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MATLAB simulation study of combined cycle (Reheat) using different fuels with supplementary heat from HRSG for optimum Work net and optimum efficiency

Abstract

In this paper, the simulation results of combined cycle power plants based on the use of supplementary fraction bypass heat from combustion chamber and gas turbine exit exhaust gases heat to use in HRSG, with reheat are presented. The analysis procedure is followed for finding both optimums Worknet and optimum efficiency. A fraction of hot gases heat from combustion chamber is bypassed to HRSG. Exit heat from gas turbine also passed through the HRSG. The simulation is carried out for different fuels and different air fuel ratios for different pressure ratios. The simulation codes are made in MATLAB. The significance of this kind of investigation give advantages of combine power plant that utilizes the waste energy for generation of steam to run the steam turbines. This leads to increase in power output in thermal efficiency. The performance of combined cycle depends upon the number of parameters like pressure ratios, types of fuel used, component efficiency, turbine exhaust temperature, degree of supplementary heating and condition of steam generation. It is noticed that fraction hot gases bypassed from combustion chamber to HRSG certainly give sufficient heat energy to generate steam at required pressure and temperature to obtain the optimum Worknet and optimum efficiency significantly.

Keywords: combined cycle power plants, supplementary heating, HRSG

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Introduction

The available literature on subject combined cycle is as: Seyedan et al.,[1] department of mechanical engineering IIT Delhi published technical paper in July 1996. In this paper optimization of waste heat recovery boiler of a combined cycle was studied. The optimum design results in reduction of total weight of power plant about 25 % at reduced cost. The computer simulation strategy was adopted for optimization of weights heat recovery boiler. T.S. Kim & S.T.R.O.,[2] turbo & power machinery research centre, Seoul, South Korea published a technical paper in 2000 on power augmentation of combined cycle plant using cold energy of liquefied natural gas. They analyzed of combined cycle power plant based on the 1350 degree Celsius class gas turbine where inlet air is cooled by the cold energy released by LNG as performed and relative power augmentation was examined in term of ambient temperature and humidity significantly. Zwebek et al.,[3] Sue et al.,[4] and A Franco et al.[5] contribution is notable.

In this context, numerous approaches are there such as Valdés et al.,[6] Cihan et al.,[7] Bassily.,[8] Sanjay Y, Singh O, Prasad BN.[9] Butcher and Reddy.,[10] T. Srinivas.,[11] investigated the heat recovery steam generator (HRSG) plays a key role on performance of combined cycle (CC). Mohagheghi M and Shayegan J.,[12] investigated the thermodynamic optimization using genetic algorithm. Isam H and Aljundi.,[13] studied the energy and exergy analysis of a steam power plant in Jordan. Godoy et al.,[14] investigated the optimal thermodynamic solutions for combined cycle. Kotowicz J and Bartela L.,[15] studied the optimal values of the design variables of a combined cycle plant. Woudstra et al.,[16] investigated the 800 MW combined cycle power plant. For high performance, better conditions for compressor, HRSG sections, steam reheater and deaerator are developed by Franco A.[17] The analysis is based on minimizing total exergy losses in order to optimize the performance of the HRSG-steam turbine system presented by M. M. Rahman and T. K. Ibrahim.[18] Optimization of the combined cycle power plants based on the supplement heat used for HRSG for different fuels (Nepthalene, CNG, LNG and Kerosene), different air fuel ratios (50, 55 and 60) and different pressure ratios, using C++ and MATLAB simulation is studied by Rajesh et al.[19]

MATLAB simulation study for optimum work net and optimum efficiency of combination of gas turbine and steam turbine cycle (Reheat) using different fuels with supplementary heat from HRSG is not investigated to the best of author's knowledge (Figures 1–3).

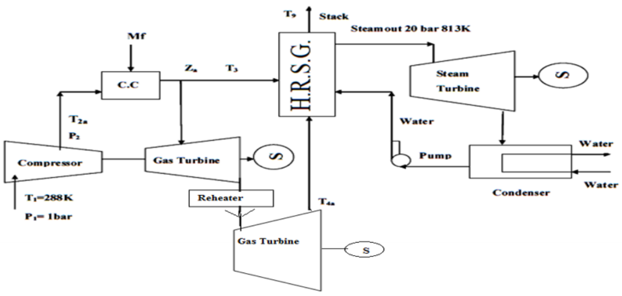

Figure 1 Schematic for an open gas-turbine reheat cycle.

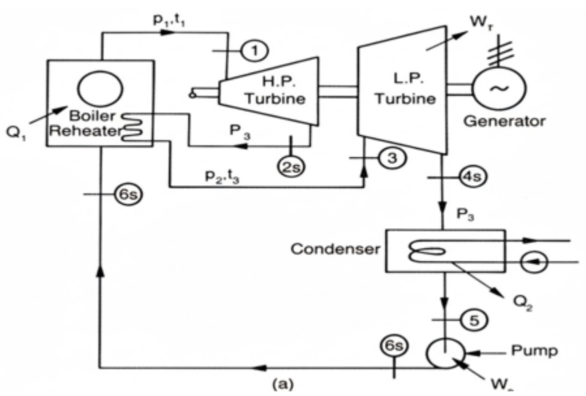

Figure 2 Schematic for a steam-turbine Reheat cycle.

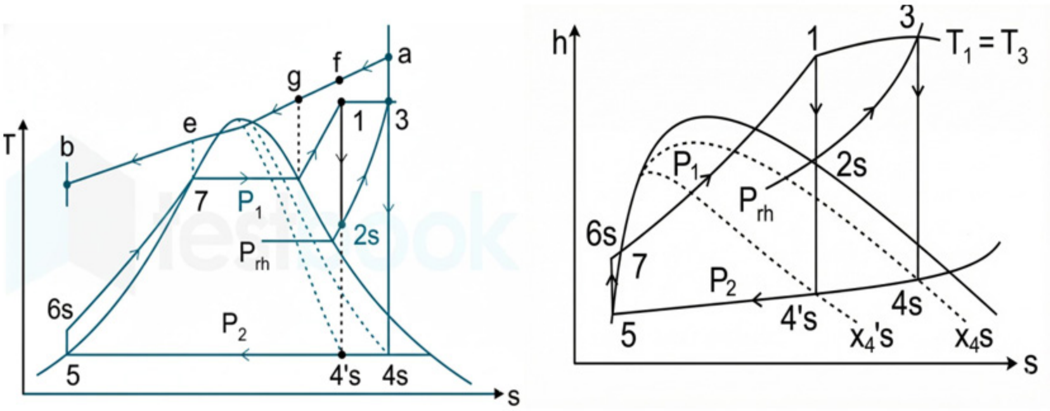

Figure 3 T-S diagram of steam-turbine reheat cycle.

Combined cycle analysis

$Worknet_3 = Work_{net1} + Work_{net2}$ (1)

$Efficiency_3 = Efficiency_1 + Efficiency_2$ (2)

Assumptions

All assumptions made for present study are mentioned in earlier published research article Ref.[19]

Investigation with reheat and without supplementary heating

For gas turbine work & efficiency

$T_3 = T_5$ (2)

$T_5 = (m_a \times lcv) + (m_a \times C_{pa} x T_{4a}) / (m_a + m_f) \times C_{pg}$ (4)

$W_C = m_a \times C_{pg} \times (T_{2a} - T_1)$ (5)

$W_{T1} = (m_a + m_f) \times C_{pg} \times (T_3 - T_{4a})$, (6)

$W_{T2} = (m_a + m_f) \times C_{pg} \times (T_5 - T_{6a})$, (7)

$W_T = W_{T1} + W_{T2}$ (8)

$Work_1 = W_T - W_C$ (9)

$Work_{net} = Work_1 / (m_a + m_f)$, (10)

$Efficiency_1 = Work_1 / (m_f \times l.c.v)$ (11)

For steam turbine work & efficiency steam is generated at 20 bar 813 K

$m_w = (m_a + m_f) \times C_{pg} \times (T_{6a} - T_9) / (h_1 - h_{f3})$, (12)

If ($T_{6a} > 813$ & $T_3 < 1400$), (13)

$Work_2 = m_w (h_1 - h_2)$ (14)

$Worknet_2 = Work_2 / (m_a \times m_f)$, (15)

$Efficiency_2 = Work_2 / (m_f \times l.c.v)$ (16)

Now

$Work_3 = Work_{net1} + Work_{net2}$, (17)

$Efficiency_3 = Efficiency_1 + Efficiency_2$, (18)

$Work_2 = m_w \times (h_1 - h_2)$ (19)

$Work_{net2} = Work_2 / (m_f \times l.c.v)$, (20)

Now

$Work_3 = Worknet1 + Worknet2$ (21)

$Efficiency_3 = Efficiency_1 + Efficiency_2$ (22)

Investigation with reheat and with supplementary heating

Gas turbine work and efficiency

$W_T = Z \times (m_a + m_f) \times C_{pg} \times (T_5 - T_{6a})$ (23)

Where $Z = 1 - Z_a$ (24)

$W_{C1} = m_a \times C_{pa} \times (T_{2a} - T_1)$, (25)

$Wc_2 = m_a x C_{pa} \times (T_{4a} - T_3)$ (26)

$Wc = Wc_1 + Wc_2$ (27)

$Work_1 = W_T - W_C$ (28)

$Work_{net1} = Work_1 / (m_a + m_f)$, (29)

$Efficiency_1 = Work_1 / (m_f \times l.c.v)$ (30)

Steam turbine work and efficiency

$T_x = (T_{6a} \times Z + T_5 \times Z_a)$ (31)

If ($T_x > 813$ & $T_5 < 1400$),

Steam is generated at 20 bar 813 K then

$$m_w = \frac{Z_a \times (m_a + m_f) \times C_{pg} \times T_5 + Z \times (m_a + m_f) \times C_{pg} \times T_{6a} - (m_a + m_f) \times C_{pg} \times T_9}{(h_1 - h_3)} \quad (32)$$

Results and discussions

The analysis procedure is followed for finding both optimum Worknet and efficiency. A fraction of hot gases heat from combustion chamber is bypassed to HRSG. Exit heat from gas turbine also passed through the HRSG. The simulation is carried out for different fuels with air fuel ratios for different pressure ratios. The simulation codes are made in MATLAB. The significance of combine power plant is that it utilizes the waste energy for generation of steam to run the

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steam turbines. The above mentioned codes in words format with reheat without supplementary heating and with reheat with supplementary heating are converted in MATLAB codes for simulation. Tables (1-8) present the optimum Worknet and optimum efficiency at air fuel ratio =50 for four kind s of fuels i.e. Nepthalene, CNG, LNG and Kerosene. Tables (9-16) present the optimum Worknet and optimum efficiency at air fuel ratio =55 for four kind s of fuels i.e. Nepthalene, CNG, LNG and Kerosene. Tables (17-24) present the optimum Worknet and optimum efficiency at air fuel ratio =60 for four kind s of fuels i.e. Nepthalene, CNG, LNG and Kerosene. Similarly, figure2, figure3 and figure4 present the comparative optimum Worknet, and optimum efficiency for air fuel ratio=50, 55 and 60 respectively.

Table 1 Naphthalene fuel having lcv = 43963.5 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=50.Worknet1, Worknet2 and Worknet3 with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	za= 0.1 to 0.5 (Fraction bypass heat from CC)				za=0.0 (without bypass)		
Pr	**Worknet 1**	**Worknet 2**	**Worknet 3**	**Pr**	**Worknet 1**	**Worknet 2**	**Worknet 3**
4	237.2582	208.9928	446.251	4	237.2582	208.9928	446.251
6	302.3757	208.3023	510.678	6	302.3757	208.3023	510.678
8	348.0473	208.6389	556.6862	8	348.0473	208.6389	556.6862
10	383.3487	209.3814	592.7301	10	383.3487	209.3814	592.7301
12	412.2039	210.3054	622.5093	12	412.2039	210.3054	622.5093
14	436.6635	211.3125	647.976	14	436.6635	211.3125	647.976
16	457.9332	212.3544	670.2876	16	457.9332	212.3544	670.2876
18	476.7816	213.4056	690.1872	18	476.7816	213.4056	690.1872
20	493.7287	214.452	708.1808	20	493.7287	214.452	708.1808

Table 2 presents the results for Naphthalene fuel having lcv = 43963.5 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=50. Efficiency1, Efficiency2 and Efficiency3 is investigated with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=20, Optimum Efficiency is 0.5305

Table 2 Naphthalene fuel having lcv = 43963.5 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=50. Efficiency1, Efficiency2 and Efficiency3 with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	**Efficiency 1**	**Efficiency 2**	**Efficiency 3**	**Pr**	**Efficiency 1**	**Efficiency 2**	**Efficiency 3**
4	0.2235	0.1968	0.4203	4	0.2235	0.1968	0.4203
6	0.2688	0.1852	0.454	6	0.2688	0.1852	0.454
8	0.2971	0.1781	0.4752	8	0.2971	0.1781	0.4752
10	0.3171	0.1732	0.4902	10	0.3171	0.1732	0.4902
12	0.3322	0.1695	0.5017	12	0.3322	0.1695	0.5017
14	0.3443	0.1666	0.5109	14	0.3443	0.1666	0.5109
16	0.3543	0.1643	0.5185	16	0.3543	0.1643	0.5185
18	0.3627	0.1623	0.525	18	0.3627	0.1623	0.525
20	0.3699	0.1607	0.5305	20	0.3699	0.1607	0.5305

Table 3 presents the results for CNG fuel having lcv = 46900 KJ/Kg, pressure ratio 4 to 16 for air fuel ratio=50.Worknet1, Worknet2 and Worknet3 is investigated with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=16, Optimum Worknet is 715.9997.

Table 3 CNG fuel having lcv = 46900 KJ/Kg, pressure ratio 4 to 16 for air fuel ratio=50.Worknet1, Worknet2 and Worknet3 with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	**Worknet 1**	**Worknet 2**	**Worknet 3**	**Pr**	**Worknet 1**	**Worknet 2**	**Worknet 3**
4	254.8436	225.0706	479.9142	4	254.8436	225.0706	479.9142
6	324.4799	223.6355	548.1154	6	324.4799	223.6355	548.1154
8	373.2025	223.4694	596.6719	8	373.2025	223.4694	596.6719
10	410.7857	223.8359	634.6215	10	410.7857	223.8359	634.6215
12	441.4519	224.4615	665.9133	12	441.4519	224.4615	665.9133
14	467.4063	225.2222	692.6286	14	467.4063	225.2222	692.6286
16	489.9446	226.0551	715.9997	16	489.9446	226.0551	715.9997

Table 4 resents the results for CNG fuel having lcv = 46900 KJ/Kg, pressure ratio 4 to 16 for air fuel ratio=50. Efficiency1, Efficiency2 and Efficiency3 is investigated with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=16, Optimum Efficiency is 0.5241.

Table 4 CNG fuel having lcv = 46900 KJ/Kg, pressure ratio 4 to 16 for air fuel ratio=50. Efficiency1, Efficiency2 and Efficiency3 with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	Efficiency 1	Efficiency 2	Efficiency 3	Pr	Efficiency 1	Efficiency 2	Efficiency 3
4	0.2259	0.1995	0.4254	4	0.2259	0.1995	0.4254
6	0.2719	0.1874	0.4593	6	0.2719	0.1874	0.4593
8	0.3006	0.18	0.4805	8	0.3006	0.18	0.4805
10	0.3208	0.1748	0.4957	10	0.3208	0.1748	0.4957
12	0.3362	0.171	0.5072	12	0.3362	0.171	0.5072
14	0.3485	0.1679	0.5164	14	0.3485	0.1679	0.5164
16	0.3586	0.1655	0.5241	16	0.3586	0.1655	0.5241

Table 5 presents the results for LNG fuel having lcv = 49400 KJ/Kg, pressure ratio 4 to 12 for air fuel ratio=50. Worknet1, Worknet2 and Worknet3 is investigated with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=12, Optimum Worknet is 702.8655.

Table 5 LNG fuel having lcv = 49400 KJ/Kg, pressure ratio 4 to 12 for air fuel ratio=50.Worknet1,Worknet2 and with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	Worknet 1	Worknet 2	Worknet 3	Pr	Worknet 1	Worknet 2	Worknet 3
4	269.8149	238.7585	508.5735	4	269.8149	238.7585	508.5735
6	343.2983	236.6895	579.9878	6	343.2983	236.6895	579.9878
8	394.6185	236.0953	630.7138	8	394.6185	236.0953	630.7138
10	434.1442	236.1417	670.2859	10	434.1442	236.1417	670.2859
12	466.3523	236.5132	702.8655	12	466.3523	236.5132	702.8655

Table 6 presents the results for LNG fuel having lcv = 49400 KJ/Kg, pressure ratio 4 to 12 for air fuel ratio=50. Efficiency1, Efficiency2 and Efficiency3 is investigated with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=12, Optimum Efficiency is 0.5114

Table 6 LNG fuel having lcv = 49400 KJ/Kg, pressure ratio 4 to 12 for air fuel ratio=50. Efficiency1, Efficiency2 and Efficiency3 with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	Efficiency 1	Efficiency 2	Efficiency 3	Pr	Efficiency 1	Efficiency 2	Efficiency 3
4	0.2278	0.2015	0.4293	4	0.2278	0.2015	0.4293
6	0.2742	0.1891	0.4633	6	0.2742	0.1891	0.4633
8	0.3032	0.1814	0.4847	8	0.3032	0.1814	0.4847
10	0.3237	0.1761	0.4998	10	0.3237	0.1761	0.4998
12	0.3393	0.1721	0.5114	12	0.3393	0.1721	0.5114

Table 7 presents the results for Kerosene fuel having lcv = 43000 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=50. Worknet1, Worknet2 and Worknet3 is investigated with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=20, Optimum Worknet is 692.6157.

Table 7 Kerosene fuel having lcv = 43000 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=50.Worknet1,Worknet2 and Worknet3 with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	Worknet 1	Worknet 2	Worknet 3	Pr	Worknet 1	Worknet 2	Worknet 3
4	231.4882	203.7175	435.2057	4	231.4882	203.7175	435.2057
6	295.1231	203.2713	498.3944	6	295.1231	203.2713	498.3944
8	339.7936	203.7729	543.5665	8	339.7936	203.7729	543.5665
10	374.3463	204.6388	578.9851	10	374.3463	204.6388	578.9851
12	402.6073	205.6607	608.2679	12	402.6073	205.6607	608.2679
14	426.5764	206.7486	633.325	14	426.5764	206.7486	633.325
16	447.4298	207.8591	655.2889	16	447.4298	207.8591	655.2889
18	465.9177	208.9696	674.8873	18	465.9177	208.9696	674.8873
20	482.5473	210.0684	692.6157	20	482.5473	210.0684	692.6157

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Table 8 presents the results for Kerosene fuel having lcv = 43000 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=50. Efficiency1, Efficiency2 and Efficiency3 is investigated with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=20, Optimum Efficiency is 0.5286.

Table 8 Kerosene fuel having lcv = 43000 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=50. Efficiency1, Efficiency2 and Efficiency3 is investigated with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	Efficiency 1	Efficiency 2	Efficiency 3	Pr	Efficiency 1	Efficiency 2	Efficiency 3
4	0.2226	0.1959	0.4185	4	0.2226	0.1959	0.4185
6	0.2677	0.1844	0.4521	6	0.2677	0.1844	0.4521
8	0.2959	0.1774	0.4733	8	0.2959	0.1774	0.4733
10	0.3157	0.1726	0.4883	10	0.3157	0.1726	0.4883
12	0.3308	0.169	0.4998	12	0.3308	0.169	0.4998
14	0.3428	0.1662	0.509	14	0.3428	0.1662	0.509
16	0.3527	0.1639	0.5166	16	0.3527	0.1639	0.5166
18	0.3611	0.1619	0.523	18	0.3611	0.1619	0.523
20	0.3683	0.1603	0.5286	20	0.3683	0.1603	0.5286

Table 9 presents the results for CNG fuel having lcv = 46900 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=55.Worknet1, Worknet2 and Worknet3 is investigated with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=16, Optimum Worknet is 651.0673.

Table 9 CNG fuel having lcv = 46900 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=55.Worknet1, Worknet2 and Worknet3 with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	Worknet 1	Worknet 2	Worknet 3	Pr	Worknet 1	Worknet 2	Worknet 3
4	229.7201	202.3658	432.0859	4	229.7201	202.3658	432.0859
6	292.9079	202.0112	494.9191	6	292.9079	202.0112	494.9191
8	337.2798	202.576	539.8558	8	337.2798	202.576	539.8558
10	371.6111	203.4901	575.1012	10	371.6111	203.4901	575.1012
12	399.6979	204.5508	604.2487	12	399.6979	204.5508	604.2487
14	423.5243	205.6712	629.1956	14	423.5243	205.6712	629.1956
16	444.2577	206.8096	651.0673	16	444.2577	206.8096	651.0673

Table 10 presents the results for CNG fuel having lcv = 46900 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=55. Efficiency1, Efficiency2 and Efficiency3 is investigated with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=16, Optimum Efficiency is 0.5160.

Table 10 CNG fuel having lcv = 46900 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=55. Efficiency1, Efficiency2 and Efficiency3 is investigated with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	Efficiency 1	Efficiency 2	Efficiency 3	Pr	Efficiency 1	Efficiency 2	Efficiency 3
4	0.2222	0.1958	0.418	4	0.2222	0.1958	0.418
6	0.2673	0.1844	0.4517	6	0.2673	0.1844	0.4517
8	0.2954	0.1774	0.4728	8	0.2954	0.1774	0.4728
10	0.3152	0.1726	0.4878	10	0.3152	0.1726	0.4878
12	0.3303	0.169	0.4993	12	0.3303	0.169	0.4993
14	0.3423	0.1662	0.5085	14	0.3423	0.1662	0.5085
16	0.3521	0.1639	0.516	16	0.3521	0.1639	0.516

Table 11 presents the results for Naphthalene fuel having lcv = 43963.5 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=55.Worknet1, Worknet2 and Worknet3 is investigated with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=20 , Optimum Worknet is 645.0440.

Table 11 Naphthalene fuel having lcv = 43963.5 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=55.Worknet1, Worknet2 and Worknet3 with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	Worknet 1	Worknet 2	Worknet 3	Pr	Worknet 1	Worknet 2	Worknet 3
4	213.7048	187.7235	401.4283	4	213.7048	187.7235	401.4283
6	272.7774	188.047	460.8244	6	272.7774	188.047	460.8244
8	314.3705	189.0697	503.4403	8	314.3705	189.0697	503.4403
10	346.6239	190.3262	536.9501	10	346.6239	190.3262	536.9501
12	373.0613	191.6587	564.72	12	373.0613	191.6587	564.72
14	395.5264	193.0035	588.5298	14	395.5264	193.0035	588.5298

16	415.1044	194.3322	609.4366	16	415.1044	194.3322	609.4366
18	432.488	195.6322	628.1202	18	432.488	195.6322	628.1202
20	448.1461	196.8979	645.044	20	448.1461	196.8979	645.044

Table 12 presents the results for Naphthalene fuel having lcv = 43963.5 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=55. Efficiency1, Efficiency2 and Efficiency3 is investigated with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=20, Optimum Efficiency is 0.5221.

Table 12 Naphthalene fuel having lcv = 43963.5 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=55. Efficiency1, Efficiency2 and Efficiency3 with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	Efficiency 1	Efficiency 2	Efficiency 3	Pr	Efficiency 1	Efficiency 2	Efficiency 3
4	0.2196	0.1929	0.4125	4	0.2196	0.1929	0.4125
6	0.264	0.182	0.446	6	0.264	0.182	0.446
8	0.2916	0.1754	0.467	8	0.2916	0.1754	0.467
10	0.3112	0.1709	0.482	10	0.3112	0.1709	0.482
12	0.326	0.1675	0.4934	12	0.326	0.1675	0.4934
14	0.3378	0.1648	0.5026	14	0.3378	0.1648	0.5026
16	0.3475	0.1627	0.5101	16	0.3475	0.1627	0.5101
18	0.3557	0.1609	0.5166	18	0.3557	0.1609	0.5166
20	0.3627	0.1594	0.5221	20	0.3627	0.1594	0.5221

Table 13 presents the results for Kerosene fuel having lcv = 43000 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=55.Worknet1, Worknet2 and Worknet3 is investigated with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=20, Optimum Worknet is 630.8687.

Table 13 Kerosene fuel having lcv = 43000 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=55.Worknet1, Worknet2 and Worknet3 with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	Worknet 1	Worknet 2	Worknet 3	Pr	Worknet 1	Worknet 2	Worknet 3
4	208.45	182.9192	391.3692	4	208.45	182.9192	391.3692
6	266.1723	183.4652	449.6375	6	266.1723	183.4652	449.6375
8	306.8538	184.6381	491.4919	8	306.8538	184.6381	491.4919
10	338.4253	186.007	524.4323	10	338.4253	186.007	524.4323
12	364.3215	187.4287	551.7502	12	364.3215	187.4287	551.7502
14	386.3399	188.847	575.1869	14	386.3399	188.847	575.1869
16	405.5389	190.2382	595.7771	16	405.5389	190.2382	595.7771
18	422.594	191.5923	614.1864	18	422.594	191.5923	614.1864
20	437.9631	192.9057	630.8687	20	437.9631	192.9057	630.8687

Table 14 presents the results for Kerosene fuel having lcv = 43000 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=55. Efficiency1, Efficiency2 and Efficiency3 is investigated with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=20, Optimum Efficiency is 0.5200.

Table 14 Kerosene fuel having lcv = 43000 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=55. Efficiency1, Efficiency2 and Efficiency3 with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	Efficiency 1	Efficiency 2	Efficiency 3	Pr	Efficiency 1	Efficiency 2	Efficiency 3
4	0.2187	0.1919	0.4105	4	0.2187	0.1919	0.4105
6	0.2628	0.1812	0.444	6	0.2628	0.1812	0.444
8	0.2903	0.1747	0.465	8	0.2903	0.1747	0.465
10	0.3097	0.1702	0.4799	10	0.3097	0.1702	0.4799
12	0.3244	0.1669	0.4914	12	0.3244	0.1669	0.4914
14	0.3362	0.1643	0.5005	14	0.3362	0.1643	0.5005
16	0.3458	0.1622	0.5081	16	0.3458	0.1622	0.5081
18	0.354	0.1605	0.5145	18	0.354	0.1605	0.5145
20	0.361	0.159	0.52	20	0.361	0.159	0.52

Table 15 presents the results for LNG fuel having lcv = 49400 KJ/Kg, pressure ratio 4 to 18 for air fuel ratio=55.Worknet1, worknet2 and worknet3 is investigated with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=12, Optimum Worknet is 637.9016.

Table 15 LNG fuel having lcv = 49400 KJ/Kg, pressure ratio 4 to 18 for air fuel ratio=55.Worknet1, worknet2 and worknet3 with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	Worknet 1	Worknet 2	Worknet 3	Pr	Worknet 1	Worknet 2	Worknet 3
4	243.3547	214.8316	458.1863	4	243.3547	214.8316	458.1863
6	310.0462	213.8996	523.9458	6	310.0462	213.8996	523.9458
8	356.7836	214.0746	570.8582	8	356.7836	214.0746	570.8582
10	392.8841	214.6972	607.5813	10	392.8841	214.6972	607.5813
12	422.375	215.5266	637.9016	12	422.375	215.5266	637.9016

Table 16 presents the results for LNG fuel having lcv = 49400 KJ/Kg, pressure ratio 4 to 18 for air fuel ratio=55. Efficiency1, Efficiency2 and Efficiency3 is investigated with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=12, Optimum Efficiency is 0.5038.

Table 16 LNG fuel having lcv = 49400 KJ/Kg, pressure ratio 4 to 18 for air fuel ratio=55. Efficiency1, Efficiency2 and Efficiency3 with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	Efficiency 1	Efficiency 2	Efficiency 3	Pr	Efficiency 1	Efficiency 2	Efficiency 3
4	0.2243	0.198	0.4223	4	0.2243	0.198	0.4223
6	0.2699	0.1862	0.456	6	0.2699	0.1862	0.456
8	0.2983	0.179	0.4772	8	0.2983	0.179	0.4772
10	0.3183	0.174	0.4923	10	0.3183	0.174	0.4923
12	0.3336	0.1702	0.5038	12	0.3336	0.1702	0.5038

Table 17 presents the results for Naphthalene fuel having lcv = 43963.5 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=60.Worknet1, worknet2 and worknet3 is investigated with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=20 Optimum Worknet is 592.2575.

Table 17 Naphthalene fuel having lcv = 43963.5 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=60.Worknet1, worknet2 and worknet3 with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	Worknet 1	Worknet 2	Worknet 3	Pr	Worknet 1	Worknet 2	Worknet 3
4	194.0126	169.941	363.9536	4	194.0126	169.941	363.9536
6	248.0312	171.1123	419.1435	6	248.0312	171.1123	419.1435
8	286.2145	172.7086	458.9231	8	286.2145	172.7086	458.9231
10	315.9196	174.3947	490.3143	10	315.9196	174.3947	490.3143
12	340.3355	176.0688	516.4043	12	340.3355	176.0688	516.4043
14	361.133	177.6959	538.8289	14	361.133	177.6959	538.8289
16	379.2967	179.2645	558.5612	16	379.2967	179.2645	558.5612
18	395.4556	180.7725	576.2281	18	395.4556	180.7725	576.2281
20	410.0361	182.2215	592.2575	20	410.0361	182.2215	592.2575

Table 18 presents the results for Naphthalene fuel having lcv = 43963.5 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=60. Efficiency1, Efficiency2 and Efficiency3 is investigated with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=20, Optimum Efficiency is 0.5139

Table 18 Naphthalene fuel having lcv = 43963.5 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=60. Efficiency1, Efficiency2 and Efficiency3 with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	Efficiency 1	Efficiency 2	Efficiency 3	Pr	Efficiency 1	Efficiency 2	Efficiency 3
4	0.2158	0.189	0.4048	4	0.2158	0.189	0.4048
6	0.2593	0.1789	0.4381	6	0.2593	0.1789	0.4381
8	0.2863	0.1728	0.4591	8	0.2863	0.1728	0.4591
10	0.3054	0.1686	0.474	10	0.3054	0.1686	0.474
12	0.3199	0.1655	0.4853	12	0.3199	0.1655	0.4853
14	0.3314	0.1631	0.4944	14	0.3314	0.1631	0.4944
16	0.3409	0.1611	0.502	16	0.3409	0.1611	0.502
18	0.3489	0.1595	0.5084	18	0.3489	0.1595	0.5084
20	0.3558	0.1581	0.5139	20	0.3558	0.1581	0.5139

Table 19 presents the results for Kerosene fuel having lcv = 43000 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=60.Worknet1, worknet2 and worknet3 is investigated with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=20, Optimum Worknet is 579.0442.

Table 19 Kerosene fuel having lcv = 43000 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=60.Worknet1, worknet2 and worknet3 with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	Worknet 1	Worknet 2	Worknet 3	Pr	Worknet 1	Worknet 2	Worknet 3
4	189.1885	165.5305	354.719	4	189.1885	165.5305	354.719
6	241.9675	166.906	408.8736	6	241.9675	166.906	408.8736
8	279.3139	168.6402	447.9541	8	279.3139	168.6402	447.9541
10	308.393	170.4296	478.8226	10	308.393	170.4296	478.8226
12	332.3121	172.1855	504.4976	12	332.3121	172.1855	504.4976
14	352.6996	173.8801	526.5797	14	352.6996	173.8801	526.5797
16	370.5153	175.5061	546.0214	16	370.5153	175.5061	546.0214
18	386.3727	177.0638	563.4364	18	386.3727	177.0638	563.4364
20	400.6877	178.5565	579.2442	20	400.6877	178.5565	579.2442

(Table 20) presents the results for Kerosene fuel having lcv = 43000 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=60. Efficiency1, Efficiency2 and Efficiency3 is investigated with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=20, Optimum Efficiency is 0.5117.

Table 20 Kerosene fuel having lcv = 43000 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=60. Efficiency1, Efficiency2 and Efficiency3 with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	Efficiency 1	Efficiency 2	Efficiency 3	Pr	Efficiency 1	Efficiency 2	Efficiency 3
4	0.2148	0.1879	0.4027	4	0.2148	0.1879	0.4027
6	0.258	0.178	0.436	6	0.258	0.178	0.436
8	0.2849	0.172	0.4569	8	0.2849	0.172	0.4569
10	0.3038	0.1679	0.4718	10	0.3038	0.1679	0.4718
12	0.3182	0.1649	0.4831	12	0.3182	0.1649	0.4831
14	0.3297	0.1625	0.4922	14	0.3297	0.1625	0.4922
16	0.3391	0.1606	0.4998	16	0.3391	0.1606	0.4998
18	0.3471	0.1591	0.5062	18	0.3471	0.1591	0.5062
20	0.354	0.1577	0.5117	20	0.354	0.1577	0.5117

Table 21 presents the results for CNG fuel having lcv = 46900 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=60.Worknet1, worknet2 and worknet3 is investigated with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=16, Optimum Worknet is 596.7796.

Table 21 CNG fuel having lcv = 46900 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=60.Worknet1, worknet2 and worknet3 with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	Worknet 1	Worknet 2	Worknet 3	Pr	Worknet 1	Worknet 2	Worknet 3
4	208.7151	183.3831	392.0982	4	208.7151	183.3831	392.0982
6	266.5118	183.9318	450.4436	6	266.5118	183.9318	450.4436
8	307.246	185.1078	492.3537	8	307.246	185.1078	492.3537
10	338.8587	186.4796	525.3383	10	338.8587	186.4796	525.3383
12	364.7888	187.9042	552.693	12	364.7888	187.9042	552.693
14	386.8361	189.3253	576.1614	14	386.8361	189.3253	576.1614
16	406.0604	190.7192	596.7796	16	406.0604	190.7192	596.7796

Table 22 presents the results for CNG fuel having lcv = 46900 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=60 Efficiency1, Efficiency2 and Efficiency3 is investigated with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=16, Optimum Efficiency is 0.5082.

Table 22 CNG fuel having lcv = 46900 KJ/Kg, pressure ratio 4 to 20 for air fuel ratio=60 Efficiency1, Efficiency2 and Efficiency3 with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	Efficiency 1	Efficiency 2	Efficiency 3	Pr	Efficiency 1	Efficiency 2	Efficiency 3
4	0.2186	0.1921	0.4107	4	0.2186	0.1921	0.4107
6	0.2628	0.1814	0.4442	6	0.2628	0.1814	0.4442
8	0.2903	0.1749	0.4652	8	0.2903	0.1749	0.4652
10	0.3097	0.1704	0.4801	10	0.3097	0.1704	0.4801
12	0.3244	0.1671	0.4916	12	0.3244	0.1671	0.4916
14	0.3362	0.1645	0.5007	14	0.3362	0.1645	0.5007
16	0.3458	0.1624	0.5082	16	0.3458	0.1624	0.5082

Table 23 presents the results for LNG fuel having lcv = 49400 KJ/Kg, pressure ratio 4 to 18 for air fuel ratio=60.Worknet1, worknet2 and worknet3 is investigated with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=12 Optimum Worknet is 583.9803.

Table 23 LNG fuel having lcv = 49400 KJ/Kg, pressure ratio 4 to 18 for air fuel ratio=60.Worknet1, worknet2 and worknet3 with fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	Worknet 1	Worknet 2	Worknet 3	Pr	Worknet 1	Worknet 2	Worknet 3
4	221.2322	194.8271	416.0593	4	221.2322	194.8271	416.0593
6	282.2452	194.8458	477.091	6	282.2452	194.8458	477.091
8	325.1511	195.6639	520.815	8	325.1511	195.6639	520.815
10	358.3879	196.7681	555.1561	10	358.3879	196.7681	555.1561
12	385.6071	197.9803	583.5874	12	385.6071	197.9803	583.5874

Table 24 presents the results for LNG fuel having lcv = 49400 KJ/Kg, pressure ratio 4 to 18 for air fuel ratio=60. Efficiency1, Efficiency2 and Efficiency3 is investigated with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0). At pr ratio=12, Optimum Efficiency is 0.4963.

Table 24 LNG fuel having lcv = 49400 KJ/Kg, pressure ratio 4 to 18 for air fuel ratio=60. Efficiency1, Efficiency2 and Efficiency3 with compressor intercooling and fraction bypass heat from combustion chamber (za=0.1 to 0.5) and without bypass (za=0.0)

	Za= 0.1 to 0.5 (Fraction bypass heat from CC)				Za=0.0 (without bypass)		
Pr	Efficiency 1	Efficiency 2	Efficiency 3	Pr	Efficiency 1	Efficiency 2	Efficiency 3
4	0.2208	0.1945	0.4153	4	0.2208	0.1945	0.4153
6	0.2655	0.1833	0.4489	6	0.2655	0.1833	0.4489
8	0.2934	0.1765	0.4699	8	0.2934	0.1765	0.4699
10	0.313	0.1719	0.4849	10	0.313	0.1719	0.4849
12	0.328	0.1684	0.4963	12	0.328	0.1684	0.4963

Figure 4 shows the Optimum Work output and Optimum Efficiency for Air Fuel ratio=50, pressure ratio (4-20), reheat system with fraction bypass heat from Combustion Chamber for different Fuels. Optimum Work output is 702.8655 for LNG at pressure ratio=12 and Optimum Efficiency is 0.5114. Optimum Work output is 715.9997 for CNG at pressure ratio=16 and Optimum Efficiency is 0.5241. At higher pressure ratio 20, Optimum Work output is 708.1808, Optimum Efficiency is 0.5305, higher for Nepthelene fuel. Here it can be noticed that LNG fuel can be used up to pressure ratio=12 and CNG fuel up to pressure ratio=16.

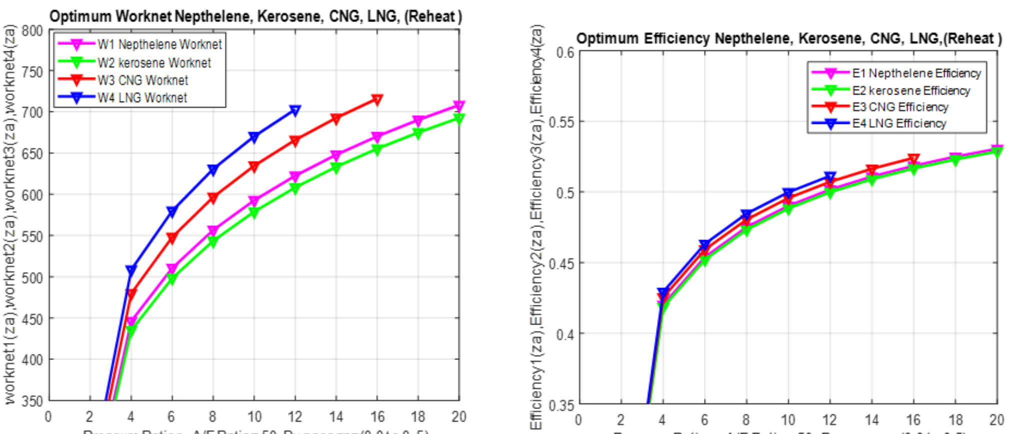

Figure 4 Optimum Work output and Optimum Efficiency for Air Fuel ratio=50, pressure ratio (4-20), reheat system with fraction bypass heat from Combustion Chamber for different Fuels.

Figure 5 shows the Optimum Work output and Optimum Efficiency for Air Fuel ratio=55, pressure ratio (4-20), reheat system with fraction bypass heat from Combustion Chamber for different Fuels. Optimum Work output is 637.9016 for LNG at pressure ratio=12 and Optimum Efficiency is 0.5038. Optimum Work output is 651.0673 for CNG at pressure ratio=16 and Optimum Efficiency is 0.5160. At higher pressure ratio 20, Optimum Work output is 645.0440, Optimum Efficiency is 0.5221, higher for Nepthelene fuel. Here it can be noticed that LNG fuel can be used up to pressure ratio=12 and CNG fuel up to pressure ratio=16.

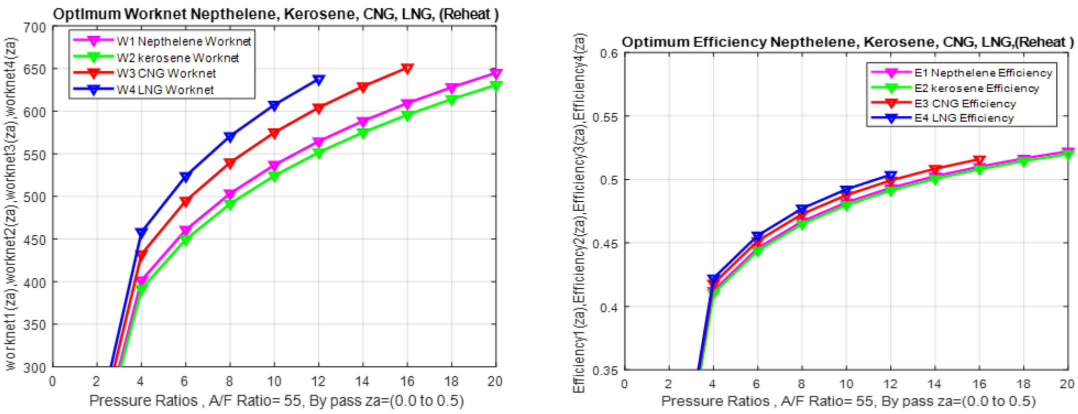

Figure 5 Optimum Work output and Optimum Efficiency for Air Fuel ratio=55, pressure ratio (4-20), reheat system with fraction bypass heat from Combustion Chamber for different Fuels.

Figure 6 shows the Optimum Work output and Optimum Efficiency for Air Fuel ratio=60, pressure ratio (4-20), reheat system with fraction bypass heat from Combustion Chamber for different Fuels. Optimum Work output is 583.5874 for LNG at pressure ratio=12 and Optimum Efficiency is 0.4963. Optimum Work output is 596.7796 for CNG at pressure ratio=16 and Optimum Efficiency is 0.5082. At higher pressure ratio 20, Optimum Work output is 592.2575, Optimum Efficiency is 0.5139, higher for Nepthelene fuel. Here it can be noticed that LNG fuel can be used up to pressure ratio=12 and CNG fuel up to pressure ratio=16.

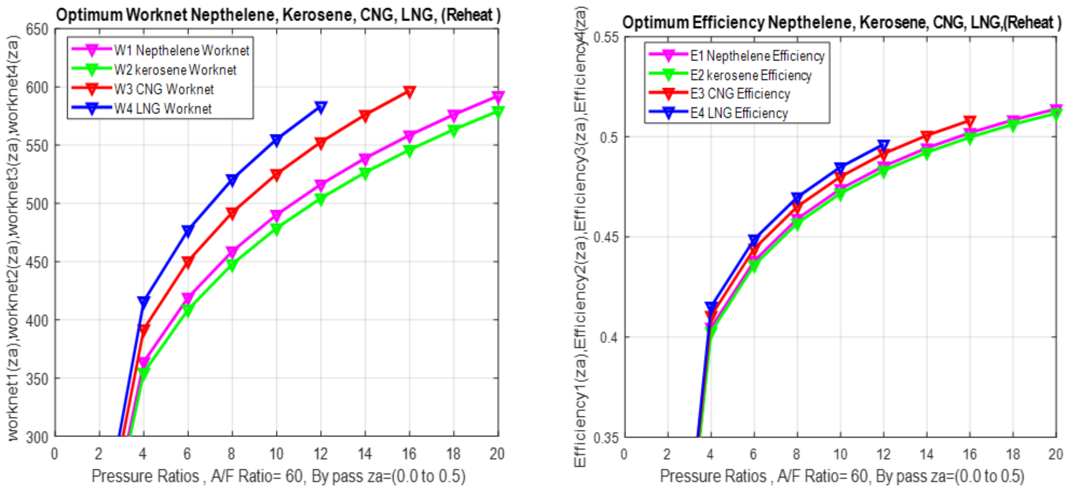

Figure 6 Optimum Work output and Optimum Efficiency for Air Fuel ratio=60, pressure ratio (4-20), reheat system with fraction bypass heat from Combustion Chamber for different Fuels.

Findings and Conclusion

The significance of combined cycle reheated power plant is found that it utilizes the waste energy for generation of steam of required pressure and temperature to run the steam turbines. This leads to increase in power output in terms of thermal efficiency. The performance of combined cycle depends upon the number of parameters like pressure ratios, types of fuel used, reheating, degree of supplementary heating and condition of steam generation as stated earlier are investigated in present research . The following points are found for conclusion.

CNG fuel with pressure ratios 16, Air fuel ratio=50, is more efficient in terms of optimum Worknet 715.9997 and optimum efficiency 0.5241, when operated with air fuel ratios 50,55 and 60 respectively. LNG fuel with pressure ratios 12, Air fuel ratio=50, is more efficient in terms of optimum Worknet 702.8655 and optimum efficiency 0.5114, when operated with air fuel ratios 50,55 and 60 respectively compared to Naphthalene and Kerosene fuels.

At lower pressure ratios LNG and CNG fuels are better options among studied fuels for getting optimum Worknet and optimum efficiency. In similar operating conditions and higher pressure ratio 20, Naphthalene fuel give more optimum Worknet and optimum efficiency at air fuel ratio=50. These are simulation results give a guidelines to optimize power plants practically. Further some more fuels can be studied for future needs.[20,21]

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Data availability: All models or codes generated or used during the study are available from the corresponding author by request. However, the database is proprietary/confidential in nature and may only be provided with restrictions.

Conflict of interest

Author has no conflicts of interest.

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