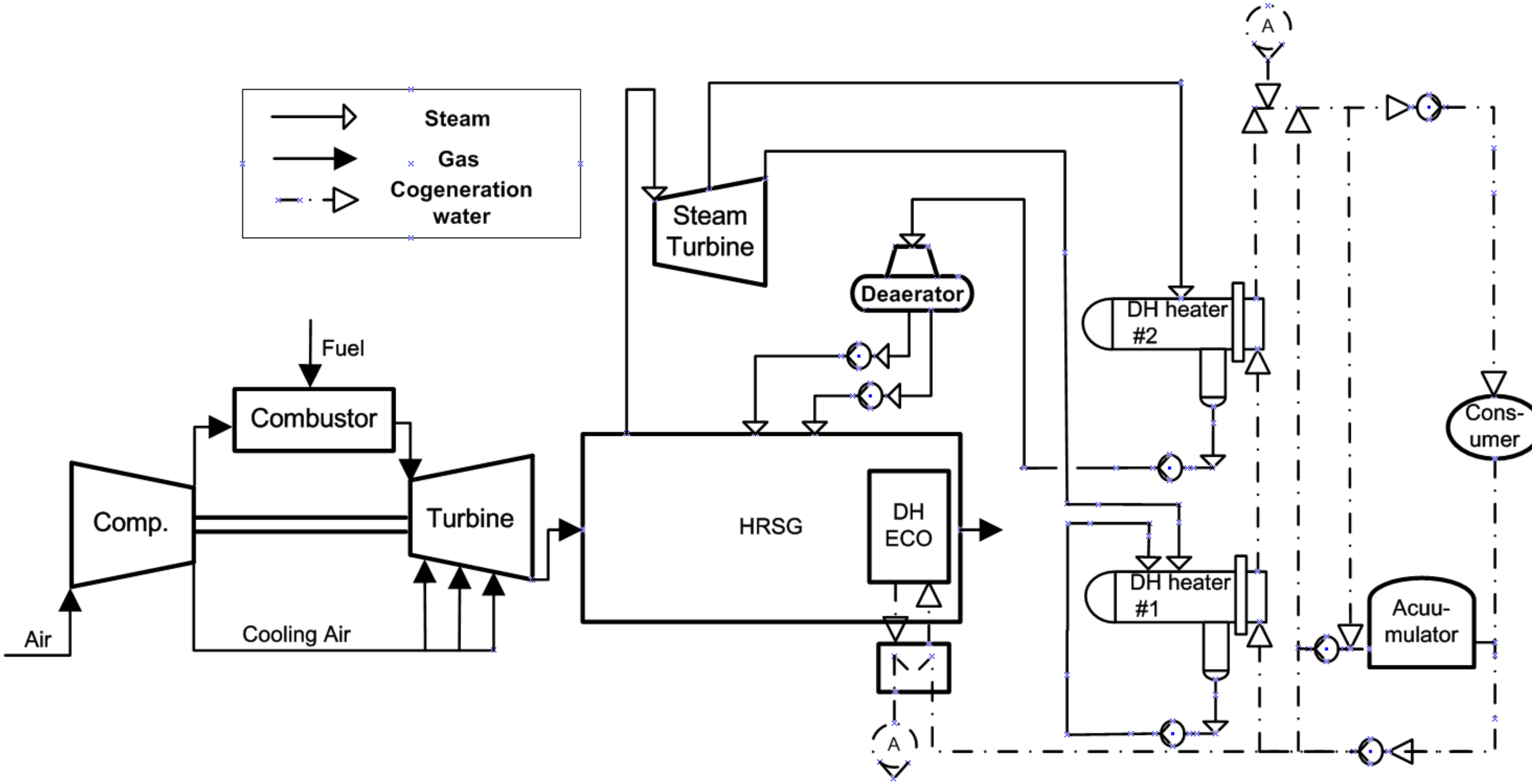
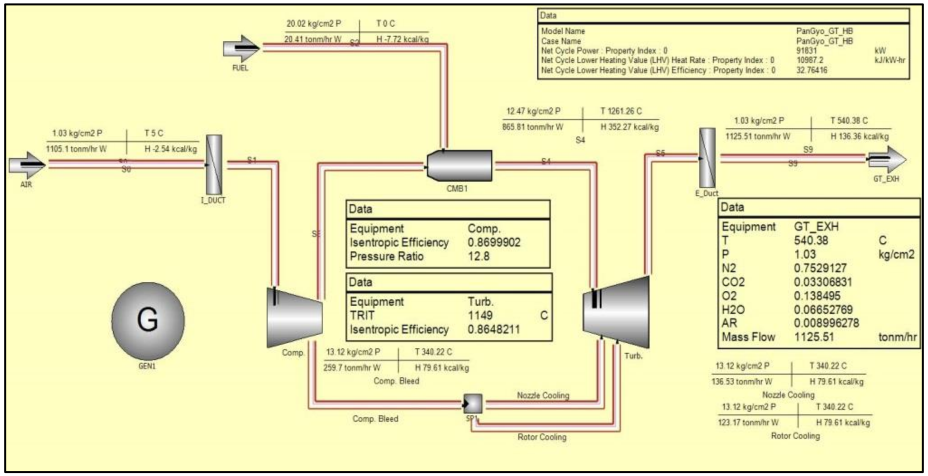
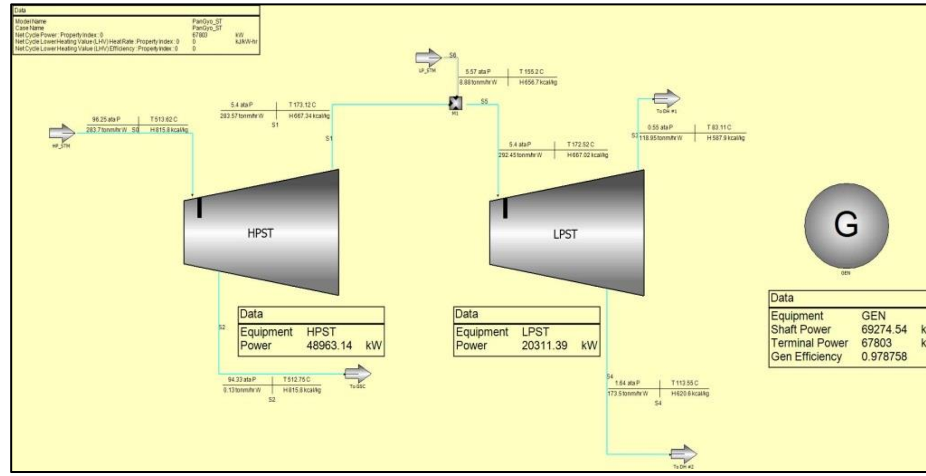


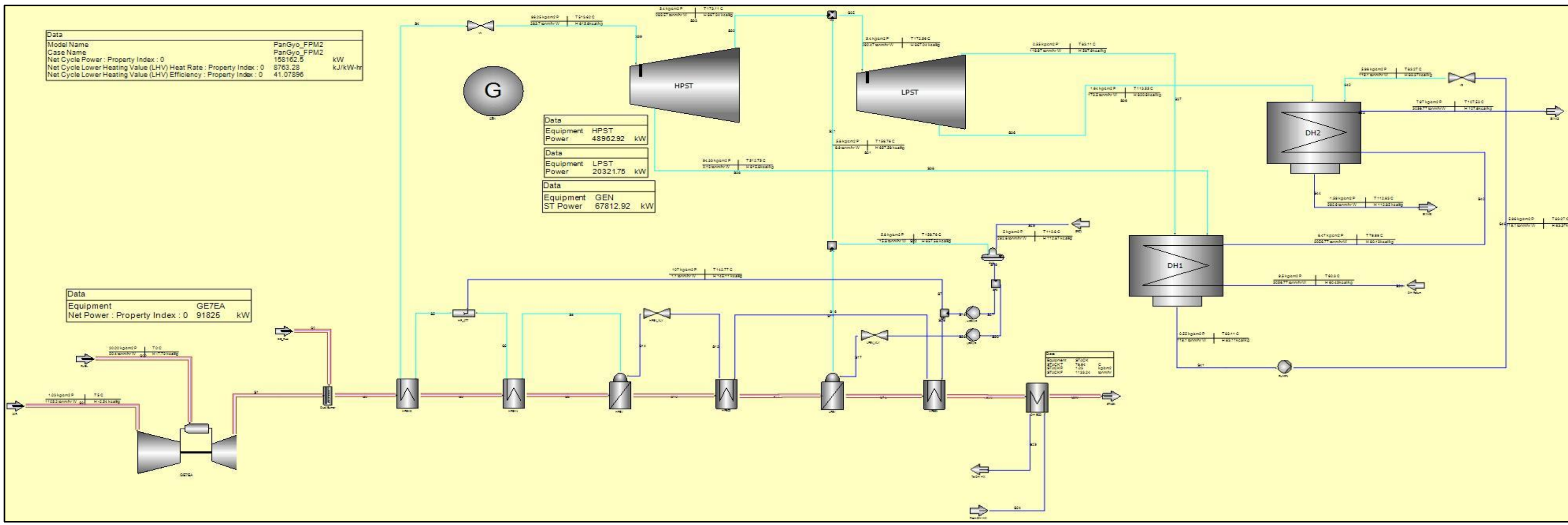
Steam
Gas
Cogeneration water
A
Steam Turbine
Deaerator
DH heater #2
Fuel
Combustor
Cons-umer
Comp.
Turbine
HRSG
DH ECO
DH heater #1
Acuu-mulator
Air
Cooling Air
A

# System Modeling

## CHP Plant System Configuration




- *GateCycle R6.1.2, GE Energy, 2014*

| | | Reference | Modeling | Error(%) |
|---|---|---|---|---|
| Ambient | Temperature (℃) | 5 | | Set |
| | Pressure(Bar) | 1.013 | | Set |
| | Relative humidity(%) | 60 | | Set |
| Compressor | Inlet Pressure Drop(mm$H_2O$) | 76.2 | | Set |
| | Pressure Ratio | Unknown*(12.8) | 12.8 | - |
| | Total Coolant bleed fraction(%) | Unknown | 23.5 | - |
| | Isentropic efficiency (%) | Unknown | 87.00 | - |
| Combustor | Fuel flow rate (kg/hr) | Unknown(20400@Curved model) | 20410 | (0.049) |
| | Pressure loss (%) | Unknown | 5 | - |
| | Combustion efficiency(%) | Unknown | 98.7 | - |
| | Turbine Inlet Temperature (℃) | Unknown | 1261.23 | - |
| Turbine | Turbine Rotor Inlet Temperature (℃) | Unknown*(1149) | 1149 | - |
| | Exhaust temperature (℃) | 540.4 | | Set |
| | Nozzle Cooling Flow (kg/hr) | Unknown | 136400(52.57%) | - |
| | Rotor Cooling Flow (kg/hr) | Unknown | 123310(47.43%) | - |
| | Isentropic efficiency (%) | Unknown | 86.48 | - |
| Exhaust gas | Gas flow rate (kg/hr) | 1125500 | 1125570 | 0.001 |
| | Exit Pressure Drop (mm$H_2O$) | 333.7 | | Set |
| Performance | Power (MW) | 91.825 | 91.824 | 0.001 |
| | Thermal efficiency (%) | 32.786 | 32.760 | 0.067 |
| Fuel | Temperature (℃) | 0 | | Set |
| | Lower heating Value (kJ/kg) | 49427 | | Set |
| Generator | Efficiency | Unknown | 97 | - |

# System Modeling
## HRSG Modeling – Gas side



| | | Reference | Modeling | Error(%) |
|---|---|---|---|---|
| HRSG Inlet | Gas Temperature(℃) | 540.4 | 540.4 | 0.000 |
| | Flue Gas Flow(kg/hr) | 1,125,600 | 1,125,599 | 0.000 |
| Duct Burner | Outlet Gas Temperature(℃) | 807.5 | 807.5 | 0.000 |
| | Fuel Gas Flow(kg/hr) | 7,580 | 7,676 | 1.266 |
| HPSH2 | Outlet Gas Temperature(℃) | 761.3 | 761.3 | 0.000 |
| | Flue Gas Flow(kg/hr) | 1,333,180 | 1,333,275 | 0.007 |
| | Energy loss fraction | Unknown | 0.0482 | - |
| HPSH1 | Outlet Gas Temperature(℃) | 660.9 | 660.9 | 0.000 |
| | Energy loss fraction | Unknown | 0.0221 | - |
| HPEV | Outlet Gas Temperature(℃) | 321.2 | 321.2 | 0.000 |
| | Energy loss fraction | Unknown | 0.0135 | - |
| HPEC2 | Outlet Gas Temperature(℃) | 211.7 | 211.71 | 0.000 |
| | Energy loss fraction | Unknown | 0.0085 | - |
| LPEV | Outlet Gas Temperature(℃) | 168.3 | 168.13 | 0.100 |
| | Energy loss fraction | Unknown | 0.000 | - |
| HPEC1 | Outlet Gas Temperature(℃) | 149.7 | 149.66 | 0.027 |
| | Energy loss fraction | Unknown | 0.01 | - |
| DH ECO | Outlet Gas Temperature(℃) | 82.1 | 82.1 | 0.000 |
| | Energy loss fraction | Unknown | 0.0071 | - |

# System Modeling
## HRSG Modeling – Steam side

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| | | Reference | Modeling | Error(%) |
|---|---|---|---|---|
| HPSH2 | Steam Outlet Pressure($kg/cm^2$) | 100 | 100 | 0.000 |
| | Steam Outlet Temperature(℃) | 515 | 515 | 0.000 |
| | Steam Flow Rate(ton/hr) | 283.7 | 283.7 | 0.000 |
| | Steam Outlet Enthalpy(kcal/kg) | 815.6 | 815.61 | 0.001 |
| | Surface Area($m^2$) | Unknown | 1254.5 | - |
| HP DSH | Steam Outlet Temperature(℃) | 433.9 | 432.89 | 0.235 |
| | Steam Flow Rate(ton/hr) | 283.7 | 283.7 | 0.000 |
| | Cooling Water Flow(ton/hr) | 1.1 | 1.1 | 0.000 |
| HPSH1 | Steam Outlet Pressure($kg/cm^2$) | 101.5 | 101.5 | 0.000 |
| | Steam Outlet Temperature(℃) | 436.5 | 436.49 | 0.002 |
| | Steam Flow Rate(ton/hr) | 282.6 | 282.6 | 0.000 |
| | Steam Outlet Enthalpy(kcal/kg) | 766.1 | 766.06 | 0.005 |
| | Surface Area($m^2$) | Unknown | 3825.5 | - |
| HPEV | Steam Outlet Pressure($kg/cm^2$) | 102.4 | 102.4 | 0.000 |
| | Steam Outlet Temperature(℃) | 311.3 | 311.27 | 0.010 |
| | Steam Flow Rate(ton/hr) | 282.6 | 282.6 | 0.000 |
| | Steam Outlet Enthalpy(kcal/kg) | 655.1 | 651.33 | 0.575 |
| | Surface Area($m^2$) | Unknown | 28996.3 | - |
| HPEC2 | Water Pressure($kg/cm^2$) | 102.4 | 102.4 | 0.000 |
| | Water Outlet Temperature(℃) | 266.4 | 266.4 | 0.000 |
| | Water Flow Rate(ton/hr) | 282.6 | 282.6 | 0.000 |
| | Water Outlet Enthalpy(kcal/kg) | Unknown | 278.46 | - |
| | Surface Area($m^2$) | Unknown | 16408.19 | - |

# System Modeling

## HRSG Modeling – Steam side (Continued)

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| | | Reference | Modeling | Error(%) |
|---|---|---|---|---|
| LPEV | Steam Pressure($kg/cm^2$) | 5.8 | 5.8 | 0.000 |
| | Steam Outlet Temperature(℃) | 156.8 | 156.76 | 0.026 |
| | Steam Flow Rate(ton/hr) | 24.7 | 24.7 | 0.000 |
| | Steam Outlet Enthalpy(kcal/kg) | 658.4 | 657.58 | 0.125 |
| | Surface Area($m^2$) | Unknown | 10672.6 | - |
| HPEC1 | Water Pressure($kg/cm^2$) | 104.6 | 104.6 | 0.000 |
| | Water Outlet Temperature(℃) | 161.3 | 161.3 | 0.000 |
| | Water Flow Rate(ton/hr) | 282.6 | 282.6 | 0.000 |
| | Water Outlet Enthalpy(kcal/kg) | Unknown | 164.04 | - |
| | Surface Area($m^2$) | Unknown | 18735.8 | - |
| DH ECO | Water Outlet Temperature(℃) | 119.9 | 119.9 | 0.000 |
| | Water Outlet Enthalpy(kcal/kg) | 120.3 | 120.36 | 0.050 |
| | Water Inlet Temperature(℃) | 65.3 | 65.3 | 0.000 |
| | Water Inlet Enthalpy(kcal/kg) | 65.5 | 65.3 | 0.305 |
| | Water Flow Rate(ton/hr) | 353.3 | 353.3 | 0.000 |
| | Surface Area($m^2$) | Unknown | 20805 | - |
| DEA | Water Pressure($kg/cm^2$) | 3.7 | 3.7 | 0.000 |
| | Water Outlet Temperature(℃) | 140.1 | 140.14 | 0.029 |
| | Water Flow Rate(ton/hr) | 308.4 | 308.4 | 0.000 |
| | Aux. Steam Flow Rate(ton/hr) | 15.8 | 15.84 | 0.253 |
| Feed Water | Water Pressure($kg/cm^2$) | 5 | 5 | 0.000 |
| | Water Outlet Temperature(℃) | 112.6 | 112.6 | 0.000 |
| | Water Flow Rate(ton/hr) | 292.6 | 292.56 | 0.014 |

# System Modeling
## Steam Turbine Modeling



| | | | Reference | Modeling | Error(%) |
|---|---|---|---|---|---|
| HP Steam Turbine | Inlet | Pressure(ata) | 96.25 | 96.25 | 0.000 |
| | | Temperature(℃) | 513.7 | 513.62 | 0.016 |
| | | Enthalpy(kcal/kg) | 815.8 | 815.8 | 0.000 |
| | | Mass Flow(ton/hr) | 283.7 | 283.7 | 0.000 |
| | Seal Steam* (HP Turbine Bowl) | Pressure(ata) | Unknown | 94.33 | - |
| | | Mass Flow(ton/hr) | 0.13 | 0.13 | 0.000 |
| | Isentropic Efficiency | | Unknown | 0.87 | - |
| | HP Steam Turbine Power(kW) | | Unknown | 48,963 | - |
| | HP Exhaust Pressure(ata) | | Unknown | 5.4 | - |
| LP Steam Turbine | LP Steam | Pressure(ata) | 5.569 | 5.57 | 0.018 |
| | | Temperature(℃) | 155.2 | 155.2 | 0.000 |
| | | Enthalpy(kcal/kg) | 656.7 | 656.7 | 0.000 |
| | | Mass Flow(ton/hr) | 8.88 | 8.88 | 0.000 |
| | LP Extraction (To DH #2) | Pressure(ata) | 1.644 | 1.64 | 0.243 |
| | | Temperature(℃) | 113.5 | 113.55 | 0.044 |
| | | Enthalpy(kcal/kg) | 620.6 | 620.6 | 0.000 |
| | | Mass Flow(ton/hr) | 173.5 | 173.5 | 0.000 |
| | Isentropic Efficiency | | Unknown | 0.871 | - |
| | LP Steam Turbine Power(kW) | | Unknown | 20,311 | - |
| | LP Exhaust Pressure(ata) | | 0.547 | 0.547 | 0.000 |
| | LP Exhaust Temperature(℃) | | 83.1 | 83.11 | 0.012 |
| | LP Exhaust Enthalpy(kcal/kg) | | 587.9 | 587.9 | 0.000 |
| Terminal Power(kW) | | | 67,803 | 67,803 | 0.000 |
| Generator Efficiency | | | Unknown | 0.9788 | - |

# System Modeling

## District Heater 1 Modeling

| Location | | Design Data | Modeling | Error(%) |
|---|---|---|---|---|
| Cooling Water | CW Flow | 2,706,086 | 2,709,120 | 0.112% |
| | CWIN T | 65.000 | 65.000 | 0.000% |
| | CWOUT T | 94.970 | 94.970 | 0.000% |
| | CWIN H | 65.200 | 65.150 | 0.077% |
| | CWOUT H | 95.200 | 95.160 | 0.042% |
| | ΔQ | 81,182,580 | 81,300,691 | 0.145% |
| | CWIN P | 9.500 | 9.500 | 0.000% |
| | CWOUT P | 8.470 | 8.470 | 0.000% |
| Main Steam | Inlet P | 0.963 | 0.963 | 0.000% |
| | Inlet T | 98.000 | 98.040 | 0.041% |
| | Inlet Flow | 161,680 | 161,680 | 0.000% |
| | Inlet H | 600.400 | 600.400 | 0.000% |
| Aux. Steam | Inlet P | Unknown | 94.330 | - |
| | Inlet T | Unknown | 512.750 | - |
| | Inlet Flow | 1,300 | 1,300 | 0.000% |
| | Inlet H | Unknown | 815.800 | - |
| Cond. Water | Inlet P | 1.263 | 1.263 | 0.000% |
| | Inlet T | 98.000 | 98.040 | 0.041% |
| | Inlet Flow | 161,810 | 161,810 | 0.000% |
| | Inlet H | 98.000 | 98.120 | 0.122% |

# System Modeling
## District Heater 2 Modeling

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| Location | | Design Data | Modeling | Error(%) |
|---|---|---|---|---|
| Cooling Water | CW Flow | 3,338,051 | 3,343,840 | 0.173% |
| | CWIN T | 72.250 | 72.250 | 0.000% |
| | CWOUT T | 100.000 | 100.000 | 0.000% |
| | CWIN H | 72.400 | 72.380 | 0.028% |
| | CWOUT H | 100.200 | 100.200 | 0.000% |
| | ΔQ | 92,797,818 | 93,025,629 | 0.245% |
| | CWIN P | 8.590 | 8.590 | 0.000% |
| | CWOUT P | 7.560 | 7.560 | 0.000% |
| Main Steam | Inlet P | 1.263 | 1.263 | 0.000% |
| | Inlet T | 105.700 | 105.720 | 0.019% |
| | Inlet Flow | 187,550 | 187,550 | 0.000% |
| | Inlet H | 618.000 | 618.000 | 0.000% |
| Aux. Steam | Inlet P | 1.263 | 1.263 | 0.000% |
| | Inlet T | 74.200 | 74.290 | 0.121% |
| | Inlet Flow | 96,530 | 96,530 | 0.000% |
| | Inlet H | 74.200 | 74.290 | 0.121% |
| Cond. Water | Inlet P | 1.263 | 1.263 | 0.000% |
| | Inlet T | 105.700 | 105.720 | 0.019% |
| | Inlet Flow | 284,080 | 284,080 | 0.000% |
| | Inlet H | 105.900 | 105.860 | 0.038% |

Introduction

System Modeling

**Results**

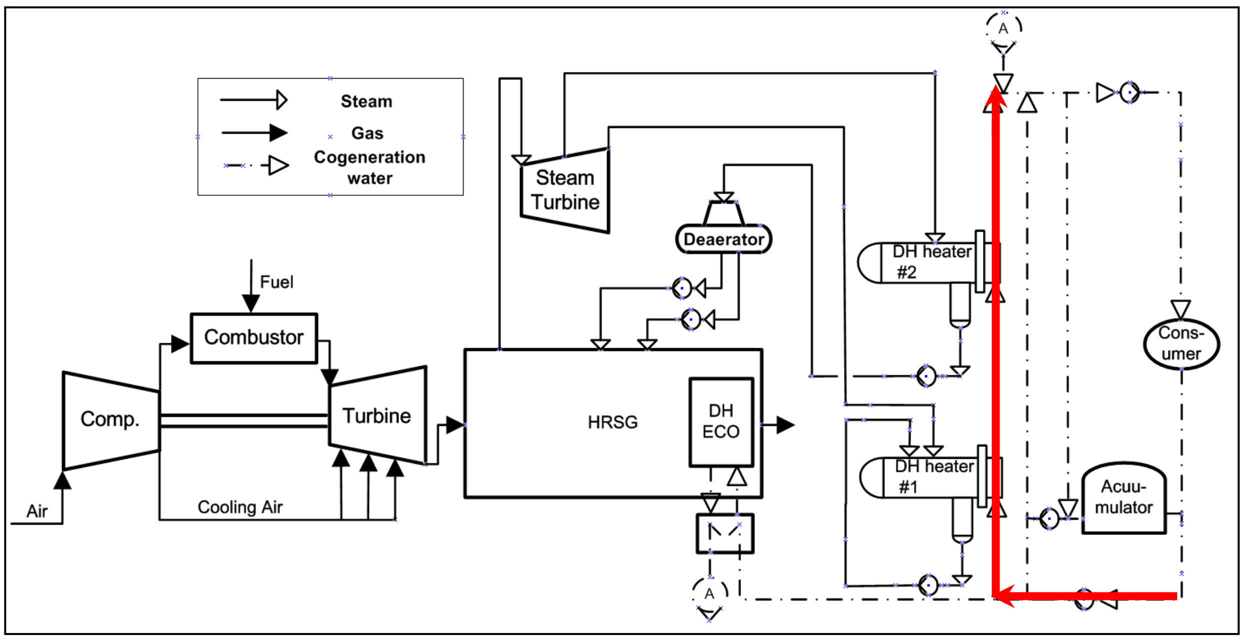
Conclusion

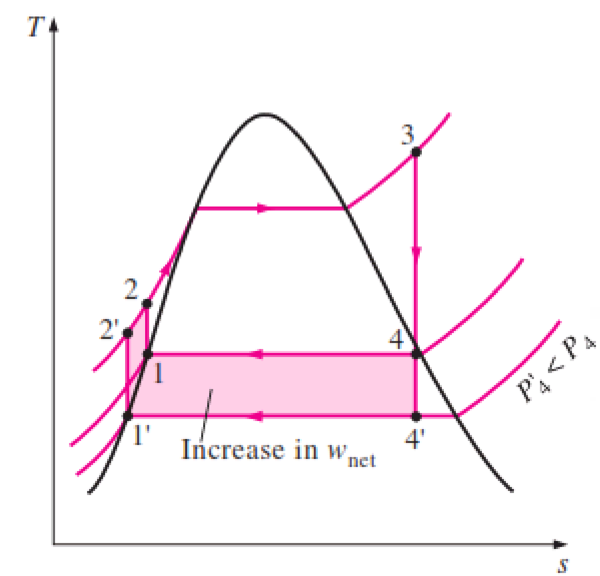
# Results

## Performance variation according to DH return Temperature

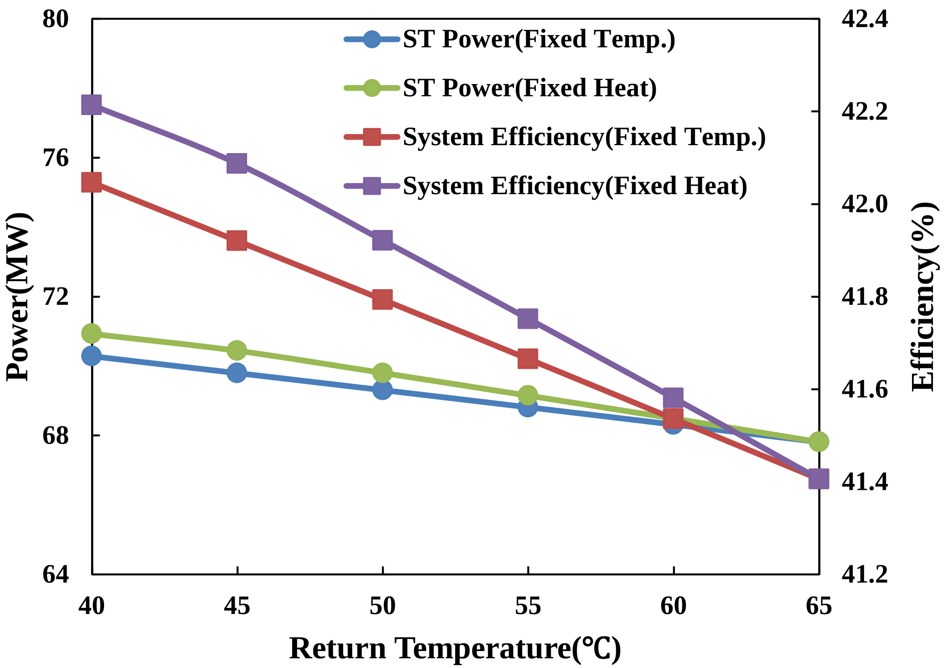


- **Performance improving by DH return temperature variations**
  - **District heater of Back pressure turbine may replace the condenser of condensing turbine**
  - **Steam turbine performance may varied according to the DH return temperature variation**

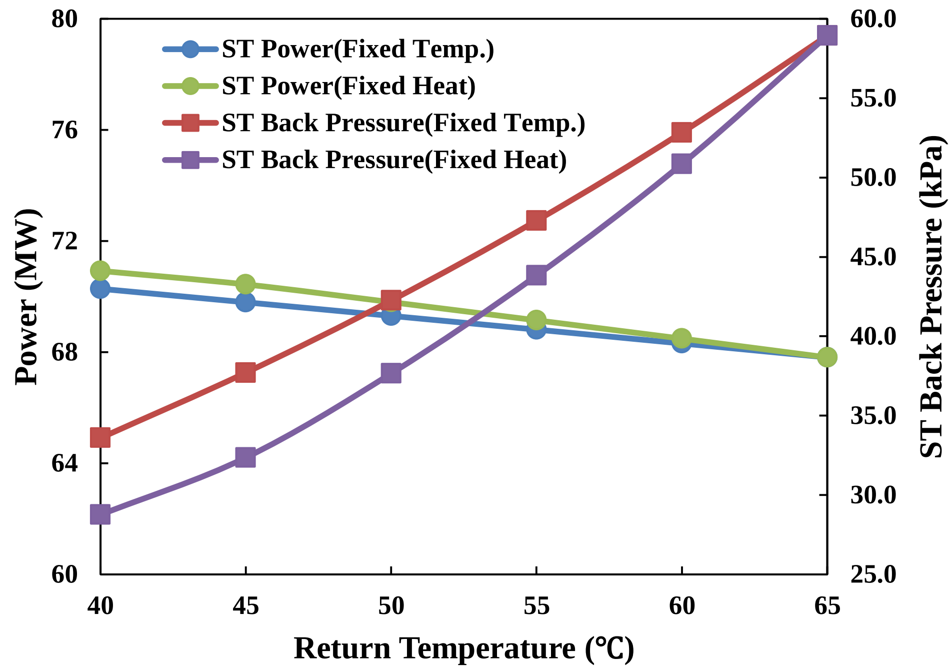


# ● CHP System performance variations by DH return temperature variations (System efficiency and Back Pressure variations)

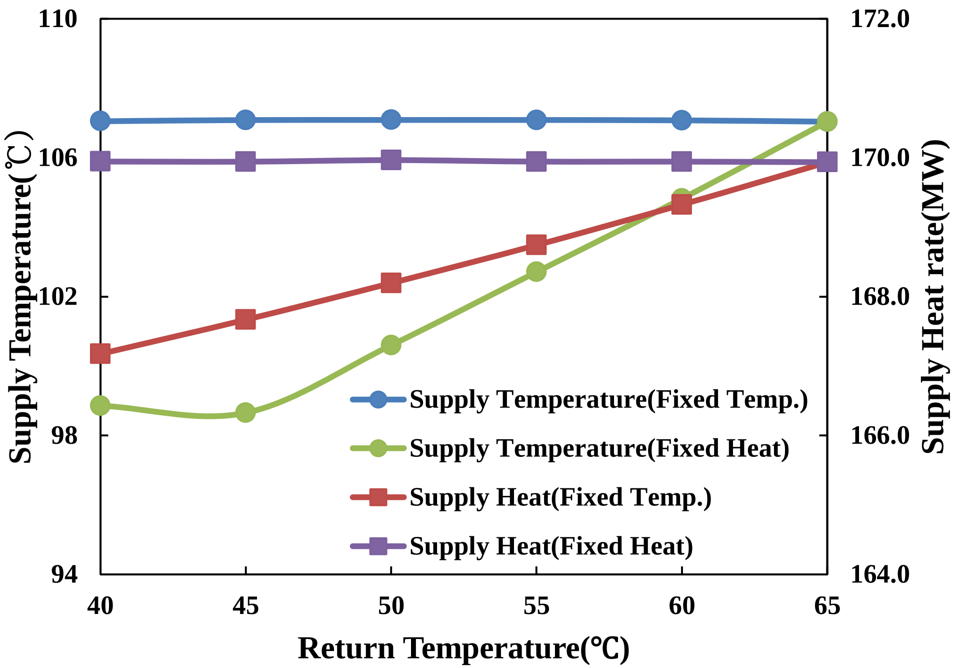


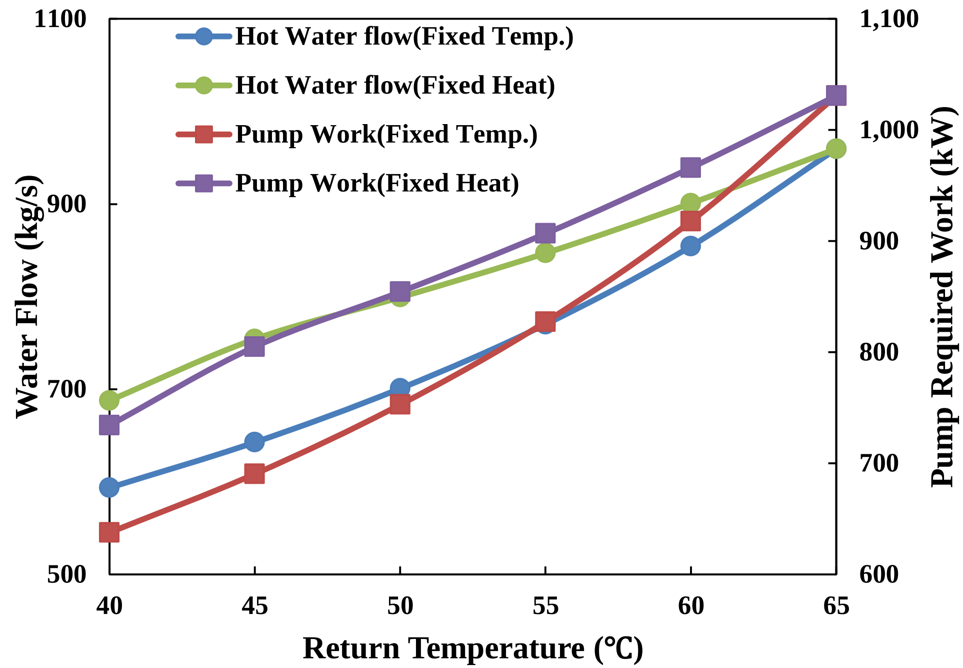

System Power and Efficiency variation vs. Returning Temperature




System Power and ST Back Pressure vs. Returning Temperature

- **CHP System performance variations by DH return temperature variations** (District heat and Pump required work variations)




**Supply Temperature and Heat rate variation vs. Returning Temperature**

**Water Flow rate and Pump Work variation vs. Returning Temperature**

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# Conclusion

- ***Analyzing CHP Performance by the DH return temperature variation which are varied by the heat consuming pattern***
  - ***CHP Performance are varied by DH Return Temp. variations***
  - ***Steam Turbine power may increases by reduction of condensing pressure***
  - ***Pump required work may decreases by required district heating flow***

- ***The maintaining supply heat consumption method shows more efficient performance than the maintaining supply temperature***
  - ***Increasing Cooling flow rate for maintaining supply heat consumption may reducing DH supply temperature***
  - ***It bring to increase of steam turbine power***

- ***Analysis of end user's heat consuming trend based on the real data may requires for more accurate results***

# Thank You for Your Attention!

## Any Questions?

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