Best-in-Class Monitoring & Control Technologies Produce Huge Savings for Coil Coaters

It's a Tough World Out There

"The coil coating marketplace has changed significantly. Extreme economic pressures have resulted in a great deal of consolidation within the industry, and some coaters have failed entirely. Those that remain live in a significantly different competitive environment[1]…"

Though the applications for pre-painted metal are continually expanding, there remains an excess capacity in marketplace. This means that margins are compressed and coaters must drive to improve their competitiveness by improving operations and reducing costs wherever possible. Often in conflict with these objectives is compliance with the depth and breadth of regulations that have been instituted to govern these extremely complex operations.

In many areas, however, these conflicting objectives can be managed through intelligent, modern process measurement and control. And one of the highest impact opportunities lies in measuring and controlling the interaction between solvent and energy usage throughout the coating line.

Focusing on the Large Costs

The most costly operation in the coil coating process is oven curing the coating after application. The oven plays two main roles in the curing process. First, it evaporates the solvents from the coating. Second, it provides the energy (in the form of heat) required to "cross-link" the paint molecules to create a contiguous coating that is tightly bonded to the surface of the metal.

Coil coating ovens typically operate at high temperatures, normally in excess of 400°F, with some zones exceeding 800°F. Solvents are typically vaporized in the early oven zones. At the same time, however, other materials like resins, plasticizers, additives and other compounds are also vaporized.

It's easy to understand why this is the most expensive operation in the process. Reaching and maintaining these high temperatures requires a great deal of energy. It's equally easy to see why it is the most regulated operation in the process. The Volatile Organic Compounds (VOC's), resins, plasticizers, additives and other compounds that are freed during curing are considered hazardous and must be removed from the exhaust stream. These are generally fed to an incinerator or RTO (regenerative thermal oxidizer)as a means of eliminating these "volatiles" prior to exhausting to the atmosphere. Incinerators and RTO's operate at even higher temperatures than the oven, and therefore also require large amounts of energy to function. As a result, this represents both the largest energy consumption and most tightly regulated part of the coating process.

While the magnitude of these costs presents the greatest opportunity for savings, any actions taken must meet a host of safety and environmental regulations. Fortunately, the two are directly related. By understanding solvent levels, steps can be taken to reduce, reuse and/or recycle the energy required to support the use of solvents to achieve better plant-wide efficiencies.

The Need for Solvents

Solvents are essential in the application of a protective and/or decorative coating to a substrate. It is the solvent that makes the coating "fluid" and the amount of solvent in the coating determines its "viscosity". Viscosity is defined as the resistance of a liquid to flow, and the viscosity of the coating during application is important. This single parameter is directly related to such finish parameters as film build, color, gloss, adhesion, blister and pop, just to name a few.

---

[1] *Bonner, Michael R. Minimizing Cleaning Costs in Modern Coil Coating Operations. Coil World, September/October 2012*

As we have already established, once the coating is applied, the "wet" strip is passed through an oven or dryer, where the solvents are vaporized, leaving behind a dry, finished surface. The key here is that all solvents must be removed as part of the curing process and therefore all solvents above the absolute minimum represents excess cost (waste) in the production process. Furthermore, as the solvents are evaporated off and blend with the air in the oven, they create a potentially explosive mixture that must be carefully managed to prevent a catastrophic situation. This introduces yet another set of regulations that must be observed by the coater.

The Lower Flammable Limit (LFL)

For every flammable substance, there is a level of concentration in air, usually expressed as a percent by volume, that is known as its Lower Flammable Limit[2] (LFL). The LFL is defined as the lowest concentration of flammable gas or vapor in air sufficient to propagate a flame, given a source of ignition. Below the LFL, the mixture of fuel and air is too lean to support combustion. Most flammable gases and vapors have an LFL between 1% and 10% by volume. Let's consider methane as an example: methane has an LFL of 5% volume gas in air. Another way of saying this is: 5% methane in air = 100% LFL of methane. Between the LFL and the UFL[3] lies the flammable range where, given a source of ignition, the mixture will readily ignite.

While it may be theoretically possible to operate safely at concentrations up to 100% of the LFL, authorities world-wide have established safety regulations which require operation well below this point. Almost all safety authorities require a 4:1 margin of safety below the LFL, based on worst-case conditions. For instance, National Fire Protection Association standard NFPA 86 mandates that enough dilution air must be used to always maintain a concentration of less than 25% of the LFL for any unprotected process.

On the other hand, a process oven or oxidizer is allowed to operate with only a 2:1 safety margin (up to 50% of the LFL) when continuous solvent vapor analyzers are used (to protect the process). The regulations stipulate that these continuous analyzers be of a real-time, fast-response type, connected in such a manner as to trigger corrective actions at predetermined alarm points[4]. So, unprotected processes, which may normally run at only 10 or 12 percent of the LFL to avoid reaching 25 percent in case of accidental upset, can operate at much higher vapor concentrations when "protected" through the use of LFL analyzers. This caveat presents the opportunity to implement significant cost reductions by reducing ventilation and/or increasing throughput.

Measuring and Controlling LFL's

"If you can't measure something, you can't understand it. If you can't understand it, you can't control it. If you can't control it, you can't improve it." – H. James Harrington

Automating damper controls to modulate the flow of fresh air and/or exhaust through an oven can reduce the ventilation air moving through the system. This reduction, in turn, greatly reduces the consumption of natural gas used for heating that "make-up" air. But care must be observed, for if the primary controller was to malfunction, and the dampers were to not open, an added risk of fire or explosion ensues.

---

[2] *Lower Flammable Limit is equivalent to LEL (Lower Explosive Limit). LFL has been adopted by NFPA-86 2011 for all instances.*

[3] *Upper Flammable Limit: Highest concentration of a gas or a vapor in air capable of producing a flash of fire in presence of an ignition source; expressed in terms of a percentage. Above this concentration, there is insufficient oxygen to support combustion.*

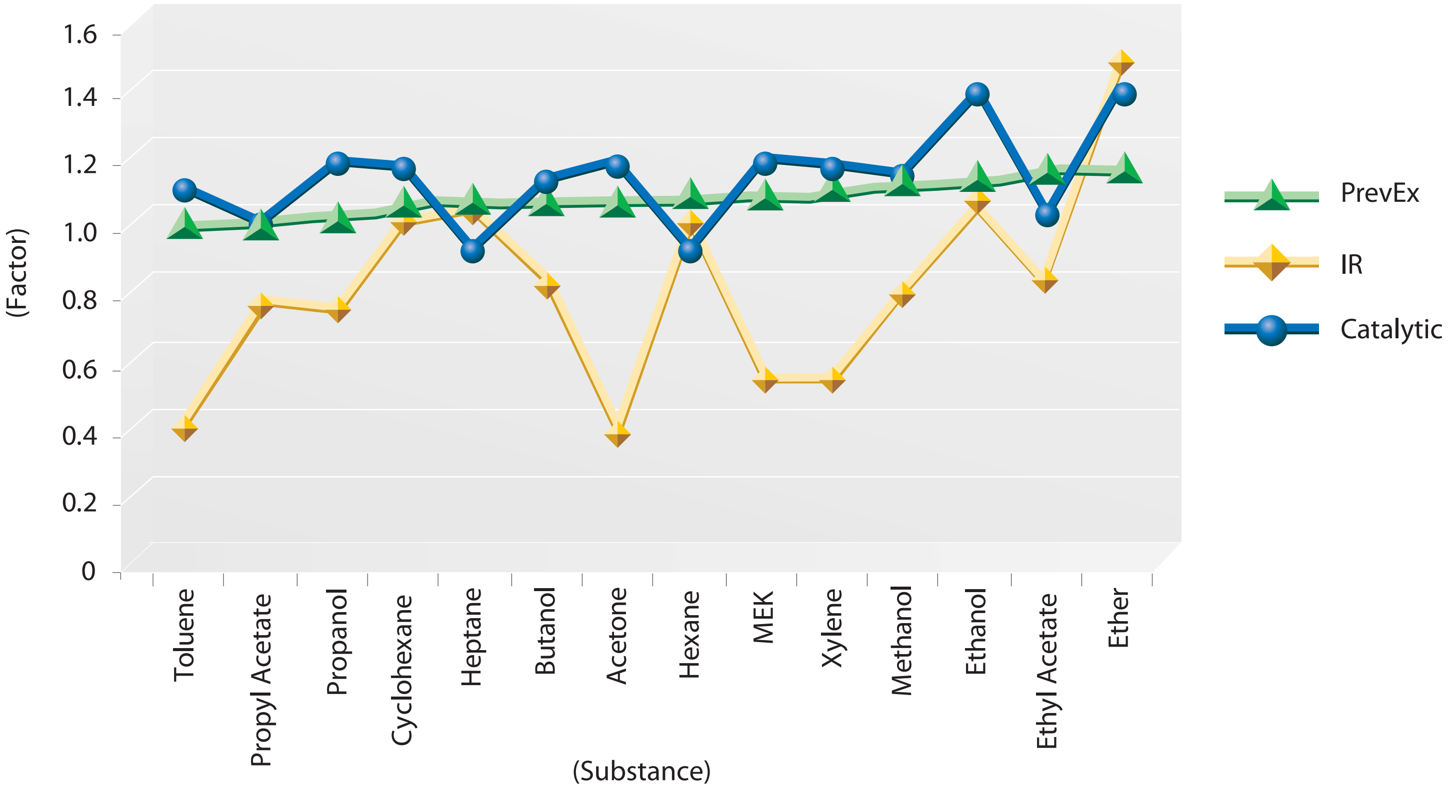
[4] *NFPA-86 2011, Sec 11.6.10*

The National Fire Protection Association's Standard for the Safe Operation of Ovens and Furnaces (NFPA-86) states that if a continuous vapor concentration controller is used to control the oven exhaust, then a secondary protection system must be used to prevent an analyzer failure from causing a hazardous condition. It goes on to state that this secondary protection system shall have a separate, continuous vapor concentration high limit controller for each zone[5].

The solvent load in ovens and dryers is comprised of a mixture of VOC's in differing proportions and concentrations. In most applications, a selection of different product is run through the ovens and dryers, so the solvent load varies as a function of the changing formulation from product to product and zone to zone in the oven.

As Harrington relates, measurement is the key to control. The more diverse the solvents that are contained in the process, the greater the error and the wider the damper will stay open, unless precise measurements are continuously taken. Measurement accuracy depends completely on how the sensor responds to each solvent. This means that the concentration of solvent vapors must be measured with the highest level of accuracy to optimize the control of damper position and achieve a balance that maximizes both safety and energy savings. The measuring principle of the sensor is crucial to achieving these goals.

The flame temperature type sensor is said to have a "universal calibration" for many common solvent vapors, because the response factors[6] are in the range of 0.9 to 1.1 (a 1.2:1 ratio). By contrast, response factors for catalytic sensors can range from 0.8 to 1.3 (a 1.6:1 ratio) and infrared sensors can easily range from 0.25 to 2.0 (an 8:1 ratio). The significance is easier to see when displayed graphically as shown here:



---

[5] *NFPA-86, Sec 11.6.8.4 – Methods for Determining Solvent Safety Ventilation*

[6] *A response factor compares a particular gas to a standard calibration. The most accurate would be a response factor of 1.0. A low response factor means low readings. A high response factor means an exaggerated or "safe-side" reading.*

Flame temperature analyzers (like Control Instruments' PrevEx Flammability Analyzer) will react accurately to most flammable substances and will usually measure both single solvents and mixtures with the same high degree of accuracy. Unlike other sensor types, flame temperature analyzers were developed for one specific purpose – to directly measure flammability. Therefore, direct flammability measurement is the best choice to precisely measure and modulate dampers and/or VFD's (variable frequency drives) to ensure that only the minimum necessary volume of make-up air is introduced into the system.

The Cost Implications of Heating Make-Up Air

When solvent laden air is sent to the RTO/Incinerator, it must be replaced with fresh make-up air. Obviously, this make-up air must be heated to maintain stable oven temperatures. This can be started with reclaimed waste heat from the RTO/Incinerator, and though "free heat", this is fairly inefficient and cannot do the whole job. The balance of heating must come from another source – usually a natural gas burner.

Moving and heating large amounts of air can be extremely expensive. Most think that the best approach to control cost is to reduce ventilation air to the point which just assures complete drying at the desired production speed. As we have already discussed, however, this could lead to a fire or explosion due to a dangerous build-up of flammable vapors.

It is important to note that, per the NFPA, the safety ventilation rate required to keep the solvent vapor concentration from exceeding 25% LFL in an unprotected process is calculated based on the oven's maximum design solvent load. If the process typically runs below the maximum solvent load, then excess ventilation air is being run through the oven. This accounts for the 10% - 12% LFL normal operating range cited above. Excess ventilation results in higher operating costs not only for heated air, but also in the cost of handling the exhaust stream, which must be run through a VOC reduction system like an RTO or incinerator.

For example, let's assume that our coating is 55% solids by volume and our process consumes two 50 gallon drums per hour. This means that we are sending a total of 45 gallons of solvent per hour to our oven. Now let's further assume that this solvent is a mixture of equal parts Isophorone, MEK and Butyl Cellosolve, as shown here:

Process Details

Solvent Mix	Gal/Hour	% of Mix	Mol. Wt.	Mol. Wt. (weighted)	Density	Density (weighted)	LFL (% by vol)	LFL (weighted)
Isophorone	15	33.0	136	44.88	0.92	0.30	0.80	0.26
MEK	15	33.0	72	23.76	0.81	0.27	1.80	0.59
ButylCellosolve	15	33.0	118	38.94	0.90	0.30	1.10	0.36
Average:			108.7		0.88		1.23	

If this is an unprotected process, using the NFPA formula, this will result in the need for just over nearly 2228,700 50026,766 ft^3 of air for every gallon of solvent used to maintain a 10% LFL as shown here:

10% LFL Ventilation Requirement Calculation

Process Data

108.67	MW	Molecular weight of solvent
0.88	d	Liquid density of solvent relative to water = 1.0
1.2%	LFL	Lower Flammable Limit of solvent as percent by volume (aka 100% LFL)
800	T	Maximum oven temperature in ˚F
184	T0	Solvent's Lower Flammable Limit temperature basis (usually 77˚F except for high flash point where it is likely to be 212˚F)
10%	C	Intended solvent concentration of oven in %LFL

Constants

359	V	Standard volume of one mole of air in standard cubic feet per pound-mole
8.33	w	Weight of water in pounds per gallon
4.36%	k	Temperature correction factor in percent per 100˚F (NFPA-86 uses 4.36% per 100˚F)

Ventilation Requirement

26,766	ft^3	Cubic feet of air per gallon of solvent

By implementing controls to precisely measure and modulate the dampers and/or VFD's (variable frequency drives) to create a "protected system", and increasing the solvent load to a conservative 40% LFL, the make-up air required per NFPA-86 drops to just under overunder 57,700 1000 ft^3/gal as shown here:

40% LFL Ventilation Requirement Calculation

Process Data

108.67	MW	Molecular weight of solvent
0.88	d	Liquid density of solvent relative to water = 1.0
1.2%	LFL	Lower Flammable Limit of solvent as percent by volume (aka 100% LFL)
800	T	Maximum oven temperature in ˚F
184	T0	Solvent's Lower Flammable Limit temperature basis (usually 77˚F except for high flash point where it is likely to be 212˚F)
40%	C	Intended solvent concentration of oven in %LFL

Constants

359	V	Standard volume of one mole of air in standard cubic feet per pound-mole
8.33	w	Weight of water in pounds per gallon
4.36%	k	Temperature correction factor in percent per 100˚F (NFPA-86 uses 4.36% per 100˚F)

Ventilation Requirement

6,691	ft^3	Cubic feet of air per gallon of solvent

This represents a 75% reduction in make-up air requirement for the same volume of solvent input – which means the same volume of production – achieved by converting to a "Protected Process" methodology. This equates to a significant reduction in heating costs for make-up air as shown here:

Air Heating Calculations Constants

Density	0.074887	lb/ft^3
Specific Heat	0.238846	BTU/lb °F
Ambient Temp	70	°F
Oven Temp	800	°F
Natural Gas Rate	3.60	$/MMBTU
Shift Duration	8	hrs
Shifts/Day	2	
Operating Days/Yr	300	

Air Heating Cost Calculations

	10% LFL	40% LFL	
Air Flow Rate	1,280,800	301,113	ft^3/hr
Air Mass Flow	95,915	22,549	lb/hr
Thermal Load	16,723,551	3,931,666	BTUH
Natural Gas Cost	$60.2048	$14.1540	$/hr
Annual Cost	$288,983	$67,939	

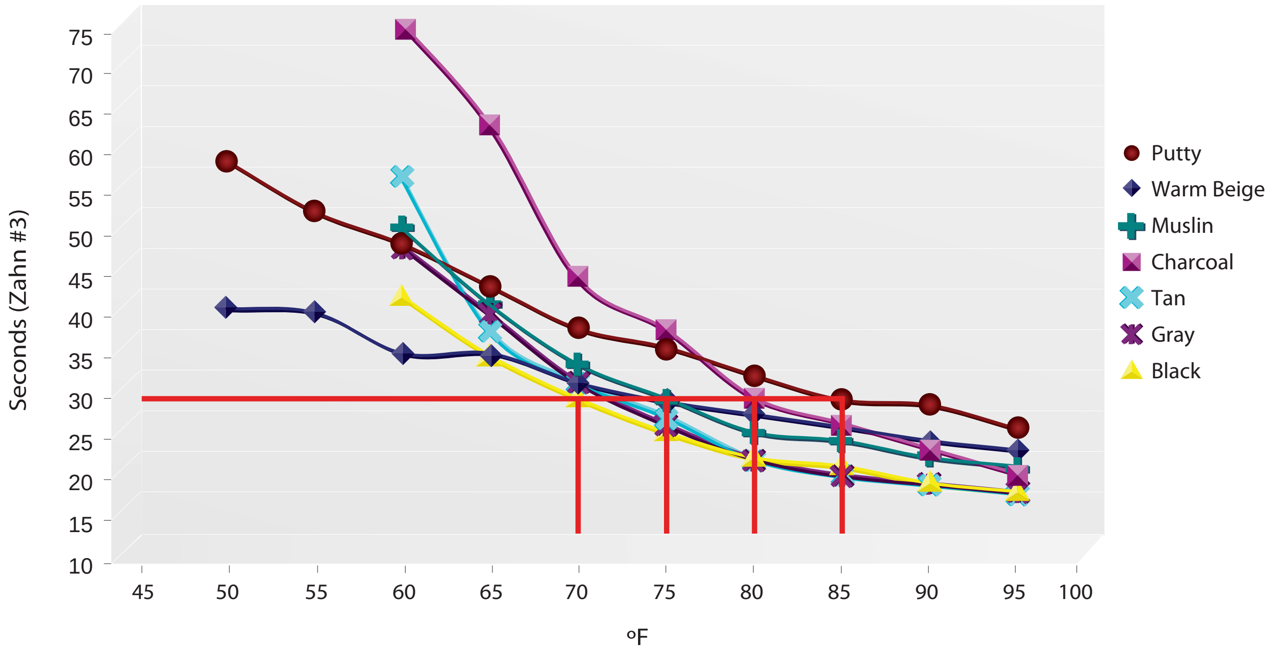
Here we can see the financial impact of this control methodology. The constants for the calculations are on the left and, on the right, the difference in make-up air usage and energy cost between operating in an unprotected mode at a 10% LFL and operating in a protected mode at a conservative 40% LFL (10% below the 50% LFL limit). This represents a savings of nearly over $22,121,700,044,000 per year in natural gas costs alone!

Without delving too deeply into the specifics of RTO operation, it is easy to understand that this control methodology allows the same volume of solvent to be sent to the RTO in a 75% lower exhaust stream. While some minor rebalancing of the RTO may be required, re-circulating a portion of the exhaust air, this allows the RTO to perform much more efficiently. If the RTO was the limiting factor in line speed, this could allow an increase in production throughput and a corresponding increase in process capacity. This "top line" (revenue) increase could easily eclipse the cost savings for natural gas, and significantly change your competitive position.

Controlling Solvent Usage

We have already noted the importance of fluid viscosity to the coating process. It is common for a coater to adopt a policy of running similar coatings at the same viscosity in an attempt to stabilize other process parameters, like roll speeds and nip pressure, thus simplifying setups and increasing the efficiency of color changes. This is the reason that the coating process generally begins with the measurement and adjustment of coating viscosity – usually through the addition of solvent.

In addition, virtually all coaters understand the inverse relationship between temperature and viscosity for coatings. As the temperature increases, the viscosity decreases and so conversely, as the temperature decreases, the viscosity increases. Unfortunately, what's often misunderstood is that this relationship varies for each color formulation – even within the same paint type.



This graph shows the Viscosity vs. Temperature curves for a group of related paint colors. Though all of the same base resin type, they display very different viscosity characteristics as a function of temperature. If all of these colors are to be run at the same 26-second viscosity and the temperature is below 70°F, all will require viscosity reduction – likely through the addition of solvent. We have already demonstrated the issues associated with the addition of solvent to the process. As a result, since its introduction in 2005, many coaters have turned to temperature control as a means of controlling coating viscosity. In the example shown above, if a constant 26-second viscosity is desired, the Black can be run at 70°F, the Muslin and Warm Beige can be run at 75°F, the Charcoal can be run at 80°F, and the Putty can be run at 85°F – all without the time, cost, and environmental impact of adding solvent. This not only provides stable, predictable coating viscosity with the minimum amount of solvent, it does so independent of seasonal ambient variations.

As we have already noted, while the formulation for every paint and process varies, it is very common to be able to reduce the total solvent volume being sent to the oven by between 10% - 20%. Since, as shown above, the make-up air calculations are based on the volume of solvent being consumed by the process (and sent to the oven) each hour, this represents an additional 10% - 20% savings in make-up air heating costs in addition to the raw solvent cost savings. This also produces a like reduction in the volume of both exhaust and solvents being sent to the RTO.

The Cost Implications of Burning Solvents vs. Natural Gas

It is often correctly noted that reducing the volume of solvents being fed to an RTO or incinerator can result in the need to burn more natural gas to maintain proper operating temperatures. This hesitation is quickly overcome when the financial impact is brought to light. With natural gas at a current industrial cost of less than $43.0060/MMBTU[7], the common solvents used in coil coatings are multiple times more expensive to heat with as shown here:

Fuel Heating Cost Calculations

Solvent	Cost/MMBTU*	Multiplier
Isophorone	$82.67	22.96
MEK	$43.40	12.06
Butyl Cellosolve	$38.76	10.77
Aromatic 100	$32.21	8.95
Gasoline	$30.90	8.58

* - Industrial Solvent Prices From 2008 Data

In short, solvents are, on the average, more than 132x more expensive to heat with than natural gas.

The Synergy of Combining Technologies

Measuring LFL's provides both the feedback and the control necessary to minimize make-up air requirements. We have already seen that, on its own, this technology can reduce makeup air requirements by upwards of 75%. But even with this control, the volume of makeup air required is totally dependent on the volume of solvent released into the oven.

Using temperature control to minimize the volume of solvent in the paint when it is applied, in turn, reduces the volume of solvents released in the oven and therefore allows the LFL control system to further reduce the makeup air required. This synergy of technologies results in the most stable oven operation possible, combining the lowest possible curing cost, the highest possible safety margin and the highest possible throughput rate. The cost savings accrue from a minimization of reducing solvents and heating requirements, the substitution of natural gas for solvent as a heating fuel, and the increase in line capacity. This is further enhanced by a minimization of regulatory efforts while simultaneously reducing the environmental impact of the coating operation.

Combined, these technologies can easily shift your bottom line performance upward by hundreds of thousands to millions of dollars annually.

---

[7] *US Energy Information Agency as of December 2013*