High Throughput Glass Mat Production

Client: Fiberteq in Danville, Illinois

Objective: Engage Ultramax® to minimize the Caliper Index (a thickness measure) of moderately high-tech fiberglass mat produced using standard glass fibers and binder systems while simultaneously meeting or exceeding all mat quality specifications. Production equipment itself resembles a somewhat intricate paper machine with commodity level products incorporated into roofing materials while very thin material made on similar production lines winds up in high-tech batteries.

Technical Result: Caliper Index (mat thickness divided by basis weight) reduced by 16.2% while meeting or exceeding - very strong mat was, in fact, produced – all other product specifications. This also boosted tensile per binder weight, a measure of how efficiently binder (a comparatively expensive raw material) is used in generating web strength by 32.3%. Notably the core of Fiberteq's process learning (optimization) occurred over a period of just under two weeks during normal production, with steady improvement in desired properties and no material scrapped as a result of the optimization.

Economic Return: Thinner mat results in more linear feet (on the order of 20%) for each roll shipped to customer sites across the U.S. This shipping cost reduction alone resulted in savings exceeding one million USD annually for Fiberteq. Hence Fiberteq's roofing customers applauded their initiative – making Fiberteq's mat, in fact, the standard against which other suppliers were judged.

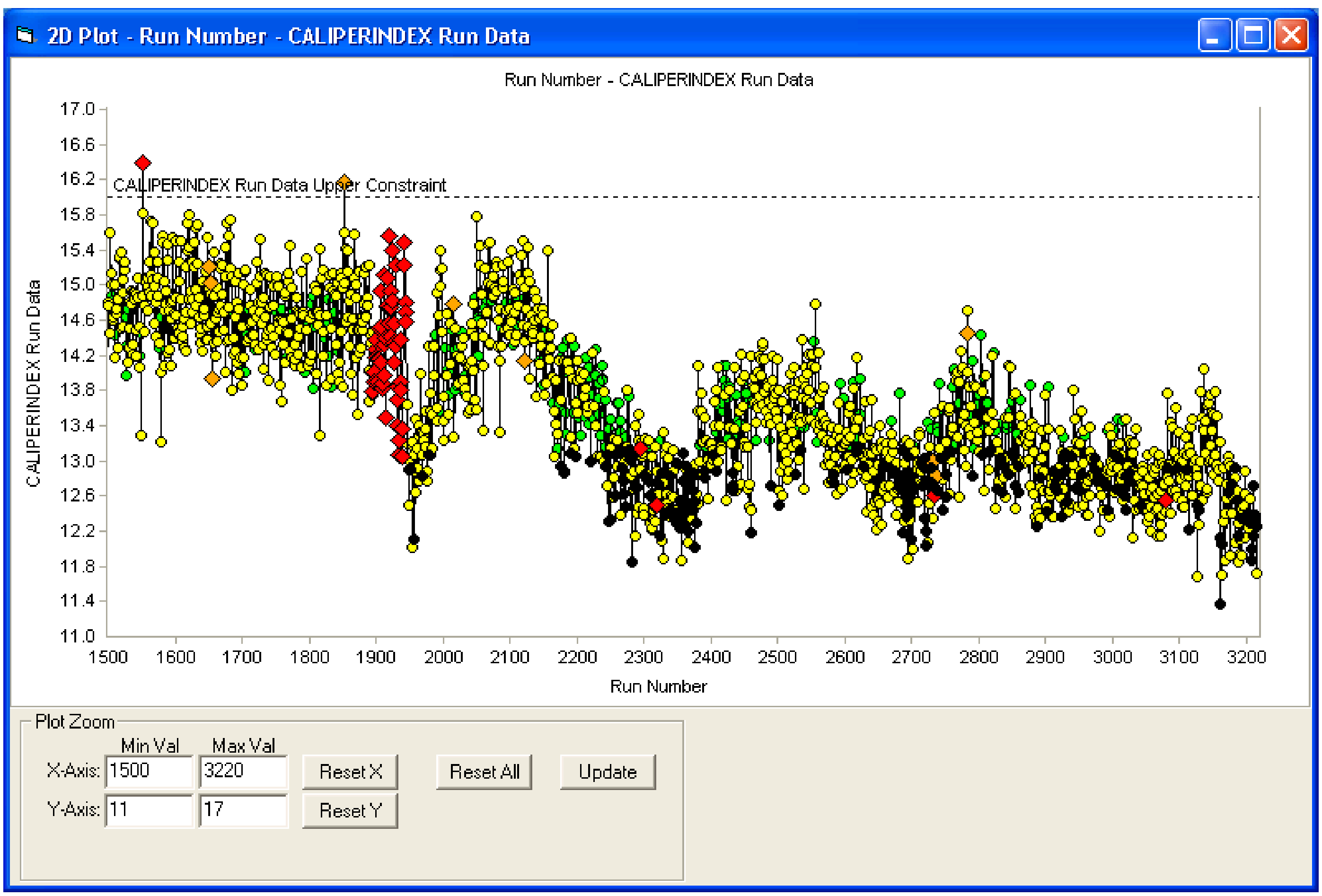

Fig. 1: Progress of Caliper Index optimization at Fiberteq. Points in black are at or near the practical optimum given external conditions.

Project Description

Per plan, the optimization project was started with an existing fiber and binder system expected – as the parent organization deliberately drove innovation, notably with basic research on their product materials – to change. This allowed shakedown of an initial problem formulation, which itself came from brainstorming combined with parallel coordinate analysis of existing data, as well as creation of Excel-based data acquisition. The latter would interrogate multiple plant databases to assemble product, process, and machine (e.g., white water property or wire mileage) data timed with the exact moment product quality samples were drawn. Importing such data into Ultramax, the sequential optimizer engaged for process learning, then allowed model building to discern the extent inputs explained outputs and thus whether any significant missing pieces ("lurking variables") remained, as well as if the projected optimum laid within or beyond the realm of existing experience. Both are key figures of merit to an optimization, which basically tell us how hard to look for unknown – and potentially uncontrollable – influences as well as how long a march to expect from existing conditions to optimum performance. For this reason technologies prone to over-fit data (Neural Networks fall into that category), based on fixed (e.g., first principles) models, or dependent on lengthy testing (since systems change as catalyst beds age, wires stretch, heat exchangers foul, etc.) from designed experimentation are of limited effectiveness for optimization work on a living, running, manufacturing line. Adaptive agility, instead, is required such that problem formulations can be rapidly evaluated from existing data, those formulations easily expanded – before optimization begins – to account for missing pieces, and process learning is swift. That learning itself, moreover, must be able to either quickly adapt from existing data to fundamental material (as in this case) or equipment changes not captured by that data, in addition to starting (or restarting) optimization from essentially zero data.

In Fiberteq's case it was elected to adapt from existing data when fiber and binder systems were changed, as those material property alterations themselves were significant but not earth-shaking, so effectively use that data to further our understanding of the process and consequently refine its formulation to the sequential optimizer. Notably, at Fiberteq, that refinement included recognition that oven air flow velocity measurements were unusably noisy, followed by their replacement with upper box pressure measurements – which drove oven air flow, and were well behaved – instead. In addition, to reduce measurement noise, the "foot" used to compress caliper measurement samples was swapped for a physically larger variant supported by the same instrument, while Cure (red dye test) reporting was switched to a scale with gradations of one tenth rather than one half. Since Cure is measured in Danville by a camera system instead of a human eye, and the resulting pixel count simply converted to a number, this necessitated only a different conversion table in the Quality Lab but resulted in considerably less noise for a product output that would eventually become the optimization's limiting factor. Finally, LOI was shifted from a manipulable to external variable (thus preventing binder application from being reduced during optimization) while pulper hold speed and time variables were de-activated in favor of treating pulper batch size and motor speed as manipulable. All this, along with loosening specifications for square foot basis weight (a very noisy product measurement) and focusing on roll average basis weight instead, yielded the refined optimization problem formulation of Figure two.

Progress using that optimization blueprint was swift, as illustrated by run count starting around 2100 in Fig. 1 – previous runs were either existing data from plant databases or reflected formulation refinement work prior to fiber and binder system change – and stretching to the Caliper Index minimum at run 2370. This covered a period of approximately 12 days, averaging between six and eight optimization moves per day conducted after process, machine, and product data for the most recent Quality Lab check were fed into the sequential optimizer. Hence, in less than 100 control moves it had been unequivocally proven that Ultramax could move Caliper Index downward while feeding-forward against uncontrollable influences. After Fiberteq took its foot off the gas, however, Caliper Index drifted back upward as standard operating procedures reasserted themselves in the Control Room. This led to two further thrusts of optimization, each pushing Caliper Index to its previous minimum or farther downward while maintaining or improving mat product properties, until standard procedures were reset to reflect low Caliper Index operation at the close of the final push. Caliper Index thereafter drifted only slightly back upward, before stabilizing under standard (manual) control at entirely satisfactory levels.

To practitioners of industrial control the above will sound much like Real-Time Optimization (RTO). It is, as the optimization intelligence engaged is often integrated with plant data and control systems to run continuously in either an advisory capacity or closed-loop. However, there are salient differences, as the process learning heuristics of Ultramax are far from those of a garden-variety Real-Time Optimizer. In specific:

1. No pre-existing models are required, simply enumeration of inputs and outputs.

2. Bayesian methods, capable of starting optimization from zero data – this is very handy in process development situations – are engaged if one has no experience with a process, or its data itself is either obviously flawed or untrustworthy… both of which are readily uncovered via parallel coordinates. From there, as reliable data is at the heart of moving step-wise from existing performance toward, and eventually onto, the practical optimum in addition to staying atop it, heuristic data weighting mechanisms are engaged. Their exact nature is proprietary, but these down-weight older data or that far removed from the optimum region in favor of recent information which drives improvement.
3. Mathematical safeguards are in play to prevent sticking on local maxima or minima, while models themselves are continuously refined from a global character, using all data at the start of optimization, to focusing around the true process optimum as the system homes-in on its target.
4. The above render optimization rapid and reliable, both from its inception and (as in this case) when fundamental materials or conditions change.

All these properties are at the heart of an adaptive agility in Ultramax that has proven effective against demanding industrial problems where other, and typically far more costly, technologies fail.

ULTRAMAX® - [F:\Fiberteq\New OC Min Stuff\New OC Min Two Items\OC Caliper Min New2.umax]No appplication Description entered yet.

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V#	Variable Name	Units	Dependency	Role	Mode	MID	Low Const.	High Const.
1	BASISWT_SETP	lbs/sqft		Input-Uncontrolled	Measured	0.03		
2	LOI	Percent		Input-Uncontrolled	Measured	5	16	22
3	LINE_SPEED	Kfpm		Input-Uncontrolled	Measured	0.1		1.35
4	Z1_UP_BOX_PT	Scale		Input-Adjusted	Measured	0.002	0	1
5	Z2_UP_BOX_PT	Scale		Input-Adjusted	Measured	0.002	0	1
6	Z3_UP_BOX_PT	Scale		Input-Adjusted	Measured	0.002	0	1
7	Z4_UP_BOX_PT	Scale		Input-Adjusted	Measured	0.002	0	1
8	Z5_UP_BOX_PT	Scale		Input-Adjusted	Measured	0.002	0	1
9	Z6_UP_BOX_PT	Scale		Input-Adjusted	Measured	0.002	0	1
10	Z7_UP_BOX_PT	Scale		Input-Adjusted	Measured	0.002	0	1
11	Z1SUPAIRSETP	Deg-F		Input-Adjusted	Measured	6	430	530
12	Z2UWAIRSETP	Deg-F		Input-Adjusted	Measured	3	360	450
13	Z3UWAIRSETP	Deg-F		Input-Adjusted	Measured	3	360	450
14	Z4UWAIRSETP	Deg-F		Input-Adjusted	Measured	3	360	450
15	Z5SUPAIRSETP	Deg-F		Input-Adjusted	Measured	5	430	550
16	Z6SUPAIRSETP	Deg-F		Input-Adjusted	Measured	6	430	550
17	Z7SUPAIRSETP	Deg-F		Input-Adjusted	Measured	5	400	550
18	ACETIC_ACID	Gal/Hr		Input-Adjusted	Measured	3.17		
19	VISCMODFLOW	Gal/Hr		Input-Adjusted	Measured	1		
20	P_BATCH_SIZE	k-Gal		Input-Adjusted	Measured	2		
21	P_HOLD_SPEED	rpm		Unused	Measured	10		
22	PULPER_TIME	Minutes		Unused	Measured	1		
23	PULP_MOT_SPD	Percent		Input-Adjusted	Measured	10		
24	RESIN_PC	Percent		Input-Uncontrolled	Measured	14		
25	LATEX_PC	Percent		Output	Calculated			
26	SOLIDS	Percent		Input-Uncontrolled	Measured	5		
27	PRODUCTWIDTH	Inches		Unused	Measured			
28	SHEETWIDTH	Inches		Input-Uncontrolled	Measured	20		
29	MEASPOSITION	Inches		Input-Uncontrolled	Measured	140		
30	SATWIRETYPE	Scale		Unused	Measured	1		
31	FORMWIRETYPE	Scale		Unused	Measured	1		
32	F_WIRE_MILES	k-Miles		Input-Uncontrolled	Measured	4		
33	FWIRETENSION	lbs		Input-Uncontrolled	Measured	2.5		

Fig 2a: First 33 variables of refined Ultramax problem formulation used in Fiberteq’s Caliper Index optimization.

34	WW_BACTERIA	Count		Input-Uncontrolled	Measured	14000		
35	WW_RENEWAL	Percent		Unused	Measured	1		
36	TIMESINCERNW	Hours		Unused	Measured	1		
37	FOAM	Inches		Input-Uncontrolled	Measured	0.5		
38	ORP	Scale		Input-Uncontrolled	Measured	120		
39	ENT_AIR	Scale		Input-Uncontrolled	Measured	1		
40	BIPH	pH Scale		Input-Uncontrolled	Measured	0.6		
41	BITEMP	Deg-C		Input-Uncontrolled	Measured	10		
42	DISP_PPM	ppm		Input-Uncontrolled	Measured	200		
43	WW_TEMP_LINE	Deg-F		Input-Uncontrolled	Measured	15		
44	FIBER9570_PC	Percent		Unused	Measured	1		
45	FIBER95XX_PC	Percent		Unused	Measured			
46	FIBER_IKO_PC	Percent		Unused	Measured			
47	WWPH	ph Scale		Input-Uncontrolled	Measured	0.4		
48	VISCOSITY	Cp		Input-Uncontrolled	Measured	0.5		
49	MEASUREX_SP	Scale		Output	Measured	0.3		
50	Z1_SUP_TEMP	Deg-F		Unused	Measured			
51	Z2_SUP_TEMP	Deg-F		Unused	Measured			
52	Z3_SUP_TEMP	Deg-F		Unused	Measured			
53	Z4_SUP_TEMP	Deg-F		Unused	Measured			
54	Z5_SUP_TEMP	Deg-F		Unused	Measured			
55	Z6_SUP_TEMP	Deg-F		Unused	Measured			
56	Z7_SUP_TEMP	Deg-F		Unused	Measured			
57	FIBER_COST	KFB/Hr		Output	Calculated			
58	BINDER_COST	KFB/Hr		Output	Calculated			
59	Z1_TO_Z4_HT	MMBTU/Mn		Output	Calculated			
60	THERMAL_LOAD	MMBTU/Mn		Output	Calculated			
61	GAS_COST	KFB/Hr		Output	Calculated			
62	RAW_REVENUE	KFB/Hr		Output	Calculated			
63	RAW_PROFIT	KFB/Hr		Output	Calculated			
64	ROLLAVGBASWT	Lbs/CSF		Output	Measured	0.02	1.65	1.85
65	SQFTBASISWT	Lbs/CSF		Output	Measured	0.25	1.3	2.2
66	CURE	Scale		Output	Measured	0.2		3
67	MD_TEAR	Grams		Output	Measured			
68	CD_TEAR	Grams		Output	Measured			
69	TOTAL_TEAR	Grams		Output	Calculated	5	900	
70	MD_TENSILE	Grams		Output	Measured	2	50	
71	CD_TENSILE	Grams		Output	Measured	1	20	
72	MD_TO_CD_RAT	Ratio		Output	Calculated	0.05		
73	WET_TENSILE	Grams		Output	Measured	2		
74	HOT_WETS	Percent		Output	Calculated	0	60	
75	TPBWI	Ratio		Output	Calculated			
76	CALIPERX	Mils		Output	Measured	0.6	12	30
77	**CALIPERINDEX**	**Thick/Wt**		**Performance Index,Min**	**Calculated**	**0.2**		**16**
78	KSQFTPERMIN	KSqFt/Mn		Output	Calculated			
79	STRING_INDEX	Scale		Output	Measured	10		200
80	AGITATOR_RPM	rpm		Output	Calculated			
81	GLASS_WEIGHT	grams		Output	Calculated			
82	TOTAL_TENSIL	grams		Output	Calculated			
83	BIND_WEIGHT	lbs		Output	Calculated			
84	Z1_AIR_VEL	Kfpm		Output	Measured			
85	Z2_AIR_VEL	Kfpm		Output	Measured			
86	Z3_AIR_VEL	Kfpm		Output	Measured			
87	Z4_AIR_VEL	Kfpm		Output	Measured			
88	Z5_AIR_VEL	Kfpm		Output	Measured			
89	Z6_AIR_VEL	Kfpm		Output	Measured			
90	Z7_AIR_VEL	Kfpm		Output	Measured			

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Fig 2b: Remaining variables of refined Ultramax problem formulation used in Fiberteq's Caliper Index optimization. Note that variables in blue are manipulable, those in red are uncontrolled external influences, grey colors outputs to be modeled as well as potentially held between a maximum and/or minimum, light gray variables are inactive, and the single variable lettered in blue on a yellow background is the performance index to be maximized or minimized.