CHAPTER 8

CONCLUSIONS

To carry out thermodynamic analysis of steam power plants, a software program capable of generating different properties of the steam in supercritical/ultra supercritical/advanced ultra supercritical ranges, such as enthalpy, entropy etc., at a given input parameters (temperature/ pressure) has been successfully developed by the present investigation.

The supercritical power cycles can generate power more than subcritical power cycles. At the outset, the performance of SCRC is evaluated in terms of its energy efficiency and exergy efficiency. The turbine inlet temperature, turbine inlet pressure, reheat pressure ratio, condenser pressure, boiler flue gas inlet temperature are found to be the key parameters, which affect the performance of supercritical/ultra supercritical/advanced ultra supercritical cycle without reheat, with single reheat, with double reheat.

After a thorough parametric study and analysis of steam power plants based on SCRC without RH/SCRC with SRH/ and SCRC with DRH, conclusions have been drawn and presented below parameter wise.

1) **Turbine inlet temperature**
The following conclusions have been drawn from SCRC cycle without reheat, with single reheat, with double reheat on variation of turbine inlet temperature.

- The energy efficiency of the mentioned supercritical cycles increases with an increase of steam turbine inlet temperature at a given pressure.

- Maximum energy efficiency occurred at a turbine inlet temperature of 800°C and at a turbine inlet pressure of 425 bar for all the cycles and at a condenser pressure of 0.05 bar. The maximum energy efficiency obtained for SCRC with double reheat was 51.52%, SCRC with single reheat was 50.06%, and SCRC without reheat was 45.66%.

- The exergy efficiency of the mentioned supercritical cycles increases with an increase of steam turbine inlet temperature from 500°C to 800°C at a given pressure.

- Maximum exergy efficiency occurred at higher turbine inlet temperature of 800°C and at higher turbine inlet pressure of 425 bar for all three supercritical cycles. The maximum exergy efficiency obtained for a SCRC with DRH was 70.14%, SCRC with SRH was 68.70%, and SCRC without RH was 65.95%.

- Total exergy loss of all the above supercritical cycles decreases with increase of turbine inlet temperature at a given turbine inlet pressure.
Minimum total exergy loss is occurred at a temperature of 800°C and a turbine inlet pressure of 425 bar. Minimum total exergy loss of SCRC with DRH was 307.6276 MW and SCRC with SRH was 314.2263 MW and SCRC without RH was 341.8306 MW for the given 1000MW capacity.

Fractional exergy loss of boiler was found to be 59.28% in SCRC with DRH and FEL of the turbine was found to be 29.57% in SCRC with DRH. FEL of the condenser was 6% and FEL of the pump is less 1% in SCRC with DRH. FEL of the exhaust was 4.36% in SCRC with DRH.

2) **Turbine inlet pressure**

The following conclusions have been drawn from supercritical /ultra supercritical/advanced ultra supercritical cycles without reheat, with single reheat and with double reheat on variation of turbine inlet pressure for the given 1000 MW capacity.

- The energy efficiency of the mentioned supercritical cycles increases with an increase of steam turbine inlet pressure in the range of 170 to 425 bar at a given turbine inlet temperature.
- Maximum energy efficiency was obtained at higher turbine inlet pressure, 425 bar which requires from 43.50% to 51.52% for a range of 500°C to 800°C of turbine inlet temperature of SCRC with DRH.
The rate of increase in the energy efficiency with turbine inlet pressure was found to be less than the rate of increase in the energy efficiency with turbine inlet temperature.

The exergy efficiency of the supercritical cycles increases with an increase of steam turbine inlet pressure from 170bar to 425bar at a given pressure.

Total exergy loss of all the above supercritical cycles decreases with increase of turbine inlet pressure at a given turbine inlet temperature.

3) Reheat pressure ratio

The performance of SCRC with SRH and SCRC with DRH was found to vary with reheat pressure ratio. In view of this the present investigation carried out thermodynamic analysis of this cycles in order to find the optimum value of reheat pressure ratio for (i) SCRC with single RH and (ii) SCRC with second reheat.

Optimum value of reheat pressure ratio for SCRC with SRH was found to be 0.25.

Optimum value of second reheat pressure ratio for SCRC with DRH was found to be 0.25.

The energy efficiency of SCRC with SRH at optimum value of reheat pressure ratio was found to be 50.06% at maximum turbine inlet temperature of 800°C and maximum turbine inlet pressure of 425 bar. Further, the maximum variation in the energy efficiency
with reheat pressure ratio was found to be 2.54% at maximum turbine inlet temperature of 800°C and maximum turbine inlet pressure of 425 bar.

The energy efficiency of SCRC with DRH at optimum value of reheat pressure ratio was found to be 51.22% at maximum turbine inlet temperature of 800°C and maximum turbine inlet pressure of 425 bar. Further, the maximum variation in the energy efficiency with reheat pressure ratio was found to be 2.82% at maximum turbine inlet temperature of 800°C and maximum turbine inlet pressure of 425 bar.

The exergy efficiency of SCRC with SRH at optimum value of reheat pressure ratio was found to be 68.7% at maximum turbine inlet temperature of 800°C and maximum turbine inlet pressure of 425 bar. Further, the maximum variation in the exergy efficiency with reheat pressure ratio was found to be 2.31% at maximum turbine inlet temperature of 800°C and maximum turbine inlet pressure of 425 bar.

The exergy efficiency of SCRC with DRH at optimum value of reheat pressure ratio was found to be 70.14% at maximum turbine inlet temperature of 800°C and maximum turbine inlet pressure of 425 bar. Further, the maximum variation in the exergy efficiency with reheat pressure ratio was found to be 2.89% at maximum
turbine inlet temperature of $800^\circ$C and maximum turbine inlet pressure of 425bar.

- FEL of components of the cycle is not a strong function of reheat pressure ratio.
- FEL of the SCRC with SRH of boiler, turbine, condenser, pump and exhaust are at a reheat pressure ratio of 0.25 are 61.19%, 28.31%, 6.1%, 0.68% and 3.72% respectively.
- FEL of the SCRC with DRH of boiler, turbine, condenser, pump and exhaust are at a reheat pressure ratio of 0.25 are 63.03%, 26.89%, 5.6%, 0.59% and 3.89% respectively at maximum turbine inlet temperature of $800^\circ$C and maximum turbine inlet pressure of 425bar.

4) Condenser pressure

The following conclusions have been drawn from supercritical/ultra supercritical/advanced ultra supercritical cycle without reheat, with single reheat, with double reheat on the performance of the cycles with variation of condenser pressure between 0.03bar to 0.1bar.

- Energy efficiency decreases with an increase of condenser pressure for all the cycles.
- The energy efficiency of SCRC with DRH was found to be high compared to other cycles at all the values of condenser pressure. Further, the maximum energy efficiency was obtained at a condenser pressure of 0.03bar for all the cycles.
The energy efficiency of SCRC with DRH was found to give maximum efficiency at a turbine inlet temperature of 800°C and a turbine inlet pressure of 425bar at all values of condenser pressure.

It is further inferred that the maximum energy efficiency of the cycle was found to be 52.64% for a turbine inlet temperature of 800°C and a turbine inlet pressure of 425bar at a condenser pressure of 0.03bar for SCRC with DRH.

Exergy efficiency decreases with an increase of condenser pressure for all the cycles.

The exergy efficiency of SCRC with DRH was found to be high compared to other cycles at all the values of condenser pressure. Further, the maximum energy efficiency was obtained at a condenser pressure of 0.03bar for all the cycles.

The exergy efficiency of SCRC with DRH was found to give maximum efficiency at a turbine inlet temperature of 800°C and a turbine inlet pressure of 425bar at all values of condenser pressure.

It is further inferred that the maximum exergy efficiency of the cycle was found to be 70.94% for a turbine inlet temperature of 800°C and a turbine inlet pressure of 425bar at a condenser pressure of 0.03bar for SCRC with DRH.

Total exergy loss increases with increase of condenser pressure for all the cycles.
Minimum total exergy loss occurred at a condenser pressure of 0.03 bar of all cycles. Minimum total exergy loss of supercritical cycle with double reheat is 318.5682 MW and supercritical cycle with single reheat is 324.1017 MW and supercritical cycle without reheat is 358.2646 MW for the given 1000 MW capacity.

Fractional exergy loss of boiler, pump and exhaust increases with decrease of condenser pressure of supercritical cycle with double reheat than supercritical cycle with single reheat and without reheat.

Maximum FEL of boiler and turbine occurred in supercritical cycle with double reheat at a condenser pressure of 0.03 bar is 64.95% and 28.93% at a turbine inlet temperature of 800°C and at a turbine inlet pressure of 425 bar.

The variation in the condenser pressure in the range of 0.03 bar - 0.1 bar had a significant effect on FEL of condenser, which increased from 1.29% to 11.63% for the rise in condenser pressure from 0.03 bar - 0.1 bar in SCRC with DRH.

5) **Flue gas temperature at boiler entry**

The following conclusions have been drawn from supercritical cycle without reheat, with single reheat and with double reheat by varying the boiler flue gas inlet temperature from 900°C to 1400°C and by keeping boiler flue gas outlet temperature as 100°C.
- Energy efficiency of all the cycles was found to be independent of boiler flue gas inlet temperatures.

- Exergy efficiency increases with an increase of boiler flue gas inlet temperature of all three mentioned supercritical cycles.

- The maximum exergy efficiency of all supercritical cycles occurred at a boiler flue gas inlet temperature of 1400°C.

- The maximum exergy efficiency of supercritical cycle without reheat was found to be 71.93%, for supercritical cycle with single reheat was 77.67%, and that of supercritical cycle with double reheat was 79.61%.

- Total exergy loss increases with an increase of boiler flue gas inlet temperature from 900°C to 1400°C of all the mentioned supercritical cycles for the given capacity.

- Minimum total exergy loss is occurred in SCRC with DRH at a boiler flue gas inlet temperature of 1400°C over all cycles. Minimum total exergy loss of supercritical cycle with DRH is 300.4138 MW, SCRC with SRH is 313.7313MW and SCRC without RH is 380.0716 MW for the given capacity.

- FEL of the boiler and turbine are insignificant in all three supercritical cycles. Maximum FEL of the boiler of supercritical cycle with double reheat was 62.9% at a flue gas boiler inlet temperature of 1400°C and maximum FEL of the turbine was 29.15% at a boiler flue gas inlet temperature of 900°C.
- FEL of the exhaust gas increases significantly with an increase of boiler flue gas inlet temperature for all the cycles. Maximum FEL of the condenser occurred at a boiler flue gas inlet temperature of 1400°C in supercritical cycle without reheat and supercritical cycle with single reheat is 20.53% and 20.36%.

6) **Flue gas temperature at boiler exit temperature**

The following conclusions have been drawn from supercritical cycle without reheat, supercritical cycle with single reheat, supercritical cycle with double reheat on their performance by varying the boiler flue gas outlet temperature from 80°C to 300°C and by keeping boiler flue gas inlet temperature is 1000°C.

- Boiler flue gas outlet temperature does not affect the energy efficiency of any cycle considered.
- Exergy efficiency decreases with an increase of boiler flue gas outlet temperature for all the cycles considered.
- The maximum exergy efficiency of all supercritical cycles occurred at a boiler flue gas outlet temperature of 80°C.
- The maximum exergy efficiency of SCRC without DRH was found to be 71.32%, for SCRC without SRH was 70.44%, and that of SCRC without RH was 64.76% at a boiler flue gas outlet temperature of 80°C.
- Total exergy loss increases with an increase of boiler flue gas outlet temperature of supercritical cycles.
Minimum total exergy loss occurred at supercritical cycle with double reheat is 300.4138 MW over remaining supercritical cycles for the given capacity at a boiler flue gas outlet temperature of 80°C.

Maximum FEL of the boiler, turbine occurred in SCRC with DRH at a boiler flue gas outlet temperature of 80°C was 63.91% and 29.21%.

FEL of the exhaust rapidly increases with an increase of boiler flue gas outlet temperatures in all mentioned supercritical cycles. Maximum FEL of the exhaust occurred in SCRC with DRH at a boiler flue gas outlet temperature of 80°C is 26.9%.

As the enhancement in the performance of supercritical Rankine cycle with double reheat over the single reheat was only marginal, the present investigation has not considered investigating the effect of further reheats on the Supercritical Rankine cycle.

After thorough thermodynamic analysis of all three cycles, the present investigation has concluded that, it is possible to obtain a maximum energy efficiency of 52.64% and maximum exergy efficiency of 79.63% of Supercritical Rankine cycle with double reheat at the following conditions (i) By providing double reheat at optimum reheat pressure ratio of 0.25 both the reheats (ii) Making use of supercritical steam at the inlet of the turbine at a turbine inlet pressure of 425 bar and turbine inlet temperature of 800°C (iii) Maintaining the condenser pressure of
0.03 bar (iv) By providing boiler flue gas inlet and outlet temperatures of 1400°C and 80°C, respectively.

**SCOPE OF THE FUTURE WORK**

- Earlier researchers have established that regeneration of steam in between expansion of the steam in turbine enhances the performance of cycle with the use of steam in the subcritical conditions. Similar studies are required to be carried out for the steam in supercritical condition.
- Thermodynamic analysis and optimization of Supercritical Rankine cycle with feed water heaters in supercritical conditions to be carried out.
- Research work on development of new material, nickel based alloys which can sustain supercritical conditions. Hence, there is huge scope for the research in the newer advanced materials.
- Emission analysis of flue gas for coal based thermal power plant may be carried out.
- Analysis of multi stage steam turbine can be done for various supercritical/ultra supercritical cycles.
- Economic analysis of supercritical power plants can be carried out to reduce the unit cost of electric power.
- Advanced coal combustion technologies could be used in Supercritical and ultra supercritical power plants.
Analysis of once through boiler technology CFB (Circulating Fluidized Bed) boilers can be done for the higher efficiency of supercritical technology.

Analysis of Once through HRSG (Heat Recovery Steam Generator) with supercritical and ultra supercritical parameters could be done.

Effect of different fossil fuels can be used for the supercritical cycles.