

Flexware®

Turbomachinery Engineers

A Veteran & Employee Owned Small Business

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Wet Steam

Typically steam turbines run well above the saturation line as any moisture in the steam can cause corrosion and erosion to the turbine blades. However, there are some cases where small turbines are used for conditions that are less than ideal as that is the steam that is available and who wants to throw away all that energy!

It was found that for this case, the best solution was to assume the inlet steam to be right on the saturation line so the inlet steam enthalpy could be determined and the turbine efficiency calculated. While not perfect, results are within 1 or 2 percentage points.

This steam turbine is running under the following conditions:

Inlet Pressure:	389.7 psia
Inlet Temperature:	442.1 F
Steam Flow:	57,878 lb/hr
Exhaust pressure:	93.7 psia
Exhaust Temperature:	320 F
Speed:	3,550 rpm

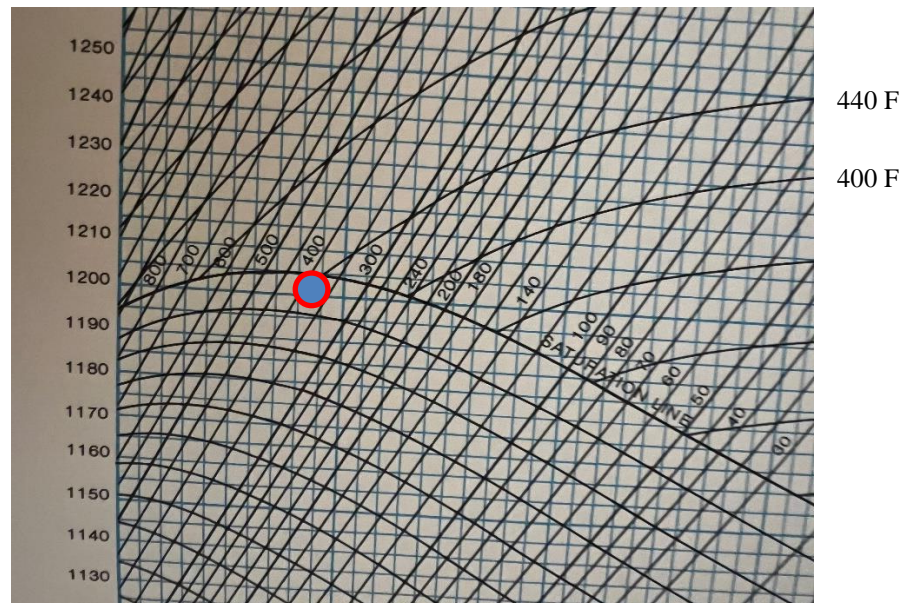


Figure 1. Looking at a Mollier diagram for Steam, we find that the steam entering the turbine is just below the saturation line. Since the constant temperature lines are discontinuous at the saturation line, it is impossible to precisely determine the enthalpy of the inlet steam to the turbine.

Example 1. Back Pressure Turbine

The screenshot shows the 'Steam Turbine Field Test' software window. The title bar reads 'Steam Turbine Field Test'. The main window has a title field containing 'Field Test Wet Steam'. Below this, there are input fields for various parameters:

Inlet Pressure	389.7000	psia
Inlet Temperature	442.1000	°F
Inlet Flow	57878.0000	lb/hr
Exhaust Pressure	93.7000	psia
Exhaust Temperature	320.0000	°F
Speed	3550.0000	RPM

To the right of these inputs are two radio button groups. The first group, labeled 'Select', has 'Temperature' selected. The second group, also labeled 'Select', has 'Back pressure' selected. Below these are buttons for 'Calculate', 'Show Report', 'Load', and 'Save As'.

Results

Inlet Specific Volume	0	ft ³ /lb
Inlet Enthalpy	0	Btu/lb
Inlet Entropy	0	Btu/lb °R
Inlet Saturation	443.7	°F
Inlet Superheat	-1.576	°F
Exhaust Enthalpy	0	Btu/lb
Exhaust Temperature	323.1	°F
Exhaust Power	0	HP
Exhaust Moisture	132.9	%
Theoretical Steam Rate	-55.93	lb/HP hr
Steam Rate	0	lb/HP hr
Efficiency	0	%

Figure 2. In this case, the operating values were entered into a steam turbine program. Note the Enthalpy is zero as we are below the saturation line. Also, note the program provides the inlet superheat as a negative number, further confirming we are in the saturated area.



Flex Live® Steam Turbine Field Test

03/11/2023 11:41:38

Version: 21.2.15

Description: Field Test Wet Steam

Inputs	Units	Value
Inlet Pressure	psia	389.7
Inlet Temperature	°F	442.1
Inlet Flow	lb/hr	57,878
Exhaust Pressure	psia	93.70
Exhaust Temperature	°F	320.0
Speed	RPM	3,550

Overall Results	Units	Value
Exhaust Power	HP	0
Theoretical Steam Rate	lb/HP hr	-55.93
Steam Rate	lb/HP hr	0
Efficiency	%	0

State Point Results	Units	Inlet	Exhaust
Specific Volume	ft ³ /lb	0	-1.526
Pressure	psia	389.7	93.70
Temperature	°F	442.1	323.1
Enthalpy	Btu/lb	0	0
Entropy	Btu/lb °R	0	0.093
Mass Flow	lb/hr	57,878	57,878
Saturation Temperature	°F	443.7	323.1
Superheat	°F	-1.576	0
Moisture	%	100.0	132.9

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Figure 3. Note with further information it is shown that the saturation temperature for the inlet conditions is 443.7 F.

Example 2. Condensing Turbine

Results	
Inlet Specific Volume	1.145 ft ³ /lb
Inlet Enthalpy	1,204 Btu/lb
Inlet Entropy	1.489 Btu/lb °R
Inlet Saturation	443.7 °F
Inlet Superheat	0.024 °F
Exhaust Enthalpy	1,171 Btu/lb
Exhaust Temperature	323.1 °F
Exhaust Power	750.0 HP
Exhaust Moisture	1.673 %
Theoretical Steam Rate	22.27 lb/HP hr
Steam Rate	77.17 lb/HP hr
Efficiency	28.86 %

Figure 4. In this example, the inlet steam was assumed to be on the saturation line so the inlet Enthalpy could be determined. Using the inlet saturation temperature from Figure 3 and the driven power to determine the exhaust enthalpy, an efficiency of 29% was calculated.



Flex Live® Steam Turbine Field Test

03/11/2023 11:54:33

Version: 21.2.15

Description: Field Test Wet Steam

Inputs	Units	Value
Inlet Pressure	psia	389.7
Inlet Temperature	°F	443.7
Inlet Flow	lb/hr	57,878
Exhaust Pressure	psia	93.70
Power	HP	750.0
Speed	RPM	3,550

Overall Results	Units	Value
Exhaust Power	HP	750.0
Theoretical Steam Rate	lb/HP hr	22.27
Steam Rate	lb/HP hr	77.17
Efficiency	%	28.86

State Point Results	Units	Inlet	Exhaust
Specific Volume	ft ³ /lb	1.145	4.635
Pressure	psia	389.7	93.70
Temperature	°F	443.7	323.1
Enthalpy	Btu/lb	1,204	1,171
Entropy	Btu/lb °R	1.489	1.589
Mass Flow	lb/hr	57,878	57,878
Saturation Temperature	°F	443.7	323.1
Superheat	°F	0.024	0
Moisture	%	0	1.673

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Figure 5. Calculation using saturated inlet steam.

Example 3. Inlet Moisture

Results	
Inlet Specific Volume	1.149 ft ³ /lb
Inlet Enthalpy	1,205 Btu/lb
Inlet Entropy	1.485 Btu/lb °R
Inlet Saturation	443.7 °F
Inlet Superheat	0 °F
Exhaust Enthalpy	1,172 Btu/lb
Exhaust Temperature	323.1 °F
Exhaust Power	750.0 HP
Exhaust Moisture	1.630 %
Theoretical Steam Rate	22.26 lb/HP hr
Steam Rate	77.17 lb/HP hr
Efficiency	28.85 %

Figure 6. Calculation using 0% inlet moisture, indicating the steam at the inlet is at saturation conditions.



Flex Live® Steam Turbine Field Test

03/11/2023 11:48:59

Version: 21.2.15

Description: Field Test Wet Steam

Inputs	Units	Value
Inlet Pressure	psia	389.7
Inlet Moisture	%	0
Inlet Flow	lb/hr	57,878
Exhaust Pressure	psia	93.70
Power	HP	750.0
Speed	RPM	3,550

Overall Results	Units	Value
Exhaust Power	HP	750.0
Theoretical Steam Rate	lb/HP hr	22.26
Steam Rate	lb/HP hr	77.17
Efficiency	%	28.85

State Point Results	Units	Inlet	Exhaust
Specific Volume	ft ³ /lb	1.149	4.637
Pressure	psia	389.7	93.70
Temperature	°F	443.7	323.1
Enthalpy	Btu/lb	1,205	1,172
Entropy	Btu/lb °R	1.485	1.589
Mass Flow	lb/hr	57,878	57,878
Saturation Temperature	°F	443.7	323.1
Superheat	°F	0	0
Moisture	%	0	1.630

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Figure 7. 0% moisture calculations. Note the efficiency is 29%

Example 4. Small 0.5% Moisture

The screenshot shows the 'Steam Turbine Field Test' software window. The title bar reads 'Steam Turbine Field Test'. The main window title is 'Field Test Wet Steam'. The input parameters are as follows:

Parameter	Value	Unit
Inlet Pressure	389.7000	psia
Inlet Moisture	0.5000	%
Inlet Flow	57878.0000	lb/hr
Exhaust Pressure	93.7000	psia
Power	750.0000	HP
Speed	3550.0000	RPM

On the right side, there are two 'Select' sections. The first section has radio buttons for Temperature, Enthalpy, Entropy, Moisture (selected), and Back pressure. The second section has radio buttons for Back pressure and Condensing (selected). Below these are buttons for Calculate, Show Report, Load, and Save As.

Results

Parameter	Value	Unit
Inlet Specific Volume	1.144	ft ³ /lb
Inlet Enthalpy	1.201	Btu/lb
Inlet Entropy	1.481	Btu/lb °R
Inlet Saturation	443.7	°F
Inlet Superheat	0	°F
Exhaust Enthalpy	1.168	Btu/lb
Exhaust Temperature	323.1	°F
Exhaust Power	750.0	HP
Exhaust Moisture	2.068	%
Theoretical Steam Rate	22.36	lb/HP hr
Steam Rate	77.17	lb/HP hr
Efficiency	28.98	%

Figure 8. In this calculation the moisture was estimated to be 0.5%. Note the efficiency is still 29%. While other calculations were completed with higher levels of moisture, the calculated efficiency was close. (An inlet moisture of 8% gave an efficiency of 31%.)



Flex Live® Steam Turbine Field Test

03/11/2023 11:58:34

Version: 21.2.15

Description: Field Test Wet Steam

Inputs	Units	Value
Inlet Pressure	psia	389.7
Inlet Moisture	%	0.500
Inlet Flow	lb/hr	57,878
Exhaust Pressure	psia	93.70
Power	HP	750.0
Speed	RPM	3,550

Overall Results	Units	Value
Exhaust Power	HP	750.0
Theoretical Steam Rate	lb/HP hr	22.36
Steam Rate	lb/HP hr	77.17
Efficiency	%	28.98

State Point Results	Units	Inlet	Exhaust
Specific Volume	ft ³ /lb	1.144	4.616
Pressure	psia	389.7	93.70
Temperature	°F	443.7	323.1
Enthalpy	Btu/lb	1,201	1,168
Entropy	Btu/lb °R	1.481	1.584
Mass Flow	lb/hr	57,878	57,878
Saturation Temperature	°F	443.7	323.1
Superheat	°F	0	0
Moisture	%	0.500	2.068

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Figure 9. Calculation assuming 0.5% moisture at the inlet.