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Study of a Canadian Gas Engine Internal Combustion- CHP, Combined Heat and Power Plant with Emphasis on Design Parameter Effect on Total Efficiency

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ABSTRACT

This Paper is a Discussion about the principle of the CHP and its application in reciprocating Engine power station in the Cornwall CHP plant in Canada The Plant operating Power & temperature and modes of control will be presented , the study will include the Power station Parameters that will be studied using EES model Including the effect of inlet temperature on Cycle efficiency in OTTO & Diesel Engine and Effect of Design Factors like Compression ratio on cycle heating and power efficiency through modeling Cycle in EEs . The relation between Engine parameters and the heating water parameters will be discussed

INTRODUCTION

CHP (combined heat and power) plant is one key example of how to increase efficiency. What happens is that electricity is produced from a conventional turbine/engine but then the waste heat is also collected for use in a process or for space heating. Overall efficiency typically rises from, say, 33% to 60–90% at peak. The problem is to find a heat demand local to the plant and cost goes up with this added equipment. But what was more expensive and more complicated and unacceptable in the days of cheap and readily available fuel may now be justified. Extra plant cost and complexity can be offset by better fuel economics and availability. As a matter of interest 2008 statistics show that the UK had installed 5569 MWe of CHP capacity of all sizes (which apart from heat duty) actually provided 7% of UK electricity supply.

The following Table Demonstrate the CHP efficiencies across different types of Power stations

CHP power generation technology	Power range (applied to CHP)	Power efficiency range (%)	CHP efficiency (peak) (%)
CCGT*	20 MW to 600 MW	30–55	85
Gas turbine	2 MW to 500 MW	20–45	80
Steam turbine	500 kW to 100 MW	15–40	75
Reciprocating engine	5 kW to 10 MW	25–40	95
Micro-turbine**	30 kW to 250 kW	25–30	75
Fuel cell	5 kW to 1 MW	30–40	75
Stirling engine	1 kW to 50 kW	10–25	80

* Combined cycle gas and steam turbines
** Micro-turbines are small, radial flow gas turbines

CHP is not only Energy friendly it is Emission reduction solution

In certain installations, the CO_2 output from the CHP system can have a value providing it can be captured and utilized . A good example is in horticulture where cleaned exhaust gas is used to introduce additional CO_2 into greenhouses, aiding plant development. A less direct benefit from CO_2 is becoming available through trading mechanisms designed to stimulate reductions in emissions. Initially only large energy users and larger CHP installations could economically benefit from these schemes, but ultimately, all CO2 saved by CHP may find a value. For smaller systems, this may come through taxation benefits, feed-in tariffs, or by valuing the recovered heat energy. Where they are applied, such

measures can significantly impact the evaluation of the benefits of a CHP installation. Though generally considered a clean technology, the potential for CHP to produce significant levels of other pollutant emissions is not being ignored. Driven by ever-tightening standards set in the USA and Europe, prime mover manufacturers have progressively reduced levels of NOx, CO, and, where relevant, SOx and particulates either by improved combustion technologies or the addition of post-combustion treatment of the emitted gases. The penalty is, however, a more complex and costly CHP installation with potentially higher operating costs.

Cornwall District Energy System

Combined Heat & Power. The CHP plant utilizes two gas-fired combined heat and power engines to produce 5 MW of electricity and 85% of the district heating system's annual thermal energy requirements. The plant incorporates a unique building design due to its sensitive location in the middle of a residential neighborhood (within 15 meters of the nearest home). The heating plant has a capacity of 38 million Btu/hour. The district heating system utilizes two natural gas-fired boilers and a heat recovery boiler to provide 120 °C hot water. Customers are Two Major Hospitals and Commercial buildings and Government buildings

Thermally, the plant has two volume coil tube boilers providing backup and peaking capability. Electrically, the plant is backed up by the Cornwall Electric distribution grid. The Cornwall system has a thermal efficiency that approaches 90% during winter compared to approximately 35% efficiency for conventional electric-only generating plants. The hot water is transported from the system to customers through pre-insulated direct-buried pipes. The unique design of the pipe allowed them to be buried cold and as a result of heat expansion.

A bellows-type expansion joint in the pipes closes once the pipes are put in service. No preheating is required for this installation. This is very important since the 4.5-kilometre distribution network goes through a residential area.

System Description and control

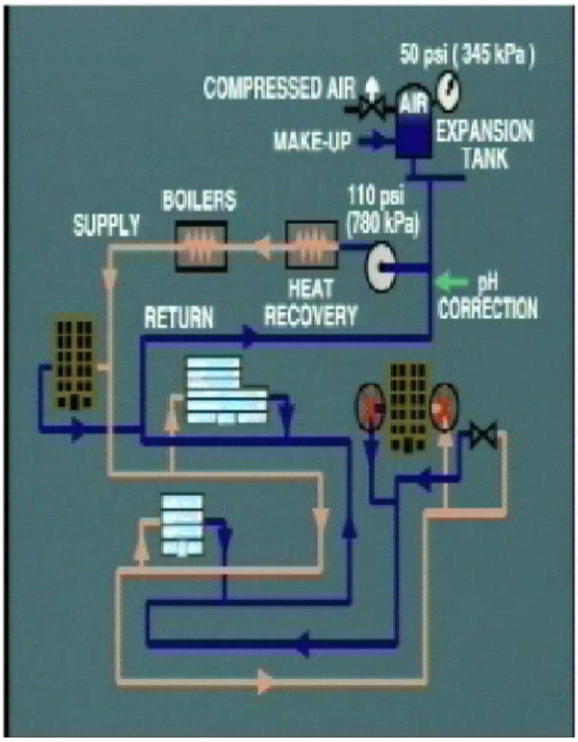


Fig-1

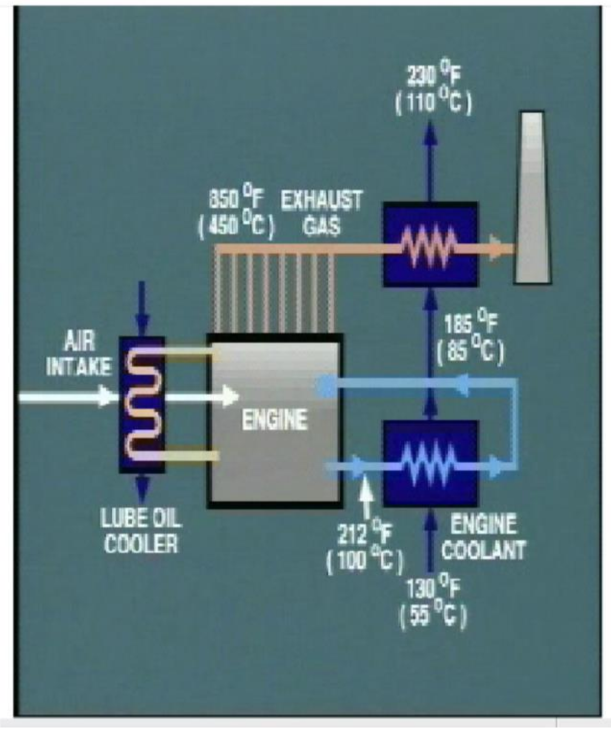


Fig-2

As it is apparent from Fig-1 The System comprises of 2 Gas Engines Each of Capacity 2.5 MW and the Heat recovery Unit and three variable speed pumps to meet the varying district heating requirements an Expansion Tank is kept to keep the system Pressure . In Fig-2 the heat recovery system is detailed where the heat expelled in the oil cooler is used to heat the Engine inlet air & the heating water is heated on two stages the first from 55c to 85c in the heat exchanger cooling the Engine coolant water and then from 85c to 110c in an economizer operated by the engine exhaust the equations representing the same are considering 10c cooling in the heat exchanger cooling the engine water with inlet temperature 90c and exist back to engine 80c.

Modeling and Equations

$$Mass_{Ew} = \frac{QEw}{10.C_{pw}}$$

$$Q_{exh} = Mass_{exh}.C_{pa}.\Delta T_{exh}$$

$$Mass_{hw} = \frac{(Q_{Ew} + Q_{exh})}{C_{pw}.\Delta T_{hw}}$$

$$T_{ia} - T_a = \frac{Q_{oil}}{Mass_a.C_{pa}}$$

$Mass_{Ew}$ = Engine coolant water Mass

Q_{Ew} = Engine Heat rejected in coolant

$Mass_{hw}$ = Heating water Mass

ΔT_{hw} = Delta Temperature for heating Water

Q_{exh} = Exhaust rejected Heat

T_{ia} = Engine inlet Temp

T_a = Ambient Temp

Q_{oil} = Heat Rejected in oil

The Layout of the Heating Sequence

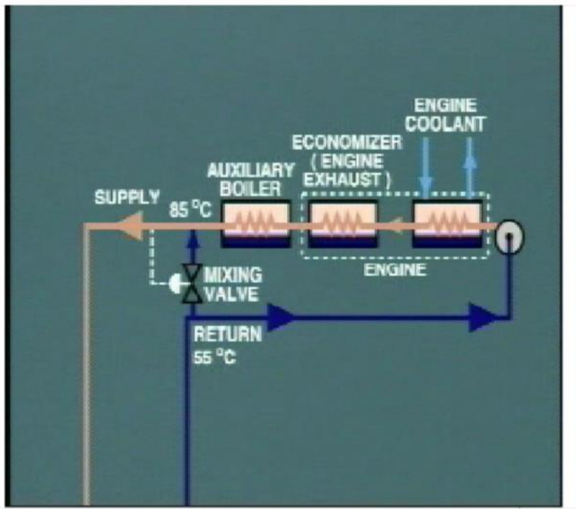


Fig-3

The control of the coolant Water circuit

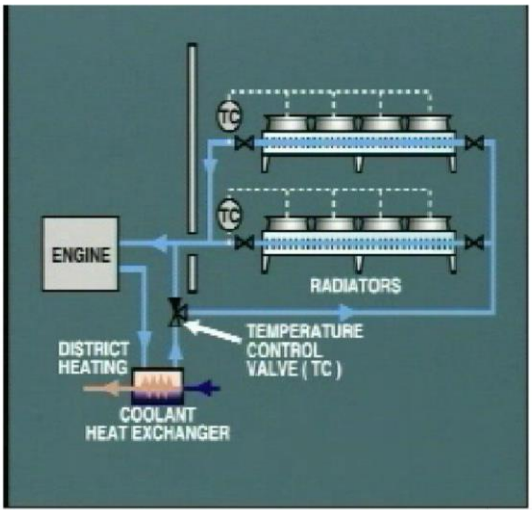


Fig-4

In Fig-4 it is clear and using the Heat Transfer mentioned Equations the CHP controller will bypass the Engine coolant water to avoid any Kind of overheating to the Engine due to a decrease in demand on district heating water, The bypassed coolant water will be cooled in the Unit radiators instead of exchanging Heat with the district cooling water. The accurate control of Engine coolant temperature is required to avoid adverse effects on efficiency.

The control of the Exhaust Circuit

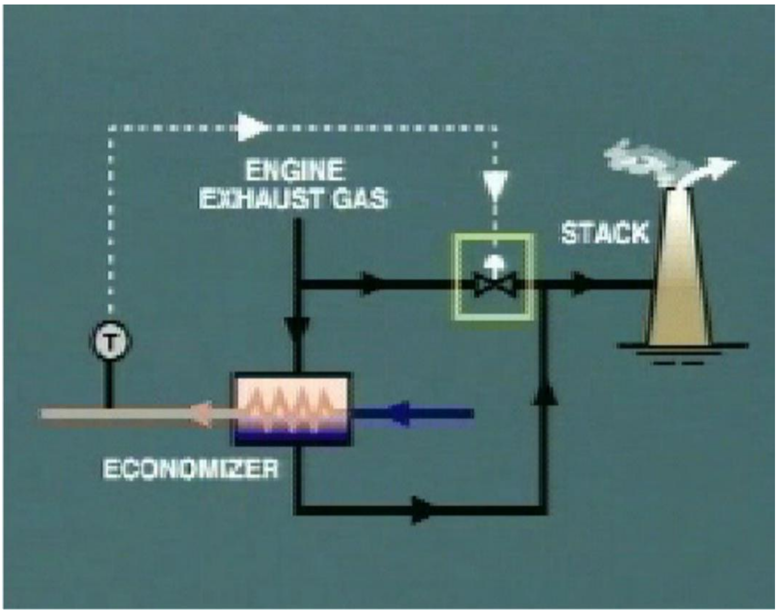


Fig-5

In the case of decrease of Demand on Heating Water the economizer will bypass the exhaust directly to the stack usually the min temperature of flue gases should be safely above the acids liquid formation and usually is kept between 130c to 150c, there is a a sensor in the outlet of economizer that will bypass the excess exhaust gases in case of temperature of district heating water had increased.

In Case of Drop of heating water Temperature the Boiler will be introduced into the operation to compensate this drop .

The Engine was estimated to be a Waukesha gas engine 2.6MW,12V275GL+,with the following Specifications.

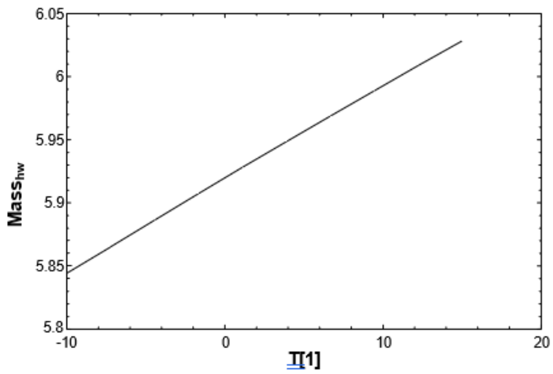
Cylinders	V12
Piston displacement	13048 cu. in. (214 L)
Compression Ratio	9:1
Bore & stroke	10.83" x 11.81" (275 x 300 mm)
Jacket water system capacity	100 gal. (379 L)
Lube oil capacity	220 gal. (883 L)
Starting system	150 psi (10.3 bar)
Fuel pressure	45 – 60 psi (3.1 – 4.1 bar)

The EES program of Otto Cycle was run and the effect of inlet temperature was studied against the Thermal and heat efficiency

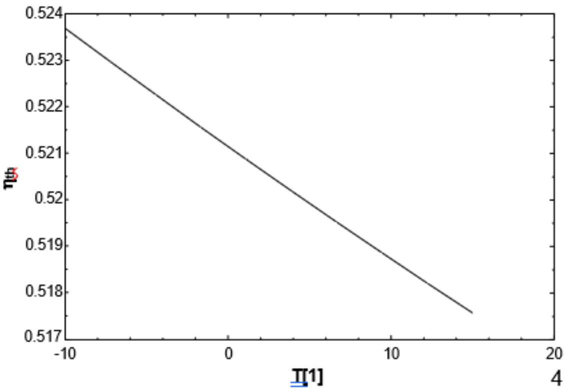
$$Thermal\ Efficiency = \frac{Work}{Inlet\ Fuel\ Heat}$$

$$Heat\ Efficiencv = \frac{Heating\ Of\ district\ Water}{Inlet\ Fuel\ Heat}$$

The Total efficiency assumed to be 90% with 5 % non- recoverable losses in friction and radiation and 5 % lost in the oil cooler and will be utilized for heating the inlet air specially in Canada cold weather .and assumed delta temperature of 70 c is assumed for the district heating water



Graph-1



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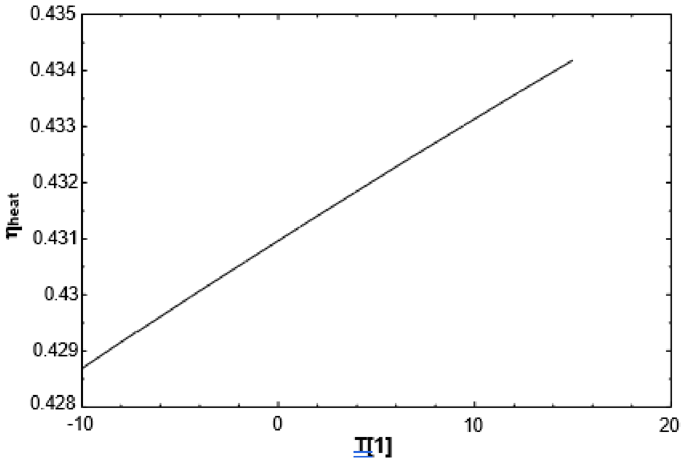
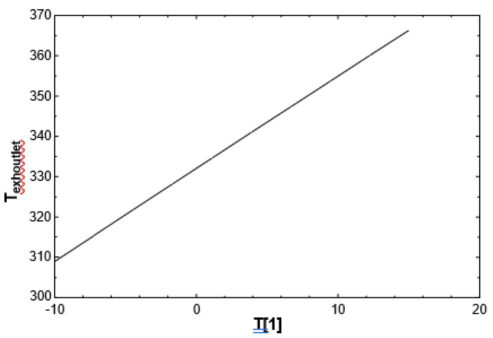
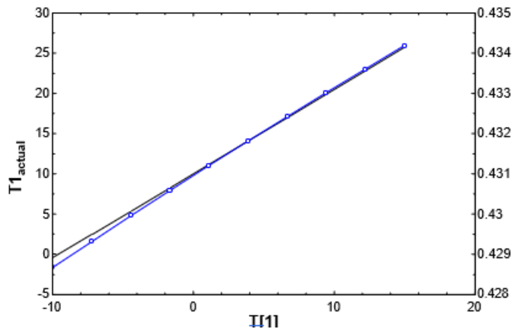


From the Graphs it is noticed that

- With increase in ambient temperature the Mass flow rate of heating water is required to be increase accordingly more water need to be bypassed to radiator.
- The thermal efficiency decreases with Increase in inlet temperature
- The Heat efficiency increase with Increase in inlet temperature

In The following Graphs we account for the heating effect made by the oil cooler to inlet air and it shows an increase in the heating efficiency and the Exhaust Temperature .





Conclusion

The CHP applied to IC Engines could be an excellent method of saving Power and decreasing emissions the main matter is that is should be mechanically non noisy as it should e installed in residential areas also it will decrease emissions , the solution is perfect for engines installed in Camps and hospitals , The control of the Engine & CHP unit is a challenge as the heating load is of great diversity nature and proper control to achieve the maximum total efficiency and avoid affecting the engine volumetric and thermal efficiency is a real challenge

References

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- Warstial Gas Engines Catalogue
- Caterpillar CHP units Catalogue

Appendix -1-EES Model & Parametric table

rpm = 1000

$\mathbf{P_1}$ = 101325

$$Vol_1 = \pi \cdot 0.275^2 \cdot 0.3 \cdot \frac{12}{4}$$

$P_3 = 85 \cdot 101325$

$CR = 9$

$N_r = 2$

state1

$v_1 = \mathbf{v}\left(Air_{ha}, T = T_1, P = P_1\right)$

$u_1 = \mathbf{u}\left(Air_{ha}, T = T_1, P = P_1\right)$

$s_1 = \mathbf{s}\left(Air_{ha}, T = T_1, P = P_1\right)$

state 2

$$CR = \frac{v_1}{v_2}$$

$s_2 = s_1$

$P_2 = \mathbf{P}\left(Air_{ha}, s = s_2, v = v_2\right)$

$T_2 = \mathbf{T}\left(Air_{ha}, s = s_2, v = v_2\right)$

$u_2 = \mathbf{u}\left(Air_{ha}, s = s_2, v = v_2\right)$

state 3

$v_3 = v_2$

$T_3 = \mathbf{T}\left(Air_{ha}, P = P_3, v = v_3\right)$

$u_3 = \mathbf{u}\left(Air_{ha}, v = v_3, P = P_3\right)$

$s_3 = \mathbf{s}\left(Air_{ha}, T = T_3, v = v_3\right)$

state 4

$v_4 = v_1$

$s_4 = s_3$

$P_4 = \mathbf{P}\left(Air_{ha}, s = s_4, v = v_4\right)$

$T_4 = \mathbf{T}\left(Air_{ha}, s = s_4, v = v_4\right)$

$u_4 = \mathbf{u}\left[Air_{ha}, v = v_4, s = s_4\right]$

$W_{net} = W_{34} - W_{12}$

$W_{34} = m \cdot \left[u_3 - u_4\right]$

$W_{12} = m \cdot \left[u_2 - u_1\right]$

mass

$$m = \frac{Vol_1}{v_1}$$

thermal efficiency

$Q_{23} = m \cdot \left[u_3 - u_2\right]$

$$\eta_{th} = \frac{W_{net}}{Q_{23}}$$

The mean effective pressure

$$mep = \frac{W_{net}}{Vol_{disp}}$$

$Vol_{disp} = m \cdot \left[v_1 - v_2\right]$

power

$$Power = W_{net} \cdot \frac{\frac{rpm}{N_r}}{60 \cdot 1000000}$$

Heat Rejected

$$Q_{41} = m \cdot \left[u_4 - u_1\right] \cdot \frac{\frac{rpm}{N_r}}{60 \cdot 1000000}$$

$Q_{oil} = 0.05 \cdot Q_{41}$

$$Mass_{hw} = 1000000 \cdot \frac{0.9 \cdot Q_{41}}{4178 \cdot \delta_{hw}}$$

$$\eta_{heat} = 0.9 \cdot m \cdot \left[\frac{u_4 - u_1}{m \cdot (u_3 - u_2)}\right]$$

$$T1_{actual} = T_1 + 1000000 \cdot \frac{Q_{oil}}{4178 \cdot m \cdot \frac{rpm}{60 \cdot N_r}}$$

Parametric Table: Table 1

	T_1	δ_{hw}	$Mass_{hw}$	η_{th}	Power	η_{heat}	$T1_{actual}$
Run 1	-10	70	*5.844*	*0.5237*	*2.088*	*0.4287*	*-0.4968*
Run 2	-7.222	70	*5.865*	*0.523*	*2.089*	*0.4293*	*2.417*
Run 3	-4.444	70	*5.886*	*0.5223*	*2.091*	*0.43*	*5.331*
Run 4	-1.667	70	*5.907*	*0.5216*	*2.093*	*0.4306*	*8.245*
Run 5	1.111	70	*5.928*	*0.5209*	*2.094*	*0.4312*	*11.16*
Run 6	3.889	70	*5.948*	*0.5202*	*2.096*	*0.4318*	*14.07*
Run 7	6.667	70	*5.969*	*0.5195*	*2.097*	*0.4324*	*16.99*
Run 8	9.444	70	*5.989*	*0.5189*	*2.099*	*0.433*	*19.91*
Run 9	12.22	70	*6.009*	*0.5182*	*2.1*	*0.4336*	*22.82*
Run 10	15	70	*6.028*	*0.5176*	*2.102*	*0.4342*	*25.74*