Faculty of Engineering and Architectural Science

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Instructor	**Prof. B. Gheynani**

Lab Report No.	4

Report Title	**Steam Quality Measurement**

Group	Sec02-Group D
Submission Date	
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I. Summary

The purpose of this experiment was to investigate and calculate the steam quality, x_1 and x_2, which is the mass fraction of saturated water vapor in steam. The values recorded during the lab were the pressure and temperature for the steam inlet, the throttling calorimeter, and the temperatures of the cooling water inlet and outlet. The mass of the beaker with water, separated water, conducting vessel, and condensate. These measurements were taken for 3 trials to reduce the error. Upon further calculations, it was found that after 3 tests, the average steam quality before throttling was 94.34% and the average steam quality after throttling was 98.73% which indicated efficient energy transfer. Understanding steam quality is essential in thermodynamics, as it plays a vital role in the efficiency and performance of thermodynamic systems. The objective is to find these values and to explain any source of error within the results.

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1. Introduction

The purpose of this experiment was to evaluate the quality of steam produced by a boiler. Steam quality refers to the fraction of steam by mass (saturated vapor) in the mixture of steam and liquid. When steam exits a boiler, heat loss causes the saturated vapor to condense, increasing the liquid content. Steam quality can be calculated using the following equation:

$$x = \frac{m_{vapor}}{m_{liquid} + m_{vapor}} \tag{1}$$

Where m_{vapor} and m_{liquid} are the masses of vapor and liquid, respectively.

To determine the steam quality at the inlet point, the following equation can be used:

$$x_1 = \frac{x_2 m_{cond}}{m_{cond} + m_{sep}} \tag{2}$$

Here, m_{cond} is the mass of the condensate, m_{sep} is the mass of the mechanically separated liquid, and x_1 is the steam quality at the inlet.

To separate liquid water from steam, two common methods are used: (1) reducing steam velocity in a vertically oriented pipe to collect water droplets at the button, and (2) forcing steam tangentially through a vertical pipe to use centrifugal force to push liquid droplets down the walls.

After separation, steam pressure is reduced at constant enthalpy, and the steam is condensed in a condenser to obtain liquid water. This process is monitored by measuring the pressure and temperature continuously.

The steam quality can be calculated using the following equations:

$$h_2 = (1 - x_2)h_f + x_2 h_g \tag{3}$$

In this equation, h_2 is the enthalpy at a specific point, and h_f and h_g are the enthalpies of the saturated liquid and vapor, respectively. In a throttling process (where enthalpy remains constant), the steam quality at a point can be determined by rearranging Equation 3 in terms of x_2:

$$x_2 = \frac{h_2 - h_f}{h_g - h_f} \tag{4}$$

2. Apparatus

- Steam Quality measuring system
  - Steam inlet
  - Throttle
  - Mechanical separator
  - Cooling water inlet and outlet
  - Condenser
  - 2 Collection containers

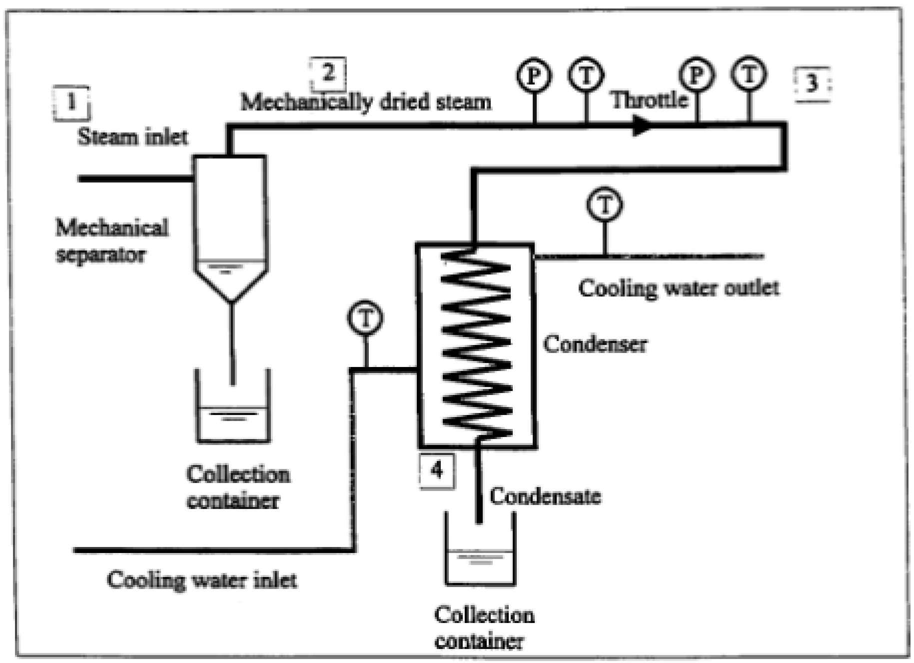

Figure 1: Steam Quality Measuring System Schematic Diagram

3. Procedure

1. Turn on the cooling water. To guarantee adequate heat dissipation throughout the experiment, turn on the condenser's cooling water supply.

2. Condensate Purge: To remove condensed water from the drain, open the steam stop valve and then slowly open the blowdown valve. After all the steam has been removed from the blowdown line, shut off the blowdown valve firmly.

3. Maintain System Stability: To ensure that the condensate cooling water intake and outlet temperatures are stable, open the separator steam inlet valve and let the system run until a steady state is achieved.

4. Get ready to collect data: To remove collected water from the separator, turn the three-way valve to the drain position. After draining, put the valve back in its working position so that liquid can start to accumulate. Set the timer to record the length of the experiment.

5. Start Condensate Collection: For the amount of time your instructor has designated, collect condensate from the condenser drain line. For reliable data, make sure the gathering procedure is consistent.

6. Note Measurements: Throughout the collecting time, note all temperature and pressure readings.

7. Closing the Collection: Close the separator steam intake valve and cease collecting condensate when the allotted time has passed.

8. Separate Mechanically-Condensed Water: To pressurize the system, slightly open the condenser steam inlet valve. To reduce the chance of burns, then pour the separated water from the three-way valve into a beaker filled with cold water that has been previously weighed. During this phase, use caution while handling any equipment.

9. Repeat for Accuracy: To guarantee consistent and trustworthy results, get a minimum of three sets of readings.

10. System Shutdown: Let the system depressurize for five minutes after closing the steam supply valve. Lastly, turn off the condenser's cooling water supply.

4. Results and Calculations

Table 1: Test results for the experiment.

Parameter	Test 1	Test 2	Test 3
Room Barometric Pressure [Hg]	29.49		
Time [min]	15	15	15
Steam Inlet Pressure [psi gauge]	47	50	49
Steam Inlet Temp. [°F]	290	293	290
Steam Temp. in Throttling Calorimeter [°F]	230	245	238
Steam Pressure in Throttling Calorimeter [Hg gauge]	3.18	2.95	2.65
Cooling Water Inlet Temp. (cal) [°F]	48	58	49
Cooling Water Outlet Temp. (cal) [°F]	156	145	123
Condensate Temp. [°F]	123	104	90

Table 2: Test results for the experiment in SI units.

Parameter	Test 1	Test 2	Test 3
Room Barometric Pressure [bar]	1.00		
Time [min]	15	15	15
Steam Inlet Pressure [bar gauge]	3.24	3.45	3.38
Steam Inlet Pressure [bar abs]	4.24	4.45	4.38
Steam Inlet Temp. [°C]	143.33	145.00	143.33
Steam Temp. in Throttling Calorimeter [°C]	110.00	118.33	114.44
Steam Pressure in Throttling Calorimeter [bar gauge]	0.1077	0.0998	0.0897
Steam Pressure in Throttling Calorimeter [bar abs]	1.1077	1.0998	1.0897
Cooling Water Inlet Temp. (cal) [°C]	8.89	14.44	9.44
Cooling Water Outlet Temp. (cal) [°C]	68.89	62.78	50.56
Condensate Temp. [°C]	50.56	40.00	32.22

Table 3: Recordings of weights for the separated water.

Parameter	Test 1	Test 2	Test 3
Wt. of beaker + cold water [kg]	1.205	1.455	1.500
Wt. of beaker + cold water + separated water [kg]	1.30	1.600	1.625
Wt. of separated water [kg]	0.10	0.145	0.125

Table 3: Recordings of weights for the condensate.

Parameter	Test 1	Test 2	Test 3
Wt. of collecting vessel [kg]	2.245	2.245	2.245
Wt. of collecting vessel + condensate [kg]	5.104	4.876	4.765
Wt. of condensate [kg]	2.859	2.631	2.520

Table 4: Recordings of the initial steam quality, x_1 and x_2, for each test. A sample calculation can be found in **Appendix B**.

Parameter	Test 1	Test 2	Test 3	Average
Initial Steam Quality before Throttling (x_1)	95.46%	93.50%	94.06%	94.34%
Initial Steam Quality after Throttling (x_2)	98.79%	98.68%	98.73%	98.73%

5. Discussion

It should be noted that **Appendix A** verifies equation (2), quality of the entering steam, and the calculated steam qualities at points 1 and 2 are shown in **Table 4**. .

What is the measured steam quality at points 1 and 2?

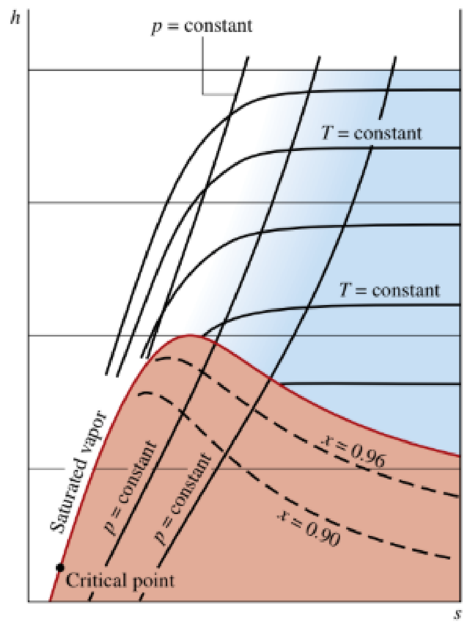

Figure 2: Mollier Chart [1].

The enthalpy-entropy diagram, or Mollier chart, in **Figure 2** indicates the theoretical values of the steam quality expected from this experiment. The dome-shaped section represents the two-phase region, in which a mixture of saturated liquid and saturated vapour exists. The two dotted lines indicate the quality of the steam, with 0.96 implying 96% vapour and 0.9 implying 0.90% vapour. The average steam quality values obtained in this experiment, 94.34% and 98.73%, closely align with the expected range and validate the accuracy of the lab data.

What are some expected sources of error in this experiment?

Possible sources of error in this experiment include inaccurate temperature or pressure readings due to sensor placement or calibration issues, timing errors during condensate collection, and inconsistent cooling water flow. Heat loss to the surroundings and incomplete or evaporated condensate collection can also affect results as it violates the conservation of mass and the assumption that all the steam was condensed. Human error, such as incorrect valve operation or data recording, and failure to reach steady-state conditions before data collection, may further compromise accuracy. Repeating trials and carefully controlling procedures can help minimize these errors.

What would be the effect of taking your measurements before steady state was reached?

Taking measurements before steady state is reached would result in inaccurate pressure and temperature readings as the system hasn't stabilized. Various conditions of this experiment wouldn't hold, such as the constant enthalpy process at the throttle and the comparison to the saturated values of the steam tables. Additional heat loss would also take place with cold pipes and valves, further differing the measurement and steam quality values from the theoretical range.

6. Conclusion

The purpose of this experiment was to investigate the steam quality of water using two distinct methods. Specifically, this was achieved by utilizing an apparatus designed to measure steam quality. Three trials of the experiment were conducted to obtain an average initial steam quality. An average steam quality of 94.34% for the first measurement (x_1) and 98.73% for the second measurement (x_2). The higher value of the second point can be attributed to mechanically separated liquid in the system, small interpolation errors, and minor heat losses. Consequently, as both x_1 and x_2 are under 1, it indicates that our steam quality measurements are valid and there is a definite presence of wet steam in the system.

7. References

[1] M. J. Moran, H. N. Shapiro, D. D. Boettner, and M. B. Bailey, Fundamentals of Engineering Thermodynamics, 9th ed. Hoboken, N.J.: Wiley, 2018.

8. Appendix

To verify equation (2), equation (1) must be considered.

$$x = \frac{m_{vapour}}{m_{liquid} + m_{vapour}} \quad (1)$$

Given a closed system, the equation (a) is true.

$$m_{liquid} + m_{vapour} = m_{total} = m_{cond} + m_{sep} \quad (a)$$

The following can also be assumed.

$$x_1 = \frac{m_{vapour1}}{m_{total}} \qquad x_2 = \frac{m_{vapour2}}{m_{cond}}$$

$$m_{vapour1} = x_1 \cdot m_{total} \qquad m_{vapour2} = x_2 \cdot m_{cond}$$

Assuming the vapour is not removed, the following inequalities are obtained.

$$m_{vapour1} = m_{vapour2}$$

$$x_1 \cdot m_{total} = x_2 \cdot m_{cond}$$

Substitute equation (a) for m_{total}

$$x_1 \cdot (m_{cond} + m_{sep}) = x_2 \cdot m_{cond}$$

By rearranging the equation above, the following equation is derived.

$$x_1 = \frac{x_2 \cdot m_{cond}}{(m_{cond} + m_{sep})}$$

∴ Equation (2) verified.

Appendix A: Verifying equation (2) for quality of the entering steam.

$Given$: $P' = 4.24\ bar,\ P'' = 1.1077\ bar,\ m_{cond} = 2.859\ kg, m_{sep} = 0.10\ kg$

From steam tables [1].

$$P' = 4.24\ bar,\ P'_1 = 4\ bar,\ P'_2 = 4.5\ bar,\ h'_{f1} = 604.74\ \frac{kJ}{kg},\ h'_{f2} = 623.25\ \frac{kJ}{kg}$$

$$h'_{fg1} = 2133.8\ \frac{kJ}{kg},\ h'_{fg2} = 2120.7\ \frac{kJ}{kg}$$

$$P'' = 1.1077\ bar,\ P''_1 = 1\ bar,\ P''_2 = 1.5\ bar,\ h''_1 = 2716.6\ \frac{kJ}{kg},\ h''_2 = 2711.4\ \frac{kJ}{kg}$$

$Solution$:

Linearly interpolate to find h'_f, h'_{fg}, and h_2

$$h = h_1 + \frac{P-P_1}{P_2-P_1}(h_2 - h_1)$$

$$h'_f = h'_{f1} + \frac{P'-P'_1}{P'_2-P'_1}(h'_{f2} - h'_{f1})$$

$$h'_f = 604.66\ \frac{kJ}{kg} + \frac{4.24\ bar - 4\ bar}{4.5\ bar - 4\ bar}(623.25\ \frac{kJ}{kg} - 604.74\ \frac{kJ}{kg})$$

$$h'_f = 613.62\frac{kJ}{kg}$$

Using the same method, find h'_{fg} and h_2.

$$h'_{fg} = 2127.51\frac{kJ}{kg}$$

$$h_2 = 2715.48\frac{kJ}{kg}$$

Plug values into equations (2) and (4).

$$x_2 = \frac{h_2-h_f}{h_g-h_f}$$

$$x_2 = \frac{h_2-h'_f}{h'_{fg}}$$

$$x_2 = \frac{2715.48\frac{kJ}{kg} - 613.62\frac{kJ}{kg}}{2127.516\frac{kJ}{kg}}$$

$$x_2 = 0.9879 = 98.79\%$$

$$x_1 = \frac{x_2 m_{cond}}{m_{cond}+m_{sep}}$$

$$x_1 = \frac{(0.9879)(2.859\ kg)}{2.859\ kg + 0.10\ kg}$$

$$x_1 = 0.9546 = 95.46\%$$

Appendix B: Sample solution for finding x_1 and x_2.