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PRO TIP: Why You Can't Rely on Temperature Measurements

Measurement of valve cap and discharge temperatures has been used for many years as a means to assess the health of compressor components. Many operators and mechanics routinely monitor these readings in order to identify leaking valves or in-cylinder recirculation of gases. However, without Pressure-Volume analysis, temperature readings can be counterintuitive and often misleading.

The volume-pressure-temperature relationships for a gas being compressed by a reciprocating compressor can be modeled adiabatically, which assumes no heat transfer to the surrounding environment. While there is some transfer of heat to the atmosphere or water jacket, the adiabatic model allows us to mathematically calculate the relationship between temperature and volume as gas is compressed as follows:

$$T_2 = T_1 \left(\frac{p_2}{p_1}\right)^{(k-1)/k}$$

where
T_2 is the discharge temperature in absolute degrees (Rankine or Kelvin),
T_1 is the suction temperature in absolute degrees (Rankine or Kelvin),
p_2/p_1 is the ratio of absolute pressures, and
k is the ratio of specific heat for the gas

If we assume a constant gas mixture and, therefore a constant specific heat value, the discharge temperature is dependent on the gas suction temperature and the pressure ratio within the cylinder. When a suction valve leak exists, compressed gas in the cylinder is recirculated back into the suction cavity at a higher temperature and causes the suction temperature to increase. This also causes the discharge temperature to increase. From the calculation, the discharge temperature will increase a proportional amount. This is true only if the pressure ratio is not changed. In practice, this means it is only true for single stage machines.

In a multi-stage compressor, leakage within a cylinder will often result in a decreased compression ratio (CR) for the stage with the leakage and an increase in CR for an adjacent stage. These changes are because the machine is trying to maintain a constant compression ratio across the entire machine. A cylinder with leakage will perform less absolute work compressing gas and adjacent cylinders need to make up that work. For a cylinder recirculating gas, the increased suction temperature may be counterbalanced by the lower compression ratio, resulting in little or no temperature increase. Healthy adjacent cylinders may show an elevated discharged temperature due to the increased compression ratio. This scenario is illustrated below:

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Table 1 – Before Discharge Valve Repair

Compressor Cylinder ID	IHP @ RPM	IHP/ MMSCFD	Capacity MMSCFD	Date	Time
1> Comp 1 H Pressure	198.0 @ 991.5	79.71	2.48388	9-08-14	16:01:48
2> Comp 1 C Pressure	201.1 @ 991.2	79.01	2.54490	9-08-14	16:03:32
3> Comp 2 H Pressure	314.3 @ 991.0	48.98	6.41673	9-08-14	16:16:55
4> Comp 2 C Pressure	282.7 @ 992.0	47.40	5.96321	9-08-14	16:18:47
5> Comp 3 H Pressure	198.7 @ 991.6	79.17	2.50968	9-08-14	16:06:57
6> Comp 3 C Pressure	199.0 @ 986.9	78.88	2.52300	9-08-14	16:09:10
7> Comp 4 H Pressure	365.0 @ 990.8	51.13	7.13873	9-08-14	16:12:39
8> Comp 4 C Pressure	314.5 @ 987.6	45.16	6.96402	9-08-14	16:14:07

	%VOL EFF		%POW/VAL LOSS		%Flow Bal	Toe Press		Comp	Temp F		Rod Load (%)		Min Rod
	Dis	Suc	Dis	Suc	Suc/Dis	Pd	Ps	Ratio	Dis	Suc	Ten	Comp	Reversal
1>	15.2	50.4	3.6	3.3	1.07	206.12	39.68	4.06	247.8	79.3	97.9	96.9	135 C
2>	15.9	52.0	3.3	3.7	1.05	205.64	39.26	4.08	247.8	79.3	97.9	96.9	135 C
3>	40.2	78.5	5.4	4.9	0.99	949.92	398.16	2.34	227.0	113.3	62.1	70.3	127 C
4>	40.6	78.5	6.4	5.9	1.03	935.21	409.28	2.24	227.0	113.3	62.1	70.3	127 C
5>	15.3	50.2	3.2	3.0	1.06	207.94	40.25	4.05	251.4	79.3	98.0	96.4	134 C
6>	15.8	51.5	3.0	3.7	1.07	207.00	40.80	3.99	251.4	79.3	98.0	96.4	134 C
7>	56.1	72.9	7.1	3.9	0.78	424.03	203.89	2.01	246.0	123.9	62.4	69.4	118 T
8>	45.6	81.4	7.3	5.3	1.07	411.38	197.24	2.01	246.0	123.9	62.4	69.4	118 T

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Table 2 – After Discharge Valve Repair

	Compressor Cylinder ID	IHP @ RPM	IHP/ MMSCFD	Capacity MMSCFD	Date	Time
1>	Comp 1 H Pressure	177.9 @ 988.2	74.63	2.38436	9-08-14	18:53:58
2>	Comp 1 C Pressure	186.0 @ 993.2	72.88	2.55269	9-08-14	18:52:55
3>	Comp 2 H Pressure	318.2 @ 991.3	46.36	6.86408	9-08-14	18:44:02
4>	Comp 2 C Pressure	286.4 @ 990.6	44.57	6.42670	9-08-14	18:45:13
5>	Comp 3 H Pressure	184.9 @ 996.0	75.84	2.43855	9-08-14	18:55:13
6>	Comp 3 C Pressure	185.8 @ 990.8	71.93	2.58329	9-08-14	18:56:11
7>	Comp 4 H Pressure	314.0 @ 984.5	53.18	5.90486	9-08-14	18:48:39
8>	Comp 4 C Pressure	308.6 @ 988.6	53.57	5.76106	9-08-14	18:50:16

	%VOL	EFF	%POW/VAL LOSS		%Flow Bal	Toe Press		Comp	Temp F		Rod Load (%)		Min Rod
	Dis	Suc	Dis	Suc	Suc/Dis	Pd	Ps	Ratio	Dis	Suc	Ten	Comp	Reversal
1>	16.7	48.4	2.9	2.6	0.98	181.65	36.96	3.80	236.6	83.5	84.2	83.0	131 C
2>	17.6	52.4	2.6	3.4	1.00	181.29	36.94	3.80	236.6	83.5	84.2	83.0	131 C
3>	41.6	79.9	5.3	5.4	1.01	959.75	418.54	2.25	218.7	111.3	60.7	69.2	125 C
4>	42.9	79.9	6.8	6.5	1.03	941.17	431.14	2.14	218.7	111.3	60.7	69.2	125 C
5>	16.8	48.4	2.5	2.8	0.97	183.49	37.38	3.81	233.3	80.1	84.2	83.1	132 C
6>	17.8	52.1	2.7	3.2	1.00	181.22	37.60	3.75	233.3	80.1	84.2	83.1	132 C
7>	34.8	71.1	6.0	4.1	1.02	440.03	174.37	2.41	239.0	119.0	77.4	80.8	131 C
8>	34.9	73.6	4.9	3.9	1.04	439.58	171.39	2.44	239.0	119.0	77.4	80.8	131 C

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The above sets of data were taken 3 hours apart, after a significant leaking discharge valves were identified and corrected in stage 2 – cylinder #4 head end. After the fix, the flow balance in that cylinder went from 0.78 (significant leak) to 1.02 (normal) (*circled in purple*). The compression ratio in that cylinder changed from 2.01 to 2.41 after the leakage was fixed (*circled in red*). On stage one of the machine (cylinders 1 and 3) the compression ratio changed from 4.0 to 3.8 as that stage no longer had to make up for the inadequacies of stage 2 (*circled in blue*). Looking at discharge temperatures, the recirculation of gases due to the leaking discharge valves in stage 2 temperatures was causing a temperature rise of 7 degrees in that cylinder (*circled in yellow*). However in the healthy stage 1 (cylinders 1 and 3), temperatures saw increases of 11 and 28 degrees (*circled in green*). This is because the decreased CR in stage 2 mitigated the temperature increase due to recycling the discharge gases. The increased CR in stage 1 (due to the leak in stage 2) caused the temperatures to increase.

If monitoring discharge temperatures and process parameters was the only means of monitoring this compressor, the elevated discharge temperatures would have pointed to a problem in the healthy stage 1, rather than the un-healthy stage 2. In this case however, the operators checked valve cap temperatures every other day and did not identify any problems. The discharge leak in the unit was significant, costing the operator $55,000 per year in excess fuel consumption.

Monitoring discharge temperature and valve cap temperatures is an effective tool to confirm leakages in a single stage compressor. In multi-stage machines, however, recirculation of gas in an unhealthy cylinder can cause a redistribution of compression across all the stages and affect all the discharge temperatures, resulting in confusing data and mis-identification of problems. In-cylinder pressure measurements and Pressure-Volume analysis is critical to positively identifying leakage in multi-stage compressors.

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