THESIS

A STUDY OF VENTILATION
OF ENCLOSED MOTORS

H. L. BUNTING   E. L. KARKAU

1920

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Motors

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A STUDY OF VENTILATION OF ENCLOSED MOTORS.

A Thesis Submitted to

The Faculty of

MICHIGAN AGRICULTURAL COLLEGE

By

H. L. Bunting + E. L. Karkau

Candidates for the Degree of

Bachelor of Science.

June, 1920.

THESIS

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P R E F A C E.

Installations of totally enclosed motors as well as box enclosed motors are so built fundamentally for fire protection.

A typical example of dust laden atmosphere harmful to motors, is a flour mill. Flour dust in these mills collects on the motors forming a caking on the windings. This in turn hinders the radiating power of the stator, causes the motor to overheat, and has been the cause of many disastrous fires.

Fire-protection broadly speaking, means the abolishing of the causes that originate fire, and secondly, the providing means which confine fire to the space in which it originates.

In motors, the first is fulfilled by enclosing the motor so that nothing but clean air comes in contact with it. The second protection, if the motor should burn out from an overload, is gotten by building the enclosure of asbestus lumber, thus confining the fire.

These small enclosures as advocated by mill insurance inspectors, require ventilation to keep from running hot, and in this thesis, we have chosen the study of ventilation obtained by natural pipe draft.

Procedure: The ventilation tests were carried on with a 5 H.P. 60 cycle 220 volt induction motor, and a 10 H.P. 60 cycle 110 volt induction motor.

The first test was made by running the motor at full load belted to a D. C. generator. The K. W. input was held constant by two wattmeters in the three phase circuit, and was kept at 4.8 K.W. on the 5 H.P., and 8.3 K.W. on the 10 H.P. machine.

$$\frac{5 \times 746}{.78} = 4.8 \text{ K.W.}$$

$$\frac{10 \times 746}{.90} = 8.3 \text{ K.W.}$$

This test was run unenclosed, and gave us the ultimate temperature rise as 25° C on the 5 H.P. and 30° C on the 10 H.P. motor.

Enclosing the motor in a wall board box with no inlet or outlet, a curve of very rapid temperature rise was obtained. In less than two hours the temperature passed the safe limit at which a motor should be run.

To ventilate such an enclosure, an inlet pipe and a variable height outlet pipe were put on the box (See Fig. 1), and tests run till the air drawn thru the enclosure by the exhaust head was sufficient to let the motor run at a constant safe temperature.

Co

Problems met in Thesis.

To get the temperature of the stator coils, a study was made of electrical temperature recording devices. As none were at hand in the department and the building of a fairly accurate electrical thermometer is a thesis in itself, we decided to use a two foot 100° C mercury thermometer. A putty pad was placed on the outside stator coils under which the thermometer was placed for registering the coil temperature. The length of the thermometer enabled us to read the scale outside of the enclosure.

The 10 H.P. machine as received by us was connected for a 2 phase 220 volt circuit. The motor had 48 slots, 6 coils in series and was connected series delta. Having 48 slots we recut the stator, putting 4 coils in series and reconnected it into a parallel star. This gave a three phase four pole 110 volt machine.

To have a steady load on the D. C. generator, we built a water barrel reostat of large enough capacity. It consisted of a cast iron plate at the bottom of the barrel and another plate suspended at a variable height above it, both being immersed in a weak salt solution.

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The anemometer used in measuring the velocity of air going thru the enclosure was calibrated by running around a toy track for a definite time. This actual velocity was then plotted against the dial reading and gave a straight line function from which to read correct velocities. (See Curve 1.).

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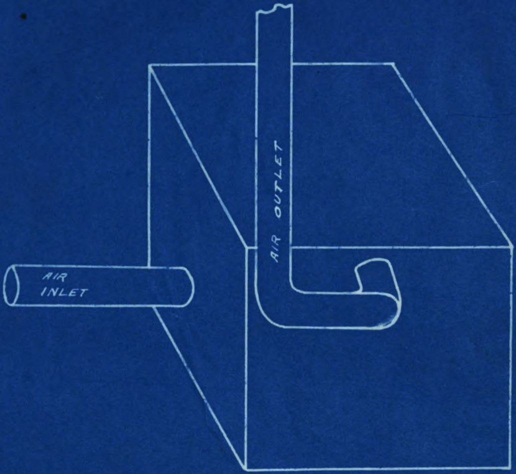
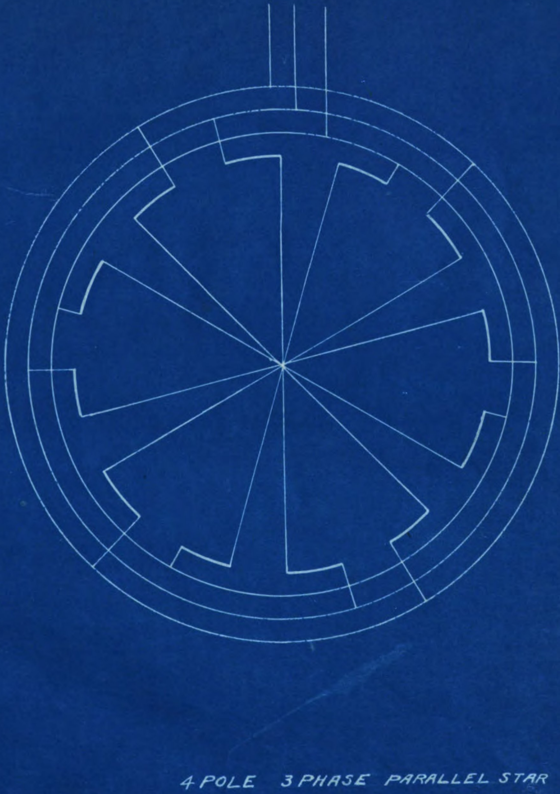


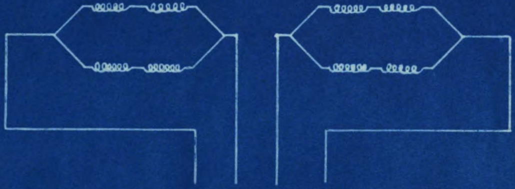
DIAGRAM SHOWING PIPING FOR VENTILATION
USED IN TESTS.

FIG 1

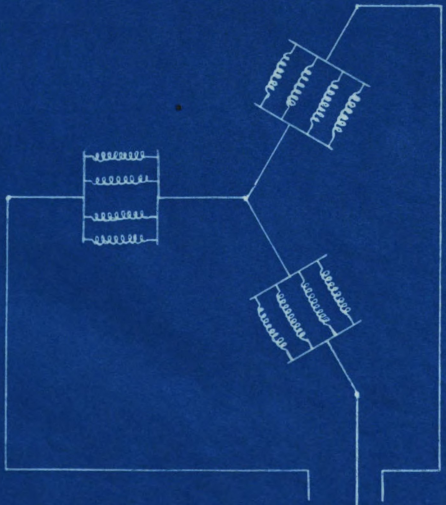


4 POLE 3 PHASE PARALLEL STAR

FIG 2



4 POLE 2 PHASE SERIES DELTA

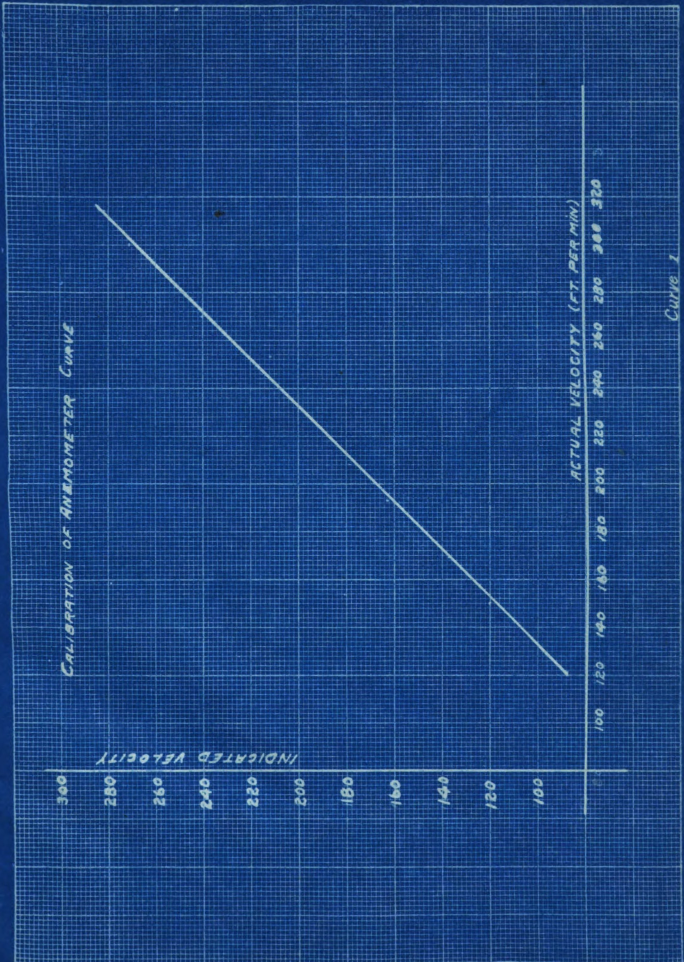


4 POLE 3 PHASE PARALLEL STAR

FIG 3

Calibration of Anemometer Data.

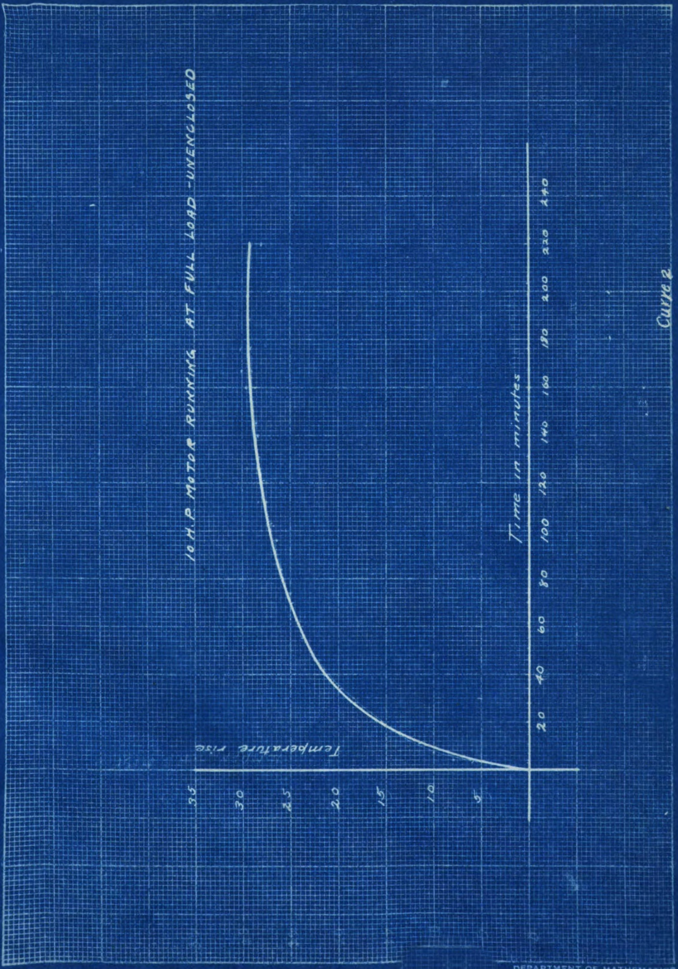
Dial Reading	Times around track.	Distance in feet.	Time in Seconds.	Actual Velocity	Dial Velocity.
110	6	135	48	168.7	137.5
119	6	135	32	253.0	212
140	7	157.5	35	270	240
203	10	225	45	300	271
202	10	225	43	314	282
194	10	225	65	208	179
190	10	225	70	193	163
180	10	225	90	150	120
164	10	225	112	120.5	88


CALIBRATION OF ANEMOMETER CURVE
ACTUAL VELOCITY (FT. PER MIN)
100 120 140 160 180 200 220 240 260 280 300 320
INDICATED VELOCITY
100 120 140 160 180 200 220 240 260 280 300
Curve 1

Test run on 10 H.P. Motor to get its temperature rise, Motor running at full load and unenclosed.

Time of Test.	Number of Min.	Temp. of Motor °C.	Temperature rise °C.
1:20	0	24	0
1:23	3	30	6
1:24	4	32	8
1:27	7	34	10
1:31	11	35.5	11.5
1:35	15	37.5	13.5
1:40	20	39.5	15.5
1:48	28	42.25	18.25
1:54	34	43.75	19.75
2:00	40	45.5	21.5
2:06	46	46.5	22.5
2:11	51	47	23.
2:15	55	47.75	23.75
2:21	61	48.25	24.25
2:30	70	48.75	24.75
2:34	74	49	25.
2:44	84	50	26.
2:56	96	50.5	26.5
3:02	102	50.75	26.75
3:03	103	51.	27.
3:12	112	51.5	27.5
3:21	121	51.75	27.75
3:31	131	52.25	28.25
3:40	140	52.4	28.4
3:45	145	52.5	28.5
4:00	160	52.5	28.5
4:07	167	53.	29.
4:16	176	53.1	29.1
4:31	191	52.4	29.4
4:39	199	52.5	29.5
4:43	203	52.3	29.3
5:00	220	51.	28.

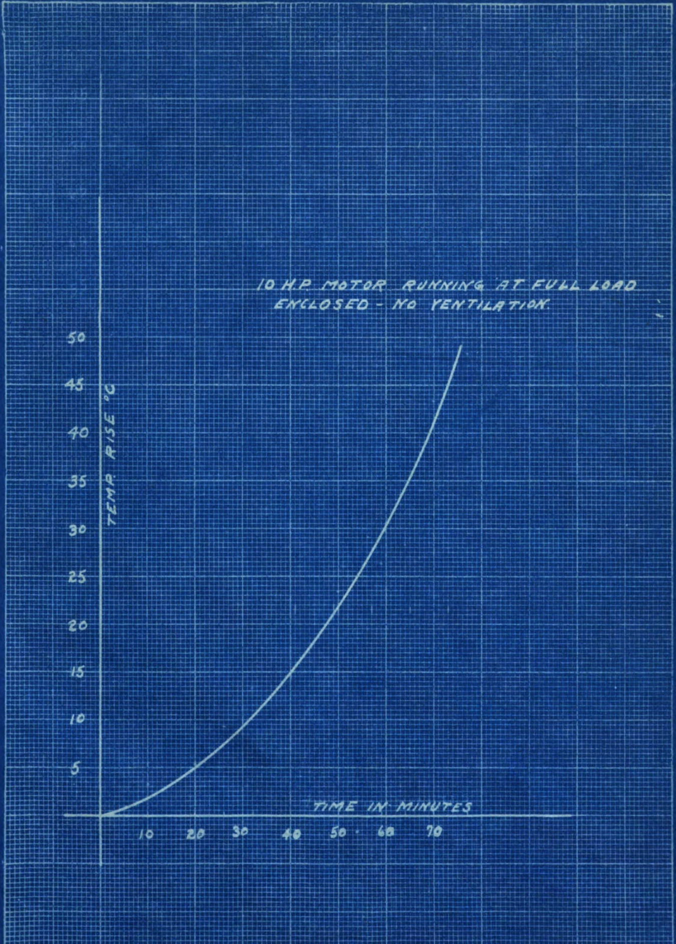
Final room temperature 23 °C.


10 H.P MOTOR RUNNING AT FULL LOAD - UNENCLOSED
Time in minutes
20 40 60 80 100 120 140 160 180 200 220 240
Temperature rise
5 10 15 20 25 30 35
Curve 2

Test on 10 H.P. Motor to get a curve of temperature rise when motor is enclosed in wall board box with no ventilation.

Time of Test.	No. of Minutes.	Temp. of Motor $^{\circ}$C.	Temp. rise $^{\circ}$C.
2:08	0	24.6	0
2:18	10	28	3.4
2:28	20	30	5.4
2:34	26	34	9.4
2:40	32	38	13.4
2:58	50	48	23.4
3:07	59	51	26.4
3:12	64	53	28.4
3:18	70	68	43.4
3:25	77	73	48.4

Box of wall board, 30 x 26 x 24 (high).

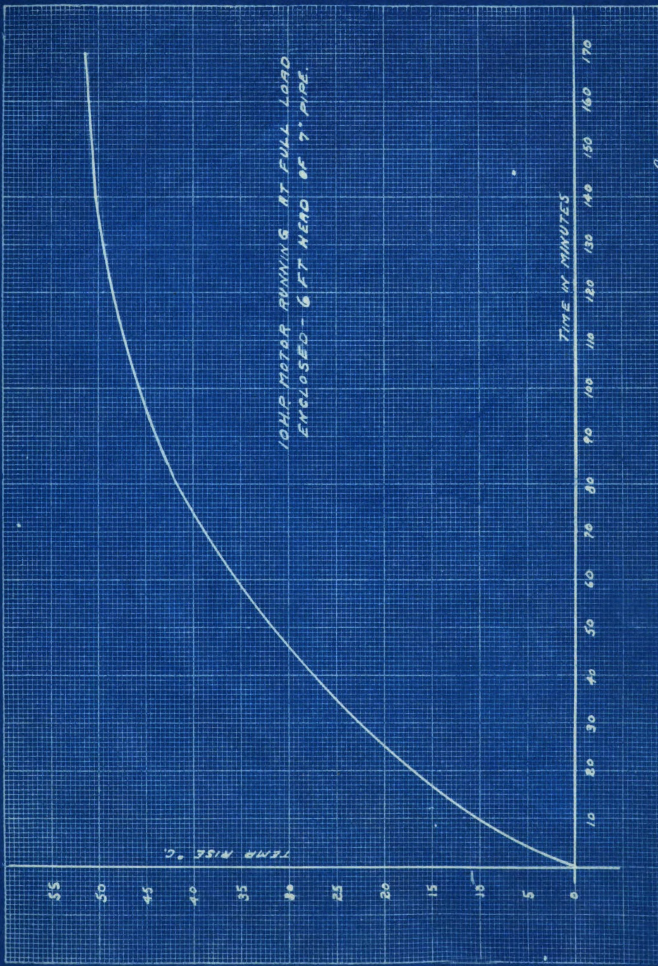

10 H.P. MOTOR RUNNING AT FULL LOAD
ENCLOSED - NO VENTILATION
TEMP. RISE °C
50
45
40
35
30
25
20
15
10
5
TIME IN MINUTES
10
20
30
40
50
60
70

Curve 3

Test on 10 H. P. Motor to get temperature rise curve when motor is enclosed b[illegible] ventilated. Height of head on enclosure was 6 ft. of 7" pipe; intake was a pipe of the same dimensions, 2 ft. long. Whole test carried on inside of the building.

Time of Test.	No. of Minutes.	Motor Temp.	Room Temp.	Temp. rise.	Velocity of air in intake feet per minute. Dial.	Velocity of air in intake feet per minute. Actual.	Volume of air thru intake, dubic feet.
2:10	0	20.05	20.05	0			
2:20	10	31.0	20.15	10.85			
2:30	20	34.5	20.3	14.2			
2:40	30	44.	20.55	23.45			
2:50	40	48.	20.06	27.4			
3:00	50	55.	20.06	34.4			
3:10	60	56.3	21.	35.3			
3:20	70	60.	21.2	38.8	140	163	37.6
3:30	80	62.3	21.3	41.	165	198	45.6
3:40	90	65.5	21.4	44.1	170	201	46.3
3:50	100	67.	21.6	45.4	195	228	52.5
4:00	110	68.5	21.75	46.75	185	218	50.2
4:10	120	71.5	22.	49.5	200	233	53.7
4:20	130	71.5	22.15	49.35	195	228	52.5
4:30	140	72.5	22.4	50.1	210	235	54.2
4:40	150	72.8	22.6	50.2	190	223	51.4
4:50	160	73.8	22.8	51.	190	223	51.4
5:00	170	74.	22.8	51.2	190	223	51.4

Average Temperature rise of air in exhaust pipe found to be 40° C.


10 H.P. MOTOR RUNNING AT FULL LOAD
ENCLOSED - 6 FT HEAD OF 7" PIPE.
TIME IN MINUTES
TEMP. RISE °C.
Curve 4
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170
0 5 10 15 20 25 30 35 40 45 50 55

Test on 10 H.P. Motor to get temperature rise curve when motor is enclosed but ventilated.
Height of head on enclosure was 11 ft. of 7" pipe (10 ft. of pipe on the outside of building).

Time of Test.	No. of Minutes.	Motor Temp.	Room Temp.	Temp. Rise.	Velocity of air in intake feet per minute. Dial.	Actual.	Volume of air thru intake, cubic ft.
2:00	0	21.25	21.25	0	0	0	0
2:10	10	32.	21.55	10.45	130	163	37.6
2:20	20	36	21.6	14.40	145	178	41.
2:30	30	40.5	21.6	18.90	155	188	43.3
2:40	40	45.	21.7	23.3	210	232	53.5
2:50	50	49.	22.05	26.95	190	223	51.4
3:00	60	55.5	22.3	33.2	210	232	53.5
3:10	70	56.	22.65	33.35	185	218	50.3
3:20	80	58.	22.9	35.1	210	242	55.8
3:30	90	60.	23.	37.	200	233	53.7
3:40	100	62.7	23.3	39.4	200	233	53.7
3:50	110	64.	23.5	40.5	220	252	58.1
4:00	120	64.6	23.7	40.9	240	272	62.7
4:10	130	65.2	23.8	41.4	205	239	55.1
4:20	140	66.3	23.6	42.7	200	233	53.7
4:30	150	67.8	23.6	44.2	185	218	50.3
4:40	160	67.8	23.6	44.2	210	242	55.8
4:50	170	67.8	23.5	44.3	200	233	53.7
5:00	180	69.6	23.55	46.05	220	252	58.1
5:10	190	70.3	23.6	46.7	210	243	56.1

The Temperature rise of air in exhaust pipe was assumed from one reading to be 30° C.

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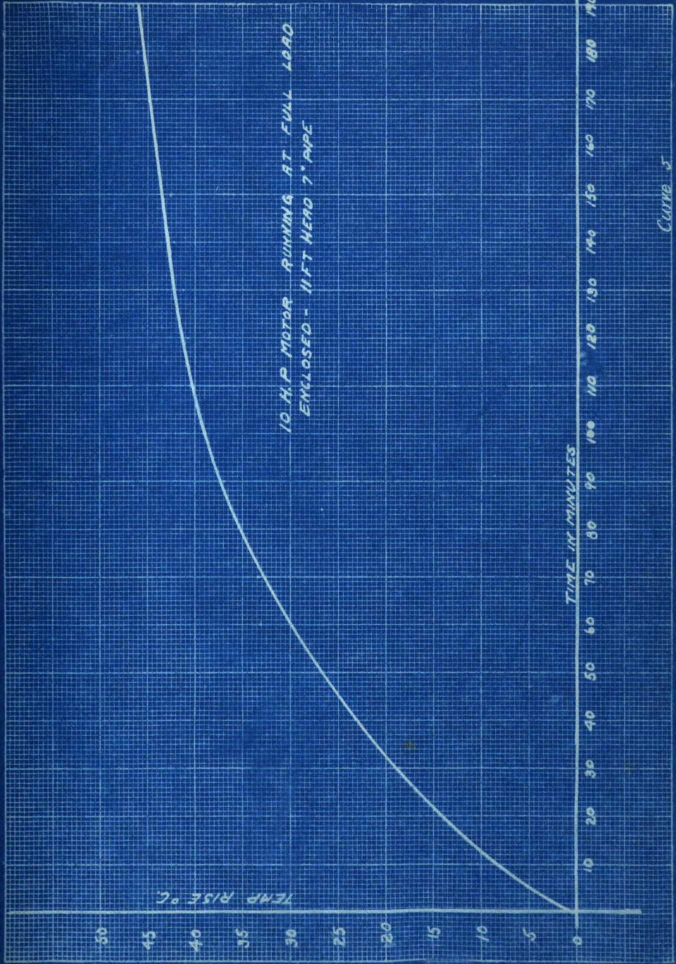

DEPARTMENT OF MATHEMATICS

Test on 10 H.P. Motor to get temperature rise curve when motor is enclosed but ventilated. Height of head on enclosure was 20 ft. of 7" pipe (18 ft. of pipe on the outside of building).

Time of Test.	No. of Minutes.	Motor Temp.	Room Temp.	Temp. rise.	Velocity of air in intake feet per minute. Dial	Actual.	Volume of air thru intake, cubic feet.
1:55	0	22.1	22.1	0	110	143	30.9
2:05	10	32.	22.1	10.1	290	264	53.7
2:15	20	38.5	22.2	16.3	240	274	62.7
2:25	30	43.5	22.2	21.3	245	277	63.8
2:35	40	47.	22.1	24.9	250	282	65.
2:45	50	50.2	22.2	28.	255	286	66.
2:55	60	53.	23.	30.	225	258	59.3
3:05	70	55.3	23.	32.3	255	286	66.
3:15	80	58.2	23.	35.2	245	277	63.8
3:25	90	59.	23.1	35.9	260	292	67.3
3:35	100	61.	23.1	37.9	230	262	60.4
3:45	110	64.5	23.3	41.2	260	292	67.3
3:55	120	66.	23.2	42.8	255	286	66.
4:05	130	68.6	23.1	45.5	280	312	72.
4:15	140	70.5	23.1	47.4	265	297	68.2
4:25	150	70.5	23.	47.5	290	320	74.2
4:35	160	70.3	23.1	47.2	310	340	76.5
4:45	170	69.4	23.1	46.3	290	320	74.2
4:55	180	70.	23.1	46.9	275	307	69.8
5:05	190	69.7	23.15	46.55	250	282	65.
5:15	200	70.6	23.25	47.35	230	262	60.4
5:25	210	71.5	23.5	48.	230	262	60.4
5:35	220	71.9	23.7	48.2	220	252	58.1
5:45	230	71.4	23.8	47.6	240	272	62.7

The temperature rise of air in pipe was assumed as 18° C. from one reading.

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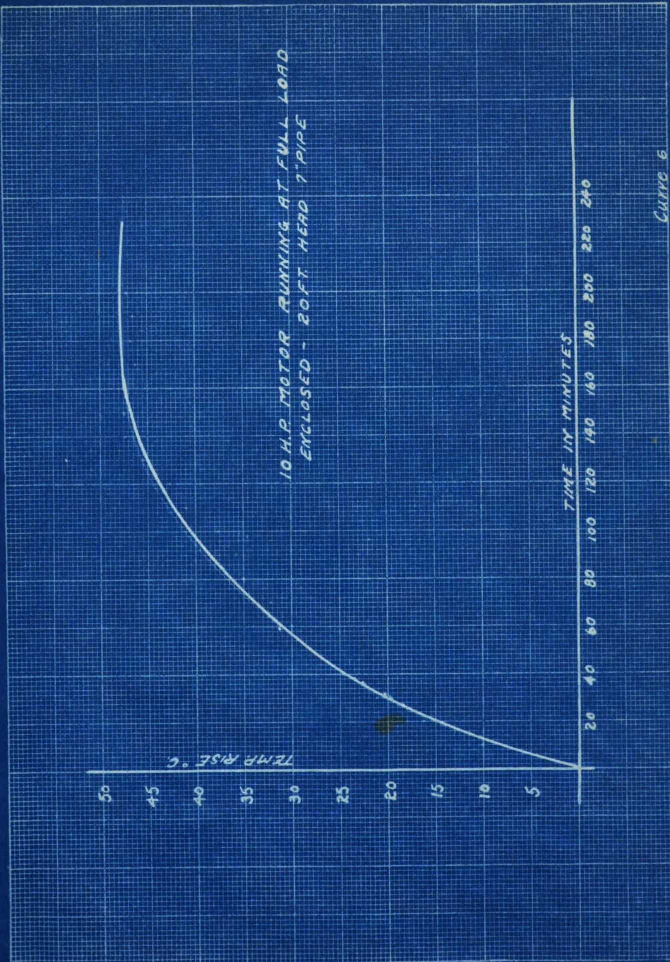
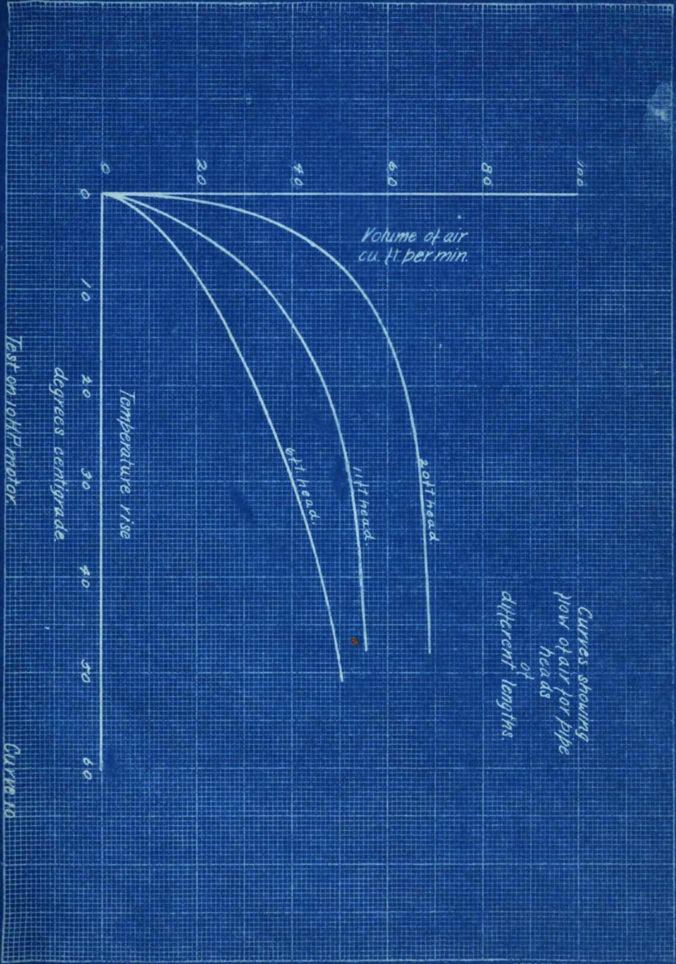
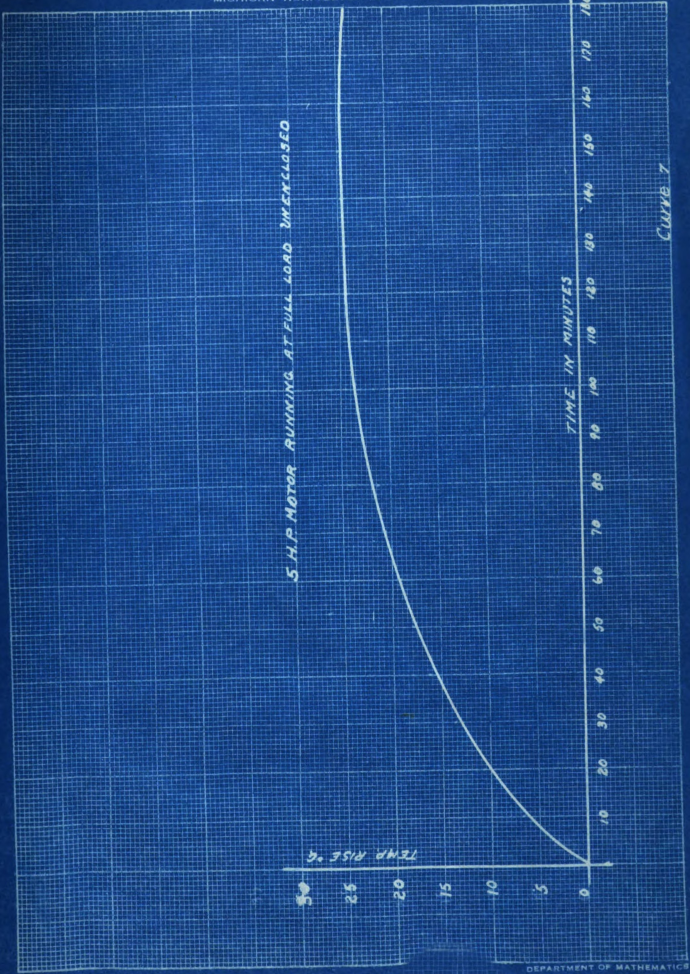

10 H.P. MOTOR RUNNING AT FULL LOAD
ENCLOSED - 20 FT. HEAD 7" PIPE
TIME IN MINUTES
20 40 60 80 100 120 140 160 180 200 220 240
TEMP RISE °C
5 10 15 20 25 30 35 40 45 50
Curve 6

Copy 1


Curves showing
flow of air for pipe
heads
of
different lengths.
Volume of air
cu. ft per min.
0
20
40
60
80
100
Temperature rise
degrees centigrade.
0
10
20
30
40
50
60
20ft head.
11ft head.
6ft head.
Test on 10HP motor.
Curve 10

Test run on 5 H. P. Motor to get its temperature rise, Motor funning at full load and unenclosed.

Time of Test.	No. of Minutes.	Temp. of Motor ^{o}C.	Room Temperature	Temperature rise ^{o}C.
6:25	0	20.6	20.6	0
6:35	10	31.9	20.4	11.5
6:45	20	35.5	20.4	15.1
6:55	30	38.6	20.5	18.1
7:05	40	41.2	20.9	20.3
7:15	50	42.7	21.4	21.3
7:25	60	44.1	21.7	22.4
7:35	70	45.6	22.	23.6
7:45	80	46.8	22.5	24.5
7:55	90	46.4	22.8	23.6
8:05	100	47.5	23.2	24.3
8:15	110	48.5	23.5	25.5
8:25	120	49.3	23.7	25.6
8:35	130	50.3	23.9	26.4
8:45	140	50.9	24.2	26.7
8:55	150	51.	24.4	26.6
9:05	160	51.5	24.6	26.9
9:15	170	51.2	24.7	26.5
9:25	180	51.2	24.9	26.3


5 H.P. MOTOR RUNNING AT FULL LOAD UNENCLOSED
TIME IN MINUTES
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
TEMP RISE °C
0
5
10
15
20
25
30
CURVE 7

Test on 5 H.P. Motor to get temperature rise curve when motor is enclosed byt ventilated. Height of head on enclosure was 6 ft. of 7" pipe; intake was a pipe of the same dimensions, 2 ft. long. Whole test carried on inside of the building.

Time of Test.	No. of Minutes.	Motor Temp.	Room Temp.	Temp. rise.	Velocity of air in intake, feet per minute. Dial.	Actual.	Volume of air thru intake; cubic feet.
1:05	0	23.1	23.1	0	0	0	0
1:15	10	30.	23.2	6.8	0	0	0
1:25	20	33.	23.3	9.7	30		14.75
1:35	30	45.	23.6	21.4	50		19.1
1:45	40	46.8	23.8	23.	54		19.9
1:55	50	49.8	23.8	26.	62		21.8
2:05	60	48.6	24.0	24.6	86	118	27.3
2:15	70	51.2	24.1	27.1	96	128	29.7
2:25	80	58.	24.2	33.8	104	136	31.6
2:35	90	61.7	24.5	37.2	104	136	31.6
2:45	100	64.2	24.6	39.6	112	144	33.4
2:55	110	66.	24.9	41.1	120	154	35.25
3:05	120	67.5	25.1	42.4	126	158	36.6
3:15	130	68.2	25.2	43.	122	156	35.7
3:25	140	69.2	25.3	43.9	125	158	36.4
3:35	150	70.1	25.6	44.5	136	170	38.95
3:45	160	70.7	25.6	45.1	150	183	42.2
3:55	170	71.3	25.8	45.5	147	180	41.5
4:05	180	71.8	25.9	45.9	143	176	40.5
4:15	190	72.5	26.3	46.2	148	181	41.7

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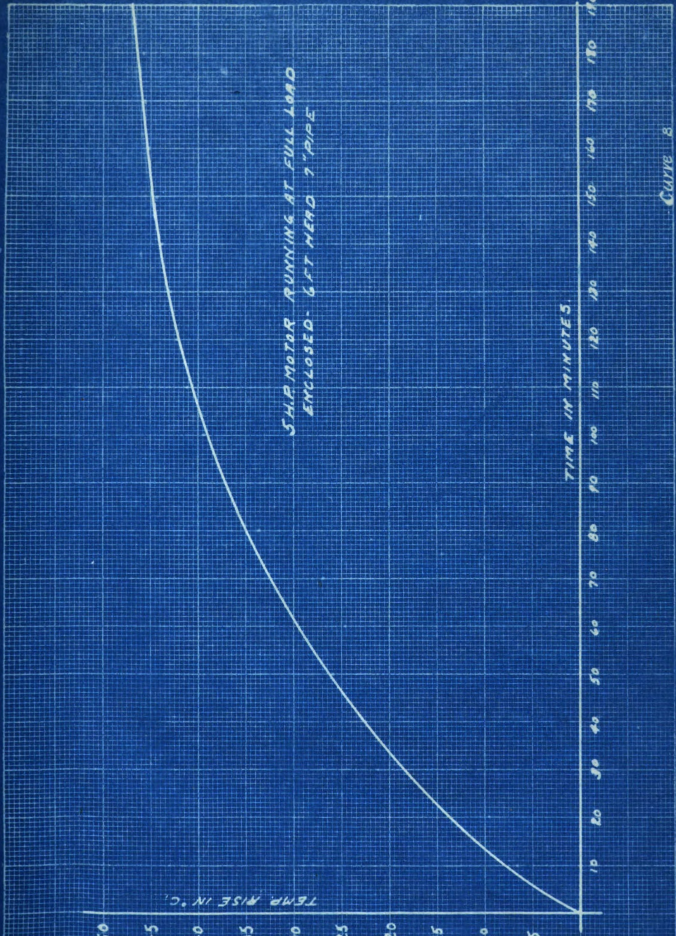

DEPARTMENT OF MATHEMATICS

Test on 5 H.P. Motor to get temperature rise curve when motor is enclosed, but ventilated.
Height of head on enclosure was 12 ft. of 7" pipe (10 ft. on the outside of building)

Time of test.	No. of Minutes.	Motor Temp.	Room Temp.	Temp. rise.	Velocity of air in intake feet per minute, Dial.	Actual.	Volume of air thru intake; cubic feet,
6:20	0	21.1	21.1	0	0	0	0
6:30	10	30.	21.1	8.9	115	148	0
6:40	20	34.7	21.2	13.5	90	123	28.4
6:50	30	39.	21.3	17.7	110	144	32.5
7:00	40	43.1	20.	23.1	110	144	32.5
7:10	50	47.	19.4	27.6	145	178	41.
7:20	60	50.	20.2	29.8	155	188	43.2
7:30	70	52.3	20.5	31.8	220	252	58.
7:40	80	55.1	20.2	34.9	195	228	52.5
7:50	90	57.6	20.5	37.1	208	242	55.5
8:00	100	59.3	21.3	38.	190	222	51.4
8:10	110	60.6	21.5	39.1	220	252	58.
8:20	120	62.3	19.8	42.5	178	211	53.2
8:30	130	63.2	20.9	42.3	215	246	57.
8:40	140	64.2	21.7	42.5	190	222	51.4
8:50	150	65.7	21.5	44.2	220	252	58.
9:00	160	65.7	21.2	44.5	170	202	46.8
9:10	170	66.5	22.	44.5	190	222	51.4
9:20	180	66.7	22.9	43.8	195	228	52.8

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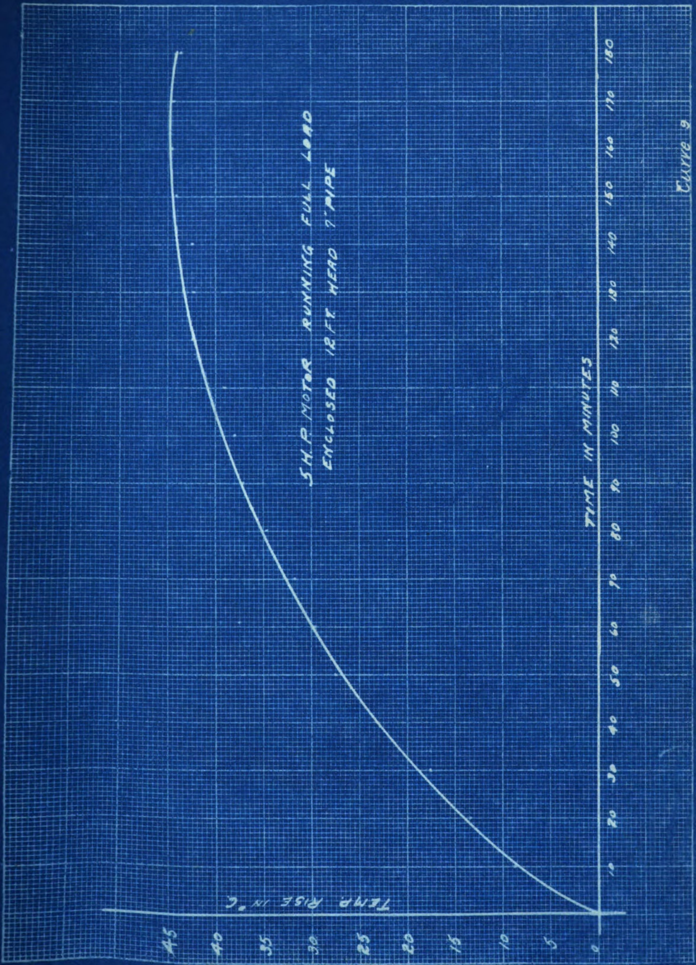
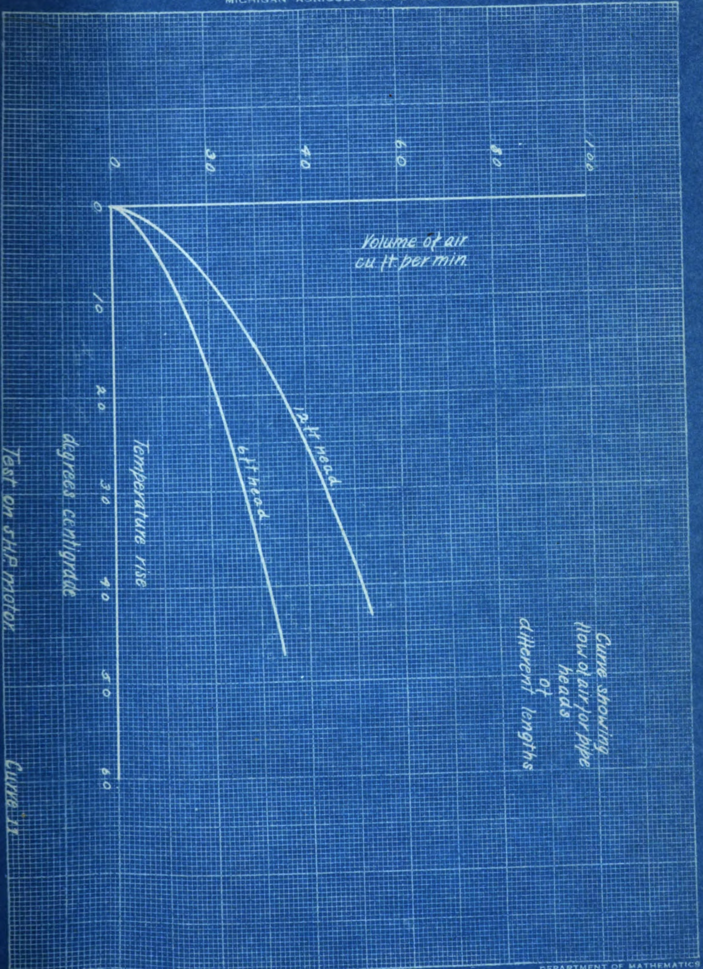

5 H.P. MOTOR RUNNING FULL LOAD
ENCLOSED 12 FT. HEAD 7" PIPE
TIME IN MINUTES
TEMP. RISE IN °C
CURVE 9
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
0 5 10 15 20 25 30 35 40 45



0
20
40
60
80
100
0
10
20
30
40
50
60
Volume of air
cu ft per min
12 ft head
6 ft head
Temperature rise
degrees centigrade
Test on 5 H.P motor
Curve II
Curve showing
flow of air for pipe
heads
of
different lengths

Motors, both alternating and direct current type, are built with the windings open in a much greater number than those with the windings enclosed. This is due largely to the fact that they operate in places in which dust is not prevalent. But in some industries, such as flour mills, grain elevators, cement factories, etc., the motors must operate in very dusty places. If these motors are not placed in rooms especially designed for them, as in the case of the steam engine, they must be housed in smaller and expensive enclosures, to be kept clean.

Such an enclosure serves a dual purpose when viewed from the insurance company's standpoint. It keeps the dust from the motor and confines the fire in case such a misfortune happens, to the seat of its source.

The first point is an advantage because dust when mixed with an oily vapor given off from the bearings, settles on the windings and forms a very good barrier to heat radiation, due to its poor ability to conduct heat. The dust also works in between the rotor and stator requiring the motor to carry an added load due to the friction set up by the rubbing oily surfaces.

The second point is an advantage because a fire started by a motor is very likely to start any inflammable material in the vicinity, thereby causing a much greater loss than the motor itself. Hence, if the enclosure be built of a fire-resistive material, the motor would be the only loss in case of a burn-out.

When such an enclosure is built, it must be ventilated in order that it may run as cool as when located in the open.

The ventilation pipes must be run to the outside of the building, and whenever possible, to the same side, so that the wind-pressure would have no effect on the draft. In case it is not possible to carry both intake and outlet to the same side of the building, some means must be devised whereby the wind will aid rather than retard the draft.

When very large motors or generators are used, and must be enclosed, a forced draft may be used very efficiently, but in the case of smaller motors, natural draft must be used in order that the system may be built and operated on an economical basis.

Hence, the problem of the engineer is to find the correct amount of air necessary to keep the motor at the desired temperature rise with only the use of natural draft. In order to do this, the correct head and the correct diameter of the pipe must be known, or possibly predetermined with some degree of accuracy.

But since very little data has been published in regard to this phase of engineering, we have attempted to make a study of enclosed motors, ventilated by natural draft in order to find a means whereby the correct amount of air necessary can be calculated, and also the proper ventilation head and pipe diameter necessary to economically carry the air.

In order to first find the natural temperature rise of the motor, it was run open, allowing the free passage of air thru the windings as was intended by the designers. This test was made mainly for the purpose of finding what margin of safety is allowed for conditions which arise, that tend to reduce its ability to operate in the manner for which it could be designed in case such conditions would not be introduced.

Then in order to find the opposite or poorest condition under which the motor may be made to operate, it was entirely enclosed, so that no air could get to it at all. This latter test shows very clearly that when operating under such conditions, it can be operated at only very low loads, or for only a short space of time.

The enclosure was then equipped with an inlet and outlet consisting of 7" galvanized iron pipe. The inlet was about two feet long and was necessary only to give the same condition as when used in actual practice, as the laws governing the flow of air through an orifice and through a pipe, are very different. The outlet was of varying lengths. Each length was decided upon with respect to the first, so that each head would give a definite ultimate temperature rise, with respect to the first. The first length was chosen merely for its convenience.

The volume of air used was measured by means of an anemometer placed in the intake. Readings were taken at intervals of ten minutes as in the case of the temperatures. Because of the fact that the anemometer did not give accurate results, it was calibrated as stated previously under the head, problems met in the thesis. The results obtained by the use of this calibration, were those used in the computations for finding the amount of air necessary to absorb the heat given off by the motor.

From the results obtained, computations show the following:

Taken from the test on 10 H.P. Motor, with 20 ft. head, for which test an ultimate temperature rise of 48° C. was obtained. But to allow for any small discrepancies which may arise, the temperature rise may be considered as being 50° C.

$\frac{10 \times 746 \times .10}{.90}$ = 829 watts given off in the form of heat.

The motor was taken as being ninety per cent efficient which means that 10% of the energy supplied is lost in the form of heat.

1 B.T.U. equals 778 foot pounds of mechanical energy.

1 H.P. equals 33,000 foot pounds of mechanical energy, during the time of one minute.

$\frac{33,000}{778}$ = equals 42.5 B.T.U. per H.P. per minute.

1 H.P. equals 746 watts.

Hence $\frac{42.5}{746}$ = .0569 B.T.U. per watt per minute.

Then .0569 x 829 equals 47.2 B.T.U. given off per minute by the motor.

According to the flow of air in pipes, the entire area of the pipe cannot be considered as carrying equal amounts over the entire area. Hence according to the direct proportion,

$$\frac{24'' \text{ actual diameter}}{22'' \text{ effective diameter}} = \frac{7.1'' \text{ actual diameter}}{X} \quad \text{or,}$$

X equals $\frac{7.1 \times 22}{24} = 6.5''$, or effective diameter of pipe.

Actual velocity in pipe as found, equals 286 feet per minute.

$\frac{286 \times \pi \times \overline{6.5}^2}{4 \times 144}$ = 66.0 cubic ft. per minute, being supplied to the motor.

.0569 x 1000 equals 56.9 B.T.U. per K.W. minute.

Then to find the volume of air necessary to absorb the heat equivalent of one K.W.:

$\frac{660 \times 56.9}{47.2}$ = 79.5 cubic ft. which may be considered as 80 cubic ft. per minute necessary to absorb one K.W. of equivalent heat energy at a temperature rise of 50°C.

According to Harding and Willard, the specific heat of air remains practically constant between the temperature 0 and 150 °C. Since the specific heat merely shows the ability of one substance to absorb heat as compared to some other substance, and since the specific heat of air is practically constant, the ratio at which it would absorb heat at varying temperatures, would be an inverse ratio.

Hence:

$$\frac{80 \text{ cu. ft.}}{x} = \frac{40^{\circ}\text{C. temp. rise}}{50^{\circ}\text{C. " "}} \quad \text{or } X = \frac{50 \times 80}{40} = 100 \text{ cu. ft.}$$

necessary to absorb one K.W. of equivalent heat energy at a 40° C. temperature rise which compares favorably with results given by the Standard Handbook for Electrical Engineers.

From Harding and Willard:

$V = \sqrt{2\, gh \frac{A-B}{A+B}}$, where A equals weight of air at outside pipe temperature and B. equals weight of air at inside pipe temperature.

Temperature, Deg. C.	Weight per cubic ft. in lbs.
1.67	.08107
4.45	.08025
7.23	.07945
10.00	.07866
12.80	.07788
15.55	.07713
18.35	.07640
21.15	.07567
23.90	.07495
26.70	.07424
29.40	.07356
32.20	.07289
35.00	.07222
37.80	.07157
40.60	.07093
43.50	.06968
46.00	.06908
49.00	.06848
51.70	.06790
54.50	.06732
57.20	.06675
60.10	.06620

(Above table based on barometric pressure of 29.921").

From the Law of Charles,-P.T. = P' T', this enabling one to find the weight at any barometric pressure.

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This introduces such a slight variation in checking the head required for ventilation, that it is unnecessary and impractical.

In order to find the effective head with the velocity and average temperature given:-

$$V = \sqrt{2\,gh\,\frac{A-B}{A+B}}$$

For an average temperature rise of 40° C which corresponds to the average temperature rise in the 6 ft. head, as actually found:

$$V = \sqrt{\frac{64.4\,h \times (.07495 - .06565)}{(.07495 + .06565)}} = 64.4 \times .0666\,h$$

$$V^2 = 64.4 \times .0666\,h \text{ or } \left(\frac{230}{60}\right)^2 = 64.4 \times .0666\,h$$

$$h = \frac{14.71}{4.25} = 3.46 \text{ feet height of head.}$$

For an average temperature rise of 30° C. as assumed in the case of an eleven foot head:

$$V = \sqrt{\frac{2\,gh \times (.07567 - .06790)}{(.07567 + .06790)}} \text{ or } h = \frac{17.31}{3.48} \quad 5.0 \text{ ft., ht. of head.}$$

For an average temperature rise of 18° C. as assume in the case of 20 ft. head:-

$$V = \sqrt{\frac{2\,gh \times (.07567 - .07093)}{(.07567 + .07093)}} \text{ or } h = \frac{22.8}{2.08} \quad 11 \text{ ft. ht. of head.}$$

For heads greater than 10 feet, the temperature difference becomes so low that its effectiveness drops below a practical point.

To find the correct diameter of the pipe, the following direct formula applies:-

$$\text{Vol.} = \frac{\text{Vel.} \times 4}{\pi D^2}$$

$$D \cong \sqrt{\frac{\text{Vel.} \times 4}{\text{Vol.} \times \pi}}$$

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In tests of the 10 H.P. Motor with 6 and 11 ft. head, draft where no constant temperature was arrived at in a three or four hour run, extrapolation of the heating curve gave us the ultimate temperature.

The method is taken from Karapetoff, and briefly is as follows: Let the abscissa of the final point of the durve be X_4 and the ordinate T_4, and their ordinates, T_1, T_2, T_3, and T_4; Measure the ordinates and solve the equation:

$$Z = \sqrt{\frac{T_4 - T_3}{T_2 - T_1}}$$

To get the ultimate temperature rise, calculate any or all of the following four expressions:

$$A = \frac{T_1}{1 - Z}$$

$$A = \frac{T_2}{1 - Z^2}$$

$$A = \frac{T_3}{1 - Z^3}$$

$$A = \frac{T_4}{1 - Z^4}$$

The average of the above four equations was taken for the ultimate temperature rise.

(10 H.P. Motor, 6 ft. head)

$$Z = \sqrt{\frac{51 - 47.5}{41.6 - 27}} = \sqrt{\frac{3.5}{14.6}} = \sqrt{.239} = .49$$

$$A = \frac{27}{1-.49} = \frac{27}{.51} = .53^{\circ}$$

$$A = \frac{41.6}{1-.239} = \frac{41.6}{.761} = 54.6^{\circ}$$

$$A = \frac{47.5}{1 -.117} = \frac{47.5}{.883} = 52.7^{\circ}$$

$$A = \frac{51}{1-.0572} = \frac{51}{.9428} = 53.2^{\circ}$$ Average temperature, 53.62°.

(10 H.P. Motor, 11 ft. head)

$$Z = \sqrt{\frac{44 - 41.3}{35.2 - 23}} = \sqrt{\frac{2.7}{12.2}} = \sqrt{.221} = .471$$

$$A = \frac{23}{1 - .471} = \frac{23}{.529} = 43.5$$

$$A = \frac{35.2}{1 - .221} = \frac{35.2}{.779} = 45.3$$

$$A = \frac{41.3}{1-.104} = \frac{41.3}{.896} = 46.1$$

$$A = \frac{44}{1-.049} = \frac{44}{.951} = 46.3$$ Average temperature, 45.3°.

(20 H.P. Motor, 20 ft. head)

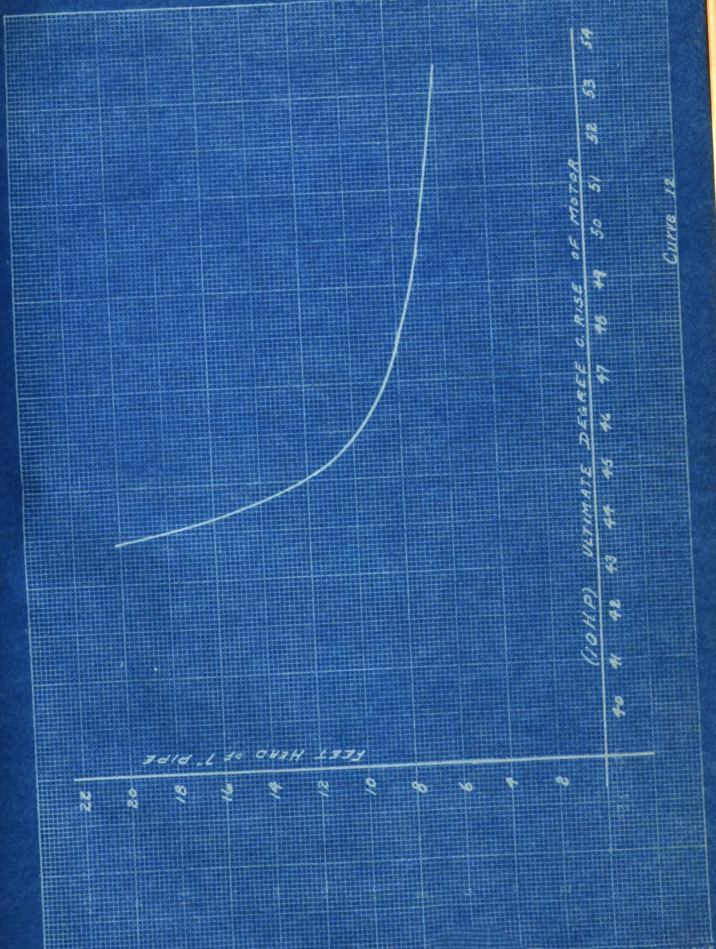
$$Z = \sqrt{\frac{47 - 46.6}{42.6 - 30.6}} = \sqrt{\frac{.4}{12}} = \sqrt{.0334} = .183$$

$$A = \frac{30.6}{1-.183} = \frac{30.6}{.819} = 37.4$$

$$A = \frac{42.6}{1-.0334} = \frac{42.6}{.9666} = 44$$

$$A = \frac{46.6}{1-.0061} = \frac{42.6}{.9939} = 47$$

$$A = \frac{47}{1-.00111} = \frac{47}{.99889} = 47$$ Average temperature, 43.85°.


(10 H.P.) ULTIMATE DEGREE C. RISE OF MOTOR
40 41 42 43 44 45 46 47 48 49 50 51 52 53 54
FEET HEAD OF 1" PIPE
22 20 18 16 14 12 10 8 6 4 2
Curve 12

Curve twelve in which height head is plotted against the ultimate temperature rise, shows plainly that bare metal piping is not dependable above a certain height for drawing air thru the enclosure. The draft created is due to the hot air enclosed in the pipe rising, but where a height of head is used above 10 feet, the radiating power of the piping is so great that further additions of length are not effective in appreciably lowering the temperature rise of the motor.

CONCLUSIONS.

In the past, very little has been done in regard to ventilation of motors, and consequently very little or no data is obtainable on this subject. Hence, in making the test, many problems were met, which were not anticipated, and many conditions which, before the thesis, were not considered of appreciable consequence, were found to be of great importance. Hence, due to our lack of knowledge in regard to the subject, and to the lack of time to make a second complete test, some of our results depend upon assumptions which we find to be more or less in error.

The particular case to which this refers, is to the calculation on the head necessary to give the correct flow of air. We are inclined to believe that the rate of cooling in the outlet ventilation pipe, is very similar to the cooling curve of the motor itself, but have no data to prove this. When making the calculations, we considered the cooling in the outlet pipe as being in accordance to a straight line function which would necessarily give a higher average temperature rise in the pipe than if the other type cooling curve was used. This may be readily seen by placing Curve 2 against a light, turning the sheet top for bottom (no end for end), and looking at the curve from the back. Consider the actual ultimate Temperature of the curve, as zero temperature rise

rise or room temperature, and the actual zero temperature of the curve as the maximum temperature of the pipe at a point just outside the enclosure. Consider the new abscissa as the length of pipe used, and the ordinate, as the temperature taken at equal intervals long the pipe. Then, if a straight line is drawn from the maximum pipe temperature rise at zero ventilation head, to zero temperature rise at maximum ventilation head, and an average of the ordinates taken at equal intervals, the average ordinate which corresponds to the average temperature rise is greater than the average when taken from the cooling curve as we believe it actually exists.

We are fairly confident that the calculations with regard to the amount of air necessary to absorb the heat given off at various temperature rises, are correct, due to the fact that they check with results given by the Standard Handbook for Electrical Engineers.

As a suggestion to any others who might wish to carry the thesis further, we submit the following outline:

I. Find the efficiency and power factor for motors from 5 H.P. to 75 H.P. at the normal full-rated load.

(a) Calculate the heat lost from this data.

II. Build resistance coils to generate the same amount of heat at the same temperature rise as the motors.

(a) One coil with taps at the proper points, is sufficient for the entire test.

III. Build the coils in the enclosure so that the temperature may be regulated by means of a thermometer.

(a) Vary the ventilation so that the temperature may be made to drop.

(1) From this data, the quantity of air necessary is found experimentally from different temperature rises.

IV. Place thermometers at intervals of one or two feet in outlet ventilation pipe.

(a) This will give the radiation along the pipe from which the average temperature rise of air in pipe may be found.

(b) By using different pipe diameters, find the radiation.

(1) By mathematics, the radiation is inversely proportional to the square of the diameter.

V. The velocity of air in the pipe should be measured with some degree of accuracy.

(A) This may be done by means of an anomometer or pitot tube.

(1) The effective diameter of each pipe should be calculated or found by experiment. This may be done as explained in the treatise on Hydraulics by Hughes and Safford, Pages 111 and 112.

If desired, insulated pipes could be used in procedure as explained under IV to find their effectiveness.

This outline, we believe, will give an efficient means of going about the test in the future, and is the outline which we would follow if we were to repeat the test.

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ROOM USE ONLY