

FURNACE SIMULATION AND FURNACE SIZING CALCULATIONS WITH FURNXPRT

An analysis with furnxpert software is compared with the conventional hand calculations. Although FurnXpert software can be used to analyze any type of batch or continuous furnaces, for the purpose of this case study, we have selected a continuous belt furnace used in powder metal sintering application. The furnace configuration is shown below.

Belt Width: 18 Inch	
Number of heating Zones: 4	1 Delube Zone of 72 Inch long, 1 Oxide Reduction Zone of 72 Inch long, 3 Sintering Zones of 60 Inch long each
Number of Cooling Zones: 3	Fast cooling Zone of length 48 Inch long, Slow cooling Zone of length 120 Inch long, Slow cooling Zone of length 120 Inch long

In this sintering furnace example the hand calculation is based on the fact that the part loading capacity is 10.15 lb/ft² and that the parts will meet 15 minutes of sintering time at temperature. The rest of the calculations involve determination of the power requirements in each of the furnace zones by analyzing the heat input to the parts, heat input to the conveyor belt, heat losses through the refractory, and heat input to the process gas. The calculations are shown in the following steps:

First determine the production speed empirically: $\text{Production Speed} = \text{Sintering Zone Length (inches)} * 0.65 / \text{Time at Temperature (min)}$

Next calculate the production rate using the following equation: $\text{Production Rate} = \text{Load Capacity (lb/ft}^2) * \text{Load Width (ft)} * \text{Production Speed (ft/hr)}$

From the available data the production speed and production rate are calculated to be 7.2 inch/min and 548 lb./hr respectively. The rest of the calculations are shown in the excel spread-sheet.

Furnace Power Systems Analysis																
Customer:	Example															
Job:	N/A															
Furnance Type:	18E-SZ		Target Output:		545 Lb/hr		Insulation Thermal Data:			Gas Data:						
Belt Width:	18 inches		Calculated Output:		548 Lb/hr		Temp F	9"	12"	HL-HS	HL-HS	Gas	Cp	Lb/ft ³		
Belt Type:	314ss		Process Gas:		1280 CFH		1000	49-757	37-986	AR	0.124	0.103				
Belt Weight:	5 Lb/ft ²	Belt Load:	270 Lb/hr	Cover Gas:	(see Proc.)	CFH	1200	75-951	57-1235	CH4	0.593	0.045				
Belt Cp:	0.12 Btu/Lb-F	Belt Mat'l:					1600	151-137	113-1773	H2	3.43	0.006				
Part Loading:	10.15 Lb/ft ²	Part Load:	548 Lb/hr				1800	202-160	152-2062	N2	0.249	0.075				
Part Cp:	0.12 Btu/Lb-F	Part Mat'l:	k33+0				2100	346-203	260-2590	NH4	0.523	0.044				
Tray Weight:	Lb/ft ²	Tray Load:	Lb/hr													
Tray Cp:	Btu/Lb-F	Tray Mat'l:		Total Output:	818 Lb/hr					Btu/H - KW			2.93E-04			
Process Speed:	7.2 in/min															
Furnace Configuration:			Percent of Process					Insulation Configure								
	Zone #	Zone Len	Ovall Length	Peak Temp.	St @ Temp	Fn @ Temp	Time @ Temp. (min.)	Ent Temp	Exit Temp	Ins. Width	Ins. Height	Thk.	Type	HL (Btu/ft ² /hr)	HS (Btu-ft ²)	
Delube	1	72	72	1200	75	100	2.5	200	1300	29	25	12	Fiber	113	1773	
Preheat	1	72	72	1800	95	100	0.1	1300	1800	29	25	12	Fiber	152	2062	
HighHeat	3	60	180	2050	15	85	15	1800	1800	29	25	12	Fiber	260	2590	
Atmosphere Gas System:																
Zone	Type	Cp	Lb/ft ³	Vol (CFH)	dTemp	Btu/H	Kw	HEAT LOSS ENERGY ANALYSIS:								
Delube	N2	0.249	0.075	350	300	1960.87	0.57	Process	Surf Area (Ft ²)	Tot Loss (Btu/Hr)	KW					
Preheat								Delube	5.03	568.93	0.17					
High Heat	H2	3.43	0.0056	15	1500	432.18	0.13	Preheat	59.03	6973.27	2.63					
High Heat	N2	0.249	0.075	1165	1500	32634.56	9.56	High Hea	59.03	15349	4.50					
Side Cover	N2	0.249	0.075	100	1500	2801.25	0.82	Subtotal	24891.2	7.30						
exit	N2	0.249	0.075	50	300	280.13	0.08									
						Subtotal:	38108.99	11.16								
Ramping Power Requirement:																
Process	dTemp / dtime	Rate (Hr)	Time in Zone (min)	Btu/H	Kw	Zone	Power Consumption	Installed Power								
Delube	1000	0.125	0.17	130897.05	38.36	1	50.98	55								
Preheat	500	0.165	0.17	49582.21	14.53	2	16.56	55								
HighHeat	400	0.05	0.14	109080.87	31.97	3	33.43	55								
				Subtotal	289560.13	84.86	4	4.25	55							
				Atmosphere Power	11.16		5	41.80	55							
				Heat Loss Power	7.30											
					Total	103.32	Total	147.02	275							

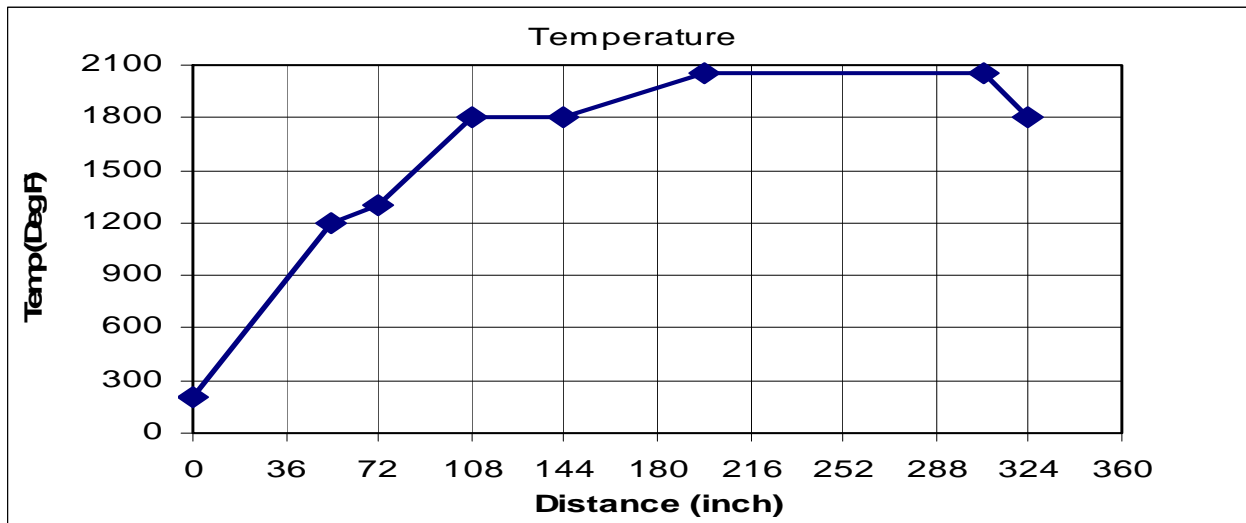
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Result Comparisons:

The results from furnxpert software are then compared with the results from hand calculation and shown in the table below:

	FurnXpert	Hand Calculation And/OR Spreadsheet
Production rate	609 Lb./hr	548 Lb./hr
Part loading	10.44 Lb./ft ²	10.15 Lb./ft ²
Time in preheat	20 min	20 min
Time in Sintering	26.67 min	25 min
Zone 1 power	42.74 kW	50.29 kW
Zone 2 power	19.67 kW	16.54 kW
Zone 3 power	25.85 kW	33.43 kW
Zone 4 power	4.10 kW	4.25 kW
Zone 5 power	44.49 kW	41.80 kW
Wall Heat Loss	15.04 kW	7.30 kW
Atmosphere Heating	17.67 kW	11.16 kW
Heat to Part	75.53 kW	84.86 kW
Radiation Loss	27.74 kW	Not accounted

It is evident from the above results that they do not vary a lot. Nevertheless there are some variations, which need to be addressed. The hand calculations are based on certain assumptions. One of the flaws in hand calculation method is to assume that the part will reach a certain temperature at certain location inside the furnace. In the above example the calculations are based on the assumption that the part will attain certain temperature along the furnace length represented by distance temperature profile shown in **figure below**.



But the actual temperature a part attains depends on many factors. First, the mode of heat transfer at low temperature is different from that of high temperature. At low temperature convection plays a dominant role and the convective heat transfer coefficient depends on the atmosphere present inside the chamber and flow characteristics around the body. On the contrary at high temperature heat transfer takes place by radiation and it is a non-linear function of temperature. Moreover, amount of heat transfer by radiation depends on the view factor between the two bodies exchanging heat. Consequently any shadowing effect changes heat transfer considerably. Therefore understanding and solving the physics of heat transfer between the furnace and the body undergoing heat treatment is the crucial step in designing, simulating and analyzing a furnace. In hand calculations it is impractical to account for these effects and are deliberately ignored.

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Next, some of these calculations are based on special rule of thumb and empirical values. For example, the belt speed of 7.2 inch/min is calculated on the assumption that the part is exposed for 16 minutes at sintering temperature for 65% of the sintering zone. This is not true since parts with different size and shape will have different temperature profile and subsequently will have different time at sintering temperature.

The refractory losses are functions of hot refractory temperature. The losses at higher zone temperature are higher than at lower temperature. The above calculations assume that refractory temperature is same as part temperature. This is not thermodynamically possible as heat flows from higher wall temperature to lower part temperature.

All the above issues are addressed in FurnXpert. FurnXpert calculations are all based on the zone temperatures. Once the user provides the zone temperatures then FurnXpert uses its algorithm to calculate the temperature the parts will see during the heat treatment process. Then it applies finite element analysis to calculate part temperature. Other factors contributing to the different results are:

- ❑ Production rate determined by hand calculation assumes the fact that the parts are uniformly loaded on the belt. FurnXpert calculates production rates from part weight and their placement on the belt
- ❑ Radiation heat loss from the last heating zone to the cooling zone is not taken into account in the hand calculation.

Conclusion:

Heat transfer calculations are complex and tedious. Solving all the little details using hand calculations and for that matter spreadsheet software is an unrealistic proposition. Unfortunately, all these little details need to be accounted for in furnace analysis and design.

Accuracy in hand calculations depends on rule of thumb and empirical values. Hand calculations can provide accurate results as long as the empirical values are correct. This is only possible if the empirical values are calibrated properly by comparing the results from the hand calculations with experimental results. Once perfected these empirical values could only be used for those furnaces for which the values have been adapted.

The primary benefit of using a software tool like FurnXpert is to perform furnace simulation fast and accurately. Not only one can perform a furnace simulation 10X faster but it also provides accurate answers. The factors that contribute to achieving accurate results are:

- ❑ Calculations are based on furnace temperature but not on the predicted temperature of the parts.
- ❑ Property changes with temperature are accounted for at each calculation steps
- ❑ All the modes of heat transfer are considered and solved at each calculation steps
- ❑ The analysis breaks the parts into smaller subparts thereby analyzing every detail of the parts

Finally, to analyze and design a furnace one has to run several cases. These cases could be different combinations of furnace design, part parameters and furnace settings. Each new calculation done manually takes additional time and consumes additional overhead. The advantage of using design and analysis software like FurnXpert is to run several cases or “what if analysis” without additional expense.