POWER CONVERSION

PRESENTED BY

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PRESENTED AT THE
APEX-ALPS MEETING
JULY 27-31
ALBUQUREQUE, NEW MEXICO

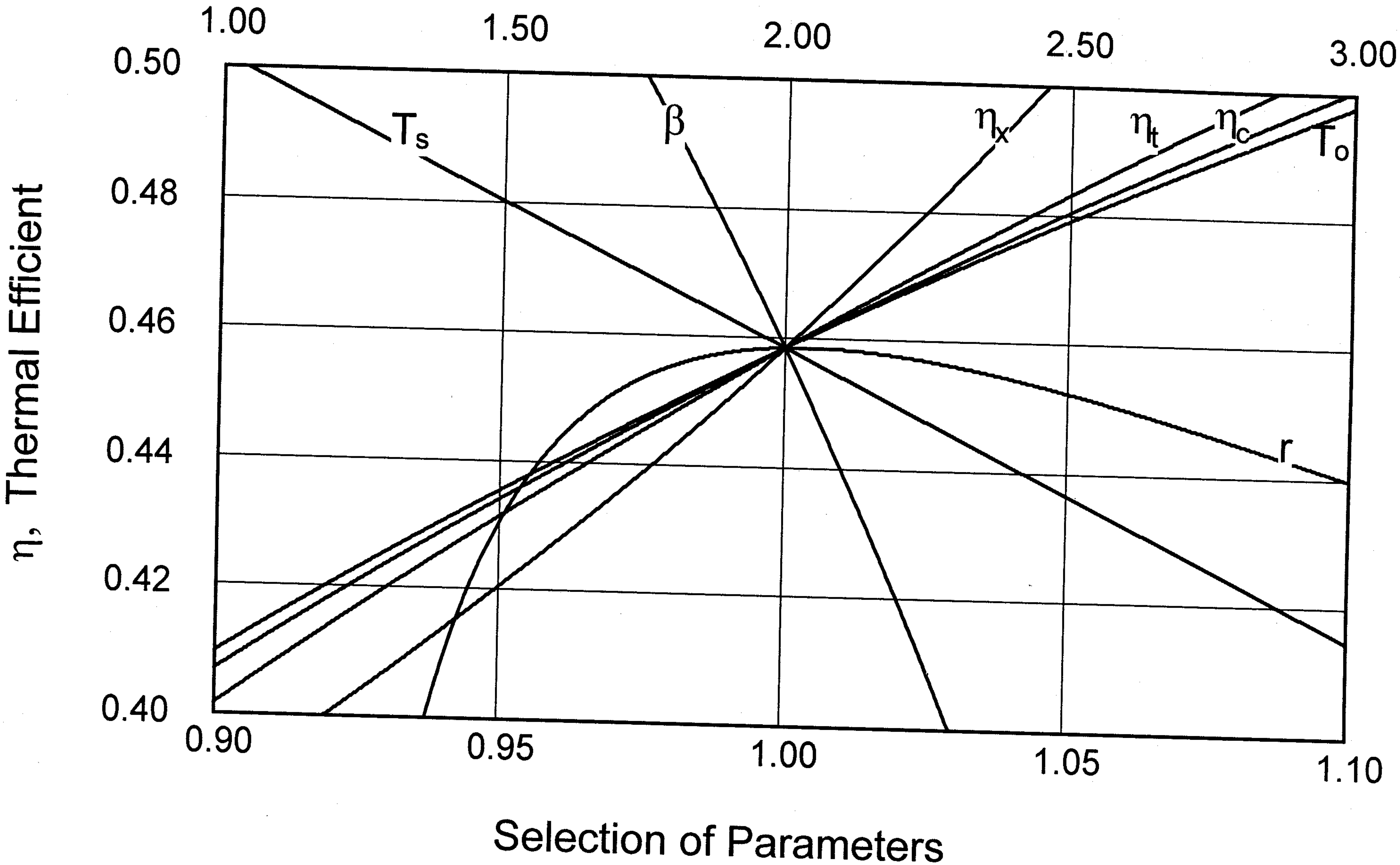
Key Parameters of the Power Conversion System (From Wong, Tillack, 1997)

T_o	923 K (650°C)
T_s	308 K (35°C)
T_o / T_s	3.00
r	2.0
η_x	0.96
η_c, η_t	0.92
β	1.02 ($\Sigma\Delta p/p=0.05$)
γ	1.66
η	46%

Comparison

	Aggressive Case	HTGR case	HTGR case with fusion parameters	Middle case
To, K	923	1200	923	923
Recup Eff	0.96	0.80	0.80	0.88
Turb Eff	0.92	0.89	0.89	0.90
Comp. Eff	0.92	0.85	0.85	0.89
Mech. Eff	---	0.98	---	---
Gener. Eff	---	0.97	---	---
Cycle Eff	0.46	0.36	0.31	0.37

The efficiency of the cycle depends strongly on the efficiencies.


1.00
1.50
2.00
2.50
3.00
0.50
0.48
0.46
0.44
0.42
0.40
Ts
β
ηx
ηt
ηc
To
r
η, Thermal Efficient
0.90
0.95
1.00
1.05
1.10
Selection of Parameters

BINARY CYCLE POWER CONVERSION

- **Topping cycle and bottoming cycle has been proposed to work together for high power converting efficiency.**

- **The usual system will have a gas topping cycle (He or K), together with a steam bottoming cycle.**

- **The predicted efficiency is usually calculated by**

$$\text{Total efficiency} = E1 + E2(1 - E1)$$

- **The system efficiency can be very high.**

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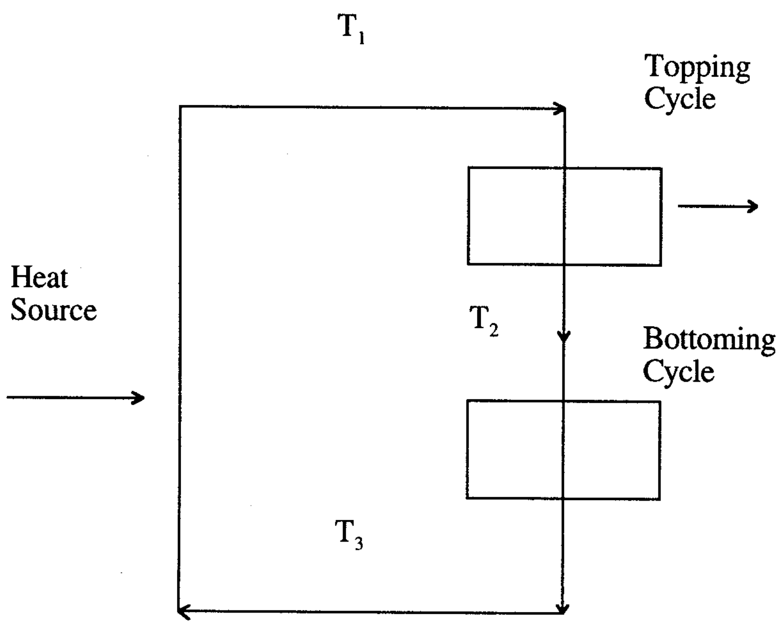
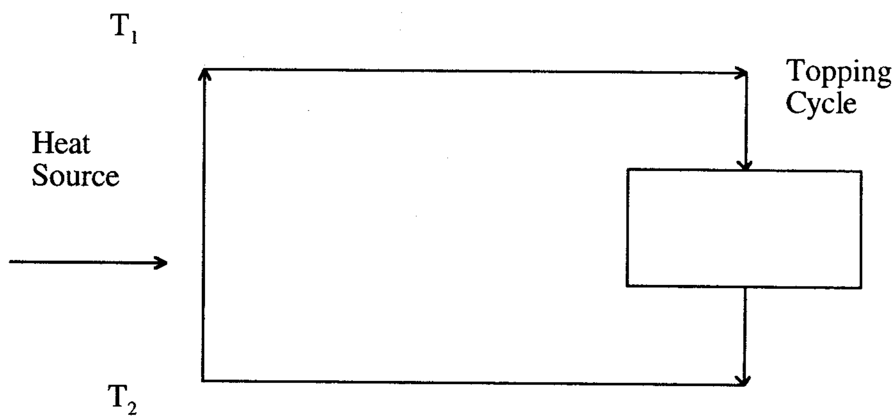
COMMONTS ON BINARY CYCLE

- The predicted efficiency use the above equation is wrong.
- The coolant flow rate is inversely proportional to the coolant DT.
- The coolant flow rate for the binary cycle case is proportional to 1/(T1-T3), while the coolant flow rate for the single cycle is proportional to 1/(T1-T2).
- Since T1-T3 is much larger thatn T1-T2, the coolant flow rate for the binary cycle case is much smaller than the single cycle case.
- The combined efficiency of the binary cycle is than the average of of the topping cycle and the bottoming cycle.
- Since by definition, the efficiency of the topping cycle is higher than that of the bottoming cycle, the binary cycle efficiency has to be lower than the single cycle efficiency, if the single cycle is the same as the topping cycle.

Comparison of Binary Cycle and Single Cycle



Binary Cycle
$\dot{m} = Q/mCp\ (Ti - T3)$



Single Cycle
$\dot{m} = Q/mCp\ (T_1 - T_2)$

CONCLUSION

- **We need to convert the thermal energy at the highest possible temperature.**

- **The binary cycle will always loss to the topping cycle along.**

POTASIUM VAPOR CYCLE

- Boiling patasium cycle has been suggested for efficient power conversion.
- Since heat vaporization is large, it has been assumed that the system can be compact.
- It is usually assumed that a binary cycle will be used for futher improvement of thermal converting efficiency.

COMPARRISON OF FLOW RATES

System	Boiling K	He	Li
Temperature,° C	1000	750	650
Coolant ΔT,° C	small	300	200
ΔH or CpΔT, j/g	2083	1584	840
Pressure, MPa	0.6	5	Low
V Vapor, m^3/s*	1100	650	
V Liquid, m^3/s*	1.7		6.0

*For 2500 MW power

POWER CYCLES TO BE DISCUSSED

- Steam cycle
- He closed cycle
- Topping cycles
- K vapor cycle

COMMENTS

- For a boiling potasium cycle to have a reasonable volumetric flow rate, the boiling temperature (and the pressure) has to be high (~1500K).
- A previews design has a potasium temperature of 977K.
- For this design, the potasium vapor volumetric flow rate is 8000 M3/s!
- The volumetric flow rate potasium liquid is a factor of three smaller than that for lithium.
- However, the lithium can use the entire blanket for coolant flow, while the K can only use maybe 10%.
- The linear velocity of the K liquid (proportional to MHD pressure drop) is about a factor of three higher than that of lithium.

rom Fraas[106]).

However,
ium–steam
1 the most

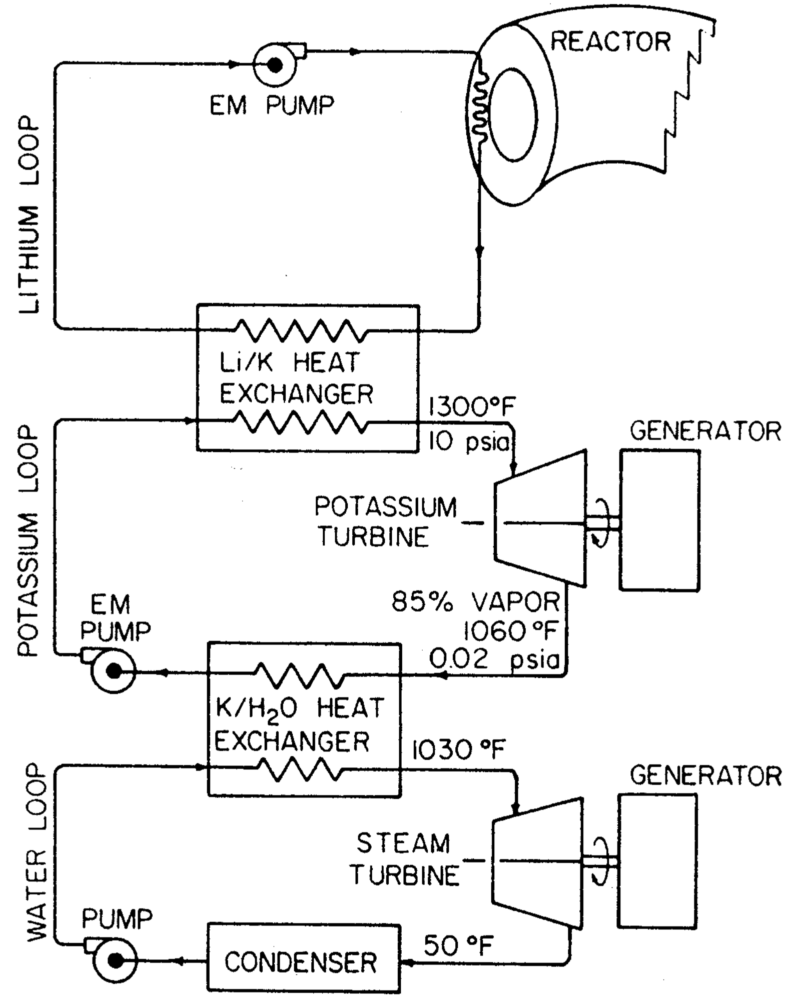


Fig. 5.36. Simplified flow diagram for the potassium–steam binary cycle with a fusion reactor (a modified version of the layout proposed by Carlson[116]).

a turbine and condensed at 590°C (0.003 atm), generating steam at 565°C and 272 atm (4000 psi) which is expanded through a conventional steam turbine. As indicated in Table 5.8, and

CONCLUSION

- The coolant thermal inertias are not that different among boiling K, He, and Li.
- To design a potasium cycle with a reasonable vapor volumetric flow rate, the temperature has to be ~1500K.
- The potasium liquid velocity is probably higher than the lithium flow velocity, for a self-cooled lithium blanket.
- Insulating coating development is necessary, if blanket is used for K-boiler.
- The development of material, with a compatible insulating coating, will have to be demonstrated.

IMPORTANT POINTS OF THE STEAM CYCLE

LOW GRADE HEAT USAGE

- A large number of feed water heaters are used to heat up the feed water to near 300°C.

- The energy for the feed water heaters is from waste heat from the condenste and is, therefore, free.

- Any power from the fusion reaction which is below 300°C has limited value.

- Therefore, the inlet temperature of any coolant should be designed at above 300°C from steam cycle power conversion point of view.

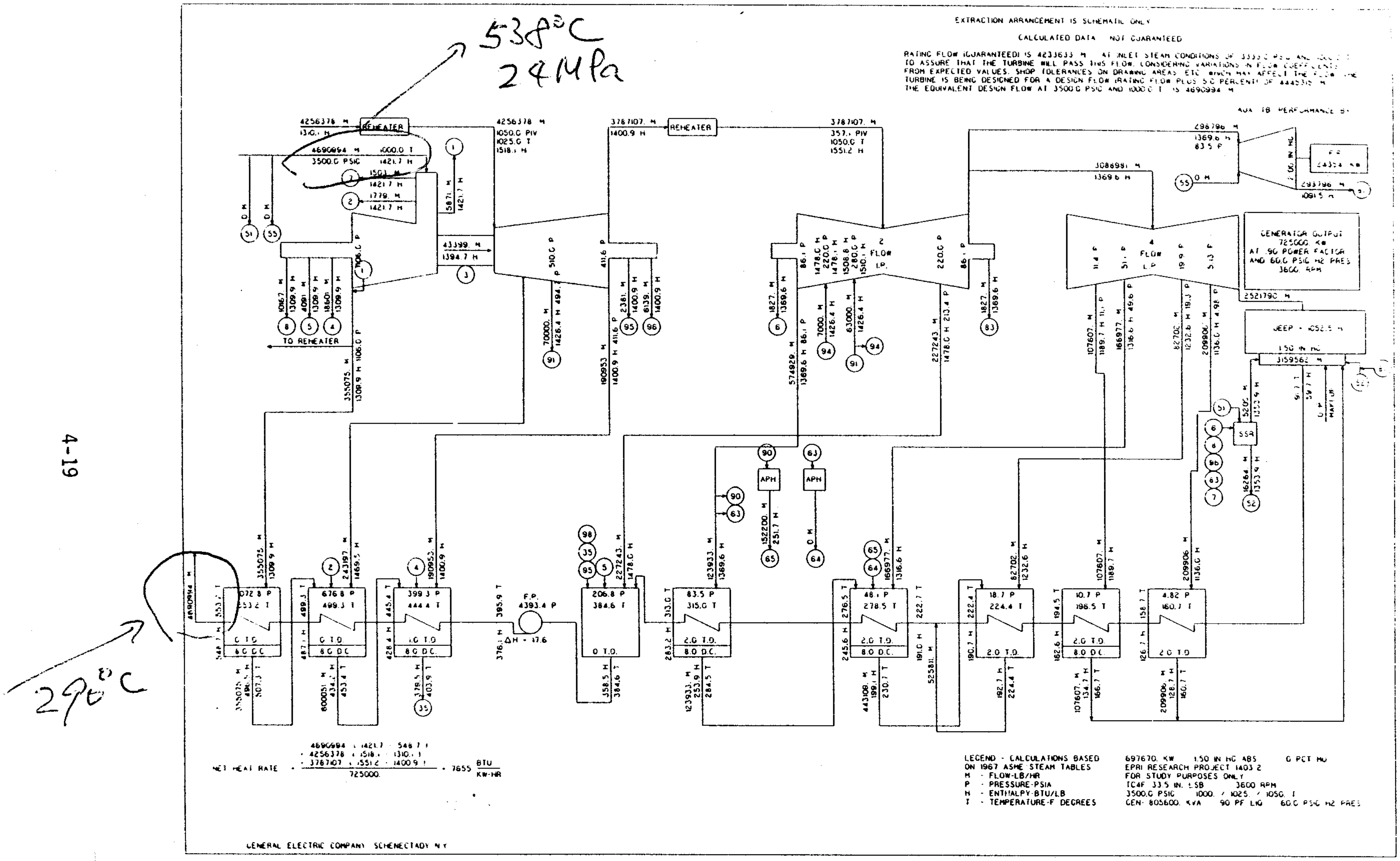
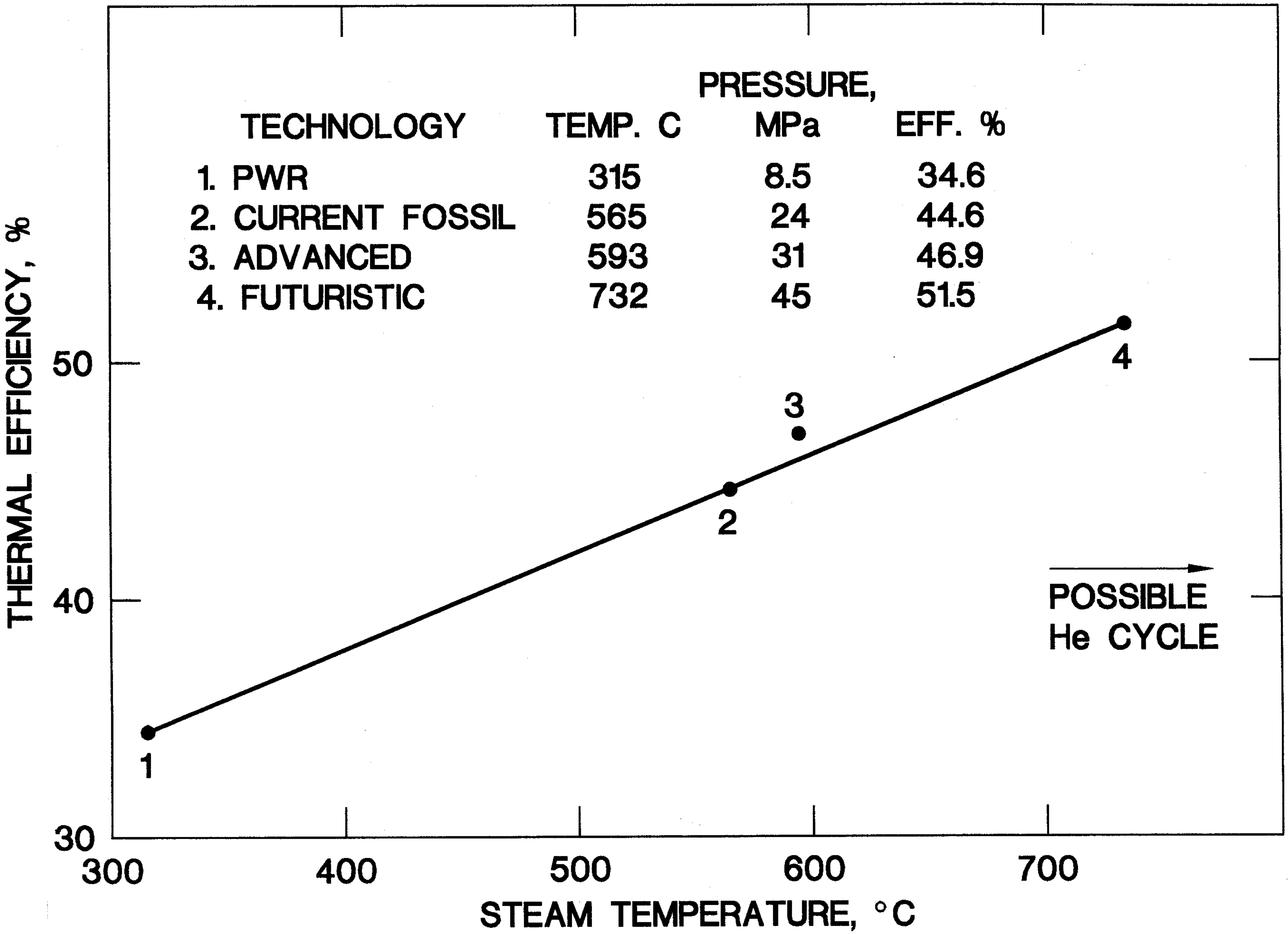


Figure 4-9. Base Plant VWO 100% Load Heat Balance

PINCH POINT CONDITION

- It is critically important to consider pinch point design.
- The pinch point DT should be about 20°C or higher.
- A negative pinch point DT makes the design of the steam cycle impossible.
- A small pinch point DT requires a large steam generator heat transfer area.



TECHNOLOGY
TEMP. C
PRESSURE, MPa
EFF. %
1. PWR 315 8.5 34.6
2. CURRENT FOSSIL 565 24 44.6
3. ADVANCED 593 31 46.9
4. FUTURISTIC 732 45 51.5
THERMAL EFFICIENCY, %
STEAM TEMPERATURE, °C
POSSIBLE He CYCLE
30
40
50
300
400
500
600
700
1
2
3
4

G11789

HELIUM BRAYTON CYCLE

- Early proposal for He Brayton requires a high He temperature (>850°C) to have efficient power conversion.

- More recent designs propsed to have a much lower He temperature (~650°C).

- By pushing efficiency of each units, and the He pressure, the net cycle efficiency of the Brayton cycle can be calculated to reach >45%.

- Whether the very high efficiencies of th eeach individual units can be achieved have to be investigated.

Cycle Efficiency

- To off set the recirculation power for the ST design, a high thermal efficiency is desirable.

- The efficiency of a He cycle can be calculated by the following equation.

$$\eta = \frac{\eta_t \frac{T_o}{T_s}\left(1-\beta\left(\frac{1}{r}\right)^{\frac{\gamma-1}{\gamma}}\right) - \frac{3}{\eta_c}\left(r^{\frac{\gamma-1}{3\gamma}}-1\right)}{(1-\eta_x)\left(\frac{T_o}{T_s}-1-\frac{1}{\eta_c}\left(r^{\frac{\gamma-1}{3\gamma}}-1\right)\right)+\eta_x\eta_t\frac{T_o}{T_s}\left(1-\beta\left(\frac{1}{r}\right)^{\frac{\gamma-1}{\gamma}}\right)}$$