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Lab/Tutorial Report NO.	3

Report Title	Lab 3, Steam Pressure Relationship

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Abstract:

This experiment explores the temperature-pressure relationship in steam undergoing a constant volume process. The experiment demonstrates the relationship between pressure and temperature fluctuations; understanding this fundamental relationship and comparing experimental observations to accepted reference values are the two primary goals of this experiment.

1.0 Introduction:

In this experiment, the relationship between pressure and temperature as it undergoes a constant volume process is investigated. This lab revolves around gauge pressure readings and steam temperature measurements taken from a WL 204 steam boiler, as those two variables will be plotted against each other to visualise the relationship between them. An important step in the experimental process is to convert the gauge pressure readings taken from the pressure gauge into absolute pressure values, as steam tables are written in absolute pressure. To do this, we use the following formula:

$$P_{abs} = P_{atm} + P_{gauge} \tag{1}$$

Used to find absolute pressure (bar)

$$\gamma = \frac{(p_{abs} - p_1)}{(p_2 - p_1)} \tag{2}$$

The pressure ratio equation used to calculate the ratio between the previous pressure's

$$T *= (1 - r)T_1 + rT_2 \tag{3}$$

Used to calculate the interpolated temperature

$$T(\%\, error) = \frac{(T - T*)}{T*} \cdot 100\% \tag{4}$$

Used to find percent error in the temperature values that we have.

After all the experimental absolute pressure values and temperature readings have been obtained, they can be plotted and compared to the corresponding pressure-temperature pairs found in the saturated steam tables from Moran and Shapiro's *Fundamentals of Engineering Thermodynamics.*

2.0 Apparatus:

The following equipment was used to perform the experiment:

- WL 204 Steamen closed model steam boiler
  The experiment WL 204 Steam pressure curve of saturated steam demonstrates the correlation between steam pressure and heating temperature on an enclosed model steam boiler. An insulated steel vessel is filled with a defined quantity of water and sealed pressure-tight. The water is heated by an electric heater and brought to the boil. To record the heating and steam temperature the unit has a temperature sensor element with an electronic evaluation unit and a digital display. The steam pressure occurring in the boiler during the experiments is calculated and indicated by a mechanical manometer. A safety valve prevents excess pressure build-up in the boiler. The setup of this bench-top unit permits the saturated steam pressure curve of water to be determined steplessly up to a pressure of 16 bar. The measurement can be compared against the tabulated values from the relevant literature. The experiment is executed as a user-friendly benchtop unit. However, for safety reasons it should only be run under the supervision of trained personnel, as experimenting with hot steam by nature involves a certain risk. It is designed only for educational and training purposes.

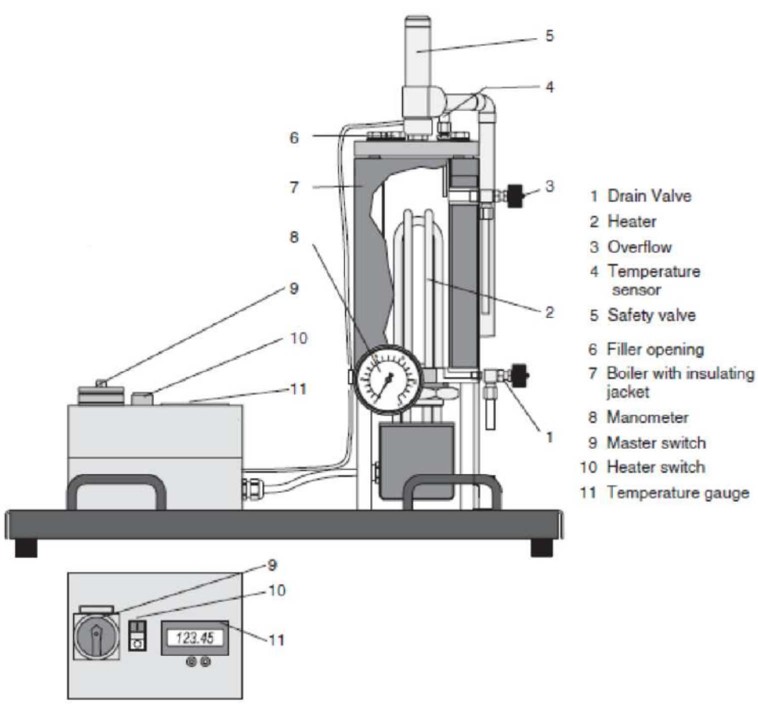


Figure 1: WL 204 general view

3.0 Procedure:

1. Measure the barometric pressure. Correct for local conditions (temperature, ambient pressure).
2. Switch on the unit at the master switch (9).
3. Switch on the heater at the heater switch (10) and heat up the boiler. The heater control is limited to a temperature of 200℃ in order to prevent excess pressure build-up.
4. Deaerating the Boiler: Heat up the boiler to 100℃. Let the water cook for approx. 1 min. so that the steam can pass through the open valve (3).
5. Log the boiler pressure and temperature values in increments of approximately 0.5 bar (Table 1).
6. Compare your own measurements with the values from the literature.
7. Shutting Down the Boiler: After the experiment switch off the unit at the master switch. Disconnect the unit from the mains power. Leave the boiler to cool down.

4.0 Results:

Table 1: Observed experimental results

Pressure, relative [bar]	Pressure, absolute [bar]	Experimental Steam temperature [℃]
0.5	1.55	110.3
1	2.05	118.8
1.5	2.55	125.9
2	3.05	132.1
2.5	3.55	137.4
3	4.05	142.5
4	5.05	150.4
5	6.05	158
6	7.05	164
7	8.05	169.8
8	9.05	174.4
9	10.05	179.2
10	11.05	183.3
11	12.05	187.1
12	13.05	190.9

13	14.05	194.3
14	15.05	197.4
15	16.05	200

5.0 Discussion and Calculations:

1. *For each gauge pressure reading, calculate the absolute pressure and the corresponding pressure-temperature pairs from saturated steam tables (eg. Table A-2 or A-3 in Moran and Shapiro's Fundamentals of Engineering Thermodynamics). Remember: Steam tables are written in absolute pressure!*
2. *Plot your results in tabular form.*
3. *Plot both your absolute pressure versus temperature results and the steam table values, as two separate curves on one plot for comparison. Determine the maximum and average percentage difference between your results and the published steam table values. Provide some plausible reasons for any discrepancies.*

Atmospheric pressure in Toronto on October 21 2023: 1.0501 bar

Table 2: Calculated Values and Percent Error

Absolute Pressure [bar]	**P1 [bar]**	**T1 [℃]**	**P2 [bar]**	**T2 [℃]**	**Ratio**	**Interpolated**	**E% of T**
1.550	1.50	111.4	2.00	120.2	0.1002	112.28	-1.765
2.050	2.00	120.2	2.50	127.4	0.1002	120.92	-1.755
2.550	2.50	127.4	3.00	133.6	0.1002	128.02	-1.657
3.050	3.00	133.6	3.50	138.9	0.1002	134.13	-1.514
3.550	3.50	138.9	4.00	143.6	0.1002	139.37	-1.414
4.050	4.00	143.6	4.50	147.9	0.1002	144.03	-1.063
5.050	5.00	151.9	6.00	158.9	0.0501	152.25	-1.216
6.050	6.00	158.9	7.00	165	0.0501	159.21	-0.757
7.050	7.00	165	8.00	170.4	0.0501	165.27	-0.769
8.050	8.00	170.4	9.00	175.4	0.0501	170.65	-0.498
9.050	9.00	175.4	10.00	179.9	0.0501	175.63	-0.698
10.050	10	179.9	15.00	198.3	0.0100	180.08	-0.491
11.050	10	179.9	15.00	198.3	0.2100	183.76	-0.253

12.050	10	179.9	15.00	198.3	0.4100	187.44	-0.184
13.050	10	179.9	15.00	198.3	0.6100	191.12	-0.117
14.050	10	179.9	15.00	198.3	0.8100	194.80	-0.259
15.050	15	198.3	20.00	212.4	0.0100	198.44	-0.525
16.050	15	198.3	20.00	212.4	0.2100	201.26	-0.627

Average Error Percentage: -0.865%

<u>Sample Interpolation and Error calculation:</u>

Pabs = P gauge + Patm

$= 0.5 + 1.0501$

$= 1.550\ bar$

Nearest (pressure, Temp) pairs on Table A.3:

P1 = (1.5, 111.4)

P2 = (2.0, 120.2)

Calculate ratio:

$R = \frac{Pabs - P1}{P2 - P1}$

$= \frac{1.55 - 1.5}{2.0 - 1.5}$

R = 0.1002

Interpolate for T*:

$T* = (1 - R) * T1 + r * T2$

$= (1 - 0.1002) * 111.4 + 0.1002 * 120.2$

$= 112.2821\ ℃$

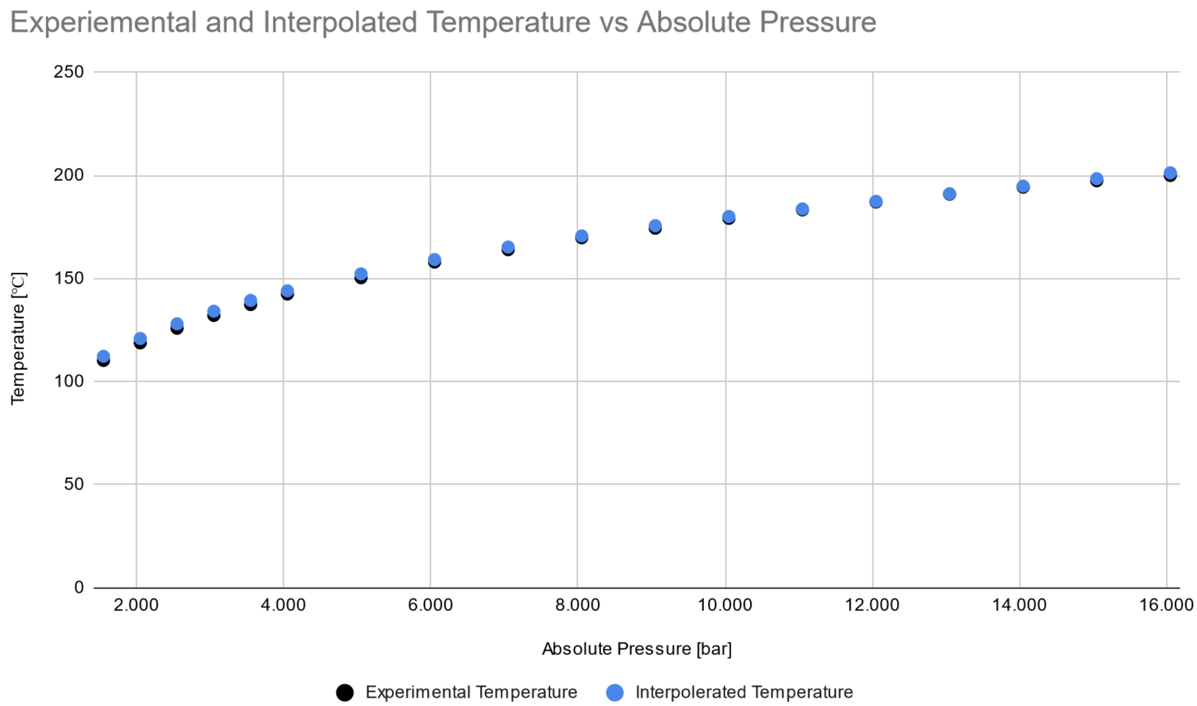
Error Percentage:

$\text{Error} = 100 * \frac{Texp - T^*}{T^*}$

$= 100 * \frac{110.3 - 112.2821}{112.2821}$

$\text{Error} = -1.765\%$

Figure 2: Graph of Experimental and Interpolated vs Absolute Pressure



The highest absolute error percentage calculated was 1.77%, and the average error percentage was 0.87%.

Observing Table 1, one can see that the pressure, temperature, and manometer are all intrinsically related. When one rises, they all rise, creating a trend in which the absolute and gauge pressure consistently rise with the rising temperature, and illustrates the the proportional relationship between both pressures and temperature. When experiencing constant volume, pressure rises and falls with temperatures, and temperature decreases and increasing depending on the pressure. This principle is in line with Gay Lussac's law, as shown above. The maximum absolute percent difference is 1.77%, and the average absolute percent difference is 0.87%. One cause for this discrepancy is that the absolute pressure values calculated are 0.05 bar above the given values in the steam table. This could be caused by differing ambient conditions compared to the standardised conditions or slight impurities in the water compared to the water used in the standard steam table.

6.0 Conclusions:

In conclusion, this lab can be deemed a success as it effectively shed light on the utilisation of the Marcet Boiler, elucidating the intricate connection between pressure and temperature concerning both water and water vapour. The error analysis conducted revealed consistently minimal discrepancies, with an average percent error of 0.87%. The computed values are closely aligned with their theoretical counterparts. Furthermore, the data presented in Graph 1 faithfully adhered to the expected theoretical trends. To enhance the experiment, it is advisable to consider conducting additional runs at varying pressure levels to yield a smoother curve in Graph 1. Moreover, instead of resorting to linear interpolation, using precise data points for each pressure level could enhance the overall accuracy of the data.

7.0 References:

[1]Naylor, D., & Friedman, J. (n.d.). MEC511 Thermodynamics and Fluid Mechanics Laboratory Manual (R. Buddy, Ed.). Toronto, ON: Toronto Metropolitan University.

Appendices:

Table A.3: Properties of Saturated water (liquid-vapour)

		Specific Volume m^3/kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg · K		
Press. bars	Temp. °C	Sat. Liquid $v_f \times 10^3$	Sat. Vapor v_g	Sat. Liquid u_f	Sat. Vapor u_g	Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Liquid s_f	Sat. Vapor s_g	Press. bars
0.04	28.96	1.0040	34.800	121.45	2415.2	121.46	2432.9	2554.4	0.4226	8.4746	0.04
0.06	36.16	1.0064	23.739	151.53	2425.0	151.53	2415.9	2567.4	0.5210	8.3304	0.06
0.08	41.51	1.0084	18.103	173.87	2432.2	173.88	2403.1	2577.0	0.5926	8.2287	0.08
0.10	45.81	1.0102	14.674	191.82	2437.9	191.83	2392.8	2584.7	0.6493	8.1502	0.10
0.20	60.06	1.0172	7.649	251.38	2456.7	251.40	2358.3	2609.7	0.8320	7.9085	0.20
0.30	69.10	1.0223	5.229	289.20	2468.4	289.23	2336.1	2625.3	0.9439	7.7686	0.30
0.40	75.87	1.0265	3.993	317.53	2477.0	317.58	2319.2	2636.8	1.0259	7.6700	0.40
0.50	81.33	1.0300	3.240	340.44	2483.9	340.49	2305.4	2645.9	1.0910	7.5939	0.50
0.60	85.94	1.0331	2.732	359.79	2489.6	359.86	2293.6	2653.5	1.1453	7.5320	0.60
0.70	89.95	1.0360	2.365	376.63	2494.5	376.70	2283.3	2660.0	1.1919	7.4797	0.70
0.80	93.50	1.0380	2.087	391.58	2498.8	391.66	2274.1	2665.8	1.2329	7.4346	0.80
0.90	96.71	1.0410	1.869	405.06	2502.6	405.15	2265.7	2670.9	1.2695	7.3949	0.90
1.00	99.63	1.0432	1.694	417.36	2506.1	417.46	2258.0	2675.5	1.3026	7.3594	1.00
1.50	111.4	1.0528	1.159	466.94	2519.7	467.11	2226.5	2693.6	1.4336	7.2233	1.50
2.00	120.2	1.0605	0.8857	504.49	2529.5	504.70	2201.9	2706.7	1.5301	7.1271	2.00
2.50	127.4	1.0672	0.7187	535.10	2537.2	535.37	2181.5	2716.9	1.6072	7.0527	2.50
3.00	133.6	1.0732	0.6058	561.15	2543.6	561.47	2163.8	2725.3	1.6718	6.9919	3.00
3.50	138.9	1.0786	0.5243	583.95	2546.9	584.33	2148.1	2732.4	1.7275	6.9405	3.50
4.00	143.6	1.0836	0.4625	604.31	2553.6	604.74	2133.8	2738.6	1.7766	6.8959	4.00
4.50	147.9	1.0882	0.4140	622.25	2557.6	623.25	2120.7	2743.9	1.8207	6.8565	4.50
5.00	151.9	1.0926	0.3749	639.68	2561.2	640.23	2108.5	2748.7	1.8607	6.8212	5.00
6.00	158.9	1.1006	0.3157	669.90	2567.4	670.56	2086.3	2756.8	1.9312	6.7600	6.00
7.00	165.0	1.1080	0.2729	696.44	2572.5	697.22	2066.3	2763.5	1.9922	6.7080	7.00
8.00	170.4	1.1148	0.2404	720.22	2576.8	721.11	2048.0	2769.1	2.0462	6.6628	8.00
9.00	175.4	1.1212	0.2150	741.83	2580.5	742.83	2031.1	2773.9	2.0946	6.6226	9.00
10.0	179.9	1.1273	0.1944	761.68	2583.6	762.81	2015.3	2778.1	2.1387	6.5863	10.0
15.0	198.3	1.1539	0.1318	843.16	2594.5	844.84	1947.3	2792.2	2.3150	6.4448	15.0
20.0	212.4	1.1767	0.09963	906.44	2600.3	908.79	1890.7	2799.5	2.4474	6.3409	20.0
25.0	224.0	1.1973	0.07998	959.11	2603.1	962.11	1841.0	2803.1	2.5547	6.2575	25.0
30.0	233.9	1.2165	0.06668	1004.8	2604.1	1008.4	1795.7	2804.2	2.6457	6.1869	30.0
35.0	242.6	1.2347	0.05707	1045.4	2603.7	1049.8	1753.7	2803.4	2.7253	6.1253	35.0
40.0	250.4	1.2522	0.04978	1082.3	2602.3	1087.3	1714.1	2801.4	2.7964	6.0701	40.0
45.0	257.5	1.2692	0.04406	1116.2	2600.1	1121.9	1676.4	2798.3	2.8610	6.0199	45.0
50.0	264.0	1.2859	0.03944	1147.8	2597.1	1154.2	1640.1	2794.3	2.9202	5.9734	50.0
60.0	275.6	1.3187	0.03244	1205.4	2589.7	1213.4	1571.0	2784.3	3.0267	5.8892	60.0
70.0	285.9	1.3513	0.02737	1257.6	2580.5	1267.0	1505.1	2772.1	3.1211	5.8133	70.0
80.0	295.1	1.3842	0.02352	1305.6	2569.8	1316.6	1441.3	2758.0	3.2068	5.7432	80.0
90.0	303.4	1.4178	0.02048	1350.5	2557.8	1363.3	1378.9	2742.1	3.2858	5.6772	90.0
100.	311.1	1.4524	0.01803	1393.0	2544.4	1407.6	1317.1	2724.7	3.3596	5.6141	100.
110.	318.2	1.4886	0.01599	1433.7	2529.8	1450.1	1255.5	2705.6	3.4295	5.5527	110.