QUALITY MONITORING OF INSTANT WHOLE MILK POWDER USING VARIOUS CONTROL METHODS

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Abstract – *Milk is one of the important fluids consumed widely all over the nation due to the health benefits on the body. Milk powders are the processed form of milk which are obtained by reducing the moisture content of milk with the help of various unit operations and unit processes. The work addresses the quality monitoring of the Instant Whole Milk Powder (IWMP) from the milk for which the simulation software VMGSim is used. The work also addresses the control tools that are used to monitor the quality which include Statistical Process Control (SPC), Design of Experiments (DOE), and Principal Component Analysis (PCA). The main objective of this research is to achieve the industrial parameters or composition of the milk powder.*

Key Words: Instant Whole Milk Powder, Quality Monitoring, Industrial Parameters, Statistical Process Control, Design of Experiments, Principal Component Analysis

1. INTRODUCTION

Milk is one of the most important fluid consumed widely all over the nation due to the health benefits on the body. Milk is composed of various chemicals and nutrients which include moisture content of 87.20% and rest total solids which include fat 3.7%, protein 3.5%, lactose 4.9% and ash 0.7%. Apart from these constituents, the milk is also a home to the calcium, phosphorus and fat-soluble vitamins which makes it the most perfect and healthy food (M.F.I kajal, 2012).

Moisture content is one of the important parameters which must be kept in mind while manufacturing milk powder as it can have a huge impact on the quality and the cost of the milk powder (Jingjing Yang, 2016). Milk powders are simply the processed form of milk which are obtained by drying milk with the help of various unit operations and unit processes which include heat exchangers, separators, evaporators, homogenizers, driers etc. Approximately 13 kg of the Instant Whole Milk Powder can be produced from 100 kg of milk (Rotronic Measurement Solutions).

With increasing technologies and process optimization techniques, the main purpose of the milk powder manufacturing companies is to produce the milk powder with minimum cost and maximum efficiency. The consumer does not want to compromise with the quality of the milk powder and thus, one of the main challenges before the manufacturing units is to produce the healthy milk powder by maintaining the right amount of constituents of the milk powder. This can only be achieved by using quality control techniques and quality analysis. The sample should be collected at regular intervals and the monitored in the lab for quality monitoring purposes. To achieve this, easiest way is to use control charts which include Statistical Process Control (SPC), Design of Experiments (DOE), and Principal Component Analysis (PCA) which will be the main area of focus in this article. Furthermore, the simulation software used for varying the industrial parameters to obtain control charts will be discussed.

1.1 Compositions of the Instant Whole Milk Powder (IWMP)

IWMP usually consists of moisture content not more than 5% and 95% total milk solids which mainly include fats, proteins and lactose. Vitamins like vitamin A and vitamin D may be added and, the emulsifying agent, soy lecithin may also be added in very small amounts not exceeding 0.5% (Canadian Dairy Commission, 2017). Table 1 shows the composition of the IWMP.

Table -1: Composition of IWMP

Composition of IWMP	
Principal Components	**%**
Lactose	36-38.5%
Fat	26-28.5%
Protein	24.5-27%
Moisture	2-4.5%
Ash	5.5-6.5%

2. METHODOLGY & SIMULATION SOFTWARE

2.1 Simulation Software

The simulation software used in this article is VMGSim developed by Virtual Materials Group. The software is based on thermodynamic principles which allows the formulation of solutions to chemical process problems from the industry. The thermodynamic engine of the software provides rigorous thermodynamic equilibrium and physical property estimation for industrially important systems.

Overall, the software is a very sophisticated chemical calculator that uses thermodynamic models to power its Gibbs Free Energy calculations and Gibbs phase rule to determine available degree of freedom for different unit operations. Figure 1 represents the model from VMGSim to produce IWMP from the standardized milk.

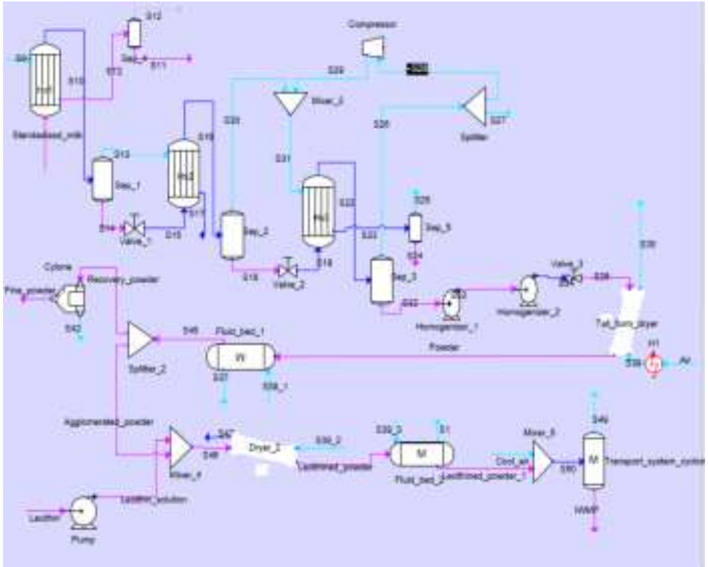

Fig -1: VMGSim model representing production of IWMP from standardized milk

Standardized milk stream with specific composition was introduced into the heat exchanger and the milk was heated using steam. The output stream was then passed through a separator which separates milk and steam. The steam separated is utilized again to heat the milk in another heat exchanger. The milk stream coming out of separator is passed through a pressure valve which controls the pressure of stream entering the heat exchanger. Similarly, the stream is passed through the third heat exchanger and the stream coming out from separator three is homogenized using two homogenizers. Homogenization helps in breaking down of Fat globules to give a uniform texture to the milk. Here, the water content of milk is present around 48% to 52%. After that the milk stream passes to the tall form dryer where the hot air is used to dry the milk to form milk powder. Powder from the drier is fed to fluidized bed drier where the fine powder separates out by passing from the cyclone separator and the agglomerated powder from the fluidized bed dryer is mixed with very small quantity of soy lecithin which is again fed to the dryer where the milk powder is further dried with the help of hot air and then the milk powder is fed into the mixer to reduce the temperature with the help of cold air. Soy lecithin is added in the milk to increase the dispersion ability of the milk powder. Finally, the separator separates the instant whole milk powder from the steam. The whole milk powder obtained is at room temperature.

2.2 Quality Control Attributes

In processing and manufacturing industries, quality control is the most important factor kept in mind while running any process. Quality includes eight dimension which are performance, reliability, durability, serviceability, aesthetics, features, perceived quality, and conformance to standards (Garvin, 1987). To monitor these quality parameters, control charts are used. Control charts used in this article are listed below:

- **Statistical Process Control (SPC)**

SPC is a powerful tool which is used to achieve process stability and improve capability of a process through the reduction of variability. SPC comprises of the Upper Control Limit (UCL) and the Lower Control Limit (LCL). All the points must lie in between these two control lines for the process to be in control and efficient (Montgomery, 2009).

• **Design of Experiments (DOE)**

Design of Experiments (DOE) is a systematic method which is helpful in determining the relationship between factors affecting a process and the process output. Simply, it is used to find the cause and effect relationship. Information obtained from the DOE is used to manage the process inputs so that the output parameters can be optimized as per the output product requirement (Sundararajan, n.d.).

• **Principal Component Analysis (PCA)**

Principal Component Analysis (PCA) is a dimension-reduction tool that can be used to reduce a large set of variables into a small set maintaining the information from the large set. It is a mathematical procedure that transforms several correlated variables into a number of uncorrelated variables called principal components. The main objective of PCA is to reduce attribute space from a larger number of variables to a smaller number of factors in a 'non-dependent' procedure.

3. RESULTS AND DISCUSSIONS

3.1 SPC

From the model as represented in figure 1, the values of temperature of feed milk or the standardized milk was varied from 75°C to 85°C (Poulsen, 2016) and also the temperature of feed steam or the steam required to heat the milk is varied from 135°C to 150°C (Aalaei, 2017). The temperature of dry air which was used to dry the milk in the tall form dryer was varied from 175°C to 185°C (Aalaei, 2017). Moisture content in IWMP varies from 2% to 4.5% by weight and the composition of total solids varies from 93.5% to 98% by weight (DMG Dairy Management Company, 2005). Therefore, our target value to be achieved should vary from 0.95 to 0.98 (basis-by weight).

By varying the temperatures of above described streams, the amount of total solids in the instant whole milk powder stream was obtained and the control charts for Statistical Process Control (SPC) were obtained. The control charts in SPC mainly included mean chart and range chart, also known as quality control charts for variables. Table 2 below represents the data for the statistical process control obtained.

Table -2: Data for SPC

	Number of Runs				
Samples	**A**	**B**	**C**	**D**	**E**
1	0.93235	0.94128	0.96744	0.94573	0.96914
2	0.94314	0.93592	0.96075	0.94666	0.96109
3	0.94284	0.94871	0.94932	0.94324	0.95674
4	0.95028	0.96352	0.93841	0.92831	0.95507
5	0.95604	0.92735	0.95265	0.94363	0.96441
6	0.95955	0.95451	0.93574	0.93281	0.94198
7	0.96274	0.95064	0.98366	0.94177	0.95144
8	0.9419	0.94303	0.96637	0.96067	0.95519
9	0.93884	0.97277	0.95355	0.95176	0.93688
10	0.94039	0.96697	0.95089	0.94627	0.9522
11	0.94158	0.97667	0.94278	0.95928	0.94181
12	0.95821	0.93355	0.95777	0.93908	0.97559
13	0.92856	0.94106	0.94447	0.96398	0.91928
14	0.94951	0.94036	0.95893	0.96458	0.94969
15	0.93589	0.92863	0.95996	0.92497	0.95471
16	0.95747	0.95301	0.95171	0.91839	0.98662
17	0.9368	0.97269	0.93957	0.95014	0.94449
18	0.94163	0.93864	0.93057	0.9621	0.95573
19	0.95796	0.94185	0.96541	0.95116	0.97247
20	0.97106	0.94412	0.92361	0.9382	0.97601
21	0.94371	0.95051	0.93485	0.9567	0.9488
22	0.94738	0.95936	0.96583	0.94973	0.9472
23	0.95917	0.94333	0.95551	0.95295	0.96866
24	0.96399	0.95243	0.95705	0.95563	0.9553
25	0.95797	0.93663	0.9624	0.93732	0.96887

The charts were plotted in MATLAB using command "st=controlchart (X,'chart',{'xbar','r'});". Chart 1 and chart 2 shows the mean chart and range chart respectively.

From chart 2, the UCL and LCL are approximately 0.07 and 0. The range chart is plotted between range and total number of samples on the Y-axis and the X-axis respectively. From chart 2, it can be observed that no point lies outside the LCL and UCL, therefore, it can be concluded that the process variability is in control and the mean chart or the $\bar{x}$ chart can be constructed.

From chart 1, the UCL and LCL are approximately 0.97 and 0.931 respectively. The mean chart is plotted between average of the sample size and the total number of samples taken on the Y-axis and the X-axis respectively. From the chart 1, it can be concluded that no point lies outside the upper control limit and lower control limit.

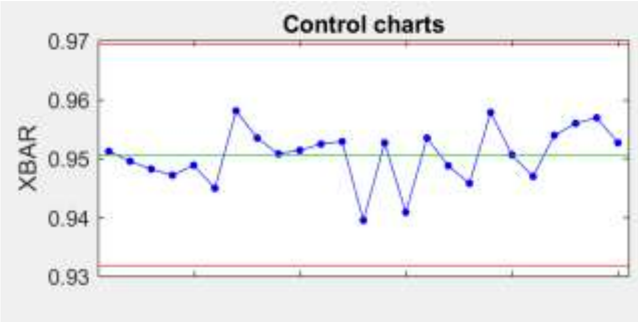

Chart -1: Mean Chart

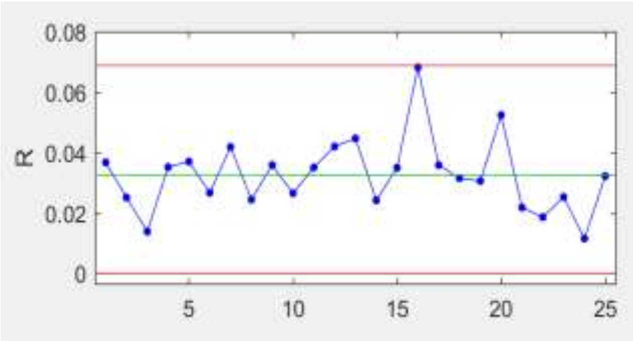

Chart -2: Range Chart

Therefore, both the charts exhibit good process control, we can conclude that the process is in control and is showing variations in between the target value set by the process i.e.0.955 to 0.98. Hence, the target value of the instant whole milk powder is achieved.

3.2 DOE

The design of experiment was performed by dividing the model in two halves. Firstly, the water content from the S32 stream after three stage evaporation was noted with 4 factors. Secondly, the drying stage was the second part of the model in which the 4 factors remained the same and the value of moisture content in the stream of instant whole milk powder was obtained. The design of experiments in this report had 4 factors with 1 replication for each part. The level of the model was selected as 2. So, the model in the design of experiment is represented by $n.m^k=1.2^4$.

Table 3 depicts the factors that were considered in plotting the QQ Plot and the normal plot with factors as stated.

Table -3: Factors for DOE

Factor	Name of Factor	Units	Low Level (-)	High Level (+)
A	Standardized milk temp.	°C	68	70
B	Standardized milk flow rate	Kg/h	16900	17100
C	Standardized milk water content	fraction	87	87.5
D	Steam pressure	kPa	430	470

Table 4 shows the full factor values of water content obtained from the S32 stream.

Table -4: Values of water content in S32 stream

Runs	Factors				Replications
	A	B	C	D	S32 water content
1	-1	-1	-1	-1	0.07356
2	1	-1	-1	-1	0.13785
3	-1	1	-1	-1	0.28197
4	1	1	-1	-1	0.28197
5	-1	-1	1	-1	0.26967
6	1	-1	1	-1	0.25036
7	-1	1	1	-1	0.28196
8	1	1	1	-1	0.2643
9	-1	-1	-1	1	0.06642
10	1	-1	-1	1	0.03778
11	-1	1	-1	1	0.15467
12	1	1	-1	1	0.27522
13	-1	-1	1	1	0.13758
14	1	-1	1	1	0.03778
15	-1	1	1	1	0.0413
16	1	1	1	1	0.15444

From this table, the various variables were calculated such as the contrast, the main effect, the interaction effect and the sum of squares. From the Analysis of Variance (ANOVA) table (table 5), the F value from the F distribution table was obtained at α=0.25, degree of freedom for numerator is 1 and the degree of denominator is 16. The F value from the F distribution table was 1.16. So, all the effects were considered which were greater than or almost near to the value of 1.16 and those factors had the significant effect. The factors which had significant effect were main effect B, main effect D and the interaction effect BD. After constructing the linear model and calculating the residuals, the QQ plot and the normal plot were plotted on MATLAB by copying all the residuals into the MATLAB variable and naming it as 'Y'. The command used for QQ plot in MATLAB is 'qqplot (Y)' and for normal plot the command in the MATLAB was 'normplot (Y)'. Dominating effects considered are B, D and BC.

Table -5: ANOVA table

ANOVA Table				
Source	Sum of squares	Degree of freedom	Mean square	Computed F-value
A	0.0005492	1	0.0005492	0.0283644
B	0.0164180	1	0.0164180	0.8479227
C	0.0005116	1	0.0005116	0.0264219
D	0.0274043	1	0.0274043	1.4153150
AB	0.0028029	1	0.0028029	0.1447600
AC	0.0010105	1	0.0010105	0.0521925
AD	0.0001897	1	0.0001897	0.0098015
BC	0.0124666	1	0.0124666	0.6438459
BD	3.33949E-05	1	3.33949E-05	0.001724701
CD	0.006439139	1	0.006439139	0.332553654
ABC	0.000525609	1	0.000525609	0.027145443
ABD	0.005638424	1	0.005638424	0.29120017
ACD	1.60886E-05	1	1.60886E-05	0.000830908
BCD	1.37681E-05	1	1.37681E-05	0.000711064
ABCD	1.49878E-07	1	1.49878E-07	7.74056E-06
Error	0.309803309	16	0.019362707	
Total	0.383823023	31		

Chart 3 and 4 shows the QQ plot and normal probability plot respectively for the S32 water content.

QQ plot is a quantile-quantile plot which is a graphical method for comparing two probability distributions. A point on the plot corresponds to one of the quantiles of the second distribution. From the charts, the points on the line do not have any significant effect on the process but the points that are farther from the line shows a significant effect on the process and this can be due to the inconsistency errors of the process. The important effects emerging from the analysis are the interaction effects of AB, AC, AD, BC, ABC & ABCD.

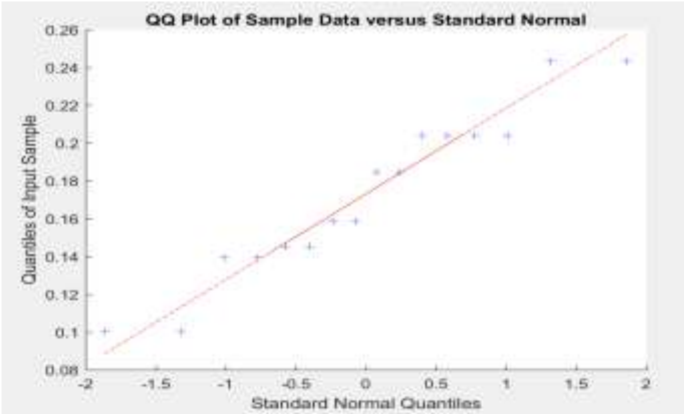

Chart -3: QQ plot for S32 water content

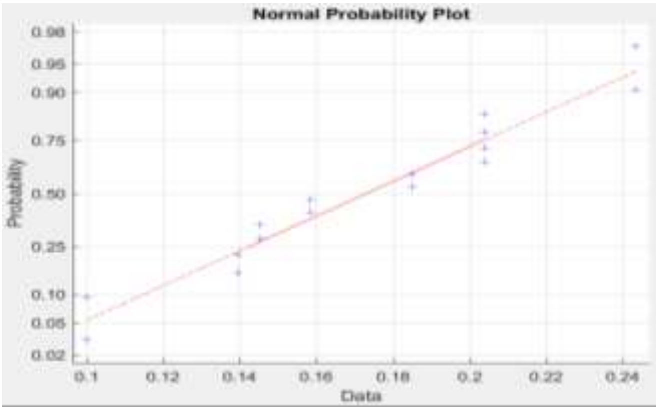

Chart -4: Normal plot for S32 water content

Table 6 shows the full factor values of water content obtained from the IWMP stream. Table 7 shows the ANOVA table.

Table -6: Values of water content in S32 IWMP stream

Runs	Factors				Replications
	A	B	C	D	S32 water content
1	-1	-1	-1	-1	0.00549
2	1	-1	-1	-1	0.00595
3	-1	1	-1	-1	0.0106
4	1	1	-1	-1	0.0106
5	-1	-1	1	-1	0.00998
6	1	-1	1	-1	0.00907
7	-1	1	1	-1	0.32375
8	1	1	1	-1	0.32326
9	-1	-1	-1	1	0.3355
10	1	-1	-1	1	0.00823
11	-1	1	-1	1	0.33149
12	1	1	-1	1	0.02197
13	-1	-1	1	1	0.33628
14	1	-1	1	1	0.00823
15	-1	1	1	1	0.00823
16	1	1	1	1	0.30085

Table -7: ANOVA table

ANOVA Table				
Source	**Sum of squares**	**Degree of freedom**	**Mean square**	**Computed F-value**
A	0.014160762	1	0.014160762	0.711920373
B	0.011705265	1	0.011705265	0.588472329
C	0.010871489	1	0.010871489	0.546554919
D	0.01328776	1	0.01328776	0.668030941
AB	0.012735282	1	0.012735282	0.640255566
AC	0.011231258	1	0.011231258	0.564642017
AD	0.014081776	1	0.014081776	0.707949426
BC	0.010261714	1	0.010261714	0.515899009
BD	0.013753941	1	0.013753941	0.691467763
CD	0.014323628	1	0.014323628	0.720108297
ABC	0.011392951	1	0.011392951	0.572771018
ABD	0.012738474	1	0.012738474	0.640416046
ACD	0.011371074	1	0.011371074	0.571671159
BCD	0.013751453	1	0.013751453	0.691342695
ABCD	0.01132663	1	0.01132663	0.569436776
Error	0.318254964	16	0.019890935	
Total	0.50524842	31		

Chart 5 and 6 is the representation of QQ plot and normal plot for the IWMP water stream.

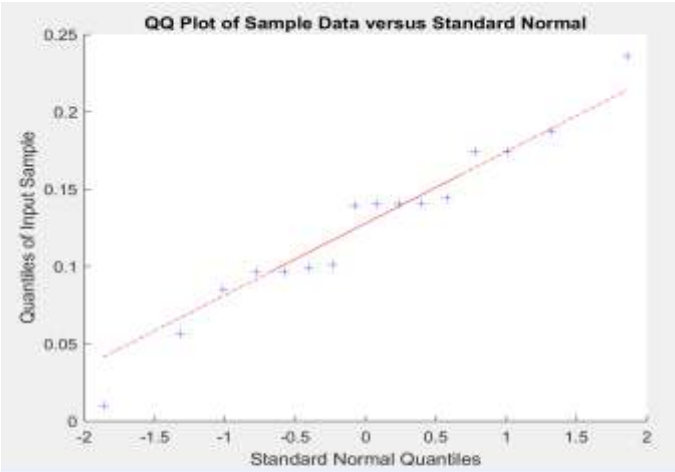

Chart -5: QQ plot for IWMP water content

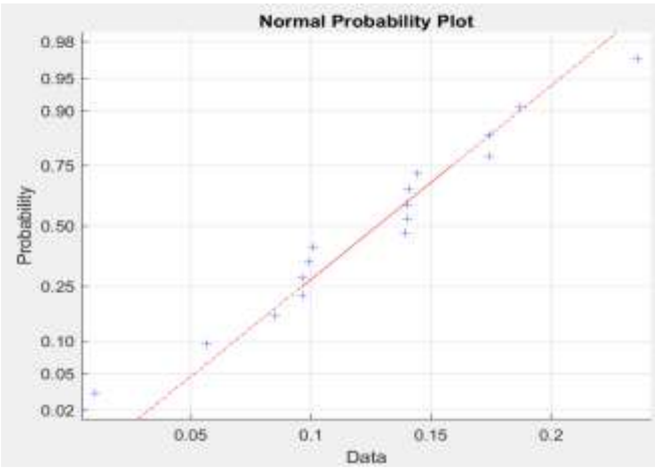

Chart -6: Normal plot for IWMP water content

From charts 5 & 6, it is observed that only 2 points are very far away from the line and hence, they contribute to a significant effect in achieving the moisture content of milk powder IWMP. These points are effects of C and interaction effect ABCD. However, the maximum points on the line confirm that the target value of moisture content of around 2% to 5% is achieved.

3.3 PCA

Figure 2 represents the data for plotting PCA. The PCA was plotted in the MATLAB using a PCA code.

Milk Temperature	Milk Flow	Steam Pressure	Steam Flow Rate	Water Content 532	Air Flow	Water Content After Dryer 1	Fluid Bed Air Flow	Dryer 2 Air Flow	Cool Air Flow	IWMP Water Content
48.7	17320	228.65	10030	0.49929823	33490	0.044557042	360	425	440	0.023411595
48.7	17320	228.55	10030	0.49011744	33490	0.044625058	360	425	440	0.023479598
48.8	17329	232	10083	0.498809874	33480	0.043177844	260	515	543	0.021872702
48.8	17329	232	10083	0.498809874	33490	0.042944744	235	480	543	0.022187566
48.8	17329	225	10088	0.499103721	33480	0.044220329	300	560	543	0.022210857
50	17320	228	10085	0.498128646	33500	0.040868608	250	500	528	0.020045138
50	17320	228	10085	0.498128646	33500	0.040868608	250	530	500	0.020051903
50	17320	228	10085	0.498128646	33500	0.040868608	230	530	528	0.020126158
50	17320	228	10085	0.498128646	33500	0.040868608	250	500	500	0.020186647
50	17320	228	10085	0.498128646	33500	0.040868608	230	500	528	0.020241123
50	17320	228	10085	0.498128646	33500	0.040868608	230	530	500	0.020248523
50.03	17320	228.2	10085	0.498233836	33490	0.040577321	230	530	528	0.019880257
50.03	17320	228.1	10085	0.498251464	33490	0.040640323	230	530	528	0.019860181
50.03	17320	227.8	10085	0.49830694	33490	0.040808163	230	530	528	0.020040873
50.03	17320	227.8	10085	0.49830694	33490	0.040808163	230	500	528	0.020212954
50.03	17320	227.8	10085	0.49830694	33490	0.040808163	230	500	500	0.020335113
50.07	17320	228.4	10085	0.498117752	33490	0.04037116	260	530	370	0.020153367
50.07	17320	228.2	10085	0.498154568	33490	0.040380759	260	530	370	0.020273668
50.1	17320	228.5	10085	0.498040281	33490	0.039898746	360	530	370	0.019899868
50.1	17320	228	10085	0.498132819	33490	0.040224185	360	500	400	0.020143496
50.1	17320	228	10085	0.498132819	33490	0.040224185	360	500	400	0.020143496
50.2	17320	228.6	10030	0.498332544	33490	0.041113661	450	450	50	0.0235384
50.3	17320	228	10085	0.497740881	33480	0.039259835	340	530	528	0.018551802
50.5	17325	233	10080	0.498135333	33500	0.040425758	230	500	500	0.019948137
52	17320	228	10085	0.494361333	33480	0.027976325	250	520	528	0.008893252

Fig -2: PCA Data

Chart 7 is the bar chart for PCA component number. From chart 7 it is observed that the milk temperature has very significant effect on the IWMP moisture content where as other factors have dominant effect on the principal component number. Chart 8 is the variance accumulation graph which shows the variation of about 85% in the process which signifies that the target value of the moisture content in IWMP stream can be achieved.

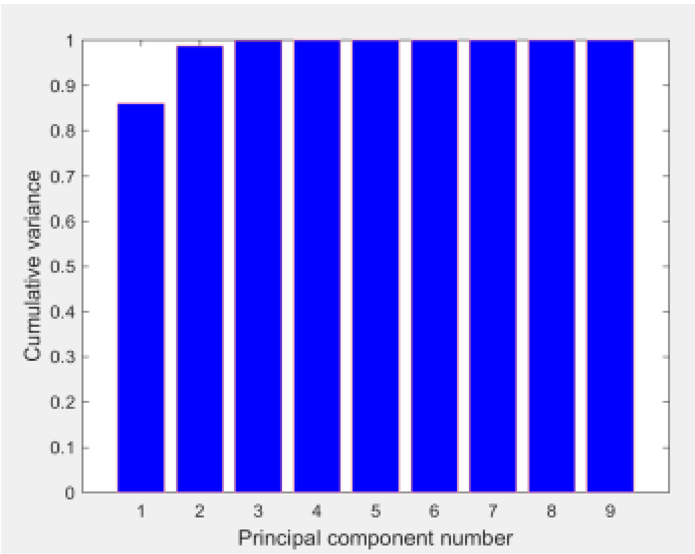

Chart -7: Bar chart for PCA

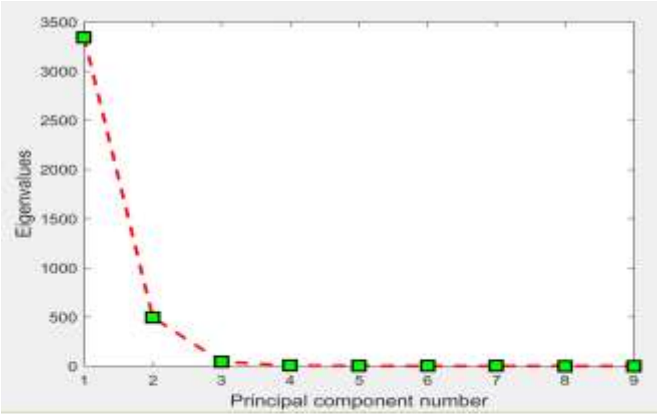

Chart -8: Variance accumulation graph

Chart 9 is the score plot for PCA which helps to select the right values and cutting down on the complex calculations, making the process easier. Chart 10 is the loading plot. The score plot and loading plot are compared and the conclusions from the data can be withdrawn as how much upset is the process.

From chart 9, there are 4 outliers viz. 2, 5, 22 & 4 and they can be due to the inconsistency in the process and hence, they can be neglected as they will upset the process and make the process deviate from the target value of the moisture content of IWMP. This will result in the poor quality of the milk powder with higher moisture content and this is not desirable. The loading plot helps in the prediction of each variable with each physical component. From chart 10, the group formed at the intersection of the line provides a significant information about the IWMP water content and the outliers does not provide any significant information,

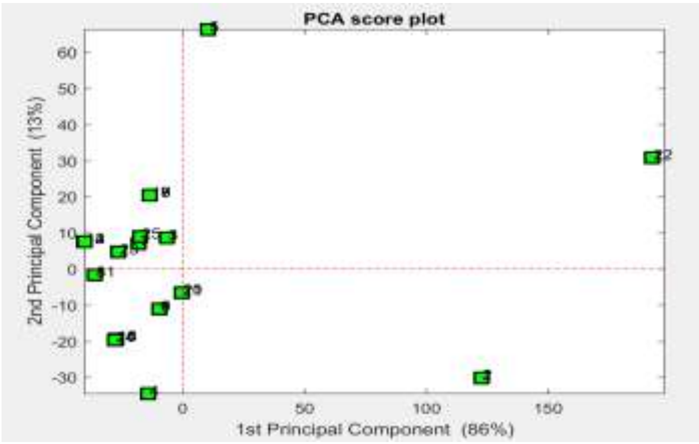

Chart -9: PCA score plot

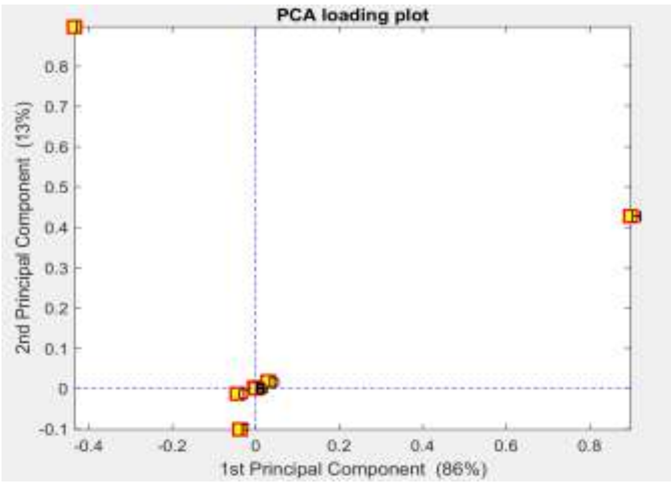

Chart -10: PCA loading plot

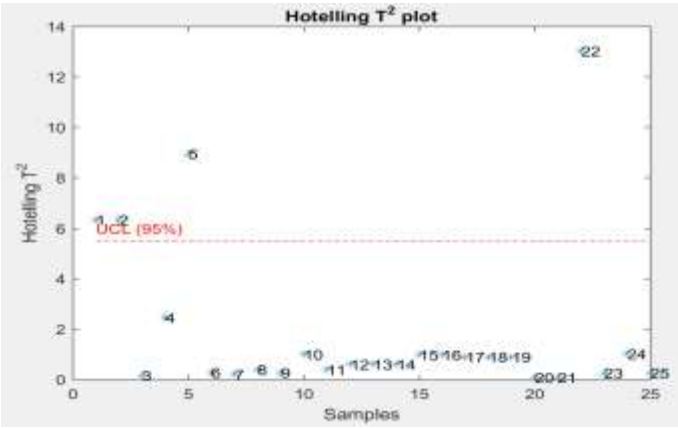

Chart -11: PCA hotelling T^2 plot

Chart 11 is the Hotelling T^2 plot which shows UCL of 95% and confirms that 4 outliers above the UCL does not contribute in the process and can be neglected from the PCA data. Also, from chart 11, the process is in control and hence, we can say that our target value for the moisture content in the IWMP is achieved.

4. CONCLUSIONS

Table 8 shows the industrial parameters in which the values obtained from the simulation software and industrial values for IWMP do not contradict each other.

Table -8: Industrial parameters

Composition	Milk	Milk Powder	Steam	IWMP Content (from model)
Moisture	87.2%	2%-5%	-	4%
Protein	3.5%	24.5%-27%	-	22%
Fats	3.7%	26%-28.5%	-	30.1%
Lactose	4.9%	36%-38.5%	-	40%
Pressure	-	-	11-17 bar	-
Temperature	75-85°C	-	140°C	-

From SPC, the value of total solids in the milk powder was found out to be varying between 94% to 96% (weight by weight basis) which means the moisture content is around 4% to 6% (weight by weight basis). From DOE, the moisture content value in the IWMP stream was found out to be around 4% to 6% (weight by weight basis). From PCA, after eliminating the outliers, the IWMP water content was in control and all these values are similar as per the industrial parameters. Hence, the conclusion can be drawn that the quality of the instant whole milk powder is under control which is beneficial both for the consumers and the industry. As the target value is achieved, the process needs no further optimization because the process is in control.

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BIOGRAPHIES

Being impromptu is what relates me but giving my work in an organized manner is my attitude. Working on new things and discovering them is my passion. Perseverance and being practical is what I work upon to define me.

Patience, attitude and discipline are the traits that completely define me. Hardwork and enthusiasm to work is my nature. Exploring and working on new things and gifting them to the world in the form of writing is my passion.