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Embracing a Digital Twin Framework to Efficiently Optimize Forced Draft Combustion Networks

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Often in large heater designs, a forced/balanced draft system is desired as it enables greater utilization of the energy released by burners. With relatively simple process control schemes, global excess air targets are met in an automated fashion, reducing the burden to operational resources. The added efficiency benefit and low supervision needed (from a combustion perspective) makes these systems desirable, especially when dealing with a large number of burners. However, experience shows that many duct design systems do not result in appropriate combustion air distribution. This introduces a significant amount of variance in burner excess air operation, leading to differences in flame temperature and shape. Often, these result in mal-distribution of heat, hot spots on process coils, and poor emission performance. In addition, the unintuitive nature of forced draft burners leaves operators with few immediate options. Even when operators are proactive, the focus is centered on fixing local problems often by applying solutions that result in a deficiency elsewhere in the heater. While there is certainly an advantage to balanced draft design application in process heating, the application of digital tools that democratizes combustion subject matter expertise is key for the realization of these advantages.

As operators attempt to address the symptoms of heat mal-distribution (e.g., hot spots on process tubes, shorter run lengths, undesirable flame shapes, etc.), but without key combustion insight these short-term mitigation strategies may migrate these issues to different part of the furnace. Uniform excess air distribution is not an easy task to achieve as conventional forced draft systems have to be designed around plot space constraints and have to deliver airflow from one source (FD fan) to a multitude of burners. In addition, depending on the heater design, burners may be located at different elevations in the radiant box, may be of different sizes, and may have completely different firing requirements. A combination of these factors, for any heater system, may lead to significant differences in burner combustion that can result in detrimental heater performance.

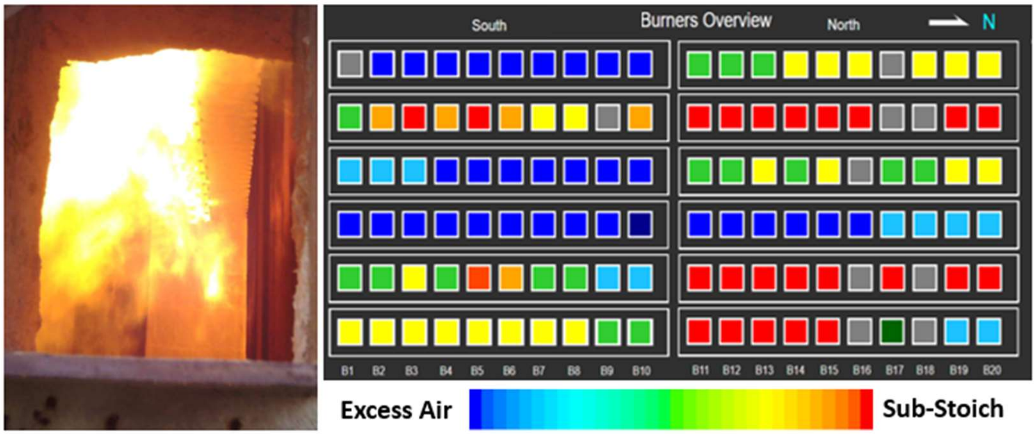


Figure 1: *Excess air map - Mal-distribution induced by un-optimized tuning.*

To mitigate the constraining condition (e.g., high temperatures in a region of the radiant box), operators often adjust burner air registers and/or take burners out of service. Unfortunately, in forced draft systems all burners are connected and by increasing airflow to one burner, a similar amount is subtracted from other burners in the system (as the global excess air is maintained by the heater automated operating scheme). As a result, burner excess air distribution found in the field tends to be insufficient in some areas of the furnace and in excess in others (see

Figure **1**), leading to undesirable burner performance that results in heater and business team constraints.

A fired heater in an ExxonMobil refinery showed some areas of opportunity consistent with typical shortcoming of forced draft networks. This fired heater has a balanced draft system with over 70 burners with inherent airflow mal-distribution (see **Figure 2**). Given the non-intuitive nature of the system, consistency in burner tuning was challenging to achieve without an SME lead/involvement. This resulted in missed opportunities for burner tuning that could improve heater optimization. Additionally, a lack of visibility to excess air operation per pass/burner resulted in uneven combustion and tube metal temperature / COT disparities which impact heater run lengths.

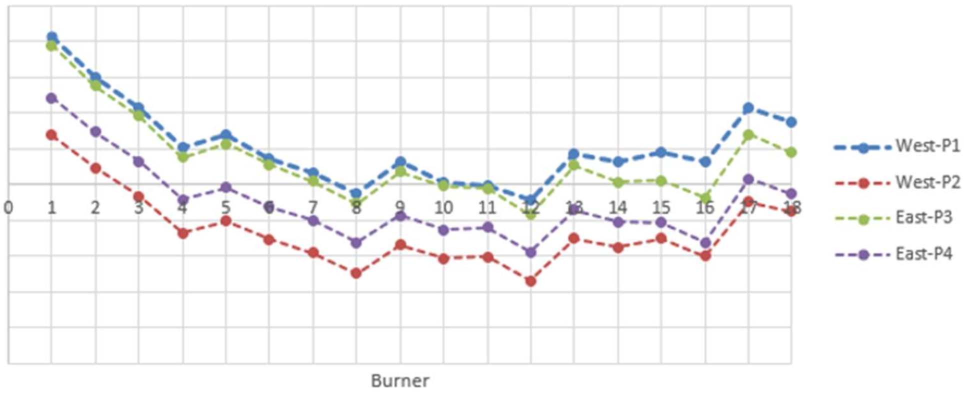


***Figure 2**: Expected airflow distribution according to CFD (all register fully open).*

The key combustion insights required for best-in-class tuning can be more efficiently generated and applied by leveraging an advantaged digital platform. Often, the knowledge required for effective tuning of a forced draft system is found in local or Original Equipment Manufacturer (OEM) Subject Matter Experts (SME). While those resources are available, their ability to provide recommendations at the needed frequency may prove difficult if not cost prohibitive. However, a digital solution that leverages the OEM combustion SME, in duct and burner design, is ideal to providing actionable insights in near real time manner. Furthermore, these actionable insights can be curated so that non-combustion SMEs can independently apply these recommendations in the field without the need of additional supervision or detailed process plan.

The application of a “digital twin” framework enriched by OEM design knowledge enhances the value proposition of the burner as these evolve to become measuring devices for fuel and air flow. The information generated from burner design knowledge can then be used to digitally tune the heater and find the ideal combination of burner and duct register positions that results in targeted combustion air distribution, at a reduced fan loading, with the best burner controllability. **Figure 3** shows how in an iterative fashion, burner air registers are adjusted until the pressure drop (from duct inlet to burner) are equalized. This approach systematically and consistently provides air register recommendations that will distribute combustion airflow as targeted.

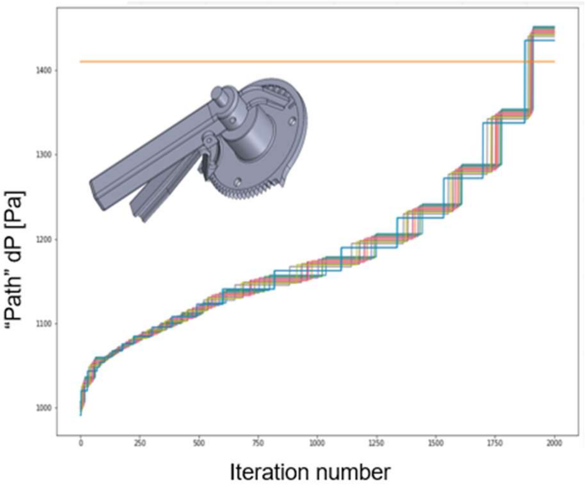
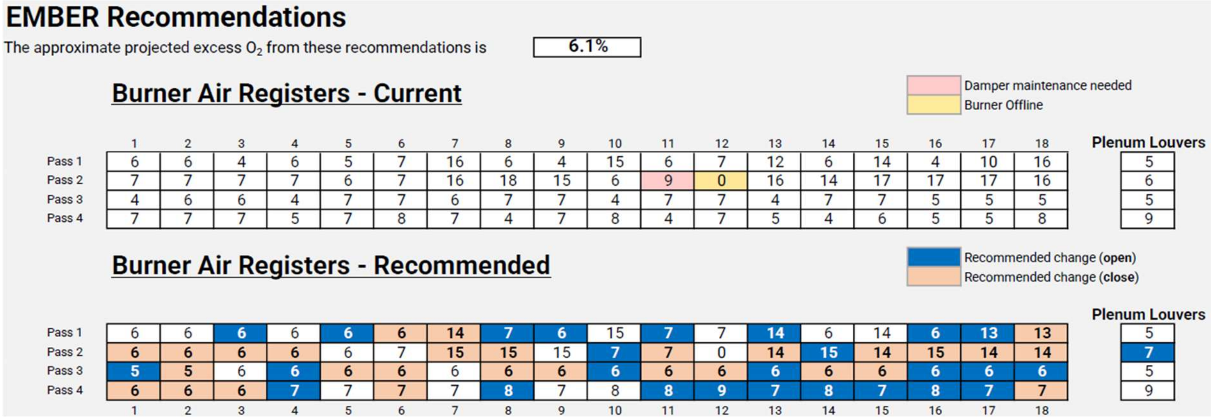


__Figure 3:__ Iteration to achieve optimal register position.

This Digital Twin platform has been implemented on two (2) fired heaters in an ExxonMobil facility. A greater level of consistency in tunings has been demonstrated, while a reduction in the amount of time required to tune has been observed. A focused view of the burners with required adjustments enables operators to quickly understand the amount and location of the work to be done. **Figure 4** is an example of the clarity needed in order to reduce field operators doubt and entice proactive tuning practices. At a single glace, operators can identify the current state of the system, which burner need adjustment, and how big of an adjustment is needed. This insight empowers operators to take the right actions and reduces the resource limitations often found in relying exclusively on combustion SME.



EMBER Recommendations

The approximate projected excess O_2 from these recommendations is **6.1%**

Burner Air Registers - Current

🟥 Damper maintenance needed
🟨 Burner Offline

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Plenum Louvers
Pass 1	6	6	4	6	5	7	16	6	4	15	6	7	12	6	14	4	10	16	5
Pass 2	7	7	7	7	6	7	16	18	15	6	9	0	16	14	17	17	17	16	6
Pass 3	4	6	6	4	7	7	6	7	7	4	7	7	4	7	7	5	5	5	5
Pass 4	7	7	7	5	7	8	7	4	7	8	4	7	5	4	6	5	5	8	9

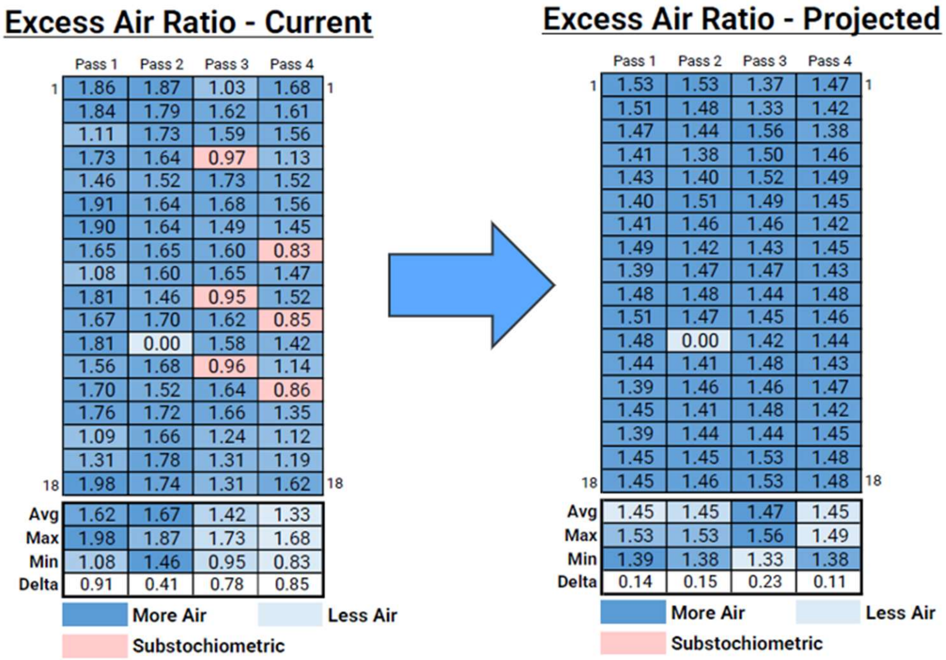
Burner Air Registers - Recommended

🟦 Recommended change (**open**)
🟧 Recommended change (**close**)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Plenum Louvers
Pass 1	6	6	6	6	6	6	14	7	6	15	7	7	14	6	14	6	13	13	5
Pass 2	6	6	6	6	6	7	15	15	15	7	7	0	14	15	14	15	14	14	7
Pass 3	5	5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5
Pass 4	6	6	6	7	7	7	7	8	7	8	8	9	7	8	7	8	7	7	9

__Figure 4:__ Curated recommendation for non-combustion SME consumption.

The calculations needed to provide the actionable insights shown in **Figure 4** can also be leveraged to understand the impact the recommended changes will bring to the combustion within the radiant box. As the "digital tuning" takes place, insights regarding the current and future state of excess air distribution are generated. Objective quantification of per burner excess air helps operations identify burners that are at a significant deficiency or should be prioritized. **Figure 5** not only shows the level of mal-distribution of current excess air, but also highlights those burners that simply do not have enough airflow to complete combustion (i.e., sub-stoichiometric combustion). The same figure also provides an understanding of the expected or projected excess air distribution if recommendations are applied. Here, operators can use the difference between current and projected values to understand if action is needed. The nature of the excess air insights offers an objective basis that can enable consistency in the adjustments and timing of tuning, regardless of whether or not there are combustion SMEs available at that given moment in time.



Excess Air Ratio - Current

	Pass 1	Pass 2	Pass 3	Pass 4	
1	1.86	1.87	1.03	1.68	1
	1.84	1.79	1.62	1.61	
	1.11	1.73	1.59	1.56	
	1.73	1.64	0.97	1.13	
	1.46	1.52	1.73	1.52	
	1.91	1.64	1.68	1.56	
	1.90	1.64	1.49	1.45	
	1.65	1.65	1.60	0.83	
	1.08	1.60	1.65	1.47	
	1.81	1.46	0.95	1.52	
	1.67	1.70	1.62	0.85	
	1.81	0.00	1.58	1.42	
	1.56	1.68	0.96	1.14	
	1.70	1.52	1.64	0.86	
	1.76	1.72	1.66	1.35	
	1.09	1.66	1.24	1.12	
	1.31	1.78	1.31	1.19	
18	1.98	1.74	1.31	1.62	18
Avg	1.62	1.67	1.42	1.33	
Max	1.98	1.87	1.73	1.68	
Min	1.08	1.46	0.95	0.83	
Delta	0.91	0.41	0.78	0.85	

More Air Less Air

Substochiometric

Excess Air Ratio - Projected

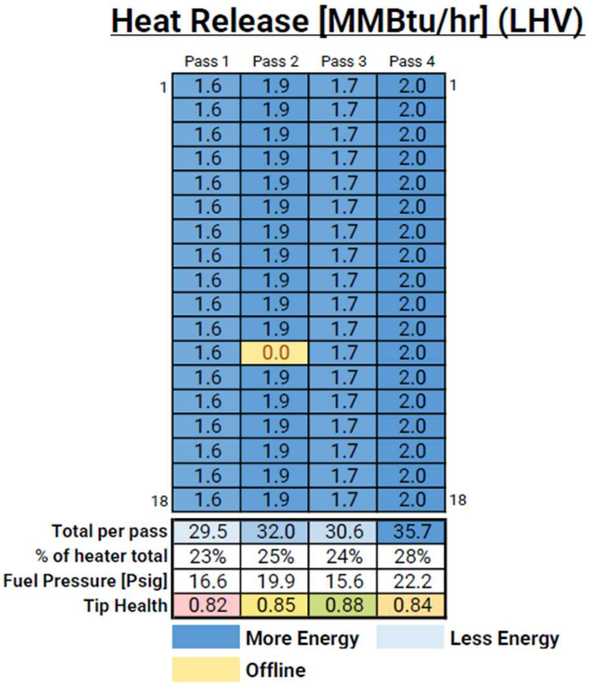
	Pass 1	Pass 2	Pass 3	Pass 4	
1	1.53	1.53	1.37	1.47	1
	1.51	1.48	1.33	1.42	
	1.47	1.44	1.56	1.38	
	1.41	1.38	1.50	1.46	
	1.43	1.40	1.52	1.49	
	1.40	1.51	1.49	1.45	
	1.41	1.46	1.46	1.42	
	1.49	1.42	1.43	1.45	
	1.39	1.47	1.47	1.43	
	1.48	1.48	1.44	1.48	
	1.51	1.47	1.45	1.46	
	1.48	0.00	1.42	1.44	
	1.44	1.41	1.48	1.43	
	1.39	1.46	1.46	1.47	
	1.45	1.41	1.48	1.42	
	1.39	1.44	1.44	1.45	
	1.45	1.45	1.53	1.48	
18	1.45	1.46	1.53	1.48	18
Avg	1.45	1.45	1.47	1.45	
Max	1.53	1.53	1.56	1.49	
Min	1.39	1.38	1.33	1.38	
Delta	0.14	0.15	0.23	0.11	

More Air Less Air

Substochiometric

Figure 5: *Excess air distribution before and after tuning*

The ability to use a burner as measuring device can further be leveraged to objectively quantify other areas regarding burner operation that are typically assessed through subjective visual observations. Gas tip pluggage is a common topic in heater operation and maintenance. Often, plugging is assessed based on field observations. A variability is assessment may be found as these truly rely on the expertise of the individual performing the survey and also the site ports available to inspect burners. While these are relevant, an overall gas tip “pluggage/health” can be estimated by evaluating the difference between the calculated fuel flow based on the heater fuel flow measurement and burner fuel pressure (**Figure 6**). Similar to gas tip plugging, the concept can be extended to quantification of tramp/leakage air, adiabatic flame temperatures, etc. These insights, derived through proprietary models, enable process engineers to develop better and more effective tuning strategies, that beyond balancing combustion airflow, can bias excess air to mitigate unique conditions that develop in heater/furnaces over time.



Heat Release [MMBtu/hr] (LHV)

	Pass 1	Pass 2	Pass 3	Pass 4	
1	1.6	1.9	1.7	2.0	1
	1.6	1.9	1.7	2.0	
	1.6	1.9	1.7	2.0	
	1.6	1.9	1.7	2.0	
	1.6	1.9	1.7	2.0	
	1.6	1.9	1.7	2.0	
	1.6	1.9	1.7	2.0	
	1.6	1.9	1.7	2.0	
	1.6	1.9	1.7	2.0	
	1.6	1.9	1.7	2.0	
	1.6	1.9	1.7	2.0	
	1.6	0.0	1.7	2.0	
	1.6	1.9	1.7	2.0	
	1.6	1.9	1.7	2.0	
	1.6	1.9	1.7	2.0	
	1.6	1.9	1.7	2.0	
	1.6	1.9	1.7	2.0	
18	1.6	1.9	1.7	2.0	18
Total per pass	29.5	32.0	30.6	35.7	
% of heater total	23%	25%	24%	28%	
Fuel Pressure [Psig]	16.6	19.9	15.6	22.2	
Tip Health	0.82	0.85	0.88	0.84	

■ More Energy
□ Less Energy
■ Offline

Figure 6: Calculated fired duty distribution.

The consistent application of optimized combustion based tuning strategies showed valuable impact on process performance. Typical of fired heater applications, desired performance and profitability is correlated to uptime. The deposition of petroleum coke inside process tubes, promoted by higher tube metal temperatures (TMTs), is one of the greater contributors to shorter run lengths. Application of recommendations, where heat distribution is maximized, is known to result in the reduction of peak TMTs, resulting in a slower coke deposition rate (ultimately extending run length). **Figure 7** shows the impact to TMT instantly after applying a recommended adjustment to burner and duct dampers. While a lower temperature is measured instantaneously, a lower rate of TMT growth is also observed. This decrease in coke deposition rate has led to a run length increase of 2 to 4 days between spalling cycles.

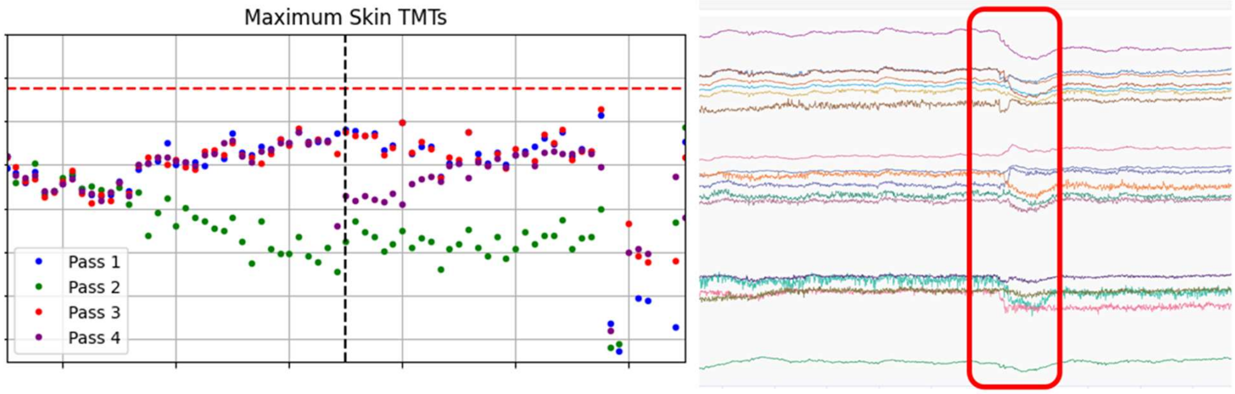


Figure 7: Combustion based tuning impact on heater maximum TMT per pass (left) and all TMTs (right).

A similar effect can be seen on other heater key performance indicators. Often, in heaters with multiple process coils, biasing of process flows is applied to mitigate deviation of Coil Outlet Temperatures (COT).

However, this biasing is intentionally limited (for example ± 7% from average) as it directly impacts the time a unit volume of process is heated. Variation in process residence time can have a negative impact on product yield or heater performance. To mitigate heavy dependency of biasing, combustion led tuning reduces the need for pass flow balancing to drive towards greater process uniformity (Figure 8).

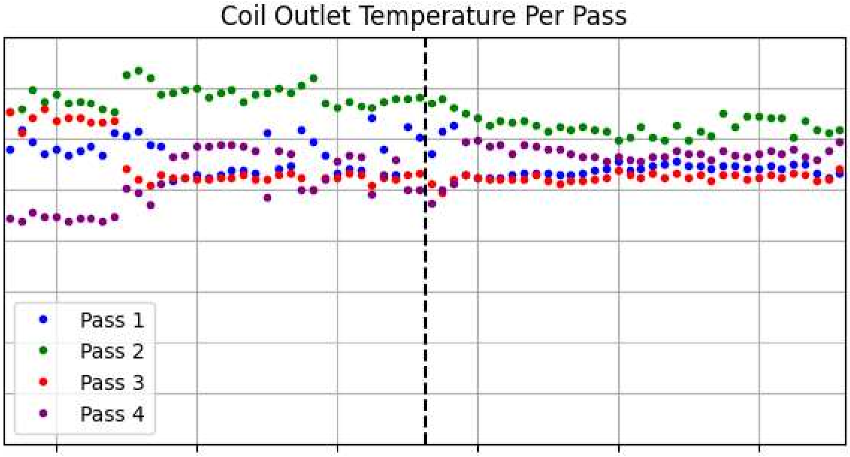


Figure 8 Impact of tuning in COT deviation and process flow bias

Embracing a digital twin framework to efficiently optimize forced draft systems has proven field benefits that may not be available otherwise (in a practical manner). The application of a digital platform that leverages combustion SME, that presents the information in a way that resonates with non-combustion experts, is key to efficiently implementing best heater tuning practices. In addition, the ability to quickly pivot tuning strategies to systematically target areas of opportunity in a heater, offers an immense reduction in the number of resources needed to optimize a heater. These generate an attractive value proposition that has resulted in a greater number of effective heater tunings performed by operations (increased the duration spent at an optimized state), better TMT performance resulting in run length improvements (2 to 4 days improvement per spall cycle), and visibly better flame shapes.