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Competitive strategies for operational excellence in optimization of enzymatic conversion of native starch cooking for size press application


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Abstract: ***Cost effective and flexible use of starch at the size press is significant to optimize in an environment of rising costs and resource limitations. Enzymatic conversion of starch for size press application can offer fully acceptable and satisfactory results at an advantageous cost. Despite these advantages, potential problems such as cooking of native starch, variation in viscosity, solid content, selection and deactivation of enzyme are challenges in the conversion process and application as well.***

TNPLs approach towards the process of optimization of native starch cooking with enzyme by driving Manufacturing Excellence concepts, methodologies, techniques, and unique tools enabled the various dimensions of the strategy to achieve operational excellence in addressing the risk factors, which are contributing the enzymatic conversion of native starch. This methodical concepts and tools have expedited the meticulous and pooled factors such as method of cooking, storage of cooked starch, temperature controls, deactivation of enzyme and enzyme activity. The methodologies adopted were promising and ensuring the consistent quality of the starch supply to the size press and thereby paper. Thus derived methodologies with systematic approaches are sustainable and provide a comprehensive model with clear roadmaps.

Introduction to- Manufacturing Excellence:

To ensure sustainable profitable growth in a highly price-sensitive appliance market, cost reduction through Manufacturing (operational) excellence is the key imperative. The methodology followed included the following:

Engage all employees to make deliberate improvements that lead to sustained results with increased value and satisfaction to our customers.

Optimize costs by improving the systems and practices that reduce consumption, increase process reliability, minimize process variations and maximize Process efficiencies and ensure sustainability. It means the Deliberate Improvements (improvement activities that are chosen using a structured process and operations and business activities to ensure they align with strategic goals) focusing on and prioritizing the "Right things" by using all the resources to achieve sustained results.

Our goal is to operate efficiently today and to find ways to run even better tomorrow. The ME principles combine long-held industrial practices with unique tools and skill sets. ME has integrated the use of modern quality management systems and techniques, the expectation for data-based decision making, the respect for standard work systems, and the reliance on structured problem-solving techniques into our manufacturing processes and business activities

Six sigma, one of the ME tools, is a quality improvement program that looks at processes with a view to analyzing process steps, determining what process elements need improvement, developing alternatives for improvement, then selecting and implementing one. It relies on a variety of qualitative and quantitative tools, emphasizing the use of data and statistical analysis

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with in a method called DMAIC, an acronym for the names of its five phases (Define, Measure, Analyze, Improve, and Control)

This case study illustrates the application of six sigma process on the improvement of products in manufacturing process. TNPL approached the process of optimization of native starch cooking with enzyme by driving preliminary concepts of Manufacturing Excellence, methodologies, techniques, and unique tools that enabled the various dimensions of the strategy to achieve operational excellence.

This methodological concepts and tools have expedited the meticulous and pooled factors such as method of cooking, storage of cooked starch, temperature controls, deactivation of enzyme and enzyme activity. The methodologies adopted were promising and ensuring the consistent quality of the surface starch supply to the size press and thereby paper quality.

Application of SIX Sigma methodology :

A Six Sigma project typically begins with a high level definition of a process, using a diagram to specify the process boundaries, inputs, outputs, customers, and requirement. In the Measure phase, a process metric is selected and used to baseline the current performance of the process. In the Analysis phase, the process is analyzed, usually with a process map and a failure modes and effects analysis (FMEA), but may include other types of analysis also. The process map shows each process step with its inputs and outputs and provides the basis for either a FMEA or a quantitative, usually statistical, analysis. Areas for improvement are pinpointed and alternatives are generated and evaluated. Once an improvement option is selected and implemented, the project enters the Control phase. In this phase, a plan is established for monitoring and controlling the process to ensure that gains are maintained.

The model of standard DMAIC method is given in the Table1.0

Table 1.0 DMAIC Method for Process Improvement

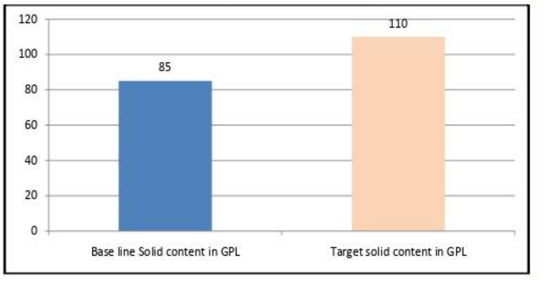
1	Define	Define - Identify an opportunity and define a project to address it
2	Measure	Measure -Analyze the current process and specify the desired outcome.
3	Analyze	Analyze - Identify root causes and proposed solutions.
4	Improve	Improve - Prioritize solutions; select, plan, validate, and implement a solution.
5	Control	Control - Develop a plan for measuring progress and maintaining gains.

Define Phase

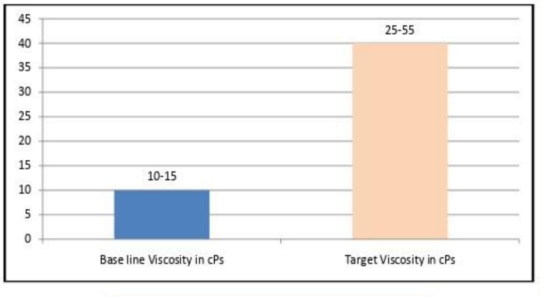
The definition of the problem is given by following template.

Project Background	As the cost of the application of surface starch on paper at size press is high and solely depends on the cost of the oxidized starch, modern paper mills have been switching over to enzymatic conversion of the native starch. Though this conversion of the starch facilitates the requirement of the surface sizing, operational problems related to cooking of raw native starch, controlling the desired viscosity, maintaining the higher solids and thereby increasing the coat weight is highly stringent one. TNPL is one among the paper mill which is using enzymatic conversion of native starch for the size press application successfully since last ten years.
Problem Statement	TNPL is facing issues regarding the stability & sustainability of the size press starch Parameters - a) Starch viscosity, b) Starch solids. Some variations in viscosity & GPL were seemed to be present in the existing process, which is ultimately impacting the final paper quality.
Project Y	Stability, sustainability and improvement of the size press starch parameters Starch viscosity, b) Starch solids.
Key Metric	Starch viscosity in cPs, Starch solids in gpl.
Project Goal	Optimization of surface starch cooking and size press application.

Base line and target objectives of the project



Base line solid content in GPL	Target solid content in GPL
85	110



Base line Viscosity in cPs	Target Viscosity in cPs
10-15	25-55

Financial benefits of the project

The following are the hard and soft savings expected.

Hard savings

Fibre savings

Steam savings

Soft savings (Indirect benefits)

Print quality increase

Improvement of morale of team

Effective utilization of resources

SIPOC- details of the project

S	I	P	O	C
SUPPLIERS	INPUT	**PROCESS**	OUTPUT	CUSTOMERS
Starch Suppliers	Native starch	**CAP**	Cooked Native starch	stock preparation
refining	refined pulp, chemicals	**STOCK PREPARATION**	furnished pulp	approach flow
stock preparation	Furnished pulp, Chemicals	**APPROACH FLOW**	screened and cleaned stock	wire part
wire part	wet web	**PRESSING**	pressed wet web	pre dryer
press part	wet web	**PRE DRYING**	pre dried sheet	size press
pre dryer	pre dried sheet	**SURFACE SIZING**	surface sized wet web	post dryer

The VOC and CTQ parameters of the project is given the following table 2.0

Table 2.0

Enzymatic conversion of native starch by cooking for size press application.		
Primary Customer & Stakeholders	**Voice of Customer (VOC)**	**Critical To Quality (CTQ)**
Stock preperation: Fiber reduction & optimization of starch conversion.	Reduce Fiber cost, consistent starch quality.	Fiber Cost reduction & consistent GPL & VISCOSITY.
Process Owner Project: Optimization of Native starch parameters.	GPL & VISCOSITY variation reduction.	Fiber reduction. Consistent coat weight on paper for quality printing.
Customer Project: Product Quality improvement	Product (Paper) Strength	Strength of paper as per specification. Avoiding Fluff generation. Printing quality

Figure 1.0 AS-IS Flow diagram of the TNPL-Paper Machine process

CHEMICAL ADDITIVE PLANT	Dispersing tank	Cooking tank	Storage tank 1	Storage tank 2		
STOCK PREPARATION	Refined Pulp in Storage Chest	High Speed Mixture(OBA, Broke, Dyes)	Receiving Chest	Machine Chest		
APPROACH FLOW	Centricleaners	Fan Pump	Pressure Screen	Head Box	Wire Part	
	Filler Addition	AKD & Sizing Chemicals	Addition of CPAM BentoFloc & APAM.			
PRESSING	Wet Web	1ST & 2ND Press	3rd Press	Pressed Wet Web		
DRYING	1st Group	2nd Group	3rd Group	4th Group	Speed Flow	5th Group
CALENDERING	Dried Sheet	Calendar Rolls Surface Finished Paper	QCS Scanner	Pope Reel		

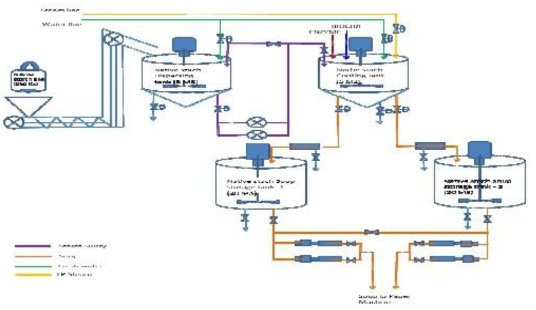


Figure 2.0 AS-IS Process Flow Diagram of starch cooking process (CAP)

Fish bone diagram

The possible factors that affects the performance of the enzymatic converted starch application in size press is given by the following fish bone diagram in Fig 3.0. Out of the all factors, prioritizing has been done with a potential team and is given by the table

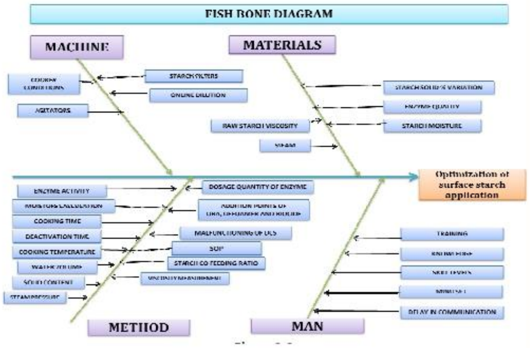


Figure 3.0 Fish bone diagram

Measure Phase

In Measure phase, after prioritizing the factors, through Pareto analysis chart major factors have been decanted to focus and made the why-why analysis.

Table 3.0 Prioritization of the factors

S.NO	(X's)	Category	Team Mem 1	Team Mem 2	Team Mem 3	Team Mem 4	**Total**
1	DOSAGE QUANTITY OF ENZYME	METHOD	9	9	9	9	**36**
2	DEACTIVATION TIME	METHOD	9	9	9	9	**36**
3	SOLID CONTENT	METHOD	9	7	9	9	**34**
4	DEACTIVATION TEMP	METHOD	7	7	9	7	**30**
7	COOKING TEMPERATURE	METHOD	7	7	7	9	**30**
6	SOP	METHOD	7	7	9	7	**30**
5	COOKING TIME	METHOD	7	7	7	7	**28**
8	KNOWLEDGE	MAN	5	5	7	7	**24**
9	ONLINE DILUTION	MACHINE	3	5	3	3	**14**
10	STARCH SOLID VERIATION%	MATERIAL	3	3	3	3	**12**
13	ENZYME ACTIVITYT	METHOD	3	1	5	3	**12**
14	MIND SET	MAN	5	1	1	5	**12**
18	STARCH Ph	MATERIAL	3	3	3	3	**12**
11	VISCOSITY MEASUREMENT	METHOD	3	3	1	3	**10**
12	AGITATORS	MACHINE	1	3	3	3	**10**
15	STARCH MOISTURE	MATERIAL	3	1	3	3	**10**
19	ADDITION POINTS OF DEFOAMER,BIOCIDE	METHOD	1	3	3	3	**10**
17	DELAY IN COMMUNICATION	MAN	1	3	1	3	**8**
16	STARCH FILTERS	MACHINE	1	1	1	3	**6**

Out of 16 factors, 8 factors Dosage quantity of enzyme, enzyme deactivation time of starch, target solid content, deactivation temperature, cooking temperature, standard operating procedure followed in terms of processing the starch, cooking time with respect to steam addition and knowledge of operating crew were found to be playing a vital role in controlling the quality of the service.

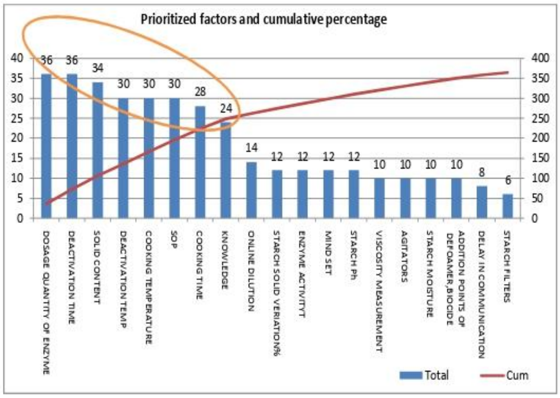


Figure 4.0 Pareto-chart of the prioritized factors

The list of prioritized factors are given by the table 4.0

Table 4.0

Primary Metric	STARCH VISCOSITY IN Cps	
Secondary Metric	STARCH SOLIDS IN GPL	
Prioritized Factors (Xs)		
1.DOSAGE QUANTITY OF ENZYME	2. DEACTIVATION TIME	3. SOLID CONTENT
4.DEACTIVATION TEMP	5. COOKING TEMPERATURE	6. SOP
7.COOKING TIME	8. KNOWLEDGE	

Process/Product Failure Modes And Effects Analysis (FMEA)

Failure Mode and Effects Analysis (FMEA) is a structured approach to discovering potential failures that may exist within the design of a product or process.

Table 5.0 FMEA analysis of the current project

PROCESS	POTENTIAL FAILURE MODE	POTENTIAL OF FAILURE EFFECTS	SE	Potential causes	OCC	CURRENT CONTROLS	DET	RPN	ACTIONS RECOMMENDED
Enzyme Deactivati on	Low Retention Time & Temperature	Low Viscosity or High viscosity of the Starch causes Breaks or low strength of paper.	9	Poor skill & knowledge. No Precised Measurement of Retention Time & temperature	7	No proper steam pressure control to maintain temperature.	3	189	Controlled steam pressure to be maintained.
Enzyme Dosage.	Low or High dosage	Low Viscosity or High viscosity of the Starch causes Breaks or low strength of paper.	9	Poor skill & knowledge. No Precised Measurement of Enzyme dosage.	7	No precised measurement.Manual Measurement of Enzyme Dosage	3	189	Precised Measurement of Enzyme dosage is being done with micro pipette.

Analyze Phase

Regression analysis

The statistical data of processing of native starch conversion by enzyme has been obtained for all factors such as cooking time, solid content, deactivation temperature, deactivation time and starch viscosity. Using outcome variable and co-varieties the correlation was obtained.

The relationship between solid content and viscosity of the starch is given the fig. 5.0. From the graph, it reveals that the significant relationship between the solid content and viscosity of the starch has been noticed.

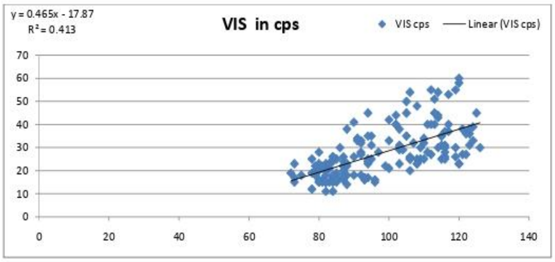


Figure 5.0 Relationship between Solid content and viscosity

The correlation between cooking time and viscosity and similarly correlation between cooking temperature and viscosity is given in figure 6.0 and figure 7.0 respectively. Both the regression shows the typical correlation between cooking time and cooking temperature against viscosity.

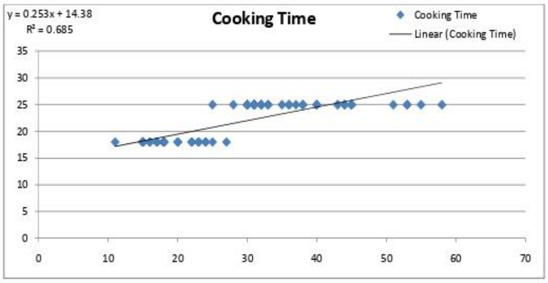


Figure 6.0 Relationship between cooking time and viscosity

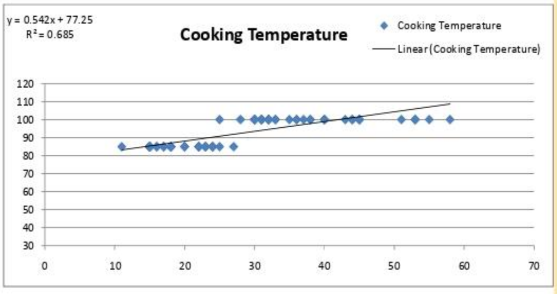


Figure 7.0 Relationship between cooking temperature and viscosity

WHY-WHY Analysis of the prioritized factors:

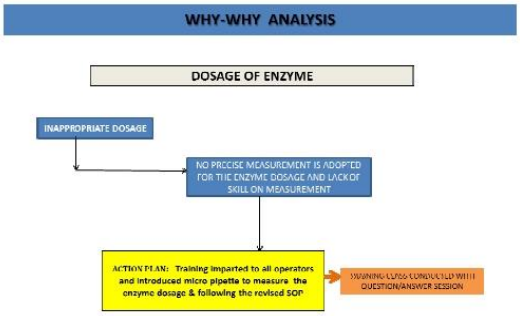


Figure 8.0 Why-Why analysis of dosage of enzyme

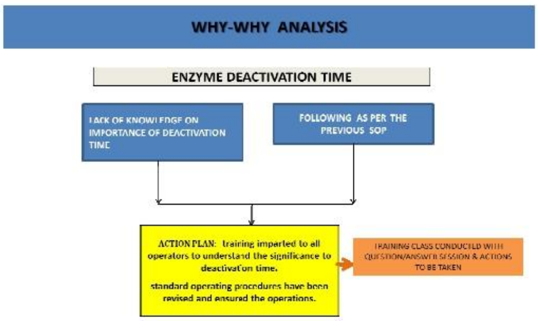


Figure 9.0 Why-Why analysis of enzyme deactivation time

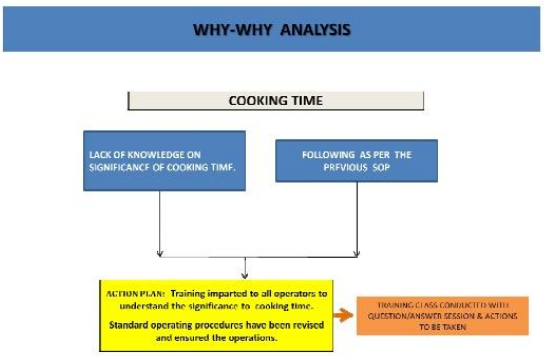


Figure 10.0 Why-Why analysis of cooking time

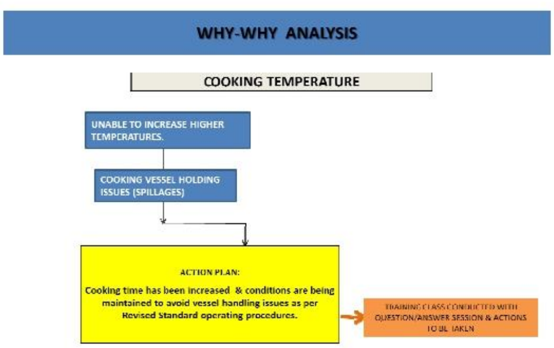


Figure 11.0 Why-Why analysis of enzyme deactivation temperature

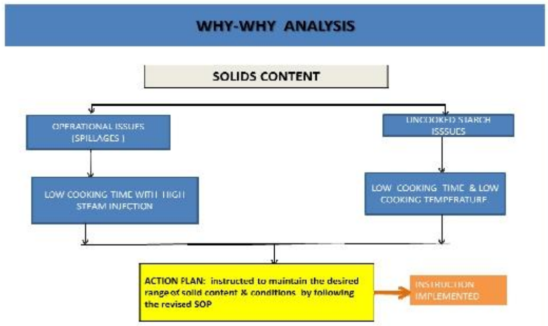


Figure 12.0 Why-Why analysis of the solid content

Identify Vital Xs & Evaluate Impact:

Evaluation of impact of prioritized vital factors are given the table 6.0

Table 6.0 Evaluation of impact of prioritized vital factors

S.No	Vital X	impact on end product quality	H/M/L	% Contribution On Y
1	Dosage Of Enzyme	poor or inconsistent surface strength	H	15
2	Deactivation Time	poor or inconsistent surface strength	H	10
3	Deactivation Temperature	poor or inconsistent surface strength	H	25
4	Solid Content	More Fibre Consumption	H	10
5	Cooking Temperature	poor or inconsistent surface strength	M	10
6	Cooking Time	poor or inconsistent surface strength	H	15
7	Sop	poor or inconsistent surface strength	M	10
8	Knowledge	poor or inconsistent surface strength	M	5

Improvement Phase

Improvement Objective: Optimization of Native starch Viscosity 10-15 cps to 25-55 cps & Solids 85.0 gpl to 110.0 gpl on an average.

There is a scope to fine tune the process parameters by improving supervision level without affecting the product specifications to make the good quality product for the customer satisfaction & organization benefit.

Prioritize Solutions: To sustain and optmise the enzymatic conversion of starch, the prioritized solutions has been derived as follows (see Table 7.0)

After optimization of the derived factors, the following results were obtained.

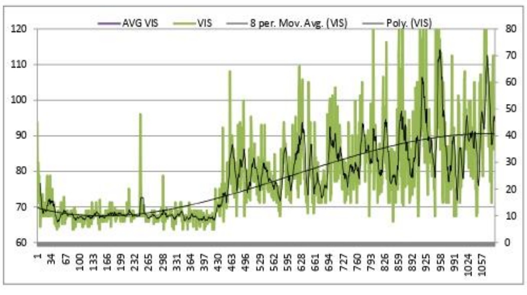


Figure 13.0 Trend of the viscosity before and after optimization

Table 7.0 prioritized solutions

Vital X	Solution	Impact on Process	Easy/Difficult Implementation	Cost of Implementation	Decision
Dosage Of Enzyme	Dosage of enzyme has been fine tuned and dosed with help of micro pipette	H	Easy	Low	
Deactivation Time	Deactivation time increase from 5 minutes to 10Minutes	H	Easy	Low	
Deactivation Temperature	Steam pressure control valve has to be incorporated in the system and Temperature is to be maintained as per SOP	M	Difficult	High	
Solid Content	Desired solid content is to be maintained	H	Easy	Low	
Cooking Temperature	Constant Cooking temperature is to be maintained as per SOP	H	Easy	Low	
Cooking Time	Cooking time extended by gradual increase of supply steam	M	Easy	Low	
Sop	Strict follow up of SOP is to be ensured	H	Easy	Low	
Knowledge	Proper training and knowledge updating of operating crew is be ensured	M	Easy	Low	

Table 8.0 Implement final solution

Sl.No	Critical Factors	Tool	Root Cause	Action Plan
1	Starch Solids Regression	Why-why	Low solids	Revised SOP
2	Cooking Time Regression	Why-why	Low Cooking time	Revised SOP
3	Cooking Temperature Regression	Why-why	Low cooking temperature	Revised SOP
4	Enzyme dosage	Why-why	High Dosage	Revised SOP
5	Deactivation Time	Why-why	More Retention time	Revised SOP
6	Knowledge	Training	-	-

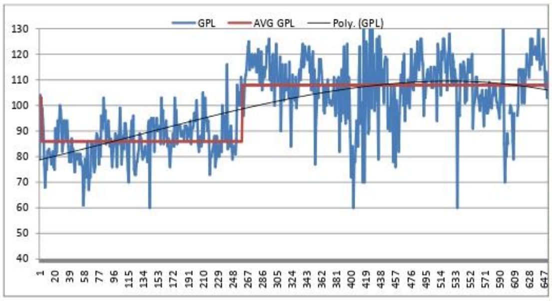


Figure 14.0 Trend of the solid content before and after optimization

Table 9.0 Standard operating procedure after optimization

SOP	Cooking temperature ^{0}C		Cooking Time @ 42-92^{0}C	Deactivation temperature ^{0}C	Deactivation time	Enzyme quantity dosage
	Initial	Final	Minutes		Minutes	ml
Before optimization	42	85	18	85	2	1-6
After optimization	42	100	25	100	10	0.5 -3.0

Control Phase

At the outset, the following (Table 10.0) control plan has been arrived for the concerned issues.

Table 10.0 Control Plan

CHARACTERISTICS			METHODS					CONTROL METHOD
SL NO.	PRODUCT	PROCESS	PRODUCT / PROCESS SPEC. / TOLERANCE	POTENTIAL RISK	EVALUATION / MEASUREMENT TECHNIQUE	SAMPLE SIZE	SAMPLE FREQ.	
1	Dosage Of Enzyme	CAP	0.5-2.0 ml	Low viscosity	Log Book	1	Thrice per day	Revised SOP
2	Deactivation Time	CAP	10 min	Low viscosity	DCS	-		Revised SOP
2	Deactivation Temperature	CAP	100 +/- 5	Low viscosity	DCS	-	Twice per week	Revised SOP
3	Solid Cotnetnt	CAP	105+/-10	Low solids	Lab report	1	Thrice per day	Revised SOP
4	Cooking Temperature	CAP	100+/-5	Low viscos-ity	DCS	-	-	Revised SOP
5	Cooking Time	CAP	22-25 min	Low viscosity	DCS	-	-	Revised SOP
6	SOP	CAP	-	Delay in action	-	-	-	Revised SOP
7	Knowledge	CAP	-	Viscosity & GPL variation.	Mutual discussion	1	As and when required	Revised SOP

Conclusion

Manufacturing Excellence concepts and six sigma methodologies have been adopted and the desired results achieved, which ensured the sustainability. The tools such as Regression Analysis and Why-Why Analysis were applied in resolving the issues pertaining to the enzymatic conversion of starch.

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