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TEMPERATURES IN CABS OF FREIGHT LOCOMOTIVES PASSING THROUGH TUNNELS OF THE CHESAPEAKE & OHIO RAILROAD

By S. H. Katz[1] and E. G. Meiter.[2]

INTRODUCTION

Railroad locomotives produce heat, gas, and smoke, which cause considerable discomfort to engine men and firemen while passing through tunnels. In order to try and improve these conditions, the Bureau of Mines has investigated[3] the composition of atmospheres in cabs of freigh locomotives while in tunnels; and some of the higher temperatures in the cabs were noted; physiolcgical effects upon men were determined and gas masks and respirators were devised to eliminate the effects of irritating and poisonous gases and smoke. These investigations were conducted in tunnels of the Baltimore & Ohio, Pennsylvania, and Union Pacific railroads; while that described in this paper was carried out in tunnels of the Chesapeake & Ohio, Railroad, situated in the Blue Ridge and Allegheny Mountains in Virginia and West Virginia. Freight locomotives used by this railroad are of the Mallet type, which have two separate cylinders and two separate sets of driving wheels on each side. In locomotive language they are of the 2-6-6-2 type. All of the cylinders act as simple engines when starting or in slow, heavy hauling; but at faster speeds the pair of cylinders on each side operate compound. Mallet locomotives are the largest and most powerful now operated.

The tendency in train operation has always been to increase the burden upon locomotives. Present traffic needs frequently load even the Mallet engines to capacity, and yet the weight of trains tends to increase. It has been suggested as a means of securing greater power units that Mallets be constructed to operate only as simple engines. This would increase the amount of steam given off as well as the amount of coal burned and the resulting volume of flue gas emitted.

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1 Associate physical chemist, in charge of industrial gas laboratory, Pittsburgh Experiment Station.

2 Assistant chemist, Pittsburgh Experiment Station.

3 Fieldner, A. C., Katz, S. H., and Kinney, S. P., Tests of gas masks and respirators for protection from locomotive smoke in railroad tunnels, with analyses of tunnel atmospheres: Bureau of Mines Technical Paper 292, 1922, 27 pp.

Kinney, S. P., Atmospheric conditions and physiological effects on trainmen by locomotive smoke in the Aspen and Wahsatch tunnels of the Union Pacific Railroad: Bureau of Mines Report of Investigations No. 2494, June 1923, 13 pp.

Heretofore the high temperatures in cabs were attributed principally to exhaust gases and steam, and in the present tests especial effort was made to determine the temperatures at different positions in the cab and the relative effect of the exhaust gases and heat of the boiler in causing discomfort. It was found that stack gases entering the cab cause only a little increase in temperature; the increased humidity is principally due to steam carried in the stack gases; the exposed parts of the boiler, however, play an important part in raising the temperature in the cab.

Efforts were made to increase the comfort of the engine crew by blowing cool and smoke-free air upon them by means of specially installed blowers from a point 24 inches above the center of the rails between the locomotive and tender, as shown in Figure 1. The enginemen and fireman found this air better to breathe, and their feeling of comfort was increased somewhat thereby. Turbulence produced by the incoming streams caused the air in the cab to impinge upon the boiler and become heated, so that outside of the direct line of the air streams little cooling was felt, and sometimes the discomfort seemed to increase.

The ill-effects and discomforts due to heat and gas may, of course, be eliminated by forced ventilation of tunnels or by substituting electric for steam locomotives, but such changes are outside the scope of this paper.

VENTILATING FANS FOR LOCOMOTIVE CABS.

On account of the high temperatures, smoke and irritating gases which cause the difficult breathing experienced by crews of freight trains in tunnels, Geo.W. Bebout, electrical engineer for the C. & O. R.R. proposed blowers or fans for ventilating cabs with pure cool air drawn from a position low in the tunnels. A trial installation was built on Mallet locomotive No. 840 by J.J. Ewing, engineer of tests. Figure 1 shows details of the steam turbine, blowers, and connecting pipes, all of which were mounted on the frame beneath the cab floor, one complete unit on each side of the locomotive.[4]

As previously stated, the intake air is drawn from a point about 24 inches above and midway between the rails, through 6-inch galvanized sheet iron pipes, to a Sirocco type rotary blower capable of delivering 1000 cubic feet of free air per minute. The discharge pipes, 4 inches in diameter, terminate at points 12 inches above the floor in front of the cab seats, and direct the air streams at the positions of the fireman and engineer. The blowers were driven at 3600 r.p.m. by small, direct-connected steam turbines, like those used for driving electric generators for the headlight. The turbine, blower, and base plate occupy a space approximately 16 by 19 by 16 inches high. Steam valves for the turbine were placed above the boiler in the cab with wheels arranged for convenient operation by the fireman.

Exact measurements of the volume of air delivered by the blowers were not made, but it was estimated to be more than 500 cubic feet each per minute, or enough to replace the cab atmosphere at least twice a minute.

DESCRIPTION OF TUNNELS

Tests were conducted in 19 tunnels between Charlottesville, Va., and Hinton, W. Va., a distance of 175.6 miles. (See Figure 2.)

4 Since this investigation the writers have learned that similar blowers for ventilating cabs of freight locomotives are being used in tunnels of the Norfolk and Western R.R. They are reported as being satisfactory. The Southern Railway also has used them but does not favor them, partly because of maintenance requirements.

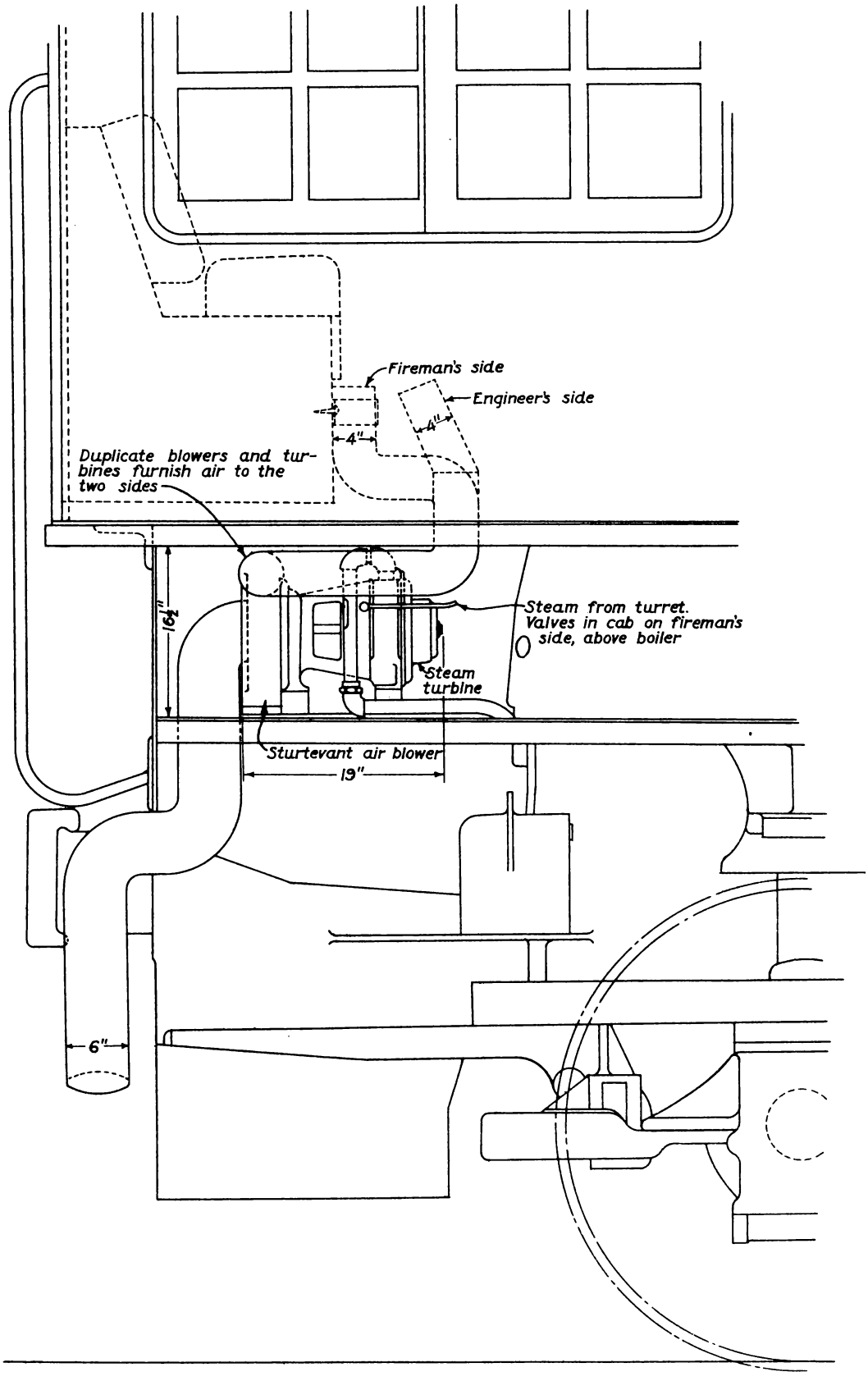

Fig. 1 Ventilating blower for locomotive cabs

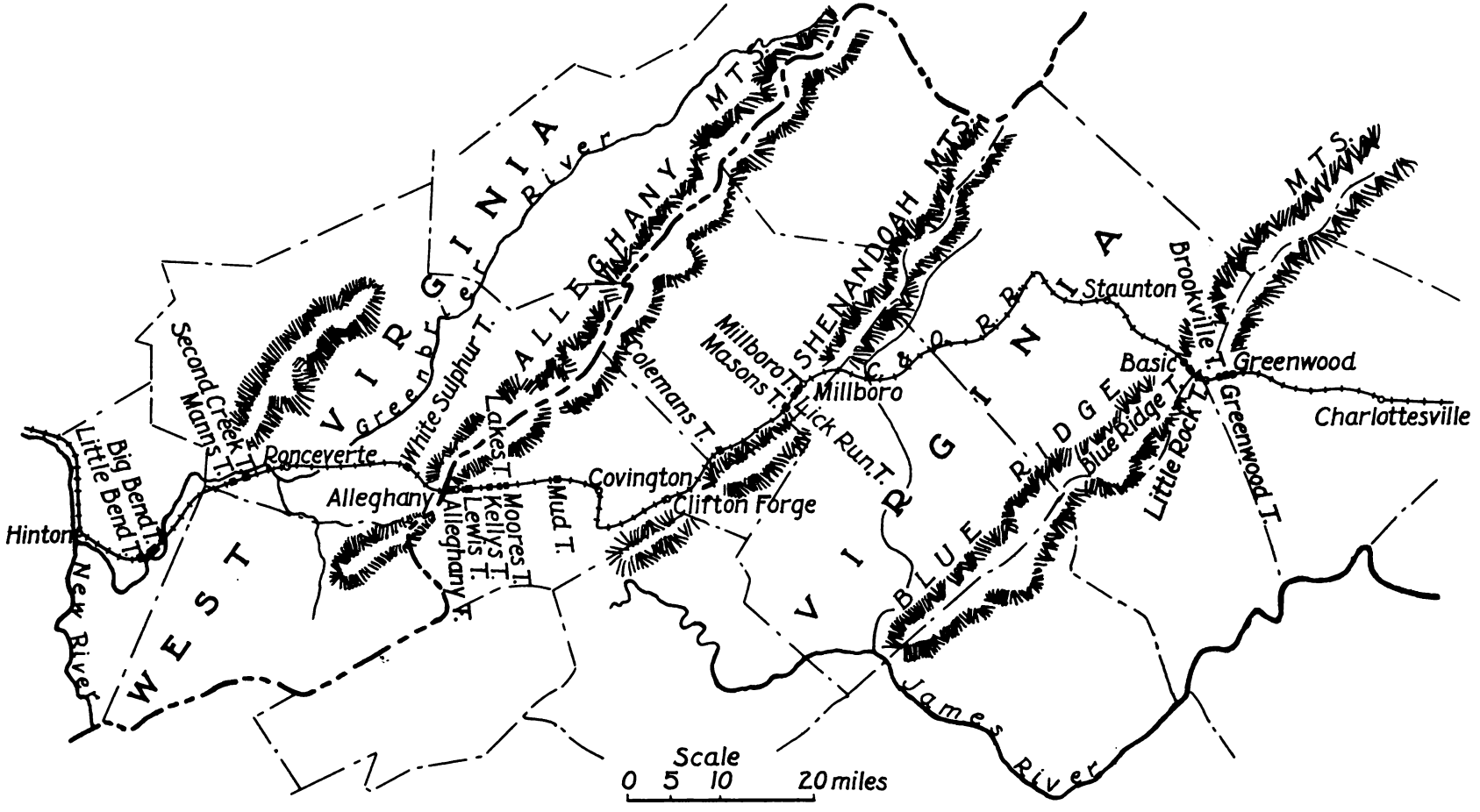

Fig.2 Map showing tunnels on C.&O.R.R. between Charlottesville, Va. and Hinton, W.Va.

This includes two districts, each of which constitutes a "run" for locomotive and crew. In the Mountain district, from Charlottesville, to Clifton Forge, Va., a distance of 96.3 miles, are eight tunnels, all single track. In the Allegheny district, between Clifton Forge, Va., and Hinton, W. Va., a distance of 79.3 miles, are eleven tunnels, three of single track and eight of double track. Table 1 gives the physical data of all tunnels and their situation.

The Blue Ridge tunnel in the Mountain District, 4263 feet long, with a grade westward of 68.7 feet per mile (1.3 per cent) is worst for westbound trainmen; while the Millboro tunnel, 1335 feet long, with a grade eastward of 74 feet per mile (1.4 per cent) is worst for eastbound trainmen. The double-tracked tunnels of the Allegheny District have much greater clearance than single-tracked tunnels, and are more comfortable as a rule. Of the tunnels on the Allegheny district the worst eastbound is Second Creek tunnel and westbound is Big Bend tunnel; both are single track tunnels. Big Bend tunnel is 6,478 feet long with grade from both ends to a point 1500 feet from the eastern portal. It is provided with a ventilating fan for blowing eastbound trains but not for westbound trains; despite a slight descending grade westbound it is necessary to work steam so that Big Bend tunnel westbound is the worst in the district. Lewis tunnel, although it is 4,019 feet long and single tracked on a grade westbound of 60 feet per mile (1.1 per cent), is not uncomfortable since it was provided with a large ventilating fan for blowing westbound trains; trains drift through it eastbound, Allegheny tunnel on the west side of Allegheny Mountain is long, nearly a mile, but it is double-tracked and gives little trouble from heat and gas.

Description of Trains.

Investigations were conducted on five trains at random. Descriptive data of the trains is given in Table 2. The five trips covered the two districts once in each direction, with one extra trip west from Clifton Forge, Va., to Hinton, W. Va.

Four of the tests were on locomotive No. 840, on which were the ventilating blowers, as described. At the time of trip No. 4 from Charlottesville to Clifton Forge, this engine went without load, so that this test was made on locomotive No. 780 which followed with the next train.

Both locomotives were of the Mallet type. No. 840 alone weighs 437,000 pounds, and with tender, 614,000 pounds. Its length is 63 feet 10-1/2 inches, and 89 feet 4-1/4 inches overall with tender; and height 15 feet 1/4 inch from rail to top of stack. The tractive force as a simple engine is 94,000 pounds, and as compound engine, 74,200 pounds. No. 840 is equipped with Duplex mechanical stokers. No. 780 is similar to No. 840 but weighs 4,000 more and has Street stokers.

On trip No. 1 from Hinton, W. Va., to Clifton Forge, Va., the heaviest train was hauled - 3623 gross tons - which is near the limit for the locomotive on the steeper grades. Two trips had maximum loads of 3370 tons, and the other two trips carried 1184 and 560 tons.

RESULTS OF TESTS

The results of the tests are given in Tables 3 and 4, which state respectively the observations in tunnels of the Allegheny district and the Mountain district.

TABLE 2.- Description of trains on which tests were conducted

Trip No.	Train No.	Starting from	Date in Oct., 1923.	Time	Bound east or west	Engine No.	Gross tonnage	Remarks.
1	Extra	Hinton, W.Va.	16	5.50 p.m.	E.	840	3623	Locomotive No. 840 has blowers for ventilating cab.
2	Extra	Clifton Forge, Va.	17	2.22 p.m.	W.	840	3370	Ronceverte to Hinton, 1633 tons.
3	First 96	"	19	1.49 a.m.	E.	840	1184	
4	49	Charlottesville, Va.	20	7.50 a.m.	W.	780	560	
5	Extra	Clifton Forge, Va.	20	10.08 p.m.	W.	840	(820 (2379 (3370	Started with 820 tons; picked up 1559 tons at Covington; picked up 991 tons at Ronceverte-2370 tons through Lewis tunnel, 3370 tons through Big Bend tunnel.

COMPOSITION OF CAB ATMOSPHERES WHEN IN TUNNELS

The gas analyses in columns 18 to 23 of Tables 3 and 4 do not indicate excessive amounts of carbon monoxide which is the poisonous constituent of flue gases produced by incomplete combustion of carbon. The highest found was 0.16 per cent in the Millboro Tunnel during trip No. 3. This might be dangerous in half an hour should a train be delayed in the tunnel or happen to stall, but would have no noticeable effect during the two minutes duration of the usual passage. Another sample of the cab air was taken during this trip through the Millboro tunnel, but the glass container was broken in shipment to the laboratory. Four gas samples taken in the Lewis tunnel during trip No. 5 gave 0.11, 0.08, 0.00, and 0.10 per cent carbon monoxide, an average of 0.07 per cent. Samples from four other tunnels gave 0.07 and 0.02 per cent, which is not important. It appears from the analyses that the gas hazard might become considerable in these tunnels only in case a train is delayed or stalled.

PROTECTION FROM SMOKE AND IRRITATING GASES BY MEANS OF POCKET-SIZE GAS RESPIRATORS

As a rule, the difficulty in breathing varies with the smoke, as is shown in columns 24 and 25 of Tables 3 and 4; but this may not always follow when smoke

TABLE 1.- Physical data and situation of tunnels on C. & O. R. R. between Charlottesville, Va., and Hinton, W. Va.

Tunnel No.	Name	Portal approx. miles west of Fort Monroe, Va.	Nearby station	Length, feet	Grade: Feet per mile	Grade: Upward slope, east or west	Height rail to crown, feet (approx.)	Width, feet, (approx.)	Tracks
		A. Tunnels of Mountain District, east to west, Charlottesville to Clifton Forge, Va., 181.4 to 277.7 miles west of Fort Monroe, Va., 96.3 miles.							
1	Greenwood	199.5	At Greenwood	536.	70-75	West	-	-	-
2	Brookville	201	1.5 miles west of Greenwood	864.	70-75	West	15-3/4	13	1
3	Little Rock	202.5	3 miles west of Greenwood	100.	70-75	West	18	13	1
4	Blue Ridge	204.7	2.5 miles east of Basic	4263	68.7	West	18	13-1/2	1
5	Millboro	260.3	0.5 miles west of Millboro	1335	74	East	19-1/3	14	1
6	Lick Run	261.	1.2 miles west of Millboro	389.5	74	East	19-3/4	16	1
7	Masons	262.5	2.7 miles west of Millboro	322.	78	West	18-1/2	14	1
8	Coleman's	271.5	4.6 miles east of Clifton Forge	355.	Level	--	21	18	1
		B. Tunnels of Allegheny District, east to west, Clifton Forge, Va., to Hinton, W. Va., 277.7 to 357.0 miles west of Fort Monroe, Va., 79.3 miles.							
1	Mud	294.1	4.4 miles west of Covington, Va.	641.	60	West	20-3/4	20	2
2	Moore's	300.8	0.6 miles west of Backbone, Va.	321.	60	West	21-1/2	27	2
3	Lake's	301.5	1.3 miles west of Backbone, Va.	727.	60	West	25-2/3	19-1/2	2
4	Kelly's	302.7	0.5 miles east of Jerry's Run, Va.	496.	60	West	25-3/4	19-1/2	2
5	Lewis	304.7	1.8 miles west of Jerry's Run, Va.	4019	60	West	16	14-1/2	1
6	Allegheny	306.9	0.5 miles west of Allegheny, Va.	4736	30	East	19-1/2	26	2
7	White Sulphur	311.3	0.6 miles east of White Sulphur, W.Va.	276	30	East	19-3/4	25-1/3	2
8	Second Creek	327.5	4.7 miles west of Ronceverte, W.Va.	1650	20	East	18-3/4	14-1/2	1
9	Mann's	329.6	68 miles west of Ronceverte, W.Va.	986	20	West	19	26	2
10	Big Bend	348.2	3.0 miles west of Lowell, W.Va.	6478.7	4 [a]	West	18	14	1 [b]
					21 [b]	East			
11	Little Bend	350.	6.0 miles east of Hinton, W.Va.	667.5	21	East	21-3/4	27	2

[a] Churchill ventilating system, blows east to west.
[b] 4 feet per mile west for about 1500 feet in east bend, then 21 feet per mile East for about 2979 feet in west end. Churchill ventilating system, blows west to east.

TABLE 3.- Atmospheric conditions in locomotive cab passing through tunnels of Chesapeake & Ohio R.R., Allegheny District, between Clifton Forge, Virginia, and Hinton, W. Va.
All tests were on locomotive No. 840 which was equipped with air blowers for ventilating the cab.

Name	Trip No.	Direction	Time in tunnel min. (approx.)	Speed miles per hr. (approx.)	Fans on or off	Windows open or closed	Temperature, Degrees F. At position Numbers (a)										Composition of atmosphere in cab, per cent.						Effect on respiration		Remarks
							1	2	3	4	5	6	7	8	Wet bulb	Dry bulb	Carbon dioxide (CO_2)	Carbon oxygen (O_2)	Carbon monoxide (CO)	Hydrogen (H_2)	Methane (CH_4)	Smoke Nitrogen (N_2)			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)
Mud	2	W	1	15	Off	0	-	100	-	-	118	120	-	-	84	-	-	-	-	-	-	-	Some smoke	Not bad	Felt some heat.
Mud	5	W	1-1/2	10	On	C	-	88	-	-	95	73	-	-	-	-	-	-	-	-	-	-	A little smoke	Little	Stoker operated. Smoke filtered in over boiler. Felt little excess heat.
Moore's	2	W	1/2	7	Off	0	-	-	84	-	-	-	-	-	73	-	0.63	20.32	0.02	0.00	0.00	79.03	-		
"	5	W	-	-	Off	C	-	80	94	-	-	94	82	-	-	-	0.14	20.71	0.00	0.00	0.00	79.15	Smoky	Irritating	Stoker operated. Felt some heat.
Lakes	2	W	1	10	Off	-	-	115	100	-	-	-	-	-	-	-	0.40	20.45	0.00	0.00	0.00	79.15	Some smoke	-	Felt hot and humid.
"	5	W	-	-	On	C	-	-	108	-	-	-	-	-	97								Some smoke	-	Curtain up at start, dropped curtain and started fans, smoke left and became cooler.
Kelly's	2	W	1/2	10	Off	-	-	97	94	-	-	106	-	-	86	-	-	-	-	-	-	-	Some smoke	Slight irritation	Little discomfort.
"	5	W	3/4	8	On	C	-	88	-	-	92	82	-	118	-	-	-	-	-	-	-	-	Little "	" "	Cool air. Some smoke near floor.
Lewis	2	W	10	4	Off	0	-	90	66	100	91	99	84	100	-	-	-	-	-	-	-	-	None	None	Cool air. Churchillventilation. No smoke.
							73	86	66	97	91	84	73	108	70	73									
							-	91	68	106	88	97	73	106	-	-									
"	5	W	5	9	On	C	75	100	78	-	-	-	-	-	77	-									
							-	82	-	140	100	86	-	125	-	-	0.48	20.31	0.11	0.00	0.00	79.10	Smoky	Difficult outside of streams from fans.	Churchill blower off. Back curtain was down, smoke entered through cracks. Engineer and fireman cool good air, center of cab hot and stifling. Outside of curtain, air cool.
							-	120	-	150	112	104	-	134	-	-	0.78	19.88	0.08	0.03	0.00	79.23			
							78	130	-	-	124	-	-	135	-	-	0.34	20.54	0.00	0.00	0.00	79.12			
Allegheny	2	W	3	20	Off	0	-	93	80	149	113	100	-	-	-	-	0.84	19.79	0.10	0.00	0.00	20.27			
"	5	W						91	82	-	-	-	-	-	-	-							None	None	No discomfort.
White Sulphur	2	W	2-3/4	25	Off	0	-	92	-	-	110	90	-	-	-	-									
"	5	W	1/6	20	Off	0	-	-	-	-	-	-	-	-	-	-							Little	None	"
Second Creek	1	E	1/6	20	Off	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	None	None	
"	2	W	2	9	Off-Right closed, left open	-	-	95	-	149	109	109	-	-	-	-	-	-	-	-	-	-	None	None	Time to short to determine temperature change. No discomfort.
							93	115	94	-	-	-	-	-	102	110	0.60	20.23	0.00	0.00	0.00	79.17	Medium thick	Choking	Hot and stifling.
"	5	W	1-1/3	15	Off	-	-	88	87	-	-	-	-	-	-	-	0.70	20.16	0.00	0.00	0.00	79.14			
							-	-	100	116	-	-	-	-	88	-	0.38	20.50	0.00	0.00	0.00	79.12	Light	Little	Warmer.
Mann's	1	E	1	11	On	C	-	95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Dense	-	Not very hot. After entering tunnel, fans drove smoke out
"	2	W	1	10	Off-Right closed, left open	-	-	95	-	-	118	97	-	-	-	-	-	-	-	-	-	-			
					Off	0	-	99	-	-	126	-	-	-	-	-	-	-	-	-	-	-	Light	None	
"	5	W					-	90	82	-	-	-	-	-	-	-	-	-	-	-	-	-			
Big Bend	1	E	-	25	Off	0	-	90	66	140	-	-	74	126	77	-	-	-	-	-	-	-	Light	Little	Not much discomfort.
			12	6	Off	0	-	84	-	-	102	-	-	-	-	-	-	-	-	-	-	-			
"	2	W	10-1/2	7	On thru last 1/2	0	73	80	70	82	80	77	72	91	-	-	-	-	-	-	-	-	Not noticeable	None	No discomfort.
							77	82	70	86	86	84	75	93	72	74							None	None	Churchill ventilation, no smoke.
							80	86	74	87	89	87	78	95	-	-									
"	5	W	4	18	On	C	-	89	-	-	-	-	-	158	-	-	0.77	19.97	0.00	0.00	0.00	79.26	Dense and hot	Choking	Fans were started when about 1/2 way through.
							-	113	120	158	-	-	-	158	107	-	0 60	20.27	0.02	0.00	0.00	79.11			
							-	122	130	140	-	-	-	145	-	-									
							-	-	82	120	100	80	-	-	-	-	0.22	20.73	0.00	0.00	0.00	79.05	Some smoke	Not very bad	
Little Bend	1	E	2	4	Off	0	-	112	-	-	112	90	-	130	100	122	0.55	20.27	0.02	0.00	0.00	79.16			
							64	122	-	-	-	-	-	135	-	-	0.94	19.82	0.04	0.00	0.00	79.20			Moisture condensed heavily. Fans delivered good cool air.
							70	107	92	147	113	104	74	140	82	94	0.28	20.52	0.00	0.00	0.00	79.20	Light	Slight irritation	Before entering tunnel temperatures were 97 to 131°.

(a) Thermometer positions were as follows: (1) In blower pipe, engineer's side; (2) By engineer, 2' from window, 3' from boiler, 4' above floor; (3) 4' above roof of cab, 1' in advance of rear edge; (4) Hanging from cab roof, 6' above floor, 18" from buckboard, 3' from boiler; (5) By fireman, 2' from window, 4' from boiler, 5' above floor; (6) Above fireman's seat, 2" from left side of cab, 2' from boiler, 3' above floor; (7) In blower pipe, fireman's side; (8) 2' left of middle of cab, 1-1/2' from boiler face, 5-1/2' above floor.

TABLE 4.- Atmospheric conditions in locomotive cab passing through tunnels of Chesapeake & Ohio R.R., Mountain District, between Charlottesville, Va. and Clifton Forge, Va.

Trip 3 was on locomotive 840 which was equipped with air blowers for ventilating the cab; trip 4 was on locomotive 780, without blowers.

Name of tunnel	Trip No.	Direction	Time in tunnel, min (approx.)	Speed, miles per hour (approx.)	Fans on or off	Windows open or closed	Temperature, degrees F. at position numbers.[a]								Composition of atmospheres in cab, per cent								Remarks
							1	2	3	4	5	6	7	8	Wet bulb	Dry bulb	Carbon dioxide (CO_2)	Oxygen (O_2)	Carbon monoxide, (CO)	Hydrogen (H_2)	Methane (CH_4)	Nitrogen (N_2)	Smoke	Effect on respiration	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Greenwood	3	E	1/2	15	Off	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Little	Little	Temperature and smoke increased slightly.
Greenwood	4	W	3/4	10	Off	C	-	76	73	115	84	93	-	106	-	-	1.08	19.63	0 00	0.00	0.00	79.29	Smoky	Choking	Some increase in temperature.
																	0.47	20.34	0.00	0.00	0.00	79.19			
Brockville	3	E	3/4	15	Off	-	-	-	-	-	-	-	-	-	-	-	0.05	20.93	0.00	0.00	0.00	79.02	Little	Little	
Brockville	4	W	1/2	20	Off	C	-	100	110	-	-	-	-	-	93	93	0.49	20.39	0.02	0.00	0.00	79.11	Smoky	Choking	Hot
Little Rock	3	E	1/6	12	Off	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	None	None	Too short for smoke or temperature to to increase.
Little Rock	4	W	-	-	Off	C	-	-	-	-	-	-	-	-	-	-							Little	Little	--
Blue Ridge	3	E	3	17	Off	1/2 C	-	94	84	126	106	98	-	130									None	None	Steam off. No excess heat or smoke.
								100	84	-	-	-	-	-	73	95	0.06	20.93	0.00	0.00	0.00	79.01			
Blue Ridge	4	W	3-1/2	15	Off	C	-	90	-	-	90	110	-	125	-	-	0.84	20.06	0.06	0.00	0.00	79.04	Heavy	Difficult	Hot and smoky. Pocket respirators used
								108	90	-	108	122	-	136	-	-	0.70	20.17	0.00	0.00	0.00	79.13	Smoke	by two men gave complete protection.	
								110	-	-	-	-	-	-	95	108	-	-	-	-	-	-			
								115	-	-	-	-	-	-	-										
Millboro	3	E	2	8	On at latter part	C	-	90	-	122	119	-	-	-	-	-	0.44	20.34	0.16	0.02	0.00	79.04	Exceedingly smoky	Highly irritating	Very hot, foggy. One man used pocket gas respirator without difficulty. Fans were started toward end, engineer and fireman cool, those in center of cab felt some cooler but still hot and smoky.
Lick Run	3	E	1/5	23	Off	0	-	88	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
Mason's	3	E	1/4	15	Off	0	-	88	-	-	-	-	-	-	-	-	0.63	20.29	0.00	0.00	0.00	79.08	Little	Little	Some heat.
Coleman's	3	E	1/5	25	Off	0	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	--	Before entering temperatures were 64, to 100°F.
																							None	None	No increased temperature.

[a] Thermometer positions were as follows: (1) In blower pipe, engineer's side; (2) By engineman, 2 feet from window, 3 feet from boiler, 4 feet above floor; (3) 4 inches above roof of cab, 1 foot in advance of rear edge; (4) Hanging from cab roof, 6 feet above floor, 18 inches from buckboard, 3 feet from boiler; (5) By fireman, 2 feet from window, 4 feet from boiler, 5 feet above floor; (6) Above fireman's seat, 2 inches from left side of cab, 2 feet from boiler, 3 feet above floor; (7) In blower pipe, fireman's side; (8) 2 feet left of middle of cab, 1-1/2 feet from boiler face, 5-1/2 feet above floor.

is light and much irritating sulphur dioxide gas is evolved with the flue gas. The writers used commercially manufactured pocket-size respirators for smoke and gas[6] when excessive irritation and difficult breathing were encountered. The worst condition was in the Millboro tunnel during trip No.3, but the respirators entirely eliminated the irritation and difficulty in breathing. These respirators were of a type having low resistance to passage of air, the resistance being one inch of water at an air-flow of 85 liters per minute (4 inches is considered a tolerable maximum in gas masks). Difficulty has been found in breathing through gas respirators of higher resistance when in hot atmospheres in tunnels of the Union Pacific Railroad[7], but no difficulty was experienced in breathing through the respirators with one inch resistance.

TEMPERATURES IN THE CABS

Especial attention was devoted to the determination of temperatures at different positions in the cab. Mercury or alcohol thermometers were used. The positions, specified exactly at the bottom of Tables 3 and 4, were taken to represent the temperatures as follows:

Position 1.- Air in the discharge pipe from the blower on engineman's side (column 6 of Tables 3 and 4) states whether the fan was blowing air.

2.- Beside engineman, inner side.

3.- Above roof of cab. Thermometer was attached horizontally to an ⌐ shaped stick, weighted on the bottom, which hung on a catch at the rear edge of the roof; the horizontal stem was directed forward. It was taken down to read the temperature.

4.- Under middle of roof near backboard.

5.- Beside fireman, inner side.

6.- Beside fireman, next to window, nearly over blower pipe.

7.- Air in the discharge pipe from the blower, fireman's side.

8.- Near boiler, man high (say 6 feet) left of center.

9.- Outer surface of boiler lagging. This was determined by hanging a thermometer against the boiler and loosely covering the bulb with suspended waste. Temperatures were not read while in the tunnels, so the records of position 9 are omitted from Tables 3 and 4. Outside of tunnels the temperatures varied from 170 to 193° F., usually dropping with the steam pressure.

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[6] Fieldner, A.C., Katz, S.H., and Kinney, S.P., Work cited.

[7] Kinney, S.P., work cited.

TABLE 5.- Average of temperatures observed at different positions in locomotive cab.

NOTE: The number of observations included in each average is indicated by subscripts

Position of thermometer		Location of locomotive						
		Passing through tunnels			Running outside of tunnels[a]	Standing still		
		General average, °F.	Blowers not operating, °F.	Blowers operating °F.	Blowers not operating, °F.	General average °F.	Blowers not operating, °F.	Blowers operating, °F.
(1)	In engineer's air pipe	$76_{(9)}$	$77_{(7)}$	$71_{(2)}$	$59_{(3)}$	$81_{(6)}$	$81_{(5)}$	$80_{(1)}$
(7)	In fireman's air pipe	$76_{(9)}$	$76_{(7)}$	$--_{(0)}$	$72_{(4)}$	$82_{(6)}$	$82_{(5)}$	$82_{(1)}$
(2)	Inby engineer	$97_{(47)}$	$94_{(35)}$	$104_{(12)}$	$90_{(5)}$	$94_{(6)}$	$93_{(5)}$	$100_{(1)}$
(5)	Inby fireman	$103_{(27)}$	$102_{(19)}$	$104_{(8)}$	$106_{(5)}$	$101_{(6)}$	$101_{(5)}$	$105_{(1)}$
(6)	Outby fireman	$94_{(25)}$	$98_{(18)}$	$85_{(7)}$	$85_{(5)}$	$94_{(6)}$	$90_{(5)}$	$115_{(1)}$
(8)	Near boiler, man high	$123_{(22)}$	$113_{(12)}$	$136_{(10)}$	$116_{(5)}$	$117_{(6)}$	$116_{(5)}$	$122_{(1)}$
(4)	Under middle of roof near backboard	$123_{(19)}$	$116_{(14)}$	$142_{(5)}$	$131_{(5)}$	$123_{(6)}$	$124_{(5)}$	$118_{(1)}$
(3)	Above roof	$87_{(28)}$	--	--	$70_{(4)}$	$85_{(6)}$	$85_{(6)}$	$85_{(1)}$

a No observations were made with blowers operating.

Wet and dry bulb temperatures to indicate the humidity recorded in columns 16 and 17 of Tables 3 and 4 were determined by a man facing the boiler and standing on the apron between the locomotive and tender, or in the center of cab and swinging a Bureau of Mines sling psychrometer. The highest temperature noted on the wet-bulb thermometer towards the end of the passage through the tunnels is recorded, but since 5 to 6 minutes are needed for exact indications by wet-bulb thermometers even in a non-varying atmosphere, and the time was frequently shorter, the wet-bulb temperatures recorded are usually low. The dry-bulb thermometers were read following the wet bulb. Dry-bulb temperatures were not recorded in some instances, when difficulty in reading the wet-bulb thermometer consumed time after leaving the tunnels, during which the dry bulb changed.

Temperatures at positions 1 to 8 were observed soon after entering the tunnels allowing some time for thermometers to change. They were usually taken in serial order, sometimes reversing the order and sometimes omitting some positions. Records were made as rapidly as possible, and the round was repeated whenever time in the tunnel allowed. The temperatures indicated can be considered only approximations because of the lag of thermometers. Higher temperatures are usually indicated on each succeeding round. The many blanks and the lack of more temperature records are due to the difficulty of reading thermometers. Vision was difficult because of the darkness, smoke, and sometimes considerable eye irritation. A flash-light was used, but it was frequently impossible to read the temperatures. For instance: in the Millboro tunnel on trip No. 3, after the first three observations no temperatures could be read, although repeated attempts were made.

Figures 3 and 4 show graphically all the temperatures at each position in the cab for trips westward and eastward, respectively.

All temperatures determined at each cab position are grouped together, each observation being placed according to the serial order of the round of observations, so that those made at one time occupy corresponding points on the graph. Figures 5 and 6 are similar to Figures 3 and 4, but indicate temperatures outside of tunnels when the locomotives are hauling trains and when standing still. The figures show the wide differences at different times in any one position; however, they all show a general increase in the temperatures in the cab with the height above the floor. In Table 5 the average temperatures at each position are given. Contrary to expectation, the table shows no important differences in temperatures whether in tunnels, running outside of tunnels, or standing still. The highest average is 142 degrees at position 4, just under the cab roof, representing the temperatures while in tunnels, with blowers operating. Temperatures at the positions near the engineman and fireman average about 100°F., whether in or out of tunnels. Since the physiological effects are not represented by the temperature alone,[8] the decrease in comfort while in the tunnels must be due to the greatly increased humidity together with air movement; it has been determined[9] that when temperatures of humid air exceed body temperature, any air motion increases the dis-

[8] McConnell, J.W., and Sayers, R.R. Some effects on Man of high temperatures. U. S. Department of Interior, Bureau of Mines Report of Investigation, Serial No. 2584, March, 1924.

Kinney, S.P. work cited.

[9] McConnell, J.W., Houghton, F.C., and Yaglaglou, C.P., Air motion - high temperatures and various humidities-reactions on human beings: Jour. Am. Soc. Heat. & Ventl. Eng., vol. 30, March 1924, pp 199-224.

comfort. It is unfortunate that more determinations of wet-bulb temperatures were not secured. However, a few records in Table 3 of 97 to 107° F. wet bulb show that sometimes the humidity is high enough to cause much discomfort.[10]

Since the stack gases which enter the cab do not increase the temperatures to a noticeable extent, it would seem feasible to reduce the temperatures by increasing the boiler lagging. The smoke deflector, which causes the exhausts to stream backward over the cab without mixing with the tunnel air has been found especially good.

SUMMARY AND CONCLUSIONS

Temperatures have been observed in cabs of freight locomotives in tunnels of the Chesapeake & Ohio Railroad in Virginia and West Virginia to determine the source of the severe discomfort felt from high temperatures experienced by enginemen and firemen while in tunnels.

The temperatures in the cab were found to increase with the height above the floor, the highest temperature of 158° F. being observed just under the middle of the roof of the cab.

Blowers were tried, these taking air from a point about two feet above the center of the track and introducing it through pipes, in streams directed upon the positions of the engine crew. The direct streams added some to their comfort, but the turbulence of the air in the cab was greatly increased so that the air impinged upon the boiler surface and became heated, with the result that outside of the direct streams no increase in comfort was felt, and sometimes the discomfort increased.

The temperatures of the mixture of exhaust gases and tunnel air above the roof of the cab were found much below those in the cab. High temperatures of exhaust gases entering the cab had previously been suspected of being the cause of the excessive heat felt, but this can not be true in the tunnels investigated. Rather the increased humidity of the cab air, while in the tunnels, due to the entrance of exhaust steam with the stack gases, seems to cause the discomfort.

Discomfort through heat may be lessened by increasing the lagging on the parts of the boiler exposed in the cab, and by means of the smoke deflector as used by the Union Pacific Railroad, which causes exhaust gases to stream backward over and away from the cab.

The tests described were undertaken through the arrangement of J. J. Ewing, engineer of tests, for the C. & O. R. R., to whom the writers are greatly indebted.-Reports of Investigation, Department of the Interior, Bureau of Mines.

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[10] Sayers, R. R., and Harrington, D., Physiclogical effect of high temperatures and humidities with and without air movement: Bureau of Mines, Report of Investigations No. 2464, April 1923.

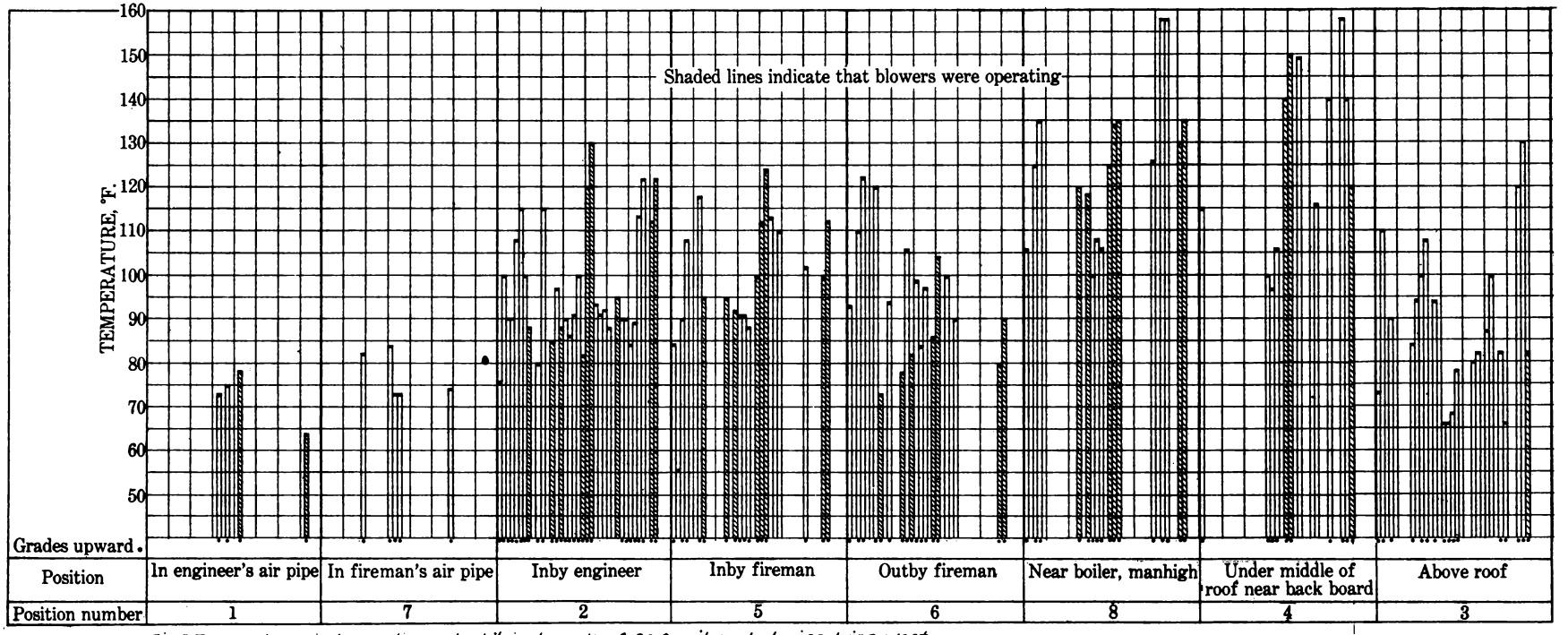
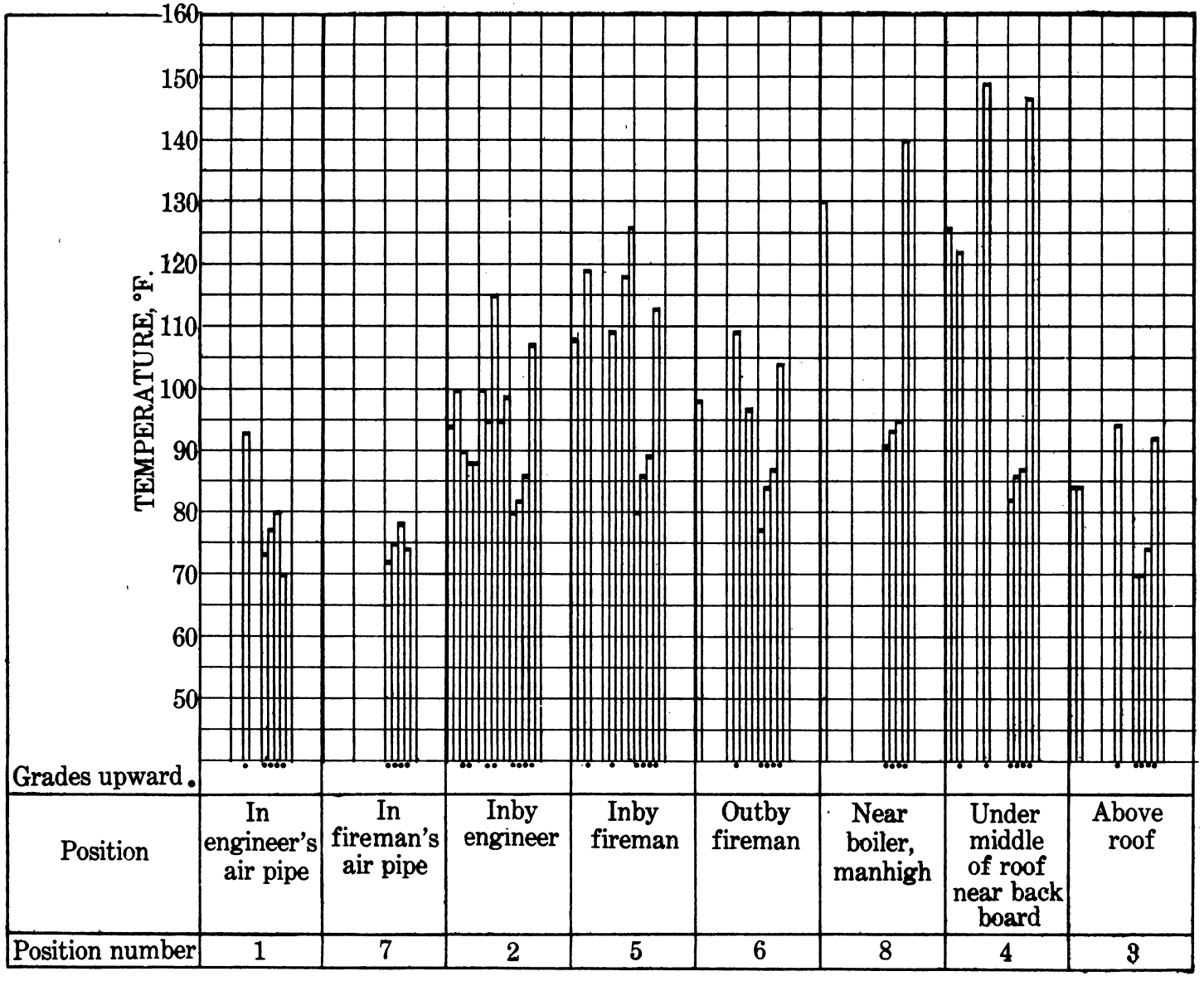


Fig. 3 Temperatures in locomotive cab while in tunnels of C. & O. rail road during trips west



Position	In engineer's air pipe	In fireman's air pipe	Inby engineer	Inby fireman	Outby fireman	Near boiler, manhigh	Under middle of roof near back board	Above roof
Position number	1	7	2	5	6	8	4	3

Fig. 4 Temperatures in locomotive cab while in tunnels of C. & O. rail road during trips east.

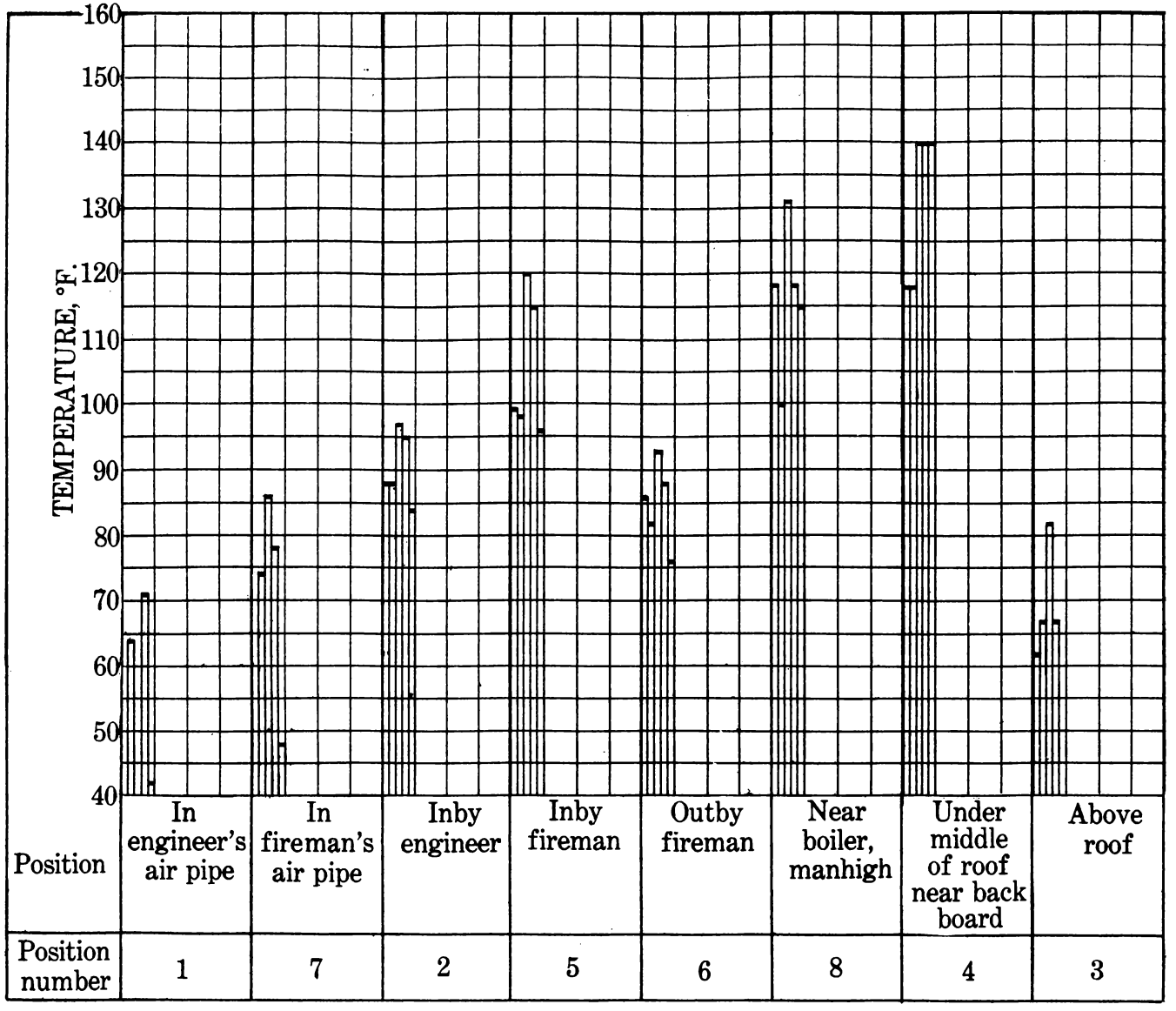


Fig. 5 Temperatures in cab of moving locomotive when outside of tunnels

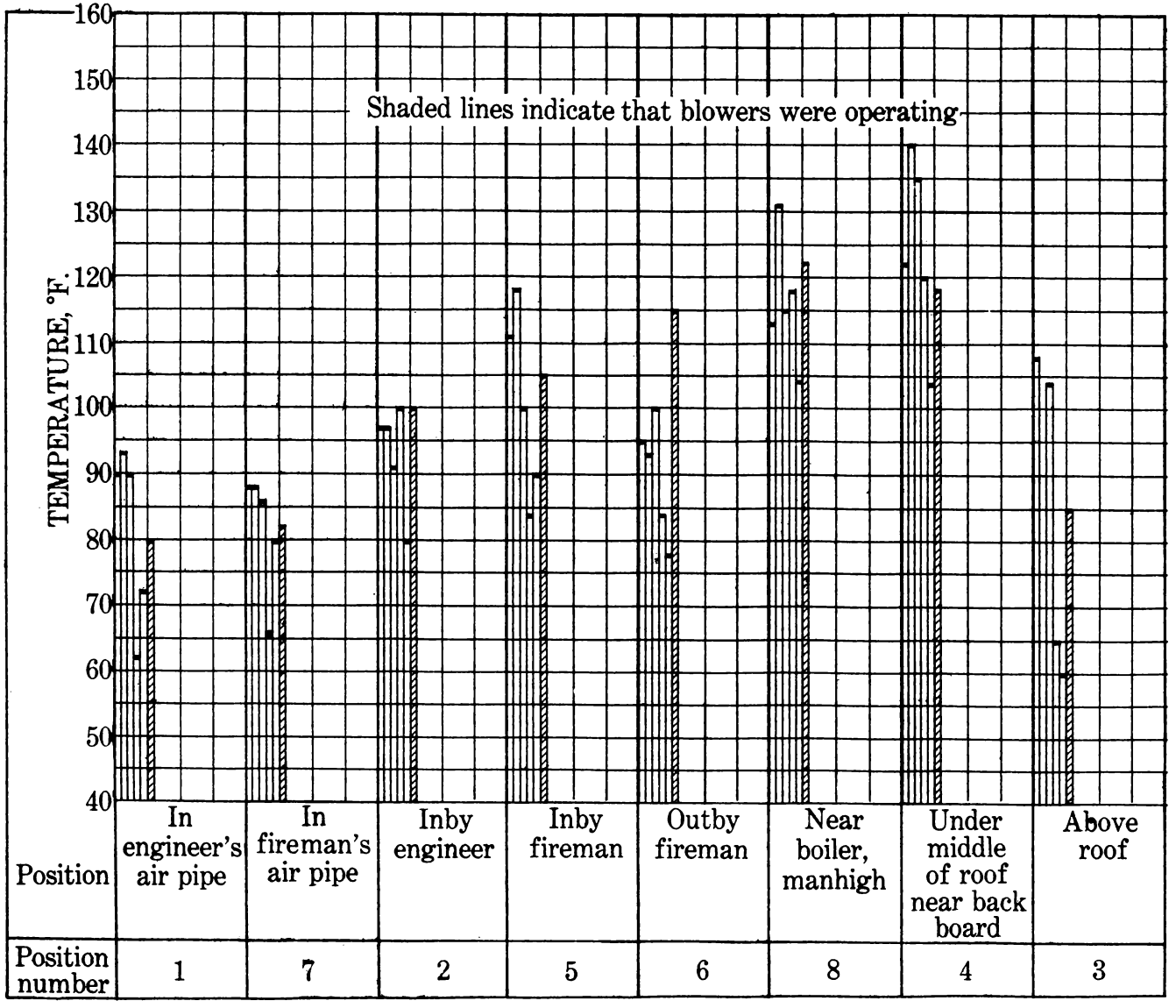


Fig.6 Temperatures in locomotive cab when standing still