Section 5: Cogeneration

Fundamentals of Turbines

Backpressure Turbines

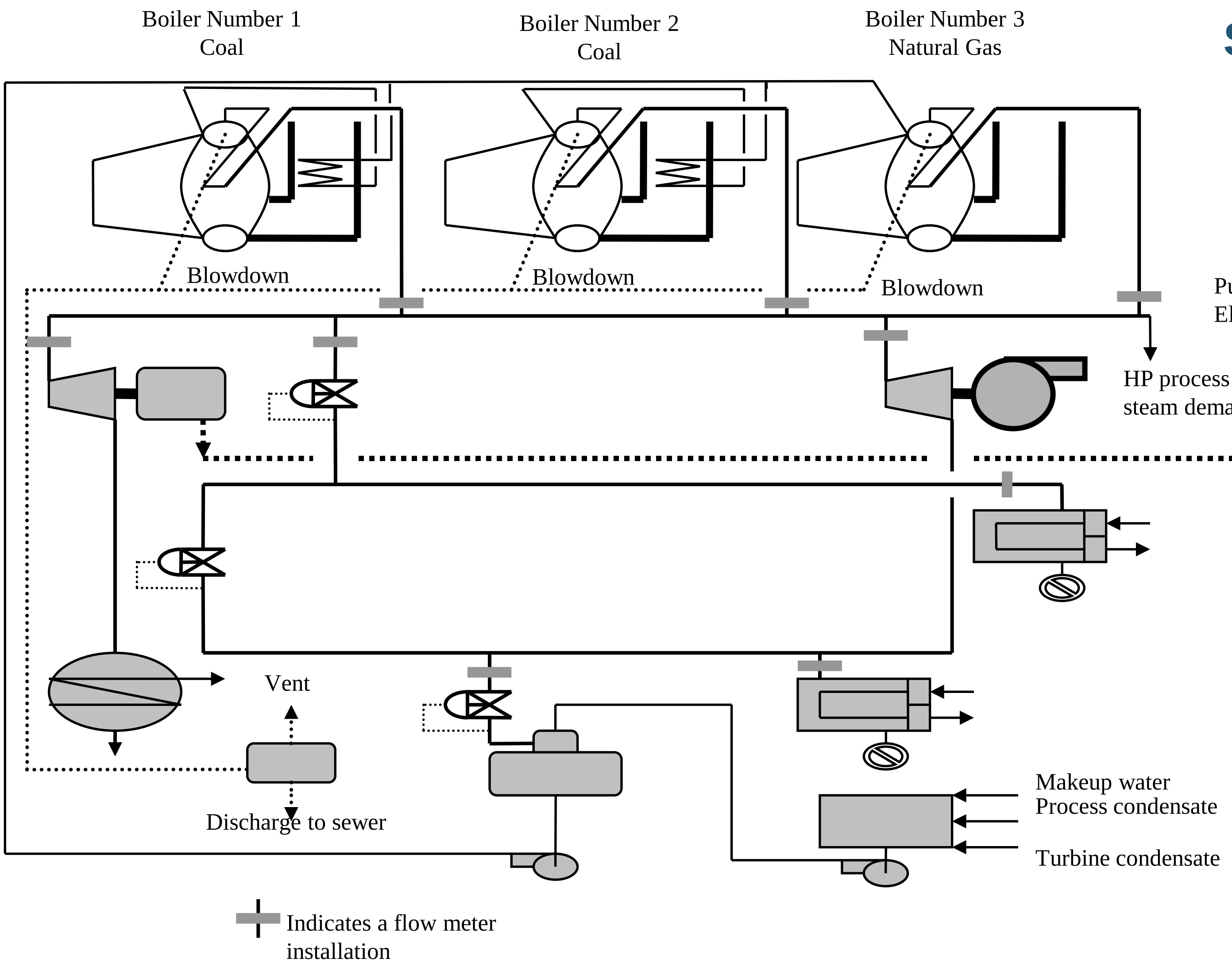
Modeling Backpressure Turbines in SSAT

Hands-On Student Exercise

Condensing Turbines

Modeling Condensing Turbines in SSAT

Steam System



Turbines 101

✓ What is a Turbine?

- Energy Conversion Device

Potential / Kinetic / Pressure / Thermal Energy

Rotational Shaft Energy

Users of Steam Turbines in Industry

✓ Heavy Steam Turbine Users

- Petrochemicals
- Petroleum Refining
- Forest Products (Pulp & Paper)
- Rubber
- Pharmaceuticals
- Manufacturing Assembly

✓ Medium & Small Steam Turbine Users

- Food & Beverage
- Plastics
- Electronics
- Metal Fabrication

✓ Steam turbine drives commonly used in industry

- Direct power generation
- Boiler feed water pumps
- Cooling tower water pumps
- Chilled water pumps
- Boiler forced draft fans
- Exhaust fans
- Air compressors
- Refrigeration machines
- Chiller systems
- Other utility services

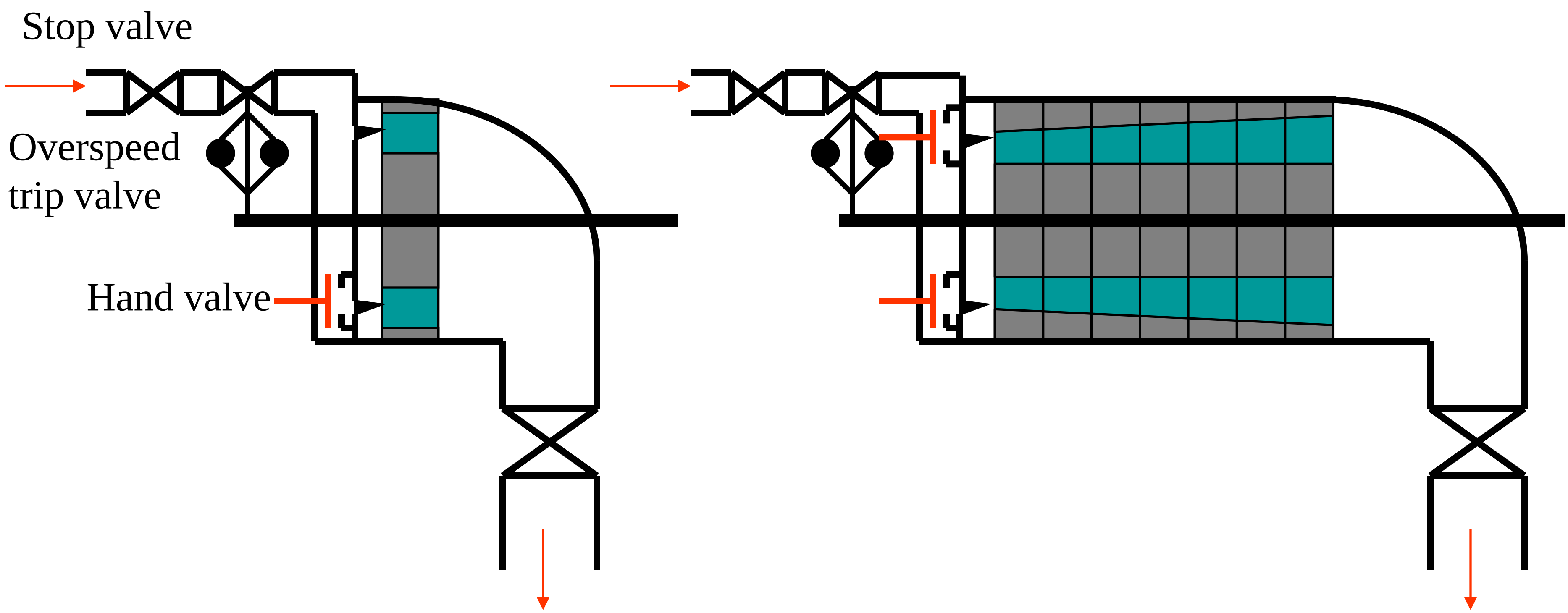
✓ Steam Turbines

- Many different kinds
  - Backpressure
  - Condensing
  - Extraction
  - Combination

- Different size and efficiency ranges
- Backpressure turbines are used in lieu of letdown stations and in parallel with letdown stations
- Condensing turbines provide maximum shaft power per unit of steam flow

Backpressure Steam Turbines

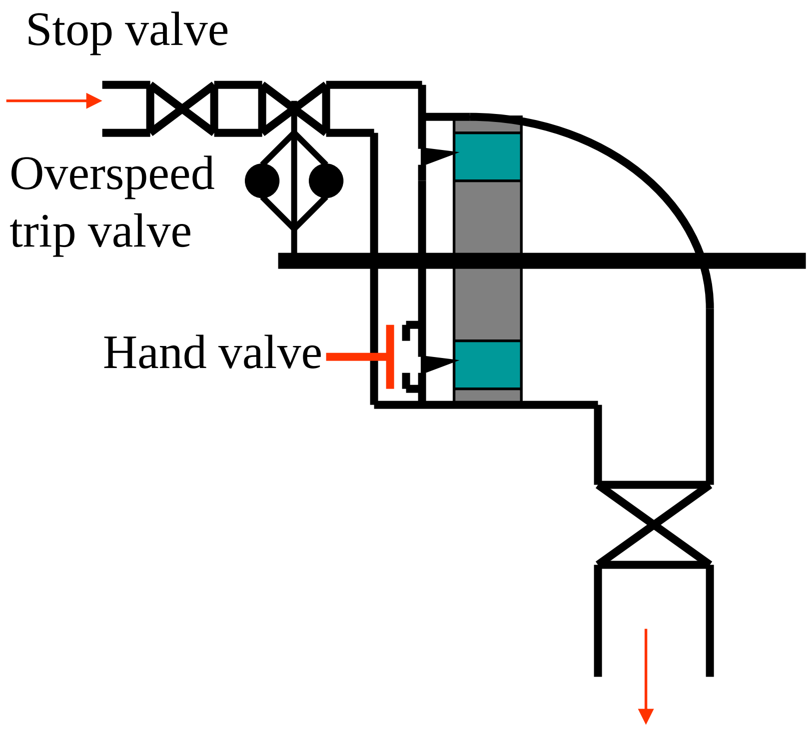
- ✓ Backpressure steam turbines discharge steam at a pressure greater than (or equal to) atmospheric pressure



Single Stage Backpressure Turbine

Multistage Backpressure Turbine

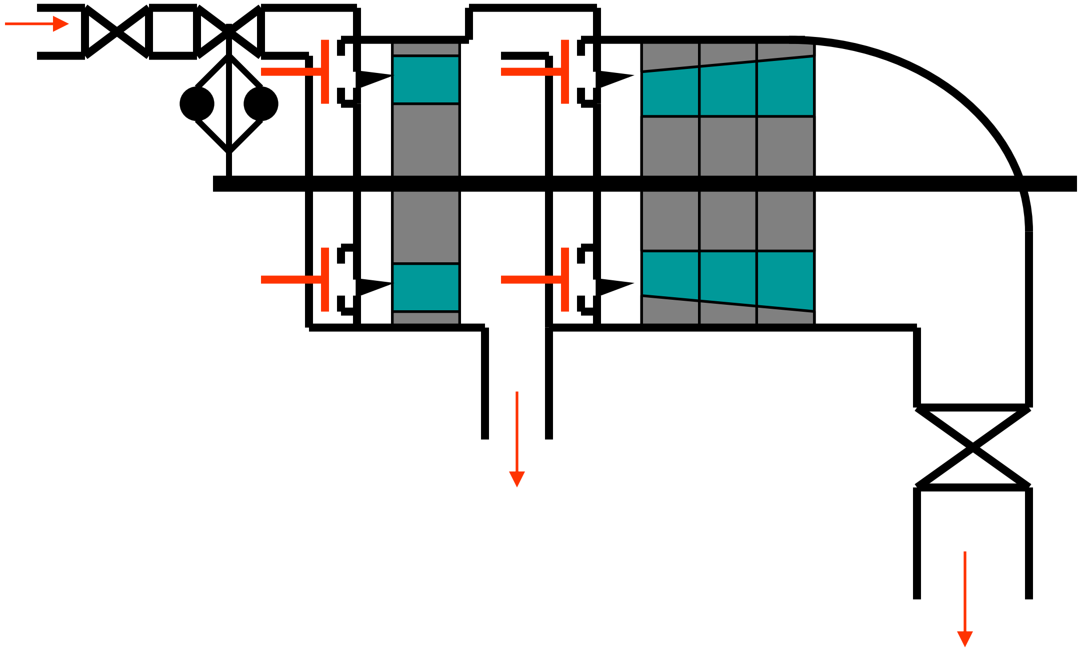
Backpressure Steam Turbines



Single Stage Backpressure Turbine

- ✓ Very common
- ✓ Simplest form
- ✓ Works against a backpressure
- ✓ Exhausts to a process load or steam header
- ✓ An excellent candidate for industrial applications

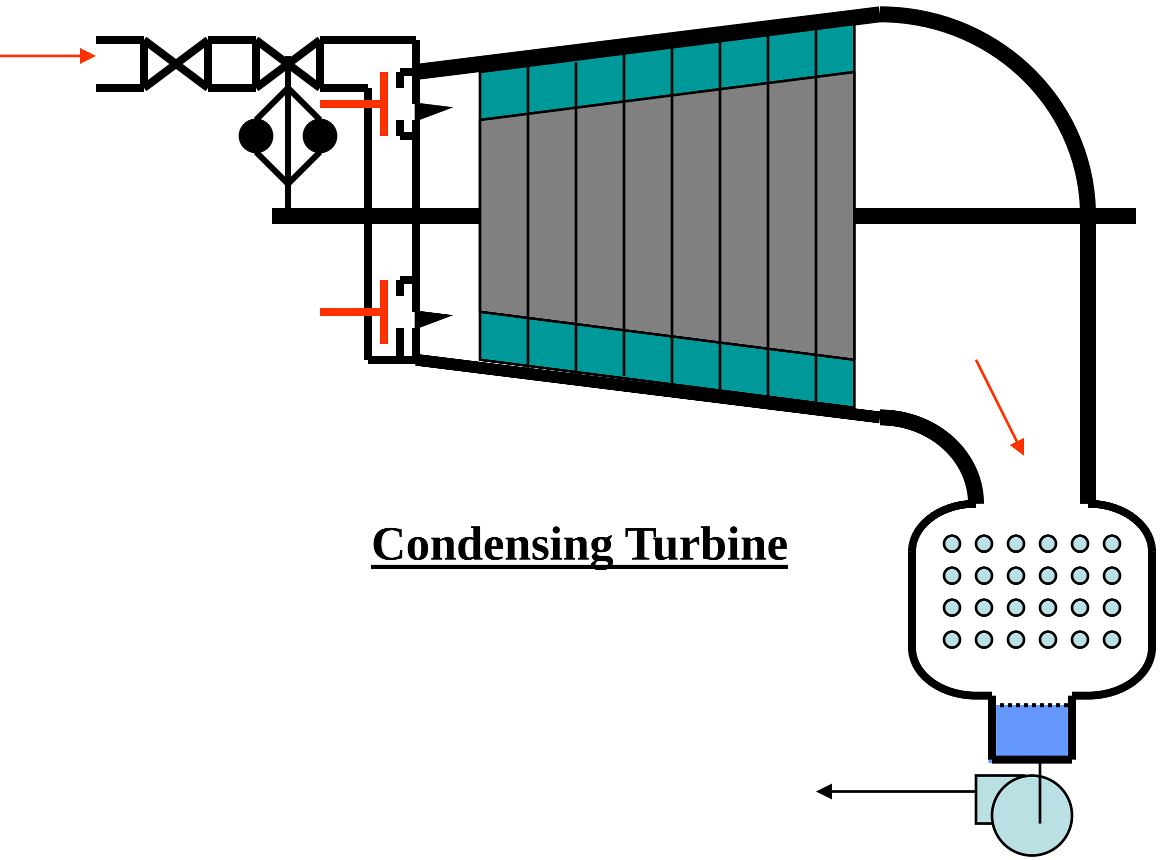
Extraction Steam Turbines



Extraction Turbine

- ✓ Very common in plants that have multiple steam pressure headers
- ✓ Works against a backpressure
- ✓ Exhausts to a process load, steam header or a condenser
- ✓ An excellent candidate for balancing headers & eliminating steam venting

Condensing Steam Turbines



Condensing Turbine

- ✓ The industry workhorse for power generation
- ✓ Will always have an associated steam condenser
- ✓ Exhausts to vacuum
- ✓ Highest operating pressure ratios
- ✓ Multistage and may even have two or three sections
- ✓ Very large sizes
- ✓ Lowest steam rates

Typical Industrial Steam Turbines Operations

- ✓ Operating pressures
  - Minimum – 10 bars (for backpressure)
  - Maximum – 100 bars
  - Vacuum conditions can exist at the exhaust!
- ✓ Operating steam temperatures
  - Saturated or a few degrees of superheat
  - Maximum – 200°C superheat
- ✓ Summary – Steam turbine technology is very diverse and operates over a broad range of pressures and temperatures

Turbine First Law Efficiency

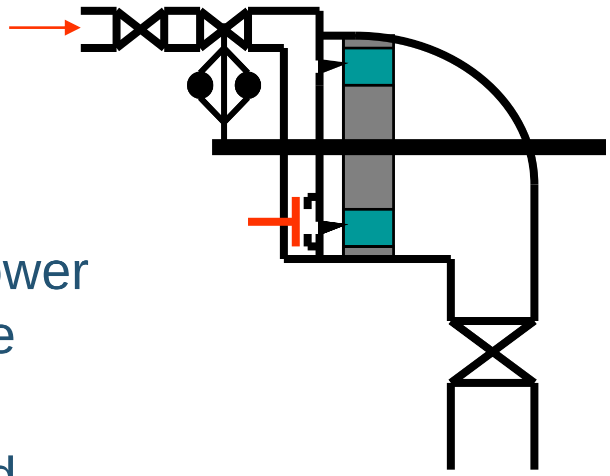
- ✓ An energy balance conducted on a steam turbine will reveal an exceptionally high efficiency
  - Essentially all of the energy taken out of the steam is converted into shaft energy

$$\eta_{first\,law} = \frac{\dot{W}_{shaft}}{\dot{m}_{steam}\left(h_i - h_e\right)} \approx 100\%$$

- ✓ Steam turbines operate with only minor “losses”
  - Bearing friction
  - Heat transfer
  - Gland losses

The Perfect Turbine

- Steam turbines are evaluated using the *Second Law of Thermodynamics*
  - The Second Law of Thermodynamics identifies that *thermal energy* cannot be converted completely into *power*
    - *Power* can be converted completely into *thermal energy*
  - This defines the maximum amount of shaft power that could possibly be produced (based on the laws of physics)
    - This defines a *perfect turbine*, which would operate *isentropically*
      - *Isentropic* is *constant entropy (no losses)*
        - » No entropy generation



Isentropic Efficiency

- Steam turbine efficiency is described as *isentropic efficiency*
  - A comparison of the actual work produced compared to a perfect (isentropic) turbine

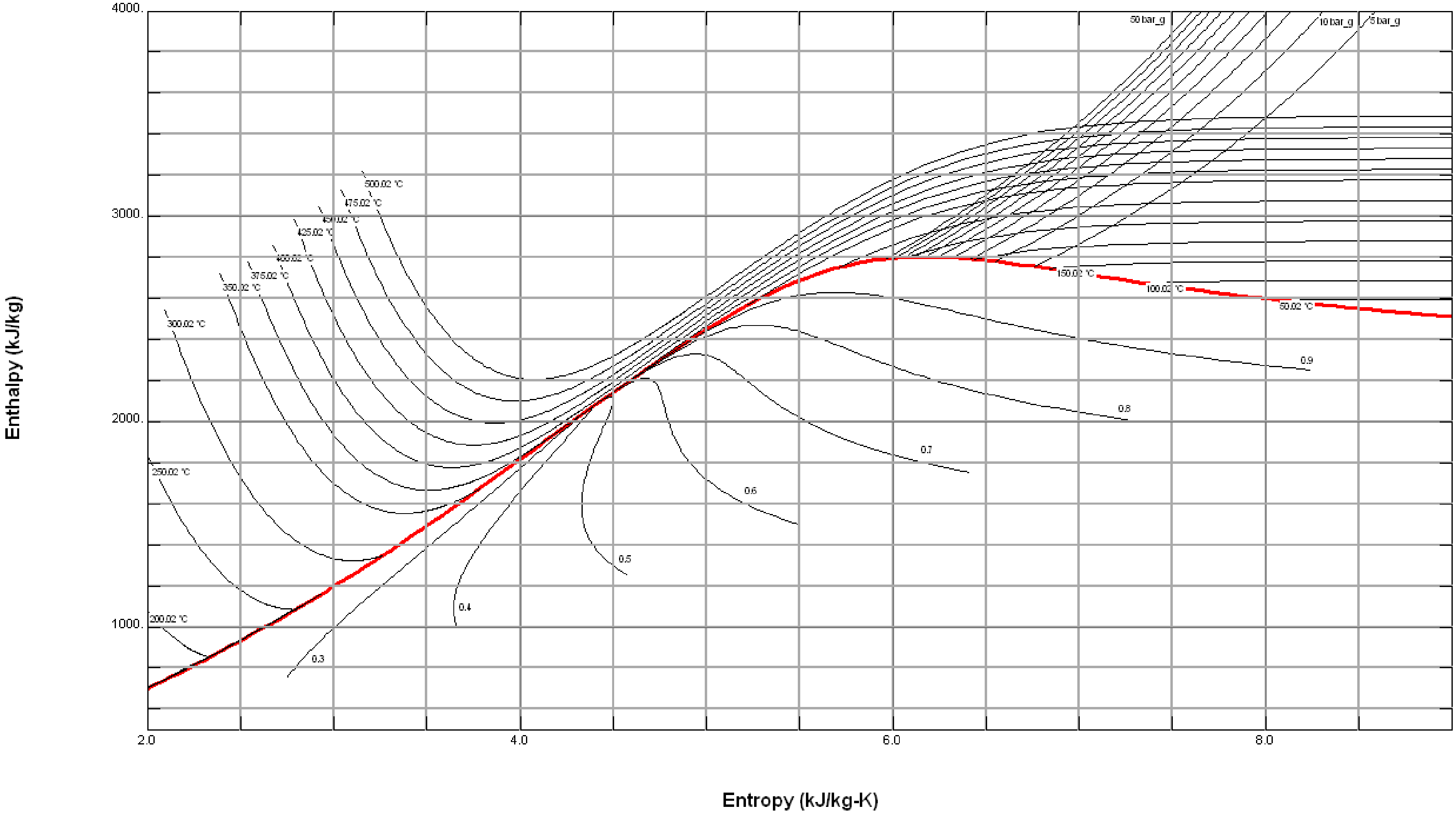
$$\eta_{isentropic} = \frac{Actual\,Work}{Isentropic\,Work} = \frac{\dot{W}_{actual}}{\dot{W}_{isentropic}}$$

$$\eta_{isentropic} = \frac{\dot{m}_{steam}\left(h_{inlet} - h_{exit}\right)_{actual}}{\dot{m}_{steam}\left(h_{inlet} - h_{exit}\right)_{isentropic}} = \frac{\left(h_i - h_e\right)_{actual}}{\left(h_i - h_e\right)_{isentropic}}$$

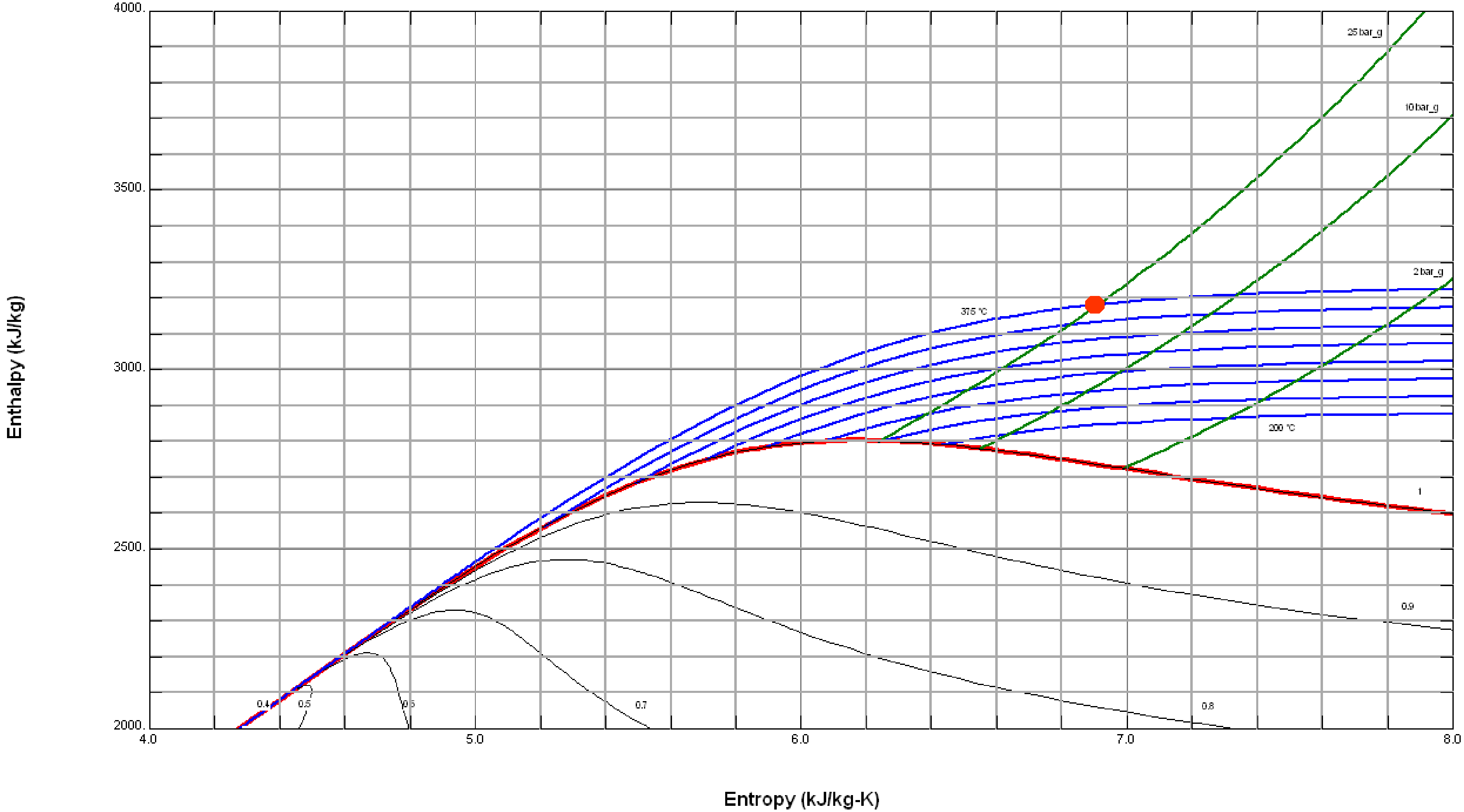
Isentropic Efficiency

- ✓ Steam turbine efficiency is not “like” boiler efficiency
  - Turbine isentropic efficiency is a comparison of the actual turbine operation to that of a perfect turbine operating with the same inlet conditions and outlet pressure
  - Isentropic efficiency is a description of how much mechanical energy is developed from thermal energy
- ✓ The steam exiting the turbine contains a significant amount of useful thermal energy

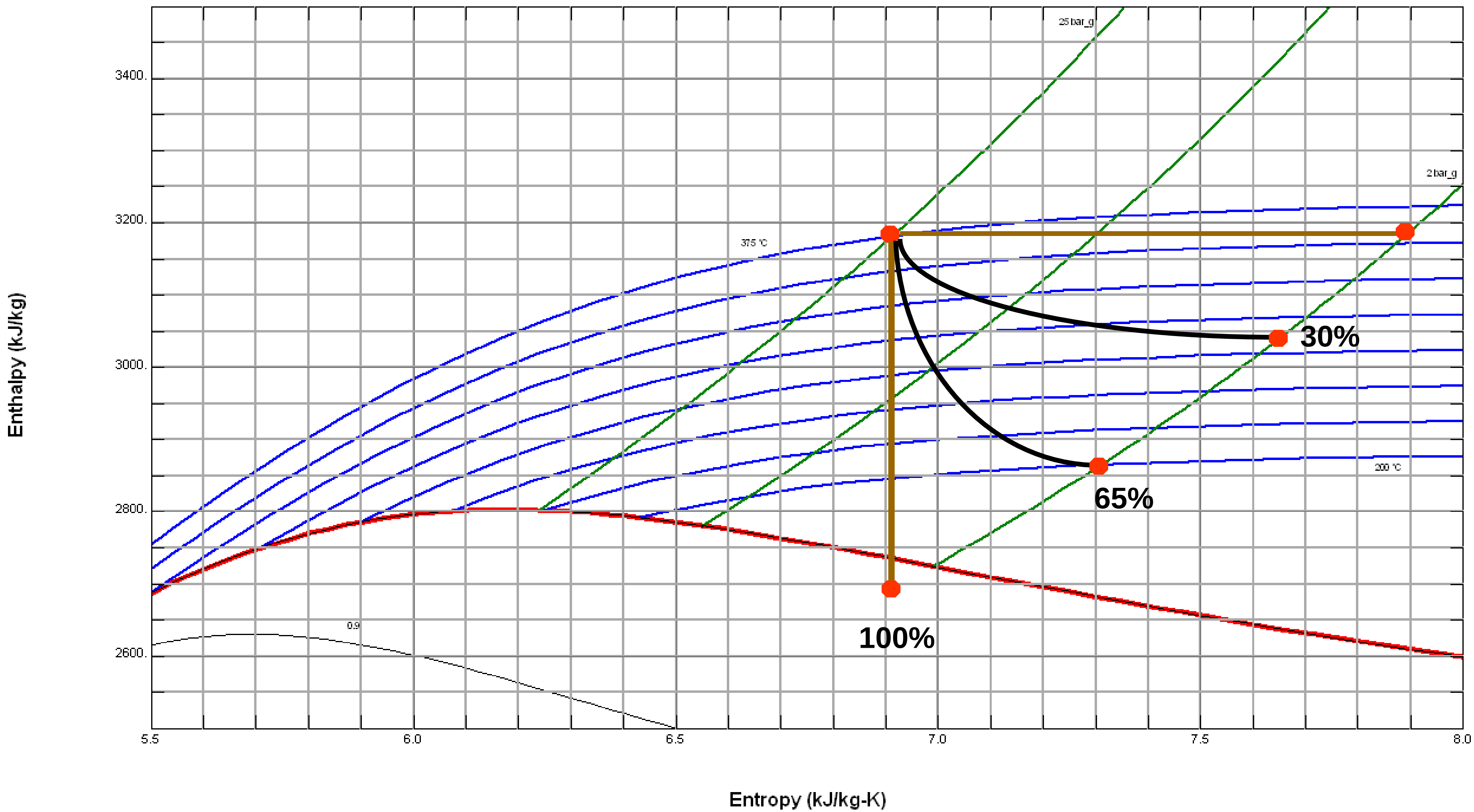
Mollier Diagram



Mollier Diagram



Mollier Diagram – Isentropic Turbine Efficiency



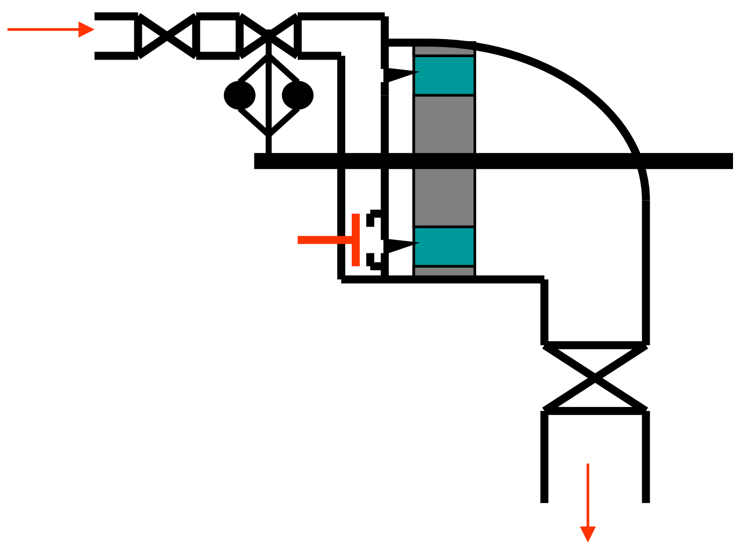
Typical Steam Turbine Efficiency

$$\eta_{isentropic} = \frac{\left(h_{in} - h_{out}\right)_{actual}}{\left(h_{in} - h_{out}\right)_{isentropic}} = 20\%\ to\ 80\%$$

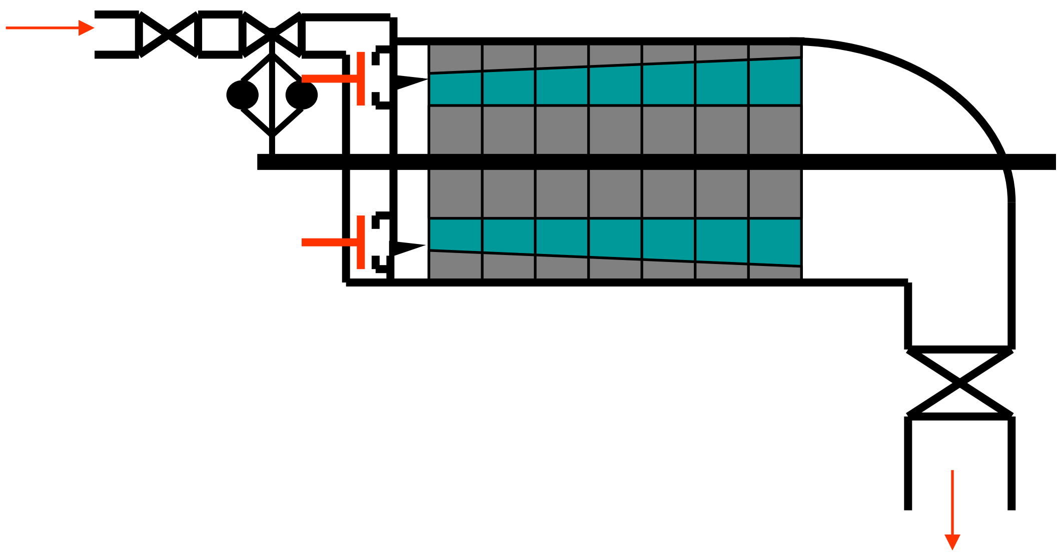
- ✓ Major contributors to isentropic efficiency
  - Turbine design
  - Control valve type
    - Single valve – throttle
    - Multi-valve – flow nozzles
- ✓ Will need this information for ANY turbine analysis

Steam Turbine Efficiency

- Generally, single stage turbines operate with lower isentropic efficiency than multistage turbines
  - Increasing steam path area (diameter) decreases losses
    - Steam exhaust velocity and wall friction decrease
  - Single stage turbines are typically more efficient than multistage turbines for small capacity machines



Single Stage Backpressure Turbine



Multistage Backpressure Turbine

Steam Turbine Efficiency

- ✓ Three methods of obtaining isentropic turbine efficiency:
  - Manufacturer specifications
    - Turbine maps / performance curves
    - Excellent starting point – for new designs also
  - Steam inlet and outlet conditions known
    - Superheated inlet along with <u>superheated</u> outlet is the most common and easiest to utilize
    - Will NOT work with saturated outlets (quality < 1)
  - Steam inlet conditions and power generation known
    - Typically used for electrical power generation units
    - Mass flow rate of steam will be required
    - Alternate option may exist for direct mechanical driven equipment but with higher uncertainty

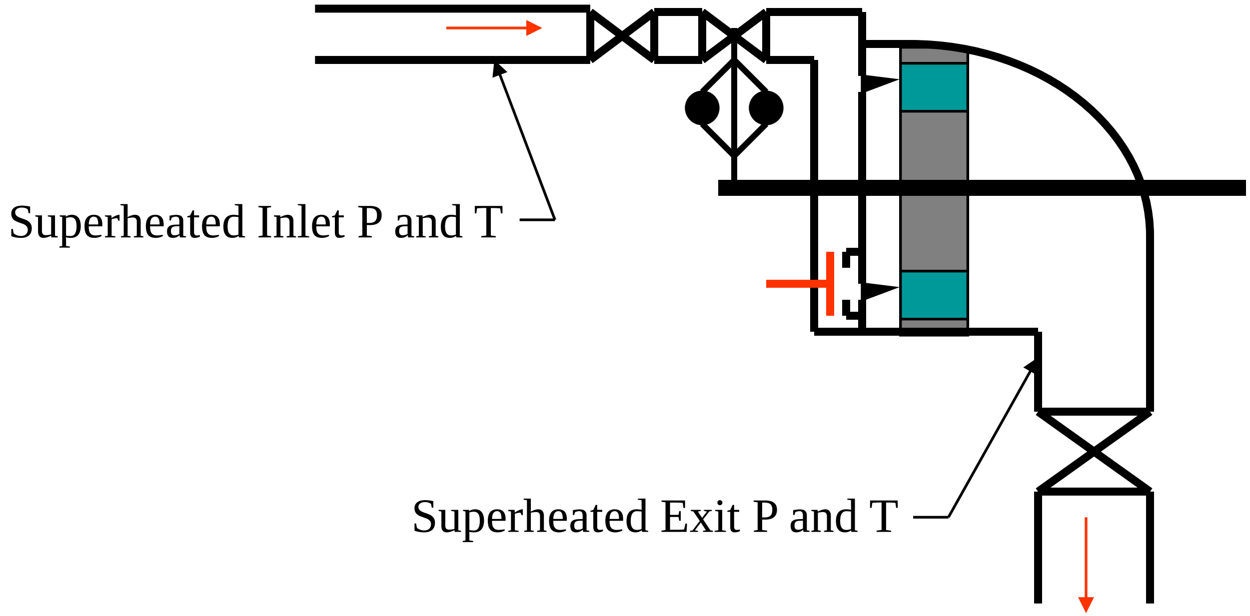
Turbine Efficiency from Inlet and Outlet Steam Conditions

- Method 2
- Turbine performance can be determined from inlet and outlet steam conditions and steam properties associated at those conditions

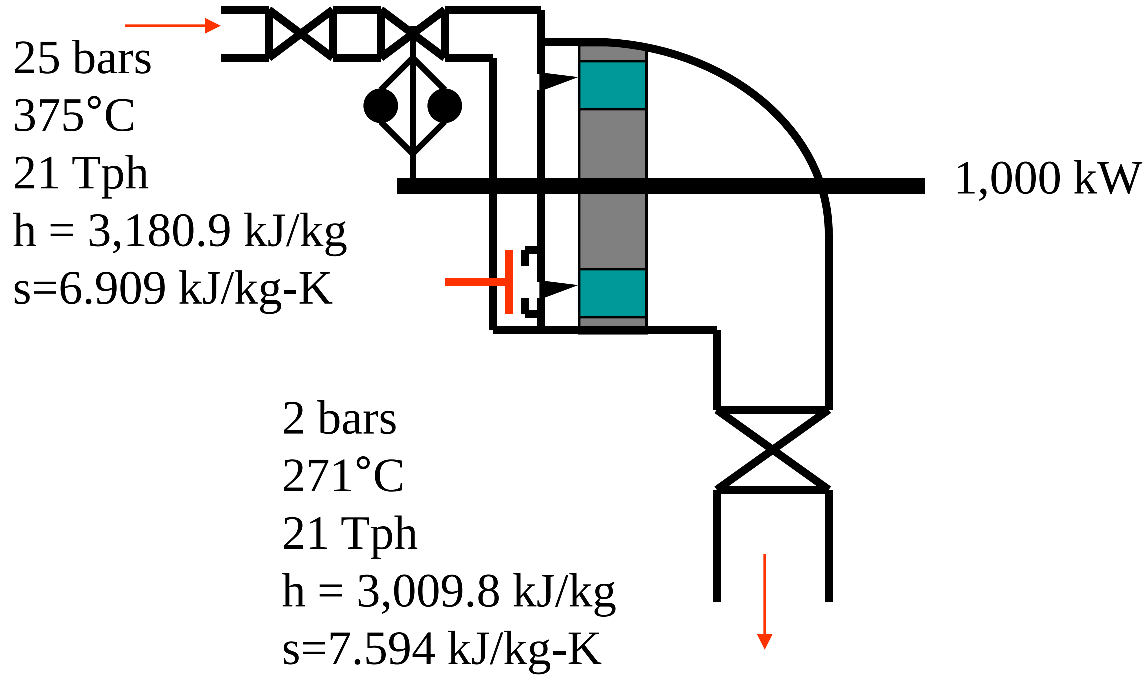
Steam Turbine Efficiency

✓ For **superheated steam** conditions at the turbine inlet and outlet

- Pressure and temperature measurements of superheated steam allow all of the thermodynamic properties to be known



Actual Operating Conditions

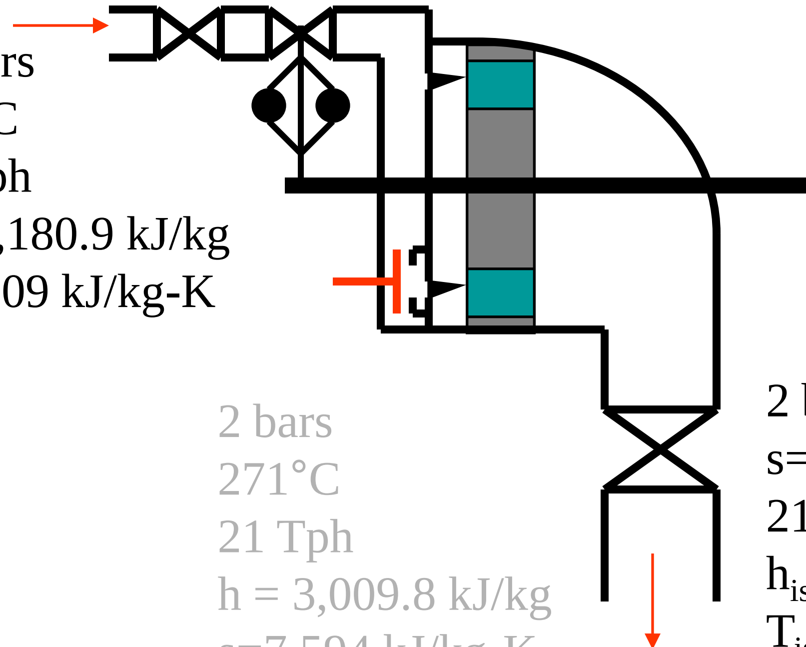


$$\dot{W}_{shaft} = \dot{m}_{steam}\left(h_i - h_e\right)_{steam} = \frac{21{,}000}{3{,}600}(3{,}180.9 - 3{,}009.8)$$

$$\dot{W}_{shaft} = 1{,}000\,kW = 1{,}000\,kW\left(\frac{1\,hp}{0.746\,kW}\right) = 1{,}340\,hp$$

Isentropic Conditions

25 bars
375°C
21 Tph
h = 3,180.9 kJ/kg
s=6.909 kJ/kg-K

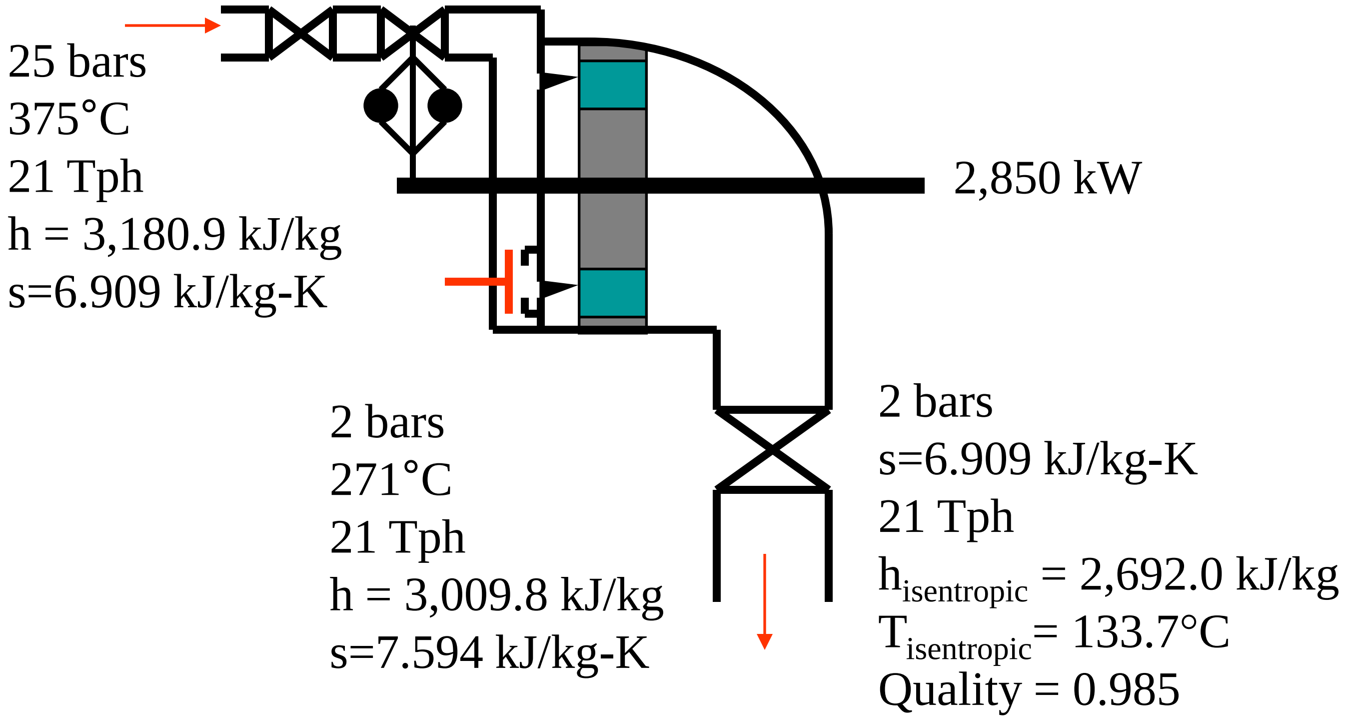


2 bars
271°C
21 Tph
h = 3,009.8 kJ/kg
s=7.594 kJ/kg-K

2 bars
s=6.909 kJ/kg-K
21 Tph
$h_{isentropic}$ = 2,692.0 kJ/kg
$T_{isentropic}$= 133.7°C
Quality = 0.985

$$\dot{W}_{shaft} = \dot{m}_{steam}(h_i - h_e)_{steam} = \frac{21{,}000}{3{,}600}(3{,}180.9 - 2{,}692.0)$$

$$\dot{W}_{shaft} = 2{,}850\,kW = 2{,}850\,kW\left(\frac{1\,hp}{0.746\,kW}\right) = 3{,}825\,hp$$



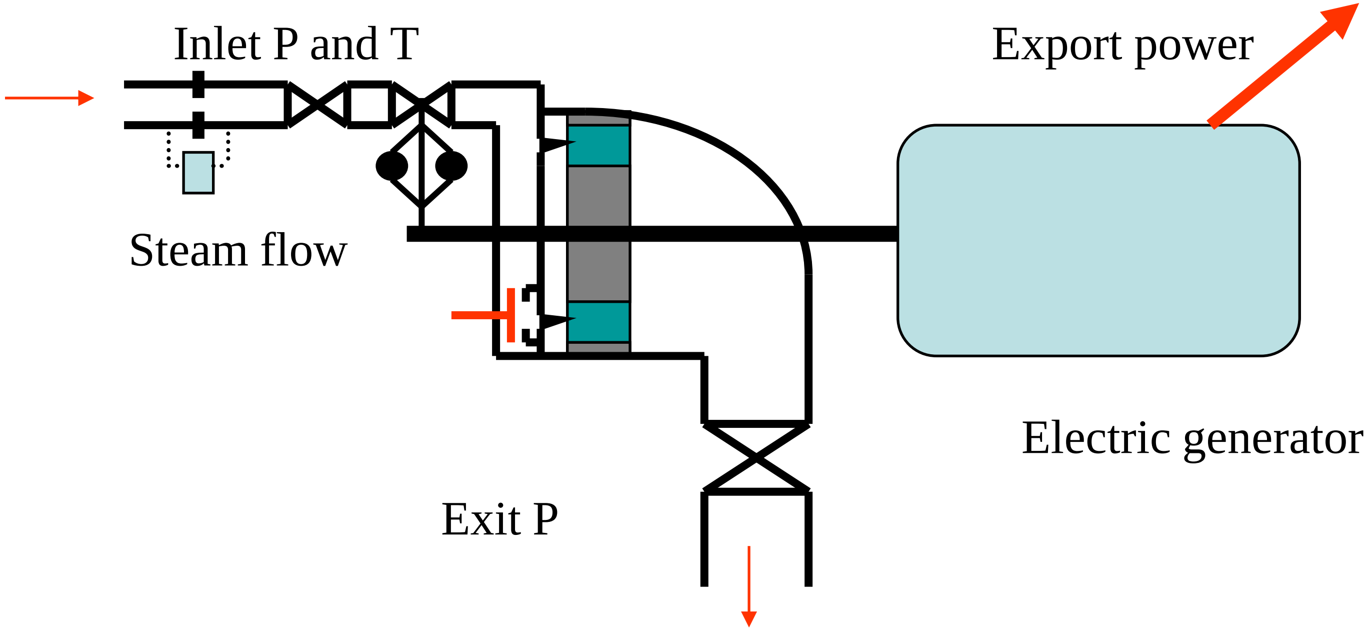
$$\eta_{isentropic} = \frac{\left(h_{inlet} - h_{exit}\right)_{actual}}{\left(h_{inlet} - h_{exit}\right)_{isentropic}} = \frac{(3{,}180.9 - 3{,}009.8)}{(3{,}180.9 - 2{,}692.0)} = \frac{171.1}{488.9} = 0.35$$

Turbine Efficiency from Steam Conditions and Power Production

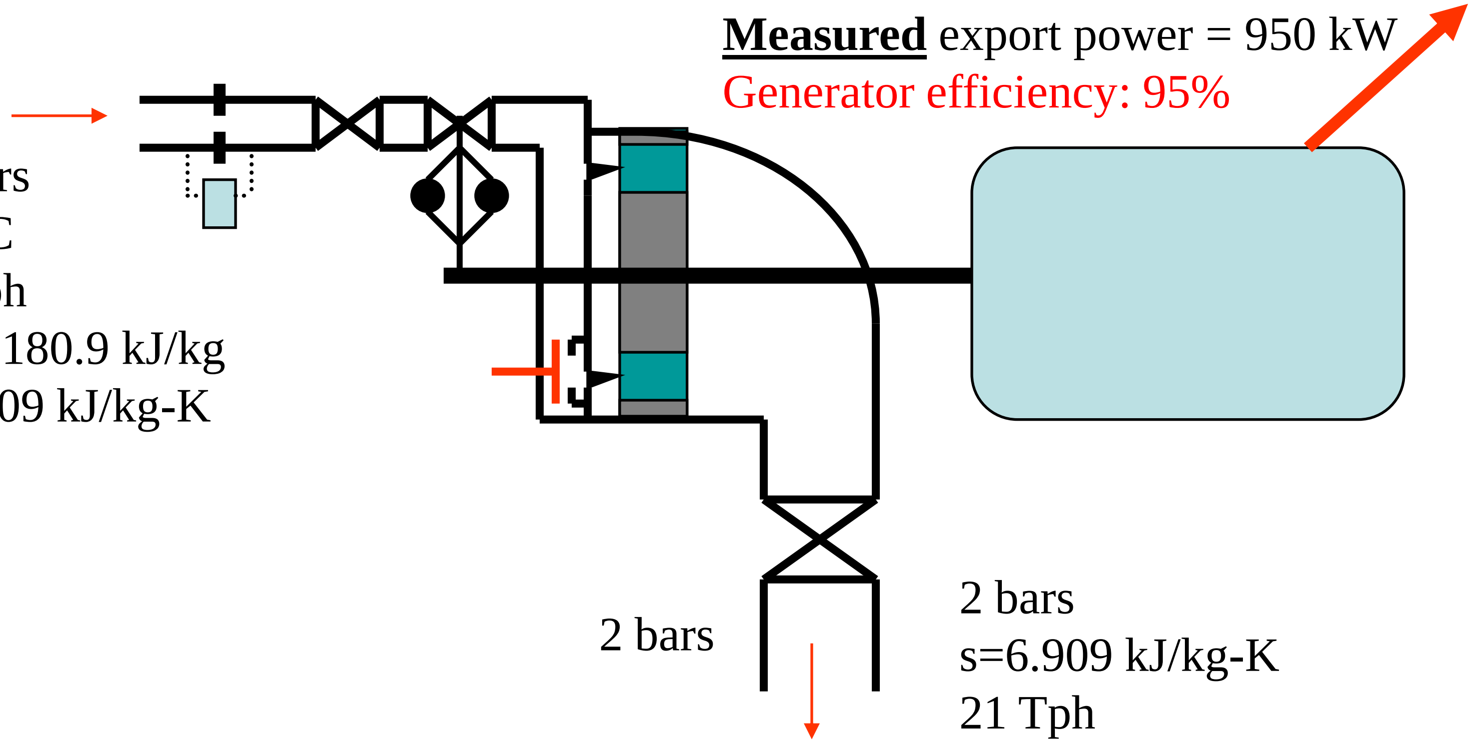
- Method 3
- Turbine performance can be determined from inlet steam properties and power production

Steam Turbine Generator Efficiency

- ✓ Steam turbines coupled with electric generators provide an additional mechanism for calculating turbine isentropic efficiency
  - Additional measurements are required to allow the efficiency determination
  - This is typically the only practical method to evaluate condensing turbine efficiency



Steam Turbine Efficiency



25 bars
375°C
21 Tph
h = 3,180.9 kJ/kg
s=6.909 kJ/kg-K

2 bars
s=6.909 kJ/kg-K
21 Tph
$h_{isentropic}$ = 2,692.0 kJ/kg
$T_{isentropic}$ = 133.7°C
Quality = 0.985

Steam Turbine Efficiency

$$\dot{W}_{generator} = 950\,kW$$

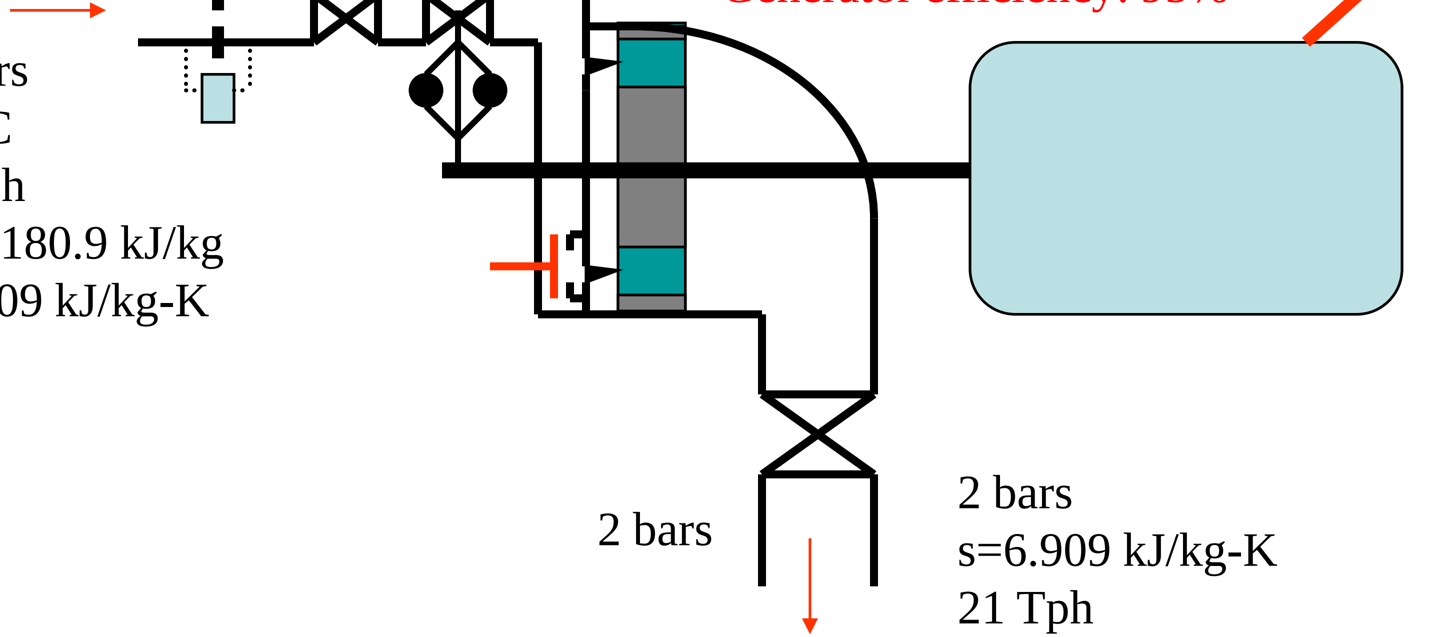
$$\eta_{generator} = \frac{Generator Work}{Turbine\,Shaft\,Work} = \frac{\dot{W}_{generator}}{\dot{W}_{turbine}} = \frac{950\,kW}{\dot{W}_{turbine}} = 0.95$$

$$\dot{W}_{turbine} = 1{,}000\,kW$$

$$\eta_{isentropic} = \frac{Actual\,Turbine Work}{Isentropic Work} = \frac{\dot{W}_{generator}}{\eta_{generator}\dot{W}_{isen}} = \frac{\dot{W}_{gen}}{\eta_{gen}\dot{m}_{st}\left(h_i - h_e\right)_{isen}}$$

Measured export power = 950 kW
Generator efficiency: 95%

25 bars
375°C
21 Tph
h = 3,180.9 kJ/kg
s=6.909 kJ/kg-K



2 bars
s=6.909 kJ/kg-K
21 Tph
$h_{isentropic}$ = 2,692.0 kJ/kg
$T_{isentropic}$= 133.7°C
Quality = 0.985

$$\eta_{isentropic} = \frac{950\,kW}{0.95}\,\frac{3{,}600\,\frac{s}{hr}}{21{,}000\,\frac{kg}{hr}}\,\frac{1}{\left(3{,}180.9\,\frac{kJ}{kg} - 2{,}692.0\,\frac{kJ}{kg}\right)} = 0.35$$

Steam Rate

- *Steam rate* is an expression used to describe the amount of steam required to produce a specific amount of power
  - *Theoretical steam rate* is the ideal steam rate
  - *Actual steam rate* is the real world steam rate

$$Theoretical\ Steam\ Rate = TSR = \frac{\dot{m}_{steam}}{\dot{W}_{isentropic}} = \frac{1}{(h_1 - h_{2\,isen})}$$

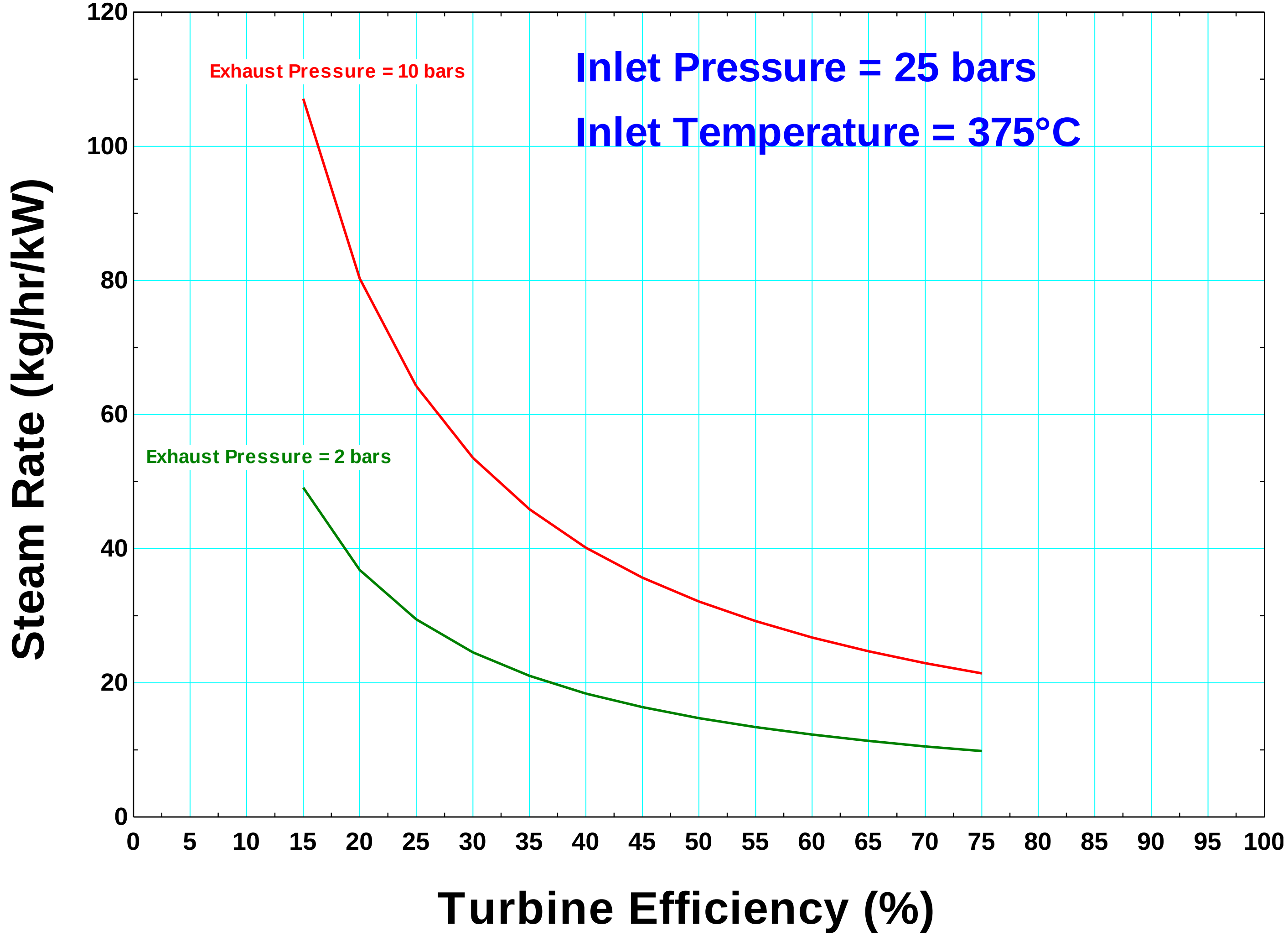
$$Actual\ Steam\ Rate = ASR = \frac{\dot{m}_{steam}}{\dot{W}_{actual}} = \frac{1}{(h_1 - h_2)}$$

$$\eta_{isen} = \frac{TSR}{ASR}$$

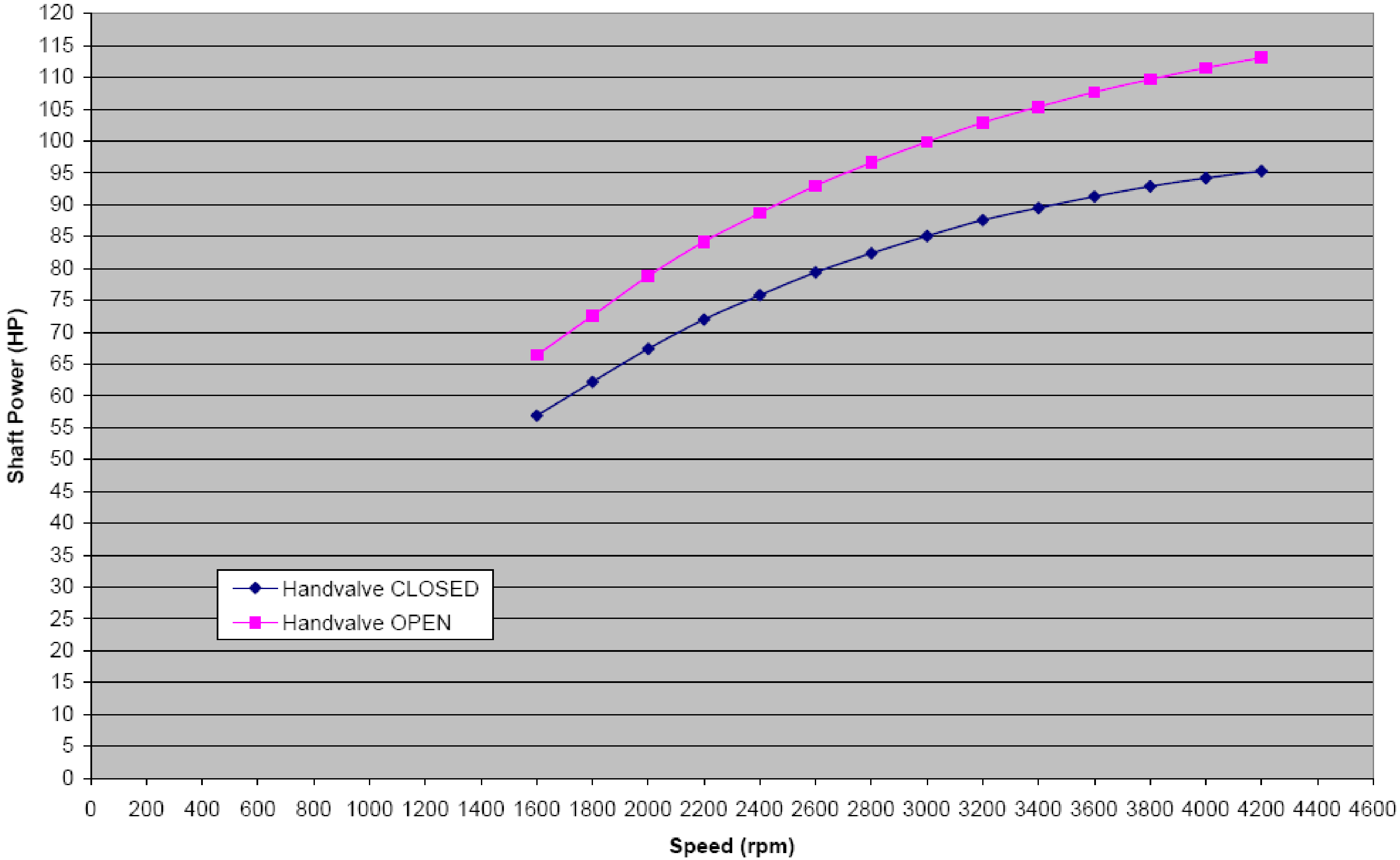
Steam Rate Factors

- Changing turbine inlet or outlet conditions will not impact isentropic efficiency significantly
  - Steam rate will change dramatically if conditions are changed
- Throttling the inlet of a steam turbine will impact the overall isentropic efficiency (valve inlet to turbine outlet)
  - The isentropic efficiency of the turbine will not change significantly (turbine inlet to outlet)
  - Steam rate will change dramatically

Steam Rate & Efficiency



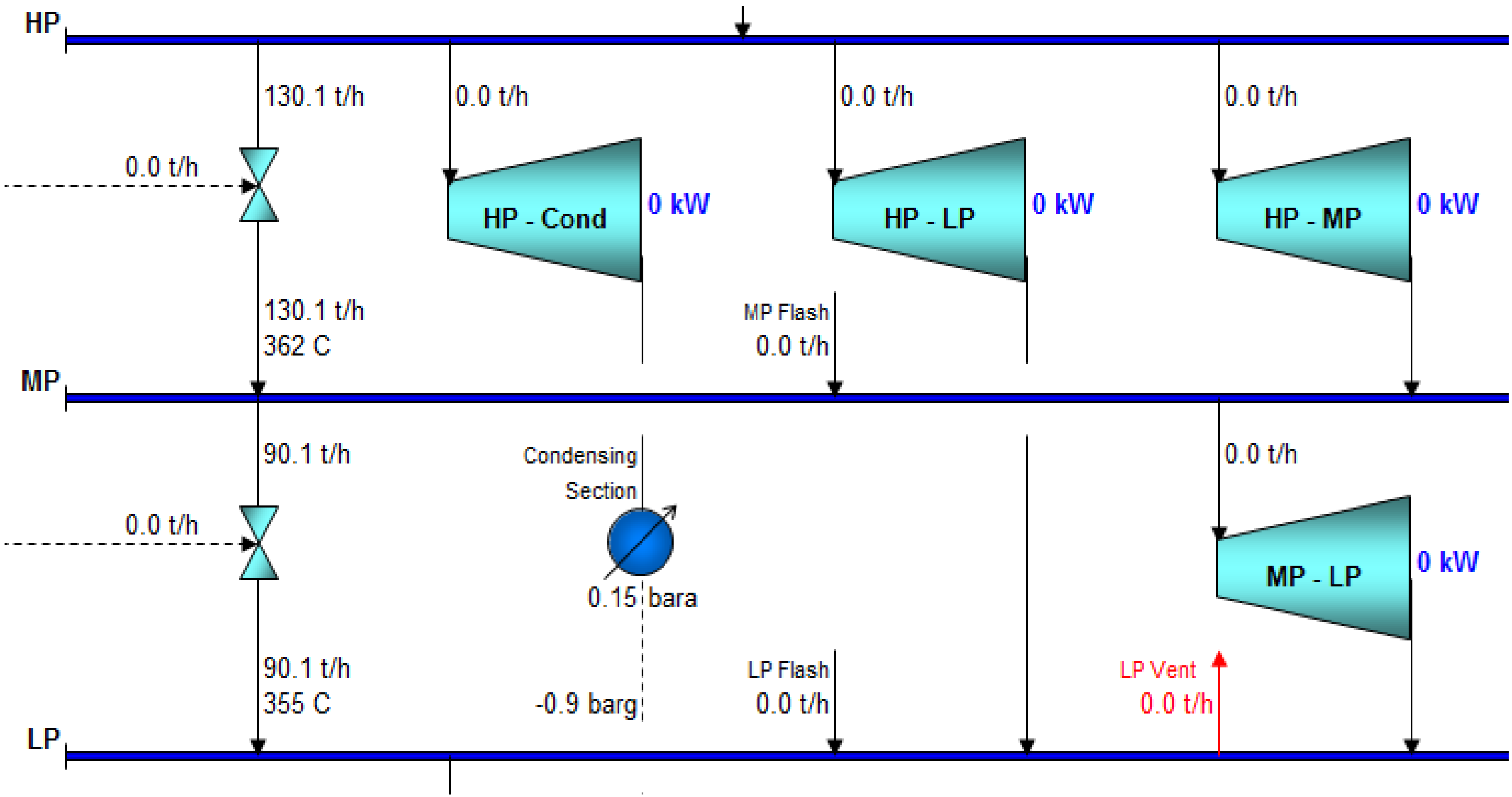
Steam Turbine Speed



SSAT Steam Turbine Applications

- ✓ **Total Site Electrical Demand** is held constant in SSAT project evaluations
- ✓ Power produced by the turbines reduces the **Power Import**
- ✓ SSAT incorporates a maximum of only four turbines
  - HP – LP
  - HP – MP
  - MP – LP
  - HP – Condensing
  - The *Impact Turbine* must be modeled
- ✓ *Site Detail* section allows actual performance to be incorporated into the analysis
  - Turbine efficiency
  - Pressure reducing valve interaction
    - Turbine capacity and control

Steam Turbines Schematically in SSAT



Steam Turbines in SSAT

Steam Turbines	
Do you have a steam turbine installed between HP and LP?	No
Do you have a steam turbine installed between HP and MP?	No
Do you have a steam turbine installed between MP and LP?	No
Do you have an HP to condensing turbine installed?	No

- ✓ Steam turbines need to be set up in the “Quick Start” section
  - Use the pull down menu to say “Yes” if a particular turbine exists
- ✓ Additional information on turbines and their control mechanism is then provided in the “Site Detail” section
- ✓ NOTE: The turbine does not have to be ON for inclusion in the system

Steam Turbines in SSAT

Configure the operation of your HP to LP turbine(s) using the options below:

HP to LP Steam Turbine(s)	Input Data	Notes/Warnings
Isentropic efficiency	35 %	

Note: If multiple turbines are installed, the operation of the impact turbine (the turbine affected by changes to the system) should be modeled

Note: A generator electrical efficiency of 100% is assumed by the model

Select the appropriate turbine operating mode	Option 2 - Fixed operation

Note: If Option 1 is chosen, the model will preferentially use the HP to LP turbine to balance the LP demand

Option 2 - How should the fixed turbine operation be defined?	Specify fixed steam flow

Option 2 - Fixed steam flow	21 t/h	
Option 2 - Fixed power generation	2000 kW	

Option 3 - How do you wish to define the operating range?	Option 3 not selected

Option 3 - Minimum steam flow	25 t/h	
Option 3 - Maximum steam flow	75 t/h	
Option 3 - Minimum power generation	1500 kW	
Option 3 - Maximum power generation	2500 kW	

- ✓ Each steam turbine included in the system will need to be configured for efficiency & control options

Steam Turbines in SSAT

Configure the operation of your HP to LP turbine(s) using the options below:

HP to LP Steam Turbine(s)	Input Data	Notes/Warnings
Isentropic efficiency	35 %	

Note: If multiple turbines are installed, the operation of the impact turbine (the turbine affected by changes to the system) should be modeled

Note: A generator electrical efficiency of 100% is assumed by the model

- ✓ Each steam turbine included in the system will need a steam turbine isentropic efficiency
  - Manufacturers' data
  - Calculated from steam input and output conditions for superheated cases
  - Calculated from power generated and steam input and outlet pressure
    - Generator efficiency needs to be included in the calculations
- ✓ Turbine operations are satisfied, then low-pressure demands are satisfied with PRV operation

Steam Turbines in SSAT

Select the appropriate turbine operating mode	Option 2 - Fixed operation

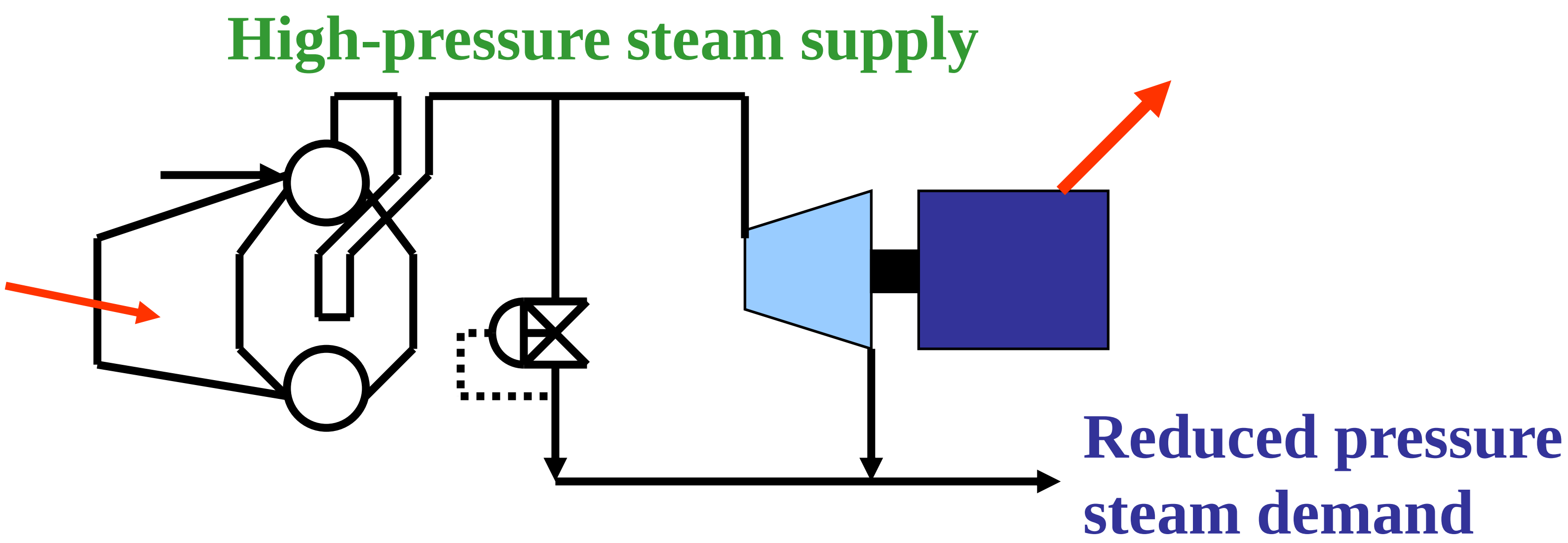
Note: If Option 1 is chosen, the model will preferentially use the HP to LP turbine to balance the LP demand

Option 2 - How should the fixed turbine operation be defined?	Specify fixed steam flow

Option 2 - Fixed steam flow	21 t/h	
Option 2 - Fixed power generation	2000 kW	

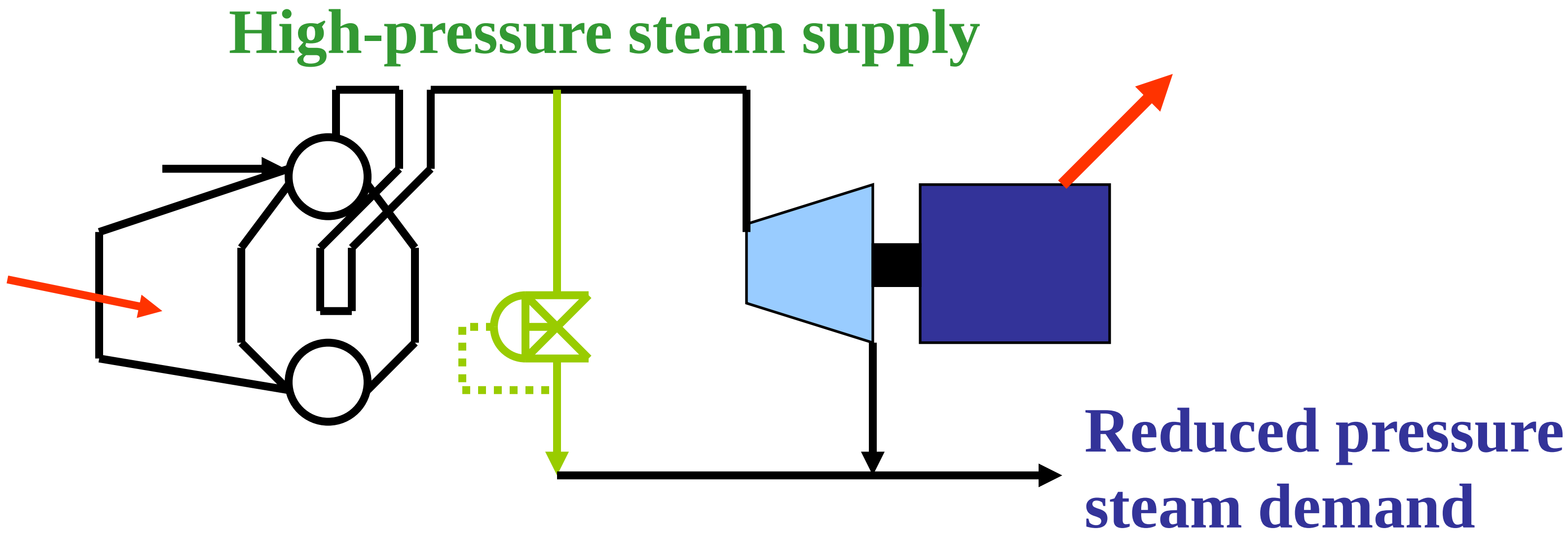
- There are four different options to setup the turbine operations
  - Steam flow to the turbine balances the “output” header demand
    - This is also the Default option
  - Turbine set up as fixed operation
    - Fixed steam flow
    - Fixed power generation
  - Turbine setup to operate between minimum and maximum limits
    - Steam flow
    - Power generation
  - Turbine NOT operating

Steam Balance Control



- ✓ The SSAT model must be established to accurately describe the **impact** a change in steam demand (or operating conditions) will have on the system
  - The **impact component** must be established
    - Steam can pass through a turbine
    - Steam can pass through a pressure reducing valve

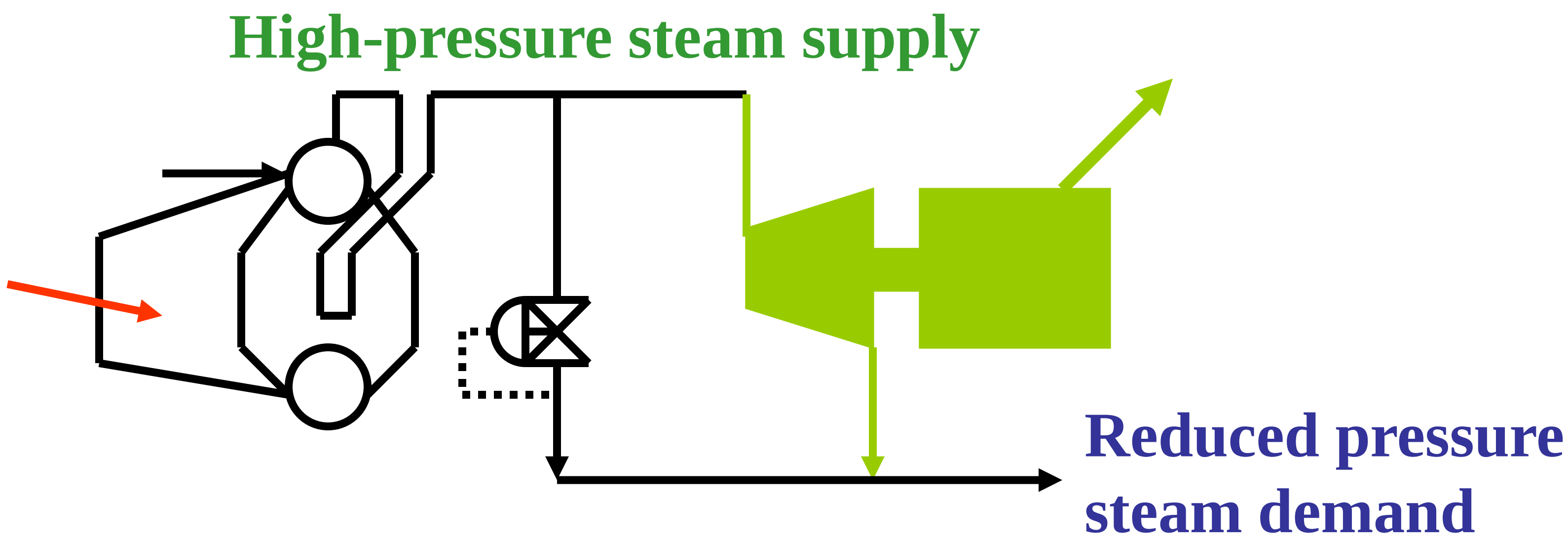
Turbine Control of Steam Balance



✓ Turbine balances reduced-pressure header

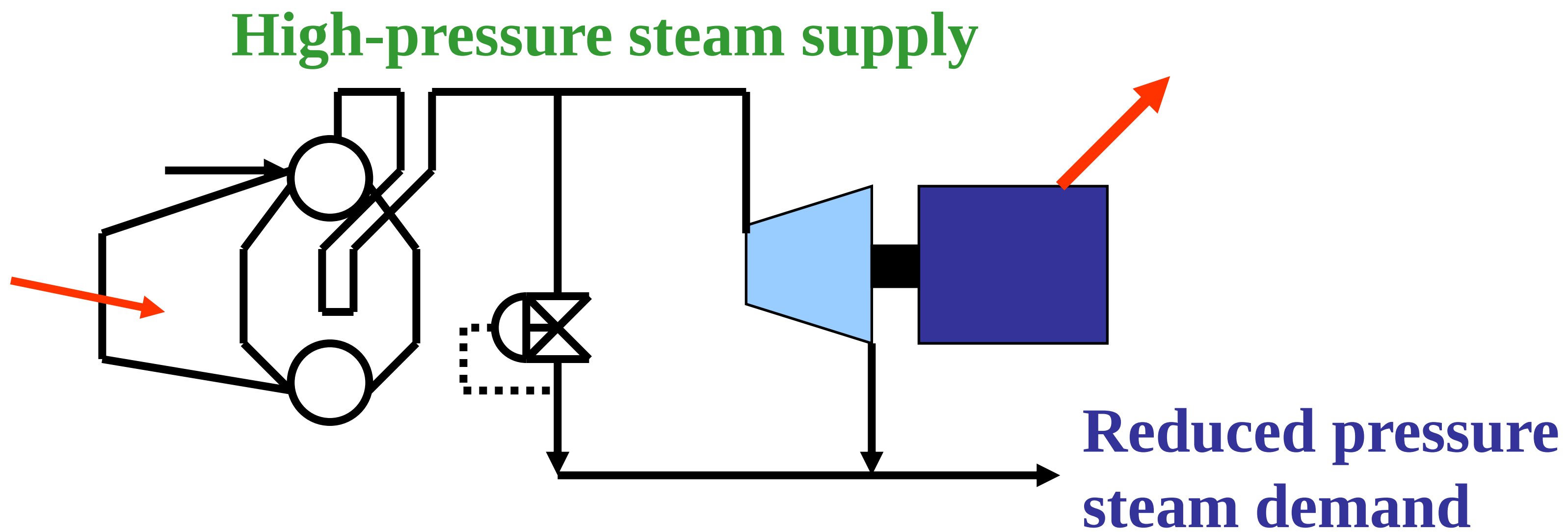
- The capacity of the turbine is limitless
- Any change in low-pressure steam demand will result in a change in steam flow through the turbine

Fixed Turbine – PRV Steam Balance Control



- ✓ Turbine is operating based on fixed conditions
  - Steam flow cannot vary through the turbine
  - Any change in low-pressure steam demand will result in a change in steam flow through the PRV
  - Process turbines are typically modeled in this manner

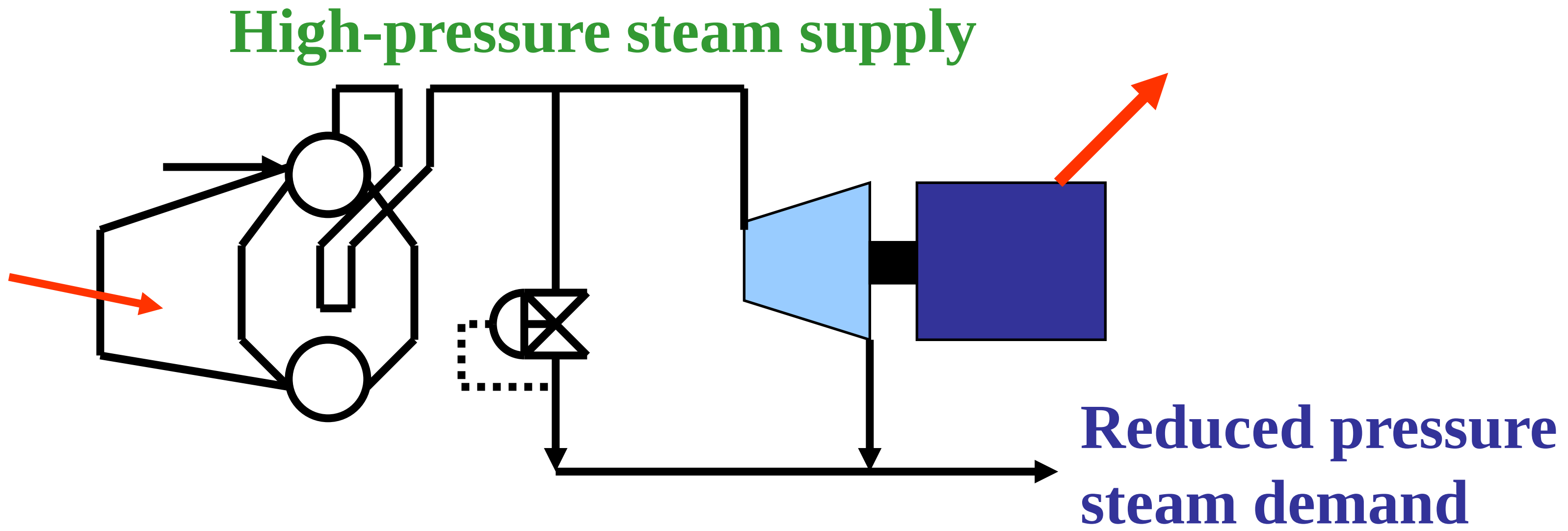
Maximum-Minimum Steam Balance Control



✓ The turbine can be forced to operate between a minimum and maximum steam flow

- The PRV will supply additional steam if the turbine capacity limit is reached
- This provides a realistic limitation based on the capacity of the turbines

Turbine On-Off Control

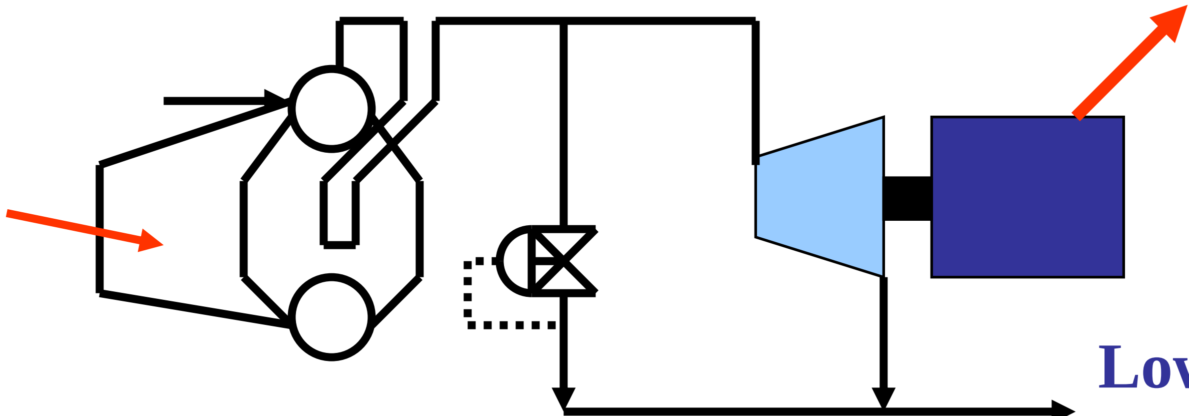


- ✓ The turbine can be turned "on" in the input model and "off" in the projects model
  - The turbine can be turned "off" in the input model and "on" in the projects model

Turbine Impact Example

High-pressure steam: 25 bars 375°C

Electrical impact cost: EGP 0.77/kWh



Low-pressure steam: 2 bars

Impact boiler: Natural gas (EGP 2.10/NM^3)

Boiler efficiency: 81.7%

- ✓ Open the 3-Header Example System Model and set up the HP-LP turbine with the following configuration
  - Turbine balancing the system
  - Turbine isentropic efficiency = 35%
- ✓ Model the economic impact of saving 1 Tph HP and 1 Tph LP steam

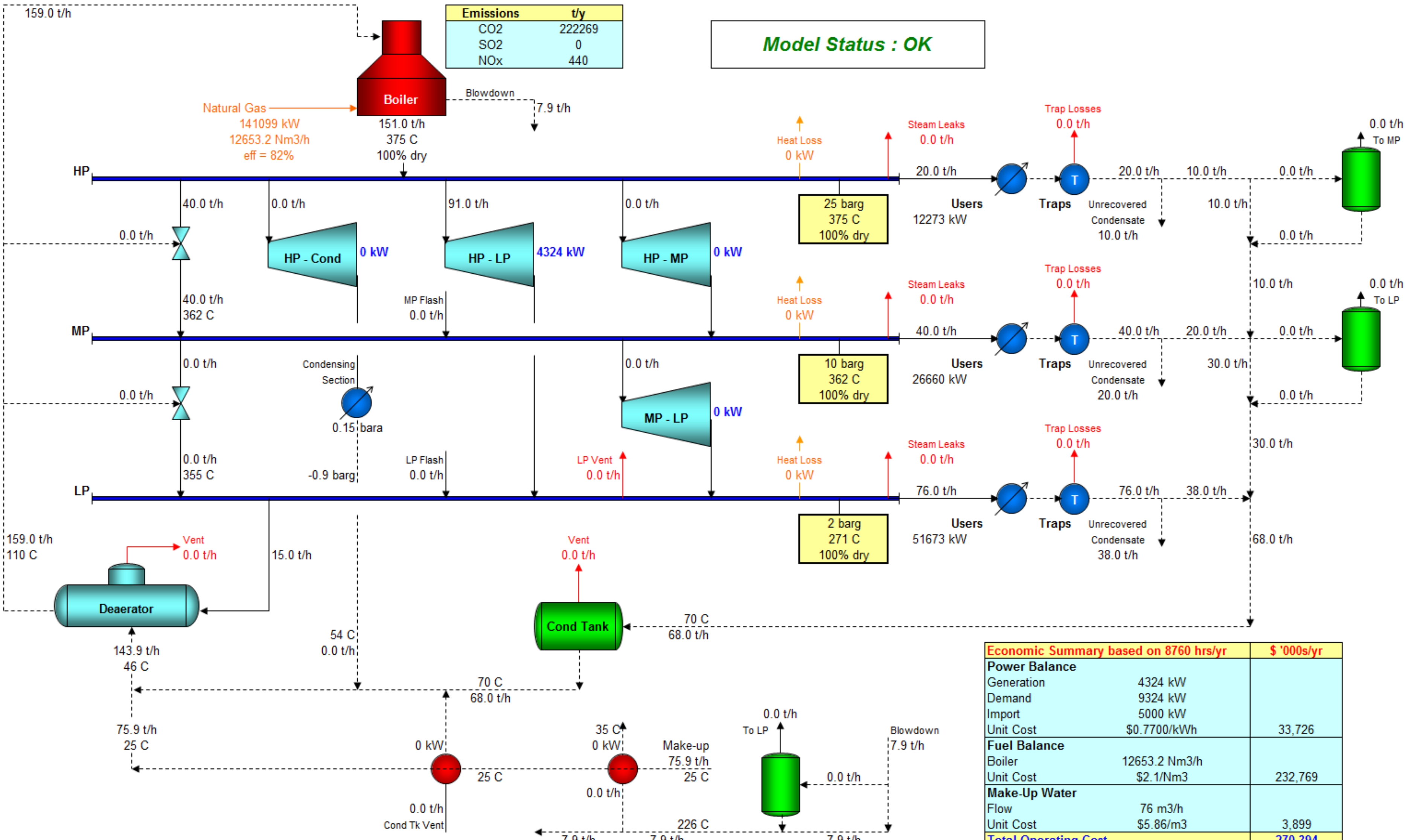
Steam System Assessment Tool

SSAT 3 Header Metric Model for User Training Egypt

Current Operation

Emissions	t/y
CO_2	222269
SO_2	0
NOx	440

Model Status : OK



Economic Summary based on 8760 hrs/yr		$ '000s/yr
Power Balance		
Generation	4324 kW	
Demand	9324 kW	
Import	5000 kW	
Unit Cost	$0.7700/kWh	33,726
Fuel Balance		
Boiler	12653.2 Nm3/h	
Unit Cost	$2.1/Nm3	232,769
Make-Up Water		
Flow	76 m3/h	
Unit Cost	$5.86/m3	3,899
Total Operating Cost		270,394

Turbine Impact Example Results

Marginal Steam Costs	
(based on current operation)	
HP ($/t)	194.62
MP ($/t)	194.62
LP ($/t)	158.03

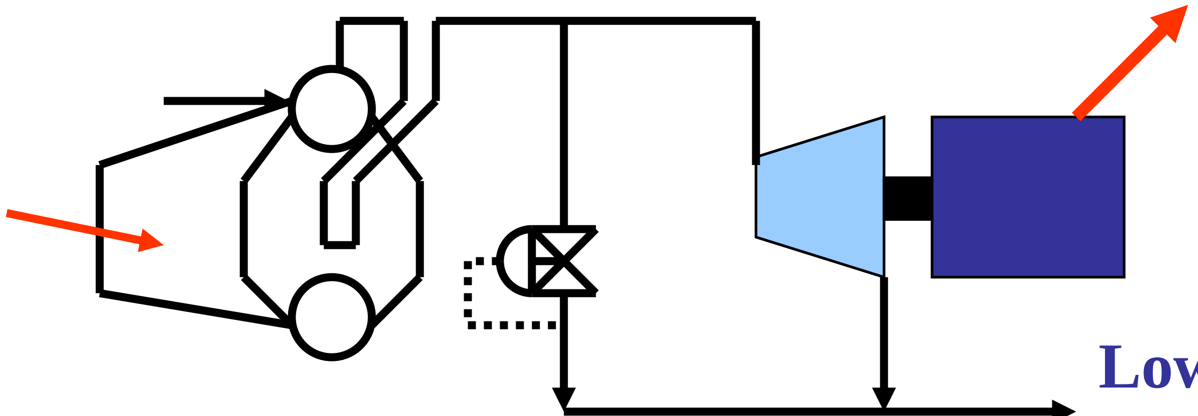
$$CostSavings_{1Tph\_HP} = 1.0 \times 8{,}760 \times 194.62 = EGP1{,}704{,}800$$

$$CostSavings_{1Tph\_LP} = 1.0 \times 8{,}760 \times 158.03 = EGP1{,}384{,}300$$

Turbine Impact Example

High-pressure steam: 25 bars 375°C

Electrical impact cost: EGP 0.77/kWh



Low-pressure steam: 2 bars

Impact boiler: Natural gas (EGP 2.10/NM^3)
Boiler efficiency: 81.7%

- ✓ Open the 3-Header Example System Model and set up the HP-LP turbine with the following configuration
  - MP-LP Pressure Reducing Valve has a flow of ~10 Tph
  - Turbine isentropic efficiency = 35%
- ✓ Model the economic impact of saving 1 Tph HP and 1 Tph LP steam

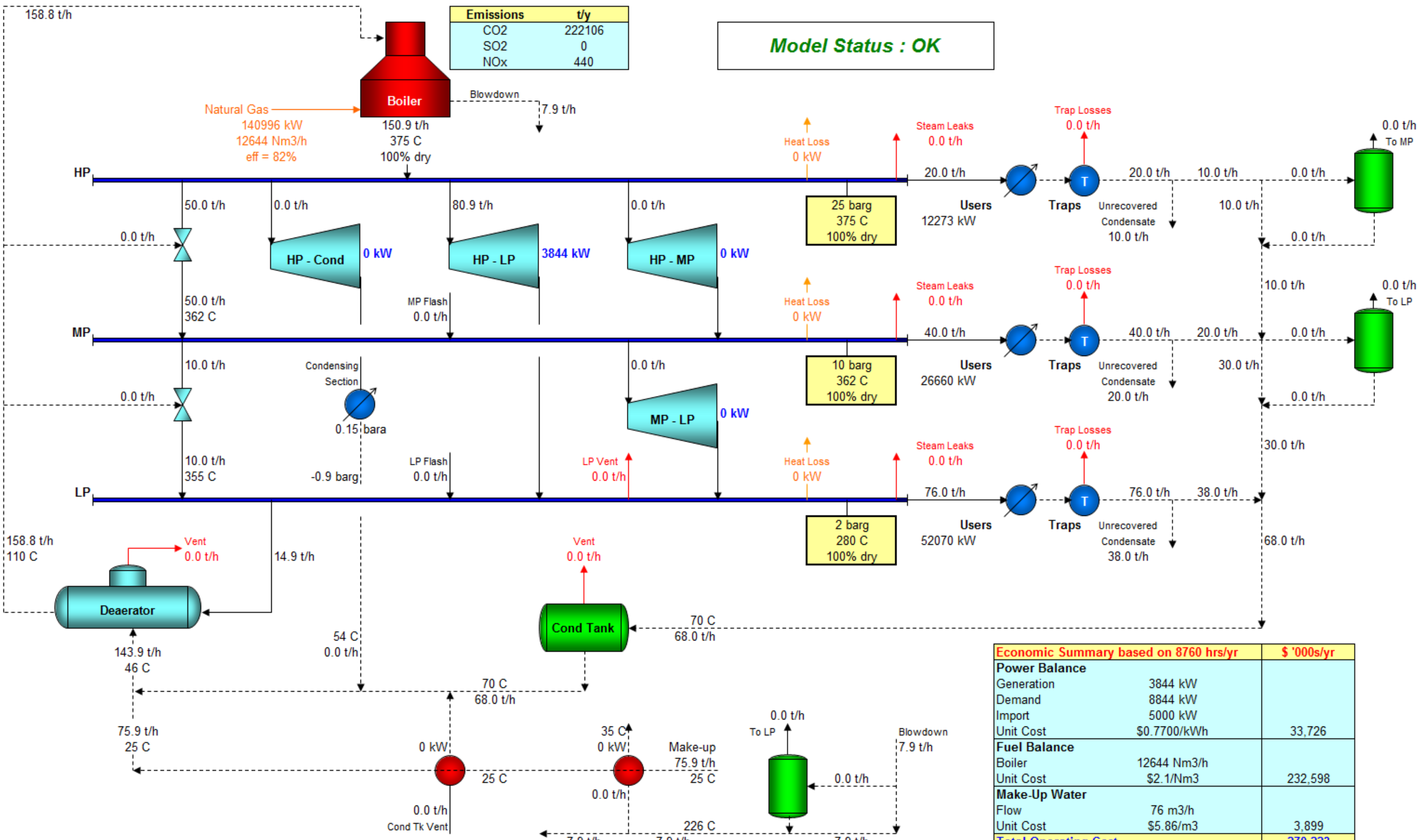
Steam System Assessment Tool

SSAT 3 Header Metric Model for User Training Egypt

Current Operation

Emissions	t/y
CO_2	222106
SO_2	0
NO_x	440

Model Status : OK



Economic Summary based on 8760 hrs/yr		**$ '000s/yr**
Power Balance		
Generation	3844 kW	
Demand	8844 kW	
Import	5000 kW	
Unit Cost	$0.7700/kWh	33,726
Fuel Balance		
Boiler	12644 Nm3/h	
Unit Cost	$2.1/Nm3	232,598
Make-Up Water		
Flow	76 m3/h	
Unit Cost	$5.86/m3	3,899
Total Operating Cost		270,223

Turbine Impact Example Results

Marginal Steam Costs	
(based on current operation)	
HP ($/t)	197.28
MP ($/t)	197.28
LP ($/t)	186.06

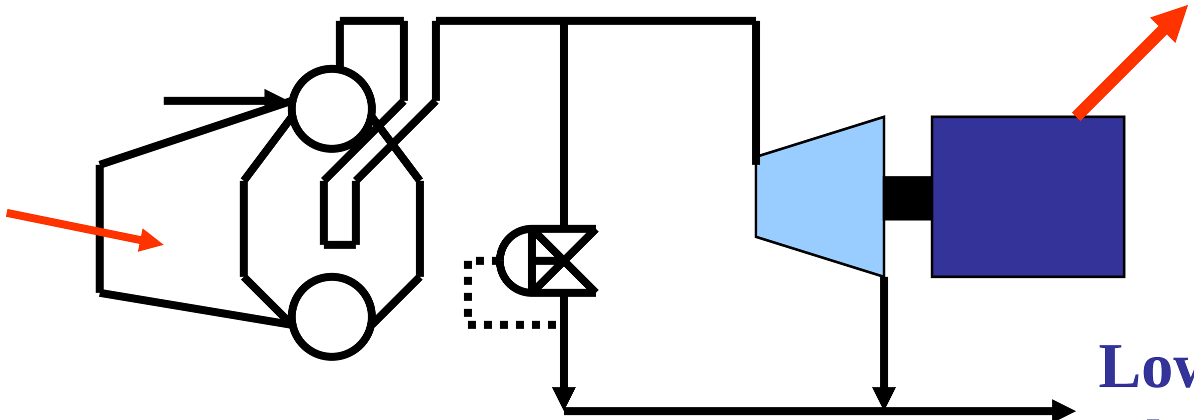
$$CostSavings_{1Tph\_HP} = 1.0 \times 8{,}760 \times 197.28 = EGP1{,}728{,}200$$

$$CostSavings_{1Tph\_LP} = 1.0 \times 8{,}760 \times 186.06 = EGP1{,}629{,}900$$

Turbine Impact Example

High-pressure steam: 25 bars 375°C

Electrical impact cost: EGP 0.77/kWh



Low-pressure steam: 2 bars

Impact boiler: Natural gas (EGP 2.10/NM^3)

Boiler efficiency: 81.7%

- ✓ Open the 3-Header Example System Model and set up the HP-LP turbine with the following configuration
  - Steam turbine flow of ~21.0 Tph
  - Turbine isentropic efficiency = 35%
- ✓ Model the economic impact of saving 1 Tph HP and 1 Tph LP steam

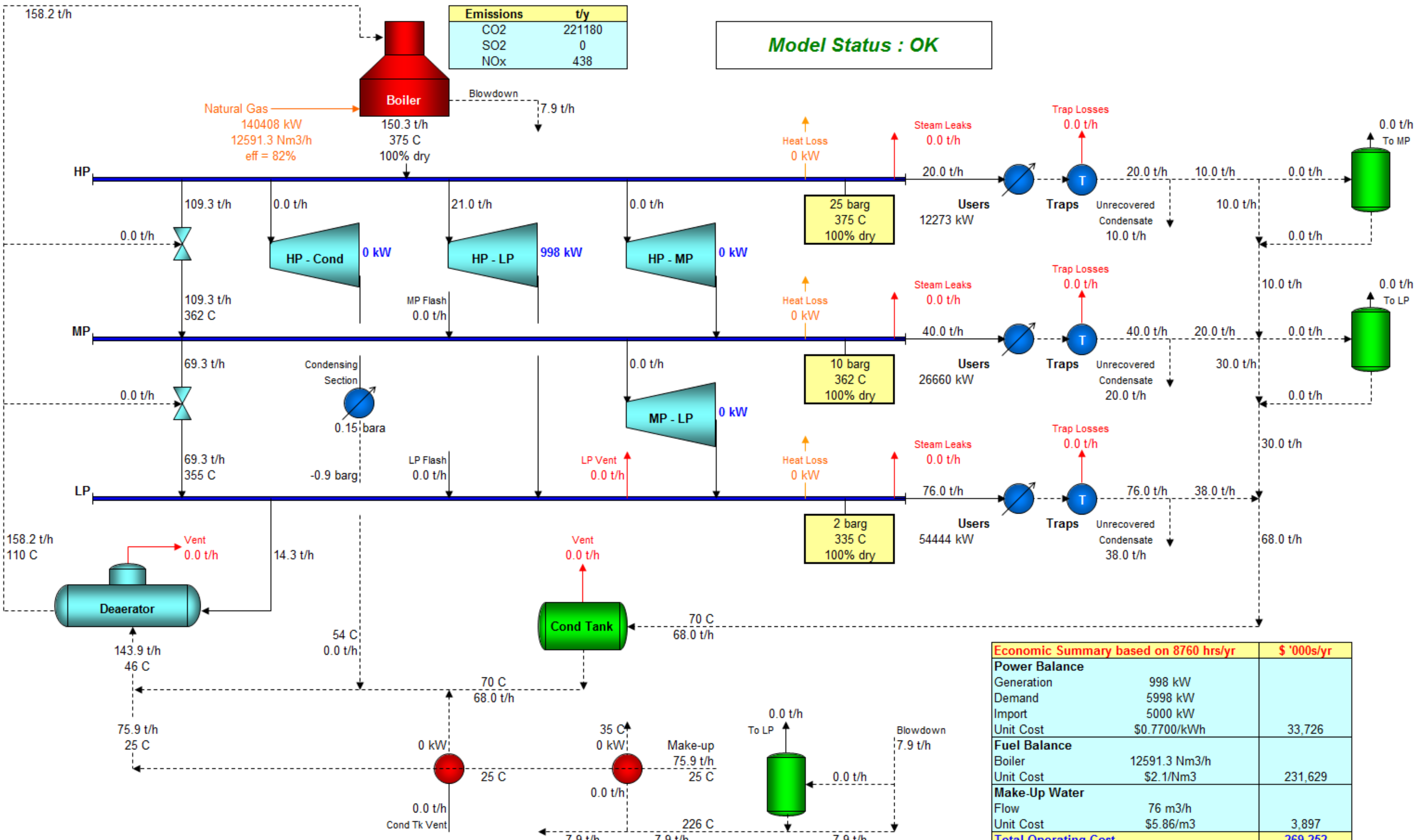
Steam System Assessment Tool

SSAT 3 Header Metric Model for User Training Egypt

Current Operation

Emissions	t/y
CO_2	221180
SO_2	0
NOx	438

Model Status : OK



Economic Summary based on 8760 hrs/yr		$ '000s/yr
Power Balance		
Generation	998 kW	
Demand	5998 kW	
Import	5000 kW	
Unit Cost	$0.7700/kWh	33,726
Fuel Balance		
Boiler	12591.3 Nm3/h	
Unit Cost	$2.1/Nm3	231,629
Make-Up Water		
Flow	76 m3/h	
Unit Cost	$5.86/m3	3,897
Total Operating Cost		269,252

Turbine Impact Example Results

Marginal Steam Costs	
(based on current operation)	
HP ($/t)	197.39
MP ($/t)	197.39
LP ($/t)	194.45

$$CostSavings_{1Tph\_HP} = 1.0 \times 8{,}760 \times 197.39 = EGP1{,}729{,}100$$

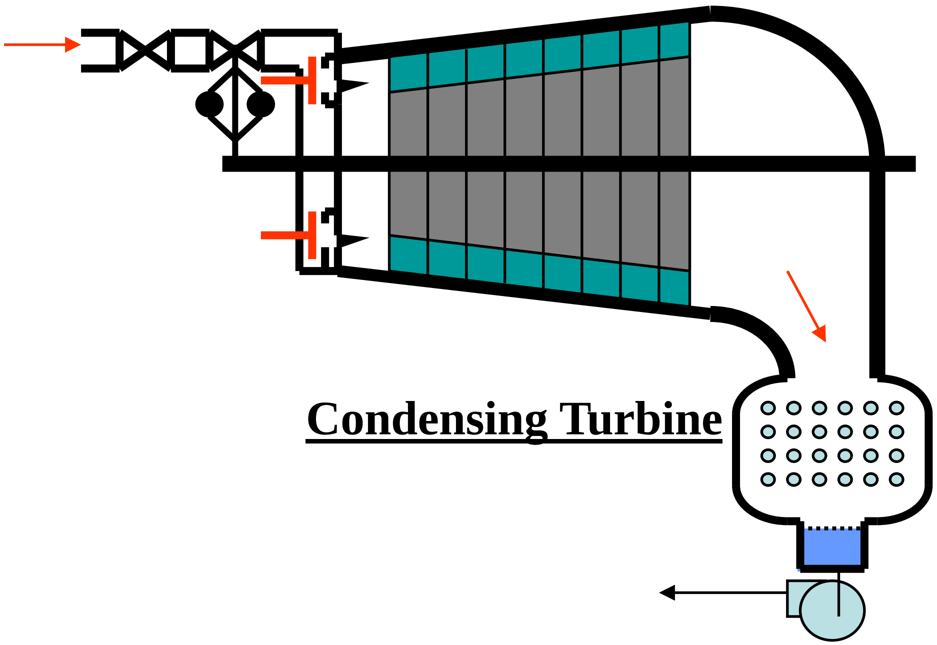
$$CostSavings_{1Tph\_LP} = 1.0 \times 8{,}760 \times 194.45 = EGP1{,}703{,}400$$

Backpressure Turbine Economics

- ✓ Most industrial systems require thermal energy (not mass flow of steam)
- ✓ The turbine will extract energy from the steam and convert it into shaft energy
  - The steam will exit the turbine with a reduced temperature
- ✓ The result will be an increased mass flow of steam required to satisfy the thermal demand

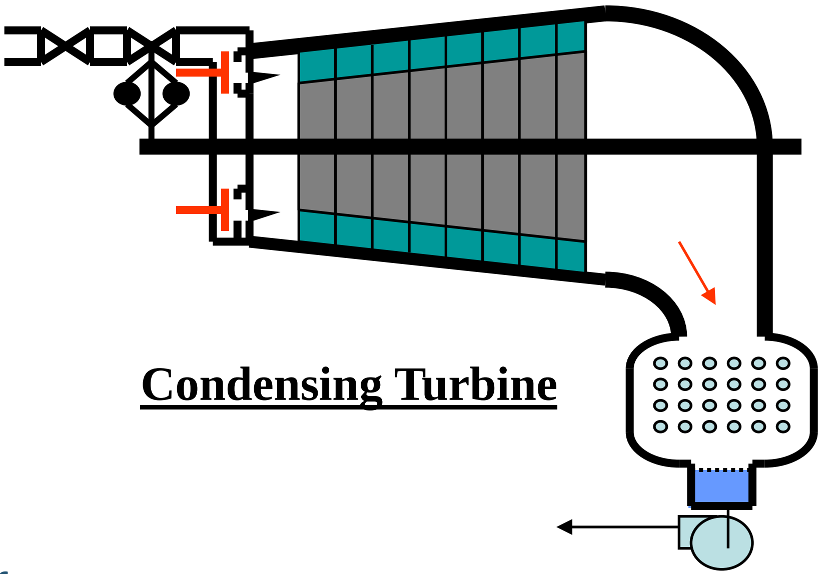
Condensing Steam Turbines

- Condensing steam turbines often operate with a discharge condition of saturated steam
  - Isentropic efficiency is typically determined by
    - Generator output, steam conditions, and steam flow
    - Estimated by manufacturer's data



Condensing Steam Turbines

- Discharge pressure has a significant effect on power production
  - SSAT units of measure are:
    - bara
    - barg
    - Inches of mercury absolute
    - Inches of mercury vacuum



- Condensing turbines are used for
  - Large amount of power generation
  - Driving large mechanical equipment

Condensing Steam Turbines in SSAT

Steam Turbines	
Do you have a steam turbine installed between HP and LP?	Yes
Do you have a steam turbine installed between HP and MP?	No
Do you have a steam turbine installed between MP and LP?	No
Do you have an HP to condensing turbine installed?	Yes

For a **Condensing Turbine**, please define how the turbine operates and then provide supplementary information below:

→ Mode of operation	Option 1 - Define fixed power generation ←

→ **Option 1** - Fixed power generation	1000 kW	←
Option 2 - Fixed steam flow	25 t/h	

- ✓ Condensing steam turbine(s) need to be set up in the "Quick Start" section
  - Use the pull down menu to say "Yes" if a condensing turbine exists
  - Information on control mechanism is also <u>required</u>
- ✓ Additional information in the "Site Detail" section

Condensing Steam Turbines in SSAT

Steam Turbines	
Do you have a steam turbine installed between HP and LP?	Yes
Do you have a steam turbine installed between HP and MP?	No
Do you have a steam turbine installed between MP and LP?	No
Do you have an HP to condensing turbine installed?	Yes

For a **Condensing Turbine**, please define how the turbine operates and then provide supplementary information below:

→ Mode of operation	Option 1 - Define fixed power generation ←

→ **Option 1** - Fixed power generation	1000 kW	←
Option 2 - Fixed steam flow	25 t/h	

- ✓ Condensing turbines have two modes of operation
  - Fixed power generation
    - Most process driven equipment operations will have this configuration
    - NOTE: SSAT assumes 100% generator efficiency
  - Fixed steam flow

Condensing Steam Turbines in SSAT

Configure the operation of your HP to Condensing turbine(s) using the options below:

HP to Condensing Steam Turbine(s)	Input Data	Notes/Warnings
Isentropic efficiency	65 %	

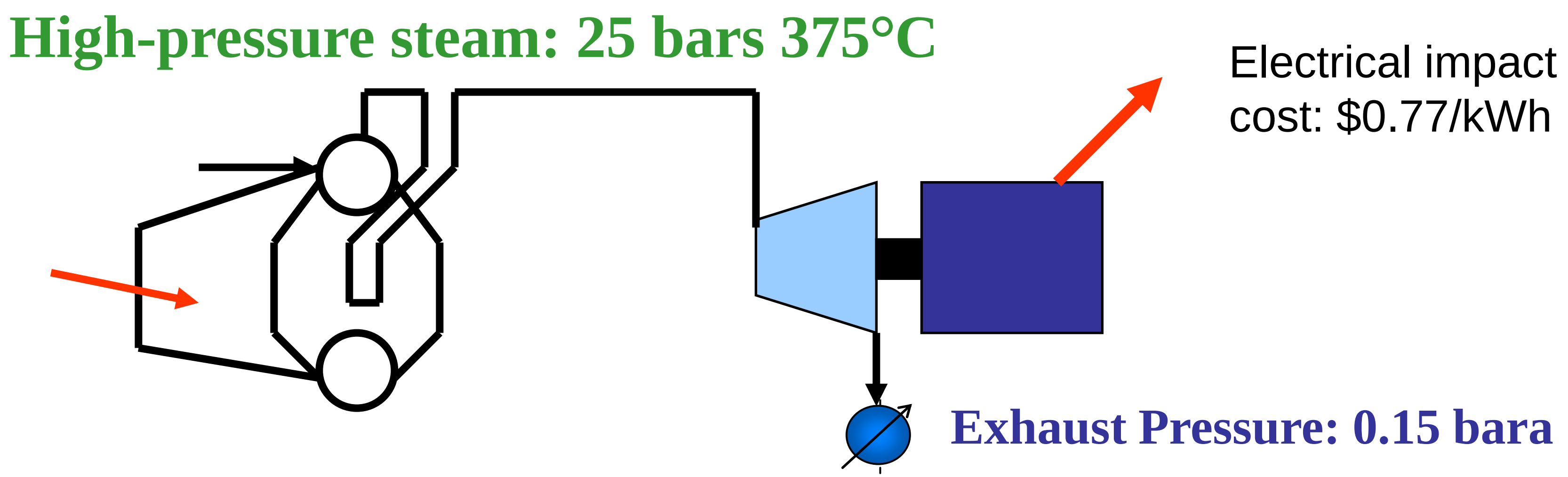
Note: If multiple turbines are installed, their data should be combined to allow them to be modeled as a single turbine

Note: A generator electrical efficiency of 100% is assumed by the model

Select the units of measure to specify the condenser pressure		bara
Condenser pressure (bara)	0.15	

- ✓ Condensing turbine isentropic efficiency is required
  - Manufacturers' data
  - Calculated from steam inlet, flow and power generated
- ✓ Condensing turbine outlet (discharge) pressure
  - Can be provided in either of the four units
  - Equivalent to surface condenser pressure

Condensing Turbine Impact Example



Impact boiler: Natural gas (EGP 2.10/NM^3)
Boiler efficiency: 81.7%

- ✓ Open the 3-Header Example System Model and set up the condensing turbine with the following configuration
  - Fixed power generation = 950 kW
  - Generator efficiency = 95%
  - Turbine isentropic efficiency = 65%
  - Condenser pressure = 0.15 bara

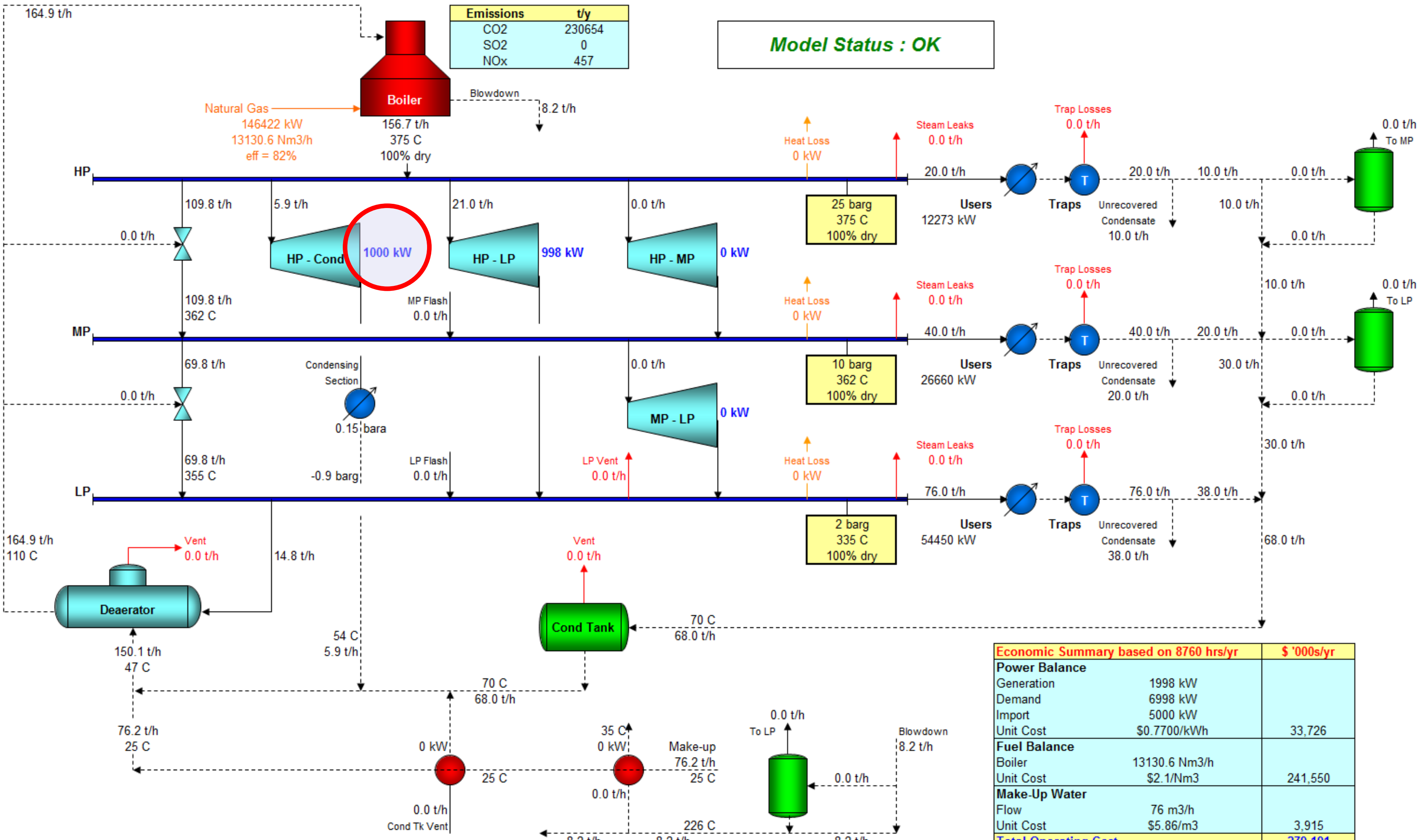
Steam System Assessment Tool

SSAT 3 Header Metric Model for User Training Egypt

Current Operation

Emissions	t/y
CO_2	230654
SO_2	0
NO_x	457

Model Status : OK



Economic Summary based on 8760 hrs/yr		$ '000s/yr
Power Balance		
Generation	1998 kW	
Demand	6998 kW	
Import	5000 kW	
Unit Cost	$0.7700/kWh	33,726
Fuel Balance		
Boiler	13130.6 Nm3/h	
Unit Cost	$2.1/Nm3	241,550
Make-Up Water		
Flow	76 m3/h	
Unit Cost	$5.86/m3	3,915
Total Operating Cost		279,191

Example System Model

- ✓ All the model “Inputs” are complete
- ✓ The 3-header model
  - Closely represents steam flows and steam balance on the headers as would be in the operating case
  - Accurately models the impact (marginal) steam costs of the system
  - DOES NOT represent total utility costs, emissions, etc.
    - NOTE: Impact fuel is used for modeling
  - Is ready to be used to accurately reflect economic impacts of energy saving and optimization opportunities in the steam system
- ✓ Make sure it is SAVED!