THE APPLICATION OF REGENERATIVE FEED WATER HEATING TO POWER CYCLES IN THE SUGAR INDUSTRY - WHERE & HOW MUCH

Morne Bester
Technology & Engineering Group
Tongaat Hulett

REGENERATION

- The purpose of regeneration (or regenerative feed water heating) in any Rankine power cycle is to increase the temperature of the working fluid so that the average temperature at which heat is supplied to the working fluid is increased, thereby approaching the Carnot cycle efficiency within the source and sink temperature limits.

- This is accomplished via internal transfer of heat from higher – temperature steam to lower – temperature feed water

REGENERATION

- Regeneration is accomplished in all large-scale, modern power plants through the use of feedwater heaters.

- A feed water heater is a heat exchanger in which the latent heat (and a bit of superheat) of small amounts of high pressure steam, extracted from the turbine, is used to increase the temperature of the feed water

HISTORY OF REGENERATION IN SUGAR INDUSTRY

- Naude (1999) proposed use of single feed water heater, interposed between two economiser banks for 6500 kPa (a), 480^{o}C boiler
- Lowry et al. (2004) experienced difficultly in justifying the use of feedwater heaters in power plants with a capacity less than 120 MW
- Magasiner (2010) proposed an enhancement in the cycle efficiency by bleeding steam from the turbine into an economiser interbank feedwater heater

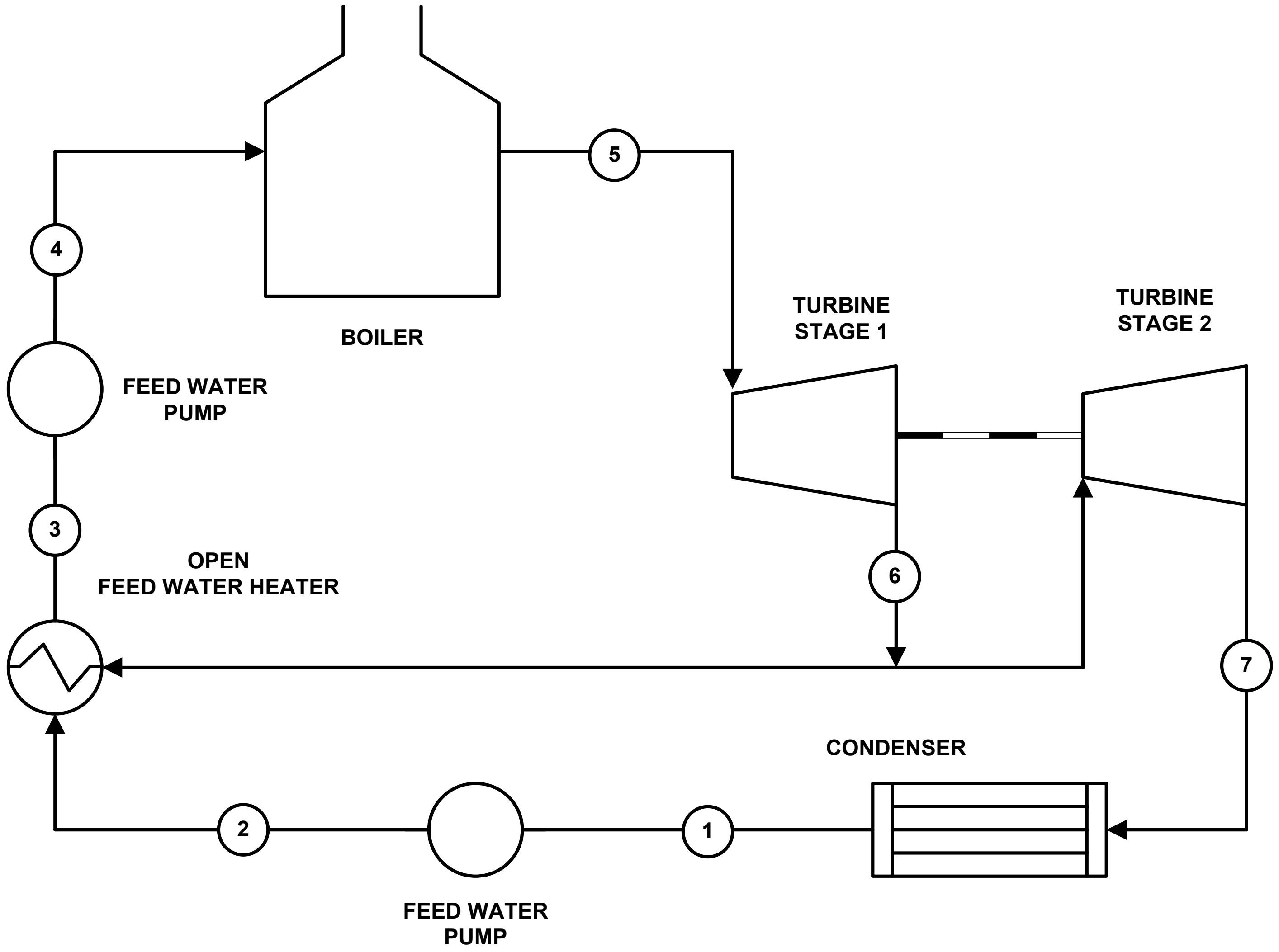
REGENERATION

- There are two types of feed water heaters
  - Open feed water heaters
  - Closed feed water heaters

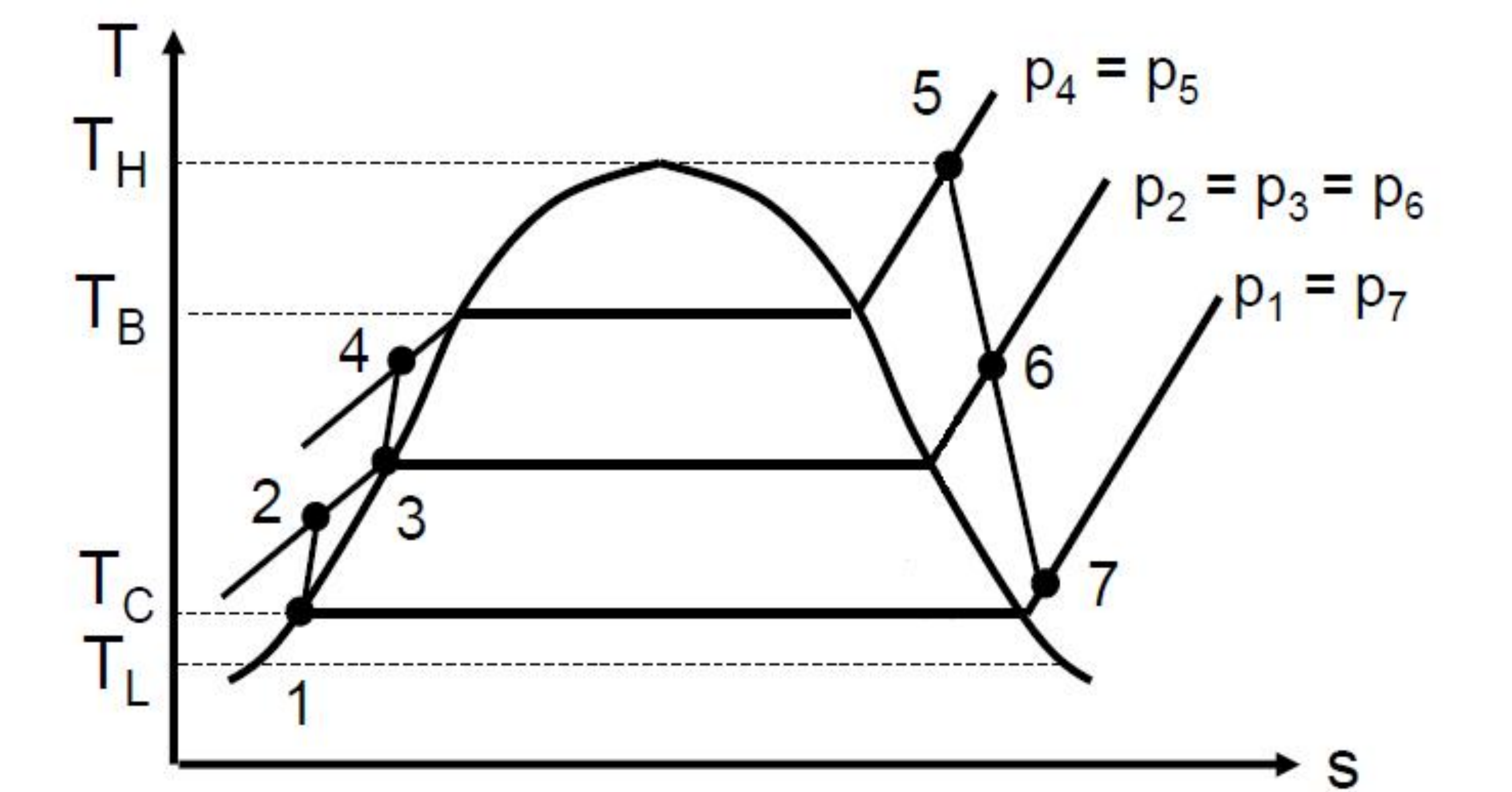
- Open feed water heaters
  - Small amount of steam drawn from turbine mixes directly with feed water to raise it's temperature

- Closed feed water heaters
  - Feed water heating is accomplished in shell – and – tube type heat exchanger
  - No mixing of extracted steam from turbine and feed water

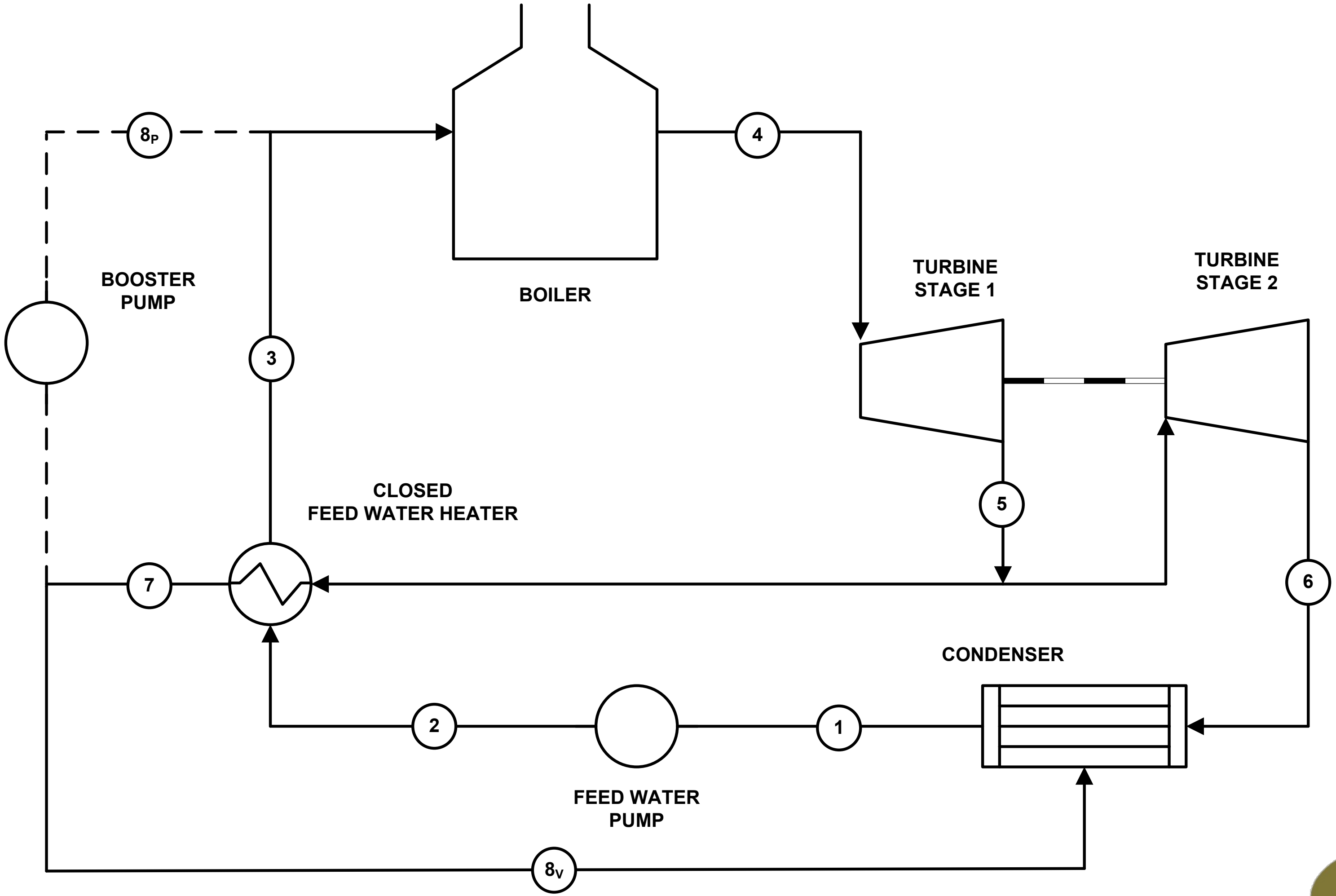
OPEN FEED WATER HEATING



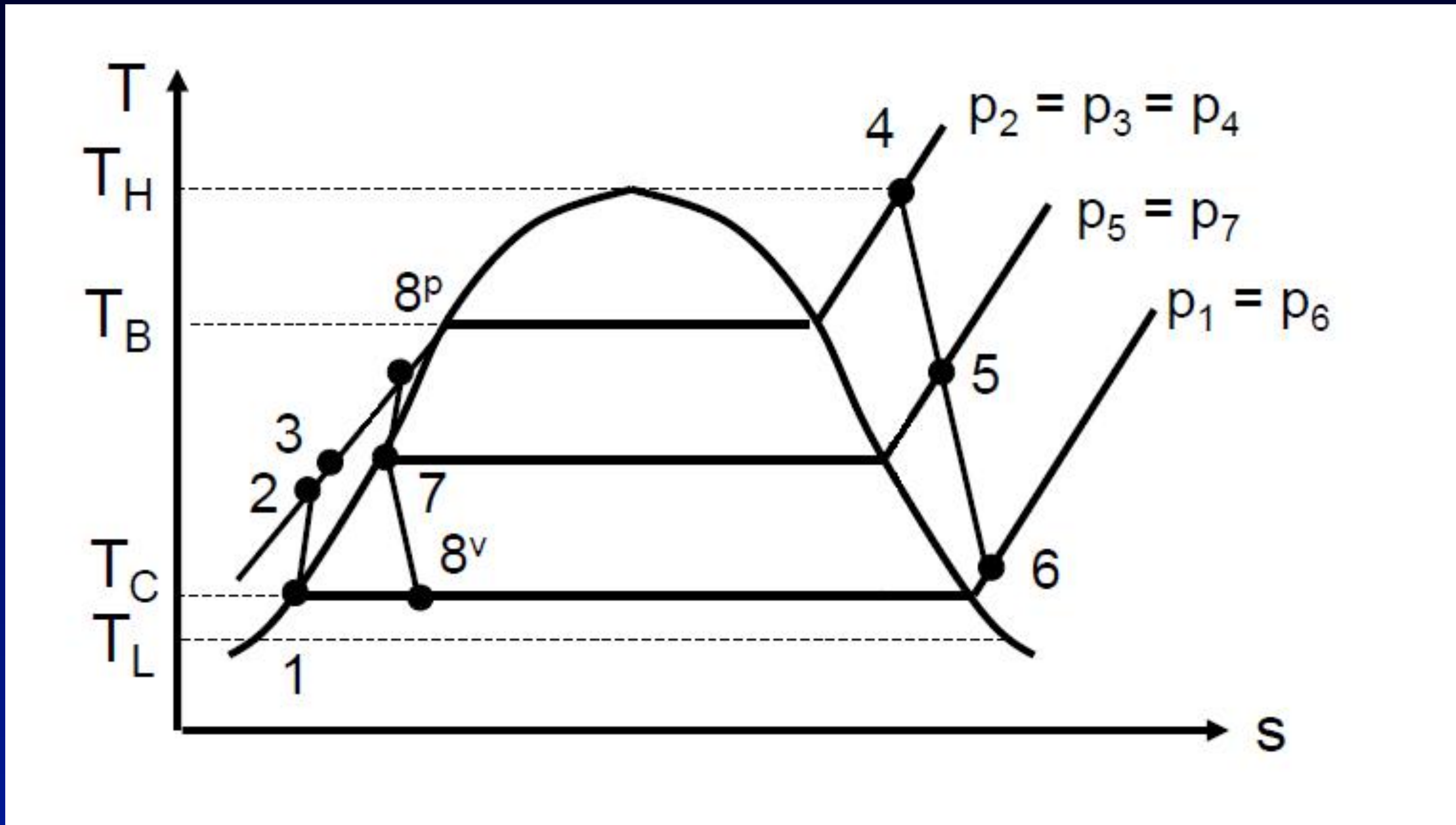
OPEN FEED WATER HEATING



CLOSED FEED WATER HEATING



CLOSED FEED WATER HEATING



FEED WATER HEATING IN BAGASSE - FIRED POWER PLANTS

- **Feed water heating require consideration of heat transfer duties within the boiler**
  - Boiling of feed water in heating stages must be avoided
  - The maximum air temperature leaving the air heater is dictated by the combustion equipment as well as clinker characteristics of bagasse (< 250 ^{o}C)
  - Metal surface temperatures should not venture below the acid dew point (ADP) of flue gas

LOW PRESSURE HEATING

- Deaerator is direct contact (open – type) feedwater heater
- Steam quality (temperature & pressure) used for heating feed water is similar to that used for process heating
- Approximately 5% of total steam flow is used to raise the temperature of the steam to the bled (exhaust) steam temperature from condenser temperature
- Sensitivity exists between the condenser pressure and the amount of steam bled from the turbine (condenser loading)
- Temperature of feed water leaving the deaerator influences number and capacity of feed water heaters upstream of deaerator

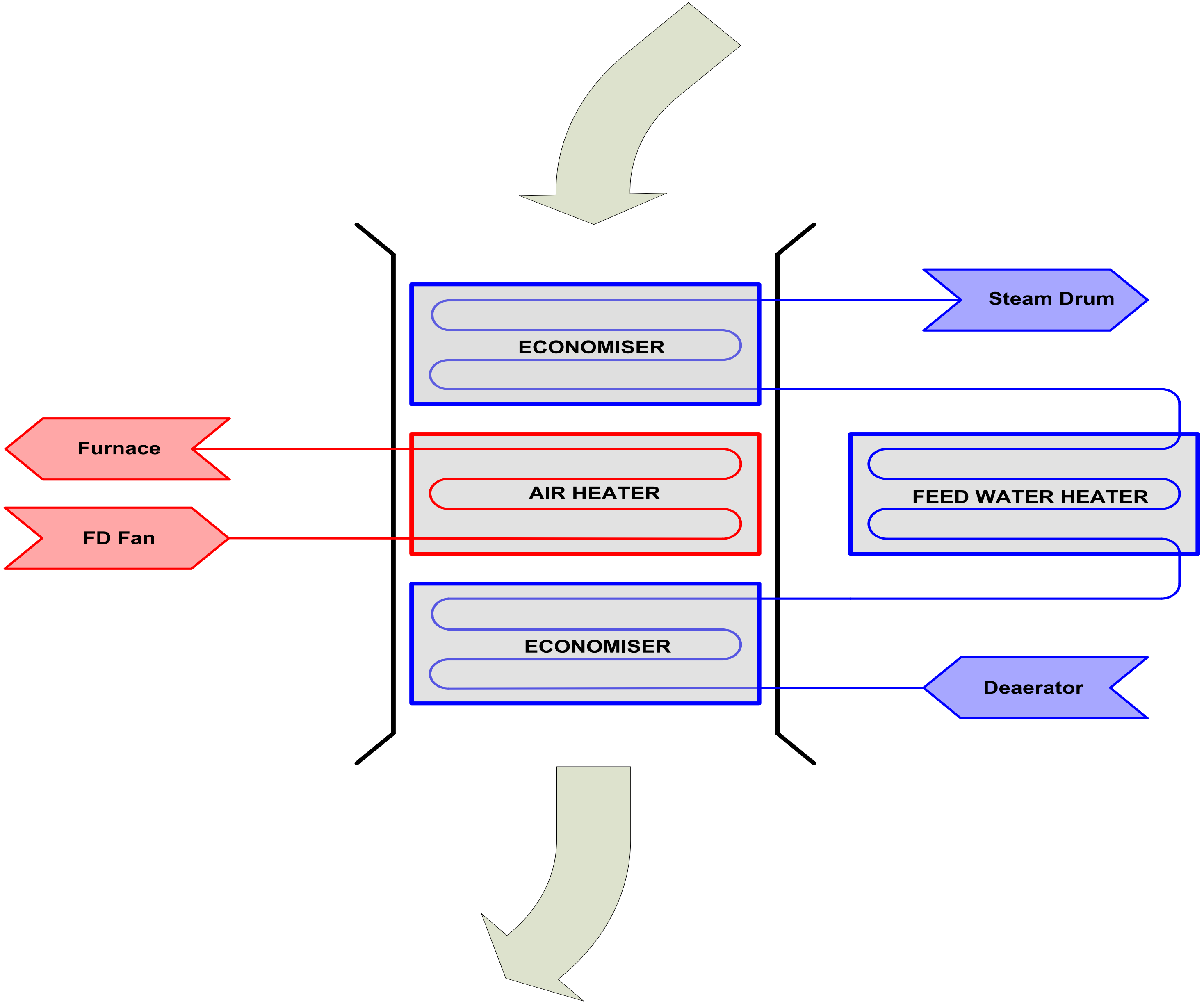
HIGH PRESSURE HEATING

- Final gas temperature when firing bagasse should in general be limited to 150^{o}C to minimise corrosion
- Feed water temperature should exceed 130^{o}C to ensure that the economiser metal temperature is above the acid dew point (ADP) for flue gas when burning bagasse
- Temperature of flue gas leaving the convection bank will be between 340^{o}C and 450^{o}C
- To avoid steaming in heat recovery equipment at MCR the feed water temperature should be approximately 30^{o}C lower than the saturation temperature at the operating pressure of the steam drum
- Air heater outlet temperature should be limited to 250^{o}C

HIGH PRESSURE HEATING

- Limitations suggest that a feed water heater is placed between economiser banks
- Arrangement optimises boiler efficiency as “low temperature” economiser bank allows for better approach towards reducing the final gas temperature (whilst minimizing the risk of ADP corrosion)
- Air heater is positioned upstream of “low temperature” economiser bank in an effort to ensure that the air heater air outlet temperature does not exceed the safe working temperature of combustion equipment
- Outlet temperature from “low temperature” economiser bank and inlet temperature to “high temperature” economiser bank is influenced by bleed steam temperature to feed water heater

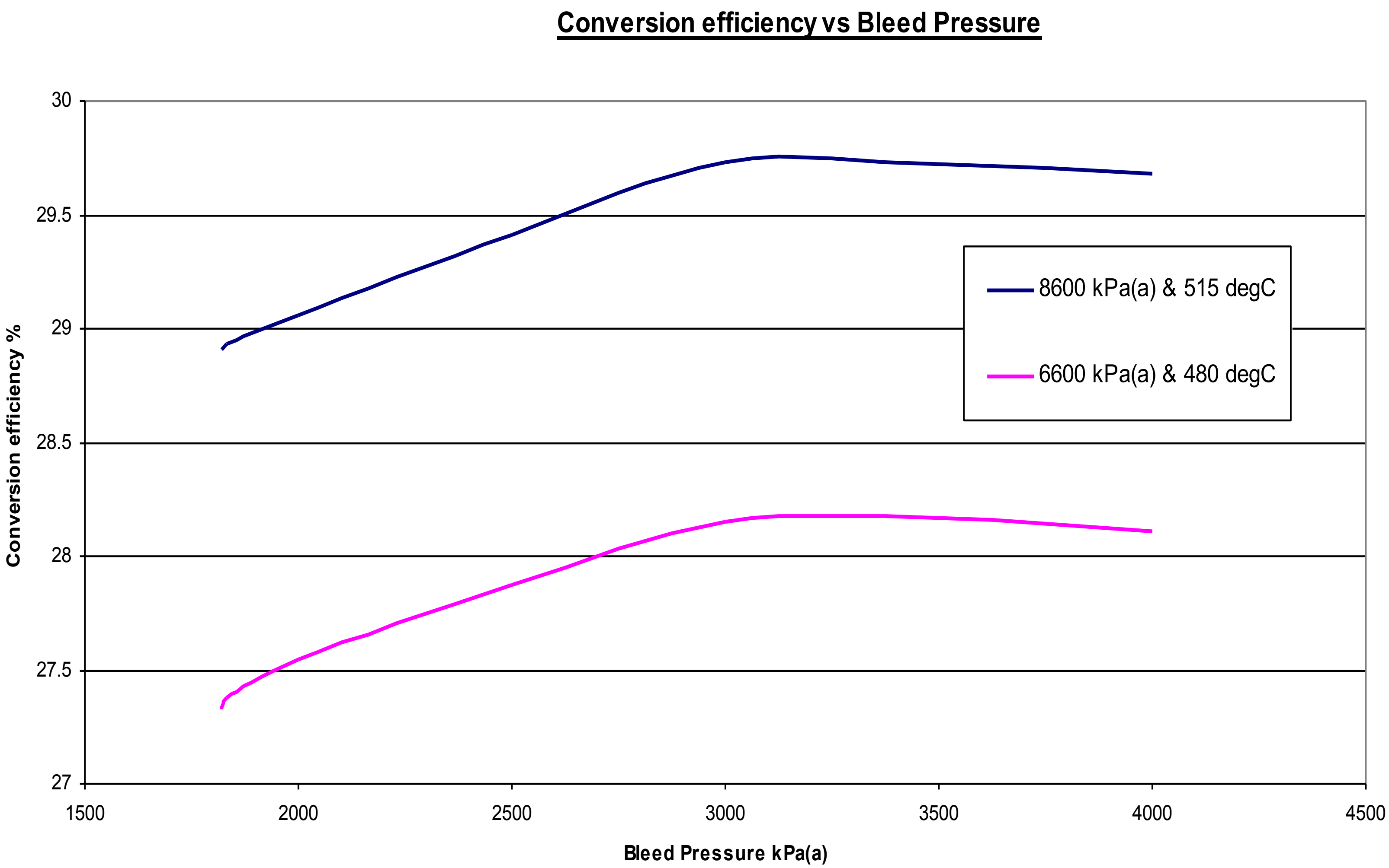
Heat Recovery Plant



INPUT DATA & CONSTRAINTS

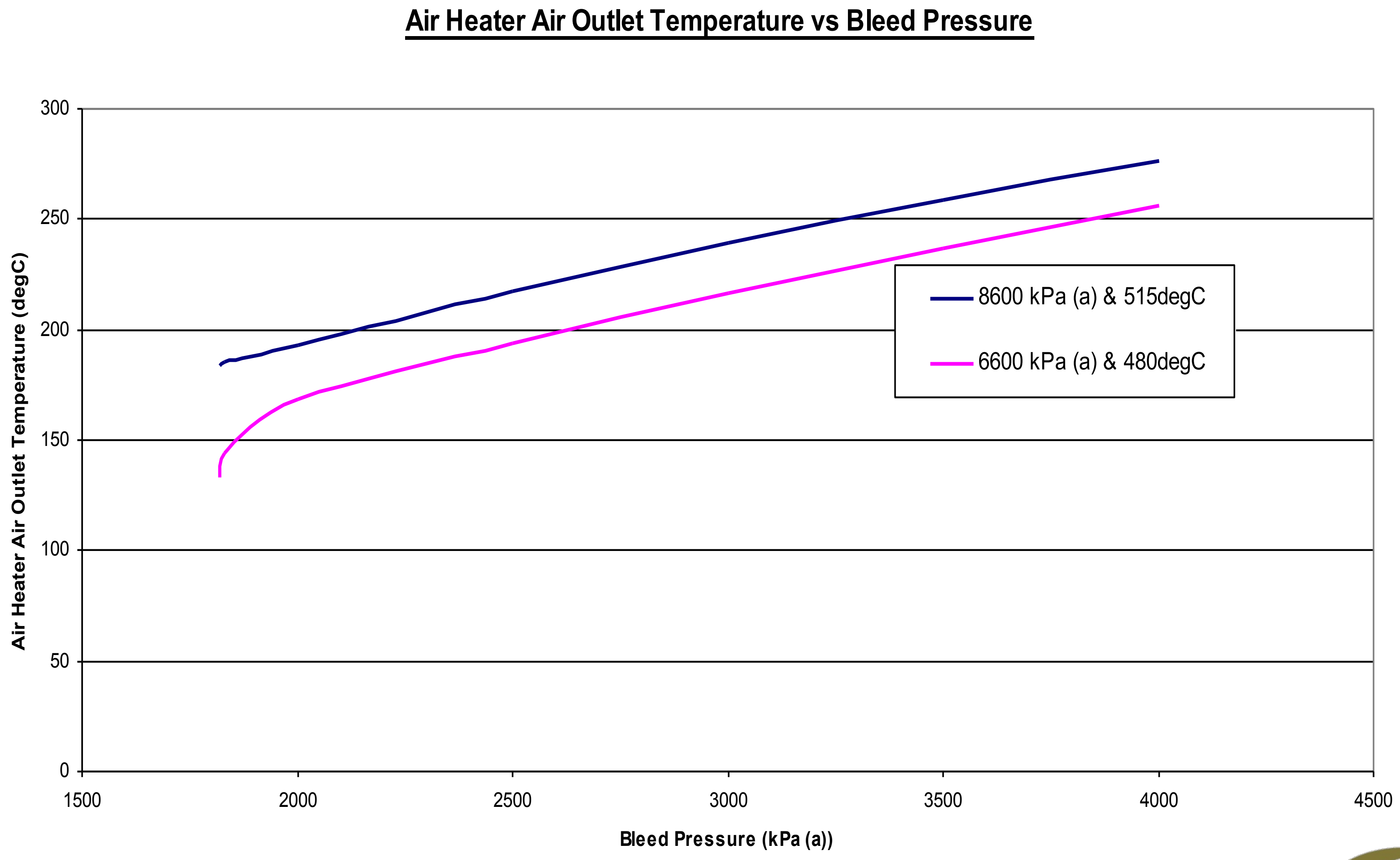
- Condenser pressure of 10 kPa (a)
- Process steam requirement per unit of cane of 45% at a pressure of 200 kPa (a)
- Turbine isentropic efficiency of 80%
- Boiler thermal efficiency of 85%
- Feed water heater approach temperature of 10^{o}C
- Bagasse with a LCV of 7289 kJ/kg
- Deaerator operating pressure of 300 kPa (a)
- Closed feed water heater with condensate pumped forward
- Economiser gas outlet temperature of 160 ^{o}C

RESULTS



Conversion efficiency vs Bleed Pressure
30
29.5
29
28.5
28
27.5
27
1500
2000
2500
3000
3500
4000
4500
Conversion efficiency %
Bleed Pressure kPa(a)
8600 kPa(a) & 515 degC
6600 kPa(a) & 480 degC

RESULTS



Air Heater Air Outlet Temperature vs Bleed Pressure
300
250
200
150
100
50
0
1500
2000
2500
3000
3500
4000
4500
Air Heater Air Outlet Temperature (degC)
Bleed Pressure (kPa (a))
8600 kPa (a) & 515degC
6600 kPa (a) & 480degC

SUMMARY OF FINDINGS

- Lower limit exists with regards to the bleed pressure
- Upper limit exists with regards to the bleed pressure
  - Influenced by the air heater air outlet temperature
- Optimal bleed pressure exists with regards to conversion efficiency
  - Increases slightly with the increase in operating pressure
  - Increase in conversion efficiency of approximately 0.77 %

FUTURE WORK

- Effect of co – firing with supplementary fuels

- Combining regenerative feed water heating with reheat at operating pressures in excess of 10.5 MPa