Influence of Various Temperatures on the Drying Time of 220/66 KV Transformer Insulations in Vapour Phase Drying Process

Mohd. Tareq Siddiqui, Jayant T. Pattiwar, Avinash P. Paranjape, Ashok J Keche

Abstract: ***Cellulose based insulation in the form of different papers and pressboard play a vital role in transformer manufacturing as very high level of voltages are encountered during transformer operation. Cellulose being hygroscopic in nature contains 8-10% moisture by weight. The life of a transformer is critically dependant on the state of cellulose insulation so much so that, paper with 1.5% moisture content ages 10 times faster than with only 0.3% moisture. For obvious reasons, it is very important that the moisture is removed from transformer insulation. As of today, the latest technology available for this moisture extraction is the vapour phase drying process. This paper evaluates the influence of temperatures at various locations on the drying time of two 220kv transformer insulations in vapour phase drying process.***

Keywords: Temperature, drying time, moisture, transformer

I. INTRODUCTION

Adequate amount of insulation in the form of cellulose based insulation due to long and positive experience is being used in transformer manufacturing as very high voltages are involved during power transfer from primary to secondary. Cellulose insulation has a significant role in transformer's life & performance characteristics [1]. However, cellulose based insulation being a hygroscopic material, may contain 8 to 10% of moisture by weight at ambient temperature [2]. This moisture is injurious to the health of the transformers since it reduces the dielectric strength, raises the dielectric power factor, increases the risk of thermal breakdown of solid insulation, lowers the lowest hot-spot temperature range for possible bubble formation, accelerates thermal aging of paper insulation, and can be the root cause of a catastrophic failure [3]. It is therefore imperative to remove this moisture from the insulation. In the drying processes used for insulation drying, temperature attained in the insulation is one of the most important factors [4]. This paper presents a statistical analysis and evaluates the effects of temperatures at various locations viz., outer, middle & innermost layers of insulation in transformer insulation drying using vapour phase drying process for two 220/66 KV, 50 MVA transformers with 4 ton insulation.

Revised Manuscript Received on March 30, 2020.

* Correspondence Author

Mohd. Tareq Siddiqui*, Department of Mechanical Engineering, PES College of Engineering, Aurangabad, India. Email: mohd.tareq.siddiqui@gmail.com

Dr. Jayant T. Pattiwar, Department of Engineering & Technology, Dr. BAM University, Aurangabad, India. Email: jayantpattiwar@gmail.com

Dr. Avinash P. Paranjape, Department of Electrical Engineering, Govt. Engineeirng College, Aurangabad, India. Email: xyz3@blueeyesintlligence.org

Dr. Ashok J. Keche Department of Mechanical Engineering, MIT College, Aurangabad, India. Email: ashok.keche@mit.asia

II.VAPOUR PHASE DRYING OF 220/66KV (I)

For the process of vapour phase drying, the 220/66 KV, 50 MVA transformer with 4 ton insulation was loaded into the vacuum chamber. The vacuum chamber has a provision of thermic fluid heating. Initially the chamber is evacuated for about 2 hours. The vacuum pressure of 20.81 mbar was observed at this point. Thereafter, the vacuum chamber is heated through thermic fluid for about 10 hours. It was observed at this point that the temperature of the outermost layer of insulation was 76^{o}c while that of the middle layer was 65^{o}c and that of the innermost layer was 55 ^{o}c. Also, during this heating, the pressure in the vessel increased to 56.8mbar. The reason for this increase in pressure is the vapourisation of moisture form the outer layers of insulation. Then, the vacuum chamber is subjected to further pressure reduction for about 3 hours at the end of which the vacuum pressure was found to be 39.16mbar. Second heating cycle was then taken for about 2 hours wherein temperature of the outermost layer of insulation was 96^{o}c while that of the middle layer was 87^{o}c and that of the innermost layer was 77 ^{o}c and vacuum pressure was 61.15mbar. Further pressure reduction was carried out for about 2 hours before kerosene vapours are introduced in the vacuum chamber. Kerosene vapours are introduced in the vacuum chamber for about 8 hours. As a result of injection of kerosene vapours, the temperature of the insulation increases such that the temperature of the outermost layer reaches up to 115^{o}c, while that of the middle layer is 105^{o}c and that of the innermost layer is 96^{o}c. The final vacuum achieved at the end of the cycle was found to be 0.1 mbar. Also, the total amount of moisture removed was about 24 litres at the end of cycle.

The following tables illustrates the readings of temperatures and the moisture removal per hour during the drying cycle.

In the table, t1 is the temperature of the outermost layer of the insulation, t2 is the temperature of the middle layer of insulation & t3 is the temperature of the innermost layer of the insulation which is nearest to the core. It may be clearly seen from the table that the temperatures in the insulation are not the same throughout. Maximum temperature is observed on the outermost layer while, minimum temperature is observed on the innermost layer. The different temperatures at different locations in the insulation have different effect on the drying time of the insulation.

Table- I: Vacuum Chamber Readings (I)

Time in Hrs.	Total Water/ Hr	t1	t2	t3	Vacuum Level (mbar)
0	0.64	37	37	37	971.1
1	1.52	37	38	36	96.71
2	1.52	49	42	37	20.81
3	1.74	52	43	38	29.4
4	1.74	55	45	40	35.77
5	1.74	56	48	41	38.99
6	1.74	60	50	44	41.87
7	1.74	63	53	45	47.73
8	1.74	65	56	47	50.93
9	1.74	69	60	49	52.3
10	1.74	71	62	52	53.41
11	1.74	76	65	55	56.8
12	1.74	81	70	59	55.22
13	2.65	87	78	63	52.16
14	4.04	90	82	68	39.16
15	4.05	94	85	72	53.77
16	4.05	96	87	77	61.15
17	5.14	98	90	81	38.69
18	8.5	106	95	84	27.26
19	13.53	110	96	86	10.63
20	15.36	112	99	88	11.65
21	18.67	110	100	91	0.16
22	20.58	112	101	92	0.1
23	23.49	112	102	92	0.1
24	23.55	113	104	94	0.1
25	23.57	114	106	95	0.1
26	23.62	115	105	96	0.1

In the drying processes used for insulation drying, temperature attained in the insulation is one of the most important factors [4]. However, to establish temperature at which location in the insulation, will have the maximum influence on the drying time, Taguchi & Regression analysis were performed using Minitab software between temperatures and drying time and temperatures & rate of moisture removal.

III. TAGUCHI ANALYSIS BETWEEN TEMPERATURES & TIME (I)

While maintaining the quality standards, it is always desirable to have lower drying times. Here quality pertains to the amount of moisture removed. Taguchi analysis between temperatures & drying time was therefore performed by taking temperatures as input factors & drying time as response variable. Signal to noise ratios were also evaluated for "Smaller the Better" (drying time). The values obtained from the analysis may summarized in tables 2 & 3.

Table- II: Response Table for Signal to Noise Ratios "Smaller Is Better" (I)

Level	t1	t2	t3
1	0		0
2	-6.0206	0	-6.0206
3	-9.5424	-6.0206	-9.5424
4	-12.0412	-9.5424	-12.0412
5	-13.9794	-12.0412	-13.9794
6	-15.563	-13.9794	-15.563
7	-16.902	-15.563	-16.902
8	-18.0618	-16.902	-18.0618
9	-19.0849	-18.0618	-19.0849
10	-20	-19.0849	-20
11	-20.8279	-20	-20.8279
12	-21.5836	-20.8279	-21.5836
13	-22.2789	-21.5836	-22.2789
14	-22.9226	-22.2789	-22.9226
15	-23.5218	-22.9226	-23.5218
16	-24.0824	-23.5218	-24.0824
17	-24.609	-24.0824	-24.609
18	-25.1055	-24.609	-25.1055
19	-26.0097	-25.1055	-25.5751
20	-26.7012	-25.5751	-26.0206
21	-27.6042	-26.0206	-26.4444
22	-27.9588	-26.4444	-27.0415
23	-28.2995	-26.8485	-27.6042
24		-27.2346	-27.9588
25		-27.6042	-28.2995
26		-28.2995	
27		-27.9588	
Delta	28.2995	-28.2995	28.2995
Rank	2	2	2

Table- III: Response Table for Means (I)

Level	t1	t2	t3
1	0.5	0	1
2	2	1	1
3	3	2	3
4	4	3	4
5	5	4	5
6	6	5	6
7	7	6	7
8	8	7	8
9	9	8	9
10	10	9	10
11	11	10	11
12	12	11	12
13	13	12	13
14	14	13	14
15	15	14	15
16	16	15	16
17	17	16	17
18	18	17	18
19	20	18	19
20	21.6667	19	20
21	24	20	21
22	25	21	22.5
23	26	22	24
24		23	25
25		24	26
26		26	
27		25	
Delta	25.5	25	26
Rank	2	3	1

The graphs generated are as follows.

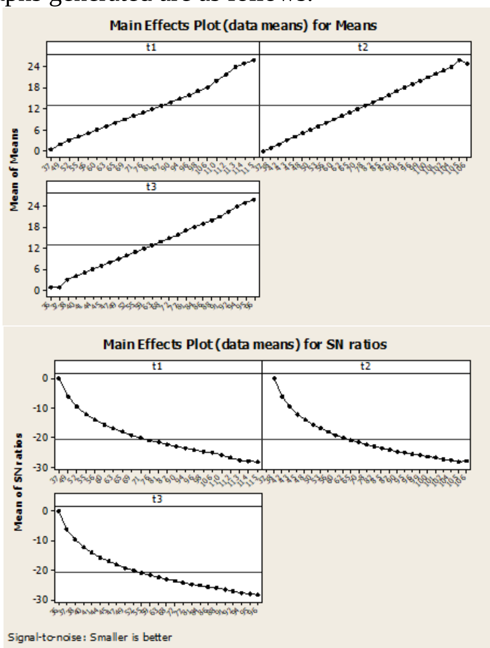

Fig. 1. Temp. Vs Time, Taguchi Graphs (I)

IV. REGRESSION ANALYSIS BETWEEN TEMPERATURES & TIME. (I)

To further asses which temperature has the maximum influence on the drying time, regression analysis was performed. Drying time was taken as the response & temperatures was taken as the predictor. The regression equation obtained is as follows.

Time in Hrs.=- 11.2 + 0.0995 t1 + 0.100 t2 + 0.130 t3 (1)

Regression in tabular form can be illustrated as follows.

Table- IV: Regression Analysis of Temperatures Vs Time (I)

Predictor	Coef	SE Coef	T	P
Constant	-11.17	0.8283	-13.48	0
t1	0.09952	0.09754	1.02	0.318
t2	0.1002	0.1675	0.6	0.556
t3	0.1304	0.1026	1.27	0.216

The regression graphs are as follows.

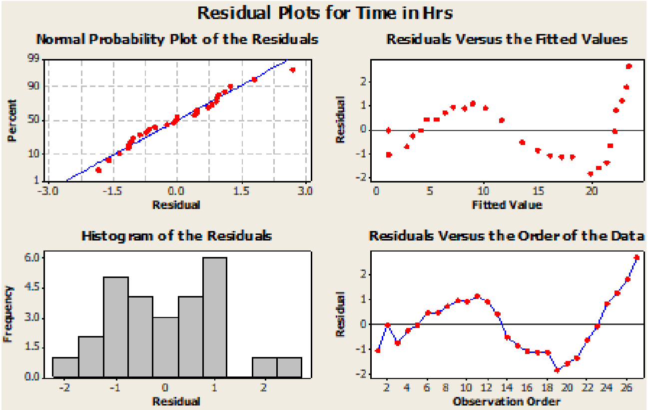

Fig. 2. Temp. Vs Time, Regression Graphs (I)

V. TAGUCHI ANALYSIS BETWEEN TEMPERATURES & MOISTURE REMOVAL RATE. (I)

By taking temperatures as input factors & moisture removal rate as response variable Taguchi analysis between temperatures & moisture removal rate was performed to determine the effect of different temperatures on the moisture removal rate and by extension on the drying time. Signal to noise ratios were evaluated for "Larger the Better" (moisture removal rate). The values obtained from the analysis may summarized in tables 5& 6.

Table- V: Response Table for Signal to Noise Ratios "Larger Is Better" (I)

Level	t1	t2	t3
1	-0.1198	-3.8764	3.6369
2	3.6369	3.6369	-0.1198
3	4.811	3.6369	4.811
4	4.811	4.811	4.811
5	4.811	4.811	4.811
6	4.811	4.811	4.811
7	4.811	4.811	4.811
8	4.811	4.811	4.811
9	4.811	4.811	4.811
10	4.811	4.811	4.811
11	4.811	4.811	4.811
12	4.811	4.811	4.811
13	8.4649	4.811	8.4649
14	12.1276	8.4649	12.1276
15	12.1491	12.1276	12.1491
16	12.1491	12.1491	12.1491
17	14.2193	12.1491	14.2193
18	18.5884	14.2193	18.5884
19	24.0244	18.5884	22.626
20	25.8048	22.626	23.7278
21	27.4398	23.7278	25.4229
22	27.4472	25.4229	26.8433
23	27.4656	26.2689	27.4398
24		27.4177	27.4472
25		27.4398	27.4656
26		27.4656	
27		27.4472	
Delta	27.5854	31.342	27.5854
Rank	2.5	1	2.5

Table- VI: Response Table for Means (I)

Level	t1	t2	t3
1	1.08	0.64	1.52
2	1.52	1.52	1.08
3	1.74	1.52	1.74
4	1.74	1.74	1.74
5	1.74	1.74	1.74
6	1.74	1.74	1.74
7	1.74	1.74	1.74
8	1.74	1.74	1.74
9	1.74	1.74	1.74
10	1.74	1.74	1.74
11	1.74	1.74	1.74
12	1.74	1.74	1.74
13	2.65	1.74	2.65
14	4.04	2.65	4.04
15	4.05	4.04	4.05
16	4.05	4.05	4.05
17	5.14	4.05	5.14
18	8.5	5.14	8.5
19	16.1	8.5	13.53
20	19.81	13.53	15.36
21	23.55	15.36	18.67
22	23.57	18.67	22.035
23	23.62	20.58	23.55
24		23.49	23.57
25		23.55	23.62
26		23.62	
27		23.57	
Delta	22.54	22.98	22.54
Rank	2.5	1	2.5

The graphs generated are as follows.

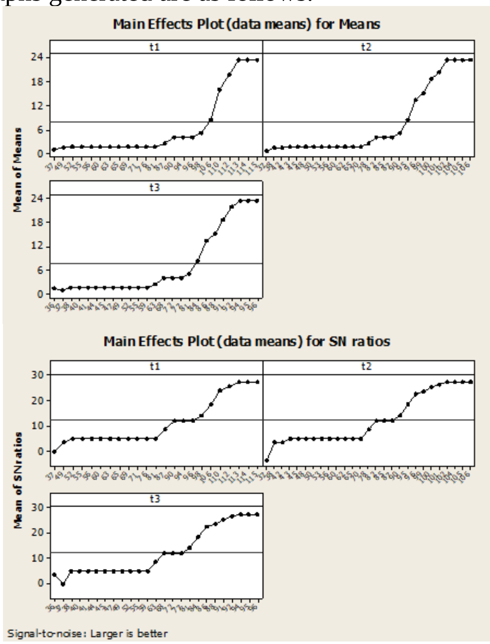

Fig. 3. Temp. Vs Moisture Removal Rate, Taguchi Graphs (I)

VI. REGRESSION ANALYSIS BETWEEN TEMPERATURES & MOISTURE REMOVAL RATE. (I)

Regression analysis was performed with moisture removal rate as the response & temperatures as the predictor. The following regression equation was obtained.

Total Water = - 11.8 + 0.129 t1 - 1.08 t2 + 1.36 t3 (2)

The following tabular form of regression was also obtained.

Table- VII: Regression Analysis of Temperatures Vs Moisture Removal Rate (I)

Predictor	Coef	SE Coef	T	P
Constant	-11.823	2.574	-4.59	0
t1	0.1292	0.303	0.43	0.674
t2	-1.0774	0.5204	-2.07	0.05
t3	1.3618	0.3187	4.27	0

The graphs generated are as follows.

Retrieval Number: E2603039520/2020©BEIESP
DOI: 10.35940/ijitee.E2603.039520
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

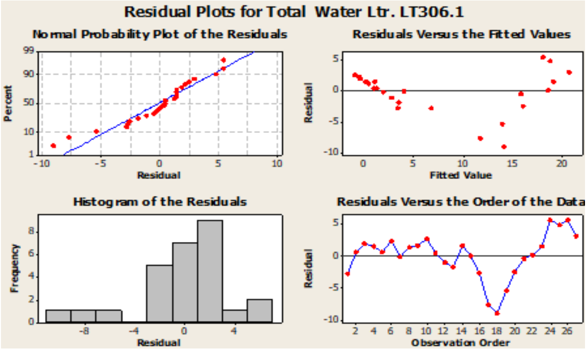

Fig 4.Temp. Vs Moisture Removal Rate, Regression Graphs. (I)

VII. VAPOUR PHASE DRYING OF 220KV (II)

For the process of vapour phase drying, the 220/66 KV, 50 MVA transformer coil with 4 ton insulation was loaded into the vacuum chamber. Initially the chamber is evacuated for about 3 hours. The vacuum pressure of 21.73 mbar was observed at this point. Thereafter, the vacuum chamber is heated through thermic fluid for about 18 hours. It was observed at this point that the temperature of the outermost layer of insulation was 113°c while that of the middle layer was 101°c and that of the innermost layer was 90°c. Also, during this heating, the pressure in the vessel increased to 80.31mbar. The reason for this increase in pressure is the vapourisation of moisture form the outer layers of insulation. Then, the vacuum chamber is subjected to further pressure reduction for about 2 hours. Next, a second heating cycle is taken for 4 hours during which the temperature of the outermost layer reaches 113°c while that of the middle layer reaches 102°c and that of the innermost layer reaches 89°c. The pressure observed at this point is 60.46mbar. Again, a pressure reduction cycle is taken for about 2 hours during which, the pressure reaches 14.63mbar. A third heating cycle is taken for about 4 hours at the end of which the pressure becomes 59.78mbar. Before introducing kerosene vapours, a pressure reduction cycle is taken for about 3 hours. Kerosene vapours are introduced in the vacuum chamber for about 12 hours. As a result of injection of kerosene vapours, the temperature of the insulation increases such that the temperature of the outermost layer reaches up to 110°c, while that of the middle layer is 99°c and that of the innermost layer is 83°c. The final vacuum achieved at the end of the cycle was found to be 0.1 mbar. Also, the total amount of moisture removed was about 38 litres at the end of cycle. The following tables illustrates the readings of temperatures and the moisture removal per hour during the drying cycle.

Table-VIII: Vacuum Chamber Readings (II)

Time in Hrs.	Total Water/ Hr	t1	t2	t3	Vacuum Level (mbar)
0	0.34	36	36	36	973.51
1	0.34	38	37	38	974.31
2	0.34	39	39	38	173.74
3	1.37	49	44	42	21.73
4	1.37	53	47	44	27.84
5	1.37	61	55	49	31.31
6	1.37	68	64	54	35.79
7	1.37	79	72	61	35.75
8	1.37	82	74	65	37.99
9	1.37	86	75	67	38.4
10	1.37	88	77	69	39.18
11	1.37	90	79	70	39.67
12	1.37	92	82	72	41.11
13	1.37	94	85	74	46.82
14	1.37	95	84	74	51.56
15	1.37	95	83	73	60.61
16	1.37	102	89	76	59.73
17	1.89	105	94	80	59.04
18	2.2	109	97	82	72.33
19	3.49	112	103	87	78.03
20	4.61	113	101	90	80.31
21	12.41	105	96	87	16.3
22	16.61	107	95	86	13.12
23	18.65	108	96	87	49.74
24	18.7	109	99	87	57.08
25	19.1	111	100	88	58.58
26	19.38	113	102	89	60.46
27	22.84	109	98	87	14.58
28	25.52	107	98	87	14.63
29	26.53	109	98	86	46.89
30	26.67	110	99	87	56.04
31	26.68	112	100	87	58.64
32	27.04	110	101	88	59.78
33	29.34	105	94	82	13.81
34	31.22	107	98	83	15.92
35	32.23	107	96	84	14.62
36	33.67	106	96	83	15.04
37	34.45	106	95	82	11.9
38	35.04	105	95	83	12.77
39	37.2	107	98	81	0.1
40	37.89	108	97	80	0.1
41	38.16	108	97	82	0.1
42	38.16	110	99	83	0.1
43	38.16	109	99	83	0.1
44	38.16	109	98	82	0.1
45	38.16	109	98	81	0.1
46	38.16	110	99	83	0.1
47	38.16	110	99	83	0.1

VIII. TAGUCHI ANALYSIS BETWEEN TEMPERATURES & TIME. (II)

Taguchi analysis between temperatures & drying time was performed by taking temperatures as input factors & drying time as response variable. Signal to noise ratios were also evaluated for "Smaller the Better" (drying time). The values obtained from the analysis may summarized in tables 9 & 10.

Table- IX: Response Table for Signal to Noise Ratios "Smaller Is Better" (II)

Level	t1	t2	t3
1			
2	0	0	-3.0103
3	-6.0206	-6.0206	-9.5424
4	-9.5424	-9.5424	-12.0412
5	-12.0412	-12.0412	-13.9794
6	-13.9794	-13.9794	-15.563
7	-15.563	-15.563	-16.902
8	-16.902	-16.902	-18.0618
9	-18.0618	-18.0618	-19.0849
10	-19.0849	-19.0849	-20
11	-20	-20	-20.8279
12	-20.8279	-20.8279	-21.5836
13	-21.5836	-21.5836	-23.5218
14	-22.2789	-23.5218	-22.6007
15	-23.2222	-22.9226	-24.0824
16	-24.0824	-22.2789	-28.3251
17	-34.8073	-24.0824	-33.4864
18	-29.4679	-27.4896	-31.8019
19	-32.9904	-32.1525	-33.0614
20	-30.8977	-30.4335	-34.0936
21	-31.8271	-31.9914	-35.563
22	-31.7973	-31.9677	-28.0482
23	-31.9971	-32.2626	-27.9748
24	-27.9588	-28.893	-29.0309
25	-27.7012	-28.0618	-28.2995
26	-27.16	-28.2995	-26.0206
27		-25.5751	
Delta	32.5527	32.2626	34.8073
Rank	2	3	1

Table- X: Response Table for Means (II)

Level	t1	t2	t3
1	0	0	0
2	1	1	1.5
3	2	2	3
4	3	3	4
5	4	4	5
6	5	5	6
7	6	6	7
8	7	7	8
9	8	8	9
10	9	9	10
11	10	10	11
12	11	11	12
13	12	12	15
14	13	15	13.5
15	14.5	14	16
16	16	13	28.5
17	55	16	47.6
18	32.2	25	40.75
19	44.6667	42.3333	44.8333
20	36.1667	35.2	51.75
21	40.4	42.1667	60
22	41.7273	41	25.5
23	41.25	43.1667	25.375
24	25	28	28.5
25	25	26	26
26	23	26	20
27		19	
Delta	55	43.1667	60
Rank	2	3	1

The graphs generated are as follows.

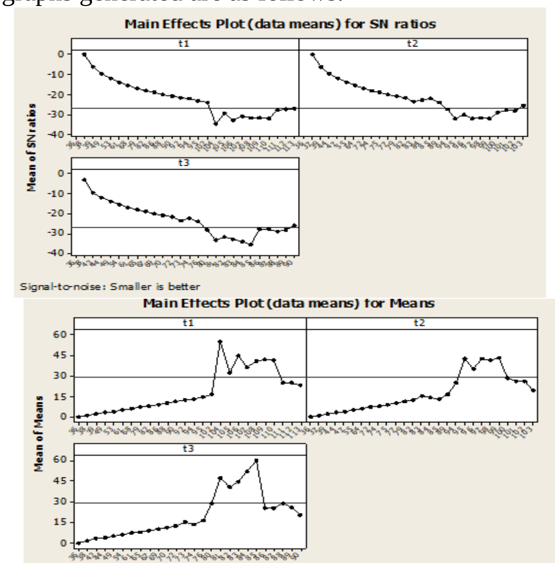

Fig. 5. Temp. Vs Time, Taguchi Graphs (II)

IX. REGRESSION ANALYSIS BETWEEN TEMPERATURES & TIME. (II)

To asses which temperature has the maximum influence on the drying time, regression analysis was performed. Drying time was taken as the response & temperatures was taken as the predictor. The regression equation obtained is as follows.

Time in hrs = - 21.8 - 1.67 t1 + 4.42 t2 - 2.28 t3 (3)

Regression in tabular form can be illustrated as follows.

Table- XI: Regression Analysis of Temperatures Vs Time (II)

Predictor	Coef	SE Coef	T	P
Constant	-21.752	9.923	-2.19	0.032
t1	-1.674	1.006	-1.66	0.102
t2	4.419	1.241	3.56	0.005
t3	-2.2831	0.7729	-2.95	0.001

The regression graphs are as follows.

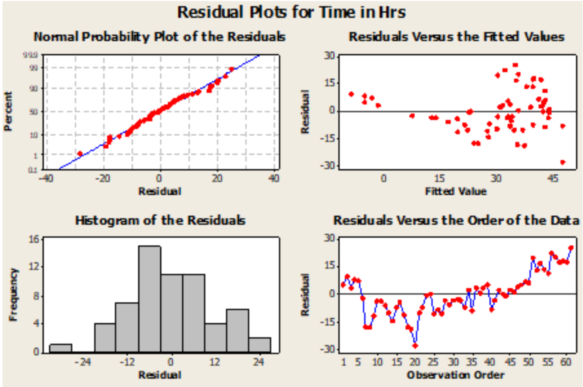

Fig. 6. Temp. Vs Time, Regression Graphs (II)

X. TAGUCHI ANALYSIS BETWEEN TEMPERATURES & MOISTURE REMOVAL RATE. (II)

By taking temperatures as input factors & moisture removal rate as response variable Taguchi analysis between temperatures & moisture removal rate was performed to determine the effect of different temperatures on the moisture removal rate and by extension on the drying time. Signal to noise ratios were also evaluated for "Larger the Better" (moisture removal rate). The values obtained from the analysis may summarized in tables 12 & 13.

Table- XII: Response Table for Signal to Noise Ratios "Larger Is Better" (II)

Level	t1	t2	t3
1	-9.37	-9.37	-9.37
2	-9.37	-9.37	-9.37
3	-9.37	-9.37	2.734
4	2.734	2.734	2.734
5	2.734	2.734	2.734
6	2.734	2.734	2.734
7	2.734	2.734	2.734
8	2.734	2.734	2.734
9	2.734	2.734	2.734
10	2.734	2.734	2.734
11	2.734	2.734	2.734
12	2.734	2.734	2.734
13	2.734	2.734	2.734
14	2.734	2.734	2.734
15	2.734	2.734	2.734
16	2.734	2.734	18.55
17	31.632	2.734	31.588
18	23.855	17.439	28.138
19	31.144	30.156	31.253
20	29.404	28.028	31.265
21	30.376	27.491	31.632
22	28.124	30.267	26.441
23	30.106	30.081	24.492
24	25.621	27.072	27.13
25	19.69	20.957	25.747
26	19.511	25.747	13.274
27		10.857	
Delta	41.003	39.637	41.003
Rank	1.5	3	1.5

Table- XIII: Response Table for Means (II)

Level	t1	t2	t3
1	0.34	0.34	0.34
2	0.34	0.34	0.34
3	0.34	0.34	1.37
4	1.37	1.37	1.37
5	1.37	1.37	1.37
6	1.37	1.37	1.37
7	1.37	1.37	1.37
8	1.37	1.37	1.37
9	1.37	1.37	1.37
10	1.37	1.37	1.37

11	1.37	1.37	1.37
12	1.37	1.37	1.37
13	1.37	1.37	1.37
14	1.37	1.37	1.37
15	1.37	1.37	1.37
16	1.37	1.37	19.89
17	38.16	1.37	37.968
18	23.368	15.615	32.0988
19	36.175	33.43	36.6875
20	30.735	27.473	36.6775
21	34.204	32.1217	38.16
22	30.6718	33.2689	21.57
23	32.5075	33.0017	19.37
24	19.1	22.89	23.07
25	15.085	15.825	19.38
26	11.995	19.38	4.61
27		3.49	
Delta	37.82	33.09	37.82
Rank	1.5	3	1.5

The graphs generated are as follows.

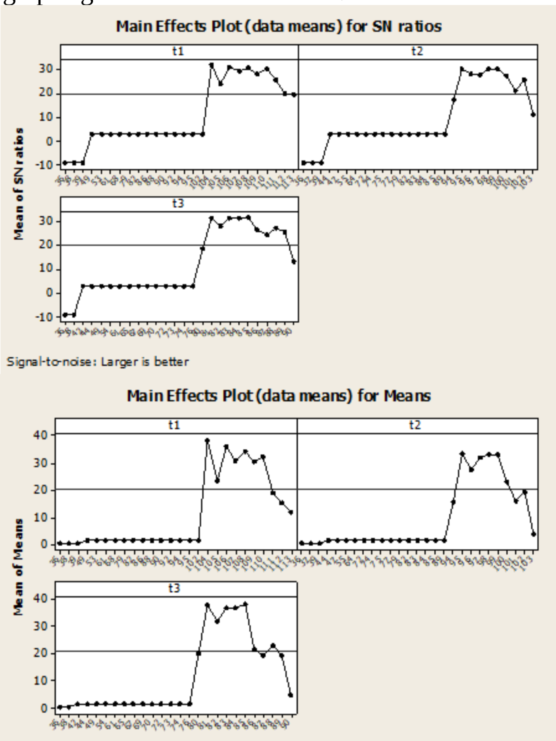

Fig. 7. Temp. Vs Moisture Removal Rate, Taguchi Graphs (II)

XI. REGRESSION ANALYSIS BETWEEN TEMPERATURES & MOISTURE REMOVAL RATE. (II)

Regression analysis was performed with moisture removal rate as the response & temperatures as the predictor. The following regression equation was obtained.

Total Water = - 23.9 - 2.41 t1 + 4.81 t2 - 1.88 t3 (4)

The following tabular form of regression was also obtained.

Table- XIV: Regression Analysis of Temperatures Vs Moisture Removal Rate (I)

Predictor	Coef	SE Coef	T	P
Constant	-23.888	9.526	-2.51	0.015
t1	-2.4088	0.9659	-2.49	0.016
t2	4.813	1.192	4.04	0.018
t3	-1.8764	0.7419	-2.53	0.014

The graphs generated are as follows.

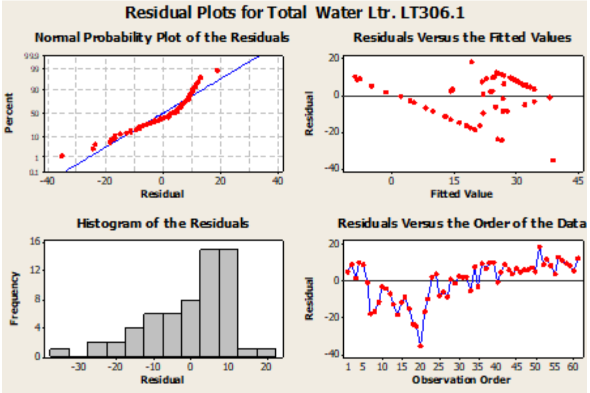

Fig. 8. Temp. Vs Moisture Removal Rate, Regression Graphs (II)

XII. RESULTS & DISCUSSIONS

The delta value and rank in Taguchi analysis (I) between temperatures and drying time is the same for the temperature of all layers of insulation as can be seen in tables 2 & 3. However, there are limitations due to which the outermost layer temperature cannot be further increased. Hence, it can be concluded that since there is still scope for increasing the innermost layer temperature, it will be the most influential on the drying time.

As can be clearly seen in table 4 for regression analysis (I) between temperatures and drying time that, P value for temperature of the innermost layer of insulation is minimum It can therefore be concluded that the temperature of the innermost layer is the most influential temperature for drying time.

As can be clearly seen in tables 5 & 6 for Taguchi analysis (I) between temperatures and moisture removal rate that the delta value & rank of the outermost & innermost layer temperature i.e t1 & t3 is same and is less than the values for t2. But, t2 cannot be increased independently and due to limitations on increasing the outermost layer temperature it cannot be increased further. Hence, it can be concluded that the temperature of the innermost layer is the most influential temperature.

It is clearly evident from table 7 for regression analysis (I) between temperatures and moisture removal rate that, P value for temperature of the innermost layer of insulation t3 is minimum & hence it is the most influential temperature on the moisture removal rate.

The delta value and rank in tables 9 & 10 for Taguchi analysis (II) between temperatures and drying time is the highest for the innermost layer temperature i.e t3. Therefore, it is clearly evident that, of all the temperatures, the innermost layer temperature of insulation has maximum influence on the drying time.

As can be clearly seen in table 11 for regression analysis (II) between temperatures and drying time that, P value for temperature of the innermost layer of insulation is minimum. It can therefore be concluded from regression analysis that the temperature of the innermost layer is the most influential temperature for drying time.

As can be clearly seen in tables 12 & 13 for Taguchi analysis (II), the delta value and rank between temperatures and moisture removal rate is the same for the temperatures t1 & t2. However, there are limitations due to which the outermost layer temperature cannot be further increased. Hence, it can be concluded that since there is still scope for increasing the innermost layer temperature, it will be the most influential on the drying time.

In table 14 it can be seen that the P value in regression analysis (II) between temperatures and moisture removal rate is minimum for temperature of the innermost layer of insulation t3 & hence it is the most influential temperature on the moisture removal rate.

XIII. CONCLUSION

Form the results of the Taguchi and Regression analysis obtained for vapour phase drying, it is clearly seen that, the temperature of the innermost layer of the insulation which is nearest to the transformer core is the most decisive temperature in reducing the overall drying time and increasing the moisture removal rate. The innermost layer temperature is predominant in positively influencing to reduce the drying time and increasing the moisture removal rate. It can therefore be concluded that if the temperature of the innermost layer of insulation is increased, the overall drying time may be reduced as, this increase in temperature will serve to increase the moisture removal rate.

ACKNOWLEDGMENT

The authors are immensely thankful to Chaitanya Electromagnets, MIDC, Waluj, Aurangabad for allowing to study and analyze the process of transformer insulation drying through vapour phase drying.

REFERENCES

1. Pierre Boss, Günter Rindlisbacher. "Practical experience with the drying of power transformers in the field, applying the LFH technology." CIGRE Session 2004. Paris, France: CIGRE, 2004. 1-8.
2. Anand Bhanpurkar, Ajay Bangar , Rajan Sharma, H.P.Tripathi. "Comparative analysis of moisture removing processes from transformer which are used to increase its efficiency." Global Journal of Researches in Engineering (Global Journals Inc. (USA)) 12, no. 5 (2012): 6-10.
3. "Water in Transformers" Rich Simonelli, Territory General Manager – Southeast SPX Transformer Solutions, Inc. Office 919-300-1522, Email Rich.Simonelli@spx.com
4. Diego F. García, Belén García, Juan Carlos Burgos. "Analysis of the influence of low-frequency heating on transformer drying – Part 1: Theoretical analysis." International Journal Electrical Power and Energy Systems (Elsevier) 38, no. 1 (June 2012): 84-89.
5. M D Wilkinson & P Dyer of Bowden Bros Ltd. UK "Continuous Moisture Management: Extending Transformer Service Life"
6. Stephanie Raetzke, Maik Koch & Martin Anglhuber "Monitoring the Drying Process of Power Transformers Using Dielectric Response Analysis"
7. Stefan Zabeschek & HelmutStrzala of Heidrich Vacuum Systems, Germany "Drying Of High Voltage Transformers In The Field With A Mobile Vapor Phase Drying Equipment"

AUTHORS PROFILE

Mohd. Tareq Siddiqui is a research scholar in Dr.Babasaheb Ambedkar Marathwada University, Aurangabad pursuing his research in vapour phase drying of transformer insulation.

Dr. Jayant T. Pattiwar .is a research guide in the faculty of science & technology in Dr.Babasaheb Ambedkar Marathwada University, Aurangabad. His area of specialization is design. He has a vast experience in industry as well as academia.

Dr. Avinash P. Paranjape is a professor emeritus in Govt. College of Engineering Aurangabad. He is a chartered engineer as well as a consultant for many industries in and around Aurangabad.

Dr. Ashok J. Keche is Head of the Department of Mechanical Engineering in MIT Aurangabad. His area of specialization is Machine Design and Manufacturing Engineering